Need a Lift?

The effect of wingtip style on a wing's percent change in weight when run through a wind tunnel

Introduction & Hypothesis

Purpose of Project:
The purpose of my project was to determine which style of winglet on an airplane wing generates the highest percentage of lift to counteract drag on the wing. My experiment measured the percent change in weight of different wingtip designs. The goal of my project was to determine which style of winglet was the most effective at combating wingtip vortices, which are pockets of spinning air that cause drag.

Background:
To better understand my project, you need to know about the aerodynamics of an airplane. Aerodynamics is the study of how forces act on a moving object. There are two main forces in aerodynamics: lift and drag. Both of these forces push air towards the surface of the wing, creating shear stress and pressure. Shear stress is the force applied to the surface of the wing. Pressure is the force applied perpendicular to the wing. (Plotkin, 2022)

- **Lift** is an upward force that causes pressure, which is needed to keep an airplane airborne by counteracting the gravitational pull on the airplane. The motion of the airplane flying through the air naturally causes pressure on the upper and lower surface of the airplane's wings. The air on the top of the wing moves faster than the air moving under the wing. This pressure difference, causing the lift, can be changed by altering the design of the airplane wing, such as by adjusting the camber (curvature) or the angle of attack of the wing. (Plotkin, 2022)

- **Drag** is an aerodynamic force that causes shear stress by pushing an object in the opposite direction. In airplanes, drag occurs from high pressure air on the underside of the wing escaping at the wingtip and causing vortices, or spinning air. These vortices pull the airplane back, creating the drag. The airplane then has to burn more fuel to maintain sufficient lift. (Plotkin, 2022) (Boldmethod, n.d.)

The best way to reduce the effect of vortices is to add winglets to the airplane wing. Winglets generate more lift perpendicular to the wind. This additional lift helps to fight the drag created by vortices. A plane with winglets has 20% less drag than one without them. (Larson, 2001)

Hypothesis:
In my experiment, I tested five different types of wingtips. The first was a wing without a winglet--this was my control design. The other four designs were Raked, Canted, Blended, and Split Scimitar. I measured the impact on lift and drag by running each through a wind tunnel and measuring the weight change before and after the wind tunnel fan was turned on.

My **hypothesis** was that the Split Scimitar winglet design would be the best at countering drag and generating lift because it would divert the high pressure air under the wing to a different place, and it has an upper winglet to reduce air from spilling onto the wing. The other wingtip designs have a much smaller winglet, so I thought they would be less effective at stopping the air from escaping at the wingtip and causing vortices that create drag.

Experiment Methods & Materials

Step 1: Designed and 3D Printed Airplane Wings and Engines
- Designed a 3D model of a wing using Blender software (blender.org). Each wing was 80 millimeters long with an angle of 7.5 degrees.
- Designed a 3D model of engine using Blender and attached 60 millimeters from the end of each wing.
- Designed 3D model of wing/engine stand using Blender (17 millimeters).
- Printed out wing/engine models with a 3D home printer.

Step 2: Designed, 3D Printed, and Attached Winglets
- Designed a 3D model of the four different types of winglets that I was testing; adjusted winglet model scale to match model wing size.
- Printed out winglets with a 3D home printer.
- Attached winglets to the end of each wing using glue and small amount of tape. (One wing did not have a winglet, because this was my control design.)

Step 3: Built a Wind Tunnel
- Designed and built a wind tunnel chamber with cardboard, clear plexiglass, and plastic straws. (Straws were needed to create uniform wind speed.)
- Placed small kitchen scale on the floor of the wind tunnel.
- Installed a small fan at the end of the wind tunnel.

Step 4: Conducted Experiment
- For each wingtip design, measured and recorded the weight of the wing on the scale when the wind tunnel was turned off.
- For each wingtip design, measured and recorded the weight of the wing when the fan was turned on at full speed.
- Repeated trial 10 times for each wingtip design (50 trials total)-- made sure to position wings in the same spot in the wind tunnel for all trials.

Step 5: Calculated Weight Change and Percent of Lift Created
- Weight Change- For each trial, subtracted the weight of the wing when the wind tunnel was turned on from the weight of the wing when the wind tunnel was turned off.
- Percent of Lift Created- For each trial, divided the weight of the plane when the wind tunnel was turned off by the weight change.

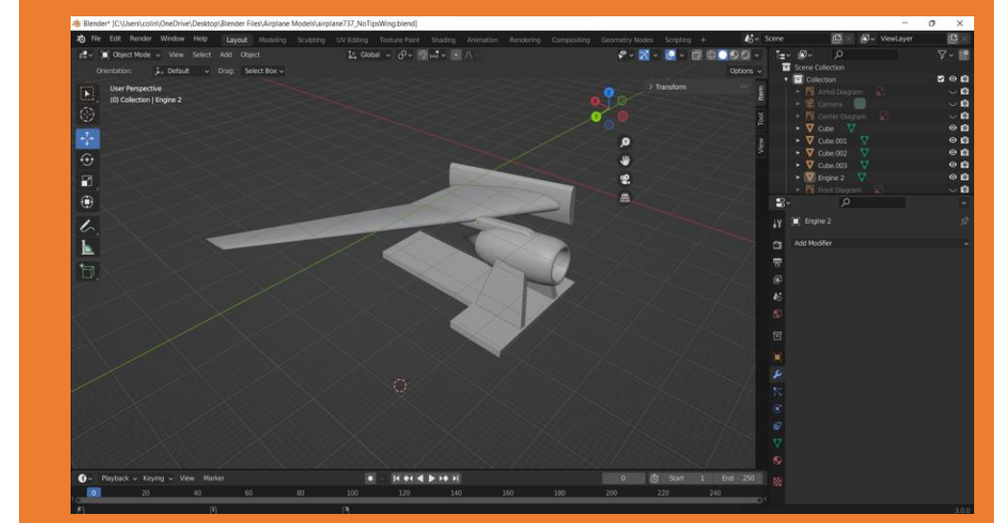


Photo Left:
Screen Shot of Blender Software

Photo by Colin Beckner

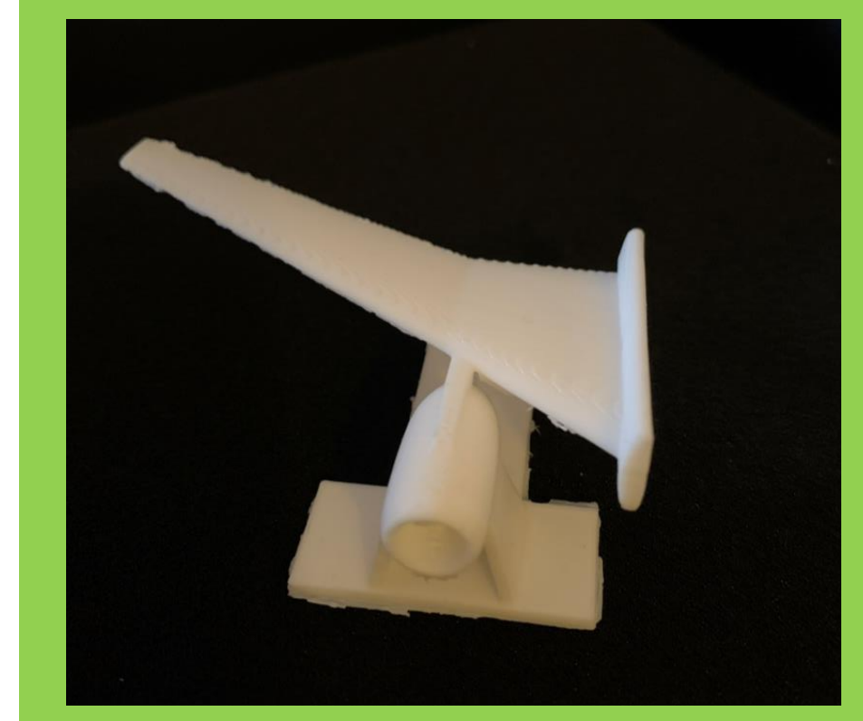
Photo Right:
Wind Tunnel Built for Experiment

Photo by Carly Kelly

Experiment Design

Levels of Independent Variable (Wingtip Style)

No Wingtip (Control)



Raked

Canted

Blended

Split Scimitar

Photos by Carly Kelly

Dependent Variable:
Percent Change in Weight When Run Through Wind Tunnel

Constants:
- Wing Design
- Wing Material
- Wing Size
- Fan Speed
- Position of Wing in Wind Tunnel
- Angle of Attack
- Mass and Shape of Stand

Experiment Data Tables & Charts

Summary

Trials	No Wingtip (Control)	Raked	Canted	Blended	Split Scimitar
Average % Change in Weight	**3.8%**	**3.9%**	**3.7%**	**3.3%**	**4.4%**
Range in % Weight Change	**1.9%**	**3.1%**	**1.9%**	**1.9%**	**1.9%**

No Wingtip (Control)

Trials	1	2	3	4	5	6	7	8	9	10	Avg	Range
Initial Mass (g)	10.7	10.7	10.7	10.8	10.7	10.7	10.8	10.7	10.7	10.7	**10.7g**	**0.1g**
Weight in Wind Tunnel (g)	10.4	10.2	10.3	10.3	10.3	10.3	10.5	10.3	10.3	10.2	**10.3g**	**0.3g**
% Change in Weight (DV)	**2.8**	**4.7**	**3.7**	**4.6**	**3.7**	**3.7**	**2.8**	**3.7**	**3.7**	**4.7**	**3.8%**	**1.9%**

Raked

Trials	1	2	3	4	5	6	7	8	9	10	Avg	Range
Initial Mass (g)	9.6	9.5	9.5	9.5	9.5	9.6	9.6	9.6	9.5	9.6	**9.6g**	**0.1g**
Weight in Wind Tunnel (g)	9.1	9.1	9.3	9.0	9.3	9.1	9.2	9.2	9.2	9.3	**9.2g**	**0.3g**
% Change in Weight (DV)	**5.2**	**4.2**	**2.1**	**5.2**	**2.1**	**5.2**	**4.2**	**4.2**	**3.2**	**3.1**	**3.9%**	**3.1%**

Canted

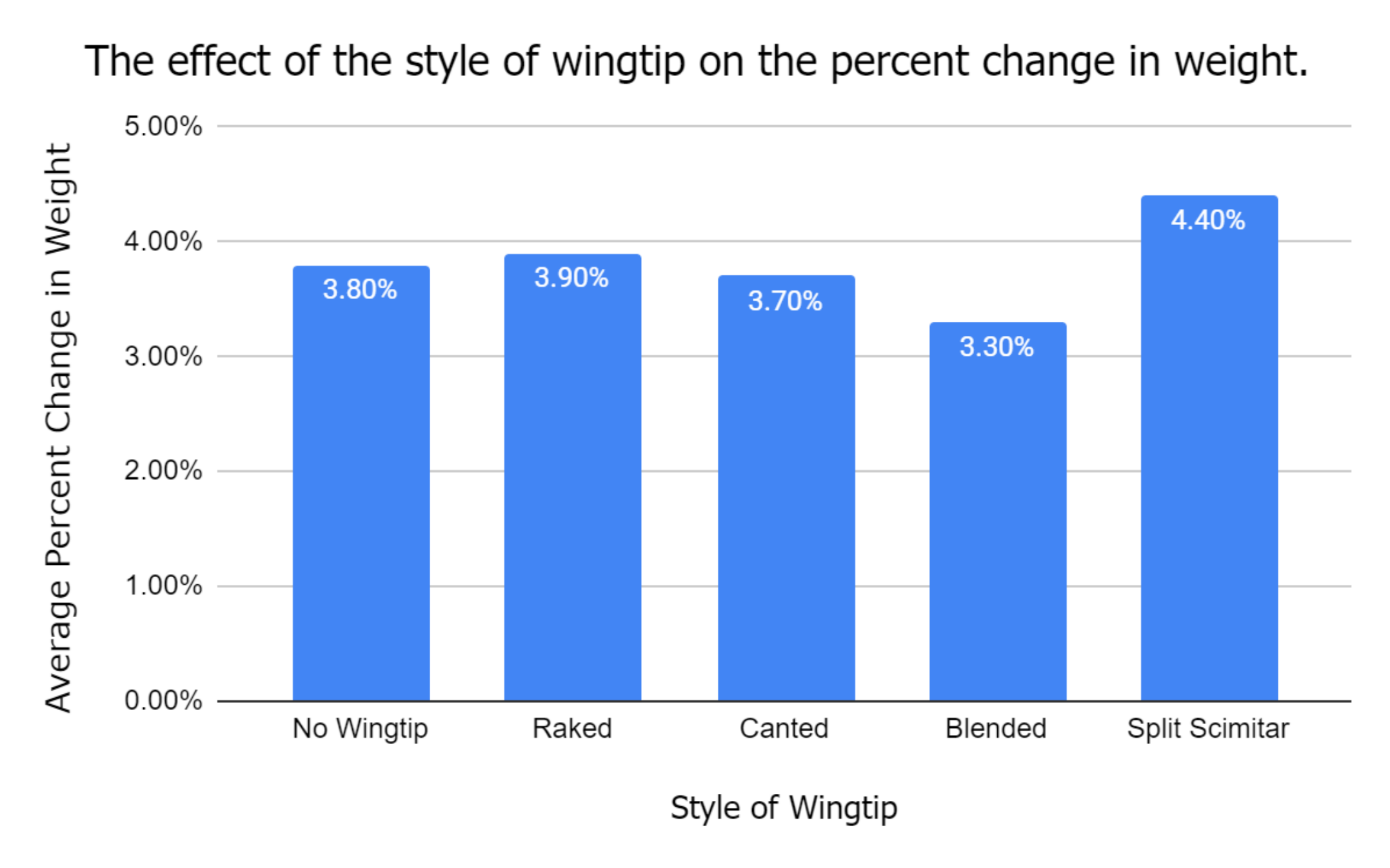
Trials	1	2	3	4	5	6	7	8	9	10	Avg	Range
Initial Mass (g)	10.7	10.7	10.7	10.6	10.5	10.7	10.6	10.7	10.7	10.7	**10.7g**	**0.2g**
Weight in Wind Tunnel (g)	10.3	10.4	10.4	10.2	10.1	10.3	10.3	10.2	10.3	10.2	**10.3g**	**0.3g**
% Change in Weight (DV)	**3.7**	**2.8**	**2.8**	**3.8**	**3.8**	**3.7**	**2.8**	**4.7**	**3.8**	**4.7**	**3.7%**	**1.9%**

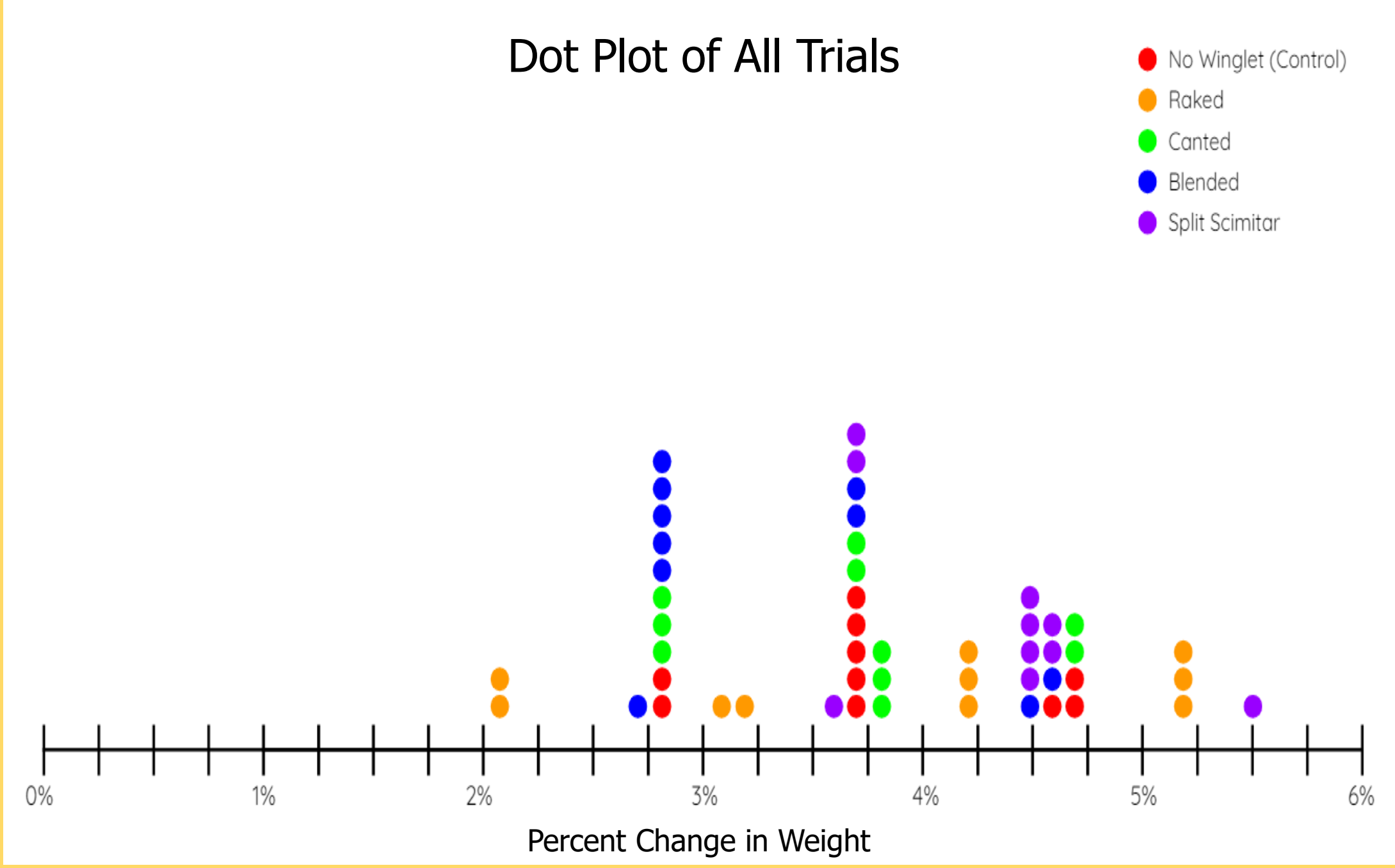
Blended

Trials	1	2	3	4	5	6	7	8	9	10	Avg	Range
Initial Mass (g)	10.9	10.9	10.9	11.0	10.9	10.8	10.9	11.1	10.8	10.9	**10.9g**	**0.3g**
Weight in Wind Tunnel (g)	10.6	10.6	10.6	10.7	10.6	10.4	10.6	10.6	10.4	10.4	**10.6g**	**0.3g**
% Change in Weight (DV)	**2.8**	**2.8**	**2.8**	**2.7**	**2.8**	**3.7**	**2.8**	**4.5**	**3.7**	**4.6**	**3.3%**	**1.9%**

Spilt Scimitar

Trials	1	2	3	4	5	6	7	8	9	10	Avg	Range
Initial Mass (g)	10.9	11.0	11.0	11.0	10.9	11.0	10.9	10.9	11.0	11.0	**11.0g**	**0.1g**
Weight in Wind Tunnel (g)	10.5	10.6	10.5	10.5	10.4	10.5	10.5	10.4	10.5	10.4	**10.5g**	**0.2g**
% Change in Weight (DV)	**3.7**	**3.6**	**4.5**	**4.5**	**4.6**	**4.5**	**3.7**	**4.6**	**4.5**	**5.5**	**4.4%**	**1.9%**





All images and graphics were created by the researcher unless otherwise noted

Experiment Results

Key Findings:
Overall, the **Split Scimitar** winglet design had the largest effect on the percent change in weight, averaging 4.4%. **This is shown on my bar graph.**

- The Blended winglet had the smallest effect, with an average percent change in weight of 3.3%. I find this interesting, because the Blended winglet and the Split Scimitar winglet are the most similar designs of all the winglets. The only difference is that the Split Scimitar has an additional fin on the side of the main winglet.

- The Raked, Canted, and Control (no winglet) averaged close together in percent change in weight, at 3.9%, 3.7%, 3.8% respectively. The Control design (no winglet) had the middle average percent change in weight among all five designs.

Data Patterns from Trials:
It is also interesting to look at the trial outcomes individually. **This is shown in my dot plot.** Overall, the **Split Scimitar** has the highest number of trials with percent weight change results above 3.82% (which was the overall average percentage weight change across all 50 trials). Additionally, it is the only design with no trial outcome with a percentage weight change value below 3.5%.

- The Raked winglet had the largest range in outcome values, with the percent of weight change ranging from 2.1% to 5.2%. In fact, the Raked winglet trials produced both the lowest percent change in weight and the second highest percent change in weight of all the designs.

- The other wing designs demonstrated more consistent results across each of their ten trials.

- Across all 50 trials, there was considerable overlap in the percentage weight change outcomes of each wing design. This makes it somewhat harder to draw conclusions from my experiment results.

Conclusion

Hypothesis Possibly Correct, But Somewhat Inconclusive:
In my hypothesis, I predicted that the Split Scimitar winglet design would be most effective at reducing drag. Based on my data, the results were inconclusive.

- **The Split Scimitar's average percentage change in weight was much higher than any of the other wing models, suggesting that I was possibly correct.** However, on the dot plot, the Split Scimitar's results overlapped with the results of the other wing models. This makes it harder to affirmatively conclude that the Split Scimitar design performs better than the other model designs.

- One reason why the data might have come out this way is that I was limited to only printing smaller-sized wing models with my home 3D printer. Also, the kitchen scale in the wind tunnel only measured to one-tenth of a gram, so the outcomes were rounded. The small size of the wing models, combined with the scale measurement limitations, may have made it harder to detect smaller differences in weight change.

- Another flaw in my experiment design was the weight of the different wingtip models. For some of the wing models, I had to use heavier materials (e.g., tape) to attach the winglet. This likely introduced variability in the weight measurement outcomes that was not attributable to the actual wingtip design.

Lessons Learned:
If I were to do this project again, I would make the wings larger and out of a more realistic material, such as metal. I would also try to increase the power coming from the fan. This might have created a more noticeable difference in the lift generated in the wind tunnel.

I might also improve the accuracy of my experiment by testing out the wings and winglets when connected to a full airplane fuselage. I could also expand my experiment to include other types of winglets.

How Does this Help the Aviation Industry?
Even though my wingtip design results were inconclusive, my project does demonstrate some fundamental lessons in aerodynamics. My experiment showed that adding a winglet can increase the amount of lift produced and counteract drag. However, for the winglet to work, it has to be built correctly. A winglet that is built incorrectly can actually create additional drag, which leads to more airplane fuel consumption and greater emissions pollution.

Airplane wing design is an important subject for aerospace engineers to continue to explore as they seek to create more fuel-efficient aircraft.

Works Cited

Larson, G.C. (2001). *How Things Work: Winglets*. Smithsonian Magazine. Retrieved from https://www.smithsonianmag.com/air-space-magazine/how-things-work-winglets-2468375/

Plotkin, A. (2022). Aerodynamics. In Word Book Advanced. https://www.worldbookonline.com/advanced/article?id=ar006080

This Is How Winglets Work. (n.d.). Boldmethod Flight Training. https://www.boldmethod.com/learn-to-fly/aerodynamics/how-winglets-reduce-drag-and-how-wingtip-vortices-form/

Ritchie, H. (2020). *Climate Change and Flying: What Share of Global CO2 Emissions Come from Aviation*. Retrieved from https://ourworldindata.org/co2-emissions-from-aviation

Did You Know?

Global aviation accounts for 1.9% of greenhouse gas emissions and 2.5% of carbon dioxide (CO_2) emissions! (Ritchie, 2020)