LIFT FORCE

Research Question: How does the width and percentage of throttle applied on a model helicopter affect its lift force?

Physics HL Extended Essay

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INTRODUCTION

The flight physics and aerodynamics describe the dynamics of the lift of a helicopter. Lift, the force that allows an aircraft to rise and remain airborne, depends on parameters such as throttle input to the rotor and the physical characteristics of the wings. In the experiment, the roles of throttle percentage and the width of the wings on the force of lift, two parameters that contribute to the flight mechanics, were investigated. These two parameters decide the ability of the helicopter to generate sufficient lift to counter the forces of gravity, therefore affecting the overall flight performance.

Through a systematic examination of throttle adjustment and wing width modification, this study hopes to quantify the impact of such factors on lift force and enhance our understanding of the primary aerodynamic principles. Bernoulli's theorem explains the manner in which changes in airflow speed produce pressure differences that contribute to lift, and Newton's third law of motion explains the manner in which the downward force of the rotor blades produces an upward reaction. These parameters must be optimized to enhance model helicopter performance, enhance energy efficiency, and provide flight stability. The implications of this study also reach into the area of drones and model-scale flight, as the manner in which throttle and wing width affect lift can guide the development of more effective drones. More broadly, the results of this study have the potential to guide the development of more energy-efficient aircraft, which is important to save fuel, reduce operational costs, and enhance overall flight safety in commercial and private flight.

The key apparatus for the experiment is a model helicopter with a throttle that is adjustable and a modifiable wing width. The apparatus enables the variables to be controlled so that the effect of throttle and wing width on lift force can be precisely measured. The model helicopter is particularly suited to this research, as it retains the most salient aerodynamic features of full-scale helicopters in a tractable, controlled, and safe system. Using a controlled test setup, the research ensures precise data collection and meaningful analysis of the relationship between throttle percent, wing width, and lift force.

Research Question

The research question for this extended essay is: "How does the percentage of throttle applied and the width of the wings of a model helicopter affect its lift force?"

This study examines the impact of throttle percent (%) and wing width (cm) on the lift force of a model helicopter. Lift force is measured with a digital force gauge to provide accuracy. The study, by varying the parameters with others remaining the same, records the impact of the factors and improves the understanding of the aerodynamics of the rotorcraft.

Background Information

The study of how throttle percentage and wing width can affect the lift force of a model helicopter demands a cursory explanation of certain basic definitions, and the pertinent physics governing principles, measurement techniques and physical parameters of interest in such lifts analyses.

Key Terms and Concepts

1. **Lift Force:** Lift is the force that lifts the helicopter into the air and counteracts the force of gravity. Lift in a helicopter is generated by the rotor blades; the pressure differences that are generated above and below the blades as the rotor blades spin. Lifting force is measurable in terms of Newtons(N) and calculated as the weight of the stationary position of the helicopter minus the minimum weight obtained in the process of lifting.[1]

$$Lift\ Force\ (N) = Weight(initial) - Weight(lowest)$$

2. **Throttle:** Throttle is the input of power to the helicopter's motor that regulates the speed of the rotational motion of the rotor blades. Throttle percentage(%) in this experiment is the ratio of the maximum power input to the motor. Increasing the throttle percentage produces an increase in the speed of the rotors, with the blades rotating faster. As the blades rotate, they push the air downwards with more force, generating more lift according to Newton's Third Law of Motion (an action produces an equal and opposite reaction). In addition, faster rotors give more airflow over the blades, giving rise to a bigger pressure difference according to Bernoulli's Principle, therefore more lift. Throttle therefore regulates the lift by changing the speed of the rotors and is therefore a critical variable in the experiment.

Figure 1: Picture of the remote control

3. **Wing Width**: The wider the rotor blades of a helicopter, the greater the area of the blade set exposed to the airflow. Increasing the width of the wing increase the area available for the wing to come in contact with air, thereby increasing the amount of lift the helicopter produces. This is a function of the equation for lift: since wing width will

[1] https://www.grc.nasa.gov/www/k-12/VirtualAero/BottleRocket/airplane/lift1.html#:~:text=Lift%20is%20a%20mechanical%20force,without%20being%20in%20physical%20contact.

determine the individual areas of the wings, it will have a linear contribution to the total lift.

Relevant Physics Principles

1. **Bernoulli's Principle:** That with the faster speed of a fluid-air in this case-the pressure decreases. The rotor blades, as they cut through the air, create areas of low pressure above and below the blade and high pressure below it, creating lift. The faster the speed of the air over the blades with increasing throttle settings, the more pressure differential, and therefore the more lift is produced.[2]
2. **Newton's Third Law of Motion:** For every action, Newton's third law of motion says that there is an equal and opposite reaction. The rotor blades push the air downward, and the helicopter experiences an upward reaction force, i.e., the lift. The more rapidly and with more force the blades push the air downward as it opens the throttle, the more force of lift will have to counteract the force of gravity.[3]
3. **Rotational Kinematics and Dynamics:** The rotational speed of the rotor blades is regulated by the throttle percentage(%), which also regulates the power input to the engine. More throttle causes the angular speed of the blades to increase, causing the tip of the blade to travel faster. This causes more air to be displaced, which increases the speed of the airflow across the blade and maximizes the pressure differential that generates lift (Bernoulli's Principle). As the blades also force more air downwards, the reaction force on the helicopter (Newton's Third Law) is also maximized, maximizing lift. Increased speed of the rotors, stronger airflow, and more force of lift result due to more throttle.

Experimental Setup and Measurement Justification

The experiment is carried out in a temperature-controlled room to eliminate temperature and air current fluctuations. A model of a helicopter is placed on a digital balance, which measures its weight loss as a function of throttle percent and change in width of the rotor (wing).

The throttle positions of 10%–50% were marked by me on the remote controller for consistency, and the width of the rotor blade is stepped up gradually (in 0.5 cm steps to 3.5 cm) with taped extensions. The helicopter is powered only to cut its weight short of full take-off to yield a stable measurement.

To measure lift force, the stationary helicopter's initial weight is taken. As the throttle is increased, the scale reading reduces, the difference being converted to Newtons (N) by the use of 9.81 m/s^2. As the helicopter is stationary on the scale, lateral motion and effects of the rotor

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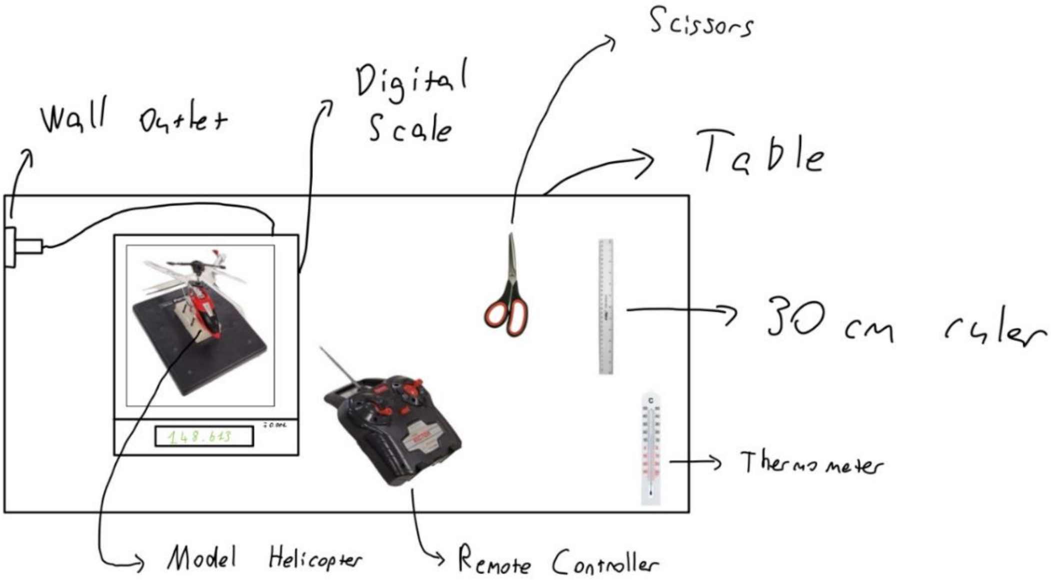
[2] NASA Glenn Research Center. (2021, June 2). Bernoulli's Principle. https://www.grc.nasa.gov/www/k-12/airplane/bern.html

[3] National Aeronautics and Space Administration. (n.d.). *Newton's laws of motion*. NASA Glenn Research Center. https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/newtons-laws-of-motion/#:~:text=Newton%27s%20Third%20Law%3A%20Action%20%26%20Reaction&text=If%20object%20A%20exerts%20a,words%2C%20forces%20result%20from%20interactions

wash are minimized, minimizing measurement errors. Trials are repeated to establish consistency and identify anomalies.

With a consistent model helicopter, the voltage of the battery, and the shape of the rotor, the experiment eliminates the effects of throttle power and blade width on lift. Using a digital scale in the controlled system enables more accurate measurements, and tables and graphs provide a clear representation of the effects of the independent variables on the force of lift.

Figure 2: Figure of Experiment



Hypothesis

Using a higher throttle percentage will produce more lift because spinning the rotor faster pushes more air downward, generating a stronger upward reaction in accordance with Newton's third law. Likewise, increasing the rotor blade width will enlarge the area over which air flows, enhancing the pressure difference and resulting in greater lift as outlined by Bernoulli's principle.

Variables

1. Independent Variables

- Throttle Percentage (%): Throttle controls the speed of the rotor, which also affects the volume of air moved and the force of lift produced. Throttle was kept between 10% and 50% in 10% intervals to have a broad data set without complete lift-off, which would make it impossible to gather data. The remote controller settings were assigned by me to have a uniform power input to the trials to avoid human error.
- Wing Width (cm): Rotor blade width impacts the surface area available to generate lift. The width was changed between 0 cm and 3.5 cm in 0.5 cm steps by attaching extensions to the existing blades with tape. The range was chosen as small changes had a large impact on lift but beyond 3.5 cm the potential for destabilizing the helicopter and inducing spinning blade impacts existed. The step size allowed for a controlled test of the impact of change in surface area on lift.

2. Dependent Variable

- Lift Force (unit: Newtons, N): Lift force is measured by a digital scale, which records the weight of the helicopter prior to and with partial lift. As the rotors create lift, the scale records a weight loss, which is the upward force on the helicopter. Lift force is found by subtracting the minimum weight with partial lift from the initial weight (at rest). The scale readings are in grams, so the values are converted to Newtons (N) by the equation F=mg (where $g=9.81 m/s^2$). The digital scale is precise to ±0.001g, a minimal change in the measurement of lift force, providing accurate and precise data.

3. Controlled Variables

To have throttle percentage and wing width as the only factors that have an effect on lift force, the variables were kept constant:

Helicopter Mass: The same model is utilized across the board to avoid mass variations, which would impact the lift force needed. Any adjustment is kept to a minimum to maintain mass as it is.

Blade Angle: Blade angle is kept the same, since varying it would also vary the magnitude of the lift force and therefore it would not be possible to separate the effects of the throttle percentage and the width of the wing.

Altitude: Since air density changes with altitude, the experiment was carried out at a fixed altitude to maintain the atmosphere conditions constant.

Material of the Rotor Blade: The material used in the additional wings could have an impact on the weight, flexibility, and aerodynamic effectiveness, all of which contribute to the lift. To prevent the variability that could result from this, the same material was used in all the tests.

Battery Voltage: To prevent power fluctuations, the batteries were charged to full capacity before each trial, and the voltage levels were monitored to provide a consistent power to the rotors.

Ambient temperature: Performing the experiment in a controlled temperature environment guarantees that air density is kept constant, eliminating the effect of temperature fluctuations on lift force.

Wind or Air Currents: The experiment was performed within an enclosed space to prevent external airflow that would interfere with the lift measurements.

By strictly controlling the variables, the experiment ensures that the lift force changes only due to the throttle percentage and the wing width, allowing for accurate and reliable conclusions.

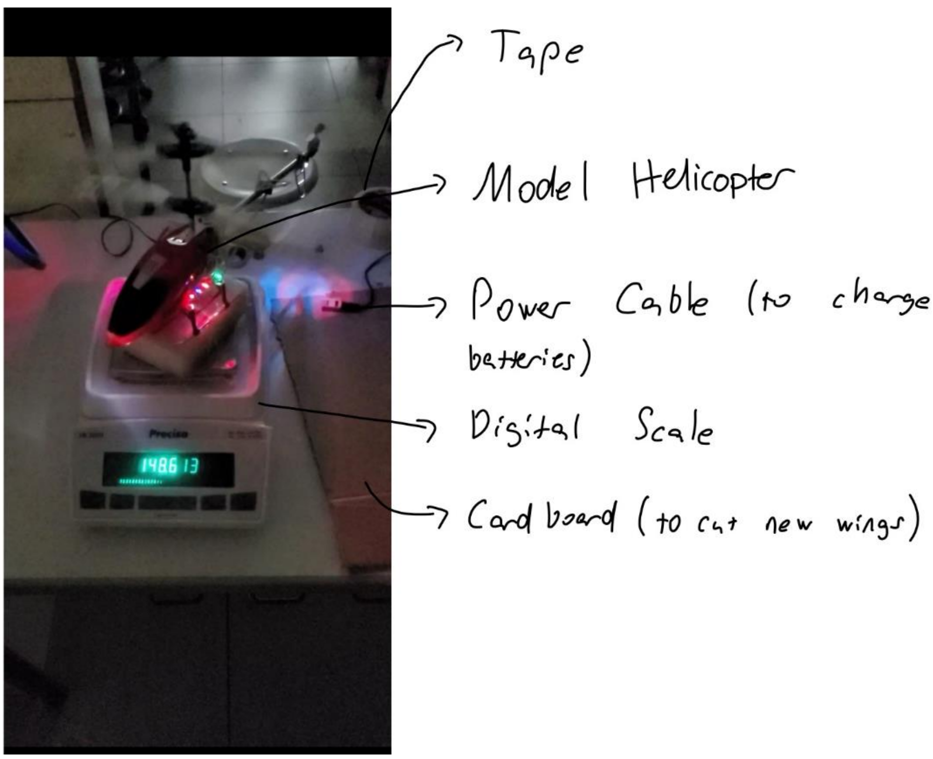
Equipment

1. Model Helicopter – A standard model helicopter with wing extensions taped on to adjust blade width in increments of 0.5cm.
2. Electronic Weighing Balance (±0.001g) – For measuring the initial and adjusted weights of the helicopter in each setting of throttle or wing width. This ensures proper measurements for lift force calculations.
3. Remote Controller – The original controller was used for consistency. Throttle positions (10%, 20%, 30%, etc.) were pre-marked to ensure precise and consistent power application in every trial.
4. Battery Pack – Fully charged before each test to maintain consistent power output. Voltage levels were monitored to prevent fluctuations affecting lift force.
5. Ruler (±0.05 cm) – Measures blade width increments to ensure accuracy in modifications.
6. Thermometer (±0.5°C) – Monitors room temperature to maintain constant air density, preventing environmental variations from influencing lift force.
7. Stable Platform – A flat, non-slip surface was used to prevent frictional inconsistencies when the helicopter was at rest, ensuring uniform testing conditions.

Methodology

This experiment investigates how throttle percentage and rotor blade width can affect the lift force experienced by a model helicopter. Controlled environment and incremental change in throttle-wing width will isolate the response of lift force against these variables. A digital scale gives accuracy and repeatability, while multiple repetitions give statistical significance to the results.

Figure 3- A picture of the experiment's setup



1. Setup and Calibration

Place the model helicopter on a flat, level surface in an indoor environment away from any drafts. Ensure that the electronic weighing balance is at 0 before any action is taken. For the first trial, do not fit any additional wings to the model helicopter.

2. Initial Weight Measurement

Record the initial weight of the model helicopter in grams using the electronic weighing balance. The measured weight here will serve as the base value for calculations of lift force during all trials.

3. Throttle Adjustment and Lift Measurement

Start to increase the switch from its resting point to whichever percentage of power you want to give. Gradually increase to your desired throttle percentage (e.g. 10%) and stop when the switch is right next to the marked spot which was marked before the trials.

4. Throttle Increments

Measure the weight that the digital scale shows when the throttle is at 10%. Repeat, increasing throttle in 10% increments up to 50%.

For each throttle setting, conduct a minimum of three trials to ensure reliability. The average lift force is taken at each setting.

5. Vary Rotor Blade Width

Once each throttle setting measurement has been taken without any rotor blades, tape the next set which in this case are the wings with 0.5cm width.

Steps 2 to 4 must be repeated over the new width of rotor blades by recording the lift force recorded for every throttle setting.

Measure this process for each 0.5cm increase in blade width, up to 3.5cm. This should be done three times per each throttle/blade width combination.

6. Data Analysis

Find the average of each throttle and blade width lift force combination. Record all data values on a data table for analysis.

Safety, Ethical and Environmental Considerations

Safety: The experiment will be conducted on smooth indoor conditions, devoid of as many risk factors as possible. The participants must be kept clear of the rotor blades to avoid injury. In each trial, the blades should be firmly screwed on to avoid dislodging during operations.

Ethics: The experiment does not require living subjects, and all the components used are reusable hence it is ethical and at minimal consequence to the environment.

This means that reusable batteries are used for the helicopter to reduce the number of battery casings thrown away, and doing the experiment indoors will prevent interference with natural forces of weather and keep energy input consistent. By following this robust methodology and accounting for the possible safety and environmental effects, this experiment can ensure a valid, ethical, and scientifically sound method to answer the research question.

Results

Table 1 - Raw Data Table (The given values are the readings from the digital scale in grams)

THROTTLE PERCENTAGES	ADDED WING WIDTHS (cm) ±0.05	Trial 1 (g)	Trial 2 (g)	Trial 3 (g)
10%	0.0	219.304	211.979	211.508
10%	0.5	222.938	222.439	219.532
10%	1.0	231.463	233.244	237.990
10%	1.5	221.271	218.702	217.344
10%	2.0	211.963	210.556	214.984
10%	2.5	194.415	193.235	182.593
10%	3.0	158.589	139.826	139.277
10%	3.5	136.866	136.869	134.931
20%	0.0	194.352	202.745	189.781
20%	0.5	108.842	111.233	113.024
20%	1.0	208.346	209.420	210.360
20%	1.5	196.621	197.152	198.460
20%	2.0	188.937	184.714	191.525
20%	2.5	116.718	120.310	136.686
20%	3.0	96.921	72.094	63.735
20%	3.5	128.086	127.973	128.355
30%	0.0	173.712	136.090	127.378
30%	0.5	170.327	173.344	170.404
30%	1.0	193.111	195.700	199.326
30%	1.5	177.175	183.146	183.157
30%	2.0	169.598	168.181	171.295
30%	2.5	90.265	85.930	89.155
30%	3.0	62.639	55.614	48.891
30%	3.5	88.815	90.930	98.983
40%	0.0	145.303	142.484	151.869
40%	0.5	142.040	148.613	149.003
40%	1.0	169.306	182.977	185.679
40%	1.5	160.104	161.681	140.341
40%	2.0	148.620	144.540	150.517
40%	2.5	113.258	115.987	110.940
40%	3.0	45.293	40.317	42.514
40%	3.5	80.036	78.737	78.994
50%	0.0	124.210	124.207	122.991
50%	0.5	129.298	127.762	128.220
50%	1.0	156.479	163.119	157.512
50%	1.5	140.341	141.363	139.959
50%	2.0	125.154	132.726	132.657
50%	2.5	99.828	97.529	98.298
50%	3.0	24.122	24.710	23.259
50%	3.5	48.725	42.241	57.212

Table 2- Lift Force Data Table (The given values are the change of the weight measured by the digital scale in grams)

THROTTLE PERCENTAGES	ADDED WING WIDTHS (cm) ±0.05	Trial 1 (g)	Trial 2 (g)	Trial 3 (g)	Average change in weight (g)
10%	0.0	84.772	92.095	92.563	**89.810**
10%	0.5	82.232	82.736	85.636	**83.535**
10%	1.0	74.404	72.653	67.905	**71.654**
10%	1.5	85.896	88.506	89.843	**88.082**
10%	2.0	94.477	95.890	91.458	**93.942**
10%	2.5	113.664	114.850	125.481	**117.998**
10%	3.0	150.587	169.356	169.893	**163.279**
10%	3.5	172.111	172.120	174.066	**172.766**
20%	0.0	101.323	109.727	114.294	**108.448**
20%	0.5	108.842	111.233	113.024	**111.033**
20%	1.0	95.572	96.116	97.534	**96.407**
20%	1.5	108.730	110.035	110.560	**109.775**
20%	2.0	117.516	114.918	121.729	**118.054**
20%	2.5	161.389	187.774	191.357	**180.173**
20%	3.0	180.639	180.897	181.022	**180.853**
20%	3.5	212.247	237.085	245.448	**231.593**
30%	0.0	127.378	130.365	136.090	**131.278**
30%	0.5	131.828	134.776	134.934	**133.846**
30%	1.0	106.572	110.199	112.785	**109.852**
30%	1.5	124.021	124.041	130.007	**126.023**
30%	2.0	136.872	138.279	135.151	**136.767**
30%	2.5	192.078	194.808	197.122	**194.669**
30%	3.0	210.013	218.051	220.171	**216.078**
30%	3.5	246.555	253.567	260.286	**253.469**
40%	0.0	152.204	158.770	161.586	**157.520**
40%	0.5	156.171	156.570	163.124	**158.622**
40%	1.0	120.197	122.930	136.564	**126.564**
40%	1.5	145.507	146.478	147.103	**146.363**
40%	2.0	157.826	161.903	155.932	**158.554**
40%	2.5	208.237	209.763	210.530	**209.510**
40%	3.0	228.947	229.999	230.251	**229.732**
40%	3.5	263.891	266.662	268.865	**266.473**
50%	0.0	179.826	179.857	181.070	**180.251**
50%	0.5	175.867	176.975	177.409	**176.750**
50%	1.0	142.727	148.370	149.387	**146.828**
50%	1.5	165.822	166.845	167.230	**166.632**
50%	2.0	181.291	173.732	173.810	**176.278**
50%	2.5	217.806	218.919	222.146	**219.624**
50%	3.0	251.769	260.258	266.258	**259.428**
50%	3.5	284.478	285.058	285.924	**285.153**

Now to convert the data into Newtons I must use the formula:

$$Force(N) = \frac{Mass(g)}{1000} * 9.81(\frac{m}{s^2})$$

To calculate the uncertainty for each data set, I used the half-range uncertainty formula:

$$Uncertainty = \frac{Max\ Force - Min\ Force}{2}$$

An example calculation for the data that had 10% throttle and 0.5cm added wings is:

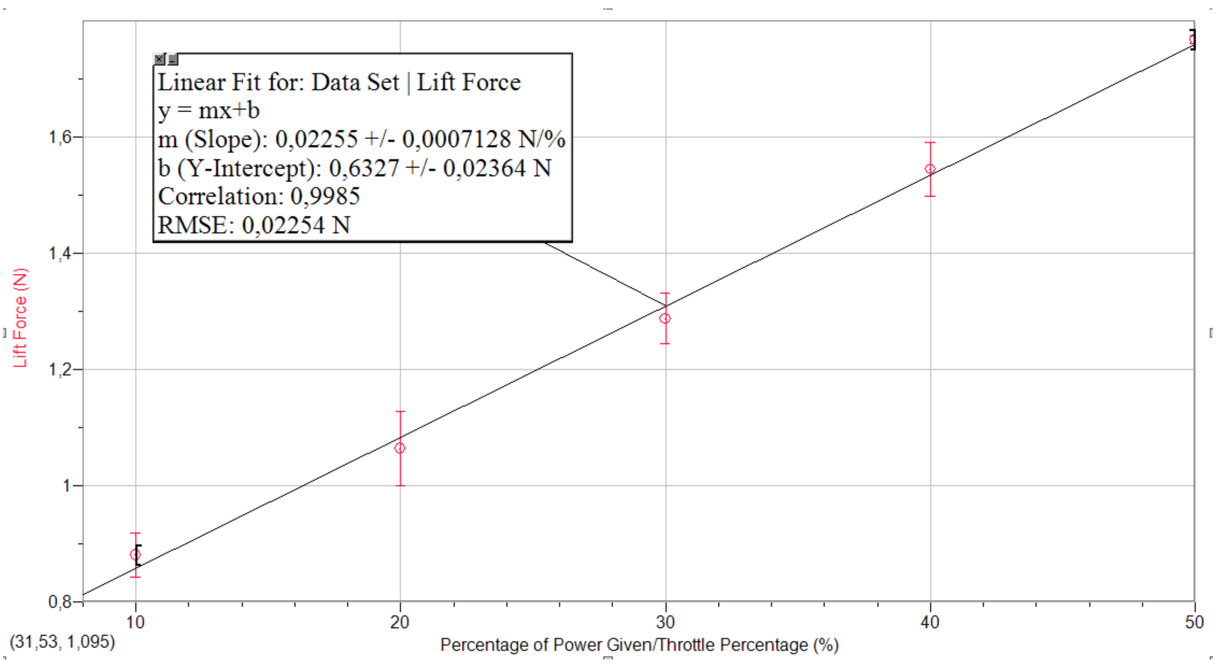
$$\frac{85.636 * 10^{-3} * 9.81 - 82.232 * 10^{-3} * 9.81}{2} \approx 0.017$$

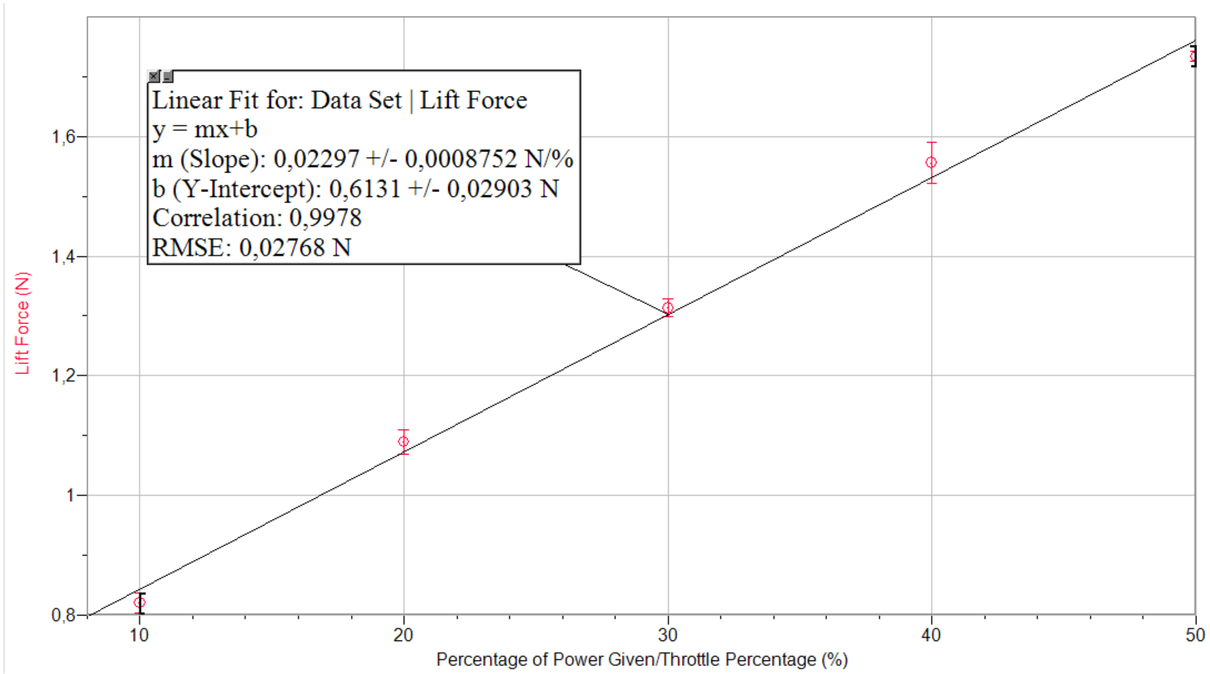
Table 3- Processed Data Table (The given values are lift force in Newtons)

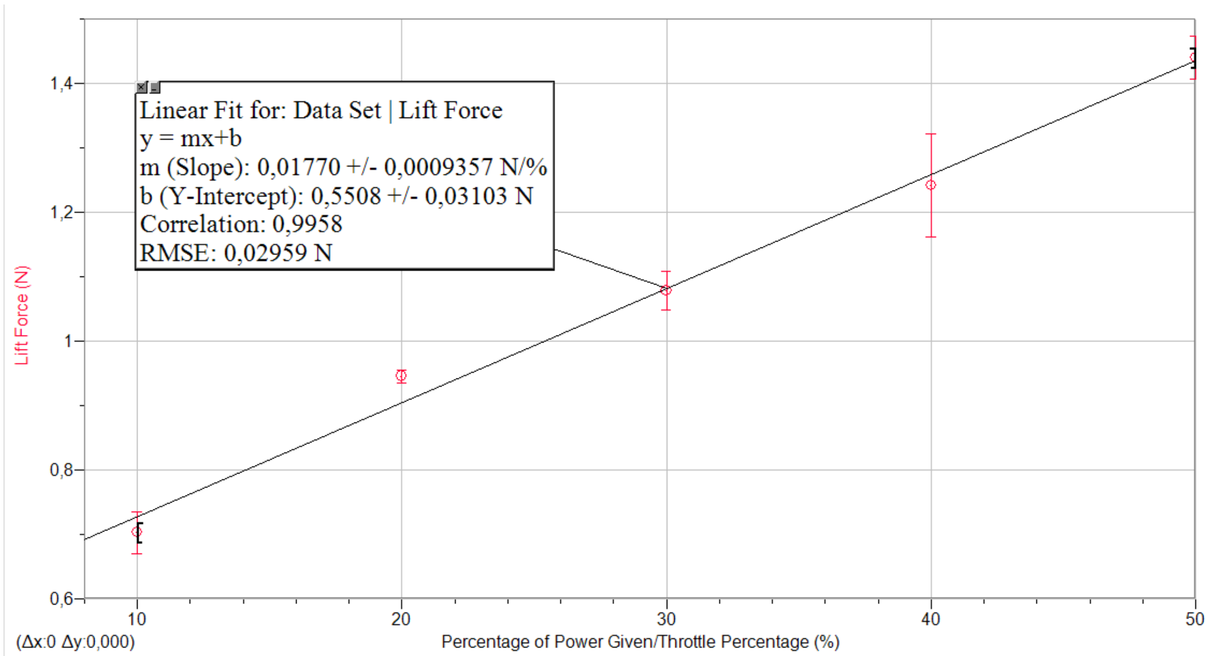
	WING WIDTHS(cm)							
THROTTLE PERCENTAGES	0.0	0.5±0.05	1.0±0.05	1.5±0.05	2.0±0.05	2.5±0.05	3.0±0.05	3.5±0.05
10%	0.881± 0.038	0.819±0.017	0.703 ±0.032	0.864±0.019	0.922±0.022	1.158±0.058	1.602±0.095	1.695±0.010
20%	1.064±0.064	1.089±0.021	0.946±0.010	1.077±0.009	1.158±0.033	1.800±0.147	1.774±0.002	2.272±0.163
30%	1.288±0.043	1.313±0.015	1.078±0.030	1.236±0.029	1.342±0.015	1.910±0.025	2.120±0.050	2.487±0.067
40%	1.545±0.046	1.556±0.034	1.242±0.080	1.436±0.008	1.555±0.029	2.055±0.011	2.244±0.006	2.614±0.024
50%	1.768±0.006	1.734±0.008	1.440±0.033	1.635±0.007	1.729±0.037	2.155±0.021	2.547±0.071	2.797±0.007

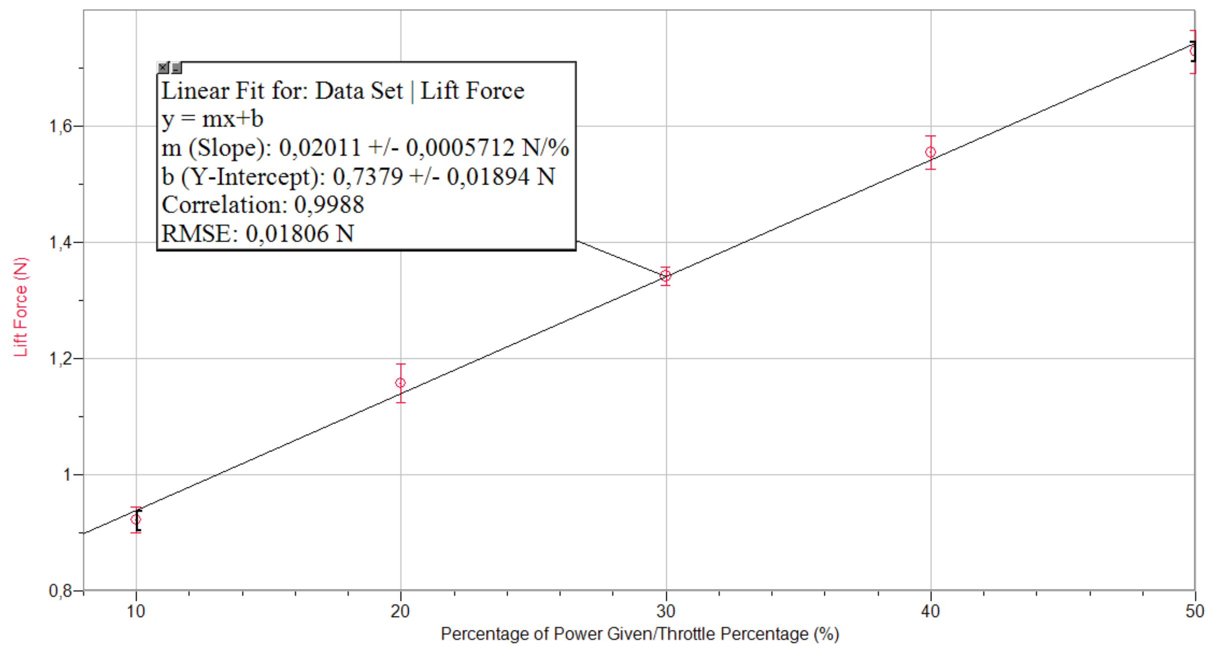
Graphs 1-8: Processed Data Displayed in Ascending Order of Wing Width

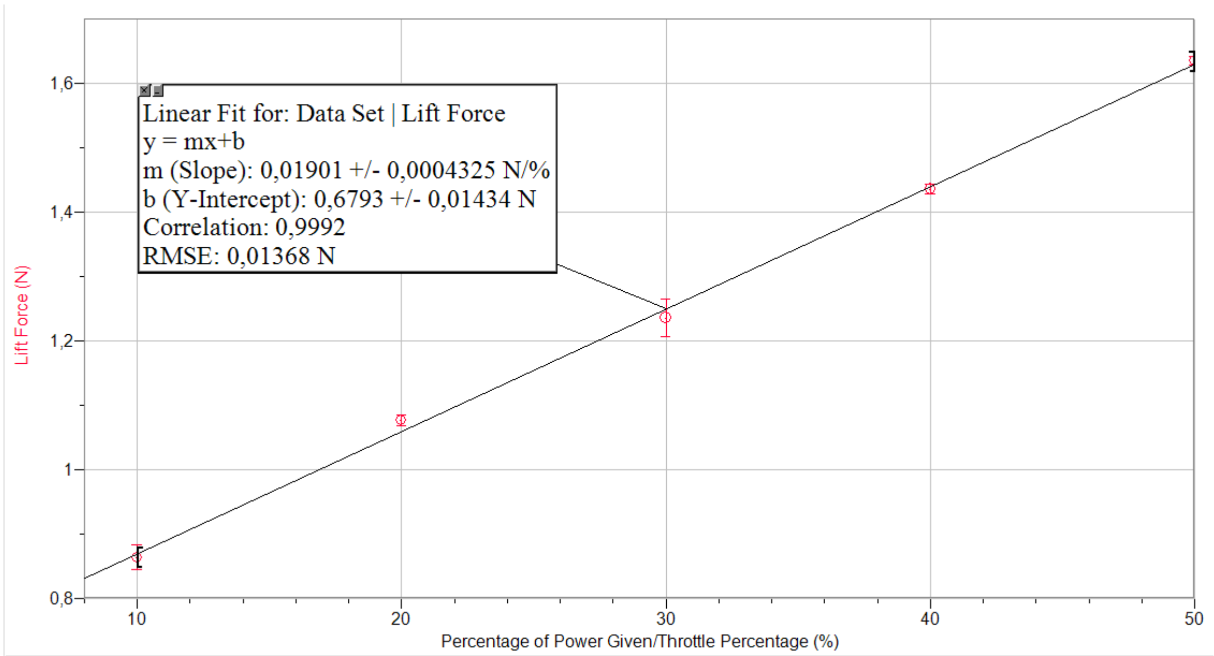
To analyse the relationship between Throttle Percentage, Wing Width, and Lift Force, eight graphs were plotted, each representing a different fixed Wing Width, increasing sequentially from 0cm to 3.5cm in 0.5cm increments. These graphs display Throttle % vs. Lift Force for each Wing Width, allowing for a visual comparison of trends. Based on graphical analysis, six of these graphs (0cm to 2.0cm and 3.0cm) were best represented by linear regression fits, while the 2.5cm and 3.5cm graphs required quadratic regression fits due to noticeable curvature in their trends. This suggests that for smaller Wing Widths (≤2.0cm), Lift Force is approximately proportional to Throttle %, but at specific widths (2.5cm and 3.5cm), a non-linear relationship emerges, requiring a quadratic model. These observations provided the foundation for further regression analysis.

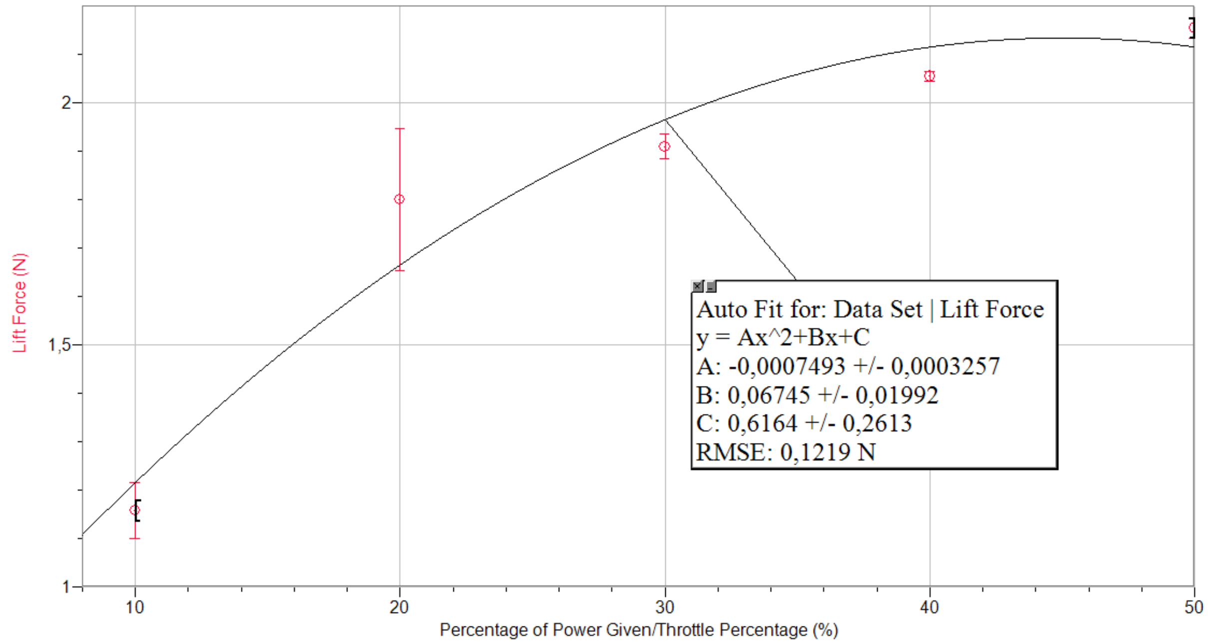


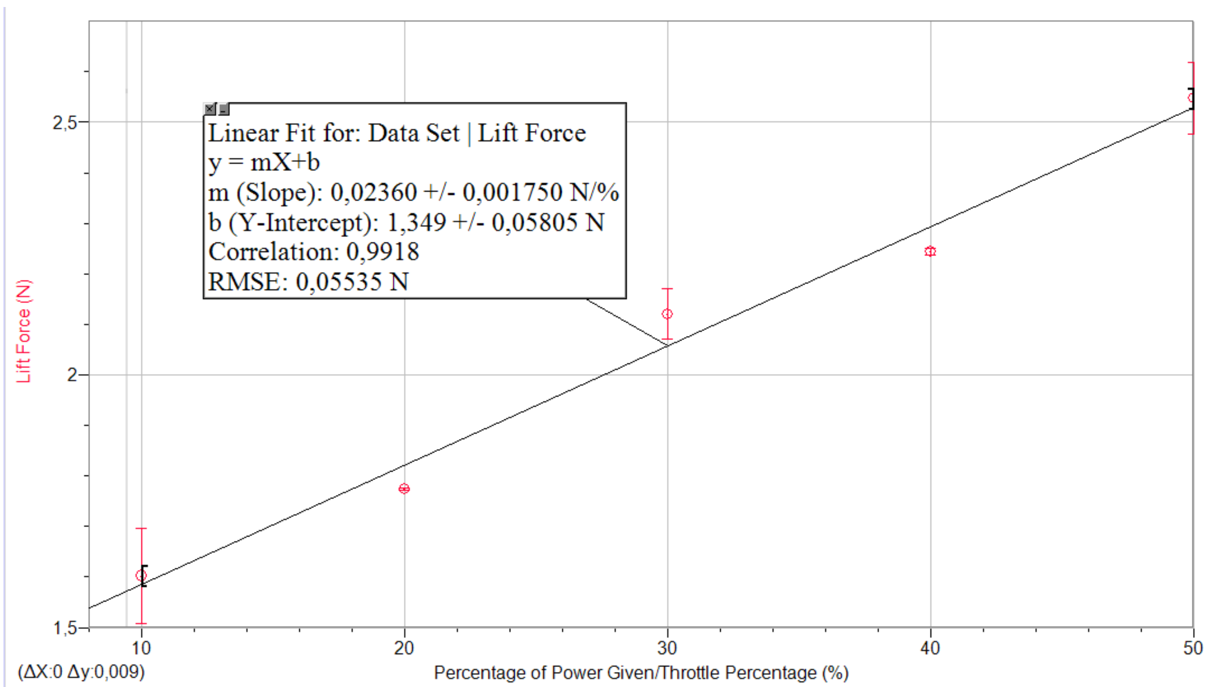

Linear Fit for: Data Set | Lift Force
y = mx+b
m (Slope): 0,02297 +/- 0,0008752 N/%
b (Y-Intercept): 0,6131 +/- 0,02903 N
Correlation: 0,9978
RMSE: 0,02768 N
Lift Force (N)
Percentage of Power Given/Throttle Percentage (%)

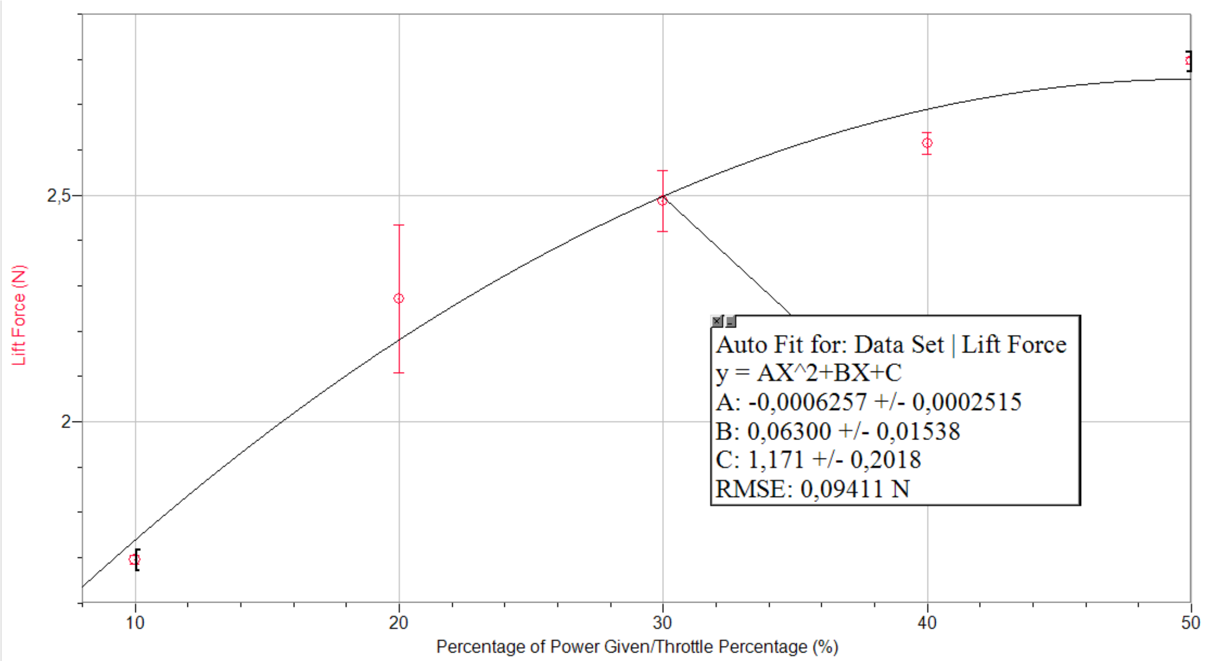

Linear Fit for: Data Set | Lift Force
y = mx+b
m (Slope): 0,01770 +/- 0,0009357 N/%
b (Y-Intercept): 0,5508 +/- 0,03103 N
Correlation: 0,9958
RMSE: 0,02959 N
Lift Force (N)
(Δx:0 Δy:0,000)
Percentage of Power Given/Throttle Percentage (%)


Linear Fit for: Data Set | Lift Force
y = mx+b
m (Slope): 0,02011 +/- 0,0005712 N/%
b (Y-Intercept): 0,7379 +/- 0,01894 N
Correlation: 0,9988
RMSE: 0,01806 N
Lift Force (N)
Percentage of Power Given/Throttle Percentage (%)


Linear Fit for: Data Set | Lift Force
y = mx+b
m (Slope): 0,01901 +/- 0,0004325 N/%
b (Y-Intercept): 0,6793 +/- 0,01434 N
Correlation: 0,9992
RMSE: 0,01368 N
Lift Force (N)
Percentage of Power Given/Throttle Percentage (%)

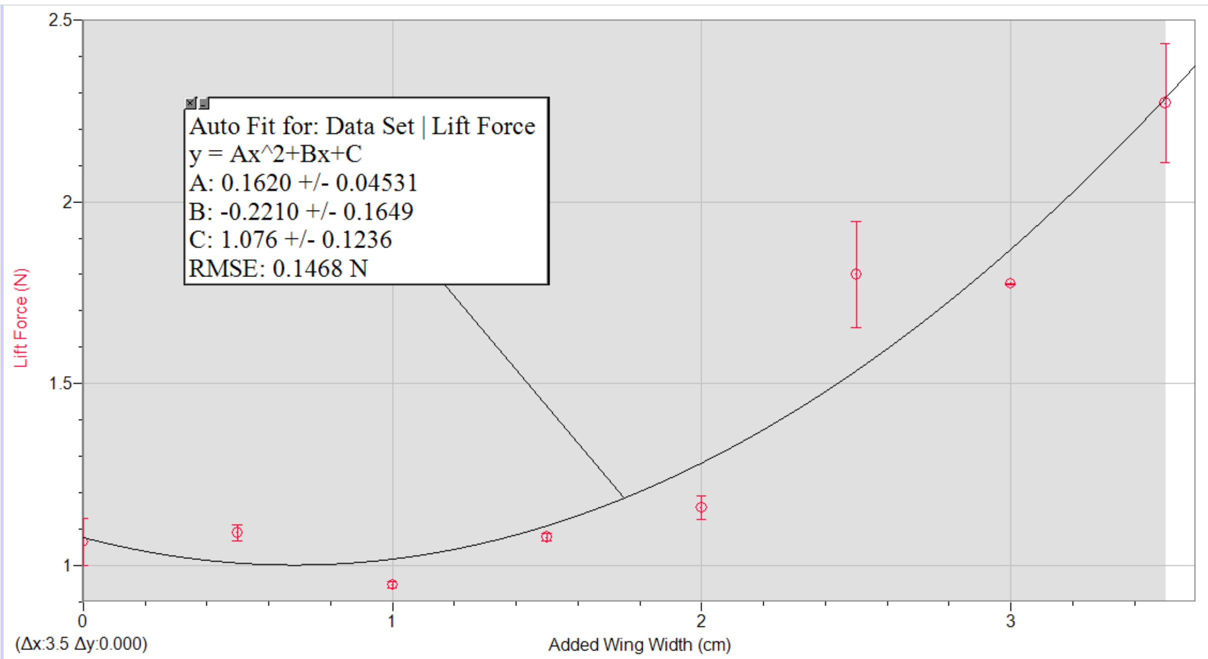

Auto Fit for: Data Set | Lift Force
y = Ax^2+Bx+C
A: -0,0007493 +/- 0,0003257
B: 0,06745 +/- 0,01992
C: 0,6164 +/- 0,2613
RMSE: 0,1219 N
Lift Force (N)
Percentage of Power Given/Throttle Percentage (%)


Linear Fit for: Data Set | Lift Force
y = mX+b
m (Slope): 0,02360 +/- 0,001750 N/%
b (Y-Intercept): 1,349 +/- 0,05805 N
Correlation: 0,9918
RMSE: 0,05535 N
Lift Force (N)
(ΔX:0 Δy:0,009)
Percentage of Power Given/Throttle Percentage (%)



Graph 9

Since we have 2 independent variables and the graphs given above is all Throttle Percentage vs Lift Force, at least 1 graph that is Wing Width vs Lift Force should be analysed since it is the second independent variable. The graph below is the display of Wing Width vs Lift Force at the Throttle Percentage of 20.



The quadratic regression model, given by $y = 0.1620x^2 - 0.2210x + 1.076$ shows a strong correlation between added wing width and lift force, with an R^2 value of 0.934. This indicates that 93.4% of the variation in lift force is explained by the model, confirming its accuracy in representing the observed trend.

Data Analysis and Trends

The experiment started by plotting eight graphs of Throttle Percentage (0–50%) versus Lift Force for different Wing Widths (0–3.5cm in 0.5cm intervals), ordered in ascending order to facilitate comparison. These plots revealed that, for Wing Widths of 2.0cm or less (and 3.0cm), the Throttle % versus Lift Force relationship could be satisfactorily modelled by a linear fit, but for 2.5cm and 3.5cm, a curvature was present that could only be modelled by a quadratic fit, with an initially negative effect of increasing wing width (due to drag) that became positive at larger widths. To numerically validate these results, a multiple quadratic regression was performed with Throttle %, Wing Width, the squared terms of these, and the interaction term as inputs. The resulting model had an R^2 of 0.9588, i.e. 95.88% of the variability in Lift Force is explained by these parameters. The statistically significant Throttle % and Wing Width^2 terms meant that Throttle is having a nearly-linear effect on Lift Force, whilst Wing Width follows a more complex, non-linear trend. The interaction term was not significant; however, i.e. Throttle % and Wing Width contribute independently. A second quadratic regression of Lift Force versus Wing Width with a fixed throttle position also provided an R^2 of 0.934, i.e. 93.4% of the variability in Lift Force is explained by Wing Width. This confirms the conclusion that although Throttle % is the dominant driver of Lift Force, Wing Width is also an important player, particularly at the higher values where the benefits of the larger surface area outweigh the initial cost of the drag.

Conclusion

The research question in this study was to identify the effect of width and the throttle percentage used on a model helicopter on its lift force. In a series of controlled lift force(N) tests with varying throttle percentages (10–50%) and wing widths (0–3.5cm), unique trends in the relationship of these factors to lift were observed.

The results indicate that throttle percent gives a nearly-linear response to lift force, but wing width gives a more complex, quadratic trend. When throttle is increased, the speed of the rotor also increases, generating a stronger downward thrust and therefore a roughly proportional rise in lift. This is to be anticipated by the third law of Newton since the stronger downward force produces an opposite and equivalent reaction upward.

Conversely, width impacts lift in a non-linear way. At smaller width intervals, extra width reduces lift, likely due to more forces of drag interfering with airflow effectiveness. At wider widths, the greater surface area of the blade presents a net benefit, eventually increasing lift by enhancing air deflection and pressure differentials, as indicated by Bernoulli's principle. The findings were also validated by a multiple quadratic regression model that yielded an R^2 of 0.9588, demonstrating that 95.88% of the variability in the lift force is explained by the interaction between throttle and wing width.

These results give valuable insight into the optimization of rotorcraft performance. That throttle affects thrust in a generally linear way, but wing width in a non-linear way, highlights the trade-off between aerodynamic performance and mechanical power in the design of the rotor. This is of practical relevance to small-scale helicopters, drones, and UAVs, in which the optimal trade-off between lift, drag, and energy efficiency is critical.

Despite the fact that this study provides a solid foundation to the understanding of the effect of throttle ratio and wing width on lift, future studies could study other aerodynamic factors such as blade angle, fluctuations in the speed of the rotors, and air viscosity that could extend and complement these findings. Experimental validation through CFD simulations or wind tunnel tests could also supplement the discovered relationships.

To conclude, this research confirms that aerodynamic design (wing width) and mechanical power (throttle) are significant but distinct parameters in the creation of lift. These results substantiate the principles of aerodynamics and have practical applications to the improvement of the efficiency and stability of rotorcraft in engineering.

Evaluation

Although the study demonstrates a high correlation between throttle percentage, wing width, and lift force, various methodological flaws and potential improvements must be considered to enhance the accuracy, reliability, and generalizability of the results.

1. Throttle Control Accuracy and Precision

One of the major shortcomings was the manually marked throttle percentages on the remote controller, which introduced potential human error into the delivery of repeatable power outputs across trials. The marks were carefully measured, but slight variability in the application of the throttle could have caused slight deviations in the readings of lift force. A servo-controlled or digital throttle system could eliminate the variability with more accurate and repeatable application of power.

2. Environmental Conditions and Changes in Air Density

Although the experiment was conducted indoors to eliminate external factors, small temperature changes in the room and air currents would have altered air density slightly, indirectly altering lift force. Since a thermometer was used to maintain temperature, an entirely climate-controlled room or vacuum chamber would eliminate extraneous variables. In addition, air currents—though minimized—would have still introduced random airflow pattern fluctuations, particularly with more throttle positions.

3. Measurement Limitations and Instrumentation Uncertainties

The electronic scale to determine lift force, although highly precise, could potentially cause random or system errors if external vibration or minor position changes of the helicopter caused the weight readings to vary. Further, potential long-term drain of the batteries could have subtly altered the speed of the rotors, and hence the lift force, in a manner that was not compensated. A voltage-stabilized power supply or a real-time RPM measurement would provide more accurate power output readings.

4. Range Limitations of Independent Variables

The test was limited to throttle percentages of 10%–50% and wing width variations of a maximum of 3.5cm, so the trends one sees here do not necessarily hold for nearly-100% throttle or significantly wider rotors. Whether the quadratic trend in wing width continues, saturates, or reverses for wider wings is unknown. Extending the range of the two variables—such as to include throttle settings near 100% and wing widths greater than 3.5cm—would provide a more complete understanding of these aerodynamic effects.

Possible future improvements

To address these deficits and provide a more accurate study, the following could be undertaken:

- With a digital throttle system to eliminate human marking errors.
- Utilizing a new or a proven battery for each test to prevent voltage drops on the rotors.
- Expansion of the range of throttle and wing width parameters that have been tested to determine trends beyond current limits.
- Performing experiments in a completely controlled wind tunnel to eliminate environmental factors and study the performance of the rotors more accurately.
- Using high-speed cameras or laser measurement systems to determine real-time rotor speed and airflow patterns.
- Validation of experiment results using CFD simulations to provide a more precise aerodynamic assessment than empirical measurements.

Final Reflection

Despite these limits, the study presents a robust foundation for the understanding of the impact of throttle ratio and wing width on lift force. The high R^2 of 0.9588 attests that throttle and wing width account for the majority of the variability of lift force, validating the trends. Further refinements and a more rigorous experiment would, however, be necessary to fully generalize the results to practical use in real-world helicopters, drones, and rotorcraft engineering.

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Appendix

Table 4 – R^2 Value Calculation (Linear)

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.899043837							
R Square	0.808279821							
Adjusted R Square	0.797916569							
Standard Error	0.243070387							
Observations	40							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	2	9.216366613	4.608	77.9947985	5.36238E-14			
Residual	37	2.186078888	0.059					
Total	39	11.4024455						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	0.3510125	0.107566085	3.263	0.002373411	0.133062912	0.56896209	0.13306291	0.56896209
THROTTLE PERCENTAGES (%)	0.02173625	0.00271761	7.998	1.38591E-09	0.01622985	0.02724265	0.01622985	0.02724265
WING WIDTHS(cm)	0.3218	0.033546901	9.593	1.4083E-11	0.253827523	0.38977248	0.25382752	0.38977248

Table 5– R^2 Value Calculation (Quadratic)

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.979200301							
R Square	0.958833229							
Adjusted R Square	0.952779292							
Standard Error	0.117498668							
Observations	40							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	5	10.93304364	2.187	158.3817689	0			
Residual	34	0.469401859	0.014					
Total	39	11.4024455						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	0.581970833	0.114774409	5.071	1.39149E-05	0.348721177	0.81522049	0.34872118	0.81522049
THROTTLE PERCENTAGES (%)	0.031238452	0.007080162	4.412	9.79606E-05	0.016849832	0.04562707	0.01684983	0.04562707
WING WIDTHS(cm)	-0.330116667	0.068320726	-4.832	2.83447E-05	-0.46896108	-0.1912723	-0.4689611	-0.1912723
Column D: Throttle²	-0.000185446	0.000111026	-1.670	0.104042301	-0.00041108	4.0185E-05	-0.0004111	4.0185E-05
Column E: Wing Width²	0.178304762	0.016216357	10.995	9.72409E-13	0.145349161	0.21126036	0.14534916	0.21126036
Column F: Throttle × Wing Width	0.000928333	0.00114667	0.810	0.423805225	-0.00140198	0.00325865	-0.001402	0.00325865