

Supporting a Wing with Hexagons in Order to Make It Lighter

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a. Introduction

This project examines if an object supported by a wing structure filled with hexagons will be more mass efficient than solid filled support structure. Aircraft are a large source of greenhouse gas emissions that lead to climate change. One way to reduce these emissions is to decrease the mass of airplanes allowing their engines to do less work. 3D printing is a modern tool used to prototype and develop numerous inventions. Unlike traditional machining 3D printers build up instead of cutting away freeing engineers from traditional limitations. A regular hexagon is one of the strongest and the most efficient shapes known. Due to its high ratio of area to perimeter it uses little material and yet still has immense strength, making it ideal to reduce mass. These two concepts were put together to test in this project if the support structure of a wing could be made more mass efficient. Sample wings were designed with a wing internal structure and then printed on a 3D printer with 1 set filled 25% with hexagons and the other filled fully. After their mass was logged, the wings were taken to a weight table which measured the force required to break each wing when deflected. The solid filled wings failed at an average of 17.12 N/g and the Hexagon filled at 19.13N/g, a 2.79N/g difference. A ttest concluded that the probability these data was random was <1%. If these data scales to the size and material of Airplanes, it could dramatically reduce mass.

b. Background

Airplanes are a leading contributor of the greenhouse gas emissions that cause global warming. While the airplane industry produces less emissions than cars, making up only 9% of the emissions of US transportation, it still accounts for a massive amount of the world's emissions. According to the center for biological diversity if the airplane industry were a country its emissions would be 6th in the world (Center for Biological Diversity). Furthermore, aviation is one of the largest growing emissions producers making this problem worse (EESI). Because of this it is vital that airplanes be made more fuel efficient both to reduce current emissions and make planes using renewable energy more viable. One way to do this is by reducing the mass of the airplane and its parts.

3D printing has become a modern tool used to prototype, develop and even innovate numerous inventions. The ability to 3D print frees engineers from traditional limitations (Morris, 2017). One field where the benefits of 3D printing are being realized is aerospace. Optimizations to reduce weight and cost as well as keeping strength are required to make aircraft more efficient (Yutko, Jenson, 2017). One area of aerospace that could be better optimized is the wing.

A way to better optimize any part of an aircraft is reducing weight. Airbus, one of the largest producers and designers of aircraft across the world calls reducing weight the “holy grail of aerospace engineering” (Airbus). Airbus, in certain parts of their engines, already have 3D printed titanium parts that have a weight half that of the former, non 3D printed part (Airbus). The reason 3D printed parts are lighter is that they use less material; this is because they use naturally strong shapes like the hexagons or triangles to make up parts rather than the parts being solid. In addition to the optimization in weight, 3D printing allows for a substantial reduction in

material usage. This is because less material is used in the final part and the creation of any parts is additive rather than subtractive leaving almost no waste (Airbus).

The basic structure of a modern aircraft wing is a spar or spars connected to the fuselage at the base of the wing and then along the spar are various ribs in the shape of the airfoil that are perpendicular to it. The wing is then enclosed with aluminum. The ribs and spar are what can be made more efficient with 3D printing.

To make the wings more efficient it is vital to pick a shape to fill them with. A regular hexagon is one of the strongest and the most efficient shapes known (Kosmala, Kemmins, 2015). Hexagons have the highest area to perimeter ratio of any shape that can tessellate. This makes them ideal for situations where strength is required with little material or weight (Kosmala, Kemmins, 2015). Previous research (Kmetko 2019-20 Science Fair) , has shown that hexagons when deflected are stronger relative to their mass. This earlier research, along with other properties of hexagons make them ideal for reducing weight and keeping strength. To produce a hexagon is not as economical as other shapes such as the square, because of its perimeter to area ratio there is much more material waste. Because 3D printers are additive meaning they build everything instead of removing like standard machining less material is lost, and they allow great design freedom (Bortz 2003). One example is a 3D printer allows the tessellation of hexagons even when they are cut off in a material making it easier to add them than more dated techniques. In addition, modern 3D printing advances allow for 3D printing in materials other than plastic, like various metals making it even easier to put Hexagons in a wing (GPI).

c. Research Question

Can hexagonal supports make a wing that can handle more force per unit mass than a traditionally supported (solid) wing.

d. Hypothesis

When supported by hexagons an airplane wing will be able to withstand more force for its mass than the full filled wings due to the strength of the shape and its small perimeter to area ratio.

e. Methods

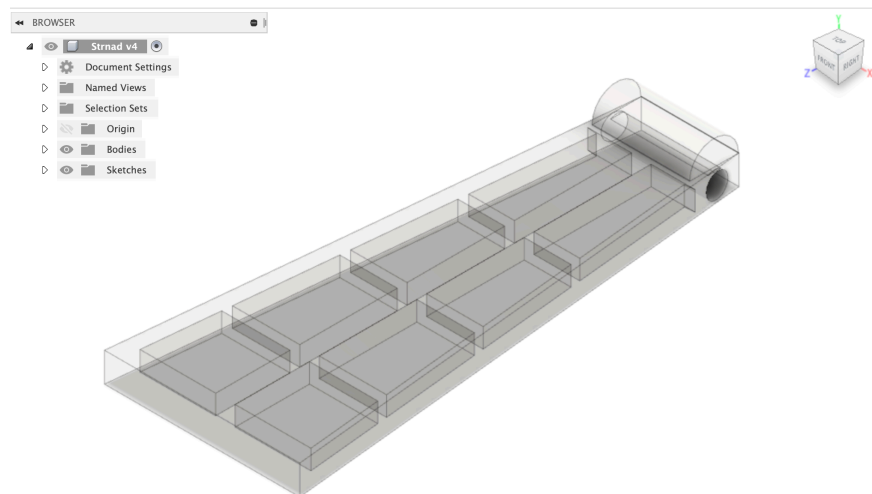


Figure 2: Wing in CAD with opacity turned down to show the internal structure

1. Design

The wing analog was designed 6,, thick with a trapezoidal shape. On the inside was a skeleton with a center spar and ribs. At the end of the wing was a half cylinder with a 5mm radius and a hole with a 2mm radius (Figure 2).



Figures 3 & 4: The school's weight table that was used for testing and the mount with a wing in it

2. Testing

Having designed the wing, the number of wings to test was set at seven of each type. 10 of each wing were printed (three extra for the first test and the force gauge not registering). The first eight of each were printed in a total of four batches to keep climate conditions similar. The remaining two of each type were printed a month later

After the wings were printed one of each type was taken to the weight table. This test was to make sure the table was working, could break the wing, and test the mount. After eye protection was put on the wing was mounted from both sides using a 4mm diameter steel bar (Figure 4). The mount was set up to keep the data consistent.

When testing, first each wing was massed. Then eye protection put on and the wing mounted to the table. After this the force gauge was reset and set to peak/max force and any initial value logged. The force was then increased gradually until the wing broke. Once it broke the peak force was logged and any pieces on the ground picked up.

After the data was collected the force required to break each wing was divided by the mass to get the force per unit mass.

Risk and Safety:

When working on my project at school me and the person helping me will be wearing masks and following social distancing guidelines. The biggest hazard of this project is when the wing fails shards falling off into eyes. To minimize this risk, I will test with the designer and builder of the weight table device and we will both be using eye protection.

f. Results

On average the Hexagon wings held 2.79 N/g more than the full wings (Figure 5; ttest <0.001).

The Hexagonal supported wings held on average $19.9\text{N} \pm 0.37\text{ SE}$ and the fully filled wings held on average $17.13\text{ N/g} \pm 0.34\text{ SE}$ (Figure 5).

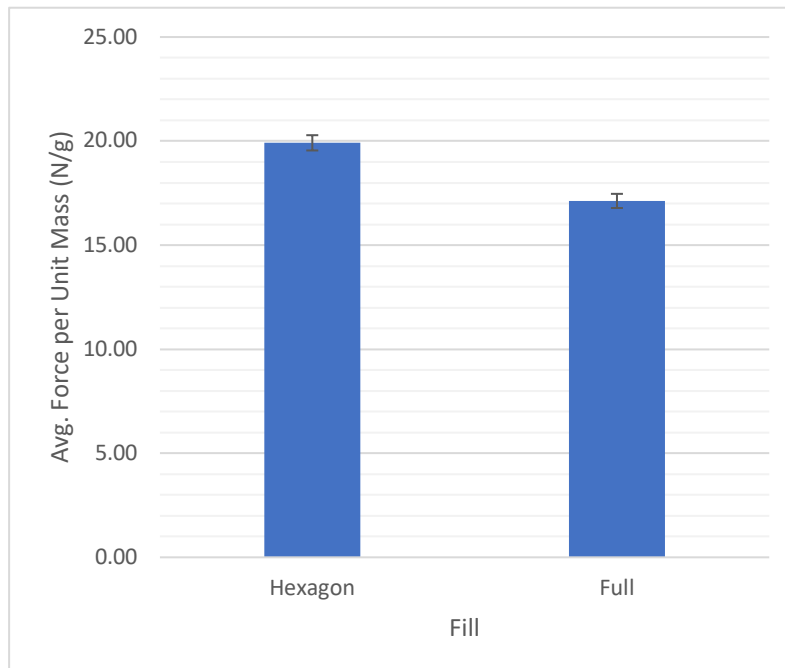


Figure 5: The average force per unit mass each wing could hold. It shows the hexagon filled wings holding on average 2.79 more N/g. ttest $p < 0.001$, error bars represent $\pm$ one standard error.

g. Discussion

The wings that had a 25% hexagonal infill on average were able to sustain more force per unit mass before failing than the fully filled wings. The average force per unit mass sustained was an average of 2.79 N/g higher for these wings. This supports the hypothesis of this experiment that the 25% hexagon filled wings would be able to sustain more force per unit mass. A ttest performed on these data further supported the hypothesis of this experiment reporting the the chance the data was due to random chance was $<1\%$ This means that if this experiment were run again the results would likely have the same outcome.

If these data scales to the size and material of planes this could reduce the mass of wing structures while maintaining the same structural integrity. This would increase the fuel efficiency of the aircraft because of the reduced mass and that decrease would likely decrease emissions. With metal 3D printing already in existence and developing further this type of wing could be produced out of the same material as many aircraft not just out of plastic and used to reduce weight.

However, there are some limitations on these data. First, on the macro scale there is no evidence either that these data will scale to a plane or to plane materials or not. In addition, some modern airliners like the Boeing 787 are build using composite carbon fiber materials (Boeing). This also reduces mass and could make any ramifications of these data obsolete. However, the combination of these if posable would further reduce mass.

There are a few posable sources of error for these data. The first is that all the wings were not printed at the same time in the same conditions. Both types were printed in 2 batches within the same week keeping the conditions as controlled as posable but do to the long nature of 3D printing, they could not be printed at the same time. Furthermore, because the force gauge did

not record some data more wings had to be printed about a month later. The different temperatures, humidity and other conditions could have affected the data. However, both types of wing were printed in alternating order and both types had to be re-printed a month later making it more likely that the climate would have increased the variability of the data rather than the difference.

Another source or error is the weight table itself. Because it is a generic, all-purpose weight table made by a class at the school I worked in it doesn't have proper jigs to line up things being tested. A different location for a wing could skew the data because the force applied to the wing is applying torque to the point where it breaks and a change in length would affect that torque and the data. This error was minimized by measuring the length every time to keep it the same and like the error of climate it could happen to both types of wings making it more likely that this problem would not skew the whole set of data.

h. Conclusion

The data in this experiment supported the hypothesis. The 25% hexagon filled wings sustained an average of 2.79 N/g over the full wings which is a 26% increase. The ttest performed on these data shows their probability of being random to be low. Some future steps could be to scale up this testing to the size of an actual plane or testing of this method of reducing weight over carbon fiber both in terms of reduction of weight and cost.

i. Acknowledgements and References

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