Paper Planes

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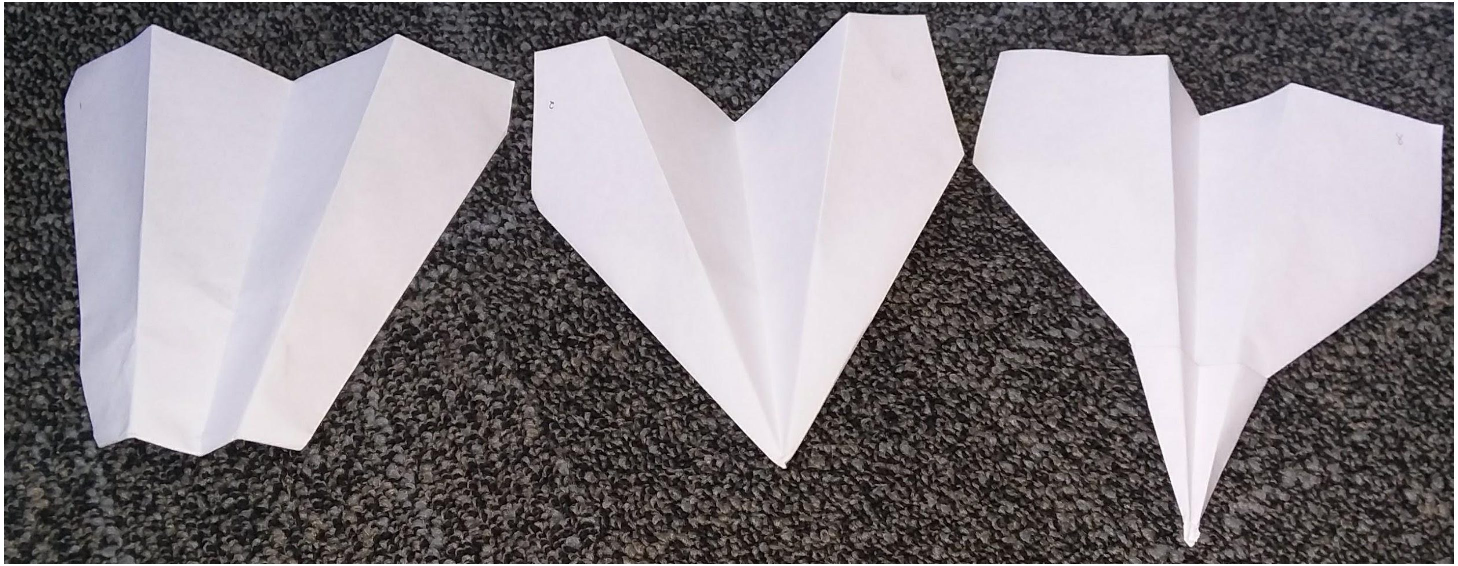
Introduction

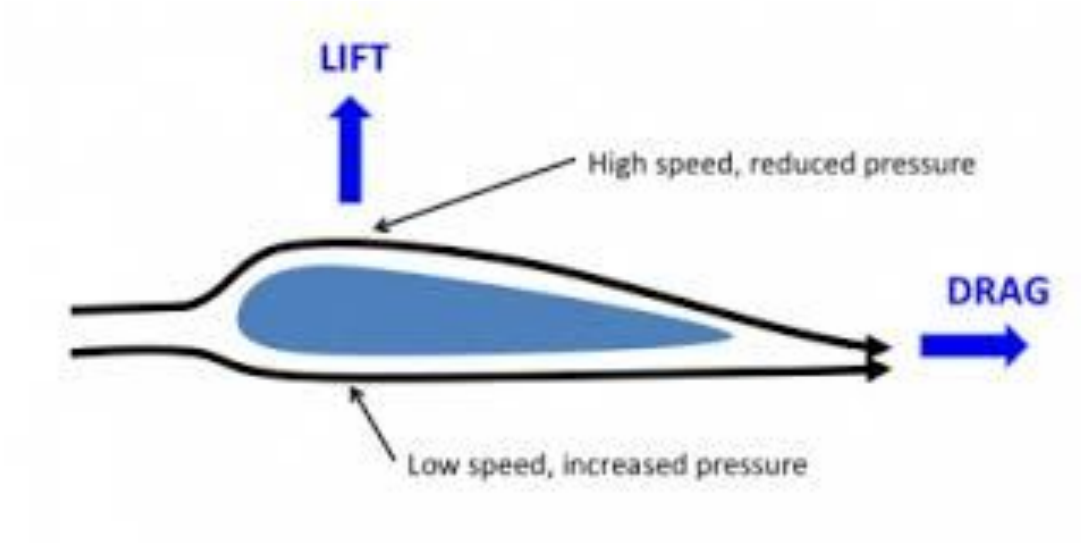
How do we fold a paper plane to maximize distance?

Factor 1: Plane design (snub, delta, and weighted.)



Introduction

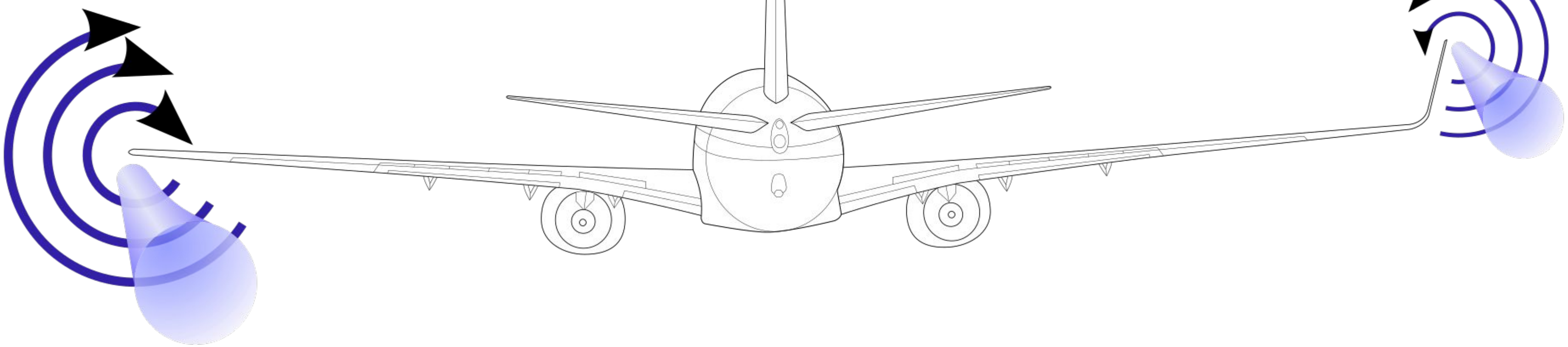
Factor 1: Design can change the ratio of lift to drag, which directly affects the distance the plane can fly



Introduction

Factor 2: Winglets

Air slipping off the ends of the wings creates vortices that steal the plane’s energy. Bending the wings up or down can help to minimize the energy lost to vortices



Introduction

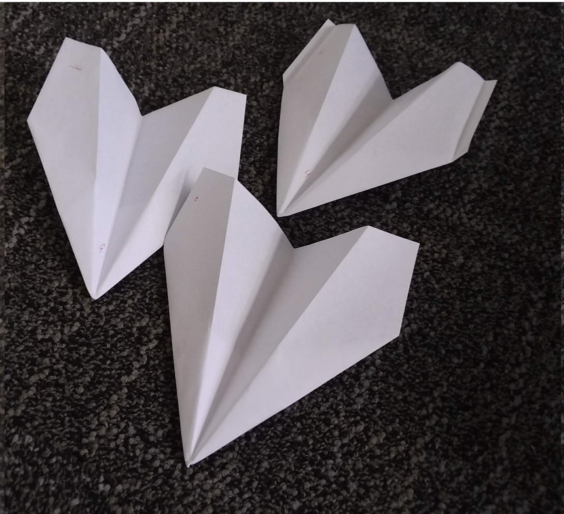
Factor 2: Winglets

Wingtips have been used on modern aircraft to increase range by up to 6%

Introduction

Factor 2: Winglets

We tried each design with straight wings, up winglets, and down winglets



Null and Alternative Hypotheses

H_0: Mean flight distance is the same for all designs.

H_a: Mean flight distance is different for at least one of our designs.

H_0: Mean flight distance is the same for all winglets.

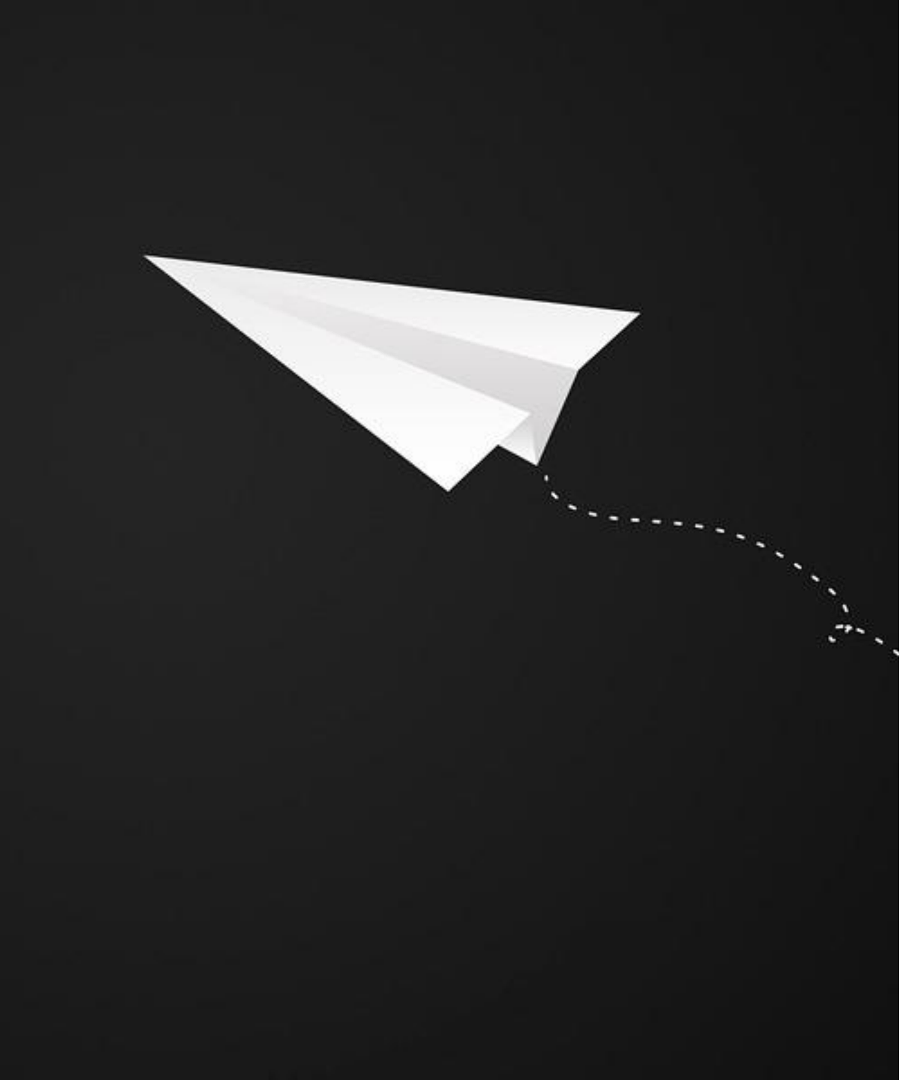
H_a: Mean flight distance is different for at least one of our winglets.

H_0: There is no interaction between plane design and winglets.

H_a: There is at least some interaction between plane design and winglets.

Controlling Nuisance Variables

- Randomization
  - 9 planes flown in random order
- Control
  - One person throwing to control for differences in skill
  - One person folding planes
  - One type of paper to control for differences in material
- Overall sample size
  - 90 observations (9 planes each thrown 10 times)



Design: Two-Way Basic Factorial

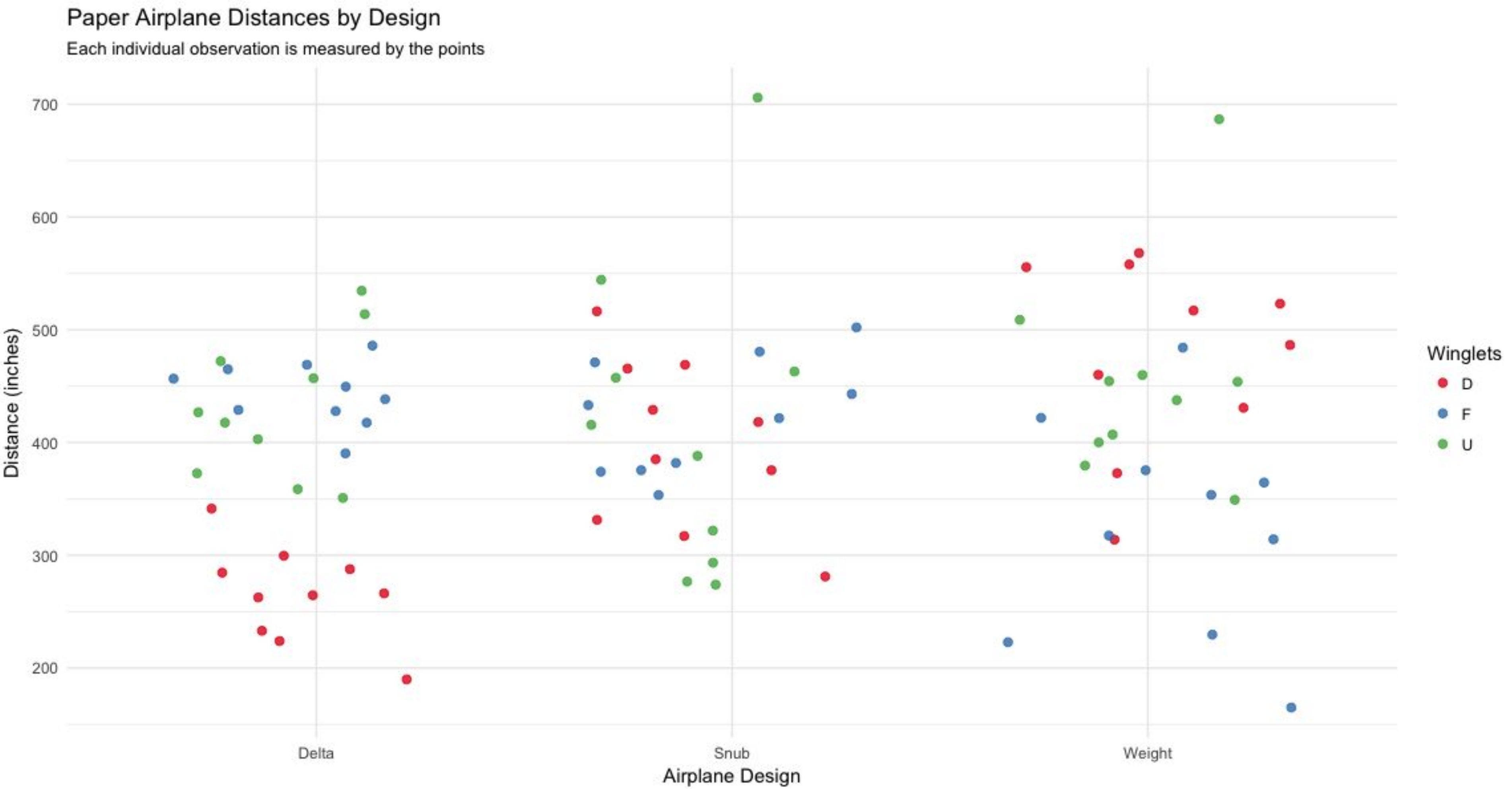
- ❖ Treatments
  - ➢ Plane design
  - ➢ Winglet (folded up, down, or no fold)
- ❖ Response
  - ➢ Absolute Flight distance from thrower

		Design		
		Delta	Snub	Weighted
Winglet orientation	Down	Plane 1 DD	Plane 2 SD	Plane 3 WD
	Flat	Plane 4 DF	Plane 5 SF	Plane 6 WF
	Up	Plane 7 DU	Plane 8 SU	Plane 9 WU

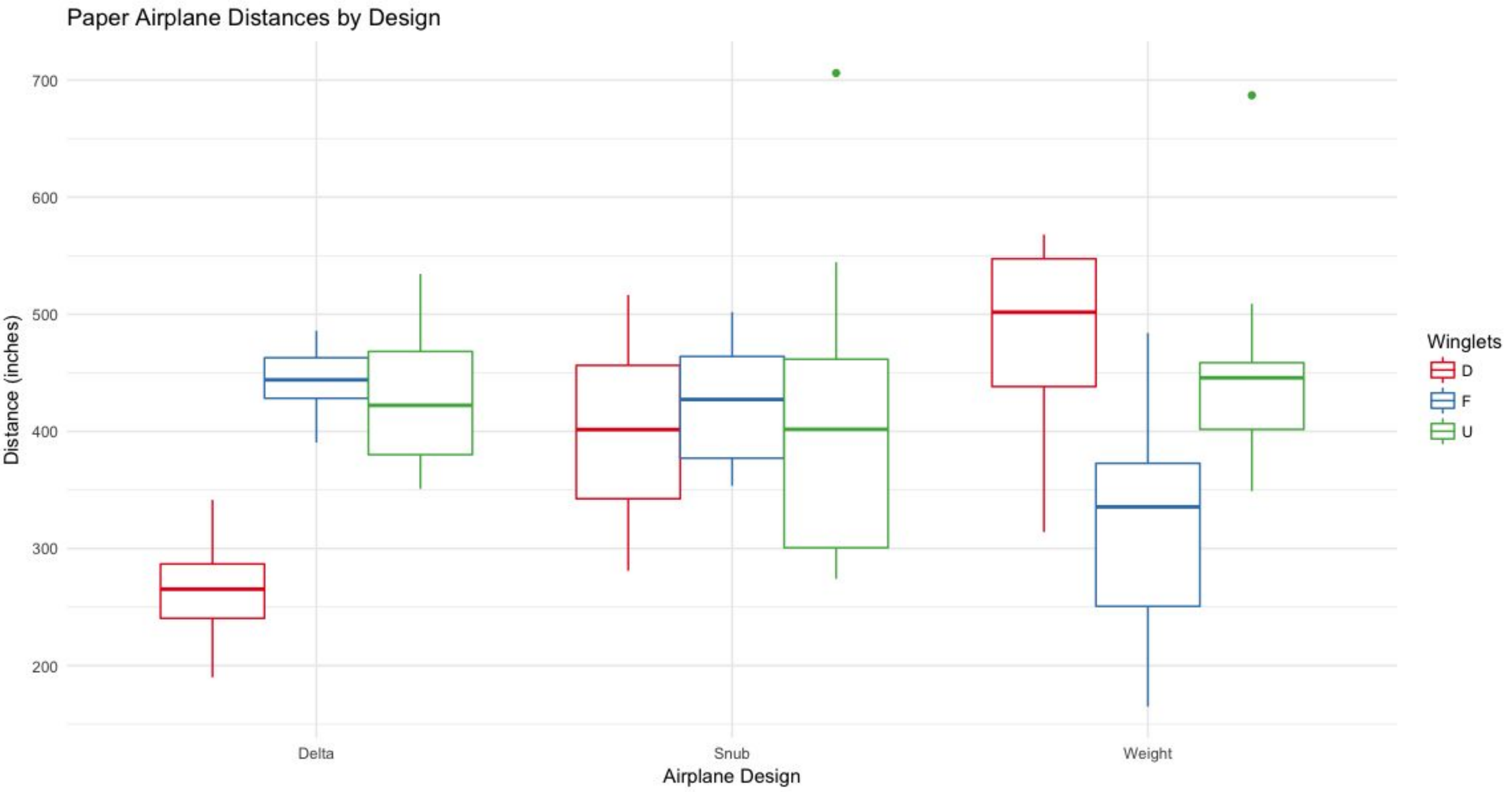
Mean	Delta	Snub	Weight
Down	265.30	398.80	478.60
Flat	442.65	423.60	324.85
Up	430.70	414.05	453.75

Median			
Down	265.25	401.50	501.75
Flat	444.00	427.25	335.50
Up	422.25	401.75	445.75

Standard Deviation			
Down	42.51222	74.78978	84.70531
Flat	28.05000	51.11903	97.13337
Up	63.26145	136.93316	93.88061



Paper Airplane Distances by Design
Each individual observation is measured by the points
Distance (inches)
700
600
500
400
300
200
Delta
Snub
Weight
Airplane Design
Winglets
D
F
U

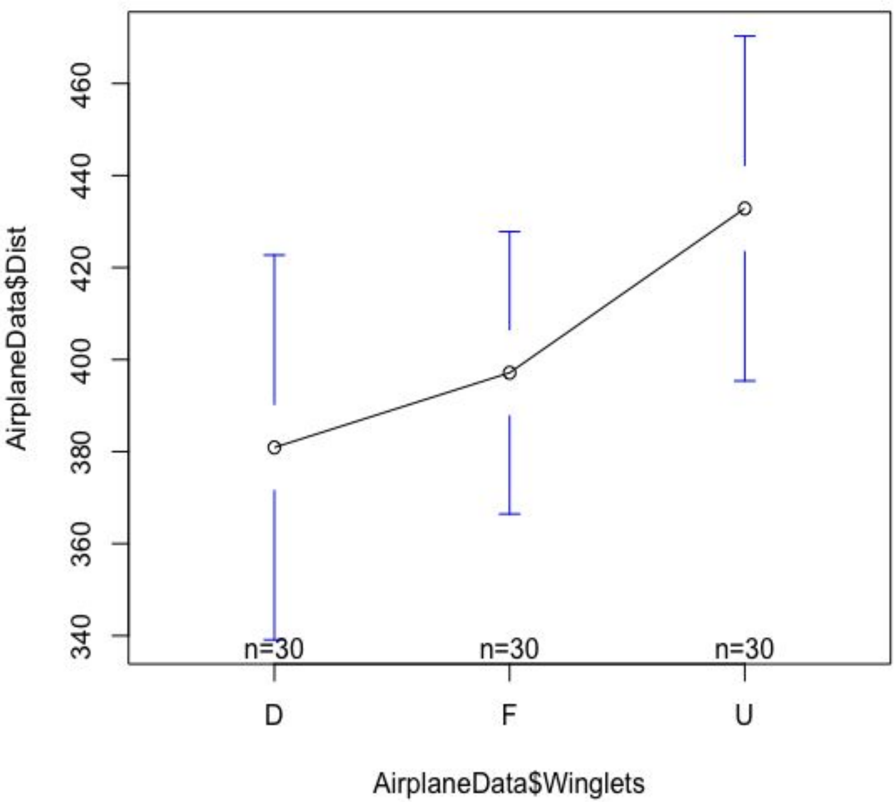

Paper Airplane Distances by Design
700
600
500
400
300
200
Distance (inches)
Delta
Snub
Weight
Airplane Design
Winglets
D
F
U

ANOVA Table

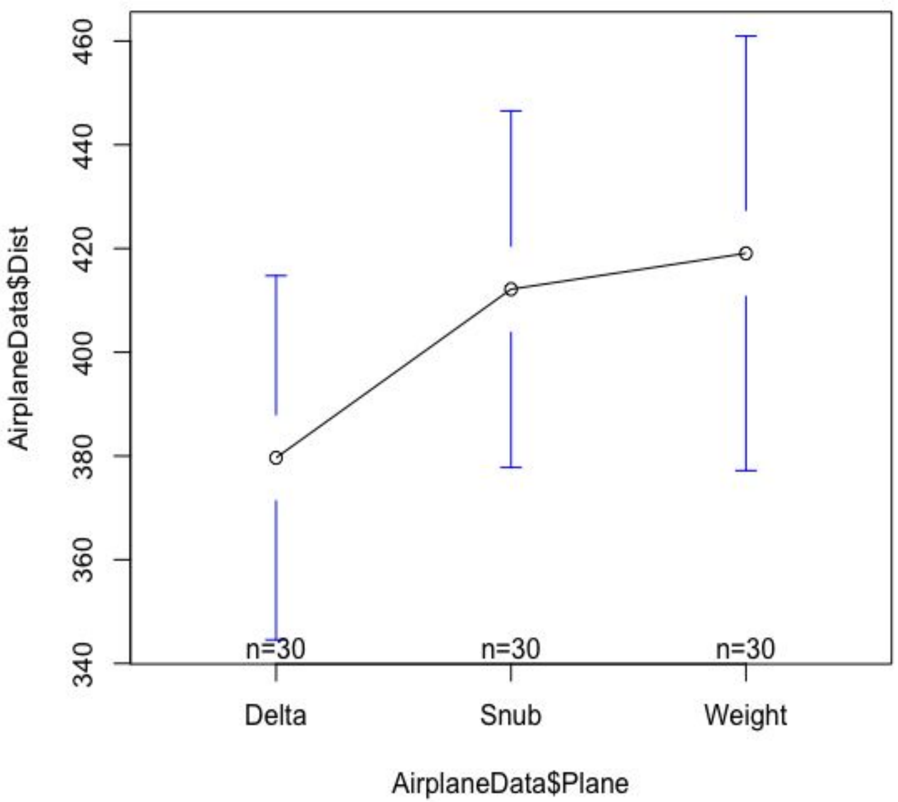
	Sum Sq	Df	F value	Pr(>F)
Design	26578	2	2.0279	0.13824
Winglets	42351	2	3.2314	0.04465 *
Interaction	293907	4	11.2127	2.741e-07 *
Residuals	530792	81		

*$\alpha = 0.05$

Mean Plots

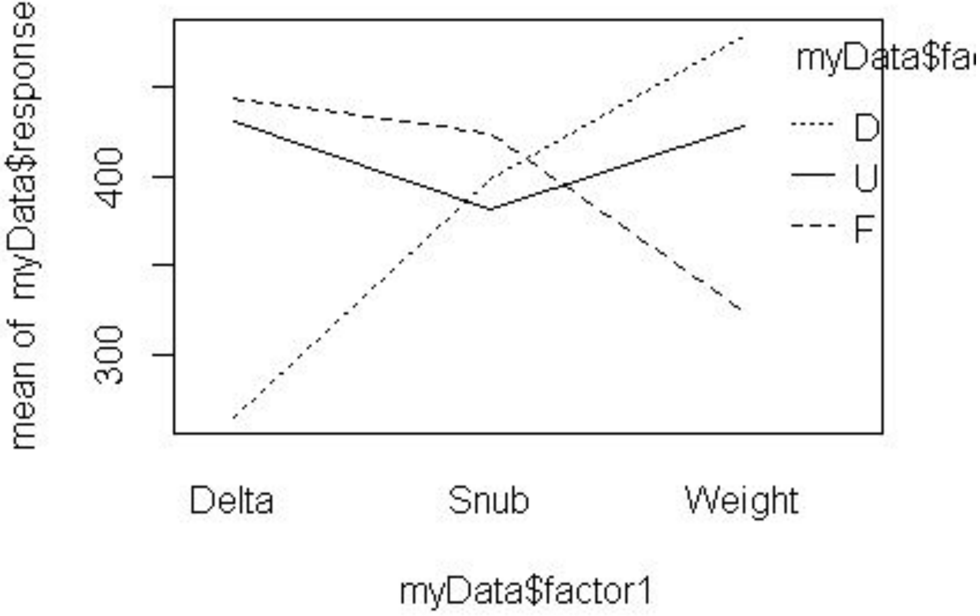


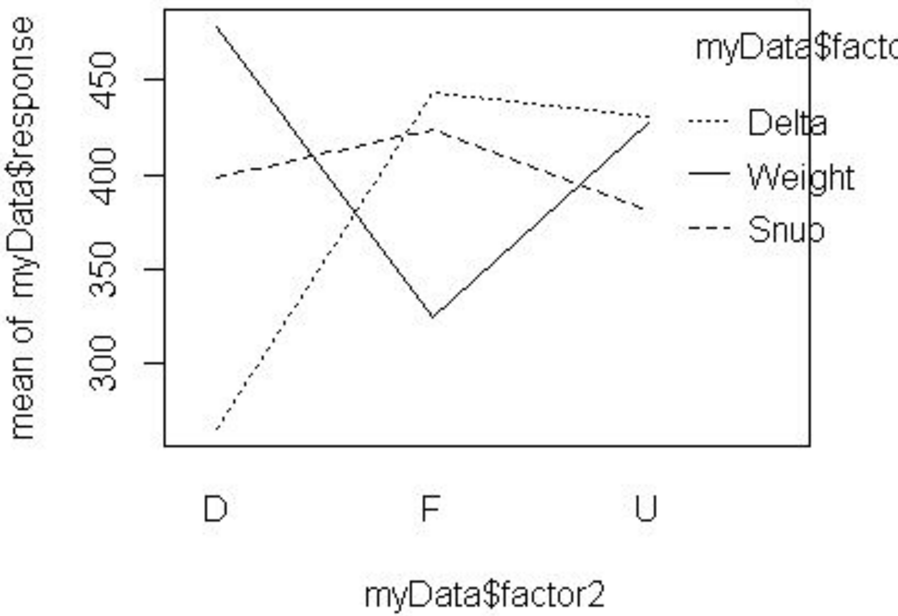
AirplaneData$Dist
460
440
420
400
380
360
340
n=30
n=30
n=30
D
F
U
AirplaneData$Winglets



AirplaneData$Dist
460
440
420
400
380
360
340
n=30
n=30
n=30
Delta
Snub
Weight
AirplaneData$Plane

Interaction Plots





Inferential Statistics

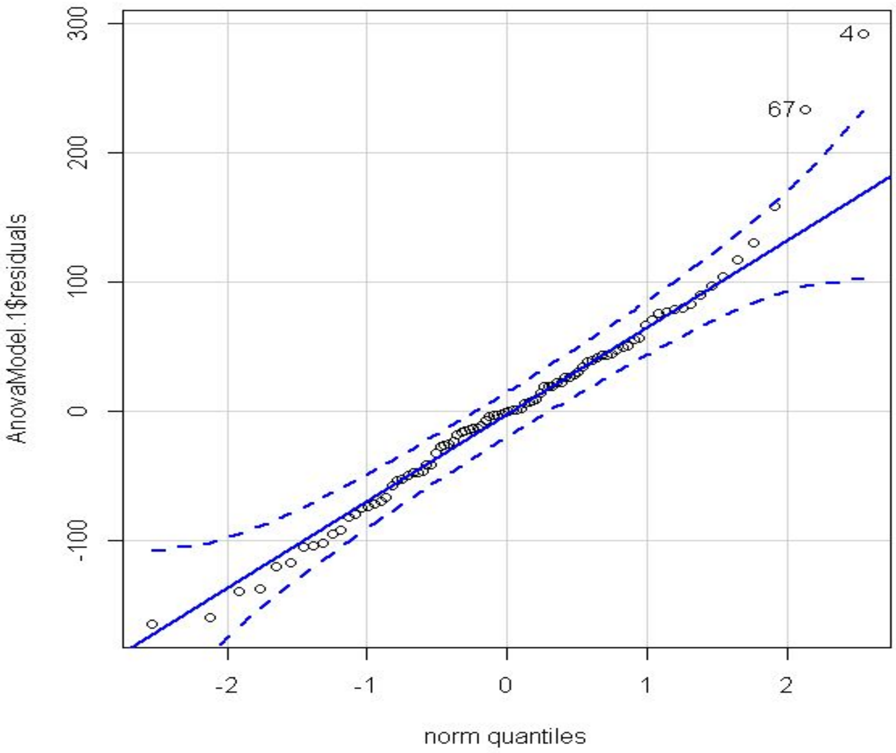
Assumptions for ANOVA:

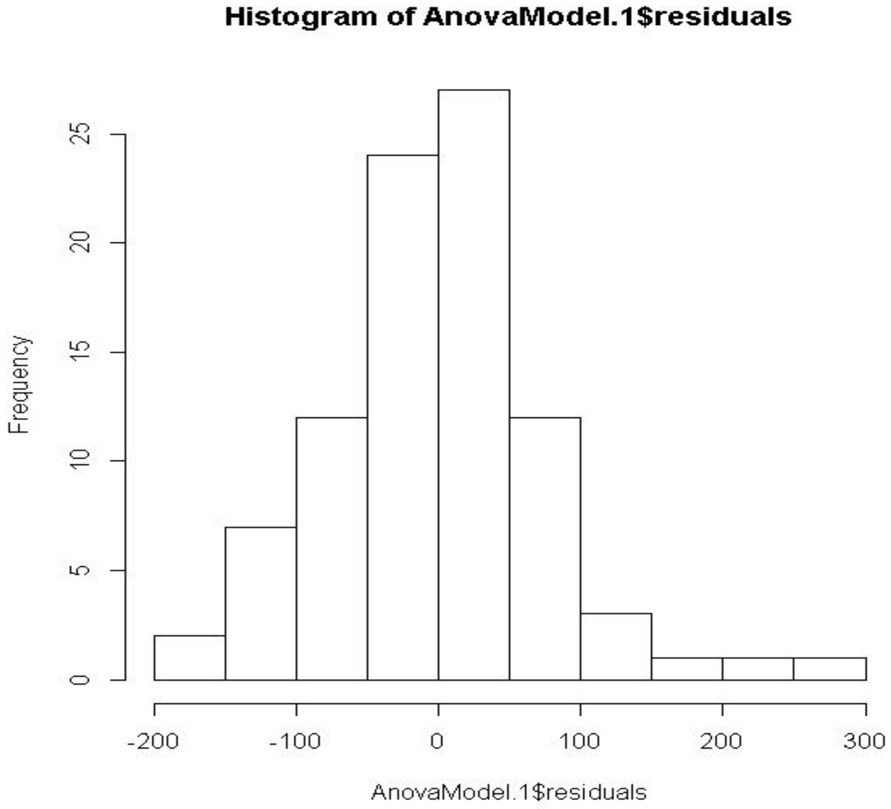
Data are normally distributed

Variance is equal for all groups

Checking Assumptions:

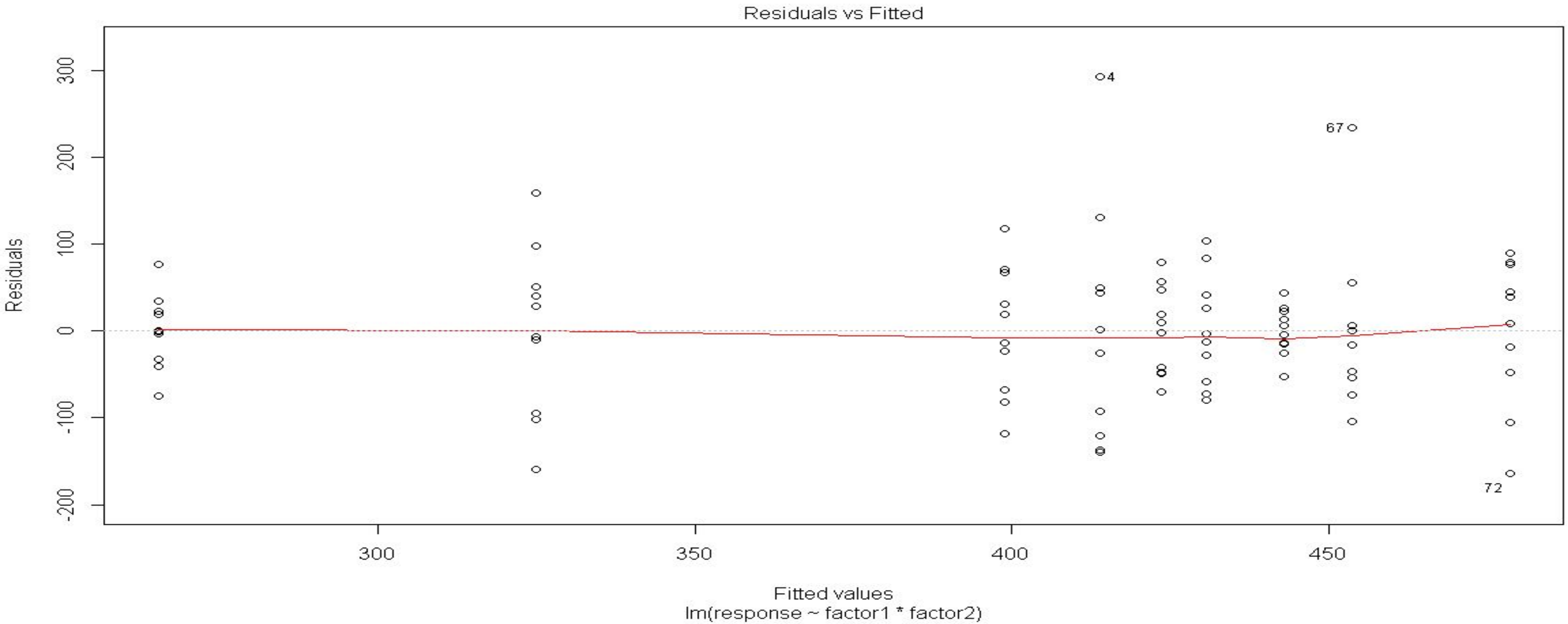
Residuals are generally normally distributed





Checking Assumptions:

Variance for each group is not the same



Results of Analysis

Design didn’t have a significant effect on distance

Winglets had a significant effect

There was a significant interaction between winglets and design

Trends in the data

Winglets of either type positively affected the weighted design

Winglets made no noticeable difference in Snub design.

Delta performed similarly with up winglets and no winglets, but performed worse with down winglets

Discussion

What would we have done differently?

More replications

Multiple copies of the same plane to prevent degradation

Find a better way to measure distance for planes that travel in an arc

Follow-up studies:

Test winglets with more plane designs

Try different sizes of winglets

References

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