Final Report

Design of Engineering Experiments

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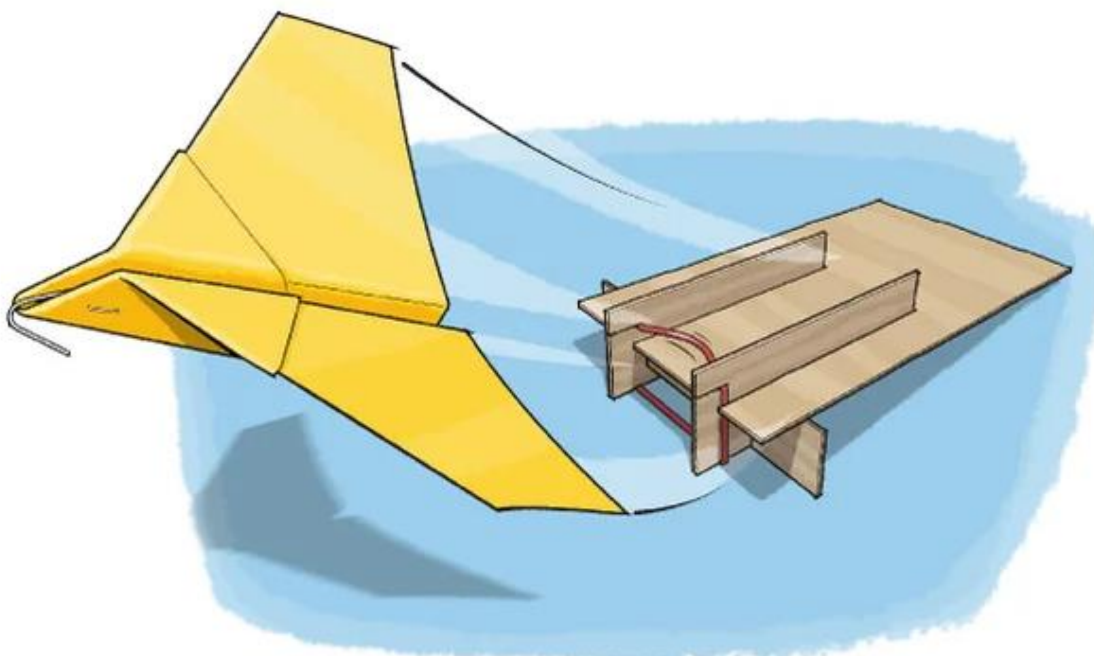


Picture from Scientific American

Description of the Problem

We want to know which factors influence the most, and the least, in the distance travel of a paper airplane.

Factors

Factors of Consideration

The factors that we consider that could affect distance travel are:

- Shape (or design, model)
- Size
- Airspeed
- Air direction
- Altitude
- Initial velocity (or dropping)
- Type of paper (mass density)
- Launching angle
- Air quality (e.g. dust, clear, other gasses)
- Rubber band quality

Nuisance Factors

However, factors that would be hard to control or we believe that does not create the main effect in determining distance travel are (nuisance factors):

- Air quality
- Airspeed
- Air direction
- Launching angle
- Rubber band quality

Uncontrollable Factors

Air

We are considering all factors of air, such as air quality, airspeed, and the air direction, to be a non-controllable nuisance factor. Although the levels might alter the distance traveled, we are not interested in these different factors and levels.

Rubber Band Quality

Something that could have little to no effect on this experiment is the weariness of the rubber band. We believe that the rubber bands that we are going to use would last the whole experiment without showing signs of degradation.

Blocking and Constants

From the nuisance factors, it would be difficult to control air quality, airspeed, and air direction. However, although blocking is not necessary, we want to keep launching angle constant.

Launching Angle

We want to control the launching angle at 0 degrees from the surface level. This is because we are not interested in how high the paper airplane will be but horizontal distance travel. Also, since we are already launching the airplane from different heights, we do not want to lose force in traveling vertically.

Factors of interest

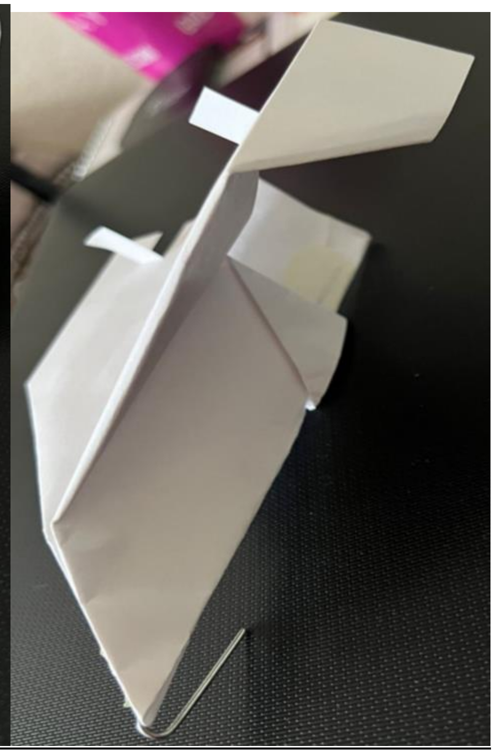
- Design
- Size
- Rubber band tension
- Type of paper
- Height

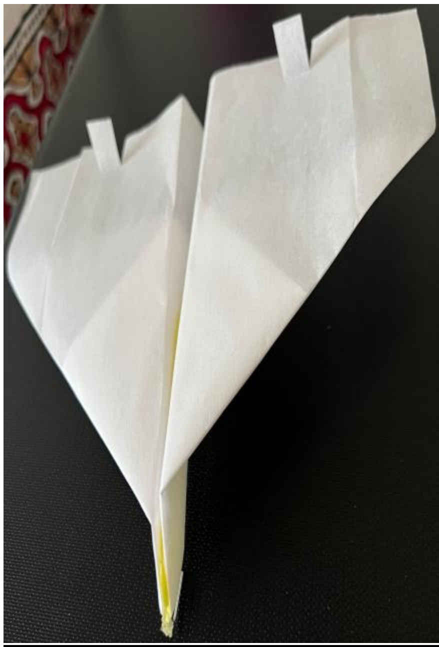
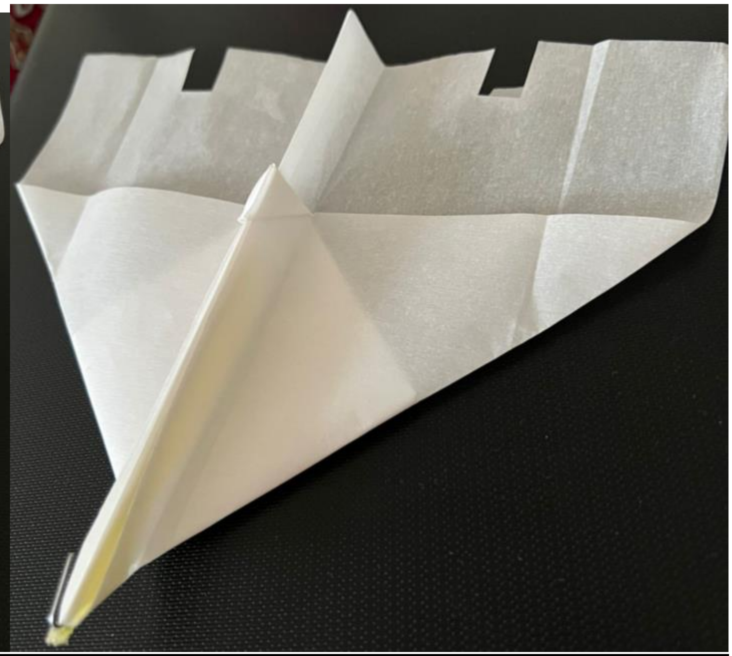
Design

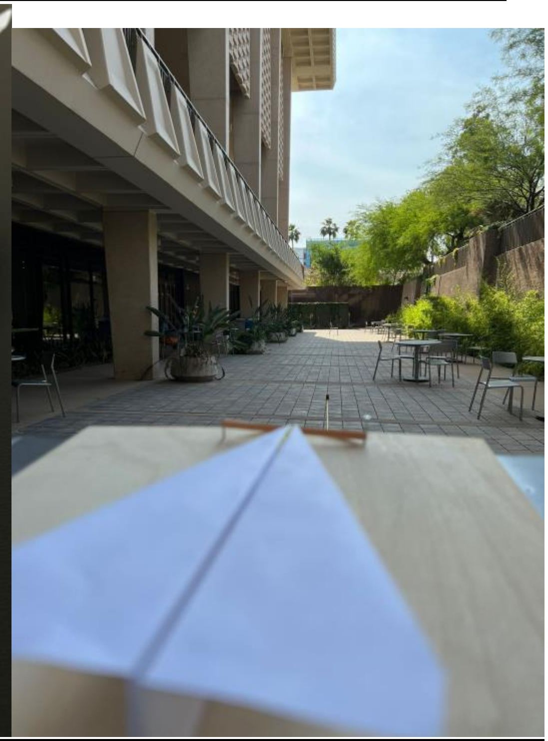
We will use three types of design for each kind of paper to analyze the nuisance factors while flying the plane. For example: In the above image, the left image of a plane is the most common design used in paper airplanes “dart”. But on the right side flaps were added to the design in order to increase the drag of the flight.

Modified Design:

To apply proper tension and learn the factors affecting the planes we modified the design by attaching a Pin to be able to pull the plane using low and high tension.



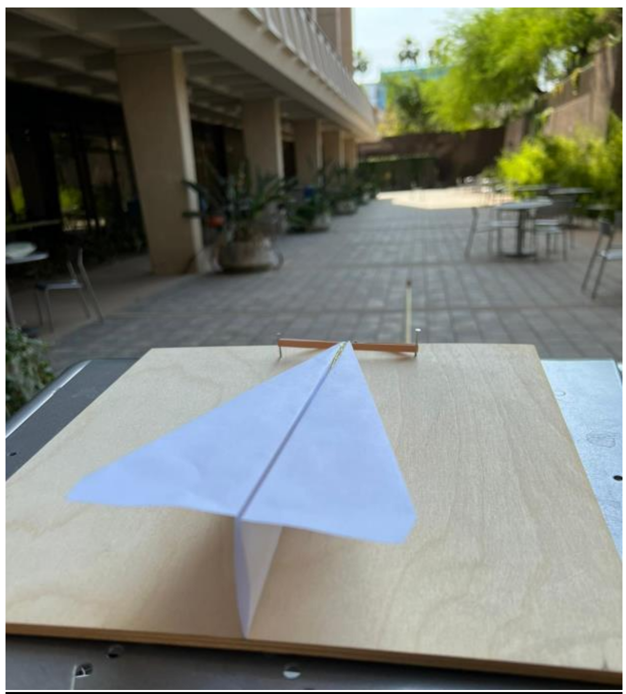


Size

Although size seems to be a variable that we want to measure, from experience, making a paper airplane in a smaller scale would be difficult to fold and make the folds connected without using glue and therefore we are not going to make it a factor. In addition, a smaller paper airplane with the same mass, for instance, folding a paper by half on both sides, the wings become so small that they do not hold for the same mass.

Rubber Band Tension (Blocking)

We strongly believe that initial velocity may impact the effectiveness of distance travel because some airplanes fly better under higher velocities than others. From past experience, we noticed that some airplanes fly better than others under high velocity and other airplanes fly better than others under low velocity. This may be because of many factors such as turbulence on the wings and weight. For example, a white paper airplane would weigh more than an airplane made of butter paper. And we have observed from previous experience that if you do not throw a paper airplane made of white paper hard enough, the airplane would not fly as well as throwing at high speed. On the other hand, a lighter paper airplane, such as made of butter paper, would fly better if you throw it slow and gently. Our belief is that if you throw at a high speed, the wings will receive turbulence and flap, making the airplane lose control and crash.



Type of Paper

Other factors like weight would also be hard to control because we assume that by adding weight to a paper airplane will dramatically decrease the distance traveled without modifying the design. To remedy this, we thought of doing the same design but using a different material. Different materials not only will change the weight of the same design but also the structure of the whole airplane will be stronger or delicate. In addition, a low-density airplane, such as made of butter paper, has higher acceleration because it has less mass and therefore requires not that much force to move it. In contrast, an airplane made of white paper must have a lower acceleration to not lose control. That is, if we launch an airplane made of a delicate material in high rubber band tension, it is likely that the rubber band will damage or destroy the airplane as the rubber band collapses faster than pushing the airplane.

Height

Although we believe that a paper airplane needs sufficient air space to accurately measure the distance traveled and determine which factors are significant, we think that height is proportional to distance travel because most airplanes travel in a straight line

Factor Levels

From the discussion above, these are the factors that we are going to consider:

Factors	Levels		
Design	A (Straight Man)	P(Dart)	R (Royal Wing)
Paper	white	butter	
Tension	low	high	

Type of Paper

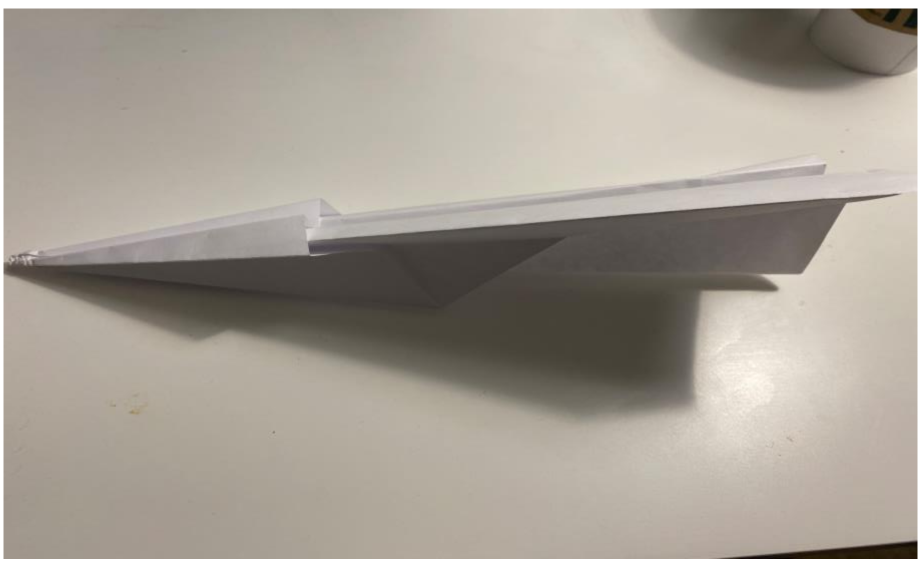
White - We will be using a normal white paper for this experiment.

Butter- A normal butter paper which is generally used in baking. Since it is light and thin it can provide some interesting readings.

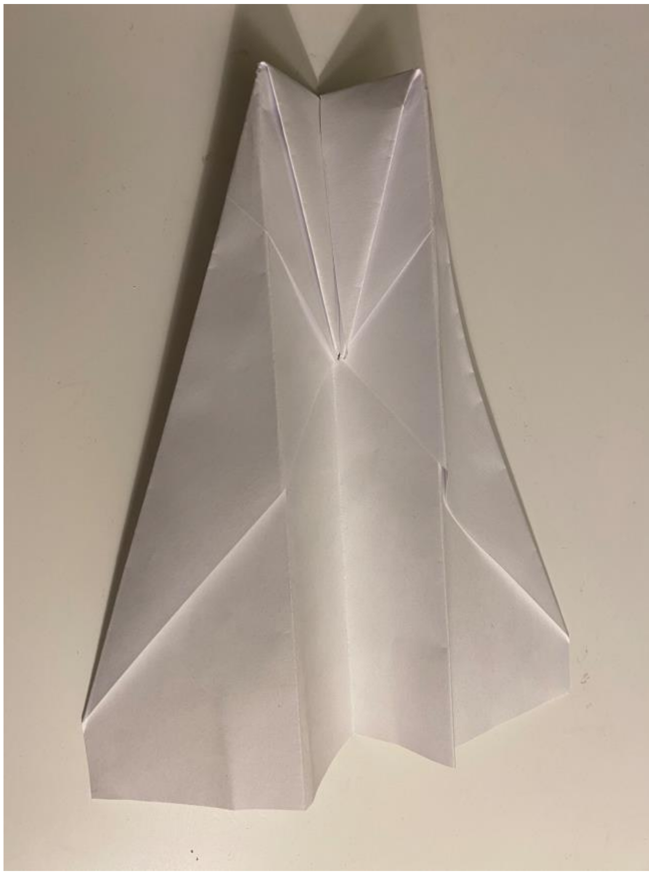
Design - This involves different types of shapes be it rectangular, square etc.

Using the three types of paper we will be designing the paper planes in 3 different designs.

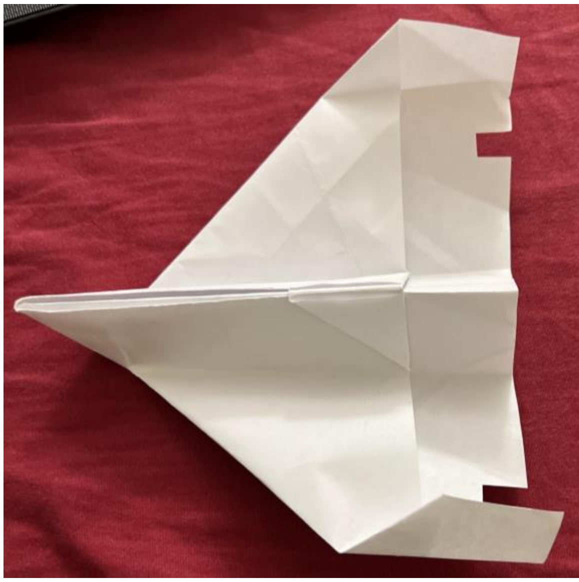
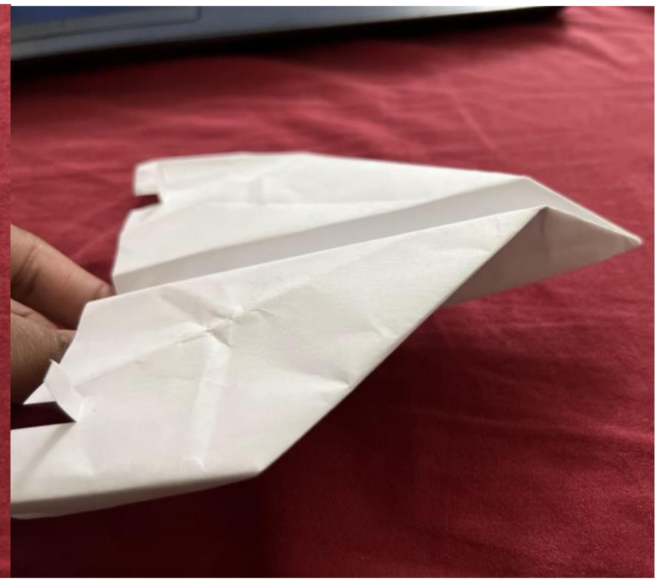
Type 1 - The most common type of design in paper planes is **dart**, we will use that for launching and flying the planes.



Type 2- Another type of design we will be designing and using for launching would be **Straight man.** As a feature, this design might fly more compared to normal dart without dissemination issues.



Type 3- The last design we would use will be a **Royal Wing,** unlike other designs it has unique features, and its take-off and landing will add a factor and distance to our experiment.

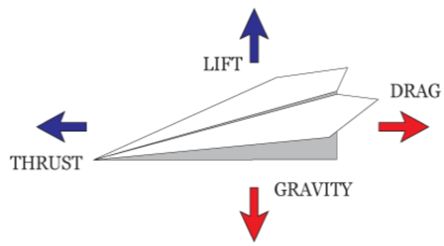



Tension

Paper planes shift broadly in plan, and those distinctions lead to significant contrasts in the manner that they fly. A few planes fly rapidly through the air, while others float gradually. In some cases, a paper plane will tip its nose up, prompting a slowdown. The mechanics of paper planes are fascinating on the grounds that they are like those of most things that move rapidly through the air. They have four essential powers following them:

The push comes from you when you toss the plane. Accordingly, the plane has not pushed in flight. The explanation that it doesn't keep on dialing back during flight is on the grounds that it is additionally falling, "changing over" it’s expected energy into push as it falls.

The lift comes from the distinction in pneumatic stress above and underneath the wing. This is brought about by the state of the wing, known as an airfoil. Lift is relative to the size of the wing and the square of the speed of the plane.



Response Variable

Our variable of interest is distance travel

Sample Size and Replicates

We are going to do four replicates for each combination. That is, a total of 48 runs.

Run The Experiment

Materials

- 3 letter size white paper
- 3 letter size butter paper
- 1 launch path
  - 3 nails
  - Hammer
  - Rubber bands
- A tape measure

Labels

We are going to assign a label to each factor level. That is, we are going to label each paper airplane model-paper-size.

We are going to measure the distance from the launching path with a measuring tape in a straight line.

Data collection

We are going to use one laptop to record the data we collect.

We are going to collect the distance once the airplane touches the ground. We will not measure the distance of landing.

Randomization

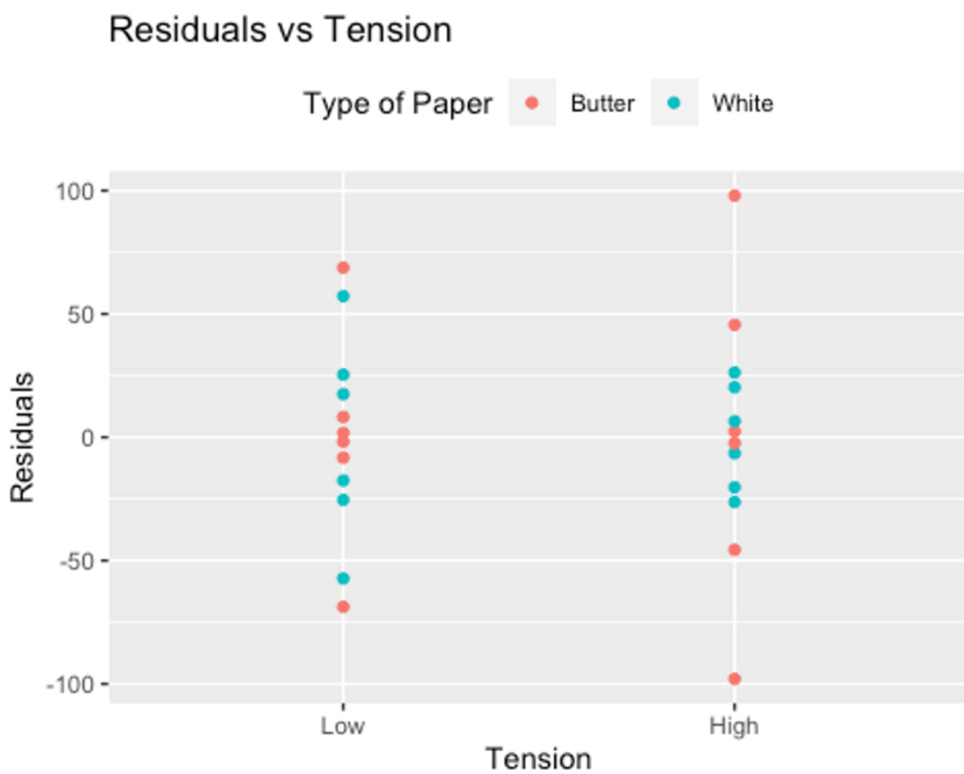
We used JMP to get our run order in a uniform randomized order.

Each Run

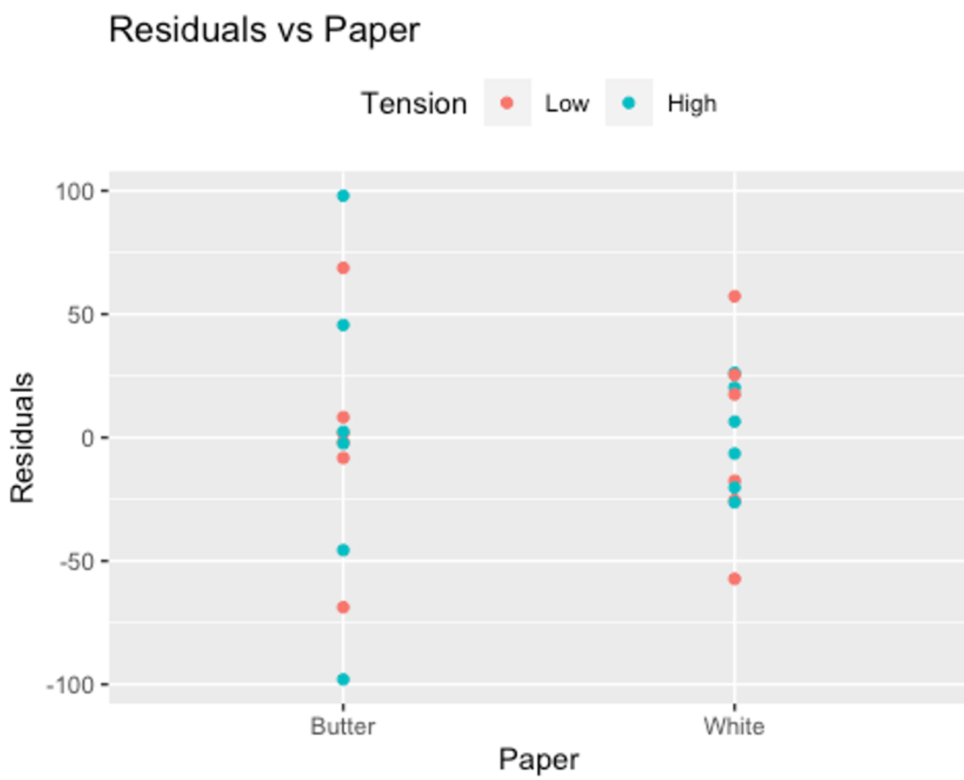
At the beginning of each run, two observers will verify the run combination. Then one will launch the airplane and then the two others will measure the distance traveled.

ANOVA Table					
	Df	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
Block	*2*	*24209.724*	*12104.862*	*3.3227659*	*0.0710622*
Tension	*1*	*266335.336*	*266335.336*	*73.1086371*	*0.0000019*
Paper	*1*	*12684.503*	*12684.503*	*3.4818763*	*0.0866664*
Tension:Paper	*1*	*14028.753*	*14028.753*	*3.8508709*	*0.0733293*
Block:Tension	*2*	*65005.984*	*32502.992*	*8.922021*	*0.0042261*
Block:Paper	*2*	*13204.693*	*6602.346*	*1.8123338*	*0.2052214*
Block:Tension:Paper	*2*	*7224.224*	*3612.112*	*0.9915191*	*0.3994645*
Residuals	*12*	*43716.094*	*3643.008*		

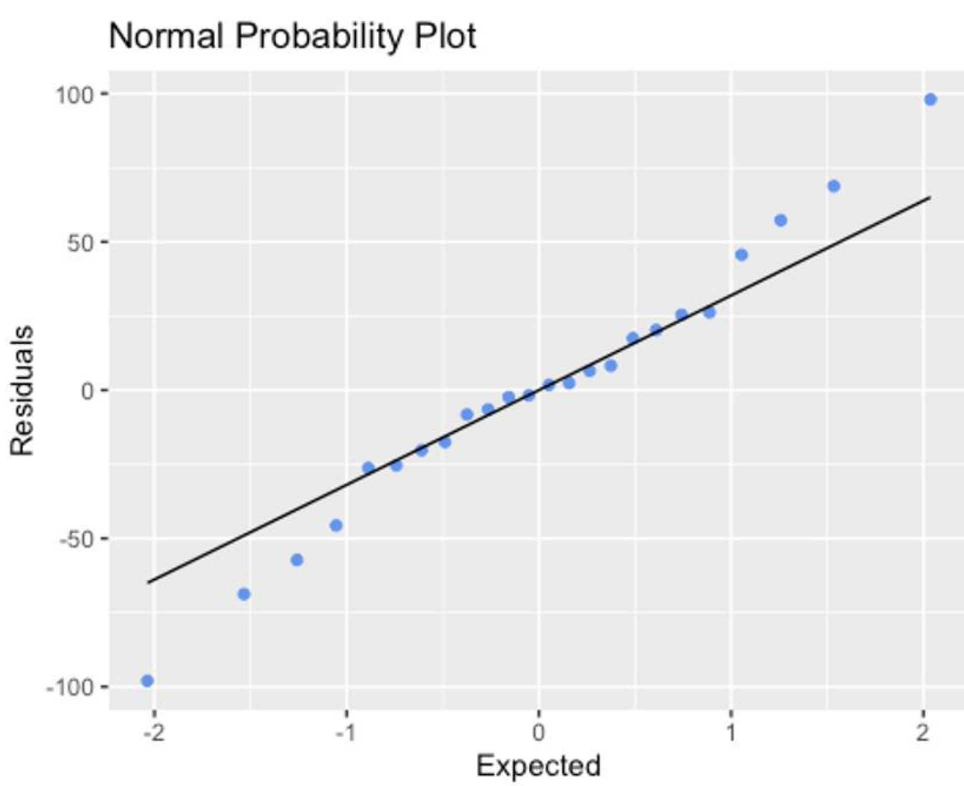
From the ANOVA table above, at .05 significance level, the tension main effect and tension with the block variable interaction effect are significant at .05.



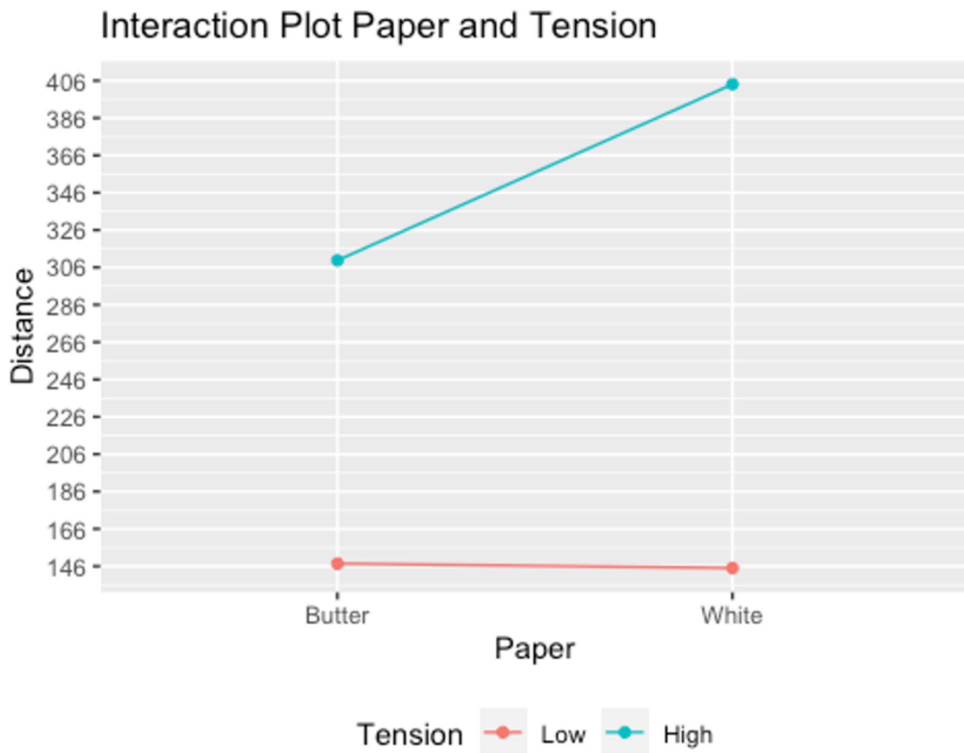
From the residual plot above, it seems that there is no violation of constant variance and no violation of the independence assumption.



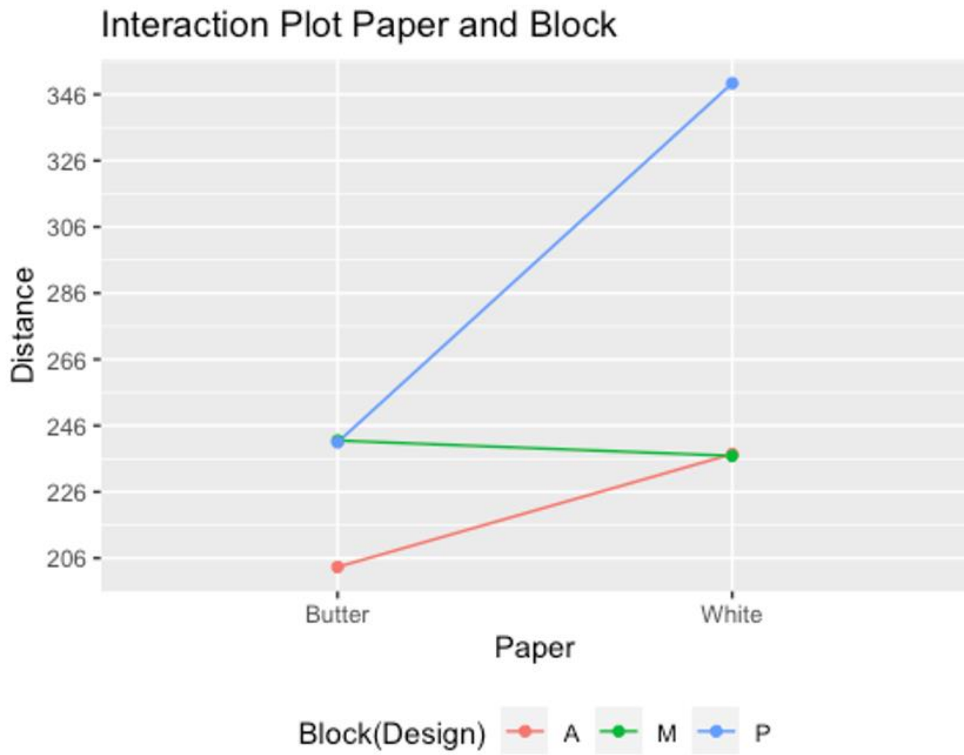
From the residual plot above, it seems that there is high variability of the residuals when there is butter paper rather than white paper.



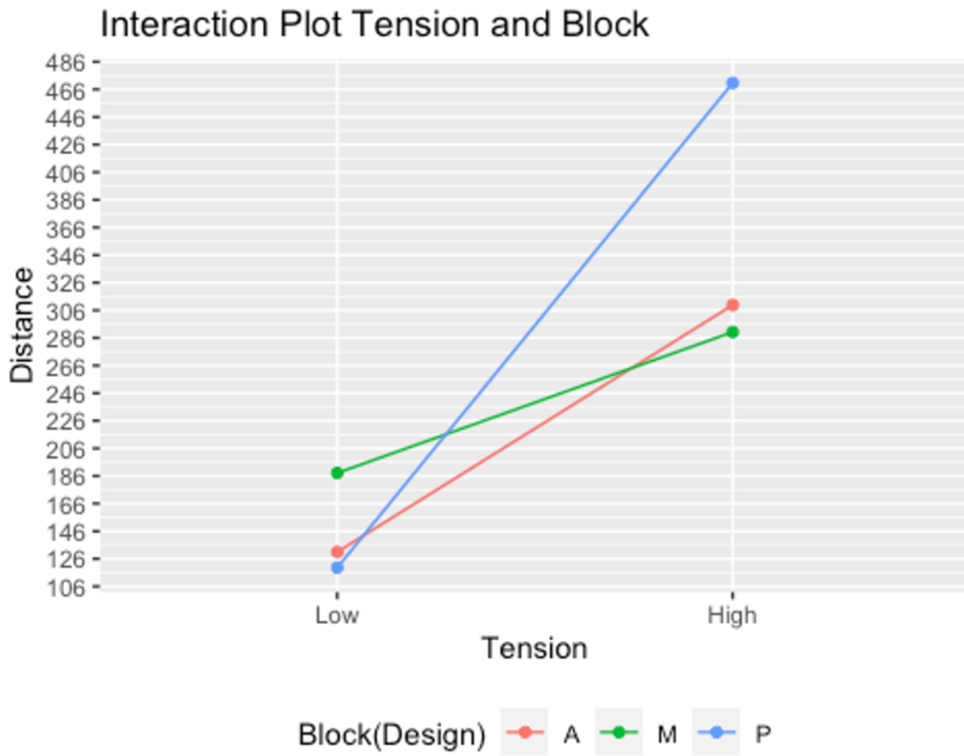
It seems that most of the residuals follow the line, so the data comes from a normal distribution.



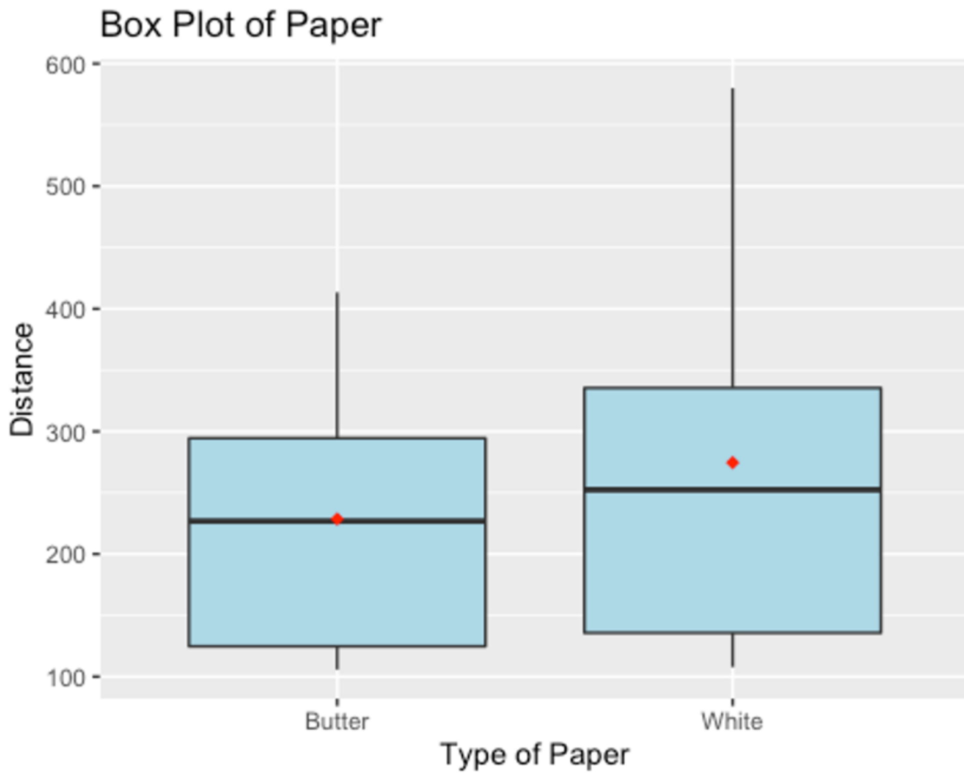
From the interaction plot above, we can see as we change from butter to white paper, the distance increases for under white paper for high tension. On the other hand, the distance decreases under white paper for low tension. We believe that it is due to the fact that white paper is heavier than butter paper, so they require a higher tension to fly properly.



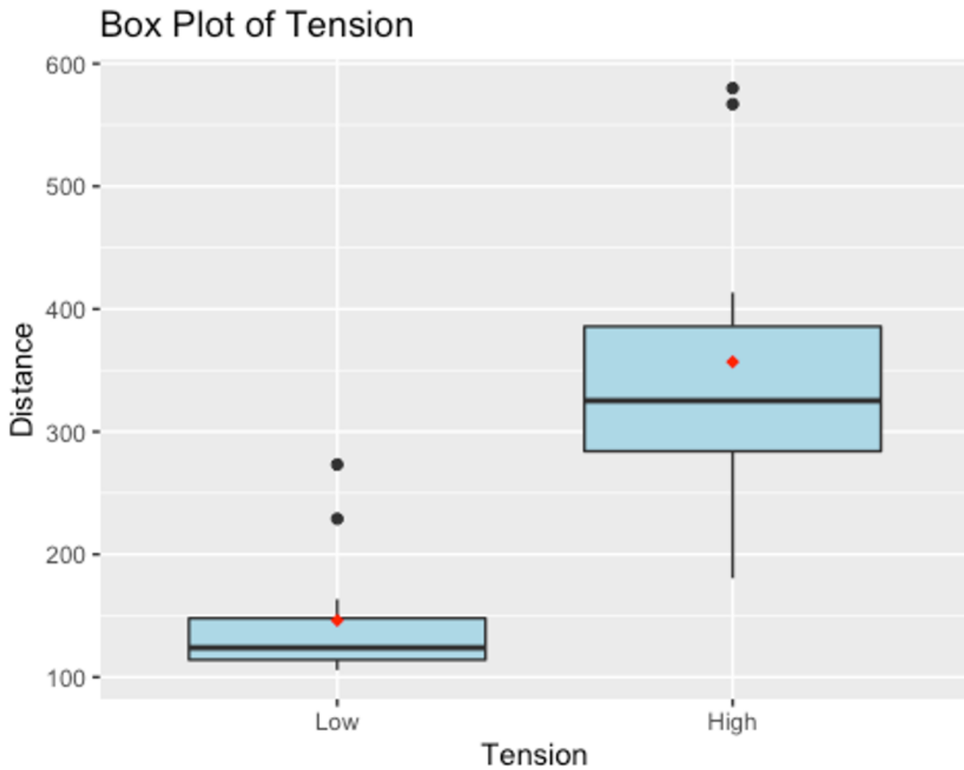
From the interaction plot above, we can see that design A and P increase their distance when we change their paper from butter to white. But design M decreases its distance when the type of paper is changed.



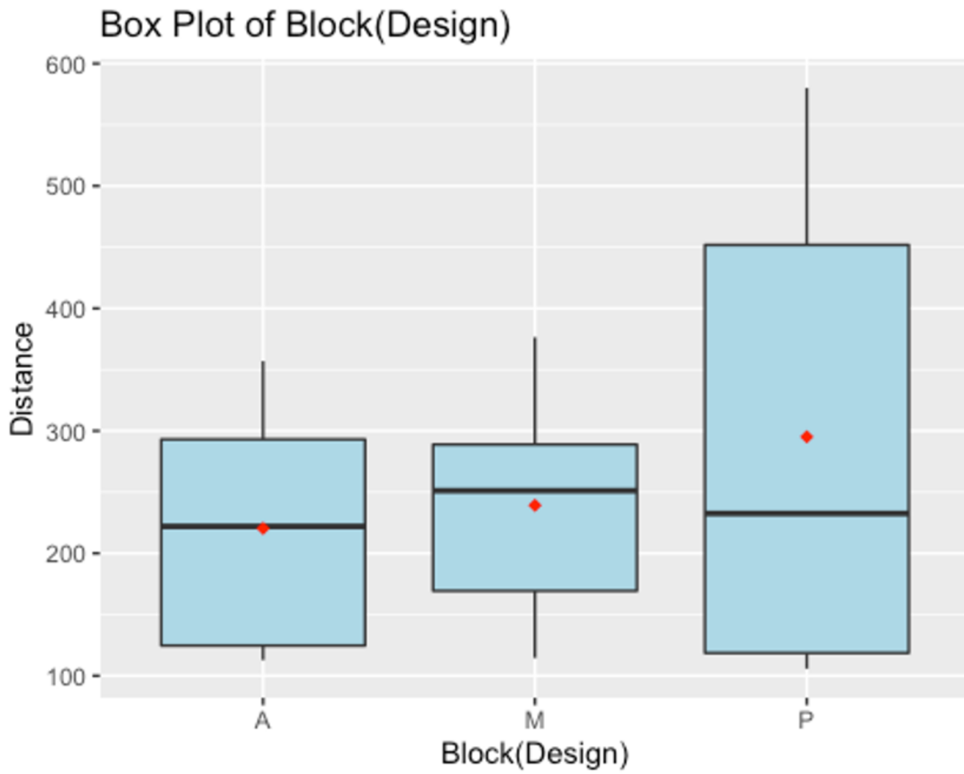
Overall, there is an increase in distance in all designs as we change from low to high tension. Moreover, in the search for the best airplane, it seems that design P performed best when it is exposed to high tension.



The mean distance using butter paper is 228.58 inches and for white paper is 274.56 inches. It seems that there is no difference in the mean distances of butter and white paper and the variance distance are about the same.



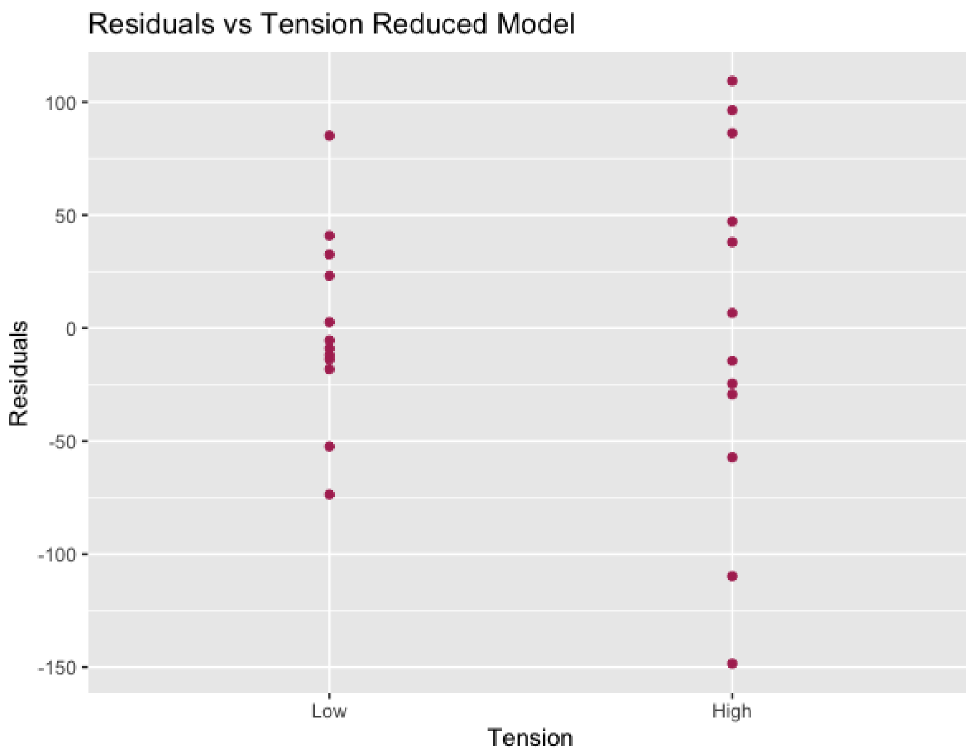
The mean distance at low tension is 146.23 inches and 356.92 inches for high tension. From here, we clearly see that there is a difference in the mean distance between low- and high-tension levels.



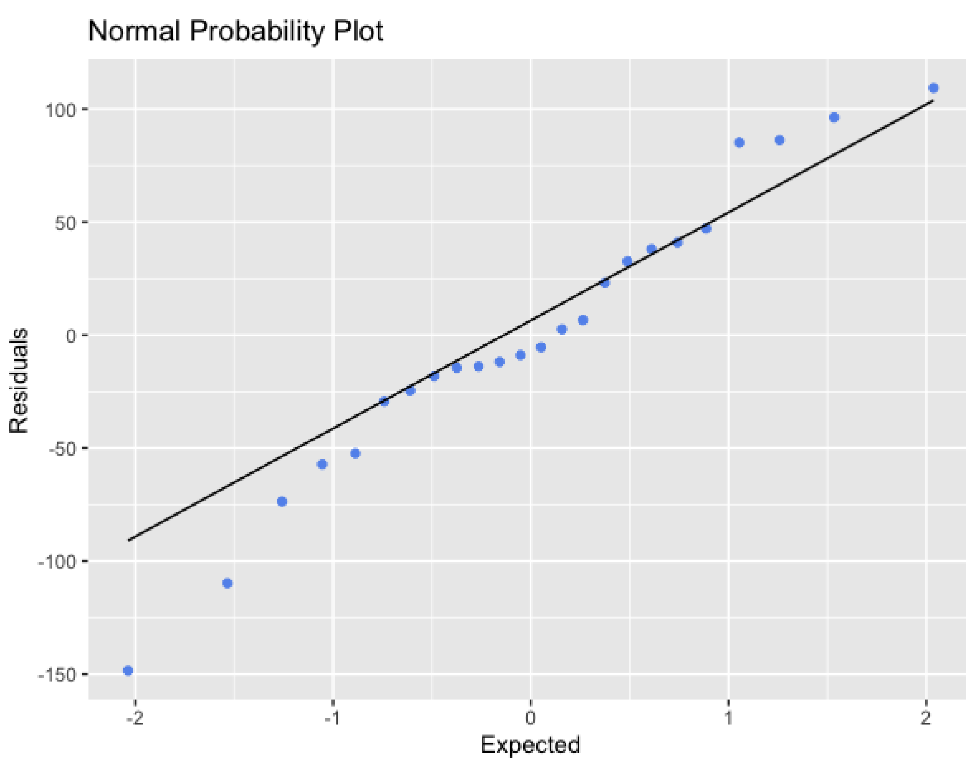
The mean distance for design A is 220.38 in, for design M is 239.19 in, and for design P is 295.16 in. It seems that there is not a difference in in the mean distance across designs.

Above Conclusions

Since tension main effect and tension with block (design) interaction effects are active, the reduced model is the model with block, tension, and the two-factor interaction.



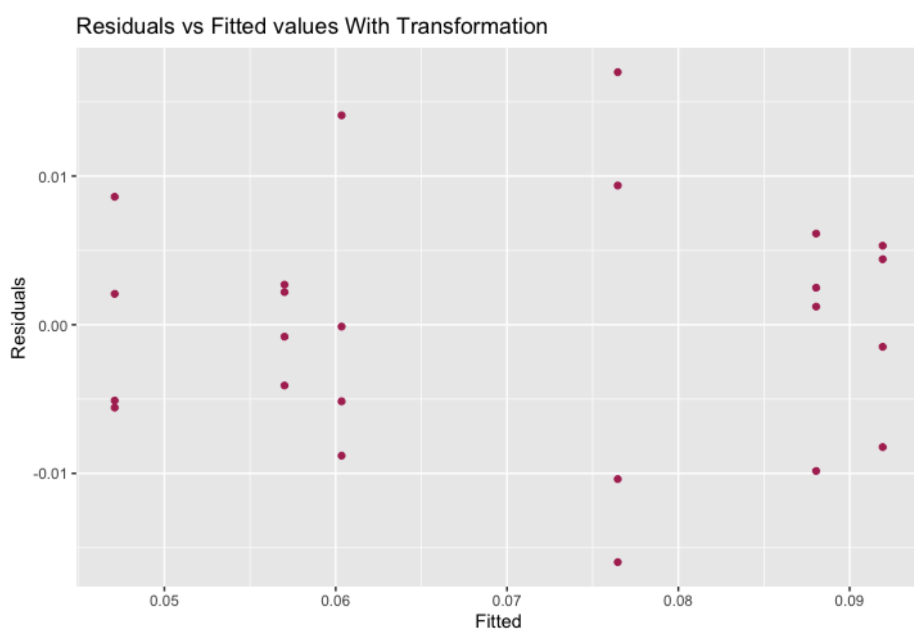
The residual plot does not look entirely random as the residuals tend to have higher variability as tension increases. Thus, it could be that there is a violation of the constant variance assumption.



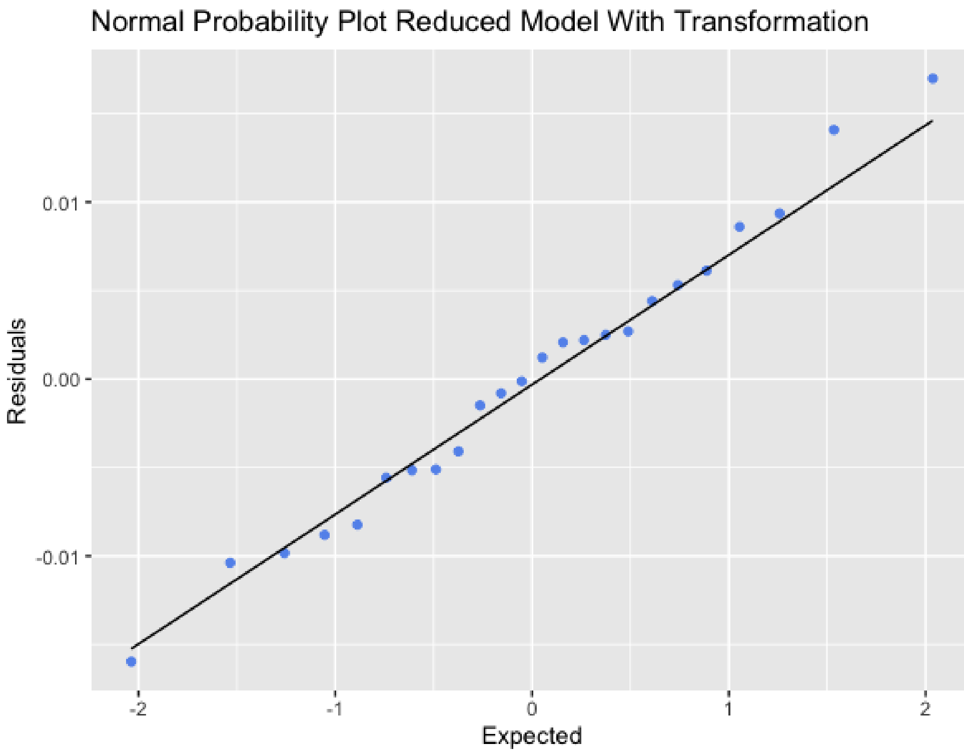
From the normal probability plot above, it seems that the residuals do not follow the y=x line which means that the data is not entirely normal distributed.

To fix this, we will do 1/sqrt(distance) or distance^ (-1/2) power transformation, as suggested by Box.

Although the residuals do not look entirely random, they look better than what we had before.



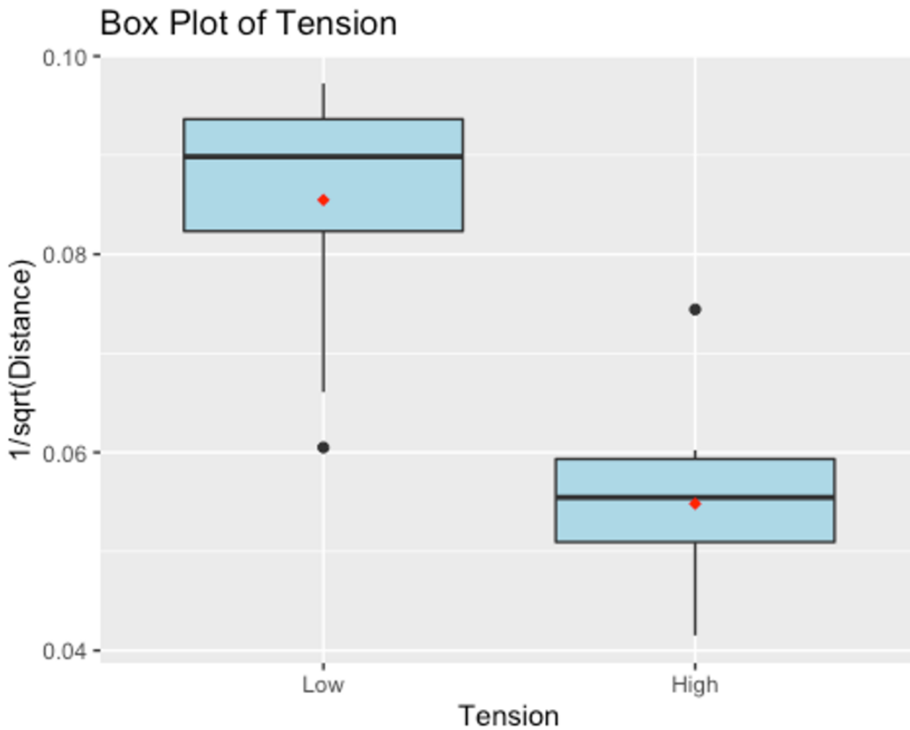
The residuals look random in the above plot. There is no violation of the independent and constant variance assumption.



From the normal probability plot above, we can see that there is no longer a violation of the normality assumption.

ANOVA Table					
	Df	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
Block	*2*	*0.0000729*	*0.0000364*	*0.4472024*	*0.6463289*
Tension	*1*	*0.0056403*	*0.0056403*	*69.2340445*	*0.0000001*
Block:Tension	*2*	*0.0008247*	*0.0004124*	*5.061716*	*0.0180234*
Residuals	*18*	*0.0014664*	*0.0000815*		

From the ANOVA table above, we can see that at .05 significance level, there is a significant difference in the mean 1/sqrt(distance) between low and high tension. In addition, the interaction effect between block (design) and tension is also significant at .05 significance level.



From the boxplot above, it seems that there is a difference in the 1/sqrt(distance) means between low and high tension. Also, we can see that the size of the interquartile range for low and high tension are about the same size, so it seems that the variances are about the same.

The 95 percent confidence interval for the mean 1/sqrt(distance) for low tension is 0.0777 and 0.0932. Similarly, the 95 percent confidence interval for the mean 1/sqrt(distance) for high tension is 0.0.0471 and 0.0626.

The difference in the mean 1/sqrt(distance) between high and low tension is -0.0306603. So the 95 percent confidence interval for the difference in the mean between high and low tension is (-0.0384018, -0.0229188).

Conclusion

After conducting the experiment, performing the statistical analysis, and investigating the underlying assumptions, we would like to draw practical conclusions about the factors affecting- The second ANOVA table, tension played a significant role in estimating distance travel. Although we are blocked by design, from the interaction plots, it seems that design P performed the best at high tension with white paper.

	Tension	Paper	Design	Distance
1	high	white	A	357
2	low	white	M	114.5
3	low	white	A	112.75
4	high	butter	P	413.5
5	low	white	M	229
6	high	butter	P	322.25
7	low	butter	M	273.25
8	low	white	P	142.75
9	low	butter	P	105.75
10	high	white	P	567
11	low	butter	A	122
12	low	white	P	107.75
13	high	butter	M	376.5
14	high	white	M	328.25
15	low	butter	A	125.5
16	high	butter	M	180.5
17	high	white	A	316.5
18	high	butter	A	285.25
19	high	white	M	275.75
20	high	white	P	580
21	low	white	A	163.5
22	low	butter	M	135.75
23	low	butter	P	122.25
24	high	butter	A	280.5

Using the Box-Cox Method for selecting variance stability transformation, we were able to run the analysis of variance on the transformed data. To conclude, the Residual vs Fitted Values with Transformation resulted in no violation of the independent and constant variance assumption.

Recommendations

We recommend using other types of delicate paper other than butter paper because we broke some airplanes when we flew them with high tension. In addition, we suggest trying other factors like different designs which might support the pins during high or alternative way for launching the planes. Some Natural factors like “wind” make it hard to take readings. Initially Cardboard (cereal box) was used to make planes but it broke when a complex design was used.

REFERENCES:

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