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Density Effects on Aerodynamic Forces

Glenn Research Center

F = Force
L = Lift
D = Drag

ρ = Density

Aerodynamic force is directly related to the air density flowing past the body.

$$F = \text{Constant} \times \rho$$

then

$$L = \text{Constant} \times \rho$$

Half the Density --> Half the Lift

and

$$D = \text{Constant} \times \rho$$

Half the Density --> Half the Drag

Lift is created by deflecting a moving fluid (liquid or gas), and drag is generated on a body in a wide variety of ways. From Newton's second law of motion, the aerodynamic forces on the body (lift and drag) are directly related to the change in momentum of the fluid with time. The fluid momentum is equal to the mass times the velocity of the fluid. Since the fluid is moving, defining the mass gets a little tricky. If the mass of fluid were brought to a halt, it would occupy some volume in space; and we could define its density to be the mass divided by the volume. With a little math which is described on the fluid momentum page, we can show that the aerodynamic forces are directly proportional to the **density of the fluid** that flows by the airfoil.

Lift and drag depend linearly on the density of the fluid. Halving the density halves the lift, halving the density halves the drag. The fluid density depends on the type of fluid and the depth of the fluid. In the atmosphere, air density decreases as altitude increases. This explains why airplanes have a **flight ceiling**, an altitude above which it cannot fly. As an airplane ascends, a point is eventually reached where there just isn't enough air mass to generate enough lift to overcome the airplane's weight. The relation between altitude and density is a fairly complex exponential that has been determined by measurements in the atmosphere.

Let's investigate the dependence of lift on density using a Java simulator.

Due to IT security concerns, many users are currently experiencing problems running NASA Glenn educational applets. The applets are slowly being updated, but it is a lengthy process. If you are familiar with Java Runtime Environments (JRE), you may want to try downloading the applet and running it on an Integrated Development Environment (IDE) such as Netbeans or Eclipse. The following are tutorials for running Java applets on either IDE:
Netbeans
Eclipse

As an experiment, set the altitude to 5300 feet and note the value of the density and the amount of lift. Now change the altitude to 26,500 feet. What is the new value of the density? What is the value of the lift? How do these compare to the previous measurement? Notice that the altitude did not double. Now take this airplane to Mars. How does the density and lift compare to Earth at the same altitude? Move the altitude up to 37000 feet. How does the density and lift compare to the original measurements on Earth?

You can download your own copy of the program to run off-line by clicking on this button:

Download Applet

You can further investigate the effect of density and the other factors affecting lift by using the FoilSim III Java Applet. You can also download your own copy of FoilSim to play with for free.

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