Designing a Mars Survey Unmanned Aerial Vehicle

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Summary

The goal of this research project was to design a quadcopter that could create sufficient lift to fly on Mars. During the creation of this quadcopter, the difficulties that need to be overcome are the lower air pressure and lower gravity of Mars. In order to optimize the lift, the effect of propeller radius on lift was tested. Four propellers of radii 3cm, 4cm, 5cm, 6cm were designed for this test. A force sensor was used to determine the lift force. First, the effect was tested at 1000 millibars, which produced data that was inconsistent and insignificant. The data at this pressure was confounding between trials and did not produce a solid trend. Then, the effect was tested at 100 millibars, where the data produced numbers that were insignificantly different than zero. This is known because the averages for each were significantly less than the standard deviation: the force was much lower than expected and the force was not much more than zero (if greater at all). Thus, no significant results were found.

Introduction

Surface missions to Mars have involved sending car-sized rovers packed with sensors that roll to the geographic features in its mission. An unmanned aerial vehicle, or UAV, would be more effective at making observations, since it can move around freely and make accurate maps from above. However, the pros of sending a UAV to Mars are countered by its difficulties. Mars has significantly less atmosphere than Earth, with only 0.6% of the atmosphere. It is barely possible for an UAV to fly: the lower atmosphere reduces the lift force, but the weight is a third what it would be on earth because of the reduced gravity. Since the reduced gravity does not recuperate the lost air pressure, the drone needs to be optimized to fly.

Recently, NASA sent the newest rover to Mars: the Mars Perseverance. With this mission, the scientist included a test drone: Ingenuity. The Mars Ingenuity is a simple helicopter UAV: it is a box with a single propeller stack as its lifting and steering force (1). The first few flights have proved it is possible to fly a single propeller drone on Mars and will yield in situ data for the helicopter (2). In this experiment, instead of the one propeller used by NASA, a 4 propeller drone will be designed to work at Mars atmospheric pressure.

A drone works on a few basic principles. First, each blade on a drone propeller creates lift described by Bernoulli's principle. On the airfoils, there is a faster fluid flow on top because the path length of the top is longer (Figure 1). Bernoulli's equation predicts that airspeed is approximately inversely proportional to pressure (3). Thus, since the airspeed is lower on the bottom of the airfoil, there is more pressure on bottom, which provides a net upward lift force.

Figure 1: A velocity vector depiction of the airflow around an airfoil. Airspeed tends to go faster over the top of the airfoil, and due to conservation of energy this must result in a decrease in the pressure. This creates a lift force.

When designing a drone, an important factor is the lift to weight ratio. For a drone to fly, it needs to have a lift/weight ratio of greater than one; if it does not, the drone cannot physically provide sufficient lift to fly. However, a ratio close to 1 is not good either: this leaves no room for error while the drone is flying. In this experiment, a lift to weight ratio of 1.5 will be considered functionally operable.

In this study, different propeller radii will be tested to attempt to optimize the propeller radius for a Mars quadcopter. Identical propellers, differing by their radius, were designed and tested for the force that they produce when attached to a brushed DC motor. This was done first at 1000 millibars pressure, which is about the pressure at sea level on earth, then repeated at 100 millibars of pressure in a vacuum chamber. If possible, the test would have been repeated at 10 millibars; however, the equipment available was not measured to produce such pressures.

The data obtained is currently insignificant at both the sea level pressure and at the 100 millibar pressure. The data is too variable and partially contradictory and hence cannot be used to make any viable conclusions. Further testing must be done to investigate if there is a significant difference in the two.

Results

Data was collected first from two trials of tests at an approximate sea level pressure of 1000 millibars. The propellers were attached to a motor and its holder, which were then attached to a force meter. This setup was run for 10 seconds at a sample rate of 50 Hz. This was done for each propeller in ascending order of length in trial 1 and descending order in trial 2.

The results are inconclusive. Trial 1 and trial 2 seem to show contradictory data, which the trends are opposite (Figures 2 and 3). The trends appear to mirror the order that the propellers were tested, which seems to skew the results. This shows that the data may be biased and should not be used to make sound statistical observations.

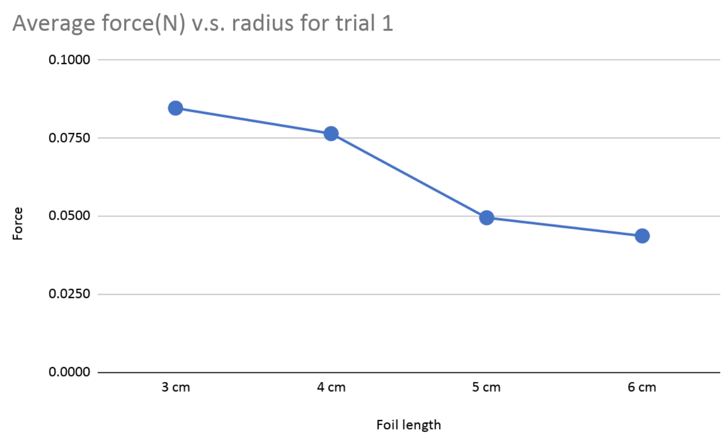

Figure 2: Force per propeller radius for trial one. In this trial, the force seemed to have an overall downward trend.

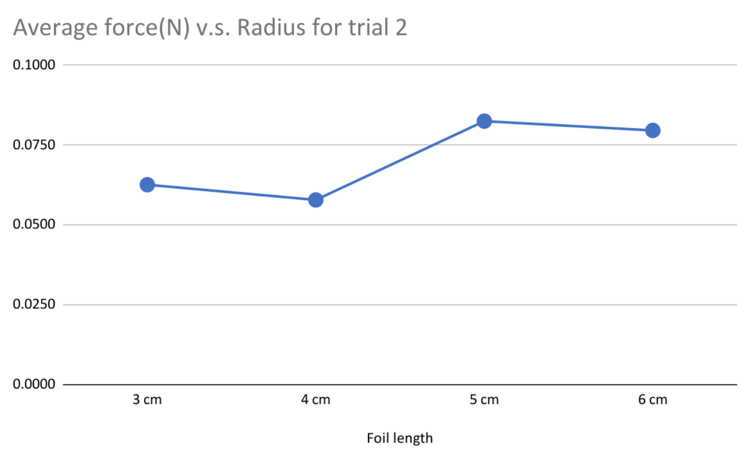

Figure 3: Trend over propeller radius for trail 3. In this trial, the force seemed to have an overall upward trend

Despite the data being inconsistent, tests were conducted in a vacuum chamber. A contraption was created to put all the necessary electronics and the force sensor inside of the vacuum chamber while still having control of the data collection from the outside. The air pressure was then reduced to 1/10th of sea level and each propeller was run for 10 seconds with a 50 Hz sample rate. The data, however, was even more inconclusive than that of the previous test, hovering around zero (Figure 4). This data is statistically insignificant and no conclusions can be made from it

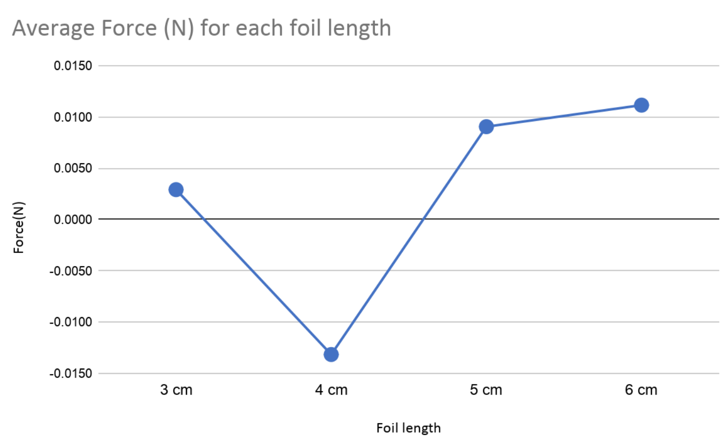

Figure 4: Average force over 10 second trials for each propeller. The trend for the foil length was overall insignificant and shows little overall tend

In order to fix the problems of these trials, more tests must be conducted to make any sound conclusions. For the vacuum trials, the standard deviation of each point was greater than the average value, and hence the data cannot be declared significantly different from zero.

Discussion

The engineering goal of this experiment was not completed because of difficulties during the testing and data collection phase of research. Overall, neither of the tests provided data that was applicable in drone building. In both the trials at 1000 millibars and at 100 millibars, the result allowed for no conclusions to be drawn, but for different reasons.

First, the trial at 1000 millibars was inconclusive because it showed statistical bias in the order that the battery was connected. When the tests were done in ascending order, the force generally decreased with larger props, but when in descending order the force generally increased with larger props (Figure 2 and 3). So that the effects of current and propeller length are not confounded, tests where batteries are charged so that their current output is the same need to be done.

The trial at 100 millibars was inconclusive because of the very low lift numbers. All the propeller radii produced force readings that were statistically insignificant 0.05 except four. This was tested by constructing T-intervals for each point at the 95% confidence level, and four, the only significant result, was negative (T-interval: (-0.0247,-0.0017) N). Furthermore, the low force values would require extrapolation to a much larger number to be applicable to create a drone, and thus this data cannot be used as a guideline to make a drone. The possible place of error could be in the electronics: there could be internal resistance in the SCR transistor used to toggle the flow that reduces the current so that it does not provide sufficient lift. Further investigation must be done to remove this source of error.

From the difficulties encountered in this study, more tests could be done to generate new numbers with better equipment that could eventually be applied to a goal of creating a flying quadcopter on Mars. However, there are specific challenges in this experiment that can be learned from to improve a future trial greatly; specifically, much can be learned from the electronics difficulties of this experiment.

The materials used in this project limited its performance. In most commercial drones, pre-crafted flight controllers, electronic speed controllers, and brushless motors. However, this project was unable to get access to those materials, so sub-optimal brushed motors and an arduino were used for the electronics instead. These heavily limited the amount of current that could be supplied to the motor because the arduino runs on a different power level. If this were to be repeated, it is suggested that 2207 2750KV

Brushless Motor or similar motors are used, along with 30A electronic speed controllers. These should be used instead because it allows for a much higher current to be achieved with less work on designing circuits. If the experimenter has access to a circuit board printer, they could make their own circuit for the drone; however, it is suggested that instead a pre-made flight controller is purchased to reduce the amount of work. If the electronics are bought like this, one can focus more on optimizing the lift and not designing circuits.

Materials and Methods

The first step was to design the 3D-printed propellers. Using the CAD program Blender, 4 three tri-bladed propellers of propeller lengths 3, 4, 5, and 6 cm and NACA 0020 profile were created. Then, using a Ender 3 3d printer using PLA filament, each propeller was 3d printed. The same process was used to create a holding module for the motor.

An electronic circuit was assembled to allow for IR communication. An Arduino was used to code an IR receiver to turn on a motor. A SRC transistor was used to trigger a 3.7V, 650 mAh lithium battery to power the motor. This setup was hooked up to the motor in the holder. The propeller was attached to the motor after that.

Then, this setup was attached to a Vernier dual-range force sensor. The force sensor was hung from a ring stand with the propeller below. Then, the propeller was turned on for 10 seconds and force was measured. The test was repeated for each propeller radius.

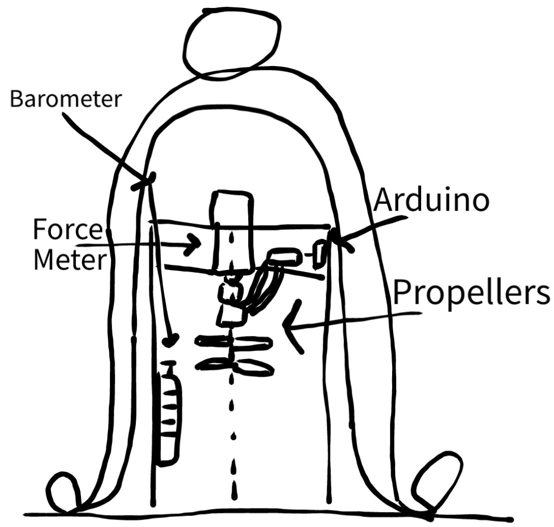

Figure 5: The setup of the bell jar experiment. Each major part inside the jar is labeled.

The test was then done inside a bell jar vacuum chamber (Figure 5). First, the release valve to the pump was opened. The bell jar was carefully placed on the platform over the testing apparatus. Then, the vacuum pump was turned on and the release valve was tightened until the pressure stabilized at the desired pressure of 100 millibars. Then, the net lift force of the propeller was measured for 10 seconds. Then, the valve was released and the air was let to leak out. This was repeated for each propeller.

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Mrs. Hemmerle for teaching me how do use a vacuum chamber

Student: ____________________________ Date submitted: _______________

1. Assignment submitted exactly as requested (*max points 4)* _____

2. Title Page (*max points 4)* _____

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Is the title succinct and descriptive of the study that was conducted?			x
Does the title page include title, all authors in appropriate order, school, location of research?			x

3. Summary (Abstract) (*max points 8*) _____

Is the abstract concise, fewer than 250 words, and only containing ideas found in the paper?			x
Does the abstract communicate the question and hypothesis under study?			x
Does the abstract communicate the methodology employed in the study?			x
Does the abstract communicate the major results and conclusions of the study?			x

4. Introduction: Rationale, Assumptions, Objective(s) (*max points 10*) _____

Does the article briefly describe the overarching scientific topic of the paper?			x
Is the background information fully developed so that the audience understands the question/relevance?			x
Is the background information fully documented with references?	x		
Is the objective/purpose/question/hypothesis/engineering goal of the study clearly stated and supported?			x
Are the conclusions briefly discussed?			x

5. Research Results (*max points 24*) _____

Is the discussion written in a logical, coherent fashion?			x
Is the rationale for each experiment present and clear?			x
Is the method of each experiment explained briefly but clearly?			x
Are references to figures that contain results included?			x

Are interpretations of the figures included such that it is clear to the reader what the results mean and how they are presented?		x	
Is there a discussion of other variables that may have affected results?			x

6. Data: Tables / Graphs (*max points 8*) _____

Are data presented in individually numbered figures that contain a descriptive caption?			x
Is the appropriate method (data table/graph/picture) used to present the data?			x
Are independent and dependent variables easily identified?			x
Are units appropriately included in all figures?			x

7a. Discussion of Results (*max points 16*) _____

Are the results discussed and conclusions drawn that are appropriate and supported by experimental data presented?			x
Are factors that could have influenced results discussed, and correct interpretation of their potential effect made?			x
Are the significance of the results and the connection to the original purpose clearly stated?		x	
Are remaining scientific questions and potential future experiments discussed?	x		

8. Materials and Methods ……………………………………..(*max points 6*) _____

Is the experiment described in paragraph form and sufficient detail that another could perform the same experiments and obtain the same results?		x	
Are materials and equipment included (specifically) within the context of the procedure?			x

9. References …………………………………………………..(*max points 6*) _____

Are citations in appropriate MLA Format at the end of the manuscript			x
Are citations within the manuscript numbered based on when they appear in the manuscript?	x		

10. Acknowledgements ……………………………………..(*max points 2*) _____

• Are acknowledgements included and consistent?			x