University of New Hampshire

Magnus Effect on Cylindrical Airfoils

Zhangxi Feng, Simon Popecki, James Skinner

ME 646

Professor Todd Gross

5/9/2017

# Table of Contents

[Table of Figures 2](#_Toc481870428)

[Table of Equations 3](#_Toc481870429)

[Abstract 4](#_Toc481870430)

[Introduction 5](#_Toc481870431)

[Methods 5](#_Toc481870432)

[Results and Discussion 7](#_Toc481870433)

[Summary and Conclusion 7](#_Toc481870434)

[References 8](#_Toc481870435)

[Appendix 9](#_Toc481870436)

# Table of Figures

Figure 1……………………………………………………………………………………………2

Figure 2…………………………………………………………………………………………....3

Figure 3……………………………………………………………………………………...…….4

Figure 4…………………………………………………………………………………………....3

Figure 5…………………………………………………………………………………………....3

Figure 6…………………………………………………………………………………………....3

Figure 7…………………………………………………………………………………………....3

# Table of Equations

Equation 1…………………………………………………………………………………………2

Equation 2…………………………………………………………………………………………3

Equation 3…………………………………………………………………………………………4

Equation 4…………………………………………………………………………………………5

Equation 5…………………………………………………………………………………………6

Equation 6…………………………………………………………………………………………7

Equation 7…………………………………………………………………………………………8

# Abstract

Our goal was to evaluate the Magnus Effect around cylindrical airfoils. Using the University of New Hampshire wind tunnel we tested rotating cylinders at different mean wind velocity and rotation speeds (RPM). By keeping the velocity in the wind tunnel constant and changing the RPM of the cylinder we were able to track the trend of the lift force. This test was completed for four different wind speeds at approximately: 12 m/s, 16 m/s, 20 m/s, 24 m/s; and three different cylinder radiuses at: 0.0290 m, 0.0419 m, and 0.0641 m. We ran an additional test on the smallest cylinder radius at constant RPM and for a range of wind speeds from approximately 11 m/s to 30 m/s to more closely see the effect of just the wind speed on lift. Theoretically, we expected to see a linear increase in lift as we increased wind speed or RPM, and quadratic growth when increasing the cylinder radius. What actually occurred was an apparent plateau at our range of tested RPM and wind speeds with our size of cylinders. Despite seeing the expected increase in lift with radius, the total magnitude of lift was not nearly as close to our theoretical values. For our smallest cylinder we reach a Reynolds number as high as 1.128x105, which is well above an appropriate Reynolds number and are now creating vortex shedding behind our cylinder which reduced the experimental lift force.

# Introduction

A spinning ball will drag more air to one side and create a force from the resulting pressure difference. For example, top spin drags more air to flow below the ball. According to Bernoulli’s principle, faster air flow results in lower pressure, which causes the ball to curve downwards [1]. This is known as the Magnus effect. For cylinders, the Magnus lift force is found using the Kutta-Joukowski equation:

(1)

Where is the Magnus lift force for a cylinder of length in a fluid of density flowing at a velocity . The spin of the cylinder will create the vortex strength found using the radius of the cylinder and angular velocity in rad/s [2]:

(2)

Combining equations 1 and 2 gives equation 3:

(3)

Equation 3 predicts a linear relationship between the angular velocity and the force, a linear relationship between the freestream velocity and the force, and a quadratic relationship between the cylinder radius and the force. This experiment aims to verify the accuracy of the Kutta-Joukouski equation at high rotational speeds by measuring the resulting lift forces on cylindrical airfoils at various radii and wind speeds.

# Methods

The testing was conducted in a subsonic open return wind tunnel. The wind tunnel test section cross-sectional area was 19.5” by 18.1”. Two uniform cylinders of diameters 2.28” and 3.3” were made from aluminum cans and a third uniform cylinder of diameter 5.05” was made from a paperboard container. The cylinders each had three wooden disks inside to strengthen the cylinder’s structures in expectation of high lift forces. One disk was in the middle and the other two disks were placed at the ends of the cylinder that were attached to bearings and a shaft that was driven by an electric Mega Motor ACn 16/15/4 that is driven by an electronic speed control which received its signal from a RC remote control. The cylinders had lengths of 5.125”, 6.938”, and 9” in order of increasing diameter. The cylinder was situated near the middle of the cross-section to minimize the effects of boundary layers from the walls. The setup was loaded in cantilever on a steel rod with the rod remained stationary when the cylinder rotated.

The steel rod was supported by an AFA2 force balance to measure lift force. The force digital reading had a resolution of 0.01 N and a fluctuation accuracy of ± 0.2 N. A handheld tachometer was used to measure the RPM of the rotating cylinder with a resolution of 10 RPM and a fluctuation accuracy of about ± 200 RPM. The dimensions were measured with calipers. The diameter of the small and medium radius cylinders had a resolution of 0.001”. The lengths and the diameter of the large cylinder had a resolution of 0.05”. A pitot-static tube was used to measure the static and stagnation pressures in the wind tunnel, which were then used to calculate the wind speed. The speed was controlled by turning a dial until the Pitot tube readings reached approximately the same level as other runs. The tube readings had a resolution of ± 0.05” of water for half the smallest tick spacing. Assuming the air density uncertainty from barometric pressure reading was negligible and the water density had an uncertainty of 0.05 kg/m3, the errors for wind speeds were propagated to be

Where is the dynamic pressure found from the difference of static and stagnation pressures from the tube readings. The errors in the 4 wind speeds were found to be (12 ± 1.2) m/s (10%), (16.37 ± 0.89) m/s (5.4%), (19.78 ± 0.74) m/s (3.7%), and (24.02 ± 0.61) m/s (2.5%).

Four trials were completed for each cylinder at the each of the wind speeds. For each trial, the cylinders were rotated at three different RPMs. The largest diameter cylinder stabilized at around 3500 RPM and the range was from 3500 to 5500 RPM. The other two cylinders covered a range from 3000 RPM to 6000 RPM. Due to the accuracy of the tachometer and the fluctuating nature of the rotating cylinder, it was ineffective to maintain the same RPM across the trials. At the RPMs in the experiment, the expected forces from equation 3 range from 3.1 N at smallest diameter and slowest wind speed to 98 N at the largest diameter and fastest wind speed. 200 RPM difference would result in 4% to 6% error, which suggested the RPMs can be treated as equal when evaluating the effect of wind speed at constant RPM.

# Results and Discussion

# Summary and Conclusion

To test the validity Kutta-Joukouski lift equation (equation 1) at high rotational speeds we tested three different sized cylinders at different wind speeds and high rotational speeds. Based on this equation, you could theoretically produce an enormous amount of lift if you kept increasing any one of the factors from equation 3. Theoretically, we expected to see a linear increase in lift as we increased wind speed or RPM, and quadratic growth when increasing the cylinder radius.

Our experiment shows that at high rates of RPM and wind speed the difference between the theoretical and the obtained values are significant. After research we found that the wind speeds we were placing our model cylinders in was producing large Reynolds numbers that was producing a turbulence vortex behind the cylinder which disrupted the flow behind the cylinder. This disrupts the low pressure region above the cylinder and the high pressure region below the cylinder, because of this we assume the magnitude of pressure on the top and bottom are both increasing due to the alternating flow path beyond the cylinder as a result of the vortex.

# References

|  |  |
| --- | --- |
| [1] | R. K. G. Kobes, "Bernoulli's Principle," 29 September 1999. [Online]. Available: http://theory.uwinnipeg.ca/mod\_tech/node68.html. [Accessed 6 May 2017]. |
| [2] | N. Hall, "Lift of Rotating Cylinder," NASA, 5 May 2015. [Online]. Available: https://www.grc.nasa.gov/www/k-12/airplane/cyl.html. [Accessed 30 4 2017]. |

# Appendix

Table A Smallest diameter cylinder experiment data

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Stella |  |  |  |  |  |  |
| P1 (inH2O) | P2 (inH2O) | Delta h (m) | Wind Speed (m/s) | RPM | Lift (N) | Test |
| 1.65 | 1.3 | 0.00889 | 12.00973309 | 3100 | 0.5 | **TRIAL 1** |
|  |  |  |  | 4060 | 1.45 |  |
|  |  |  |  | 6000 | 1.96 |  |
| 2 | 1.35 | 0.01651 | 16.36650742 | 3024 | 1.25 | **TRIAL 2** |
|  |  |  |  | 4130 | 1.48 |  |
|  |  |  |  | 5960 | 2.28 |  |
| 2.45 | 1.5 | 0.02413 | 19.78614266 | 2950 | 1.35 | **TRIAL 3** |
|  |  |  |  | 3930 | 1.27 |  |
|  |  |  |  | 5950 | 2.31 |  |
| 3 | 1.6 | 0.03556 | 24.01946618 | 2800 | 1.43 | **TRIAL 4** |
|  |  |  |  | 4000 | 1.17 |  |
|  |  |  |  | 5870 | 2.11 |  |

Table A Medium diameter cylinder experiment data

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Budweiser |  |  |  |  |  |  |
| P1 (inH2O) | P2 (inH2O) | Delta h (m) | Wind Speed (m/s) | RPM | Lift (N) |  |
| 1.65 | 1.3 | 0.00889 | 12.00973309 | 3200 | 2.3 | **TRIAL 1** |
|  |  |  |  | 4940 | 3.17 |  |
|  |  |  |  | 5800 | 1.65 |  |
| 2 | 1.35 | 0.01651 | 16.36650742 | \* | \* | **TRIAL 2\*** |
|  |  |  |  | \* | \* |  |
|  |  |  |  | \* | \* |  |
| 2.45 | 1.5 | 0.02413 | 19.78614266 | 3291 | 10.13 | **TRIAL 3** |
|  |  |  |  | 4700 | 21.92 |  |
|  |  |  |  | 5844 | 13.91 |  |
| 3 | 1.6 | 0.03556 | 24.01946618 | 3100 | 10.25 | **TRIAL 4** |
|  |  |  |  | 4860 | 13.11 |  |
|  |  |  |  | 5916 | 8.97 |  |

Table A Largest diameter cylinder experiment data

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Oats |  |  |  |  |  |  |
| P1 (inH2O) | P2 (inH2O) | Delta h (m) | Wind Speed (m/s) | RPM | Lift (N) |  |
| 1.65 | 1.3 | 0.00889 | 12.00973309 | 3720 | 3.72 | **TRIAL 1** |
|  |  |  |  | 4560 | 3.14 |  |
|  |  |  |  | 5560 | 4.35 |  |
| 2 | 1.35 | 0.01651 | 16.36650742 | 3660 | 6 | **TRIAL 2** |
|  |  |  |  | 4470 | 4.97 |  |
|  |  |  |  | 5630 | 5.26 |  |
| 2.45 | 1.5 | 0.02413 | 19.78614266 | 3675 | 8.42 | **TRIAL 3** |
|  |  |  |  | 4050 | 7.25 |  |
|  |  |  |  | 5500 | 7.67 |  |
| 3 | 1.6 | 0.03556 | 24.01946618 | 3000 | 10.6 | **TRIAL 4** |
|  |  |  |  | 3160 | 15.5 |  |
|  |  |  |  | 5200 | 10.43 |  |

Table A 4 Smallest diameter cylinder high wind speed experiment data

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| P1 (inH2O) | P2 (inH2O) | Delta h (m) | Wind Speed (m/s) | Lift (N) | RPM |
| 1.5 | 1.2 | 0.00762 | 11.11885229 | 0.67 | 3760 |
| 2 | 1.35 | 0.01651 | 16.36650742 | 0.61 | - |
| 2.5 | 1.5 | 0.0254 | 20.30015404 | 0.5 | - |
| 3 | 1.65 | 0.03429 | 23.58664756 | 0.4 | - |
| 3.5 | 1.8 | 0.04318 | 26.46816261 | 0.36 | - |
| 4 | 1.9 | 0.05334 | 29.41771802 | 0.47 | 3760 |