Physics Lecture 8 - Air Drag 101

Summary/Conclusions

Fundamentals of air drag are presented that show the different types of air drag on an object. The effects of streamlining, as measured by a drag coefficient, are explained. Drag coefficients for various car body shapes and wheel types are given. The air resistance force is also calculated. The air flow around different body shapes is shown.

Fundamentals

There air two fundamental ways that air interacts with a body that is traveling faster than about 1 mph or 1.5 ft per second. One way produces pressure forces caused by air impacting perpendicular to the body surface. The other way is by air rubbing tangentially or parallel to a body surface. These drag forces are called pressure drag and skin friction drag respectively. One key factor in determining air drag on a body is the projected area, called A_B, that is the largest cross section perpendicular to the direction of travel. Another key factor is the streamlining or shape factor called drag coefficient C_B. The cross sectional area is pretty easy to measure, but the drag coefficient is more subtle.

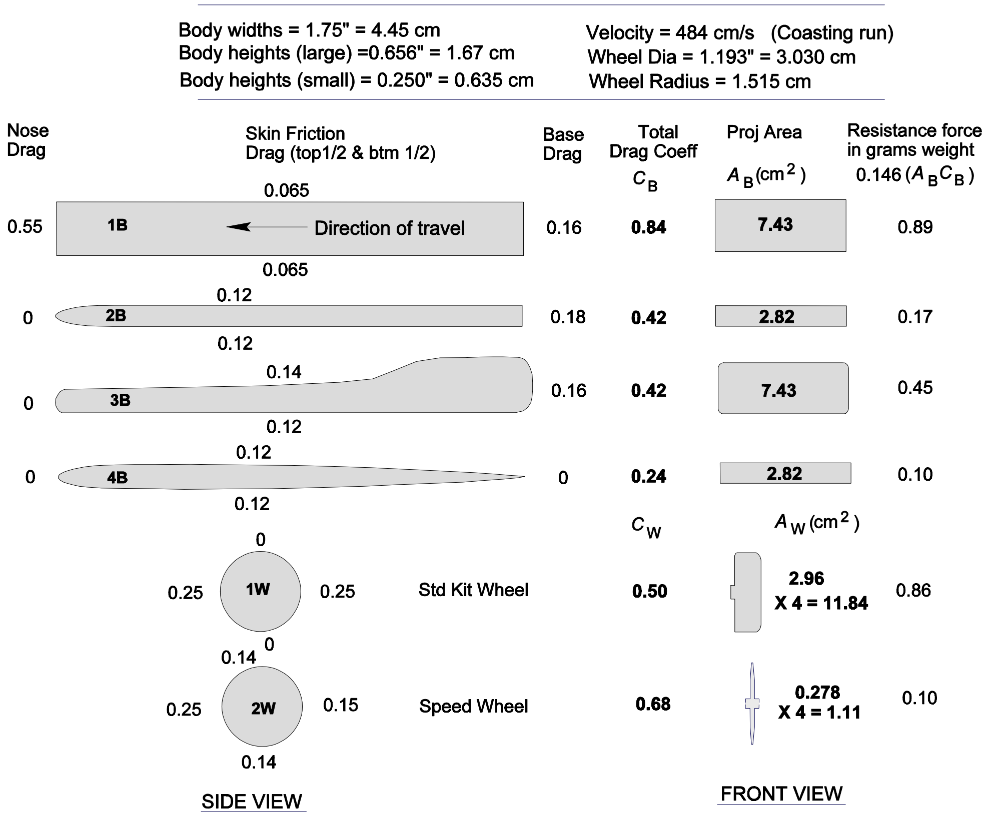

Figure 1 - *Showing some body and wheel shapes and their projected areas, drag coefficients, and net air drag deceleration force in grams weight.*

Streamlining

Streamlining is the reduction of drag coefficient. First, consider a plain unstreamlined block shape **1B** at the top of **Figure 1** that has over half its drag coefficient (0.55) caused by air piling up in front of its flat face. As this air flows around the sharp 90° angle front corners turbulence or rotational eddies are formed that keep the air from rubbing much in a parallel fashion against the sides (see **Figure 2**). So the skin friction drag is fairly modest (0.065 + 0.065) = 0.13 compared with pressure drag. The skin friction drag shows up only where the air flow "reattaches" to the surface towards the back. At the rear of the block you have a partial vacuum because air takes time to fill in a space where once there was a solid object (and zero air) and then all of a sudden the rear of that object isn't there anymore (it moved forward). Because this negative pressure or suction is also pushing to the right perpendicular to the rear its retarding contribution must be added as another component of pressure drag giving the $C_B = 0.84$ total.

Next consider shape **2B**. The rounded nose with no sharp corners allows oncoming air to separate smoothly and flow around the sides with zero pressure drag from the nose. There is however more skin friction drag from the smooth air flow over all the sides and also the pressure drag from the rear partial vacuum is about the same magnitude as the flat rear end of shape **1B**. The net result is a total air drag coefficient of 0.42, or only half that of the rectangular block.

Shape **3B** is interesting. The drag coefficient contribution from skin friction is slightly larger for the top surface because it has more area than the bottom surface. But note that rounding the rear end hasn't changed the partial vacuum suction drag very much. The reason is that although air can be separated smoothly without turbulence by a round nose it can't come together smoothly to fill in a partial vacuum by just the same rounding of corners. The net result for shape 3B is the same as shape 2B, namely C_B = 0.42. All those supposedly streamlined automobiles you see on the street with rounded rear ends do not reduce rear end suction drag appreciably. On the other hand, it is evidently impractical to have a long tapering rear end like an airfoil on a car and still have appropriate passenger capacity and maneuverability.

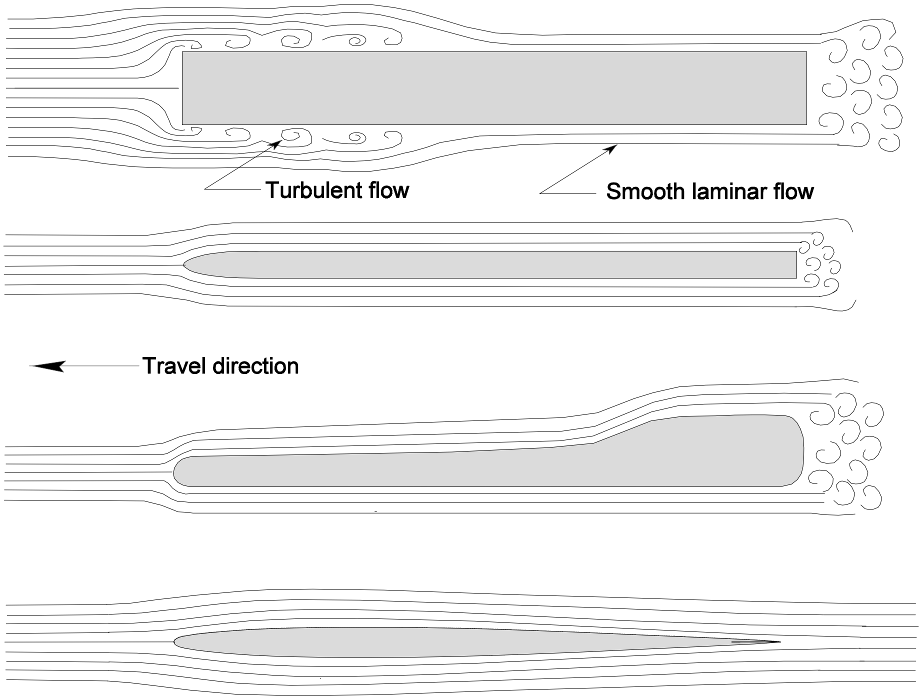

Figure 2 - *Showing a notional representation of smooth laminar flow and turbulent areas of air flow around the bodies of Figure 1.*

Considering shape **4B**, it has the rounded nose but it also has the gently-tapering-to-a-point rear that lets the air come together gently at the back without turbulence. This is the famous airfoil shape used in airplane wings and propellers and in helicopter blades. Here the pressure drag is zero and the only drag is the skin friction type for a total C_B = 0.24. For objects (like airplane wings) that travel at a much higher velocity the skin friction drag is substantially less so that we might have C_B = 0.10 or even 0.05 for wings of a well designed airplane.

Regarding wheels, the relatively thick Standard wheel **1W** is all pressure drag with enough turbulence created to keep skin friction drag negligible. Cylinders approximating the general width to height ratio of this wheel have C_B = 0.69 Measurements on these pinewood derby wheels using a wind tunnel give closer to 0.60 for a single wheel. But the rear wheel is close enough to the front wheel that drafting causes it to have a somewhat lower C_B = 0.40. The average for such wheel pairs is thus C_B = 0.50. By comparison, the thin "Speed Wheel" **W2** (www.winderby.com/m02_040829.html) has a substantial skin friction drag component because of its large per cent of smooth surface. Its C_B is close to 0.68 but when you consider its much smaller projected area, as below, you see its net air drag force is only 12% of the Standard wheel.

Overall Air Drag

The overall air force on the moving system (body plus wheels) is one-half the drag coefficient X projected area X air density X velocity squared. The density of air at sea level is about 0.001225 gram/cm^3 or about 800 times less dense than water. And the velocity of a PWD car on the coasting run to the finish is about 11 mph = 484 cm/s. It turns out if you multiply one-half the air density X velocity squared and divide by the acceleration of gravity (g = 980 cm/s^2) you get numerically the constant factor 0.146. Now when you multiply 0.146 times the projected area times the drag coefficient you get the retarding force in grams that is opposing the gravitational driving force. On an inclined plane ramp that is 4 ft high and 16 foot long you get about 1/4 the *g* force of 5 oz (141.75 grams weight) or 35 grams weight force. As you can see from **Figure 1** the block shaped body 1B and 4 Standard wheels **1W** give 0.89 + 0.86 = 1.75 grams weight retarding force, or 5% of the driving gravity force at the ramp bottom. On the other hand, an airfoil shaped body with speed wheels (4B + 2W) has only 0.10 + 0.10 = 0.20 grams or 0.57% opposing the gravity force.

In the next lecture we shall use the virtual race program to look at the effects of air drag on car lengths difference at the finish line.