HOMEWORK #2

LIFT FORCE

1) Provide the equation for the **Lift force** on an airfoil. Define each of the terms in the equation and provide their units.

2) Provide the equation for the **Drag force** on an airfoil. Define each of the terms in the equation and provide their units.

3) What role does **Angle of Attack** have on the Lift Coefficient? What happens to Lift when Angle of Attack gets too high?

4) Provide **a concise** history of how the Wright brothers sized their airplane wings. What equations did the Wright brothers use, and what issues did they have with the values for some of the parameters. How did they resolve these issues. What roles did John Smeaton, Sir George Cayley and Otto Lilienthal have? (Be concise)

5) Air France 447 Accident: Explain how a failed pitot tube resulted in an aerodynamic stall. (**Be concise**)

Between 1900 and 1905, the Wright brothers designed and built three unpowered gliders and three powered aircraft. As they designed each aircraft, how did they know how big to make the wings?

The Wright brothers operated a bicycle shop in Dayton, Ohio, and had a good working knowledge of math and science. They knew about Newton's laws of motion and about forces and torques. They knew that they needed to generate enoughaerodynamic lift to overcome the weight of their aircraft. They had written to the Smithsonian when they began their enterprise in 1899 and received technical papers describing the aeronautical theories of the day. There were mathematical equations which could be used to predict the amount of lift and drag that an object would generate. The lift equation is shown on this slide.

The amount of lift generated by an object depends on a number of factors, including properties of the air, the velocitybetween the object and the air, the surface area over which the air flows, the shape of the body, and the body's inclination to the flow, also called the angle of attack.

By the time the Wrights began their studies, it had been determined that lift depends on the square of the velocity and varies**linearly** with the surface area of the object. Early aerodynamicists characterized the dependence on the properties of the air by a pressure coefficient called Smeaton's coefficient which represented the pressure force (drag) on a one foot square flat plate moving at one mile per hour through the air. They believed that any object moving through the air converted some portion of the pressure force into lift, and they represented that portion by a lift coefficient. The resulting equation is given as:

$$L = k * V^2 * A * cl$$

where **L** is the lift, **k** is the Smeaton coefficient, **V** is the velocity, **A** is the wing area, and **cl** is the lift coefficient. This equation is slightly different from the modern lift equation used today. The modern equation uses the dynamic pressure of the moving air for the pressure dependence, while this equation uses the Smeaton coefficient. Modern lift coefficients relate the lift force on the object to the force generated by the dynamic pressure times the area, while the 1900's lift coefficients relate the lift force to the drag of a flat plate of equal area.

The 1900's equation assumes that you know the perpendicular pressure force on a moving flat plate (Smeaton coefficient). Because of measuring inaccuracies at the time, there were many quoted values for the coefficient ranging from .0027 to .005. Lilienthal had used the .005 value in the design and testing of his wings. When the Wrights began to design the 1900 aircraft, they used values for the lift coefficient based on the work by Lilienthal so they too used the .005 value. During thekite and glider experiments of 1900 and 1901, the brothers measured the performance of their aircraft. Neither aircraft performed as well as predicted by the lift equation. The 1901 aircraft had been designed to lift itself (100 pounds) plus a pilot (150 pounds) when flown as a kite in a 15 mile per hour wind at 5 degrees angle of attack. But in flight, it could barely lift itself in a 15 mile per hour wind at a much higher angle of attack. So the brothers began to doubt the .005 value for the Smeaton coefficient and they determined that a value of .0033 more closely approximated their data. The modern accepted value is .00326.

The brothers also began to doubt the accuracy of Lilienthal's lift coefficients. So in the fall of 1901, they decided to determine their own values for the lift coefficient using a wind tunnel. The brothers built a clever balance to directly measure the ratio of the lift of their models to the drag of an equivalent flat plate. We have developed an interactive tunnel simulatorso that you can duplicate their wind tunnel results. In the process of testing many airfoil models, the brothers discovered the importance of wing shape on the lift coefficient. They determined that the Lilienthal data was correct for the wing geometry that he had used, but that the data could not be applied to a wing with a very different geometry. Lilienthal's wings had a rather short span and an elliptical planform, while the brothers used a long, thin, rectangular planform. The brothers tested over fifty different models to determine how lift and drag are affected by various design parameters and they used this data to design their 1902 aircraft using the lift equation shown on the slide with their own lift coefficients.