The Totally FREE Airfoil Primer

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Note: All aerodynamic data shown was produced by DesignFOIL.

An Airfoil Is Not A Wing

I collect old books about aerodynamics and I've noticed how some books use the following terms interchangeably: Airfoil, Profile, Airfoil Section, Wing, and Wing Section. Before we can get into the really fun part of airfoils, somebody has to explain the differences. Read on.

A **wing** is a three-dimensional object. You can touch it, taste it (yuck!), and even sleep underneath of it. In addition to providing shelter, a wing also produces a vertical "lifting" force when you push it through the atmosphere. A **Wing Section** is a special type of wing that has a constant chord as you move spanwise; most often used for wind tunnel models. They don't have any twist or taper or any changes along their span. Since the cross-sectional shape is constant, we can trace the outline on paper and keep it in a convenient library; allowing us to use the two-dimensional drawing to represent our three-dimensional wing section. We refer to this two-dimensional shape as an **Airfoil** or as the British often spell it, an **Aerofoil**. Wing sections are synonymous with Airfoil. You may even hear some Europeans and elitist Americans calling them **Profiles**. Personally, I use the word Airfoil to refer to all of them except the Wing. I guess old habits die hard.

So the next time you overhear somebody at Oshkosh discussing a book called Theory Of Wing Sections (that wonderfully cheap blue book from Dover Publishing), stand proud that you know they are really talking about airfoils. The first thing we must do is destroy the myth about bad airfoils.

The Good, the Bad, and the Mediocre.

There is no such thing as a bad airfoil. Yes, there are some unsafe ones, but the airfoils that get a bad reputation are usually victims of bad construction; like the GAW airfoil used on the Piper Tomahawk. The GAW in and of itself is not a bad airfoil, unless you use it on a wing that's constructed from sheet metal and rivets. If it's constructed out of smooth composites to an exacting tolerance, then it performs relatively well.

Much like visiting the optometrist, airfoil selection comes down to comparing various choices. Instead of deciding whether Lens A or Lens B makes your doctors' diploma look sharper, you will be telling your customer (usually you) that Airfoil A will produce *more* lift than Airfoil B, but with *less* drag. Okay, now on to what makes them fly.

What really makes an airplane fly?

“Money” is the cynical answer, but you deserve a better explanation. If I paid you to build a machine that could move lots of air down as it traveled through the atmosphere, you would most likely reinvent something we already call a **wing**.

Certainly, a large sheet of plywood could accomplish this same task, but it wouldn’t do so very efficiently. The secret to making this air mover more efficient is the use of a cross sectional shape that’ll let the air flow smoothly over it; ideally avoiding any gross separations of the airflow over the top of this “wing”. Historically, this desirable shape has been **round in the front and sharp in the back**. You may know it by a more popular name: an **Airfoil**.

So now you have a device that moves air down. Who cares? Millions of airline passengers care! Every EAA member cares! As simple as wings are, they push down on enough air to *nearly* counteract the weight of the airplane. Notice that I haven’t brought in Bernoulli’s Principle yet. Instead of blaming all these wonderful wing attributes on Mr. Bernoulli, I instead like to use some lesser-known laws called the **Conservation of Mass** and **Conservation of Momentum**. These two conservation laws are needed to explain how the wing interacts with the air while it’s creating the wonderful downwash. These are important because unlike a hammer, air can’t apply a point force to an object. Instead, it can only apply a force using two methods: pressure and friction.

Nature will direct the airflow around an airfoil in such a way as to absolutely guarantee that the conservation laws are obeyed. As a result, the air accelerates over the top of the airfoil as it goes around causing pressure reductions on the upper surface during its’ long trip. Why is the pressure so low on top? Think of it as the airs’ attempt at trying to fill the empty void of all that air you just pushed down behind it. Just exactly how much air gets displaced depends on surface curvature and angle of attack (explained later). The end result is that the pressure difference between the lower and upper surface literally sucks the wing up.

In conclusion, **Lift** comes from a combined effort of the wing being sucked upwards and the wing pushing down on air. The effects are so intrinsically *linked* together that we can measure the lift force by measuring only the surface pressures on the wing.

Now you know how airfoils work. It’s a little more complicated than “Why is the sky blue?” Let’s get on with learning the practical stuff.

Basic Terms & Geometry

If anything, just remember that airfoils should be **round in the front and sharp in the back**. That's the main rule. Everything else is just tweaking and optimization. For our purposes, all diagrams will assume air movement from left to right; Europeans often assume the opposite and that's just strange.

For fun, let's take the airfoil shown in Figure 1 and start blowing air over it. Note that the airfoil is symmetrical and pointing straight into the oncoming wind. Right now, the air is approaching at about 60 miles per hour and since the airfoil is parallel with the wind, we can't measure or feel any perpendicular (Up/Down) forces. The Lift is zero. However, the airfoil feels a small tugging force on it caused by the air being dragged over the surface (friction). We'll call this force **Drag**.

Figure 1. Example of a generic symmetric airfoil.

Now let's tip the nose up as shown in Figure 2. Suddenly, there is a noticeable force pushing upwards while the Drag force increases slightly. We'll call this upward pushing force **Lift**. As all pilots know, creating Lift causes more Drag. What you've discovered is that by increasing the angle between the chordline (an imaginary line between leading edge and trailing edge) of the airfoil and the oncoming wind, you increase the lifting force. This special angle is called the **Angle-Of-Attack**, or **AOA** for short. What you need to know is that increasing the AOA will increase both the Lift force and Drag force up until about 15 degrees where the Lift force will start to fall off. However, Drag will continue to rise!

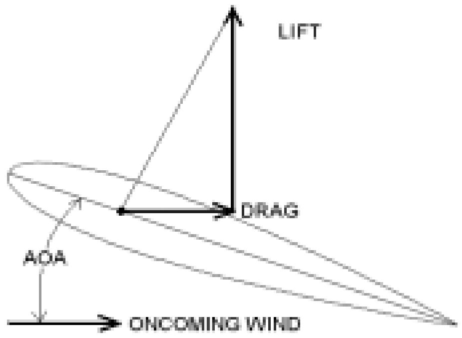

Figure 2. The airfoil from Figure 1 after increasing the Angle-Of-Attack.

Figure 3 shows the airfoil with the important parts labeled. The Upper Surface is the outer airfoil skin on top from the leading edge to the trailing edge. The Lower Surface is the outer airfoil skin on the bottom from leading edge to trailing edge. The Chordline is an imaginary line between the leading edge and trailing edge; this is used for setting Angles-Of-Attack (AOA).

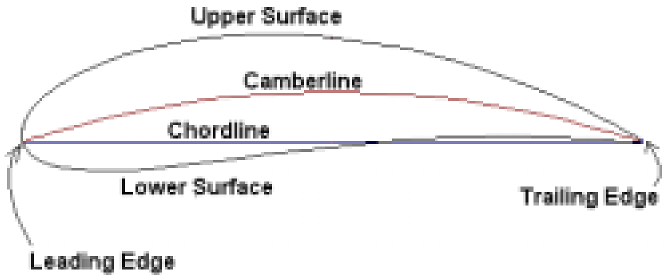

Figure 3. General geometry, layout, and vocabulary of airfoils.

Not to be confused with the Chordline is the Camber line. The Camber line is an imaginary line that divides the airfoil into upper and lower halves. On a symmetrical airfoil, the Camber line is the same as the Chordline. But if you bend up the middle of the Camber line, the airfoil will start to create lift; even if the AOA is zero degrees! The thing to remember is that **increasing camber increases lift**.

The perfect airfoil would allow you to change the Camberline in flight; having lots of camber for takeoff and very little during cruise. Unfortunately, it's hard to bend aluminum on demand, so we create a compromise with something called **Flaps**. Flaps allow us to droop down the trailing edge of the airfoil; effectively increasing our camber.

Coefficients Are Easy: Part 1 of 2

If you are lucky enough to own a wind tunnel, you could put wing models (airfoils) inside of it and measure the lift and drag forces you get when you blow air down the tunnel. It would be really nice to chart this force as a function of *something* and share it with your friends and family so they could reproduce that lifting force in their own applications (airplanes, fans, propellers, etc...) But what would that *something* be?

As it turns out, a lot of very smart guys dealt with this same question in the late 1800's and early 1900's. The main problem was that the Lift was not just a function of *something*; it was a function of *many* things. Here are a few things they knew:

1) As air density decreases (climb a mountain where the air is thinner), so does the lift force produced by the same wing.
2) When airspeed is **doubled**, the Lift force is **quadrupled**!
3) As wing area increases (birds eye view), so does the lift force.

From knowing these three characteristics, those same smart guys stated that Lift was **directly proportional** to the wing area, the square of the velocity, *and* the air density. But even after they figured all this out, it still wasn't an *exact* equation. For example, they couldn't say that Lift was *equal* to some combination of speed, density, and wing area. The best they could do was say that Lift was *sort of* equal. *Kind of* equal. But not *exactly* equal to a combination of all those things.

To fix this problem, they settled on using a *fudge factor*. In engineering, a *fudge factor* is a special number that is used to make your answers agree with what you expect, measure, or predict; especially with natural phenomena where many of the lesser influences are lumped into that single special fudge factor. After time passes, special fudge factors get special names. In the world of aeronautical engineering, we began calling them **Coefficients**. And there are a lot of them. There are coefficients for Lift, Drag, Moment, etc... all used so we can make sense out of equations that just don't equal anything *exactly*. Of course, these coefficients themselves must be a function of something that we *can* measure. In aeronautical engineering, we make them a function of **Angle-Of-Attack**. That way, if we know what our angle-of-attack is, we know what our fudge factor (Lift Coefficient) is, and subsequently we can predict the total lift force on a wing. It may seem like a contrived complicated mess invented just to predict aerodynamic forces, but it turns out to work really well.

Coefficients are great for many reasons. Not only do they make it possible to predict the aerodynamic forces on an untested wing, but they also make comparisons between airfoils simpler. For example, if our airplane needs a lift coefficient of 0.3 to stay aloft, we can choose the airfoil that produces the least amount of drag at *that lift coefficient*. And coefficients are fairly robust. You can usually trust that a chart of coefficients will remain unchanged except for one small problem. The Reynolds Number, which is a reflection of boundary layer effects, tends to throw a wrench into things. Read on.

Ozzy Reynolds And His Special Number

I'm standing next to a wind tunnel. Inside the tunnel, mounted on a stick is a quarter-scale model of an airplane. Let's call it a Pipessna 150. The control panel tells me that the air inside the wind tunnel is traveling at almost 160 miles per hour. Although I'm just a mediocre pilot, I know this airplane could *never* go that fast. So I ask the operator about this speed discrepancy and he says, "Oh, we're just trying to match the Reynolds number to full scale." Huh?

The world of engineering is filled with special numbers named after people long gone whom you and I will never meet. One of these people was Osborne Reynolds, an Englishman from the late 1800's. Unlike you and I, Mr. Reynolds was very much an obsessed man. Obsessed with watching colored dye flow through pipes, especially how the dye flow would start out as a smooth streak (**Laminar low drag**) and invariably break down into eddy-filled turbulence (**Turbulent and draggy**). None of the technical books ever seems to focus on *why* he was so taken by these phenomena.

Reynolds didn't know it, but he was really studying the concept of **boundary layer growth**; a subject that is of paramount importance in aerodynamics. In the absence of boundary layer phenomena, aerodynamics is downright simple! Unfortunately, major things like "top speed" and maximum lift are very dependent on boundary layers. At the beginning of the 20th century, a German researcher named Ludwig **Prandtl** formulated the equations needed to describe how boundary layers grow (they get thicker as they progress downstream); he used a subset of the previously known Navier-Stokes equations for his procedure. *Very* complicated stuff and Prandtl was a *very* smart guy.

The thing to know is that the simple **Reynolds Number (Re)** contains a lot of information. It conveys nearly everything you need to know about a certain "flow situation" and it doesn't even have any units. No feet. No inches. No pounds. Nothing. It is a product of the fluid density, fluid velocity, **important** length, and the reciprocal of the fluids' viscosity. Think of it as a meat grinder where you pour all the environmental ingredients in one end and the **unitless** Reynolds Number plops out the other end.

With a little experience, you can gleam useful information about a fluid flow situation just from knowing the magnitude of the Reynolds Number. For example, if you see wind tunnel data taken at Reynolds Numbers of 200,000 or less, it is safe to assume that those airfoils were meant for model airplanes and will have relatively low maximum lift coefficients and increased drag. Between about 500K and 6million, it usually applies to general aviation; this is the regime where most of the wind tunnel tests are run. When you get above about 9million, you're usually talking about fighter jets or passenger airliners. Of course, this is just a rule of thumb and subject to debate.

HOW TO CALCULATE THE REYNOLDS NUMBER:

1) Find out what your velocity is in feet per second. To do this, multiply MPH by 1.4667 or you can multiply KNOTS by 1.689.
2) Find out what your air density is. Remember that this changes with altitude and it must be in slugs per cubic foot. You can use the WingCrafter module in DesignFOIL to find the air density at altitude. For simplicity, 0.002377 slugs per cubic foot is used for a sea level density.
3) Find out the viscosity of air. Use 0.00000037373
4) Decide what the important dimension is. For wings and airfoils, that dimension is the chord length. For spheres, it is the diameter.

Now use this formula:

Reynolds Number = AirDensity * Velocity * Dimension / Viscosity

If you're a rigorous mathematician, you can work out the dimensions and see that they all cancel out leaving a unitless number. Or, you can use the **simplified formula** suggested by my friend Neal Willford:

Reynolds Number = 9360 * V(mph) * Length (feet)

Let me quickly return to this sections' beginning because I need to mention wind tunnel tests. It's easy to assume that any coefficient data that you get from a wind tunnel applies to the full-scale airplane at the same speed. However, the coefficient data is only "good" for the Reynolds Number that it was taken at; not the speed.

Let's use a half-scale model for an example. To get full-scale Reynolds Number data from the wind tunnel, you have to double the airspeed over the model in an effort to get the Reynolds number up. Or you could double your air density, but that is *very* expensive and difficult to do. Just remember that if you cut the wing chord in half, the Reynolds number also gets cut in half. To compensate, you'd have to **double** the airspeed to keep the same Reynolds Number. It can be very confusing sometimes.

Coefficients Are Easy: Part 2 of 2

From the previous section, we know that the special aerodynamic fudge factors used to make the Lift, Drag, and Moment equations usable are called **Coefficients**.

So how much lift can a wing produce? That's where the special Lift equation comes into use; it's one of the most commonly used formulas in the world of aerodynamics. If we spell it out in English terms, it looks like this:

Lift = (Lift Coefficient) * 0.5 * Density * (Velocity * Velocity) * (Wing Area)

Or in engineering terms it looks like this:

$$L = C_L \bullet \frac{1}{2} \bullet \rho \bullet V^2 \bullet S$$

"CL" is a shorthand notation for the Lift Coefficient. ρ (pronounced "row") is the Greek symbol used for air density. "V" is simply the magnitude of the Velocity. S is **NOT** speed. Instead, "S" is the common term used for the birds-eye view **wing area**. More often, the term "**planform area**" is used instead of birds-eye view area.

So we've got the equation, but how do we use it? Hopefully we know the speed (V) and we can measure the planform area (S) by various methods. Most pilot-operators handbooks will actually tell you the area of an aircraft's wing. Air density gets smaller with altitude. Normally, we use sea level for our beginning calculations. That is 0.002377 slugs per cubic foot. Slugs are what the non-metric world uses as a unit of mass. *The DesignFOIL Manual explains slugs in much more fun detail.*

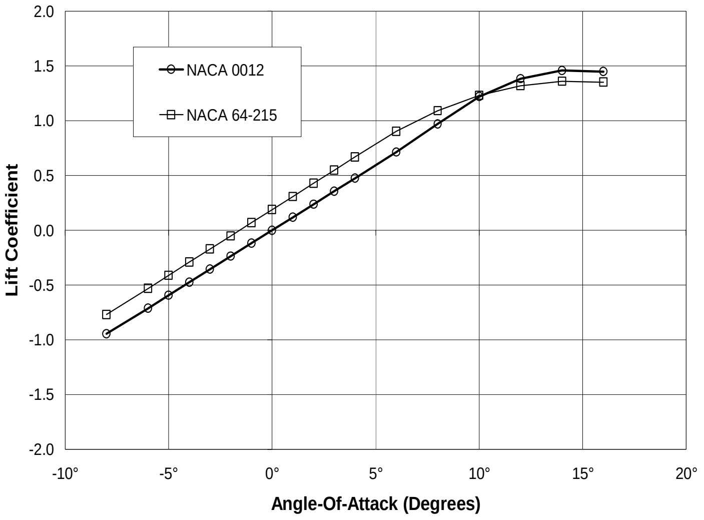

Figure 4. Lift Coefficient versus angle-of-attack.

So it would seem that the one thing we don't know is the Lift Coefficient. Well, all we have to do is find out what airfoil is used on our wing and measure the angle-of-attack. With that info, we can look at a chart above to find our lift coefficient.

Let's put our imaginary wing model in the Ohio State University's' three foot by five foot wind tunnel. It will span the entire width of the test section wall to wall; that means the span will be 3 feet. Our chord is roughly 2 feet. That gives us a wing area (S) of about 6 square feet.

Ohio State University is at an altitude of roughly 900 feet above sea level so the density today is 0.002315 slugs per cubic foot. We turn on the wind tunnel fan and blow air over the model at about 100 feet per second. I forgot to tell you that we used the most common airfoil ever produced: the NACA 0012 symmetrical airfoil section. Fortunately, it's on the chart shown on the previous page. At first, our angle-of-attack is **zero degrees**. According to the above chart, that means the Lift Coefficient is roughly zero. Our Lift Equation looks like this:

Lift = (Lift Coefficient) * 0.5 * Density * (Velocity * Velocity) * (Wing Area)

Lift = 0.0 * 0.5 * 0.002315 * 100 * 100 * 6 = 0 pounds.

We have no lift. It looks like we're going to have to do something to make the Lift Coefficient equal to something *other* than zero. We can do that! Ask your assistant to turn the knob that tilts the airfoil model slightly up. We note that it is at 5 degrees angle-of-attack now. According to the chart, that makes our Lift Coefficient equal to about 0.55. With that information, our Lift equation now looks like:

Lift = (Lift Coefficient) * 0.5 * Density * (Velocity * Velocity) * (Wing Area)

Lift = 0.55 * 0.5 * 0.002315 * 100 * 100 * 6 = 38.2 pounds.

You can see that the Lift force increased as we tilted up the wing. It will continue to increase until we reach a special angle called the **Stall** Angle. Often, this occurs when the angle-of-attack is at about 15 degrees. At that point, the air no longer flows smoothly over the wing. The lift will decline after that, but drag will continue to rise!

But we're not stalled just yet. Our wing is still producing roughly 38 pounds of lift and we want to know how much Drag is being made. For that, we use a similar formula but now we look at a different chart called a **Drag Polar**. This new chart (Figure 5 on next page) shows the Lift Coefficient Versus Drag Coefficient. Here is the equation for drag:

Drag = (Drag Coefficient) * 0.5 * Density * (Velocity * Velocity) * (Wing Area)

Since we know that the Lift coefficient is roughly 0.55, we can gleam from the graph below that the Drag coefficient is roughly 0.0075. Drag coefficients are always shown with four decimal places. When we talk about Drag Coefficients, we consider the ten-thousandths place to be a **Drag Count**. So, for example, the NACA 0012 airfoil shown below has a drag coefficient of seventy-five **Drag Counts** at the same time that the Lift Coefficient is 0.55.

Note that I didn't tell you what the Reynolds number was. In this case, it works out to be about 1.2 million.

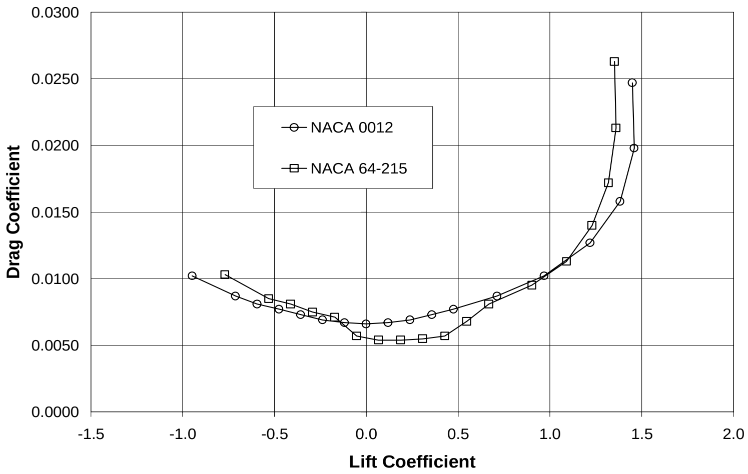

Figure 5. Drag Polar: Drag Coefficient versus Lift Coefficient.

Realistically, Drag is a lot more complicated because it's comprised of both friction forces and pressure forces (and induced drag for a 3D wing). At lower AOA's, most airfoil drag comes from the friction of the air sliding over the surface. However, when the angle gets too steep and air begins to separate, pressure drag becomes the dominant factor. Since Drag, in the big picture, is so closely tied to lift, the Drag Coefficient is often charted against the Lift Coefficient instead of Angle-Of-Attack. As I've mentioned before, this is called the Drag **Polar**.

Now that you understand everything about Lift and Drag (including draggy boundary layers), we need to throw in the lonely **Moment Coefficient**. Most folks always forget the poor old moment, but it's very important especially for **trim drag**. For those not familiar with "Moment", that is the engineering term for what most people call Torque. Remember:

Moment is the fancy name for Torque.

When an airfoil is flying along producing lift, it has a tendency to want to flip end over end; often called Nosing Over. Some airfoils produce a very *strong* Moment and some do not. To counteract this inherent desire to flip nose over, **your tail has to push down**. History has shown that the Moment Coefficient stays pretty constant when measured about the 25% chord position. Because of this, almost all data about airfoil Moments are presented about the 25% of chord position. Engineers call this the "**Quarter Chord**". The equation for Moment is similar to the Lift and Drag equations, but it has the actual Chordline Length thrown into it:

$$M = \bar{c} \bullet C_M \bullet \frac{1}{2} \bullet \rho \bullet V^2 \bullet S$$

Drag Buckets Are Filled With Low Drag Air

Stories come and go about the legendary airfoils on the WWII era P51 Mustang. It is often said that the airplane's high speed was a result of its special low-drag "laminar flow" airfoils. While it is true that the wing drag was probably reduced, metal construction at the time prevented those airfoils from reaching their full potential on drag reduction. It's more likely that the excessive speed was a result of the absurd power from the Merlin engine.

The "magical" laminar flow airfoils have been around since even before WWII; they were children of Eastman Jacobs, an engineer at the NACA during the 1930's. In the preceding 30 years, smart people like Germanys' Ludwig Prandtl learned that great things could come from **controlling** the shape and growth-rate of the **boundary layer**; a thin layer of slower moving air that coats all moving objects.

So what is a boundary layer after all? In the region of air very close to the surface of a solid object, the effect of **viscosity**, or resistance to strain, is **amplified**. On a microscopic level, even the smoothest surface looks like a mountain range. Air molecules that try to maneuver these peaks often get stuck. So these molecules of air that were originally moving with the speed of the oncoming flow are halted and brought to zero velocity right at the surface! On a larger scale this effect is felt as a **friction drag** force applied to the wing surface. The velocity of the air directly next to the wing is zero and over a distance of just a millimeter or two, the air accelerates to match the freestream velocity. Viscosity plays a very important role here.

Let's follow a "chunk" of air as it flows toward an airfoil at high speed:

1) The oncoming air slams into the very leading edge and stops. This point is called the **Stagnation Point**.
2) From there it begins moving along the surface again and accelerating. As long as the air is accelerating, it flows smoothly and stays relatively thin. This portion of the boundary layer is called **Laminar** and it's main characteristic is that it exerts very **small friction forces** on the wing. One way to think about this is to imagine it acting like a deck of laminated playing cards: they slide smoothly over each other because they are not connected or "mixed" with each other.
3) When the air stops accelerating (max velocity) and begins to slow down, the Laminar boundary layer gets thicker. As it gets thicker relatively fast, disturbances known as eddies grow larger and more profound. As they mix, they begin grabbing air from the outer freestream air and pulling it into the boundary layer making it even thicker still. This mixing makes the boundary layer **Turbulent** and the result is a **marked increase in the friction drag** applied to the wing.
4) If the slowing down (**adverse pressure gradient**) is strong enough, the surface friction will become zero and the boundary layer will explode from the surface, causing a **stalled** condition resulting in *severe loss of lift*.

There are of course some variations to this script. If the flow condition is at a very low Reynolds Number, the laminar airflow sometimes skips becoming turbulent and just separates never to be heard from again! Sometimes it immediately reconnects forming a thicker turbulent boundary layer than normal. The region between the laminar separation and the *turbulent reconnection* looks like a bubble and is often called a **Laminar Bubble**. Sometimes it doesn't reconnect and the air just leaves the airfoil at that point and the wing flies around in a semi-stalled condition.

You may have seen radio controlled airplanes with zig-zag tape on the upper surface of the wing to combat this problem. Those pilots are taking matters into their own hands and *forcing* that sensitive laminar boundary layer to trip itself into a turbulent boundary layer. After all, a draggy turbulent layer is better than separation and stall! Some folks have used this trick to get their RC planes to carry more weight than normal (*hint, hint for the SAE Cargo Plane contestants*).

Luckily, this tendency to go from laminar directly to separated lessens as the Reynolds number is increased.

Key Points To Remember About Air Flowing Right Next To A Surface:

1. Laminar boundary layers love air that is accelerating, but will disappear at the instant the air begins slowing down. Laminar means **LOW DRAG**.
2. Turbulent boundary layers will form from the laminar boundary layer once the air begins slowing down. Turbulent means high**ER** drag, but not *terrible* drag.

You may be thinking the same thing that Eastman Jacobs was thinking back in the 1930's. Why not design an airfoil that **only has laminar flow boundary layers**. That way, you could have ultra low friction drag!

As with communism, it only works *in theory*. Over the years, we have discovered that creating and maintaining a laminar boundary layer can be tricky. For one thing, they are *very* sensitive to surface defects. Have you seen the leading edge of general aviation airplanes? They are coated with insect guts and laminar flows just don't like that. Also, to achieve good laminar flow, the surface must be built from a high-tolerance composite material. The Piper Tomahawk uses a laminar flow airfoil made from sheet metal and rivets and it doesn't work as well as the designers had planned, especially at stall conditions. Most Tomahawks have been retrofitted with leading edge **stall strips** that ensure predictable stall characteristics. Many aerodynamicists consider that to be a form of aerodynamic "duct tape" used to fix something that is broken.

Rule of Thumb:

A laminar flow wing built poorly will often be worse than a turbulent flow wing built poorly.

Now lets get back to Drag Polars. You may have noticed that Figure 5 had a strangely shaped drag polar; it shows a dip (called the **Laminar Bucket**) in the usually parabolic shape. That is an area of lower drag due to extensive laminar boundary layer flows.

You may notice the advantage already. If you design your airplane so that the *desired Lift Coefficient* falls inside the Drag Bucket, you can take advantage of the lowered friction drag, resulting in **higher cruise speeds**.

Modern Airfoil Design, Remarks & Conclusion

Since about the late 1930's, maximizing the length of laminar flow has been the goal of many prominent airfoil designers. After all, this would result in lower frictional drag! However, various impracticalities keep this from happening. As mentioned earlier, one big deterrent is insects. Insects cause the laminar boundary layer to start becoming turbulent earlier and increase the drag. And it's impossible to avoid insects; they just love impacting and sticking to your leading edge. There is usually a good compromise where you can get some laminar advantages while not producing a super-sensitive airfoil. One of these would be the NACA 64-215.

Another thing to consider is the ability to control the wing contour during construction. The surfaces of metal airplanes tend to "oilcan" during flight and this can change the contour enough to trip the boundary layer. Rivets are also bad. When using composites, it's important to keep close tolerances on the airfoil contour. It's more often the case that a laminar flow airfoil built poorly will give worse performance than a non-laminar flow airfoil also built poorly.

Since laminar flow is much easier to sustain on the lower surface, another design method also based on boundary layer management is to maximize laminar flow on the lower surface while utilizing mostly turbulent flow on the upper surface. Now don't let the names confuse you. Turbulent doesn't mean that the air is a *huge mess*. It just means that the boundary layer thickness is growing relatively quickly as it progresses down the airfoil.

So now you know more than you ever wanted to know about airfoils. But just remember, put the round end in front and the sharp end in back and you'll be fine.

NOTE: All of the subjects in this primer and many more are expanded upon in the DesignFOIL User Guide which is included when you purchase the DesignFOIL software.