A Hole in a Wing: Not Always a Bad Thing

By Vladislav Ternovsky

Introduction

An airfoil is a device that provides reactive force when in motion relative to the surrounding air. Usually the force created is lift because of the pressure differences over the top and bottom surface. Airfoils have many purposes. They produce lift on an airplane wing, keep a race car close to the road surface, lift a boat’s hull until it is totally outside the water, and many more.

Most of the time, airfoils are designed to produce the maximum lift yet leave as little drag as possible. Such airfoils are ideal for most applications because an airfoil is used to move an object in a desired direction. However, I thought of a simple idea of how an airfoil could be used for a different purpose.

My project consists of two parts. In the first I experimented with my idea of putting a hole through the airfoil, connecting the upper surface and lower surfaces. My hypothesis for this part was that when a hole is placed in a wing, airflow velocity in the hole will be faster than surrounding airflow velocity. Endplates and a hole will redirect the airflow vortex to go through the hole.

In the second part I hoped to find a new purpose for an airfoil with a hole.

Procedure – part 1

For the first part of my project, I had to build a set-up which would produce laminar airflow. It was difficult to achieve because the fan in my set up blew air out rather than suck air in, but I solved the problem by enclosing the fan in a tunnel to keep air from escaping, and a grid at the front of the tunnel to straighten the overall direction of airflow. Next, I built some airfoils for testing. I chose the ideal profile which was based on a NACA 6324 airfoil design.
The airfoil design fit the application because it had a large camber (% chord) and the overall shape was thick and compact, yet it’s capable of making a lot of lift.

To find out some data about the airfoils, I built a device which could measure airflow velocity. The device uses a fiber optical sensor that calculates the number of times its light ray is blocked by an object. The object is a small three bladed propeller that spins freely even at low velocity speeds. A counter displays the number of times the blades pass by the sensor; however it does not display the wind speed so I decided to calibrate it. To do this, I bought a weather station which displayed wind speed, and I placed the included anemometer near another smaller fan which I built earlier. I found out the wind speed at that point, and then placed my device in the same location. Then I compared the counter reading to the wind speed, and was able to create a conversion chart from the counter reading to wind speed. Next, I started experimenting and writing down data.

The majority of the experiments I did consisted of writing down the counter reading at specific points near the top and bottom surfaces of the airfoil. I placed a different hole in the airfoil for each experiment, and was then able to create graphs to better understand the effects each hole had on the airflow velocity over the airfoil. However, the first experiment I did focused on the best angle of attack for the airfoil. I did this experiment first because it was crucial to find the angle where the airfoil would create the most lift at the maximum pressure difference location. If the angle would be too steep, then the airfoil would not create any lift, and the hole wouldn’t serve a purpose, as there would be no pressure difference. If the airfoil would have an angle of attack of zero, then it also wouldn’t create the most lift capable.

While doing these experiments, I realized that a classifying system for the holes would be helpful. I called it HPC, or Hole Properties Coefficient. It consists of 6 coefficients, each
telling information about the proportions and co-ordinates of the hole in relation to the airfoil. An example of an HPC for one of my holes is HPC 24 6 51 – 24 6 29. Using this system, I was able to find the HPC of the holes I built, and from there I could come up with a conclusion for which HPC of a hole works best in the airfoil.

**Results - Part 1**

After conducting many experiments on the effects a hole has in an airfoil, I came up with many results on which type of hole works best. These results are important, because from them, I could start expanding on my project, and applying it to various applications. Here are just a few:

1. A hole with an area of less than 2% of the airfoil, does not allow air to enter easily, because the opening is too small for viscous air ($K_5=0.05$, HPC 24 6 51 – 24 6 29).

2. A hole which faces forward allows air to enter more freely, therefore increasing airflow velocity in the hole ($K_3 =1.3$, HPC 13 20 35 – 13 20 43).

3. Highest increase in airflow velocity was observed on holes where $B > A$ (HPC 13 7 32 – 13 16 39).

4. Airflow velocity does not depend on $K_4$. It depends only on the area of the smallest opening of the hole (HPC 13 7 32 – 13 16 39 and HPC 12 19 42 – 12 6 44).

5. The best angle of attack for the particular airfoil at my testing conditions is about 7 degrees. Any more, and there begins to be turbulence at the maximum pressure difference location.

**Part 2**

Now that I knew which hole worked best in my airfoil, I started coming up with various applications for an airfoil with a hole. The first was an Air break for aircrafts. Flaps in the airfoil would open, allowing air to flow through the opening, therefore slowing down the aircraft. My
second idea for an application was to Control the lift of an airfoil, for all purposes and applications. When a propeller is placed in the hole, it could control the amount of airflow through the hole, therefore controlling the amount of lift the airfoil creates.

My best idea was a Wind Generator. By placing a rotor into the hole, it would spin faster than the same rotor without the airfoil. An advantage of such a design is it takes up less space, doesn’t make a lot noise and spins at low wind speeds compared to today’s common three bladed wind generators. The wind generator was my best idea, so I decided to expand on it, and build a prototype.

My hypothesis was that when there are two airfoils side by side, airflow velocity in the hole will increase even more. I also think the Savonius rotor will spin faster when it’s outside the hole, because airflow over the airfoil will make the rotor spin faster.

**Procedure - Part 2**

For the second part of my project, I expanded on my idea of the wind generator in an airfoil. I did experiments with different Savonius rotor designs and then placed the one that span fastest into the hole with HPC 32 30 39 – 33 32 38 in an airfoil based on a NASA 6324 profile, at the ideal angle of attack \((7^0)\) with endplates. I chose this hole because it had the best aerodynamic qualities from the holes which I tested earlier. The Savonius rotor fit my application because it could easily be placed in a rectangular hole, and spin in any wind direction. Some other experiments I did for this part of the project were testing if two airfoils side by side increased airflow velocity even more, and then finding the ideal distance between the two airfoils. I also did an experiment on the best location of the Savonius rotor. I checked if it span faster inside or outside of the hole.

**Results - Part 2**
I found out important information from the experiments for the wind generator. Some of the findings were that 2 airfoils increase airflow velocity even more, the ideal distance between the airfoils is approximately 75 mm, and that the rotor span faster when it was placed partly outside of the hole.

**Conclusion**

A hole in a wing is not always a bad thing, as outlined in my project. I observed airflow enter the hole, potentially at a faster speed. I proposed to use my HPC classifying system, to identify holes in airfoils. Using the system, I tested various holes, and found the most effective one. Looking for ways to increase the airflow velocity through the hole even more, I added endplates and a second airfoil to the set-up. Finally, I thought of some uses for the set-up, such as the wind generator where I tested to find the ideal Savonius rotor and its position in the hole. I believe that my wind generator is perfect for urban use, as it has a compact design. It could be placed between houses, where air flows faster. It could be placed at higher altitudes on the roofs of sky scrapers and condos. The final design could have many vertical airfoil sections, which would rotate according to the direction of the wind. Although one generator won’t produce enough electricity to power an entire city, it will dramatically reduce our dependence on non-renewable resources. Wind energy will always stay with us, so it is important that we start harvesting it, wherever possible. I think that my wind generator is a small step in the right direction for our future energy needs.

**Acknowledgements**

I worked on my project alone for the majority of the time. The only time when I got any assistance was when my father helped me with the electrics in my set-up.
**Bibliography**

**Books**


**Web Sites**
1 Hanley Innovation Race Car Wings  
   http://www.hanleyinnovations.com/racecar1.html
2 See how it flies (John S. Denker)  
   http://www.av8n.com/how/#contents
3 http://www.cfd-online.com/Links/education.html
4 Ground school – Theory of Flight  
   John Brandon  Aerofoils and wings  
5 Velocity and Pressure Distributions  
   http://www.mh-aerotools.de/airfoils/velocitydistributions.htm#defCoefficients
6 Appendix 3, 4 and 5 Digit Sections  
   http://www.pdas.com/sections45.htm
7 Flexible flaps for separation control on a wing with low aspect ratio  
   http://www.bionik.tu-berlin.de/user/giani/vortrag/sld001.htm
8 Method for calculating wing characteristics by lifting-line theory using nonlinear section lift data  
   http://www.soton.ac.uk/~jps7/Aircraft%20Design%20Resources