

Drag

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All physical objects that move are affected by the fluid in which they move. The fluid creates lift and drag forces on the body. The drag opposes motion and is non-conservative. That is, the force required to overcome drag cannot be recovered. Pressure and viscous effects in the fluid cause drag. The types of fluid motion and flow regions influence the drag produced. Aircraft drag depends on body shape and the lift produced.

Fluids have two observable modes of flow, laminar and turbulent. A smooth, consistent and layered flow is a laminar flow. A flow with random, nonsteady and non-layered flow is a turbulent flow.

Laminar flows are layered and smooth. The motion of a laminar is consistent and uniform. Streamlines in the flow show the fluid particles moving in the direction of motion and sliding across other particles. The streamlines of a laminar flowing fluid past an object tends to follow the object's shape. Streamlines may change their relative closeness as the pressure changes; however, the fluid still is smooth and layered in flow. Generally, The streamlines for a laminar flow have regular and calculatable shapes. (Figure 1)

Turbulent flows are random and non-layered. Although the average velocity may be uniform when taking a large volume of fluid, individual particles may be moving in any direction or may be rotating (Figure 2). A transition is required to go from laminar to turbulent flow. In the transition stage, the streamlines of the flow are not totally irregular but are unstable. Small disturbances amplify when is the transition stage. Turbulent flow on flat plates usually occurs at a Reynold's number of 300000 based on length. Pressure gradients, surface roughness and disturbances also strongly influence when a flow becomes turbulent. Compared with laminar, the drag is increased for turbulent flows (Figure 3).

The drag associated with the flow of a fluid over a body is commonly divided into two

parts depending on the drag process involved. The viscous drag is due to shear friction of the fluid. The pressure drag is due to mismatches in the pressure caused by fluid flow.

Viscous drag is due to the stickyness of the fluid in contact with an object. Because the fluid sticks to the surface, the moving body is required to expend energy to change the speed of the fluid to the object's surface velocity. This changing of velocities forms a shear stress along the body's surface. This shear stress times the area of the surface is the effective viscous drag force. The difference in flow between cold honey and gasoline is due to the viscosity. The gasoline flows faster due to less internal viscosity and thus less internal energy dissipation. Energy dissipated by drag is given to the surroundings as heat.

Pressure drag is the drag due to a mismatch of pressure forces in the direction of motion. The pressure at the front of an object is higher than atmospheric pressure due to the moving object compressing the air in front. This pressure times area creates a force opposing the movement direction. In an ideal flow, the back of the object would have similar pressures and thus similar forces. The front and back forces would completely cancel each other with the result of no drag. In the real world, the smooth flow along the body eventually becomes separated from the object and is replaced with turbulent flow. This turbulent flow exerts less pressure than laminar flow. Thus, the reduced pressure due to turbulence means the front and back forces are now no longer balanced. This unbalanced force results in pressure drag.

Because the pressure drag depends on the flow over a body, the pressure drag can suddenly change if there is a change in flow. A circular cylinder at high speed has a smaller pressure drag than at low speeds due to changing flow patterns. At a high Reynold's

number, a circular cylinder has a lower pressure drag due to a smaller area of low pressure on the back of the cylinder. For the high Reynold's number flow, the flow actually stays attached to the cylinder further back. Because the flow stays attached, the pressure is more evenly matched and the pressure drag is less. At low Reynold's numbers, the flow separates and becomes turbulent after passing the widest part of the cylinder. This separation creates a poor pressure recovery in the rear of the cylinder and thus a large drag (Figure 4).

An object moving through a fluid is idealized as being surrounded by two regions of flow. Ideal flow is the region away from the body where few changes occur. The boundary layer is the region near the body where a flow slides on the surface. These two regions operate nearly independently which allows for simplifications of flow and drag modeling.

The ideal flow region occurs away from the body. The fluid is unable to effectively 'feel' the presence of the object only other surrounding fluid particles. The fluid might be deflected away slightly but the relative arrangement of fluid particles is not being changed. No relative velocity between fluid particles effectively makes the viscosity of a fluid irrelevant.

Near the body, the fluid can feel the object. No slipping at the fluid-object boundary forces the fluid to zero velocity at the object surface. The fluid particles are being dragged with the object creating a boundary layer region. In this boundary layer region, the fluid velocity goes from the ideal 'free-stream' velocity far from the body to zero velocity at the object surface. In the boundary layer region, the viscosity is important due to the changes in relative fluid velocity (Figure 5).

The boundary layer builds up as it progresses downstream along an object. For laminar flows along a plate, the thickness of the boundary layer is proportional to the

square root of the distance traveled along the plate. The build-up is most rapid when in transition from laminar to turbulent. After reaching a turbulent flow, the layer increases proportionally to the four fifths power of the distance traveled (Figure 6). The net effect of boundary layer's reduced velocity is to push oncoming fluid particles away from the body. This makes the body 'thicker' as seen from a fluid particle. The boundary layer thickness is often given as the apparent body thickness as seen by the fluid (Figure 7).

Flow separation occurs when a flow is unable to conform to the object's surface. The flow may be unable to conform due to a sharp turn of the surface or due to a pressure gradient. With flow separation, a recirculation zone of non-uniform and circulating fluid particles is formed. A recirculating zone normally has a pressure near the ambient pressure. With a wing, separation along the top surface frequently occurs due to excessive pitch, angle of attack, which is called a stall. The separation point moves forward from the trailing edge as the wing becomes more stalled until the separation point has destroyed the lift production along the entire wing. Behind the separation point is the recirculation zone in which little to no lift is produced. The increase in turbulence and change in pressure increases both viscous and pressure drag in flow separations and recirculation zones.

In aircraft, drag is divided into parasite and induced drag. The parasite drag is due to the viscous and pressure drag caused by the aircraft as it moves through the air. The parasitic drag of an object is proportional to the square of the velocity. Thus parasitic drag is highest with high speeds. The induced drag is the drag component directly caused by the production of lift. The induced drag of an object is proportional to the inverse square of the velocity. Thus, induced drag is highest with low speeds. When combined, the total drag of an aircraft has both squared and inverse squared terms (Figure 8). This combined

total drag means that the minimum drag corresponds to a non-zero flight velocity and increases rapidly as the flight velocity deviates from the minimum drag.

Drag affects bodies that moves in a fluid. Drag removes energy depending on the body shape and the flow characteristics of the fluid. The fluid viscosity and body area affect the skin friction drag while the body shape affects the pressure drag. Drag is an aircraft is related to the body shape and the lift being produced.