More Efficient Helicopter Blades Based on Whale Tubercles

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Summary

The goal of this project was to increase the efficiency of the helicopter blades on the Double Horse 9053 RC Helicopter by adding tubercles based off those of a humpback whale. Increases in efficiency were determined by measuring the wind speed of control blades at three different speeds and then comparing these speeds to the wind speeds of tubercle-designed blades. The control blades had no tubercles while the tubercle blades had a set of 8 or 4 tubercles per blade. After analysis of increases in wind speeds based off the control, it was found that the 8-tubercle blades often had an increase in speed. The 4-tubercle blades had a decrease in output. The data supports the idea that the number and placement of tubercles matters. This small-scale experiment shows potential for improvements in the efficiency of full-scale helicopters.

Introduction

Biomimicry is the science of copying nature to produce more efficient and useful products. Biomimicry makes use of the millions of years in which evolution has been slowly perfecting various aspects of natural life. For example, when the Shinkansen Bullet Train in Japan goes through tunnels, it creates a large thunder clap from the air pressure differences it creates in the tunnel. Looking at animals that moved elegantly at high speed though different mediums produced a train modeled after the beak of a Kingfisher, a bird that dives headfirst into water to catch prey but makes a minimal splash. The Biomimicry Institute reporting on the study noted that “modeling the front-end [sic] of the train after the beak of kingfishers… resulted not only in a quieter train, but 15% less electricity use even while the train travels 10% faster.” [1]

Dr. Frank Fish, founder of Whale Power, first noticed the strangeness of tubercles on the tail of the humpback whale when he was in a gift shop. He saw a model of a tail and assumed that the artist got the model wrong because there were tubercles on the front of the tail, not the back like he expected. When he found out that the tubercles did actually go on the front, he was fascinated because he knew that they must have evolved like that for some purpose. After some testing, Dr. Fish found that humpback whales have evolved tubercles on their tails in order to increase efficiency while swimming [2]. The whale tubercles improved the effective angles of the fin without stalling, reduced drag, and increased lift. When the humpback whales search for food, they have to take relatively tight turns in order to move underneath their prey [3]. The benefits from the decrease in stalling angles means that the whale can position its fin at sharp angles without losing the ability to push itself through the water. The increase in lift from the tubercles means that with each push from the fin, more power is generated. The decrease in drag means that as the whale moves along, there is less resisting force to its movement. Drag is the term for friction between a solid object and a liquid or gas object. Just as a hockey puck will slide across ice easier than wood because the friction between a hockey puck and ice is less than that of a hockey puck and cement, the tubercles act as a type of “ice” or a way to reduce friction between the whale and the water. The tubercles work by creating vortices behind the bumps on the fin. In turn, the different parts of the fin change the distribution of pressure over the fin. This pressure distribution means that these different areas would stall at various times, but as a whole, the fin maintains its stability through a wide breadth of angles [4]. The same principles could be applied to turbine blades: friction between the air and blade would be reduced, operating angles would be broader, and less wind would be required to turn a turbine. As a result, Dr. Fish founded the company Whale Power, which has pioneered tubercle technology. They have developed various fans and wind turbines based on tubercle design, all of which have shown improvements in efficiency.

Tubercles could possibly improve any type of blade or fin moving through some sort of medium, be it water or air. Helicopter blades fit this exact criteria. We wondered if they could also be made more efficient by the addition of tubercles, thereby contributing to the Green Earth movement. We wanted to design something that could save fuel and reduce emissions while being able to fly, maneuver, and accelerate at the same, if not better, level and quality.

This research study was made in the hopes that more efficient helicopter blades can be developed. Adding tubercles to the RC Helicopter blades was hypothesized to produce a higher wind speed than regular blades under the same conditions. A higher wind speed would indicate a higher efficiency because a higher wind speed at a base energy input implies the idea that equal wind speeds could be produced by the new blades on a helicopter using less energy than conventional means.

Testing on a real helicopter is prohibitively expensive so we used a high quality RC Helicopter as a model. The Double Horse 9056 RC Helicopter fit the requirements for price limit, size, and accuracy. We decided to make the tubercles out of FIMO Soft Clay, which is not porous and would allow for the least air resistance. It is also easy to mold and to attach to the blades. The design of the tubercles had to go on the front of the blade like the whales’ did. They also had to lie low enough so as to reduce extra air resistance while spinning. We varied the number of tubercles to see what effect that would have but kept them evenly spaced so that they covered the length of the blade.

The results partially support the hypothesis that adding tubercles to helicopter blades would increase their efficiency. On one hand, the 8-tubercle blades showed an increase in output across the board, creating between a 1.54% to 4.20% increase in average windspeed per input level. On the other hand, the 4-tubercle blades had a decrease in output, creating between a 1.44% and 3.38% decrease in average windspeed per input level. These results match what is known about tubercles. Our data suggests that the closer the tubercles are together, the better the outcome. This correlation can be tied to the fluid dynamics physics that apply to tubercle-blades. If tubercles are too far apart, the vortices that create the differentiating air pressures on the blade become impossible to create. These results point to the need for tubercles to be close together. It also helps to show that there is a point at which the tubercles stop helping but actually decrease efficiency.

Results

This experiment was conducted to see if tubercle technology could be applied to helicopter blades to make them more efficient and thus eco-friendly. The hypothesis was that adding tubercles would improve the efficiency of the helicopter blades. The Double Horse 9053 RC Helicopter was strapped down to a base which was clamped onto two desks (Figure 1,2). This kept the helicopter stationary and stable while the blades rotated. Control (normal) blades, 8-tubercle blades, and 4-tubercle blades were all tested at three speed settings in three independent experiments with three trials per experiment (for a total of nine trials) (Tables 1, 2). In each experiment, a new set of tuberlces was used.The tests measured the wind speed forced down by the different blades through an anemometer that was attached to the base.

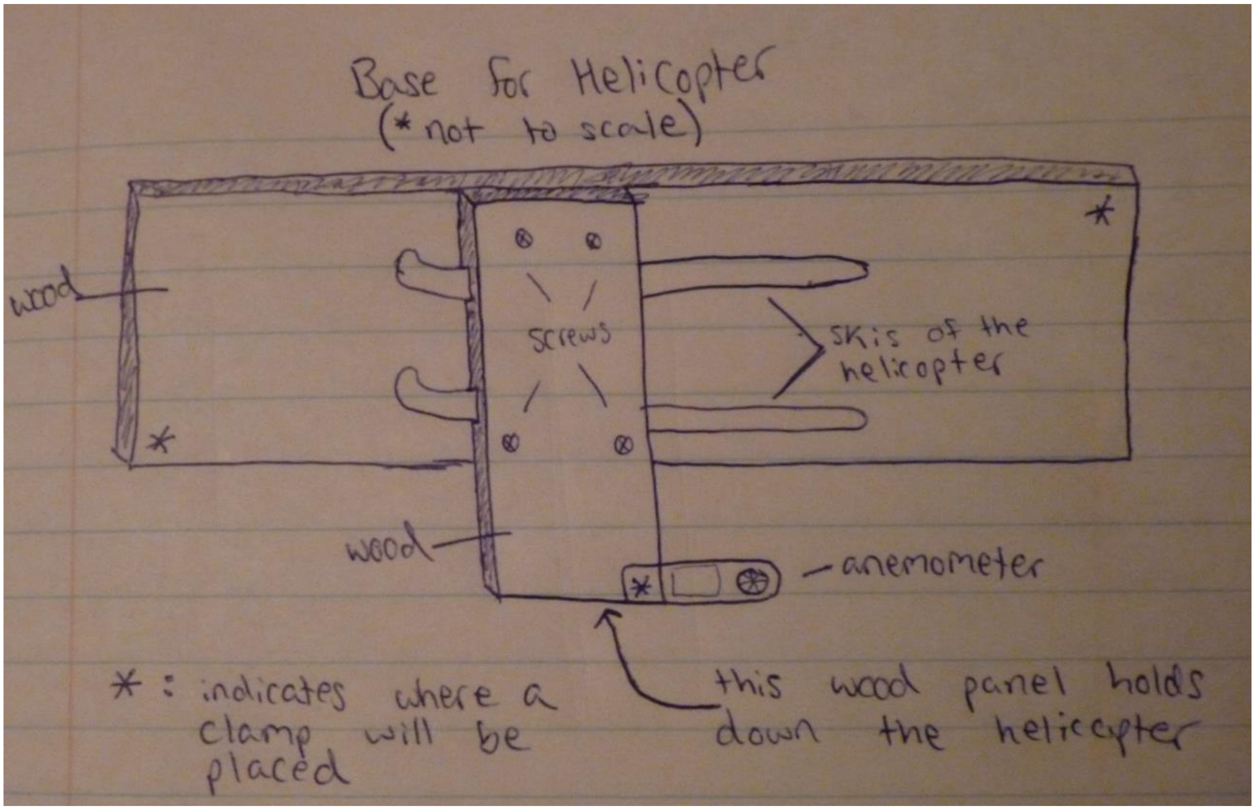

Figure 1: A diagram of how the base of the helicopter was made and how it supported the helicopter.

Figure 2: Helicopter Setup (A) A diagram of the set-up of the experiment. The helicopter attached to the base was clamped to two desks. Then the trials were conducted. (B) The Double Horse RC Helicopter is in the supporting frame. The wood over the skis holds the helicopter to the larger board while the blades are spinning and the larger board is clamped to two desks to ensure stability. In this image, the helicopter has 4-tubercle blades. (C) The set of 8-tubercle blades. The tubercles are made out of yellow FIMO clay. (D) A 4-tubercle blade is above the anemometer. The anemometer is clamped to the same frame the helicopter is so that its position is consistent.

Experiment 1

Trial 1			
Speed	Control	8-Tubercle	4-Tubercle
1	3.5	3.8	4
2	3.9	4.2	4.3
3	4.55	4.8	4.9
Trial 2			
Speed	Control	8-Tubercle	4-Tubercle
1	4.2	4.7	4.2
2	4.9	5.1	4.9
3	5.1	5.3	5.3
Trial 3			
Speed	Control	8-Tubercle	4-Tubercle
1	4.2	4.7	4.2
2	4.7	5.1	5
3	5	5.45	5.45

Experiment 2

Trial 4			
Speed	Control	8-Tubercle	4-Tubercle
1	4.8	4.9	4.4
2	5.3	5.2	5.1
3	6	6	5.6
Trial 5			
Speed	Control	8-Tubercle	4-Tubercle
1	4.9	4.9	4.2
2	5.3	5.1	4.7
3	6	6.2	5.3
Trial 6			
Speed	Control	8-Tubercle	4-Tubercle
1	4.9	4.7	4.3
2	5.3	5.1	4.9
3	5.9	5.6	5.1

Experiment 3

Trial 7			
Speed	Control	8-Tubercle	4-Tubercle
1	4.2	4.2	4.1
2	4.55	4.7	4.9
3	4.9	5.3	5.2
Trial 8			
Speed	Control	8-Tubercle	4-Tubercle
1	4.1	4.2	4
2	4.4	4.7	4.3
3	5.1	4.9	5.1
Trial 9			
Speed	Control	8-Tubercle	4-Tubercle
1	4	4.2	3.8
2	4.9	4.55	4.2
3	5.1	5.1	4.7

Table 1: Windspeed Data from Three Experiments Recorded speeds of each type of blade for each speed and each trial in miles per hour. Trials 1-3, 4-6, and 7-9 are from three independent experiments.

	8-Tubercle	Trial 1	Trial 2	Trial 3		4-Tubercle	Trial 1	Trial 2	Trial 3
Experiment 1	Speed 1	8.57	11.90	11.90		Speed 1	14.29	0.00	0.00
	Speed 2	7.69	4.08	8.51		Speed 2	10.26	0.00	6.38
	Speed 3	5.49	3.92	9.00		Speed 3	7.69	3.92	9.00
		Trial 4	Trial 5	Trial 6			Trial 4	Trial 5	Trial 6
Experiment 2	Speed 1	2.08	0.00	-4.08		Speed 1	-8.33	-14.28	-12.24
	Speed 2	-1.89	-3.77	-3.77		Speed 2	-3.77	-11.32	-7.55
	Speed 3	0.00	3.33	-5.08		Speed 3	-6.67	-11.67	-13.56
		Trial 7	Trial 8	Trial 9			Trial 7	Trial 8	Trial 9
Experiment 3	Speed 1	0.00	2.44	5.00		Speed 1	-2.38	-2.44	-5.00
	Speed 2	3.30	6.82	-7.14		Speed 2	7.69	-2.27	-14.29
	Speed 3	8.16	-3.92	0.00		Speed 3	6.12	0.00	-7.84

Table 2: Percent increase or decrease in wind speed from control to tubercle blades.

The results showed that adding tubercles to the blade had a varying effect depending on which type of blade was used. All the 8-tubercle blades had an average increase in output (Figure 3) while all the 4-tubercle blades had an average decrease in output (Figure 4). As seen in Tables 3 and 4 the highest change in performance was Speed 1 with the 8-tubercle blades, which had an increase of about 0.167 mph. In Table 4, it is clear that the 8-tubercle made a change in the output. Speed 1 had a 4.2% increase. The 4-tubercle blade hindered the efficiency of the blade. Table 4 shows that for the 4-tubercle blade, all the speeds had an average percent decrease. It ranged from a 1.44% decrease in Speed 3 to a 3.38% decrease for Speed 1. These data show that there is a significant relationship between the number of tubercles and the efficiency that can be achieved. From the data, there are conclusive results that the 8-tubercle blade increases efficiency while the 4-tubercle blade decreases efficiency.

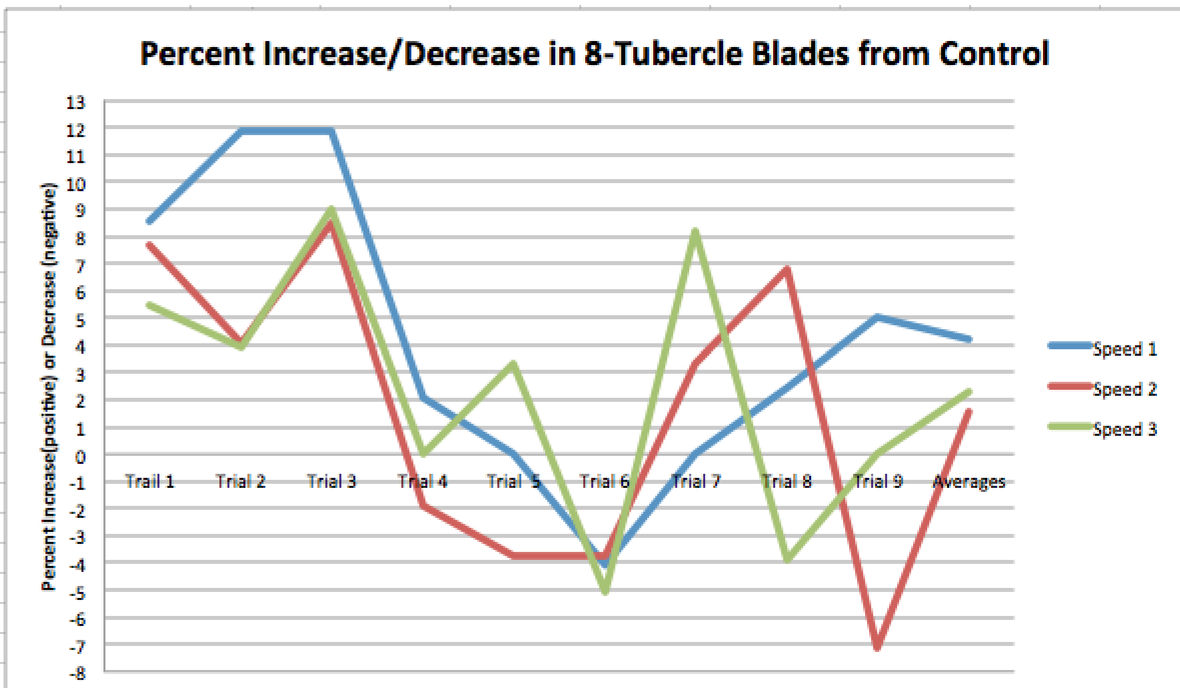

Figure 3: Percent increase or decrease in wind speed the 8-tubercle blades had from the control blades.

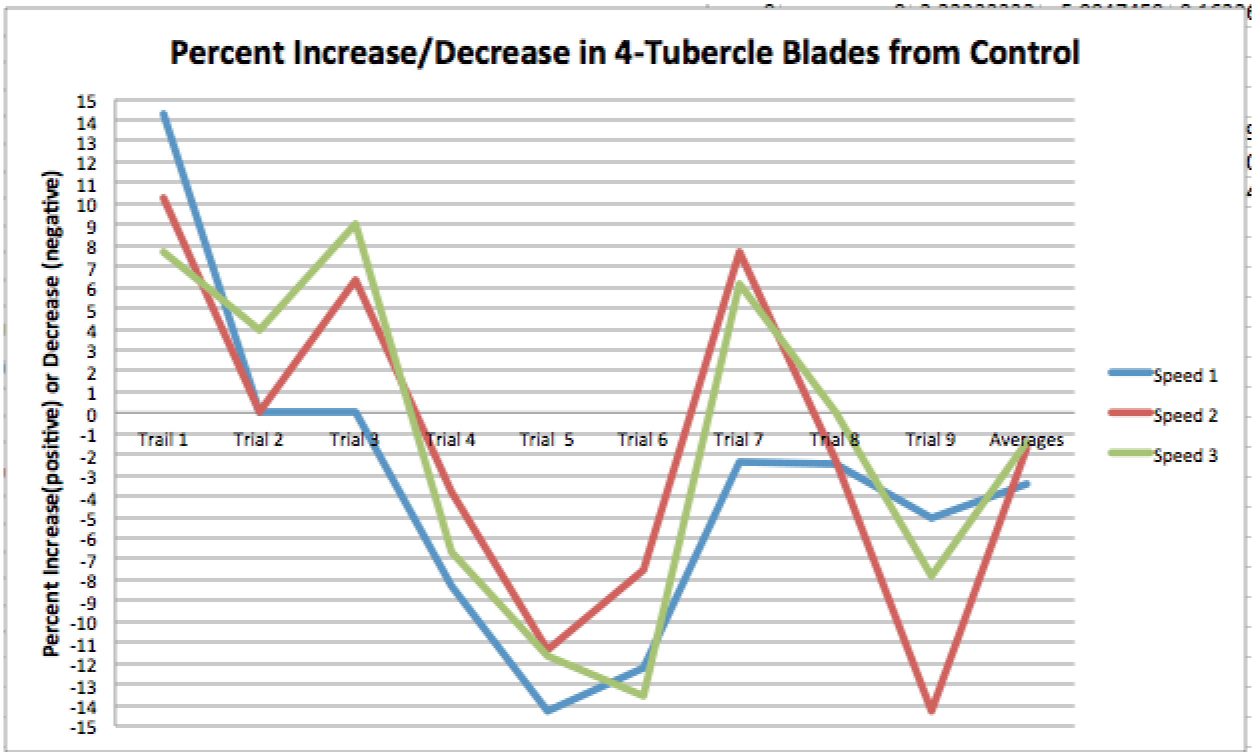

Figure 4: Percent increase or decrease in wind speed the 4-tubercle blades had from the control blades.

	8-Tubercle	Trial 1	Trial 2	Trial 3	4-Tubercle	Trial 1	Trial 2	Trial 3
Experiment 1	Speed 1	0.3	0.5	0.5	Speed 1	0.5	0	0
	Speed 2	0.3	0.2	0.4	Speed 2	0.4	0	0.3
	Speed 3	0.25	0.2	0.45	Speed 3	0.35	0.2	0.45
Experiment 2		Trial 4	Trial 5	Trial 6		Trial 4	Trial 5	Trial 6
	Speed 1	0.1	0	-0.2	Speed 1	-0.4	-0.7	-0.6
	Speed 2	-0.1	-0.2	-0.2	Speed 2	-0.2	-0.6	-0.4
	Speed 3	0	0.2	-0.3	Speed 3	-0.4	-0.7	-0.8
Experiment 3		Trial 7	Trial 8	Trial 9		Trial 7	Trial 8	Trial 9
	Speed 1	0	0.1	0.2	Speed 1	-0.1	-0.1	-0.2
	Speed 2	0.15	0.3	-0.35	Speed 2	0.35	-0.1	-0.7
	Speed 3	0.4	-0.2	0	Speed 3	0.3	0	-0.4

Table 3: Differences between the control and the test blades in miles per hour.

8-Tubercle	Average difference in speed (mph)	Average percent change in speed
Speed 1	0.166666666666667	4.20
Speed 2	0.0555555555555556	1.54
Speed 3	0.111111111111111	2.32
4-Tubercle	Average difference in speed (mph)	Average percent change in speed
Speed 1	-0.177777777777778	-3.38
Speed 2	-0.105555555555556	-1.65
Speed 3	-0.111111111111111	-1.44

Table 4: Average differences between blades and control for each blade type and speed in miles per hour and average percent increase or decrease in output wind speed from each blade type and speed.

Discussion

The results partially support the hypothesis that adding tubercles to helicopter blades would increase their efficiency. On one hand, the 8-tubercle blades showed an increase in output across the board. On the other hand, the 4-tubercle blades had a decrease in output. These results match what is known about tubercles. Tubercles were specifically designed to improve the efficiency of fan or blade-like objects moving through some sort of medium. This effect has been seen with humpback whale tails moving through water and wind turbines made by Whale Power moving through air. Tubercles in nature are successive, meaning that there are numerous tubercles all next to each other. Our data suggests that the closer the tubercles are together, the better the outcome. This correlation can be tied to the fluid dynamics physics that apply to tubercle-blades. If tubercles are too far apart, the vortices that create the differentiating air pressures on the blade become impossible to create. To create the vortices, there cannot be large amounts of space between tubercles. These results point to the need for tubercles to be close together. It also helps to show that there is a point at which the tubercles stop helping but actually decrease efficiency. Because the 8-tubercle blades had much less space between tubercles, they were a closer model to real tubercles. Because they were a closer model, they had an overall increase in output.

The results of Whale Power's studies and testing from actual whales were positive enough to warrant further studies that would explore the possibility of application to a real helicopter. First, testing would need to occur on a blade spinning motor that enabled finer speed adjustments and more definite speed levels. Also, a mold for the tubercles would be made that would allow them to be of a consistent size and shape. Then the number of tubercles, shape of the tubercles, tubercle position, and effects at different speeds could all be tested to find the most efficient combination. After confirming the most efficient design, the next step would be to apply the technology to life-sized helicopters. The tubercles should be part of the blade, not just attached, for full production.

The tubercle dimensions most likely varied from that of a humpbacks'. Research about tubercles resulted in little specifications about how to make them or the proportions to blade or fin size. To design the tubercle dimensions, only pictures and common sense were used. The tubercles had to lie low in order for the aerodynamics of the blade to be relatively sound. They were 1 cm long because that way the tubercle covered a significant part of the front of the blade but left the back of the blade completely regular. They were 3 mm wide because this width gave the tubercle a nice round shape rather than being too wide and flat or too skinny and pointy. These dimensions resulted in a tubercle that would change the dynamics of the blade but would not be too heavy for the helicopter motor to have a significant decrease in power or obviously ruin the aerodynamics of the blade.

By looking at the standard deviation of trials within each day of experimenting (three trials over three days) and the standard deviation between the averages of each day of experimentation, the quality of the data can be assessed. Between each set of experiments, there was a noticeable standard deviation (Figure 5D). The statistics show that while the trials did deviate, it was not extreme or unpredictable. The variation between each day of experimentation probably stemmed from the fact that the helicopter was battery-powered. Each new day of experimenting, the helicopter battery may have been at different power levels. On some days, the helicopter could put out higher wind speeds in general and shift the data up while on other days the reverse could happen. The variation between data within each experiment was much smaller (Panels A, B, and C in Figure 5). With the exception of the first day of experimentation, the standard deviations were on the low end. A possible reason for the higher variability in the first day of experimentation was because it was the first time the project had been fully tested. By the time of the second experiment, there was a familiarity with the project that made collecting data easier and more precise. A factor that could have added to all the variation could have been the anemometer. The anemometer used was not high-end and behaved spottily at times. For example, it would jump back and forth between two numbers like 4.5 and 4.7 without ever settling on one indefinitely. A better anemometer that could have just read the wind speed at a consistent "4.620 mph" would have made data collection much more accurate and reliable. Having a helicopter with a power source connected to a constant power would eliminate any variability that came from the ability of the helicopter to perform on any given day.

Figure 5: All four panels show the raw windspeeds taken during measurement. Panels A, B, and C correspond to individual experiments (each experiment contains three trials). The average windspeed is measured in miles per hour on the y-axis and was calculated by averaging the three windspeeds found in each of the three trials for the particular experiment. The three speeds tested are on the x-axis and the three different colors represent the three types of blades. The black error bars represent the standard deviation of the trials within each experiment. Panel D shows the overall windspeeds between all the experiments. The windspeeds plotted are the average of the three experiment's averages.

Tubercle technology is a worthwhile biomimicry application. The numerous blade technologies that could be improved present an exciting future. For helicopters, the addition of tubercles is a realistic application that could raise the efficiency of the helicopter by few percent. This few percent however means millions of dollars in gasoline and huge reductions in waste products. The number or closeness of tubercles plays an important role in efficiency, just like in humpback whales. The experiment shows that investment in more research for helicopters with tubercle-blades is viable and would lead to productive results.

Materials and Methods

The Double Horse 9053 RC Helicopter (Double Horse) is a battery-powered helicopter. The blades are 25 cm long and ranged 1.3 cm and 2.2 cm in width at each end to 4.4 cm in width at its widest.

Base construction

Constructing a base for the helicopter was the first step (Figure 1). The helicopter needed a base so that it would not move up or shake when the blades were spinning. The base makes sure that the helicopter remains static; therefore, the wind speeds can remain constant. A base for the Double Horse 9053 RC Helicopter was built out of wood and screws. The skis of the helicopter were held to a thick piece of wood by a thinner piece of wood placed over the skis but under the body of the helicopter. Another long piece of wood was placed perpendicular to the main base and attached by screws to hold the anemometer (Model HP-816A, Holdpeak). An anemometer is a device for measuring wind speed. For testing, the base was clamped to two desks and an anemometer was clamped to the area on the base designed to hold it (Figure 2A, B).

Tubercle construction

The tubercles were made out of yellow FIMO Soft clay (FIMO). There were two types of blades: the 8-tubercle and the 4-tubercle. The tubercle blades were a separate set from the control blades and were only used with the tubercles on. The 8-tubercle blades had 8 tubercles on each blade spaced 1.7 cm apart, so 16 in total (Figure 2C). In total, the two 4-tubercle blades had 8 tubercles (Figure 2D). The tubercles on the 4-tubercle blade were spaced 3.7 cm apart. The tubercles were about 1 cm long, 3 mm wide, and 2 mm tall. They were made slightly bigger toward the base of the wing and smaller toward the end. They took up about a third of the blade toward the inner part of the blade (around 3 cm wide) and about half the blade toward the outer end around 2.5 cm wide). The tubercles were all handmade and varied slightly each time because a mold for the tubercles would have prevented them from sticking to the blade correctly. The purpose for leaving the clay tubercles unbaked was that it allowed them to be pressed onto the blades and stick without using additional adhesive. In separate tests, the 8-tubercle and 4-tubercle blades were attached and the same process was completed as with the control blade. Three trials of each test were completed using new tubercles each time in order to ensure repeatability. In total, nine trials were preformed over a series of three tests.

Blade speed testing

The blades were tested at three speeds and the wind speed below the blade was recorded. The three speeds were dictated by the first three notches in power on the helicopter's remote. In order to keep the speed for each trial consistent, the first three speeds on the remote were used each time. Percent increase and decrease were calculated using the following formula:

$$Percent = \frac{Tuber\ Speed - Control\ Speed}{Control\ Speed}$$

(Eq 1)

Averages were taken by summing up the wind speeds of all the trials in a particular group and then dividing the total sum by the number of trials included. The standard deviation was taken using the formula

$$\sigma = \sqrt{\frac{\sum(x-\mu)^2}{n-1}} \quad \text{(Eq 2)}$$

where σ is the standard deviation, x is the value of an individual trial, n is the number of trials, and μ is the average of the n trials used.

Acknowledgements

All the research was done in Mrs. Lambert's classroom in King Philip Regional High School. Mrs. Lambert, Jake Quinn, and Eric Cote assisted with the data collection. Mrs. Lambert helped with guidance throughout the project. Mr. Kramer helped explain some of the statistics for the project.

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