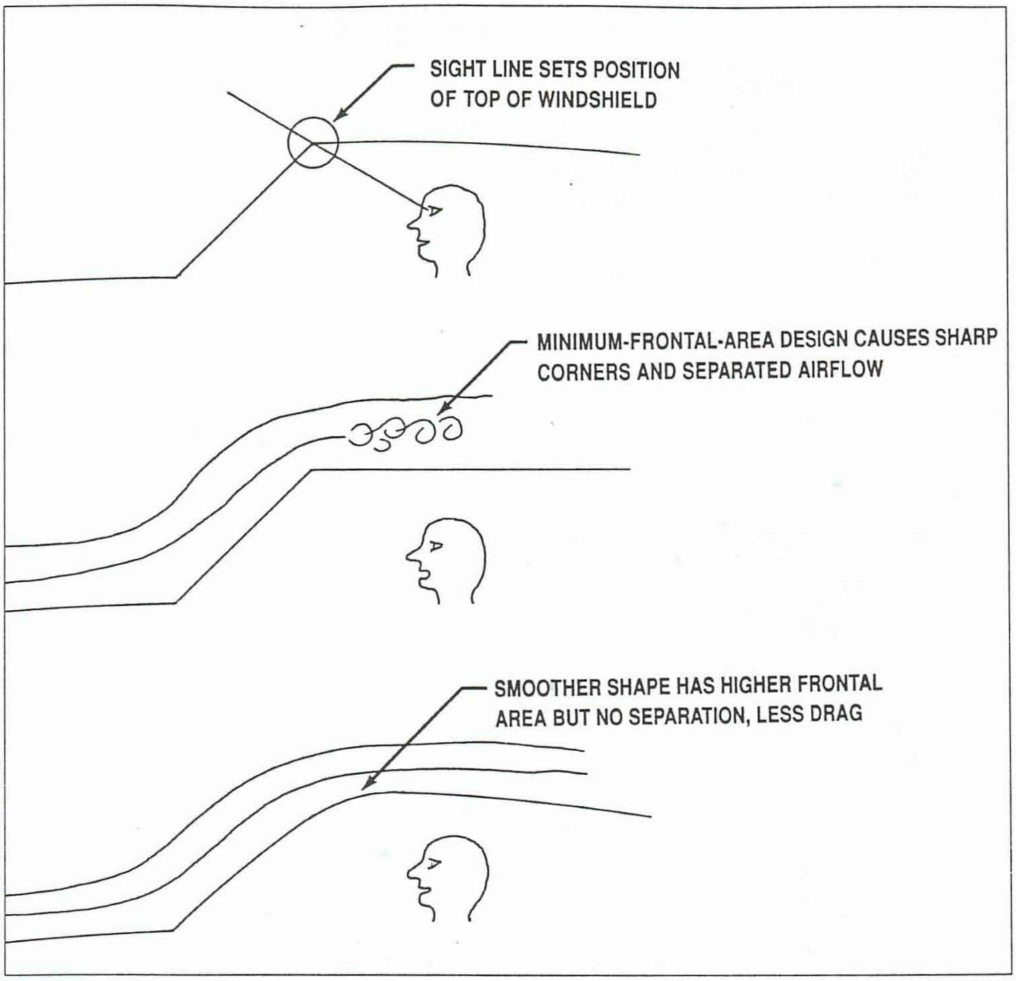

Figure 2. If corners are too sharp, separated flow may result. Despite less frontal area, the shape with separated flow will have higher drag.

wake like this, the drag of the wake, called the *base drag* of the body, is so much larger than the drag caused by other factors that it is completely dominant.

The base drag of a body is determined by the size of the wake, and for a car-shape body, the cross section of the wake has approximately the same area as the frontal area of the body. (This has changed for the better in recent years as fuel economy becomes more important.) Under such circumstances, the drag of the body is very close to proportional to its frontal area.

In summary, there are some areas where frontal area is a useful parameter and gives a good indication of the drag one can expect. The familiarity of most people with automobiles, the use of frontal area as the reference area for aircraft-body drag coefficients, and the fact that drag is proportional to frontal area for bodies of the same shape but different size, give the impression that frontal area is a primary determinant of drag.

Unfortunately, in airplane design, there are other parameters about a body that can have an effect that is as great or greater than frontal area on the drag of the airplane.

There are two sources of drag on a non-lifting body. The first of these is skin friction, and the second is base drag caused by separated flow. The airplane designer's task is to shape the body to prevent flow separation and minimize skin friction.

The aerodynamic drag of ground-based vehicles like cars and trucks is dominated by base drag, which is a phenomenon of separated flow. Unlike ground vehicles, airplanes operate with attached airflow over most, if not all of their surface. It is this difference that makes frontal area a deceptive parameter to use to estimate airplane drag.

The drag of an object with fully attached airflow is almost exclusively skin friction drag. Skin friction is far more sensitive to the details of the shape of the body than the drag produced by the separated wake of a bluff body. In attached flow, it is possible to have two bodies that have the same frontal area and very different drag. If a designer sets minimal frontal area as his goal in a attempt to minimize drag, it is quite possible that he will inadvertently increase rather than decrease the drag of the airplane by shaping the fuselage in a way that decreases frontal area, but in some other way increases either skin friction or separation.

Wetted Area

The best way to reduce skin friction drag is to simply reduce the amount of skin rubbing on the air. The amount of skin in contact with the airflow is called the *wetted area* of the airplane. The term wetted area is a throwback to ship design, where the flow they were concerned with was actually wet. In attached flow, the drag is proportional to wetted area rather than frontal area. A body of revolution with a fineness ratio (length divided by diameter) of 3:1 has a drag coefficient based on frontal area of about 0.04 if there is no laminar flow. A similar body with a fineness ratio of 7:1 has a C_D of about 0.06 under the same conditions. If the two bodies have the same frontal area, the fineness-ratio-7 body has 1.5 times the drag of the fineness-ratio-3 body.

If we look at it a little differently,

WIND TUNNEL

Let's check out frontal area and its effect on drag.

BY BARNABY WAINFAN

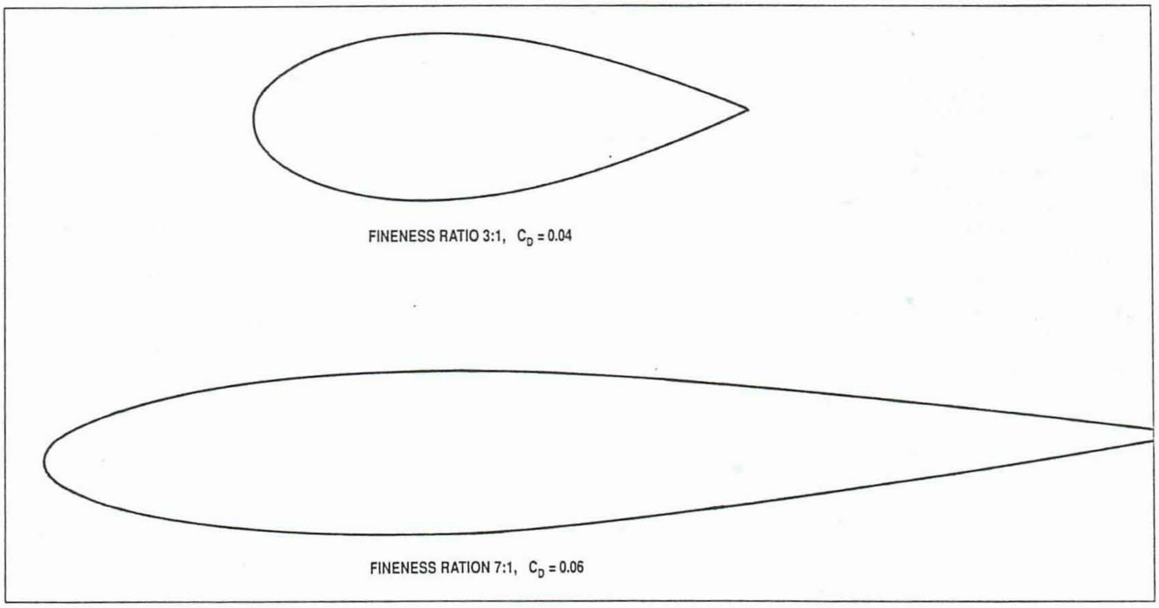

Figure 1. Although these two bodies have the same frontal area, the higher wetted areas of the lower form results in 50% more drag.

Frontal area is one of the most misunderstood parameters in applied aerodynamics. It is not uncommon to read about a designer's quest to "minimize the frontal area of the airplane to make it low drag." Similarly, one often sees statements like: "I raised the top of the canopy 3 inches so I will fit in the airplane. I know this will increase frontal area and drag, but I need the room." Both of these statements imply that the frontal area of the fuselage is a primary determinant of the drag of the airplane.

In fact, this is not the case. The designer of the "low frontal area" airplane is likely to end up with a cramped airplane that is not particularly low-drag, and the person who fattened his airplane for comfort, if he does it right, will likely find that the performance of the airplane has hardly changed.

The obvious question is: "If frontal area is an unreliable measure of drag, why do people worry about it so much, and why is it considered important?". There are several reasons.

The first is that frontal area is a good parameter for comparing geometrically similar bodies. For example, if I have a body with a frontal area of 1 square foot, if I scale it up and produce a body that is geometrically identical but twice as big, the new double-size body will have a frontal area of 4 square feet. (Remember that area changes as the square of the linear-dimension scale factor.) The double-size body will have approximately 4 times the drag of the original body if they are both at the same airspeed and angle of attack. This direct scaling of drag as a linear function of frontal area only works if the two bodies being compared are essentially identical except for size.

A second reason for the apparent importance of frontal area arises in part from the scaling phenomenon we have just discussed. For nonlifting parts of airplanes such as fuselages, landing gear and tiptanks, frontal area is commonly used as the reference area for the drag coefficient (C_D) of the component.

Drag coefficient (C_D) is defined as the drag of the component divided by the dynamic pressure of the airflow, and also divided by a reference area. It is these drag coefficients that we find in reports describing experimental drag measurements, and in tables of drag data. By putting the data in coefficient form, we remove the influence of size and airspeed from the data and make the data describe the characteristics of the shape itself.

As we have seen, for a given nonlifting shape, drag is indeed proportional to frontal area, so it is appropriate to use frontal area as the reference area for the drag coefficient.

Another place where frontal area is commonly used as a measure of drag is the automotive world. Until recently, automobile bodies were all, from an aerodynamic viewpoint, bluff bodies. The airflow around most car bodies separated on the aft portion of the body, and the car generated a large, separated wake as it moved through the air. If a body has a large the fineness-ratio-3 body could have 1.5 times the frontal area of the fineness ratio-7 body and have the same drag.

As we can see from this example, the frontal area alone is a poor indicator of drag because it is possible to have two bodies that have the same frontal area and such dramatically different drag—or conversely, to have two bodies with the same drag and drastically different frontal area.

If the body is designed so that the flow over it remains attached, the drag is determined primarily by wetted area, not frontal area. The large drag difference between the two bodies in the example is primarily caused by the much larger wetted area of the longer high-fineness-ratio body.

If our example builder from earlier who pushed the roof up to increase headroom did it properly, and the new shape of the canopy does not cause flow separation, he is likely to see little or no measurable change in the performance of the airplane. Although his modification changed frontal area significantly, it probably only increased wetted area slightly.

Flow Separation

Another important factor in the design of a low-drag body is the need to prevent flow separation and keep the air flowing smoothly over the entire body. It does no good to pare a fuselage down to an absolute minimum of frontal area (or wetted area) if the flow over it is separated.

In the mistaken quest to decrease frontal area, it is not uncommon for a designer to create a shape that causes flow to separate, giving a large increase in drag. The most common such mistake is producing a shape that turns sharply aft after going around an engine or the crew.

The designer, trying to minimize frontal area, tries to turn the lines of the body aft as quickly as possible. Unfortunately, air is not good at turning sharp corners. If the fuselage shape has a sharp break that is not parallel to the airflow, some separation will almost inevitably occur. If the corner angle is small enough, the flow will separate at the corner and then reattach further downstream. This separation bubble causes drag and thickens the boundary layer downstream of itself. It also increases the chance that the flow will separate prematurely somewhere downstream of the bubble.

Lastly, there is no chance of preserving laminar flow in the area downstream of the separation bubble. In short, the separation bubble will cause some drag increase. If the break angle is relatively small and the flow does reattach, this drag penalty may be small, but it is still a drag increase.

If the corner angle is too large, or the radius of the corner too small, the flow will separate completely at the corner and not reattach aft of the break. This situation will cause large amounts of drag. In addition, any tail surfaces mounted aft of the break are likely to experience either blanketing or buffeting or both. Needless to say, the designer should try hard to avoid such a situation.

Two areas where sharp corners and separation are common are engine cowlings and windshields. Many light airplanes have engine cowlings that have relatively sharp corners between the upper lip of the cooling air inlets and the top of the cowling. When this cowling is at low angles of attack, the flow is attached. When the angle of attack is increased—for example during the climb—the airflow must turn sharply to follow the tight contour of the upper cowling lip. The flow cannot make this corner and separation on the upper portion of the cowling results. This problem can be solved by recontouring the upper lip of the cowl to give it a larger radius, and soften the corner the air must turn to get from the lip to the cowl top. Moving the inlets down can also help make this recontouring easier.

The junction between the windshield and the top of the canopy or cabin can be a troublesome area for separation. It is not uncommon to use a flat-wrapped windshield to make it easier to make and prevent optical distortion.

Unfortunately, a flat-wrapped windshield cannot be joined to a flat-wrapped cabin roof without forming a sharp corner. If a compound curved fairing at the top of the windshield is not used to guide the flow around the corner between the windshield and the roof, the flow will separate at the corner.

The position of the top of the windshield and the angle of the windshield are set by visibility considerations. For the contour of the fuselage to curve smoothly from this point aft, the top of the cabin must be some distance above the top of the windshield. A cabin with a lower roof would cause the airplane to have less frontal area, but the sharp corner between the windshield and the cabin top would cause separation, and a significant increase in drag despite the decrease in frontal area.

In summary, frontal area is a useful parameter for comparing the drag of objects of approximately the same shape. Reducing the frontal area of a body by making it smaller while keeping its shape the same does indeed reduce drag. Thus, frontal area is useful in sizing wheel fairings and similar bodies. Reshaping the fuselage of an airplane specifically to reduce frontal area will often increase, rather than decrease the drag. The fuselage designer should pay attention primarily to minimizing wetted area rather than frontal area, and should be careful to avoid shapes that can cause separation. ❑

Readers with aerodynamic questions of a general nature should write to "Wind Tunnel" c/o KITPLANES, P.O. Box 6050, Mission Viejo, CA 92690.