HOMEBUILT AIRCRAFT DRAG REDUCTION - Case Study with a Lancair IV – Part 1

The objective of this report is to assist others reduce parasitic (friction) drag on their homebuilt aircraft. It describes the modifications I have made to my early slow-build Lancair IV kit (non-pressurized) powered by a Performance Engines high compression IO-550 engine of about 330 HP. While most of the modifications were made during construction, flight testing and improvement still continue. The sum total of all these improvements has been to reduce the simplified flat plate drag area (which will be explained) from the published figure of 2.12 square feet for the original turbocharged Lancair IV prototype to 1.80-1.85 square feet in the latest flight tests, a reduction of about 15%. Maximum recorded cruise speed (9,900 foot density altitude, 2700 RPM, wide open throttle, best power mixture) has been 257 knots TAS, with 230 knots at economy cruise (65% power, mixture 50F lean of peak.) Most of this benefit was obtained in reduced cooling drag, but attention to detail elsewhere also contributed to this favourable result.

In the following sections I will cover some general background on aircraft drag so that the reader will gain an appreciation for *why* particular improvements were undertaken, and then focus on specific modifications I implemented to improve performance. Some changes are easy, others are very time consuming. Because I made many modifications during construction, I could not test them one by one. Consequently in only a few cases can I quantify the improvement of a particular improvement. However, my work follows on that of others, and all this development effort has shown that major performance improvements arise from lots and lots of little, sometimes tiny, improvements that are individually too small to measure. Together they add up. Patience and persistence are the keys to success.

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1- BACKGROUND

Sources of Aircraft Drag

Generally aircraft drag is broken into two segments**: induced drag** (arising from the generation of lift) and **parasite drag** arising from the direct effects of friction. For this discussion I have borrowed liberally from the text Aerodynamics for Naval Aviators available from Aviation Supplies and Academics, Renton, WA (highly recommended and not copyrighted so copying is legal).

Induced drag depends on the weight and basic design of the aircraft – wing span/wing aspect ratio and weight being the most important factors. Parasite drag depends on how "slick" the airplane is, that is, how well it can defeat friction.

We want to distinguish between drag from lift and drag not due to lift (friction). Lifting directly from the book, we can write the following for drag coefficients:

$$C_D = C_{D_p} + C_{D_i}$$

where

C_D = airplane drag coefficient

C_{D_p} = parasite drag coefficient

C_{D_i} = induced drag coefficient

$$= 0.318 \frac{C_L^2}{AR}$$

C_L is the lift coefficient and AR is the Aspect Ratio of the wing (wing span squared divided by wing area). The factor 0.318 comes from a mathematical analysis in the theory of lift.

Incidentally, weight feeds into the lift coefficient and from above you can see that induced drag goes as lift coefficient squared. Thus induced drag goes as the SQUARE of the weight. Ten per cent more weight yields 20% more induced drag, important at low speeds, but less so at cruise. Build light!

Long skinny wings (sail planes) have high aspect ratios and thus low induced drag at low speeds while fighter planes have low aspect ratios and high induced drag at low speeds. This is why fighter planes need full afterburner to get around a nine G turn – the induced drag is out-of-sight with all that "weight." However small wings mean reduced parasitic drag with is mandatory for supersonic flight.

Strictly speaking, the parasite drag coefficient and the induced drag coefficient both vary with lift coefficient which is to say they vary with speed at constant weight. But our focus here is on cruise speeds where lift coefficients are in the range 0.2-0.5 corresponding to low angles of attack.

For this narrow range it is considered acceptable to lump in the constant part of parasite drag into the induced drag by a constant factor which is defined as the "airplane efficiency factor" which greatly simplifies our analysis and understanding. For our general aviation airplanes, this factor is in the range of 0.85. By this method of accounting the airplane drag coefficient is expressed as:

$$C_D = C_{D_{P_{min}}} + \frac{C_{D_i}}{e}$$

$$C_D = C_{D_{P_{min}}} + 0.318\left(\frac{C_L^2}{ARe}\right)$$

where

$C_{D_{P_{min}}}$ = minimum parasite drag coefficient

C_{D_i} = induced drag coefficient

e = airplane efficiency factor

The total airplane drag is the sum of the parasite and induced drags:

$$D = D_p + D_i$$

where

D_i = induced drag

$= \left(0.318\,\frac{C_L^2}{ARe}\right) qS$

and

D_p = parasite drag

$= C_{D_{P_{min}}} qS$

Here q is the dynamic pressure measured by the pitot tube (equal to a half density times velocity squared) and S is the total wetted surface area of the airplane that is subject to the frictional effects of the flow.

An alternate expression for the parasite drag is:

$$D_p = fq$$

where

f = equivalent parasite area, sq. ft.

$f = C_{D_{P_{min}}} S$

q = dynamic pressure, psf

$= \frac{\sigma V^2}{295}$ V KNOTS

or

$$D_p = \frac{f\sigma V^2}{295}$$

Here sigma is the density ratio which is equal to 1.0 at sea level, standard day, and varies with altitude and temperature. For convenience I have copied a table of properties for the atmosphere below.

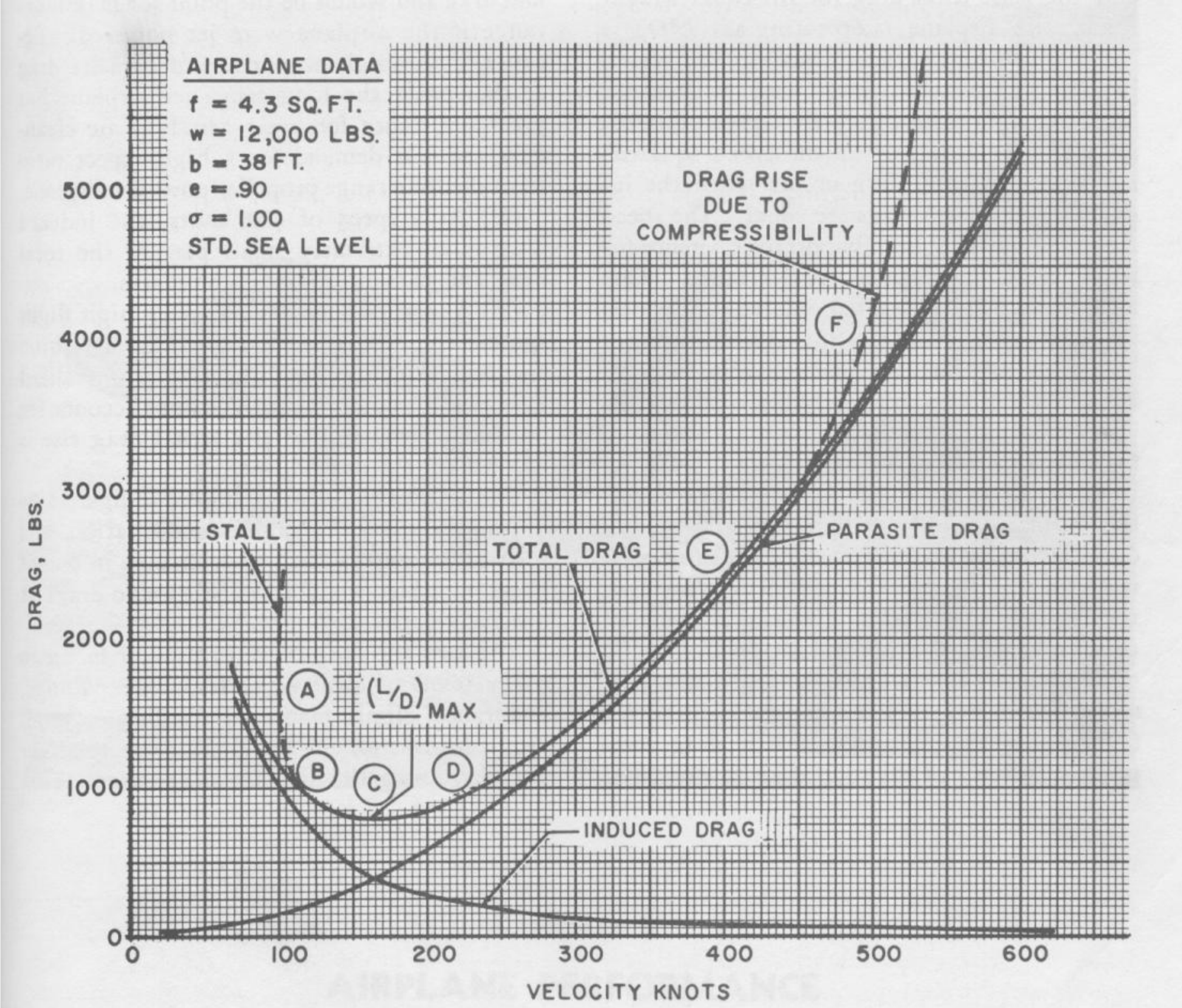
ICAO STANDARD ATMOSPHERE

ALTITUDE FT.	DENSITY RATIO σ	$\sqrt{\sigma}$	PRESSURE RATIO δ	TEMPERATURE °F	TEMPERATURE RATIO θ	SPEED OF SOUND a KNOTS	KINEMATIC VISCOSITY ν FT^2/SEC
0	1.0000	1.0000	1.0000	59.00	1.0000	661.7	.000158
1000	0.9711	0.9854	0.9644	55.43	0.9931	659.5	.000161
2000	0.9428	0.9710	0.9298	51.87	0.9862	657.2	.000165
3000	0.9151	0.9566	0.8962	48.30	0.9794	654.9	.000169
4000	0.8881	0.9424	0.8637	44.74	0.9725	652.6	.000174
5000	0.8617	0.9283	0.8320	41.17	0.9656	650.3	.000178
6000	0.8359	0.9143	0.8014	37.60	0.9587	647.9	.000182
7000	0.8106	0.9004	0.7716	34.04	0.9519	645.6	.000187
8000	0.7860	0.8866	0.7428	30.47	0.9450	643.3	.000192
9000	0.7620	0.8729	0.7148	26.90	0.9381	640.9	.000197
10000	0.7385	0.8593	0.6877	23.34	0.9312	638.6	.000202
15000	0.6292	0.7932	0.5643	5.51	0.8969	626.7	.000229
20000	0.5328	0.7299	0.4595	−12.32	0.8625	614.6	.000262
25000	0.4481	0.6694	0.3711	−30.15	0.8281	602.2	.000302
30000	0.3741	0.6117	0.2970	−47.98	0.7937	589.5	.000349

As an aside, the column showing the square root of sigma is useful for correcting IAS to TAS. For a standard day at 10,000 feet, the IAS will be about 86% of the TAS, while at 25,000 feet the IAS will be 67% of the TAS (assuming you corrected IAS for compressibility and aerodynamic heating when checking temperature, but I digress).

Effect of Speed

Math is nice but some of us prefer pictures. We can plug numbers into the equations and plot the resulting parasitic drag and induced drag for a typical aircraft. The textbook has done this for a 1950's era fighter aircraft that has about double the flat plate drag area of a Lancair IV, four times the weight, and a wingspan of 38 feet. The results are shown on the following page.



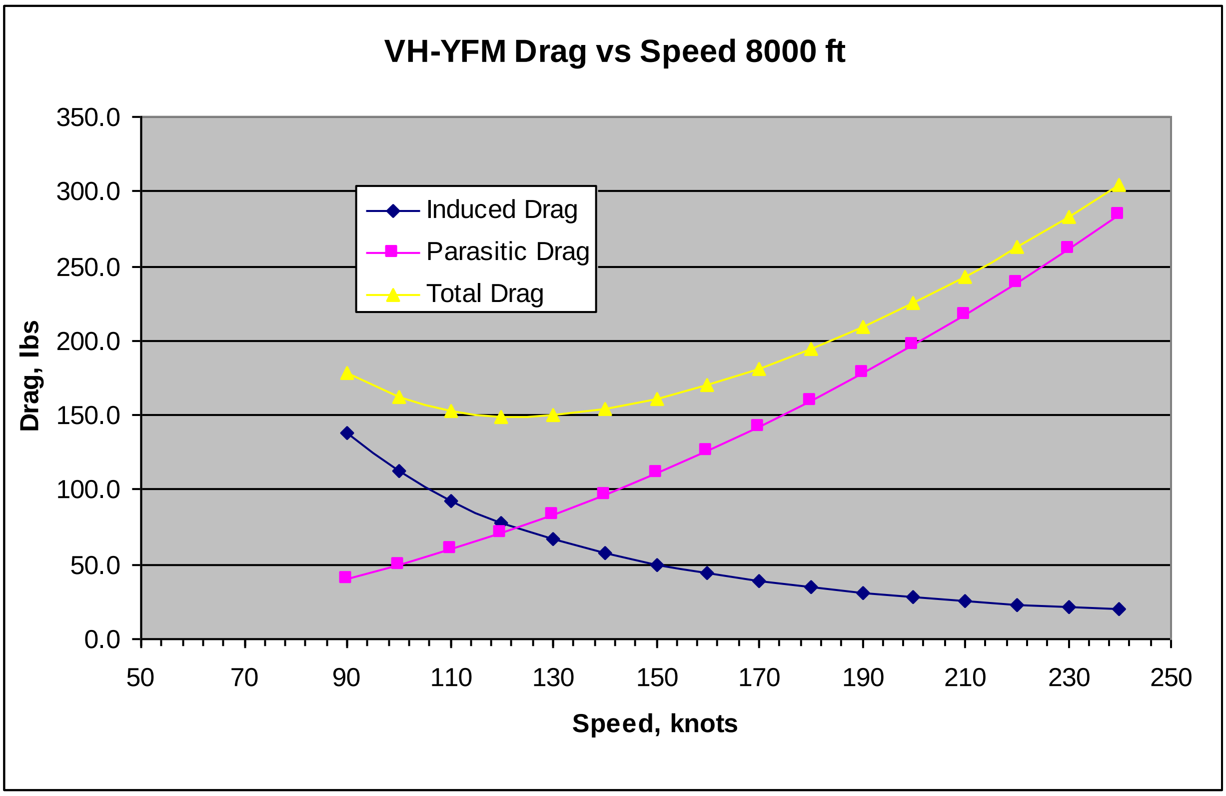
This chart is for sea level where TAS = IAS. For higher altitudes you have to use IAS and then correct to get TAS, but since we use IAS to fly the airplane, this chart remains useful at all altitudes.

Key points of interest:

- A- **Stall** which is 100 knots clean for this aircraft. For my Lancair IV (which I shall use for reference) the clean mid weight stall speed is ~77 knots.
- B- **Minimum rate of sink** rate for power off which is 124 knots on the chart above. Note that induced drag is 75% of the total drag. For a propeller airplane, this is the maximum endurance air speed. This would correspond to 95 knots on my Lancair IV.
- C- **Point of minimum drag** which is also known as the best L/D speed or best glide speed. It is shown here as 163 knots. For a **propeller powered** airplane, this is the maximum range speed. Note that at this point induced drag equals parasitic drag. For my Lancair IV, this suggests a speed of (77/100)x163 = 125 knots which is not far off the recommended best glide speed of 120 knots listed in the Lancair IV data.
- D- Maximum range speed for a **jet aircraft**, 32% greater than the speed for best L/D. This is where long range airliners like to operate.
- E- High cruise speed. Note that at high speeds induced drag is a very small part of the total drag which is now overwhelming dominated by parasitic drag.
- F- At speeds corresponding to a Mach number greater than about 0.3, compressibility effects start becoming significant as do aerodynamic heating effects that can affect your OAT readings. NOTE: the Chelton EFIS system corrects for these effects when it displays OAT

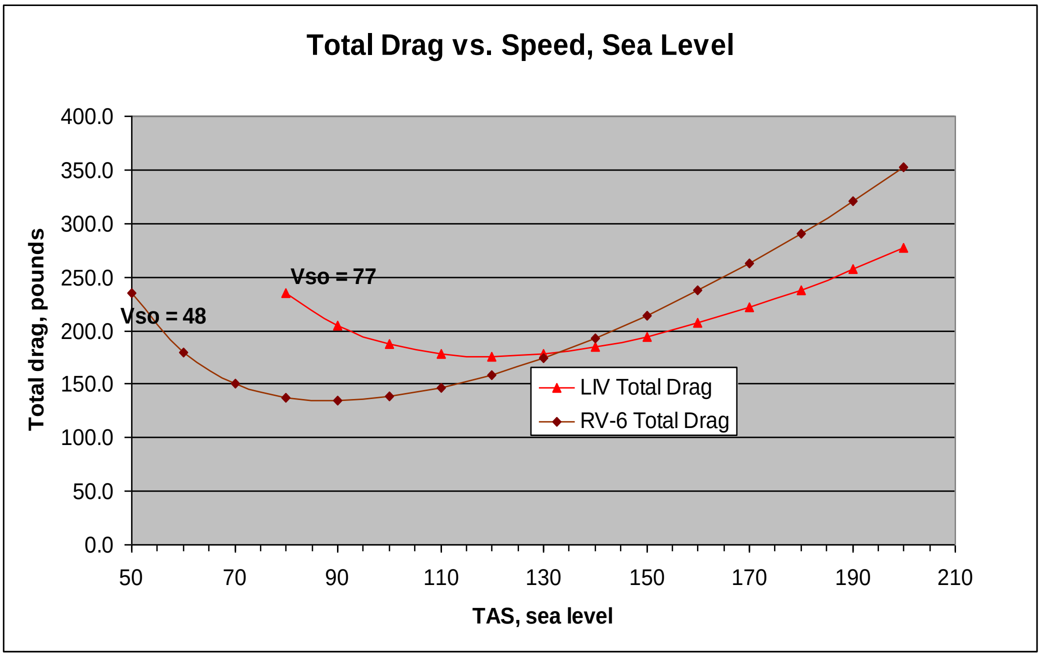
and TAS on the MFD screen. For other EFIS systems, check your instruction book. If you fail to take these effects into account, your E6B or that correction ring outside your airspeed indicator will yield an erroneously high calculation for TAS. At 200 KTAS the error is about 5 knots. At 300 KTAS the error is more like 13 knots.

For the Lancair IV, cruise IAS will typically range from 190-220 knots depending on altitude. This is approximately three times the stall speed. If we go to the chart, we can see that at three times stall speed, **induced drag is only 10% of the total drag**. Ninety percent of the drag is parasitic (friction) drag. This is confirmed in the drag profile I calculated for the Lancair IV shown below using the equations from the textbook. It assumes 2700 pound operating weight and a simplified flat plate drag area of 1.95 square feet at normal crise speed.



This is why we focus on parasitic drag for performance improvement. Except for weight, induced drag is defined by the wing geometry and is beyond our control when building kit aircraft.

It is always interesting to compare aircraft. Our club is filled with RVs of all kinds, particularly RV-6 aircraft. Using the factory figures for the RV-6 I compared the drag with my Lancair IV using higher weight and some different assumptions. The results are shown below.



Here are the key comparisons
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Aircraft	Wingspan, ft.	Wing area, sq. ft.	AR, aspect ratio	Wing Loading, lbs/sq ft	Span Loading, lbs./ft	Gross Weight
Lancair IV	30	98	9.2	32.6+	107+	3200+
RV-6	25	110	5.7	14.5	64	1600

The RV-6 has comparatively large wing area per weight yielding lower wing and wingspan loading. Consequently the RV has much lower induced drag than the Lancair IV at lower speeds, but much higher parasitic drag at higher speeds because of its metal construction and comparatively large non-laminar flow wing. The flat plate drag area of the RV is about 2.5 square feet. A really clean RV-6 with a 160 HP engine (we have an excellent example locally) will economy cruise about 170 knots at 8000-9000 feet. Assuming comparable engine efficiency, the Lancair IV will get better fuel economy over the ground than the "average" RV-6 at speeds above about 160 knots TAS at 8000 feet while carrying twice as many people. This clearly demonstrates the benefits of low parasitic drag.

Side Note on Winglets

Winglets help reduce INDUCED drag at lower indicated speeds, but adding additional surface area increases PARASITIC drag which hurts at high speed. Winglets help improve overall drag in the in the lower portion of the drag curve, near the region of minimum L/D. If you are flying your Lancair IV at jet altitudes like 37,000 feet where the air is very, very thin, the indicated air speed will be low, and you will be mushing along at a higher angle of attack. Under these conditions your winglets will significantly reduce cruise drag. But under normal cruise flight conditions when the airplane is **not** mushing along in thin air or flying slowly at low indicated speeds with lift coefficient greater than about 0.6-0.7 the winglets create **more** overall drag and thus less speed.

<u>So, for the speed crazed, remove your winglets!</u> (Sorry.) However, you may want to retain them for improved high altitude flight stability and slightly reduced approach and landing speeds. Aviation is a constant compromise. You pays your money and you takes your choice.

We can make a final simplification for high speed cruise and lump the small amount of induced drag in with the parasitic drag since induced drag is so small (~10%). We can then calculate a **"simplified" flat plate drag area** which represents the area times the air flow impact pressure that yields the total drag of the airplane. This gives us an easy comparison of various aircraft drag figures for the high speed cruise portion of the flight envelope. Here are some figures, most of which I dug up from Bruce Carmichael's book Personal Aircraft Drag Reduction (1995):

Aircraft	Simplified Flat Plate Drag Area
1950's era jet fighter used in the example above	4.3 square feet
Cessna 172/C182 class (they vary a lot – antennas etc.)	around 6
C-210/Beech Bonanza class (same comment)	around 4
Columbia/Cirrus	around 3
Voyager (remember, it flew very slowly)	5.4
A.J. Smith's AJ-2 (1980) 200 HP, 280 MPH top speed	1.14
Bellanca Skyrocket 1983	2.83
Lancair 200 (0-200 engine, calculated by Carmichael)	1.61
Mike Arnold's tiny AR 5 (213 mph on 65 HP)	0.88
Nemesis (formula 1)	0.6-0.72
Lancair ES	around 3
Lancair IV prototype (calculated by Martin Hollman)	2.12
VH-YFM, Fred Moreno's modified Lancair IV, non-turbo	~1.80-1.85

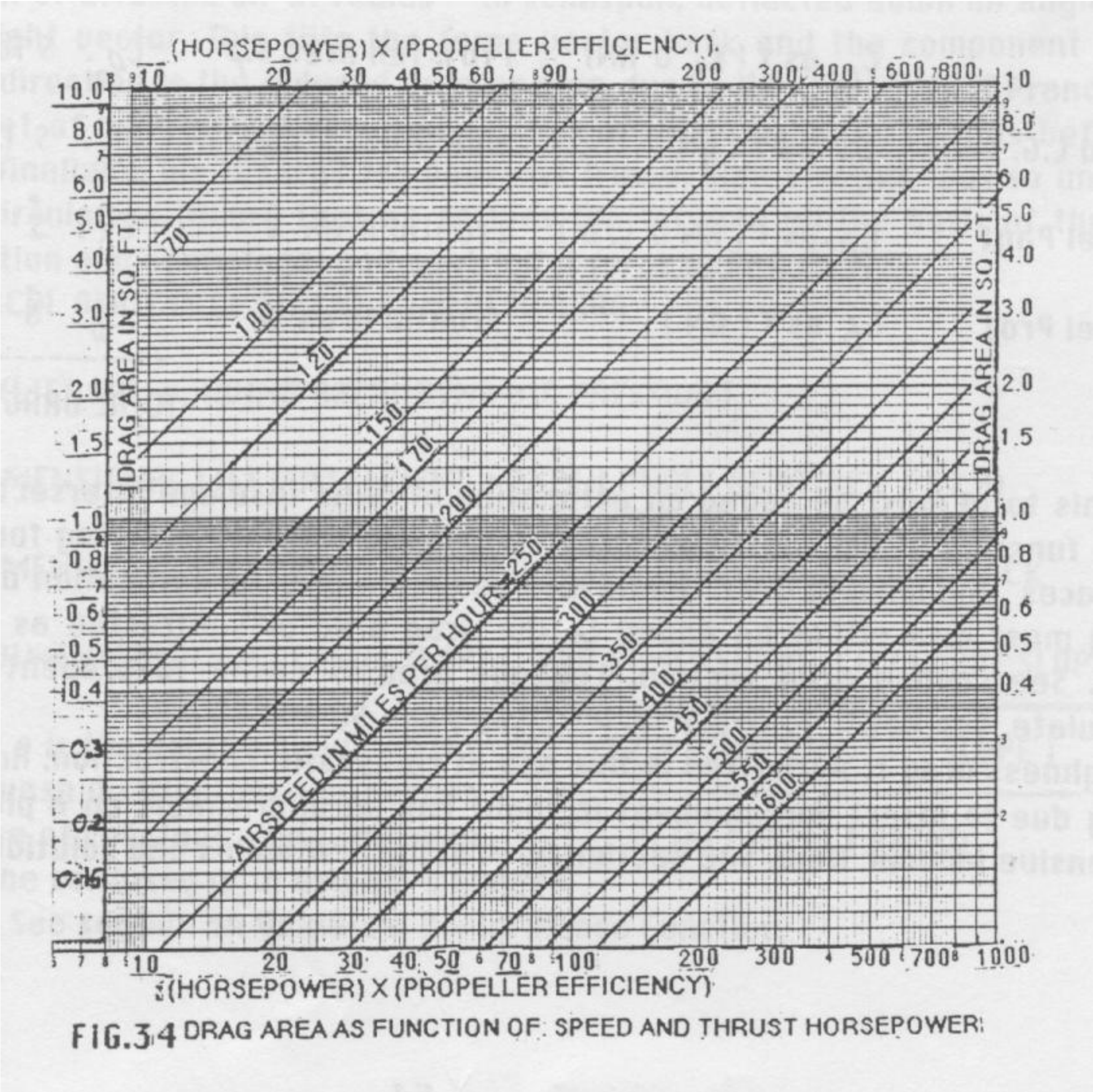
To calculate the simple flat plate drag area you need to calculate thrust horsepower which is the engine shaft horsepower at the power setting and mixture setting of the test (contains much uncertainty) multiplied by the propeller efficiency generally taken as 0.85 (more uncertainty). Because of the large amounts of uncertainty, the reader is cautioned that calculations of simple flat plate drag area (including my own) are very dodgy and can easily vary by 10% run to run if test conditions are not very tightly controlled.

Bruce Carmichael provides a neat graph in his book that allows one to estimate flat plate drag area. It is reproduced on the following page. It assumes you make a speed run at sea level, standard day, that you know the horsepower, and that you know the propeller efficiency. If you want to test your airplane, you can make a full throttle blast on a 59F day and assume your engine is putting out 100% power (careful: you will get more if you are getting some ram pressure benefit). Then assume 85% propeller efficiency and do a two way GPS average, up and down wind. Then use the graph. Note that the graph is in miles per hour. One knot = 1.15 miles per hour.

Or, correct for altitude. For constant power, speed increases roughly 1% per thousand feet for the first 10,000 feet or so. Using this and data from my plane one can make the following rough estimate of drag area using the chart and some other assumptions. I recorded a maximum speed of 257 knots at 9900 feet density altitude and my power charts showed the engine was putting out about 84% power, or about 273 HP for my high compression IO-550. Assuming a prop efficiency of 0.85 yields a thrust power of 232 HP. At sea level, a rough estimate of sea level speed would be about 90% of the speed at 10,000 feet (a 10% adjustment for altitude change), or 231 knots or 267 MPH. Using the chart, the flat plate drag area would be roughly 1.8 square feet which checks well with my more careful calculation of about 1.85 square feet even though we have used a lot of simplifying assumptions. Keep in mind that this includes all drag: induced and parasitic including cooling drag.

But the previous caution applies: because there are a lot of estimates in power and prop efficiency and potential errors in air speed measurement and temperature, it is hard to get flat plat area accuracy to better than 10%. Multiple flight tests are needed to confirm data and do some statistics, more than most of us are willing to do.

Be wary of single point test data. It is easy to get a data point that looks really good. But you will only be fooling yourself.



This chart assumes data collected at sea level, standard day.

Benefits of Drag Reduction

Here is the simplified but ruthless mathematical logic of speed, power, and drag at high cruise speeds in propeller airplanes.

- True air speed is proportional to the cube of power
- True air speed is proportional to one over the cube root of drag area for fixed power
- Power is proportional to drag at a fixed true air speed.

Since we are making small changes, we can use a math simplification in calculating changes. Applied to the rules above, it yields:

- 10% more power gives only 3% more speed (but 10% more fuel burn, even more if you have to richen the mixture to avoid detonation or keep things cool)
- 10% less flat plate drag area gives only 3% more speed at the same power (and fuel burn).
- But 10% less flat plate drag area requires 10% less power if you slow down to your old true air speed prior to reducing the drag (3% speed reduction). This yields **10% less fuel burn**, and a greater savings can be obtained if you can operate lean of peak and keep things cool

So the real benefit of drag reduction is improved fuel economy and less engine wear which equals **spending less money!** It is also helpful to win races and improve bragging rights when talking to spam can owners and the guys in the hangar next door.

Laminar and Turbulent Flow

Much is said about laminar and turbulent flow wings. Some explanation is helpful. These terms refer to the character of the boundary layer, the thin layer of air on the surface where the air speed varies from zero (on the surface) to the free stream velocity at the edge of the boundary layer. The boundary layer is illustrated in the simplified figure below for a flat plate, knife leading edge, oriented parallel to the flow. (Figures are taken from Aerodynamics for Naval Aviators).

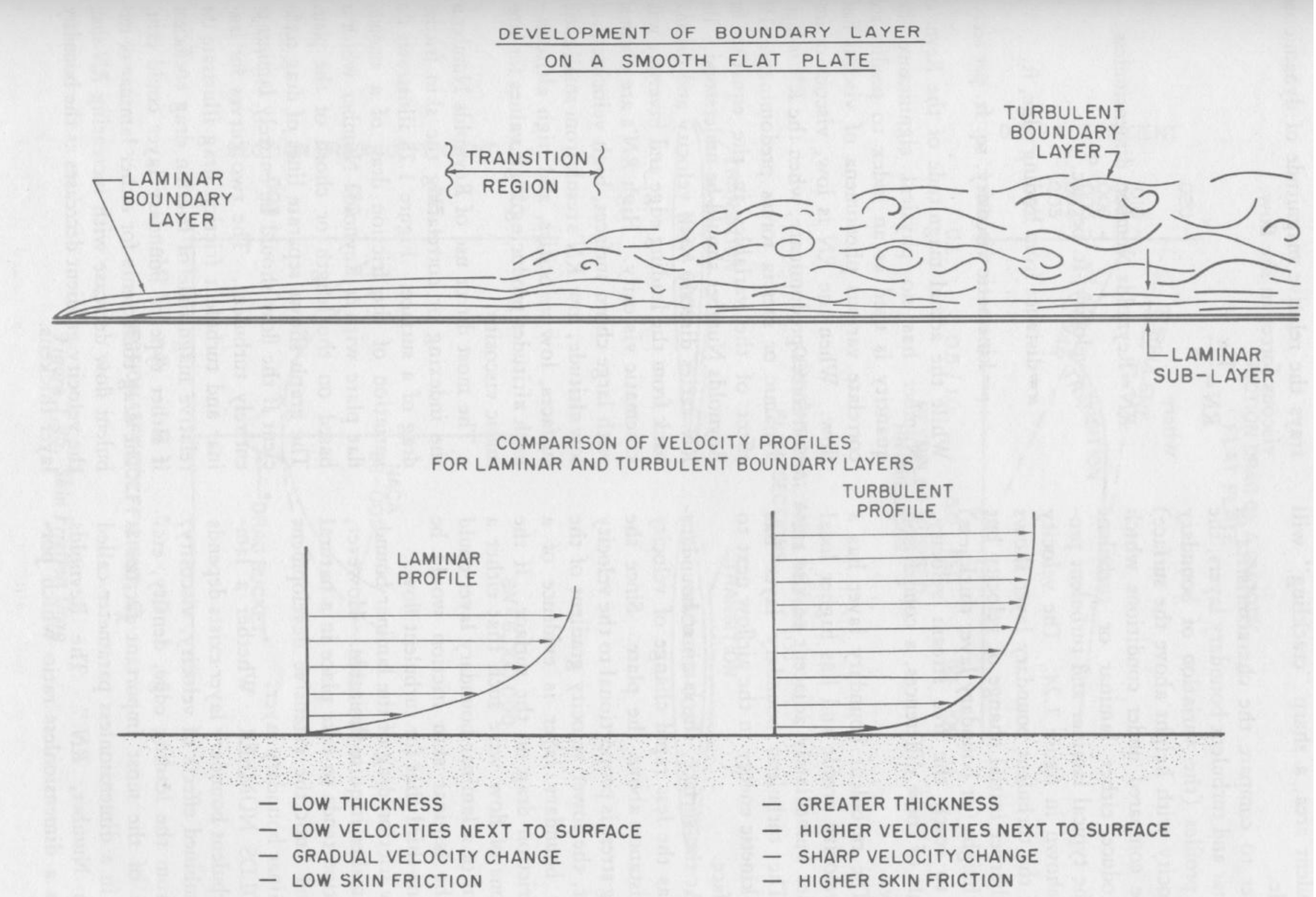
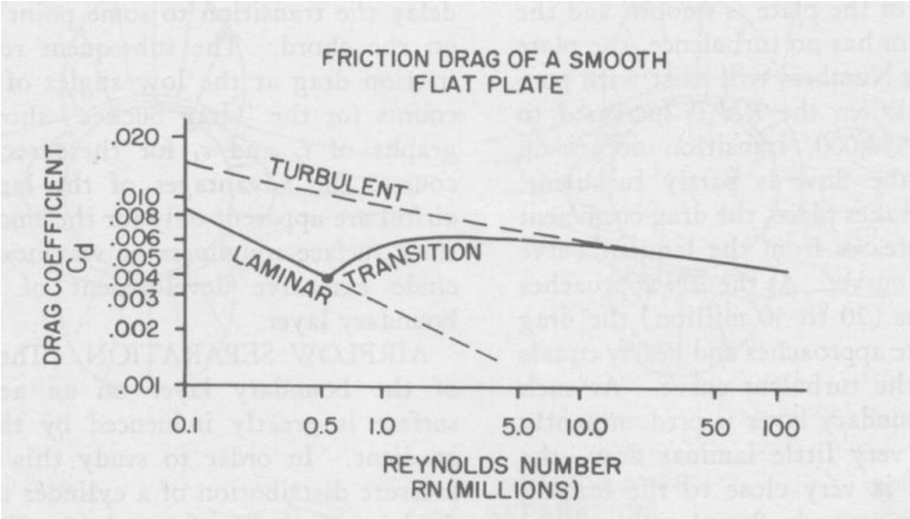


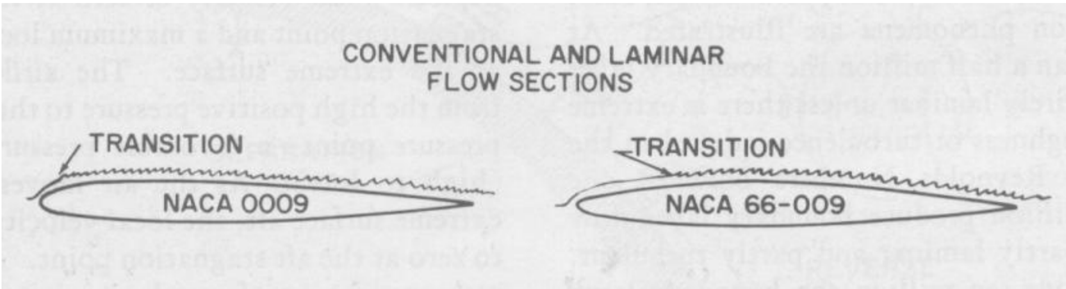
Figure 1.24. Boundary Layer Characteristics

The friction of the turbulent boundary layer is much greater than for the laminar boundary layer as illustrated in the figure below. If the velocity and air properties are held constant (which occurs at a typical cruise condition), the Reynold's number becomes a measure of the distance from the leading edge of the flat plate. (For our planes think of a Reynold's number of one million being roughly 1 foot at our normal cruise conditions.) Thus you can think of the chart as showing friction factor as a function of distance from the leading edge. Note that at the beginning of transition, the laminar friction coefficient is about 0.04 while the turbulent coefficient would have been about 0.10, or about 2.5 times greater. This is why we want to keep the boundary layer laminar as far as possible. If we can delay transition to a higher Reynold's number (farther along the surface), the difference between laminar and turbulent becomes even greater, approaching a factor of nearly 10 at a Reynold's number of five million.

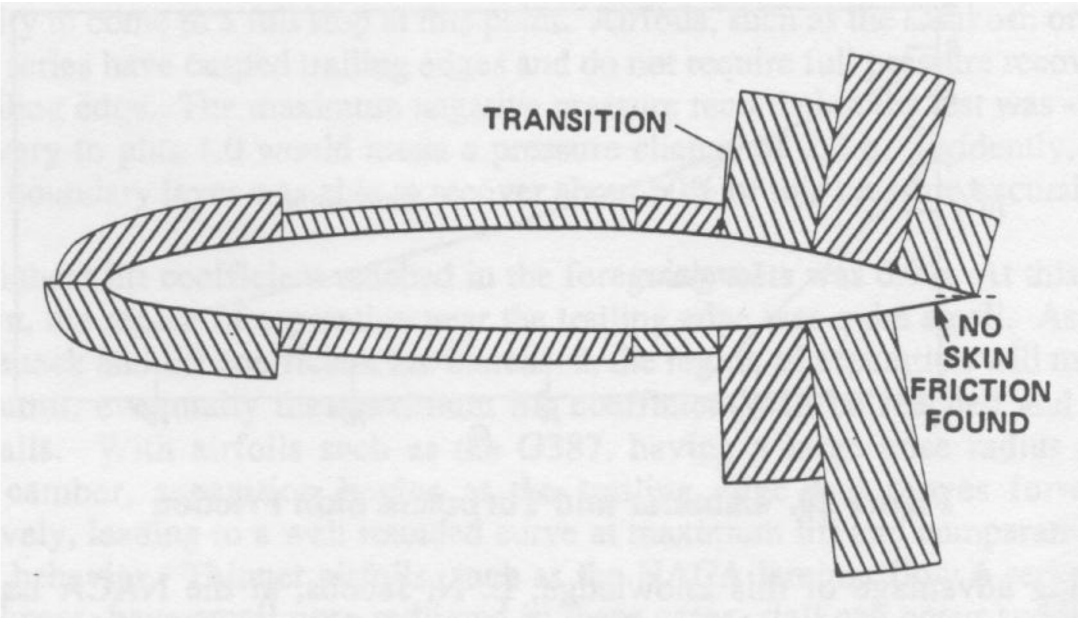


Two things control the transition from laminar to turbulent: surface roughness and the shape of the wing which controls the pressure distribution along the wing. <u>The pressure is constant on a flat plate</u>. <u>Not so with wings</u>. On a wing, maximum pressure occurs at the leading edge where the flow hits and comes to a stop, and then the pressure falls as the flow moves away from the impact point. It continues to fall reaching a minimum near the point of maximum wing curvature or thickness (more or less). Falling pressure causes the boundary layer to stay laminar longer while rising pressure can cause transition to occur.

Laminar flow wings are shaped to put the minimum pressure point as far from the leading edge as possible as shown below.



The following figure shows the distribution of skin friction around a particular very low drag laminar air foil, NACA 27-212.



Friction distribution along a particular laminar flow wing (NASA 27-212)
Source: Modern Subsonic Aerodynamics by R.T Jones, 1998

Since laminar flow has such low friction, we should shape the wing to get as much as laminar flow as possible, right? Not necessarily. As with all of aviation, there are tradeoffs. Wings like that shown above show ideal low drag performance only over a very narrow range of lift coefficients (angles of attack) and are VERY sensitive to surface roughness. Sometimes they have funny characteristics such as sudden and unpredictable stall, or they stop lifting in the rain which can be a bit a problem. An example is shown with the early Quickie aircraft that would not hold altitude nor take off in the rain due to peculiarities of the front aerofoil section. As usual, compromise is necessary.

A major benefit of composite aircraft is that you can make the wing skin stiff (particularly with honeycomb construction), control the shape very closely, and make the surface very smooth, all of which prove to be very difficult with metal wings formed by mere mortals. The Lancair IV has an aerofoil designed by Rick McWilliams. It is compromised toward laminar flow (more speed!) at the cost of less than ideal stall behaviour. It is also fairly thick which permits a taller spar section and more room for fuel. I have read that the Lancair IV wing in its ideal form is about 40% laminar on the top, and 60% laminar on the bottom.

Why all this discussion about boundary layers and laminar/turbulent flow? Because the aircraft builder has control over the key factors that govern how much turbulent flow you will get on your wings:

- Wing shape is critical, as noted above. You need to build your airfoil as close as possible to the shape intended by the wing designer. Keep that in mind when bonding on wing skins and when applying micro filler and then sanding it off. Very small deviations can move the transition point back and forward substantially. Later I will describe how I controlled the wing shape during fabrication.
- The surface has to be smooth (no defects, bumps, or waviness) to prevent premature transition. How smooth? Anecdotal reports suggest that the little step created by the application of leading edge tape can cause premature transition leading to a loss of up to 10 knots depending on aircraft, tape width, and tape thickness. Bugs are bad as well. Each bug splat causes a widening, wedge-shaped region of turbulent flow behind the splat having a half angle of about seven degrees. With enough bugs, these wedges can meet and cause large areas of prematurely turbulent boundary layer. If you can feel it with your fingertips, it is probably worth smoothing out.

- Don't forget the bottom of the wing! There is potentially more laminar flow area there (ideally) than on the top, so make sure the bottom is smooth, clean, and lacks defects and waviness.
- Avoid waviness on the skin. How much waviness? It depends where it occurs with the greatest sensitivity near the leading edge where the boundary layer is thinnest. A rule of thumb is that waviness should be no more than 3 mills (0.003 inches) per inch. You can see this easily as optical distortion when the surface is glossy. Using a reflective soapy water film and looking at the reflection of a fluorescent light tube to check is therefore useful when sanding. It is too late when you are doing the final polish of your top coat of paint.

Cooling Drag

One could write a book about cooling drag alone. We will try to keep it simple, yet comprehensive since cooling drag is the place where overall drag can be reduced the most on the otherwise very clean Lancair IV airframe. As usual we will start with some basics to assist the reader in understanding why we do what we do before we launch into the details of how one can reduce cooling drag in both finished aircraft and those still under construction.

There are two cooling air flows of interest:

1) <u>Cooling air</u> starts in the free stream which is slowed pretty much to zero as if flows into the cowl and into the space above the engine. The slowing creates higher static pressure as velocity energy is transformed into pressure energy. Some of this pressure energy is then lost to friction as the cooling air passes over cooling fins. If there is any pressure left over, we can then re-accelerate the flow aft and recover some of the momentum we lost when the flow was stopped initially.
2) <u>Leakage air</u> also flows through the cowl inlets and then leaks out of the cowl, out the gap behind the prop spinner, and around the engine through holes in the baffling where it contributes nothing to cooling. If there is surplus pressure left over below the engine, leakage air leaks out gaps, seals, landing gear doors and anywhere else that it can so that it does not flow rearward out the discharge nozzle.

Our goal is to maximize the capture of pressure above the engine, minimize friction (usually fixed by the engine itself), maximize the conversion of pressure to velocity below the engine where the flow is accelerated aft out hot air nozzles, and to totally eliminate leakage.

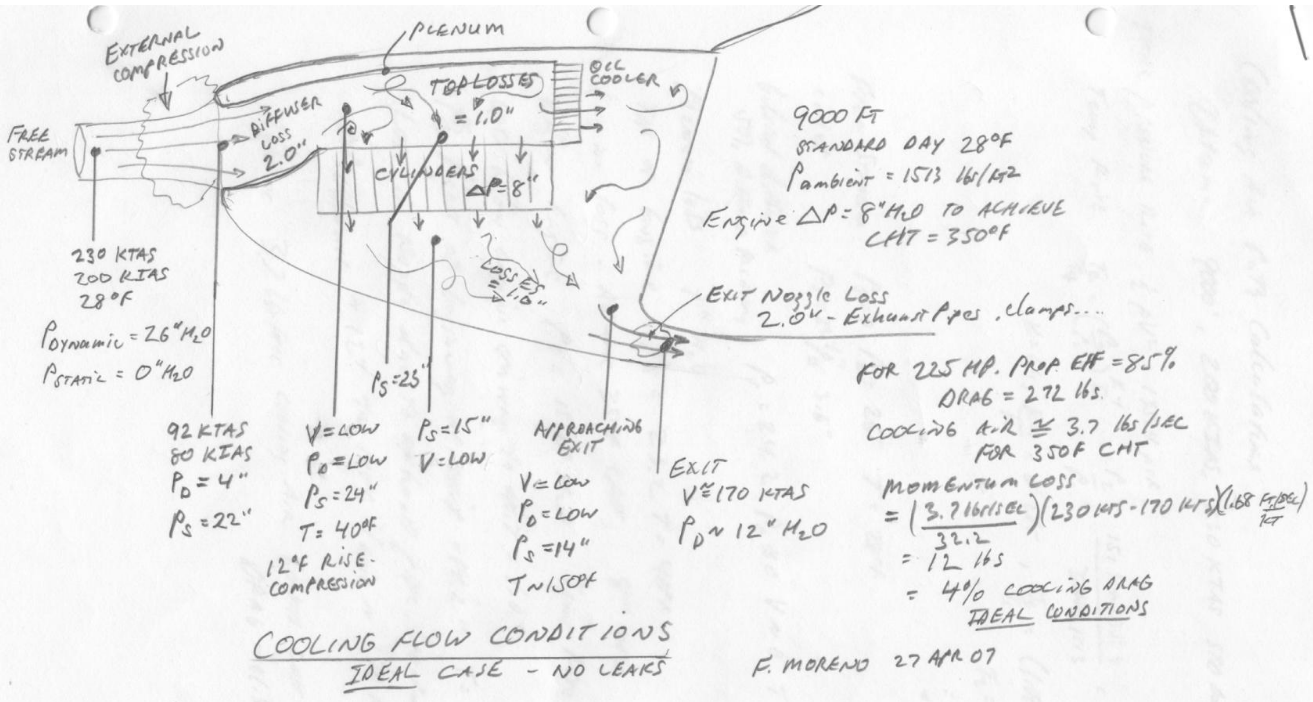
You should be compulsive about eliminating air leakage. It steals speed everywhere it occurs. Two stories help provide prospective.

I once had dinner with the chief turbine engine designer for Rolls-Royce. He said that a program to reduce internal air leakage (out of compressor stages and through the core and elsewhere) on an early version of the RB-211 engine yielded a 10% power improvement with no increase in fuel flow. They found air squirting everywhere inside the engine, and it was all power loss.

On my first trip to OSH in the 70's, I (and my buddies) had dinner in downtown Oshkosh at the Roxy with R.T. Jones, one of the world's leading aerodynamicists. We got thrown out much, much later when the restaurant closed in the wee hours. One interesting story was about full scale wind tunnel testing of the P-39 Cobra which was supposed to have lots of laminar flow and thus be fast. It was not. Testing showed two causes for excessive drag. First, the metal work was not smooth enough. Second, the wing-mounted radiator ducts collected and pressurized air in front of the radiators. The ducts leaked, pressurizing the interior of the airplane, wings, and fuselage. This pressurized air then escaped out every hole, crack, seam, and gap on the airplane. Imagine thousands of tiny fountains spewing air out through holes in the skin with jets directed perpendicular to the free stream. These little jets created a lot of drag and doomed any hope of laminar flow.

Leakage is the enemy, primarily around the engine, but also throughout the airframe.

Let's review the typical cooling air flow path for a Lancair at mid-altitude. To get 350F cylinder head temperature at 9000 feet requires about 8 inches of water pressure drop across the cooling fins. If you fly at 25,000 feet, the low density of air at that altitude doubles the required pressure drop to provide the same cooling. Cooling losses are much higher at high altitudes than low. I drew the figure below to summarize my calculations and estimates for my IO-550 Lancair IV which I knew I would be flying mostly in the range of 7,000-12,000 feet.



In the figure above, the total ram pressure available at 200 KIAS/230 KTAS 9000 feet is about 26 inches of water. (1.0 psi = 2.036 in. Hg = 27.7 in. H20 = 144 pounds/sq. ft.) I assume that with good inlet and diffuser design, I get about 23 inches above the engine and the data supports this. A loss of eight inches across the engine leaves fifteen inches below the engine which is used to accelerate hot air rearward out the exit (controllable area using cowl flaps) to about 170 knots recovering about 170 TAS/230 TAS = roughly 70% of the momentum lost when the flow was first stopped.

CAUTION: If you pressurize the cowl by closing cowl flaps, the pressure loads try to make the cowl blow up into a balloon and separate cowl halves. These loads become significant. From the conversion factors above, 15 inches of water pressure in the lower cowl equals about 80 pounds per square foot. The area on which the pressure is acting is roughly four feet wide times four feet long minus a bit for the rounded nose area, call it 14 square feet. Then the pressure load is 14 sq ft. times 80 lbs/sq. ft. or about 1100 pounds. At Vne the pressure will be about twice this. So you may have to beef up your cowl and add some stiffeners to help the cowl keep its shape, particularly the flattened top cowl. (I chose to do this.) I would hate for you to do a Vne dive and have your cowl depart the airplane. It would make for a very bad day. End of Caution.

First rule of cooling drag reduction: if you do not accelerate the flow aft to the maximum extent possible, then you are giving up momentum recovery (thrust) you could use to reduce drag. Unfortunately, the optimum exit area depends on speed – smaller for high speeds, larger for lower speeds such as climb. This is why minimum drag requires cowl flaps – 1) to control the total flow (more for high power, less for low power) AND 2) to accelerate the flow aft through a (hopefully) smoothly converging low friction nozzle.

You don't want the complexity of cowl flaps? I understand. They were very time consuming to construct and debug. However, if you are a speed fanatic, cowl flaps will have to be part of your recipe for drag reduction.

Note for turbo-charged aircraft operating at high altitudes. You are pretty much screwed. (Sorry.) First, you need a lot more cooling air flow because you are making a lot more power at altitude. Then you need more cooling air flow for the intercoolers. Then you need more cooling air flow for the oversize oil cooler. You need a lot more cooling air flow VOLUME (cubic feet per second) due to low air density. Finally, at high altitude the required engine pressure drop could be over 20 inches of water to keep things cool on a warm day. This leaves little leftover pressure below the engine to accelerate the flow aft through nozzles. Turbos and high altitude mean more required airflow and less available pressure to accelerate the flow rearward after you are finished with the cooling air. That means you are double screwed. Cooling air drag at 24,000 feet may be as much as 20-25% of total drag, possibly more.

But all is not lost because more than likely there is still a huge amount of LEAKAGE that you can reduce or eliminate if you are patient and diligent. The results of an effective leakage reduction program will be substantial: much cooler operation during climb and cruise and lower drag.

Leakage is also a bugaboo in the wings and fuselage when air flows in and out places where such air flow is not necessary. It ALWAYS causes more drag. So we will address engine leakage first, and then air frame leakage, areas where already-flying aircraft can benefit. Then we will venture into more difficult territory reserved for those still building who may want to get more drag reduction than is possible with the simple retrofit steps described initially.

What follows are four sections:

- Reduced cooling leakage/drag for already flying aircraft
- Reduced airframe drag for already flying aircraft
- Advanced methods for reducing cooling drag in aircraft still under construction
- Advanced methods for reducing airframe drag in aircraft still under construction

You can pick and choose as you desire. I wish I could tell you what each modification is worth in terms of speed, but as noted earlier, I can not. All I can say is 1) lots and lots of little details too small to measure individually DO add up when all combined, and 2) compared to the prototype Lancair IV with turbo engine, my Lancair IV with non-turbo engine and all the modifications listed obtained about a 15% improvement (decrease) in drag area. (I continue to search for more, of course.)