



The Effect of Surface Roughness on Lift and Drag in a Low-Speed Homemade Wind Tunnel

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Problem

Surface texture plays a large role in aerodynamic performance. Even at low speeds, small changes to a wing's surface can affect airflow, lift, drag, and overall efficiency. This is important especially for small aircraft, drones, and RC planes that operate at lower Reynolds numbers, because airflow is more sensitive to surface conditions. While smooth airfoils are the industry standard, different surfaces such as dimples or rough finishes may change how the air flows over the airfoil. The purpose of this experiment is to investigate how different surface textures affect the lift-to-drag ratio of a small airfoil in a low-speed, homemade wind tunnel. Four identical airfoils with different types of surface texture were tested to determine how surface texture affects aerodynamic efficiency. This project aims to improve understanding of how surface texture can impact low-speed airfoil performance and whether certain surface textures can improve efficiency.

Hypothesis

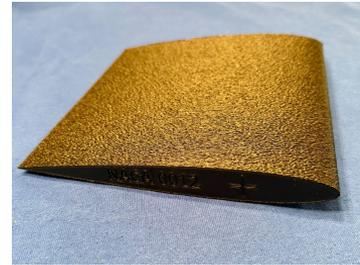
If the surface of a wing is made rougher, then drag will increase and lift behavior will change because texture alters the boundary layer and airflow attachment.



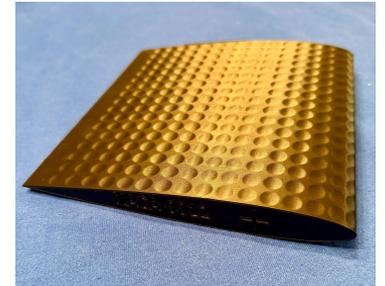
Smooth - Photo taken by researcher



Sandpaper - Photo taken by researcher



Rough 3D printed - Photo taken by researcher



Dimpled - Photo taken by researcher

Method

Airfoil Manufacturing

- Four NACA 0012 airfoils 3D printed with different textures: smooth, dimpled, 3D rough, sandpaper rough

Wind Tunnel Setup

- Reassembled homemade wind tunnel (contraction cone, test chamber, diffuser with fan)

Testing System

- Aluminum testing rack with adjustable angle of attack
- Two load cells measure lift and drag

Electronics

- Arduino MEGA 2560 + HX711 amplifiers
- Custom code used to record sensor data



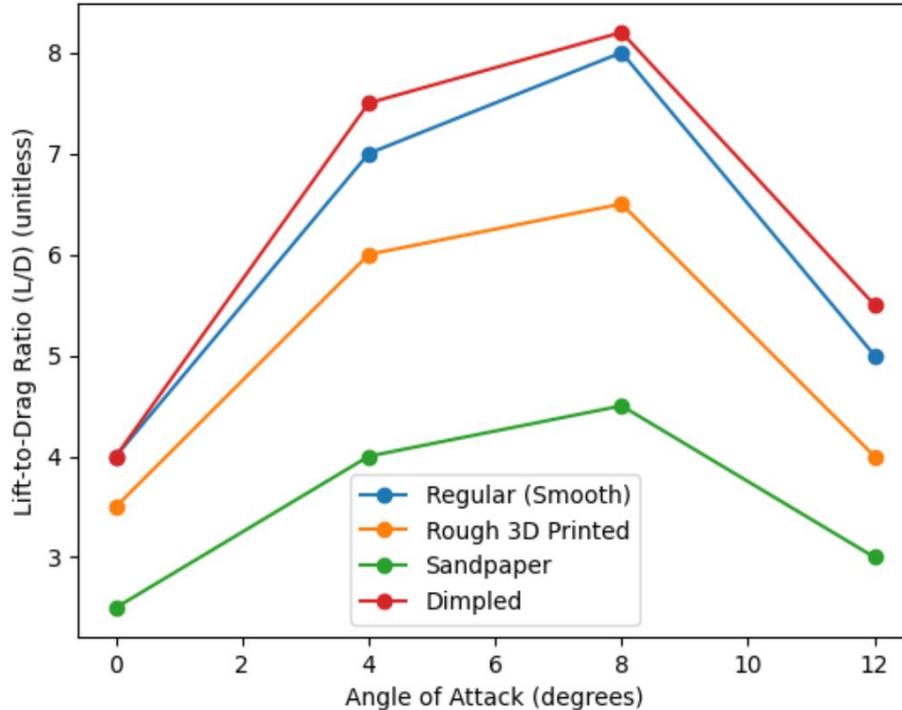
Wind Tunnel with mounted wing - Photo taken by researcher



Fully assembled wind tunnel- Photo taken by researcher

Results Graphed

Lift-to-Drag vs Angle of Attack



Airfoil Surface	Angle of Attack	Trials					Mean		Standard Deviation	Standard Error
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Lift/Drag Ratio	Median		
Smooth	0°	4.18	3.87	4.06	3.94	4.11	4.03	4.06	0.13	0.06
Smooth	4°	6.88	7.22	6.94	7.05	7.13	7.04	7.05	0.13	0.06
Smooth	8°	8.34	7.91	8.07	7.86	8.19	8.07	8.07	0.19	0.09
Smooth	12°	5.11	4.83	4.97	5.06	4.88	4.97	4.97	0.12	0.05
Rough 3D Printed	0°	3.61	3.42	3.58	3.47	3.39	3.49	3.47	0.09	0.04
Rough 3D Printed	4°	6.17	5.88	6.03	5.94	6.11	6.03	6.03	0.12	0.05
Rough 3D Printed	8°	6.79	6.38	6.61	6.46	6.52	6.55	6.52	0.16	0.07
Rough 3D Printed	12°	4.22	3.91	4.06	3.83	4.02	4.01	4.02	0.15	0.07
Sandpaper	0°	2.62	2.41	2.53	2.37	2.46	2.48	2.46	0.10	0.04
Sandpaper	4°	4.19	3.88	4.11	3.97	4.04	4.04	4.04	0.12	0.05
Sandpaper	8°	4.68	4.29	4.47	4.39	4.56	4.48	4.47	0.15	0.07
Sandpaper	12°	3.17	3.04	3.22	3.11	3.06	3.12	3.11	0.07	0.03
Dimpled	0°	4.12	3.93	4.05	4.08	3.97	4.03	4.05	0.08	0.04
Dimpled	4°	7.64	7.38	7.55	7.71	7.49	7.55	7.55	0.12	0.05
Dimpled	8°	8.41	8.03	8.22	8.29	8.15	8.22	8.22	0.14	0.06
Dimpled	12°	5.73	5.32	5.48	5.61	5.46	5.52	5.48	0.16	0.07

Results

The results of this experiment showed clear and consistent aerodynamic trends across each of the different surface textures. The smooth and dimpled airfoils produced the highest lift-to-drag ratios, especially at angles of attack near 8 degrees, where aerodynamic efficiency peaked. The rough 3D printed foil showed moderate performance, while the foil with sandpaper produced the least efficient results due to increased drag. All airfoils demonstrated aerodynamic behavior that was expected. Performance decreased at higher angles of attack as the drag increased. The data displayed logical trends, which are in line with existing professional data, showing the reliability and realism of the data.



Foil in Wind Tunnel. Photo taken by researcher

Discussion

The hypothesis stated that increased surface roughness would decrease aerodynamic efficiency compared to a smooth surface due to disrupted airflow and increased drag. The results of this experiment supported this hypothesis. The smooth and dimpled airfoils produced the highest lift-to-drag ratios, indicating higher efficiency. The rough 3D printed and sandpaper airfoils showed the least efficiency (lower lift to drag ratio). Peak efficiency for the airfoils occurred near moderate angles of attack, which follow normal aerodynamic trends in lift-to-drag data. The sandpaper airfoil likely increased friction along the surface and caused earlier flow separation, which reduces overall efficiency. The dimpled pattern may have helped control airflow by mixing the faster moving air with the slower moving air near the surface of the wing, helping the airflow stay attached to the airfoil for a longer period of time. This would allow higher performance at certain angles. There may have been some inconsistencies in the data due to irregular airflow, slight angle measurement differences, and the overall sensitivity of the sensors. Overall, the trends in the data that were observed are consistent and realistic, indicating that surface textures and designs do play a major role in the efficiency of an airfoil.

Conclusion

The purpose of this project was to determine how surface roughness affects aerodynamic efficiency in a low-speed, homemade wind tunnel. The results supported the hypothesis, which said that surface texture can affect lift-to-drag performance. The smooth and dimpled airfoils had the most efficient results, while the rough 3D printed and sandpaper surfaces showed the least efficiency due to increased drag and decreased lift. All airfoils demonstrated expected aerodynamic results, showing the arc in the graph due to the rising and falling of efficiency at different angles of attack. Although expected results occurred, there may have been errors in the experimental set up. Turbulence from non-perfect surfaces and conditions in the wind tunnel, slight variations in the angle of attack, and extreme sensitivity from the sensors all may have negatively affected results. Also, small surface deformities from the 3D printer may have given off unintended data.

Conclusion Cont.

Future improvements could include better airflow with wind tunnel refinements, a more advanced and precise angle measurement system, and improvements to the sensors hardware and software/coding. Testing at different airflow speeds could also be an interesting addition, as well as more angles of attack. Although the dimpled pattern showed to be most efficient, this does not necessarily correlate with real world application in the commercial industry. Full scale airplanes operate at much different speeds, and with much heavier materials, which may negate the limited positives of the dimpled pattern. Additionally, dimpling the wings could provide structural problems and potential surface wear over time. However, further experimentation could introduce new methods for the use of the dimpled pattern and may prove to be useful in the future. For smaller airfoils, low speed planes, RC planes, and drones, this dimpled pattern could be potentially revolutionary in the present age, because of the low risk of testing. Overall, the findings in this experiment highlight the importance of surface texture of airfoils, especially in a low-speed setting.

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