Such a Drag

As the saying goes, ‘Less is More’, and this has never been more true than in the case of drag. Less drag means a better rate of climb, a longer glide and a faster (or more economical) cruise. Not only are all these things nice to have, the first two significantly improve flight safety. In fact, with the possible exception of acrobatics the only phase of flight when more drag is actually desirable is approach and landing; a time when adding drag is as easy as flying a bit faster, applying crossed-controls or just extending full flap. Reducing drag on the other hand, is much more of a challenge, But before you rush out to your hangar, cloth in hand ready to buff your machine to a high gloss, let’s take a closer look at our adversary.

At the most basic level drag is simply the force that opposes thrust in the familiar ***lift-weight-thrust-drag*** ‘forces of fight’ diagram, but this simplistic view lumps all the many separate drag sources into a single ‘total drag’ value. I want to dig a little deeper, so I’ve dissected the ‘total drag’ for you in Figure 1, so we can see where all this drag is really coming from:

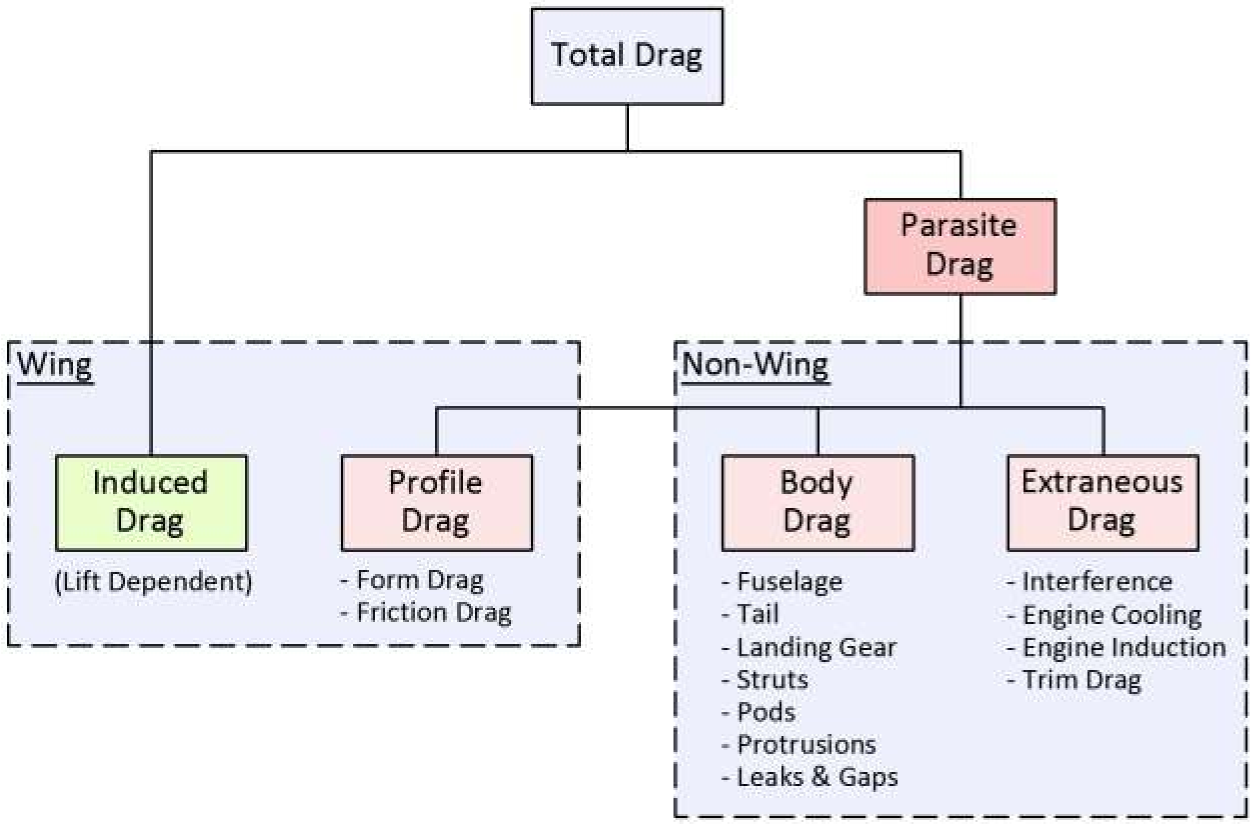

Figure 1 – Typical Drag Breakdown

Induced Drag – As discussed previously, this is the drag that results from the production of lift. Induced drag is unique in that it's the only source of aerodynamic drag which *decreases* the faster you fly. Of course there is no free lunch – it also increases rapidly at low speeds – hence why flying slower than your plane's 'best glide' speed requires significant power and why flying on the 'backside' of the power curve can get you into all kinds of trouble.

Parasite Drag – Covers all the remaining drag once the induced drag is removed. As the name suggests it consumes energy without providing any benefit in return, it increases approximately linearly with airspeed squared, i.e. doubling your airspeed will roughly quadruple the parasite drag.

Profile Drag – Is the drag a wing produces irrespective of whether it's producing any lift and is a combination of two parts; the wing's *Form Drag* (sometimes called pressure drag), and *Friction Drag,* both of which are described further below. From an aircraft performance point of view the Profile drag is just another part of the overall parasite drag, however for a designer it's useful to group all the wing related drag together, so the Profile drag often gets separated from the Parasite drag allowing it to be combined with the induced drag for design calculation purposes.

Form Drag – Depends on the frontal cross section of an object and also how streamlined it is. At typical flying speed air flowing around a bluff body will turbulently separate from the rear surface forming vortices and creating an area of low pressure in the wake. This low pressure area, along with an area of raised pressure front of the body, leads to a significant pressure differential between the front and rear surfaces resulting in a net drag force.

Friction Drag – Depends on surface or 'wetted' area and originates from a fluid's tendency to be pulled along by a passing body due to viscosity. When an object moves through air any molecules directly in contact with the surface stick to it firmly without slipping, however moving away from the surface the air molecules can slide over one another, meaning they are dragged progressively less and less the further from the surface you go. This process forms a thin ‘boundary layer’ between the air stuck to the surface and the air far enough away to be completely unaffected. Any air molecule that passes through this boundary layer will get dragged along to some extent, extracting energy from the passing body and carrying it away in the wake.

For an object the size of an aeroplane, travelling through air at 100 knots, form drag is much more influential than friction drag. This means a streamlined body (which limits flow separation and thus minimises form drag) is far more efficient than a bluff body, even when a large difference in wetted area exists. To visualise this Figure 2 shows two cross sections, representing a cylinder and a 25% thick aerofoil. Remarkably, despite a dramatic difference in size, these two cross sections produce the same drag!

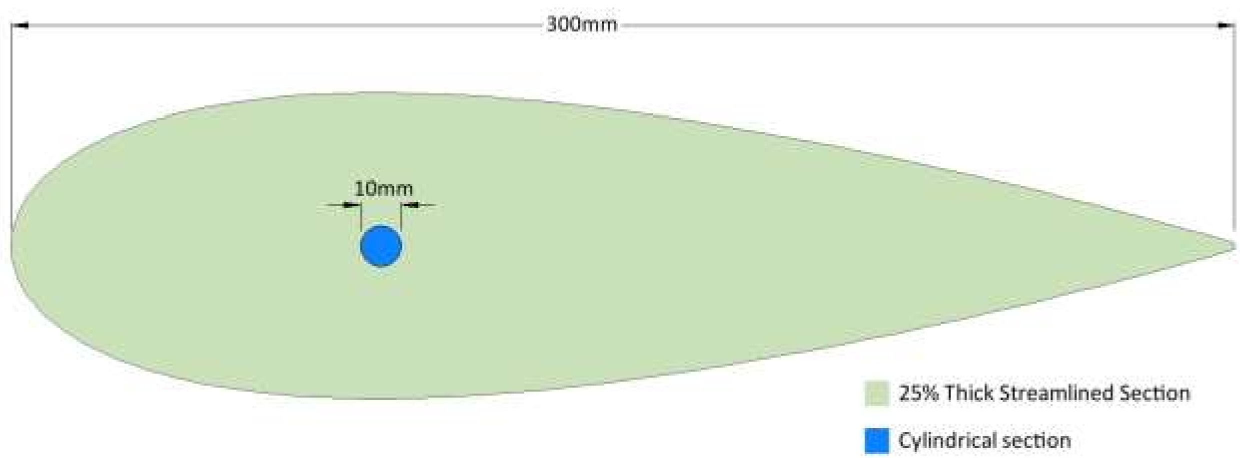

Figure 2 – The importance of streamlining, both of these cross sections have the same drag.

Body Drag – Is primarily the combined form and friction drag produced by the remainder of the airframe, excluding the wings. However it also includes the drag caused by gaps and leaks. Air which leaks into the aircraft will be accelerated to the speed the aircraft is flying at, and will then leak out again taking the energy it has just gained with it. So a whistling door seal is doing more than just making an annoying noise, it's also slowing you down.

Extraneous Drag – This is really the catch-all term for what's left, but added up it can represent a significant portion of the total drag:-

Powerplant related drag – A great deal of research has been put into minimising the losses associated with powerplant installation. Inevitably there are intake losses involved in capturing passing air and trading its speed for increased pressure, be it for more power or efficient cooling. A well-designed exhaust can claw some of these losses back, but for cooling the holy grail is the mystical (and slightly controversial) 'Meredith Effect'; using the heat energy gained from cooling the engine to actually provide thrust, and, theoretically at least, eliminate cooling drag altogether!

Interference drag – Occurs when the airflows around separate parts of an airframe interact, causing additional drag above that which would occur if the parts were operating in isolation. The classic case is wing-body intersections, but any sharp junction where parts meet at an angle of 90° or less (such as wing struts for example), can be a problem. Interference drag is usually minimised by using fillets and fairings to provide smooth rounded junctions between surfaces.

Last up is ***Trim Drag*** – To allow trimming most aeroplanes are provided with a tail to generate lift and counter the aeroplane's pitching moment. During cruise this lift will typically be downwards, and so has to be compensated for by additional lift from the main wing. Both this extra wing lift and the tail's lift result in additional induced drag, referred to as trim drag. This trim drag can certainly be minimised, gliders almost universally opt for long tails with small surfaces, and low pitching moment aerofoils have had plenty of research, but for transport category aircraft the usual solution is to simply move fuel around the plane, adjusting the trim by tweaking the weight distribution rather than using aerodynamics.

Turbulent vs Laminar

No discussion of drag would be complete without mentioning laminar vs turbulent flow. In laminar flow a fluid remains in well-defined layers with no mixing between them, this allows for a thinner boundary layer and reduced friction drag. Viscose fluids like syrup and small scale objects such as insect wings naturally promote laminar flow, but in air, especially at the scale of an aeroplane wing, laminar flow is extremely hard to achieve and maintain, requiring very smooth surfaces and carefully controlled pressure gradients to prevent a breakdown into turbulence. In addition laminar flow doesn't like turning corners, so it tends to separate from surfaces with lots of curvature causing a dramatic increase in drag.

Turbulent flow on the other hand causes more friction drag due to its thicker boundary layer, but it is much less prone to separation.
Taking the humble golf ball as an example, it is not amenable to streamlining (it’s a ball!), but the dimples ensure the boundary layer is turbulent which allows the flow to stay attached to the surface for longer, massively reducing the profile drag and more than offsetting the increased friction drag caused by the turbulence.
In my view laminar flow is a worthwhile goal, (especially if you are designing a glider!), but unless your surfaces are precisely manufactured, mirror smooth, impeccably clean and located outside of the prop-wash you’re unlikely to see much benefit. Having said that, even with turbulent flow most modern ‘laminar’ aerofoil profiles will perform just as well, if not better, than traditional ones, so there’s really no harm in trying!

Summing up, hopefully you are all now drag experts, so it’s time to go streamline your struts, seal your gaps, wash the bugs off your leading edge, pop on your wheel spats and then sit back and marvel at the stunning improvement in your plane’s performance!
Talking of performance, I’ve been doing a little work on my own design. Taking some conservative drag estimates I’m hoping for the following:

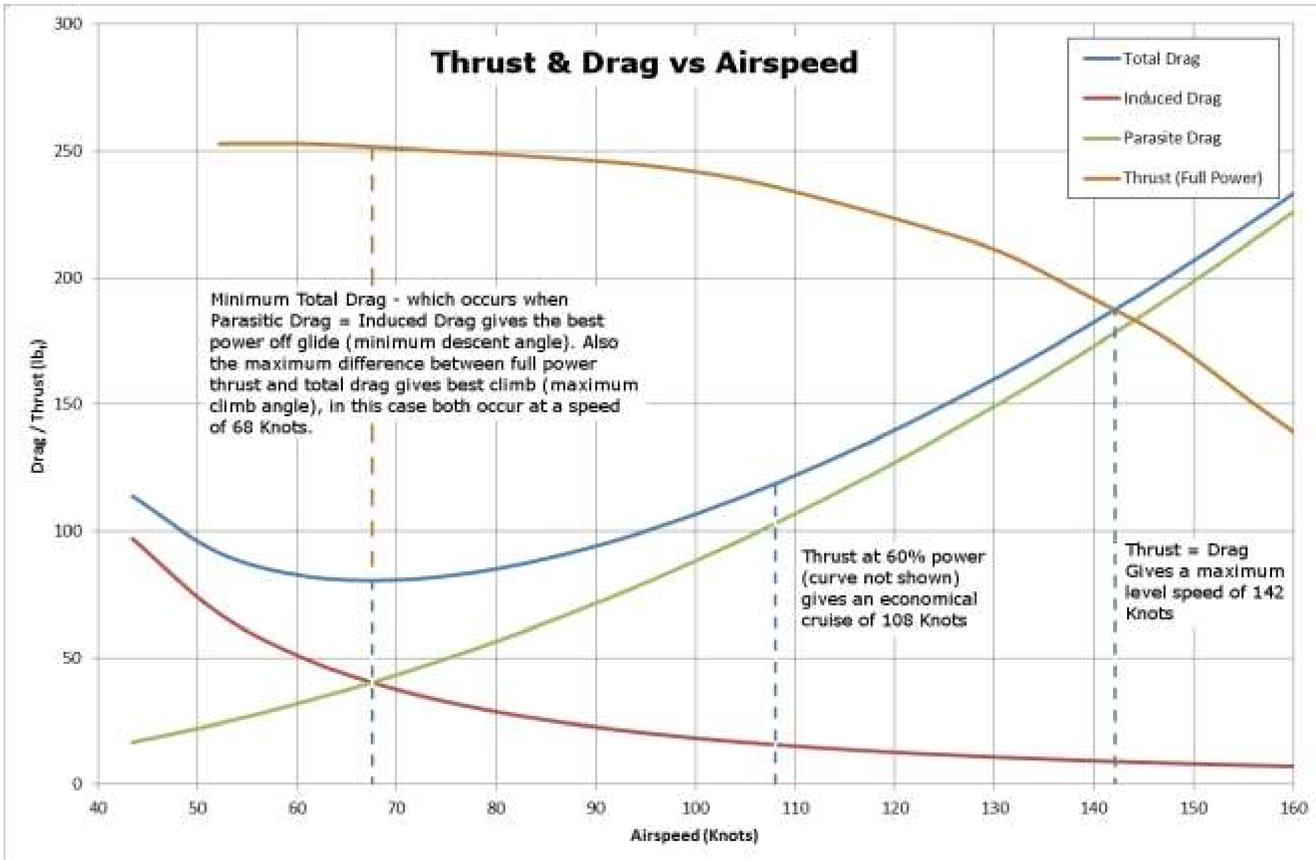

Figure 3 – Example performance plot (for Project-Ex) illustrating how the relationship between drag and thrust determines aircraft performance.

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