The Wittman W-10 Tailwind Airfoil Secrets: Exposed!!!

One of the most elusive airfoils for study has been the Wittman W-10 used on the Wittman Tailwind W-10. It is my understanding the airfoil on the Tailwind W-8, Bonzo and Buttercup is not the same as the W-10. These boxy airplanes do have an element in common, however: they are all exceedingly fast for such low horsepower.

Racing airplane designers of the 1930's needed every advantage they could get: Speed was the ultimate goal and fast enough was never, well, fast enough. Small engines were often inline four cylinder models or the Continental opposed cylinder models. Steve Wittman did everything to improve the horsepower output of these engines, but he was also very successful with his work on drag reduction.

When one views the plans of the W-10 Tailwind, the airfoil is listed on the prints as a "NACA 4309 Modified". There is no other specification as to exactly how the airfoil was modified or how *much* it was modified. At first and second glance the profiles of the NACA 4309 airfoil and the W-10 airfoil do not appear to be similar. When I first compared the two, I thought Wittman was pulling everyone's leg.

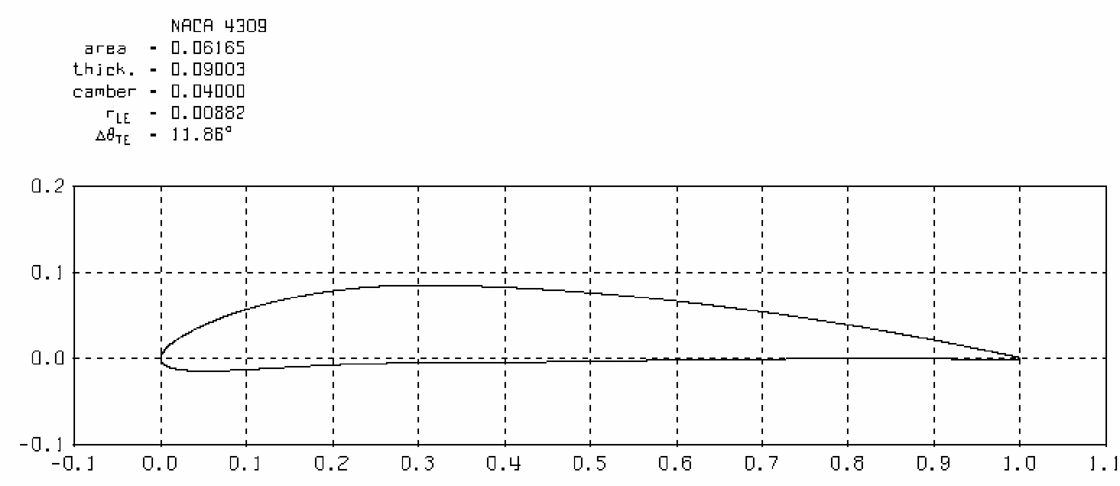


Figure 1The NACA 4309 Airfoil

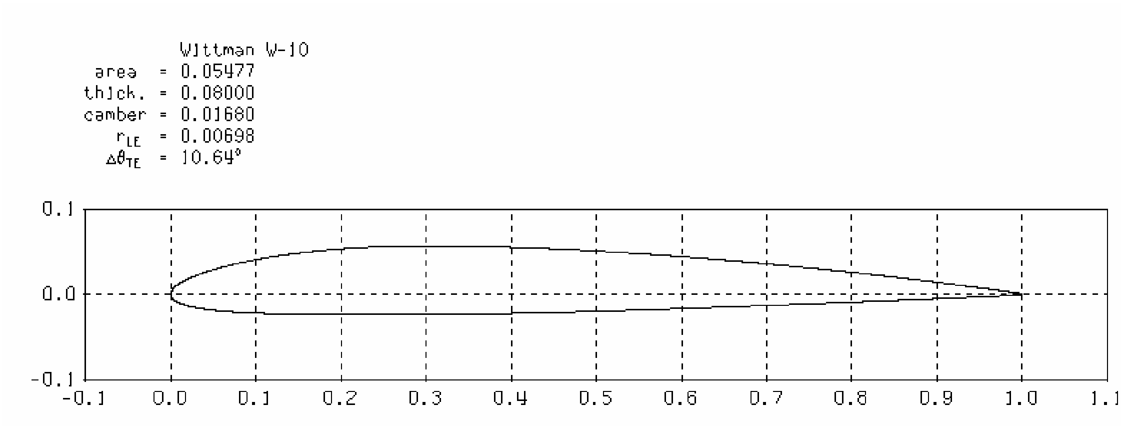


Figure 2 The Wittman W-10 Tailwind Airfoil -- Shuck Derivation from Tracing

They don't appear to have a whole lot in common on first appearance. But appearances aren't everything. The answer is in the numbers. But there really is more in common than one might think. But to assume that a *simple* modification has been made does not tell the whole story. A little review of airfoil basics is in order.

Airfoils consist of a thickness profile and a camber profile. In simple terms, the thickness profile is the shape that occurs before the camber, or curvature, has been added. The camber adds the needed lift. Lift is good! But adding lift with camber comes at a price: 1. Drag and increased pitching moment that results in even more drag. Airfoils are designed to fit a particular mission profile of the airplane. Generally, thick, highly-cambered airfoils are great on bush planes where short takeoff and landing is required. Back then, faster airplanes often had thinner airfoils. Always a compromise, thinner airfoils also stall at higher airspeeds, but the thicker, higher drag foils produce too much drag to be as fast as their thinner counterparts, equal power for each assumed.

The W-10 airfoil here is derived from the plans sold by Aircraft Spruce. I made a tracing on gridded vellum made over the plans rib and sheeting. That way the true airfoil is used and not a tracing of a rib alone without the sheeting. Airfoils from rib drawings alone has been done by others, but it's not entirely accurate, at least when doing computational analysis of these two airfoils. The results from this W-10 tracing were used to find the SECRET to this airfoil mystery!

How *did* Wittman modify the NACA 4309 to result in the successful W-10 airfoil? One story is that he drew it on his hangar floor in chalk…and by gosh, that's what worked! I can hear him now…"Hey, that looks about right!"

No way.

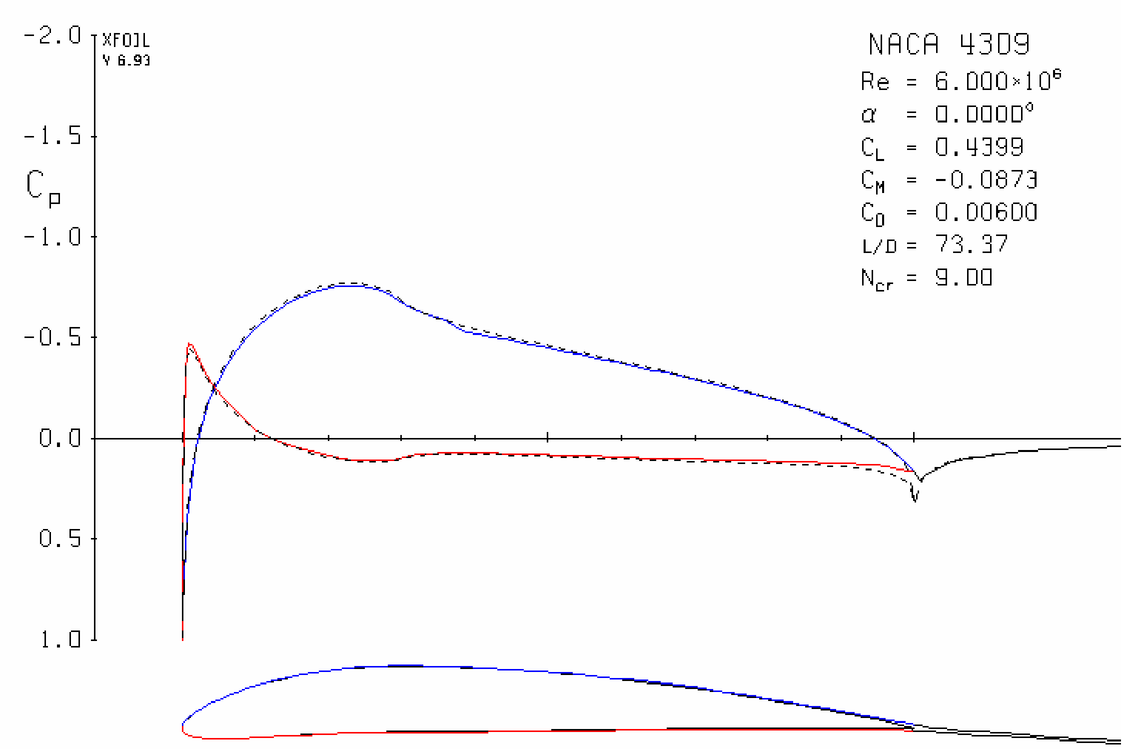
And besides, wasn't it Bernard Pietenpol who did that?

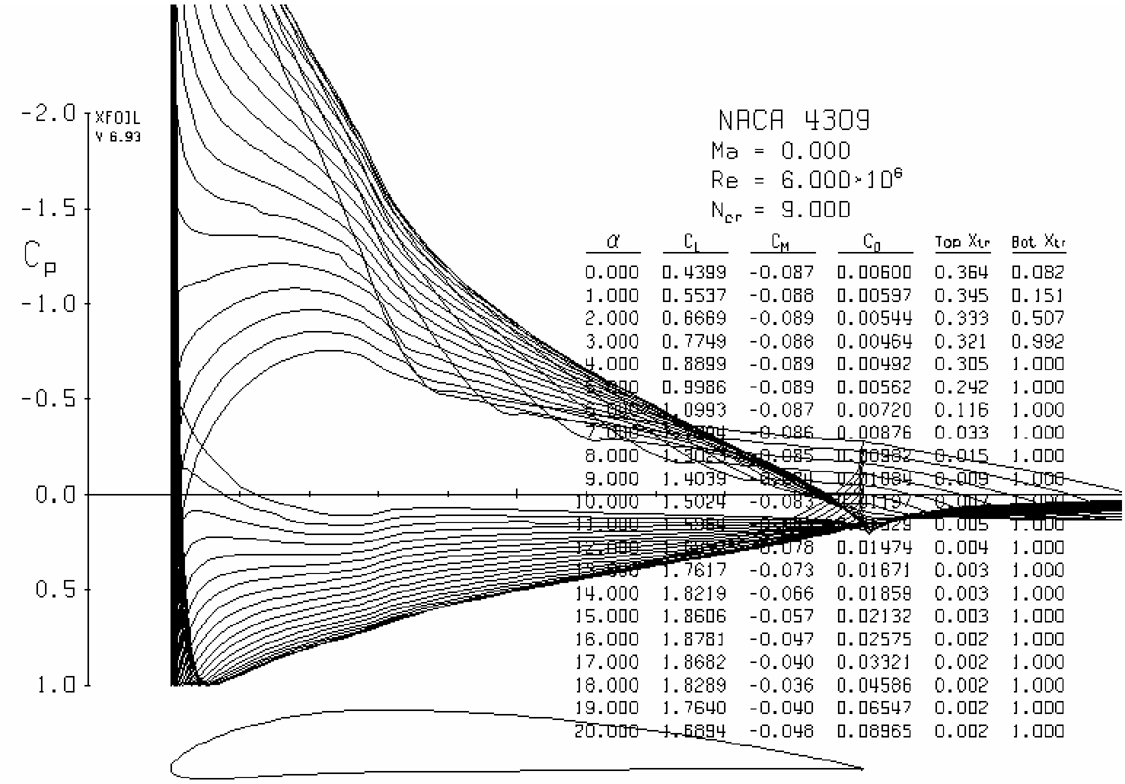
Let's look at the performance of the Mother Foil (NACA 4309) first. The RN (Reynolds number) used is 6 million for the cruise configuration and an RN of 2 million for the stall configuration. It is important to note here that this analysis is of a two dimensional airfoil, not of a whole wing or a whole airplane. Two-dimensional analysis tells us a lot, though. The analysis programs I use produce *viscous* solutions, meaning the algorhythms which help derive the final results take into account the viscosity of the air. Most programs out there do not take this viscosity of the air into account.

Big mistake.

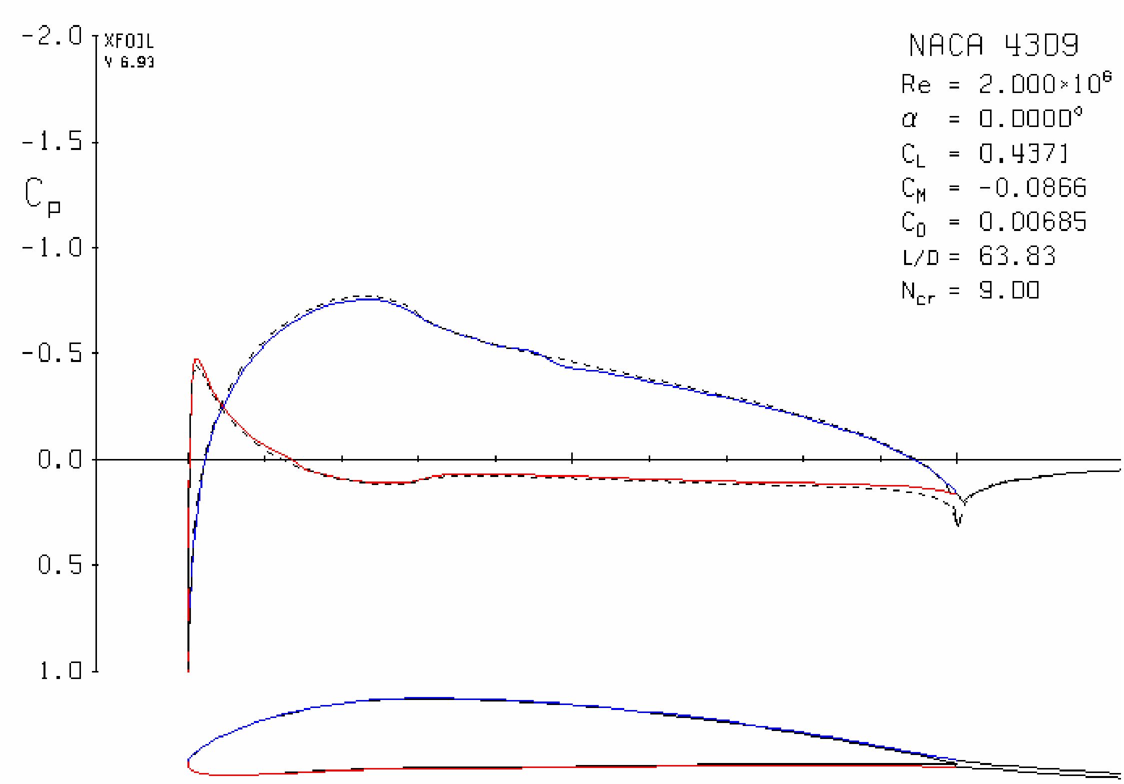
Airfoils which are used on wings that fly in the real world fly in *viscous* mediums, that is, real live genu-wine air. Air has "thickness". Therefore, these results better approach real world conditions (as much as 2-D analysis can). I use Mark Drela's program, *Xfoil 6.93*. I use *VisualFoil 4.0* for most of my comparative analysis. *Xfoil* iterates on the boundary layer. That is a good thing. Eppler's program, *Profil*, does not iterate on the boundary layer. But it was one of the first computer programs to derive performance without strictly using wind tunnels alone.

Here are the performance figures for the NACA 4309:





-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
Cp
XFOIL
V 6.93
NACA 4309
Ma = 0.000
Re = 6.000×10^6
Ncr = 9.000
α CL CM CD Top Xtr Bot Xtr
0.000 0.4399 -0.087 0.00600 0.364 0.082
1.000 0.5537 -0.088 0.00597 0.345 0.151
2.000 0.6669 -0.089 0.00544 0.333 0.507
3.000 0.7749 -0.088 0.00464 0.321 0.992
4.000 0.8899 -0.089 0.00492 0.305 1.000
0.9986 -0.089 0.00562 0.242 1.000
1.0993 -0.087 0.00720 0.116 1.000
7.000 -0.086 0.00876 0.033 1.000
8.000 -0.085 0.015 1.000
9.000 1.4039 0.009 1.000
10.000 1.5024
11.000 0.005
-0.078 0.01474 0.004 1.000
1.7617 -0.073 0.01671 0.003 1.000
14.000 1.8219 -0.066 0.01859 0.003 1.000
15.000 1.8606 -0.057 0.02132 0.003 1.000
16.000 1.8781 -0.047 0.02575 0.002 1.000
17.000 1.8682 -0.040 0.03321 0.002 1.000
18.000 1.8289 -0.036 0.04586 0.002 1.000
19.000 1.7640 -0.040 0.06547 0.002 1.000
20.000 -0.048 0.08965 0.002 1.000



-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
Cp
XFOIL
V 6.93
NACA 4309
Re = 2.000×10^6
α = 0.0000°
CL = 0.4371
CM = -0.0866
CD = 0.00685
L/D = 63.83
Ncr = 9.00

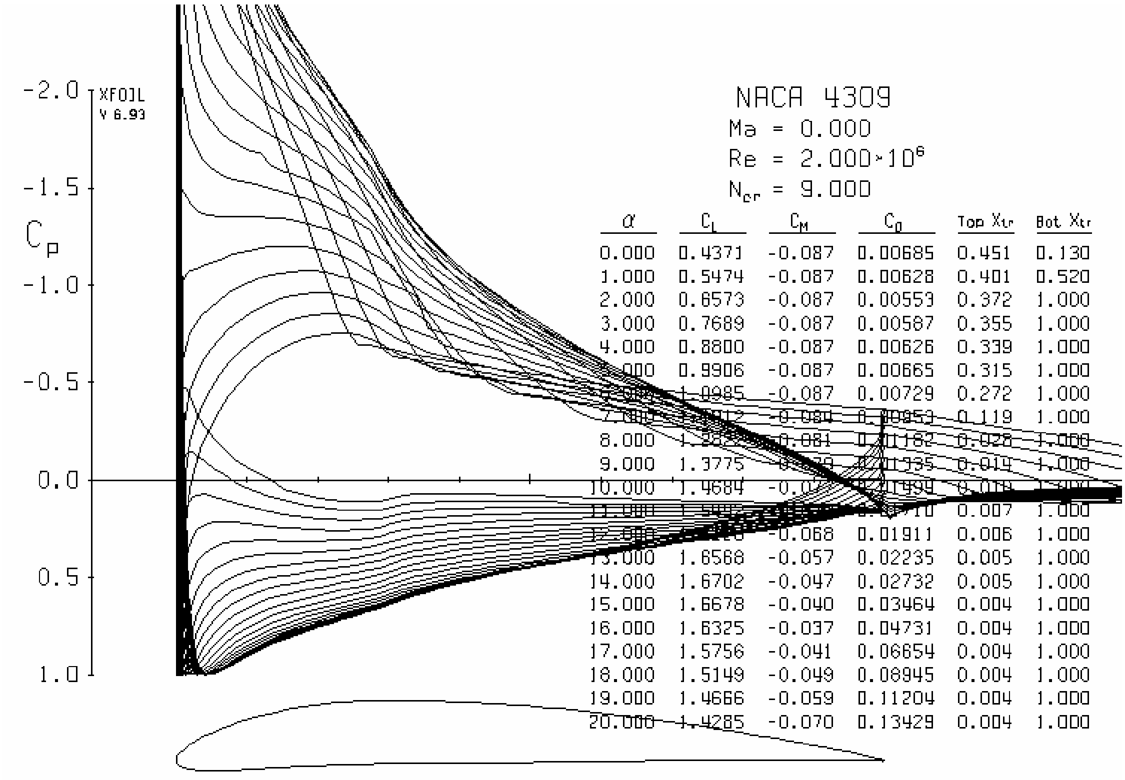


Figure 3 Performance Polars for the NACA 4309

Not bad performance for an airfoil designed in the 1920's.

Not good enough for racing, though.

Why? Too much drag at cruise. The cl at RN 6M for cruise configuration is .4399. A lot of lift. But a lot of lift is not necessary for a race plane. The whole idea is **speed**. And when one only has so much horseypower, then the *most direct way* to achieve faster speed is to reduce drag. Not easy to do. Another fly in the Marvel's Mystery ointment is the high negative pitching moment, or negative cm (coefficient moment). This is the tendency of a wing with a negative Cm airfoil to pitch down after the tail falls off. Before that occurs, though, the Cm adds a lot of trim drag, too, to the airplane because the tail is needed to counter the negative pitching moment of the wing.

When an airfoil is thick and has high drag with a lot of negative pitching moment, it is put on a Piper Cub. Piper Cubs lift a lot on low horsepower, but they fly slowly due to lots of drag and high pitching moment.

I suspect Wittman knew this. So why didn't he use a very thin, *symmetrical*, airfoil? That is what is used on today's aerobatic airplanes with **big** engines. They are lower in drag and have no pitching moment, therefore, almost no trim drag. The answer: symmetrical airfoils are limited on producing much lift; the Clmax is often less than on a cambered airfoil. Wittman and his friends were getting a lot of performance out of small engines, so the airfoil was the next place to start to decrease drag and increase the performance of the airplane, that is, make it go faster on limited horsepower.

Ok. Ready for the BIG secret?

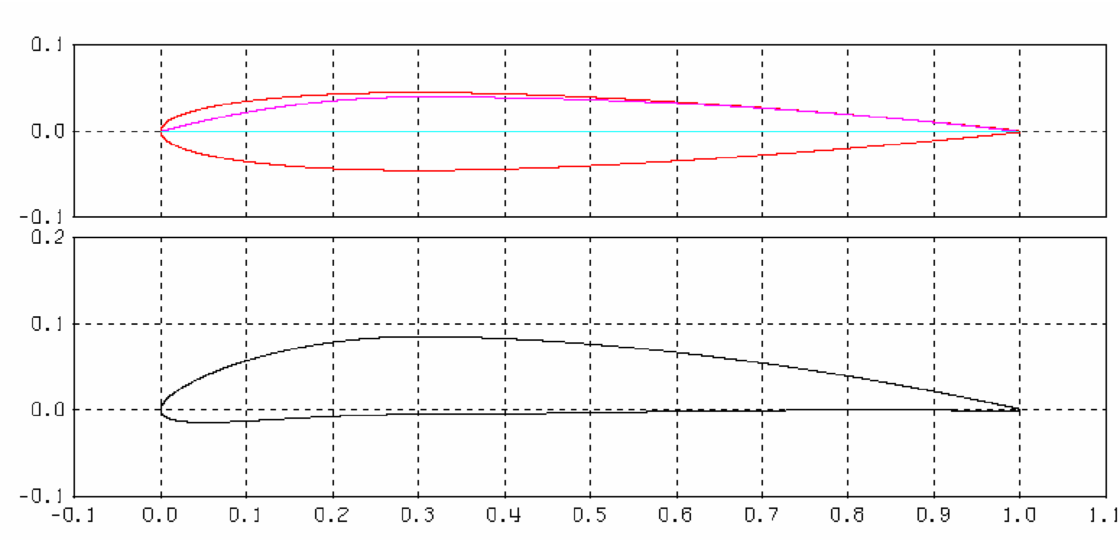
Wittman did indeed, in my opinion, use the NACA 4309 for his initial design. But, to reduce the drag, he used a thinner airfoil. He reduced it one percent; the W-10 is *not* a nine percent thick airfoil: it is **eight** percent! The "43***09***" is nine percent thick.

And how about that camber thing? Wittman didn't need a cl of .4399. He needed enough to climb to altitude quickly on not a whole lot of horsepower, at least not lot compared to today's racing planes. Remember. Camber can cause an increase in drag. So, he did the common sense thing: he reduced the camber.

And he reduced it by a lot!

The original camber of the airfoil was .0400. That's a lot of curvature and a lot of lift. By my analysis, I calculated that he reduced it to .0168. Look at the difference in the figure below.

From this:



to this:

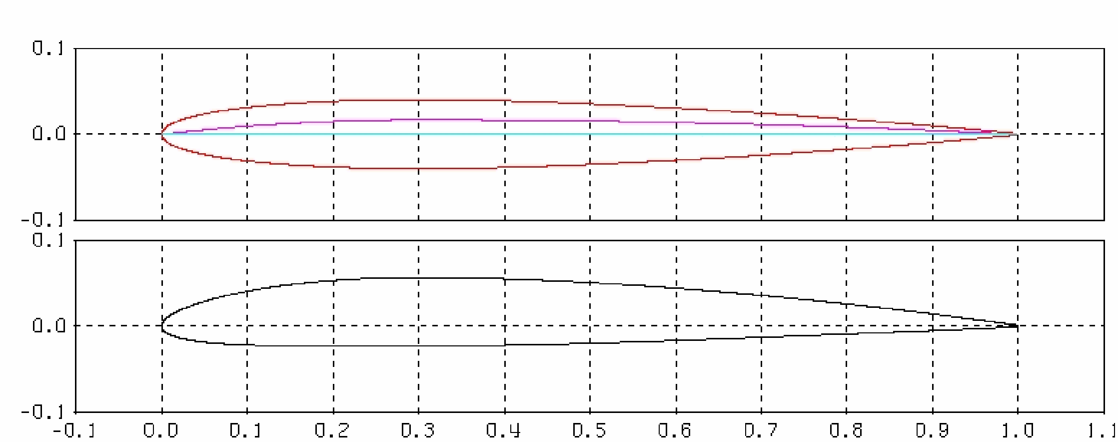
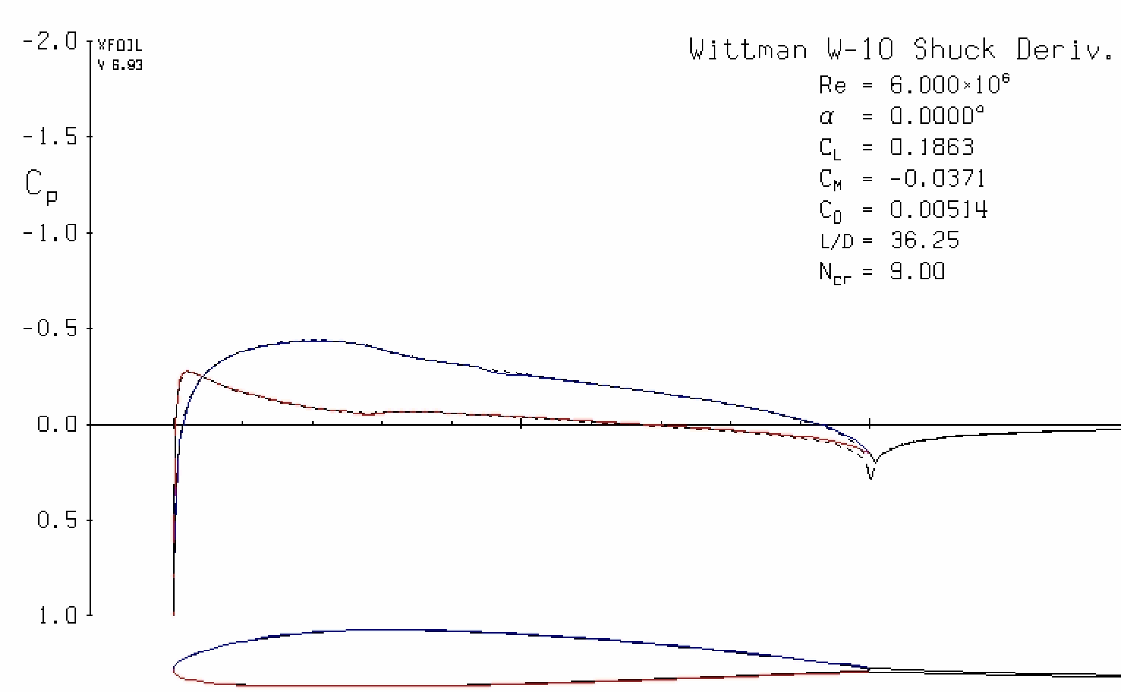
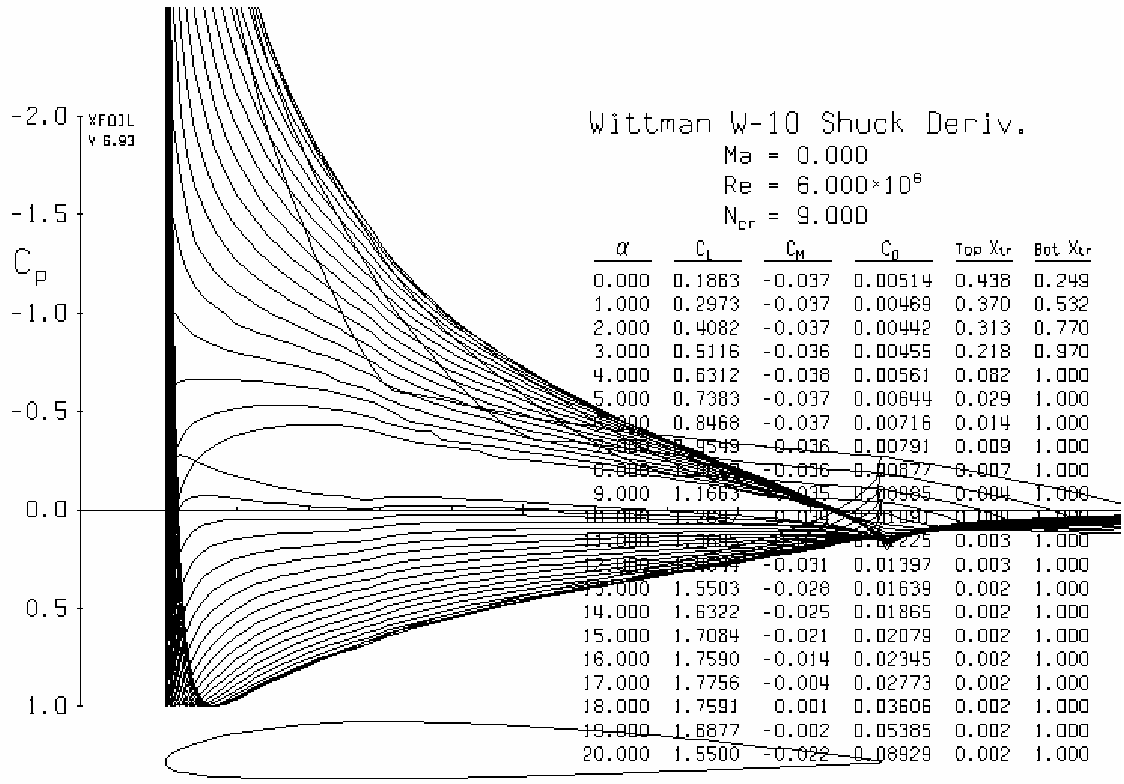


Figure 4 Comparison of the Camber of NACA 4309 to the W-10


-2.0
XFOIL
V 6.93
-1.5
Cp
-1.0
-0.5
0.0
0.5
1.0
Wittman W-10 Shuck Deriv.
Re = 6.000×10^6
α = 0.0000°
CL = 0.1863
CM = -0.0371
CD = 0.00514
L/D = 36.25
Ncr = 9.00


-2.0
XFOIL
V 6.93
-1.5
Cp
-1.0
-0.5
0.0
0.5
1.0
Wittman W-10 Shuck Deriv.
Ma = 0.000
Re = 6.000×10^6
Ncr = 9.000
α CL CM CD Top Xtr Bot Xtr
0.000 0.1863 -0.037 0.00514 0.438 0.249
1.000 0.2973 -0.037 0.00469 0.370 0.532
2.000 0.4082 -0.037 0.00442 0.313 0.770
3.000 0.5116 -0.036 0.00455 0.218 0.970
4.000 0.6312 -0.038 0.00561 0.082 1.000
5.000 0.7383 -0.037 0.00644 0.029 1.000
0.8468 -0.037 0.00716 0.014 1.000
0.00791 0.009 1.000
-0.036 1.000
9.000 1.000
0.003 1.000
-0.031 0.01397 0.003 1.000
1.5503 -0.028 0.01639 0.002 1.000
14.000 1.6322 -0.025 0.01865 0.002 1.000
15.000 1.7084 -0.021 0.02079 0.002 1.000
16.000 1.7590 -0.014 0.02345 0.002 1.000
17.000 1.7756 -0.004 0.02773 0.002 1.000
18.000 1.7591 0.001 0.03606 0.002 1.000
1.6877 -0.002 0.05385 0.002 1.000
20.000 1.5500 0.002 1.000

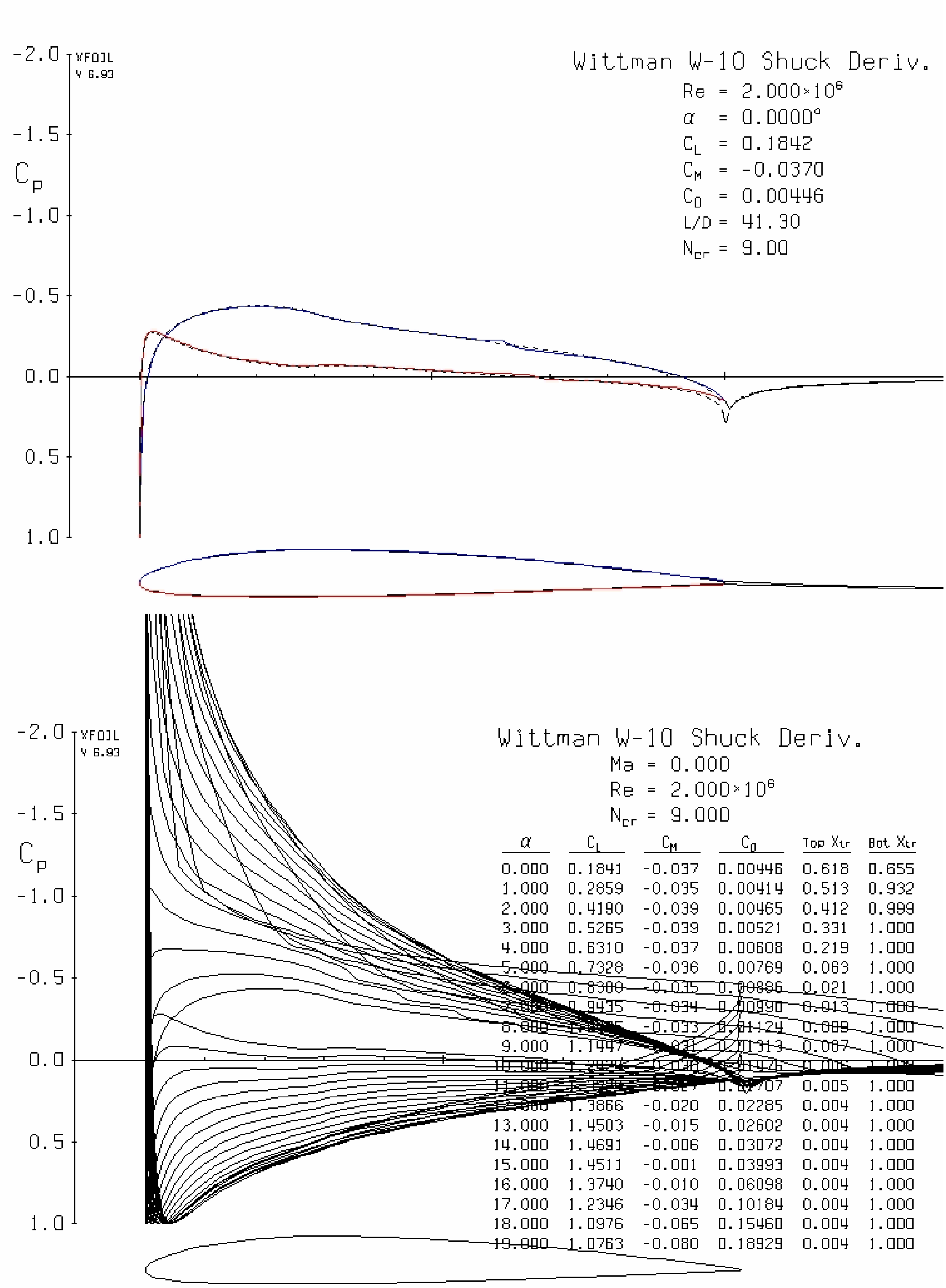


Figure 5 Performance Polars of the Wittman W-10

So, the drag was reduced by decreasing that ever-so-helpful camber and reducing the thickness of the "wing" by one lousy percent. Was it worth all the trouble? Yep.

At cruise speed, Wittman decreased the airfoil drag from 0.0060 to 0.00514. That is, he reduced the drag by 11.4 drag counts. That's significant! It is important to know that some of the early NACA laminar airfoils (which are supposed to be such low drag) had more drag than this. Well, a couple anyway. But this is not technically a laminar flow airfoil. It's majority of thickness and camber is at thirty percent of chord. Most laminar flows have thickness further back, some around *fifty* percent of chord. Yikes! But everyone knows that real world "wings" operate in dirty, lip-smackin' bug-wackin' environments, and that's sometimes just while still in the hangar. Laminar flow wants to go at least 30 to 50 percent before transitioning to turbulent flow. The old-fashioned W-10 does about as well without all the finickyness of laminar flow airfoils.

Now, something else happens. Laminar flow airfoils are loved for their drag buckets. Drag will decrease at the first two or three degrees of alpha for even more benefit. Usually, turbulent flow airfoils do not do this. But at an RN of 6 million, the drag decreases from .00514 to a mere .00442 at an alpha of three degrees…that's in the climb range where less drag really helps. See the previous figures.

Even in the twenties, there was no such thing as a free lunch. True then and true now. For the decrease in drag and thickness, the airfoil pays a big penalty. At the lower values of RN, say 2 million, the lift goes to heck in a hand basket. The above polars tell us that at an alpha of twelve degrees, the airfoil is only getting a Clmax of 1.38. Pretty cruddy, all things considered. The original 4309 gets a Clmax of 1.62 at 12 degrees. Is that much of a difference? Yes, it's a ***BIG*** difference. Stall speed here is higher at low Reynolds numbers with the W-10 airfoil for the Wittman Tailwind than the NACA 4309. Heavily loaded on a hot day, the plane on final approach may come down more like a rock than a rocket.

But folks, remember the mission of the airplane's airfoil. It was designed to go **fast**. And with Wittman's flaps and better-than-average flying skills, its stall speed was just fine. Today, this airplane is used for a lot more than just the parameters needed for racing, but still does quite well. The trick is to get to the higher RN's as fast as you can (duh) to enjoy the benefits of this airfoil. So, a bigger engine is nice in this case because Wittman actually designed it for several different engines of differing horsepower. Below you can see the differences thickness and camber can make.

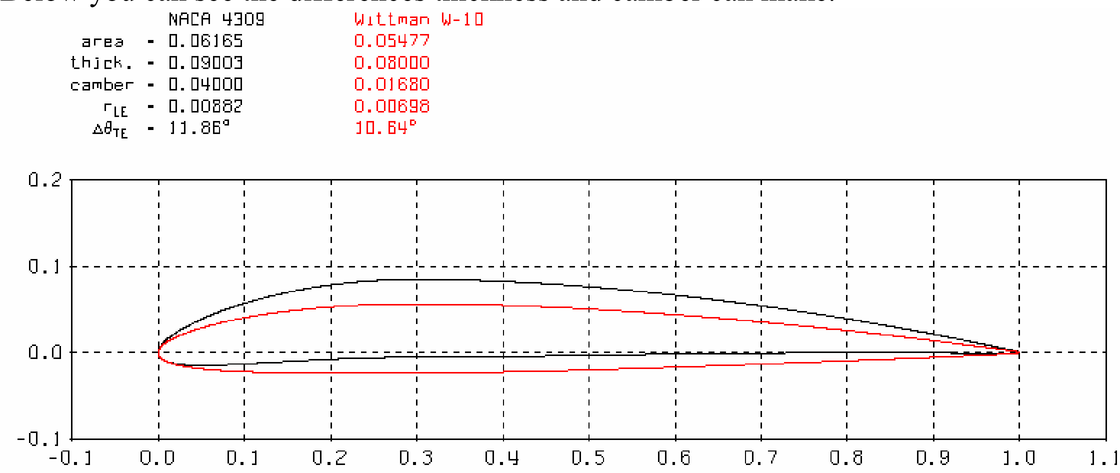


Figure 6 Superimposition of the Two Airfoils

Remember that 2-D analysis of the airfoil doesn't tell us much about the whole airplane. But the wing is the producer of the highest amount of drag and lift, so a lot of special attention must be paid to it. Fuselage lift analysis? Another time. The real truth is in the *wind tunnel testing* and *actual* flight of the airplane. Those are the places for the real answers.

So, these are the secrets: decrease the camber and decrease the thickness!!! Looking back on it, it really was all very simple. Following the original plans, though, is extremely important. Though Wittman's airfoil is still very utilitarian, you must remember its lesser points: it's thin and it has much less camber.

Why do we care?

Thin airfoils generally mean a heavier structure underneath. Less camber, as described above, means the aircraft will really benefit in speed from as much horsepower and the designer can allow. But weight in aircraft is usually the enemy. And low camber at higher weights than the design calls for usually means the aircraft can have the descent rate of a fully-loaded Coke machine. What would you rather have an engine failure in? An empty Coke can or a loaded Coke machine? Ok, neither, but you catch my drift.

The low aspect ratio wings don't help in the lift department. Their purpose of design is obvious, though. They are usually lighter than high aspect ratio wings and usually stronger per weight. Small aspect ratio wings are easier to build in a small area, too. Unfortunately, some builder/pilots begin to load the Tailwind with all kinds of additional items, such as the heavier full IFR instrument panels, wing tanks, cabin furnishings, etc. These can add a lot more weight than you might think! Plus, the "over 40 factor (gaining weight as we age) doesn't help. Wittman wasn't exactly chubby. Low aspect ratio wings have significantly higher induced drag on climb out than the higher aspect ratio wings. They just do. Wittman overcame this because he kept his aircraft very, very light. And he used a lot of power in his airplanes to overcome the evil of induced drag. He also knew that at cruise speed and altitude the induced drag was then at its lowest where high aspect ratio really is no longer much of an advantage over low aspect ratio wings. Unless you want to fly very high.

For practical purposes, this is the end of the discussion on how Wittman changed the NACA 4309 airfoil for the purposes of a high performance aircraft. But, you know, we can all dream a little; in doing so, we can break the golden rule of never making changes to the designer's plans…and come up with some airfoils that might be more utilitarian for uses in this aircraft other than racing.

What would happen if we increased the camber? We'll add drag, but that extra lift might be just pretty nice, though, especially with the added weight of a high Bubba factor passenger. A lot of times, the added drag of increased camber affects only the top end performance, but affects cruise performance much less. If the mission of your airplane is to race, then that is unacceptable. But if the mission is local and cross country flying at sixty-five to seventy-five percent power, then that added camber, done reasonable, may not decrease performance as much as one might think.

What would happen if we increased the thickness? Drag will increase, particularly in these non-laminar flow airfoils. But by a lot? Again, most of the performance decrease will be seen at the top speeds. Most pilots do not cruise at top speed however. Race pilots fly at top speeds. Increased thickness for them is automatic air brakes. Where do we see reasonably thick airfoils? Cessnas have 12% thick airfoils.

So do most Pipers. Those airplanes have pretty good performance in most cases. None, however, are known as race planes.

If I were to commit sacrilege to the golden rule of not changing the designer's plans, I would change the thickness and camber back to the parameters where I fly. I'm not a race pilot. But I want to go reasonably fast. I want an airplane that is light, though, because the Tailwind's wings have low aspect ratio, and I need to keep within those confines. When one starts lengthening wings, then all the moments about the airplane begin to change and one has a big mess on his hands. The tail surfaces and tail volume often have to change; fuselages must be lengthened, and on and on. So, don't make changes to the dimensions of the airplane; if you make dimensional changes, you can increase camber some and thickness some. This may mean changing the horizontal surface decalage, but in a lot of homebuilt airplanes, that might be acceptable. Often, however, one small change screws everything else up in big ways.

There is talk that some Tailwind builders want to put wing tanks in. A thicker airfoil would provide increased tankage in this case. Greater tankage means the airplane will have less weight available for payload, though. Have the struts been proven capable of sustaining hard landings with larger tanks when full of fuel with an engine out? How about the landing gear? Have stress calculations been made at this higher weight? Will roll coupling become a major factor to consider if fuel tanks are added to the wings? How will tail sizing and decalage be affected?

Yep. Small changes make for big changes. Don't go about changing the designer's weights, either. Not dimensions. Not weights. What's worse than good? Better.

That's my take.

Michael Shuck