THE GROUND UP - ADVANCED FLIGHT SIM TUTORIALS

LESSON 001 - GETTING TO KNOW YOUR AIRCRAFT

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A COMPLEMENT TO THE GROUND UP - ADVANCED FLIGHT SIM TUTORIALS VIDEO SERIES

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OBJECTIVES:

- To understand the concepts of lift, weight, thrust and drag

- To be able to identify the various different components on aircraft

INTRODUCTION

Welcome to The Ground Up - Advanced Flight Sim Tutorials. Before continuing, it is important to note that the aircraft you choose is very important to follow along with this series. I will be using a Piper PA-28R Arrow III from JustFlight as the first training aircraft, and I suggest that you find something similar or identical to it in order to maximise your learning. This PDF guide will accompany lesson 001, available on YouTube. In this lesson, we will be going over the basic concepts around aviation, getting to know the aircraft, and understanding the different components and what role they play in aviation.

1.1 - COMPONENTS OF A LIGHT AIRCRAFT

It is key to understand your aircraft and how it works before you get into the air for the first time. In addition to the various controls, dials and displays inside, it is vital to know all the different parts outside, what they do, and how some of them work. The focus on the series is going to be on aeroplanes, rather than helicopters, though we may visit them at a later date, and they will be mentioned and referenced time to time.

1.1.1 - FUSELAGE

A nice simple thing to start with. The fuselage is the main body of the aircraft. Generally long and slender, this is where we have the cockpit/flight deck, cabin for passengers and cargo hold, as well as the electronics for the aircraft. In some aircraft, fuel is also stored in the fuselage, as are the wheels (sometimes) when the aircraft is in flight.

1.1.2 - ENGINE

We may now have a fuselage for our aircraft, but we have yet to make it move. To do this, we need to have something apply a force upon it, in accordance with Newton's first law of motion: An object at rest will remain at rest unless a force is acted upon it. That could be a person pushing it, but of course that would be rather useless in the air. So instead, we use an engine to generate the required forces for us to fly.

When it comes to engines, aircraft have various different types, but broadly broken down into two categories - propeller and jet. Each type can be broken down further, but we will be focussing on the different types as we come across them. Our training aircraft using a piston propeller engine, mounted on the nose of the aircraft. We call this a single prop aircraft. Later on, we will be exploring twin prop, and then jet aircraft, and potentially another type somewhere in between.

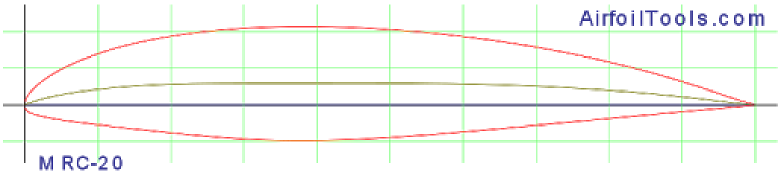
Our piston propeller engine works on a very simple concept. We have an internal combustion engine, similar to the one you find in a car, in which you inject fuel and air, compress and ignite it, and produce a high pressure that pushes down on a piston, which in turn moves a shaft around. That shaft is connected to a propeller, which will then spin. The exhaust gas of the engine will be expelled through exhaust ports, either at the bottom of the aircraft nose, like our aeroplane, or on the sides, such as on a Supermarine Spitfire. These gases are considered waste for the piston engine, except in the case of a supercharged or turbocharged engine, where the exhaust gases can be partly recycled to produce additional power before being sent out into the world. The order for the engine to work can be remembered as 'Intake, Compression, Combustion, Exhaust'. For every time that this happens, some power is produced to move the drive shaft around. The more power that is produced, the faster the drive shaft goes, and the more the propeller will spin. This spinning motion of the propeller is what determines the forces being generated on the aircraft. This is a very important concept, and as we progress through the lessons, you will learn more about the process and how it is controlled. As a bit of a side note, our engine here is a six litre 180 degree V4.

You may notice that propeller has a very specific shape, and that different aircraft have a different number of blades on them. Some, like this one, have three blades. Others have two, and some have four or more. This is to do with the requirements of the aircraft and the engine. The more blades you have, the more of these forces you can generate. The force being generated that we are most interested in is called thrust. More on that later. The downside of course to more blades is the expense and the mass of them. The more massive a propeller, the more weight it will have. In addition to that, two blade propellers tend to be somewhat more efficient that any others, so there is a fuel cost to take into account as well.

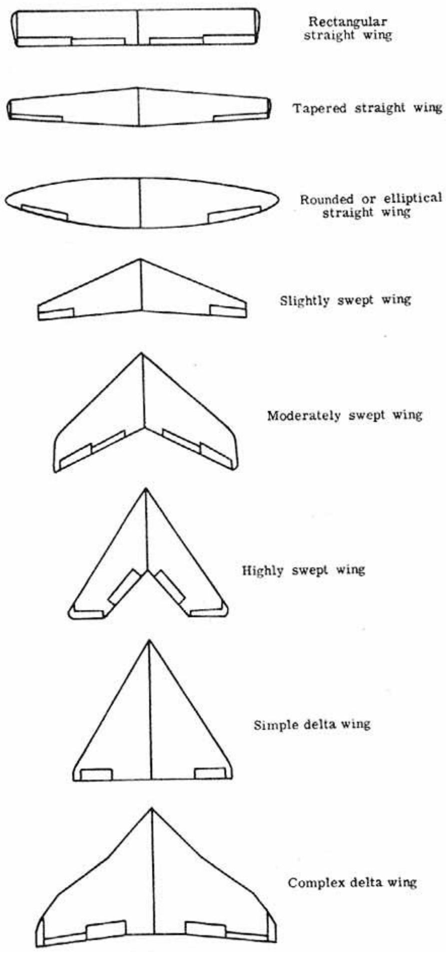
So now we have a basic understanding of our engine, it is time to look more closely at the shape of the propellers. But to do so, it is vital that we understand another part of our aircraft first - the wing.

1.1.3 - WINGS

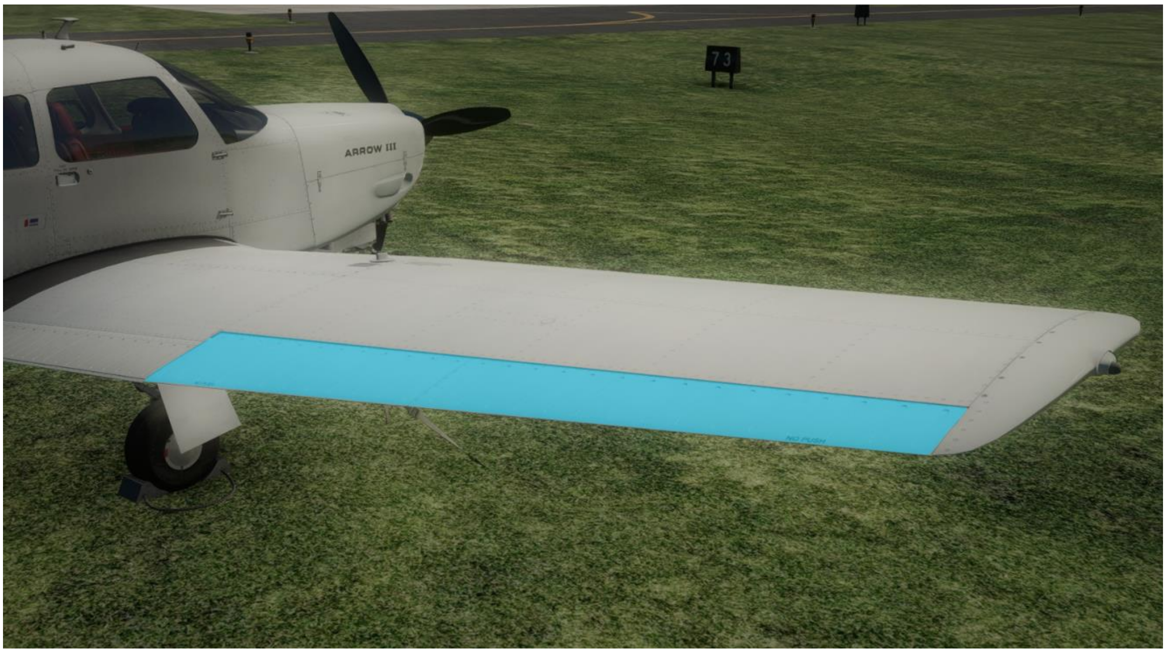
This is of course the part of the aircraft that everybody knows the use of. A wing is what allows an aircraft to fly. Right? Well, whilst that is true, there is more to a wing than just that. For example, if you place a wing on an F1 car, it sticks to the ground instead. Of course, if you turned the wing around, the car would lift into the air. See where I am getting at? The *shape* of the wing is what gives it the properties that it has. This is why you will see so many different aircraft wing designs, from the elliptical wings of a Spitfire, to the tapered wings of our aircraft, to the swept back wings of a jumbo jet, and the famous delta wing of Concorde that gave it the distinctive shape. Often, these types are combined together to give a final wing shape. In addition to that, there is a shape to be considered from the side of the aircraft too. We call this an aerofoil. This shape is what gives the wing the primary lift characteristics. An aerofoil can take many shapes, but as an example, this is the aerofoil shape of the wing on a Piper PA-28:



The red line you see is the border of the aerofoil, the part that is above is called the upper surface, and the part below is called the lower surface. If you look at the aircraft wing side on, that is what you will see. The olive-green line is what we call the mean camber line. This is the line that fits halfway along the aerofoil at all times - the distance above and below that line to the edge of the aerofoil is identical. The line that is along the X-axis is called the chord. This line represents the length of the aerofoil, from the front to the back. The front point of the aerofoil is called the leading edge, whilst the rear is called the trailing edge. There are also parts not on the diagram that mark the maximum thickness of the aerofoil, i.e. the maximum height between the upper and lower surface, and the maximum camber, which is the largest distance between the chord line and the mean camber line. By changing these different properties, you can change the entire way a wing works, and what it can be used for. In fact, these aerofoil shapes are found on anything that needs to generate some force by movement of a liquid or gas. So a bird wing will have an aerofoil shape. Flippers on sea creatures will also have the same, as will turbines on a jet engine, or blades on a propeller. Depending on the use, the aerofoil could be symmetrical (the upper and lower surface are mirrored around the chord line and the chord line is the mean camber line), asymmetrical, like the one above, as well as fat or thin, with high or low camber. Over the span of a wing (from one side to the other), the aerofoil shape could also be twisted a bit, such as what you see on a propeller. This is to aid the characteristics of the propeller taking into account the way the wind will interact with the blades.



Looking at the wing from above, the part of the wing that is connected to the fuselage is known as a wing root. Think of it like a plant. The root is what keeps the plant in contact with the ground and in place, and the root here is what keeps the wing in place on an aircraft. On the opposite side, we have the wingtip. These can be complicated little things, but thankfully for us this aircraft has a nice simple wingtip. It is not unusual for the wing tip and wing root to have different aerofoil shapes. So you may notice that if you were to cut away a section of the wing root, the shape will not match what you see on the wing tip. This is intentional and will be explained a little later on in this tutorial. When looking at a wing from the top, we call it a plan form. The distance from one side to the other across the wing is called the wingspan. Different aircraft have different plan forms, and I will show you some here, courtesy of NASA.



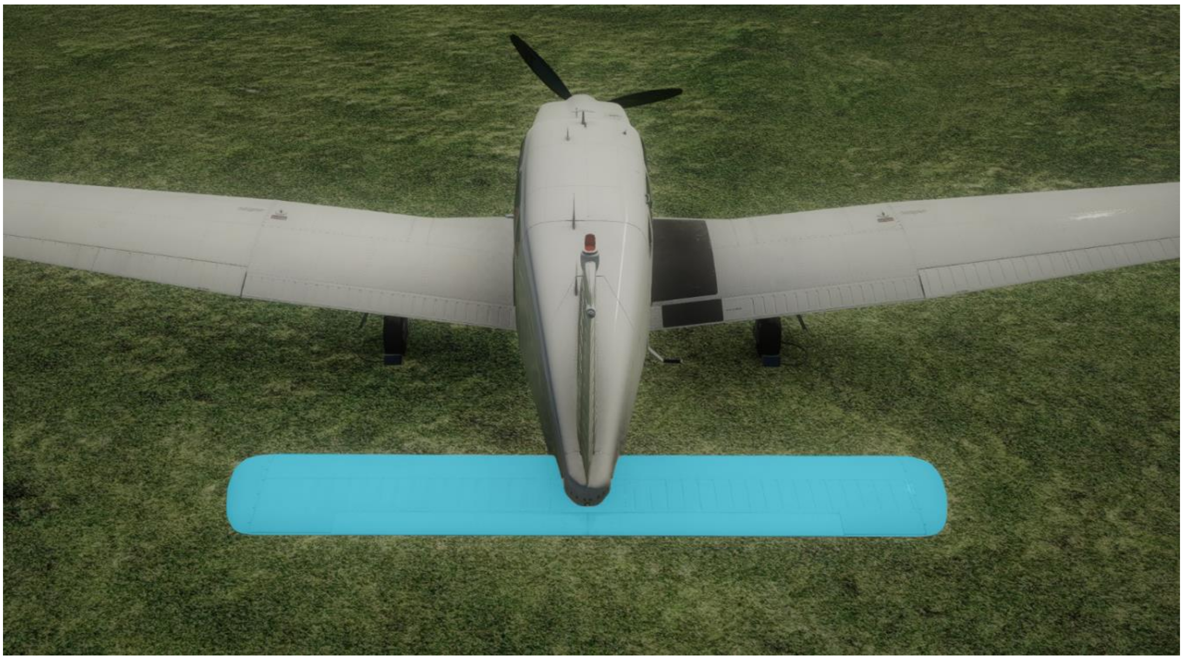
Taking a closer look at the wings, the back of a wing will contain some moving parts. We call all of the moving parts on a wing, tail and fin 'control surfaces'. The control surfaces on a wing like this are called 'ailerons'. An aileron is what is responsible for rolling an aircraft, allowing it to turn. We call the roll a 'bank'. When we move our controls inside the aircraft, it will cause ailerons on one side to lift up, and the other side to drop down. This will cause the 'up' wing to push downwards and the 'down' wing to push up, rolling the aircraft in a direction. This action in turn will cause a force to the side, which allows the aircraft to turn. You can try this with a paper aeroplane. make two cuts on each wing to create a little flap, and then tilt one of them upwards. You will notice that it will cause the aircraft to turn. Interestingly enough, what you have created is actually called an 'elevon' (elevator and aileron), but that is something that is covered when it comes to delta wings. Also, I called it a flap. In aviation, a flap is something different, but it is on the wing.

Flaps are important parts of a wing that can be deployed when the aircraft is taking off or landing, or travelling at a very slow speed. In simple terms, they change the aerofoil shape of the wing overall, by moving and lowering an entire section of wing. This makes the wing generate more lift at a slow speed, allowing the aircraft to fly. Without flaps, some aeroplanes would have to land at over 200mph, meaning they would need even more runway space to stop than they already do. However, flaps also have a downside that will be covered more in section 1.2.1, which means that wings cannot be designed to have a shape like they do with flaps deployed all the time. Knowing when to use flaps, and what they are going to do, will allow you to plan ahead and ensure your takeoffs and landings are smooth and controlled.

Some aircraft also have additional parts on their wings, such as winglets, stabilisers, leading edge flaps (flaps on the front of the wing), and slats. We will discuss these as we come across them.

Lastly, in aviation there is a mix of using everyday terms such as left and right, and nautical terms such as port and starboard. Over this course, I will be using these terms interchangeably. Port is left and starboard is right.

1.1.4 - TAIL PLANE



Moving rearwards from the wing, and we come across what looks like a small wing at the back of the aeroplane. This is called the tail plane, or horizontal stabiliser. It is a far simpler device than a wing, but it has an extremely important function. As the name suggests, this is responsible for keeping the aircraft stable horizontally. This helps the aircraft when it comes to deal with the changes in the speed and pressure of air, which will cause the nose of the aircraft to lift or drop, and then want to continue to do so. The tail plane will work to counteract those. So, if a gust of wing causes the wings to lift the aircraft, the aircraft will naturally want to continue lifting. The tail plane will try to bring the nose back down and level the aircraft off, balancing out the forces. Not all aircraft need this, however. Some aircraft, depending on their wing type, will have the stabilisers built into the wing itself. Your paper aeroplane for example does not have one, but flies. As with the wing, the plan form of this tail plane will have a specific shape - in this case a rectangular straight section with elliptical tips - and the side form will have an aerofoil shape too.

A tail plane will also contain another control surface, called the elevator. From what has been said above, and the name, I am sure it is easy to guess that the elevator is responsible for bringing the aircraft nose up or down. We call this pointing of the nose up or down 'pitch'. If we lift the elevator, the back of the aircraft will be pushed downwards, and the nose of the aircraft will raise - we call this pitching up. If we lower the elevator, the opposite will happen, and that is called pitching down.

On some aircraft, the entire tail plane will move, acting as both the stabiliser and elevator. On others, only part of it will move.

Tail planes can be either connected to the fuselage, or to the fin - in the middle, or at the top (called a T-Tail).

1.1.5 - FIN

Like the tail plane, the fin places a vital role in keeping an aircraft stable. In fact, you can think of it as a tail plane placed on its side. Instead of providing horizontal stability, the fin is responsible for vertical stability. The fin is also called the vertical stabiliser, and its job is to make sure that the aircraft does not rotate more than it should, or on its own. If it does, it will result in the aircraft spinning out - naturally a very bad thing. to help it do this, a fin contains a control surface called a rudder. Like the elevator, this can move in either direction, and causes movement at the back of the aircraft. If you move the rudder to have it stick out to the right, the back of the aircraft will move to the right. If you move it to the left, the back of the aircraft will move to the left. We call this movement yaw. A pilot has to be careful with yaw, as if they do not keep an eye on the yaw of the aircraft, and use the rudder to stabilise it, the aircraft can spin out of control. Almost all aircraft have fins, except for flying wing aircraft, such as the B2 Stealth Bomber. This is because of the way the wing is designed - the elevons can act as rudders.

1.1.6 - LANDING GEAR

The last of the basic components we will be covering will be the landing gear. Depending on the aircraft, the size of the gear, the type of gear and the positioning of the gear will be different. For light aircraft, the most common type is a tricycle style fixed landing gear. This is a single wheel towards the front, close to or on the nose, and two wheels further back, usually on the wings, or fuselage at the position of the wings. A fixed landing gear will stay in position at all times. Our Piper Arrow III has a retractable landing gear - this means that it will fold back into the body of the aircraft to give the aircraft better performance. We will cover this in section 1.2.2.

1.2 - UNDERSTANDING LIFT AND DRAG

Now that you are aware of the basic components of an aeroplane, it is time to dive into some concepts and theories of how they work. We already know that we have a requirement for an engine to give us the thrust required, and we need wings to lift our aircraft into the sky, but how do they work? Why is it that aeroplanes need to be at specific speeds to be able to take off? Why is it that some aeroplanes just cannot fly at certain heights, or beyond certain speeds? All of that will be briefly covered in this section. I say briefly because if I could, I would go on for hours about these topics.

1.2.1 - LIFT AND WEIGHT

When we talk about lifting something up, what we are actually saying is that we are applying a force that is able to counteract the weight of the object we are lifting. When it comes to engineering and aviation, the distinction between mass and weight is extremely important. What we refer to as the 'weight' of an object is actually the mass of an object, as we have defined it on earth. So, if a bag of sugar had a mass of 1kg, we would see 1kg on Earth as the 'weight'. However, the actual weight of this bag of sugar is the mass multiplied by the acceleration due to gravity, which is 9.81 metres per second squared. So, 1kg of sugar has a weight (on Earth) of 9.81 Newtons. You will notice that Newton, along with other physicists and mathematicians will be popping up a lot in these tutorials. Now, why do I say on Earth? Simply because, if you were to put that same 1kg bag of sugar on the scales on the moon, the scales would read 200g or thereabouts. This is because the acceleration due to gravity is around 1/5 of the gravity on Earth. So, the weight of the sugar is divided by five to give roughly 1.96 Newtons. Because of this, the scale, which is calibrated for the Earth, shows an incorrect mass. Why is this important in aviation? Well, a force is measured in Newtons as the standard metric unit. We can also use other units, but to keep it simple, I will try to stick to one unit as much as possible. That means, we need to know what the weight of our aircraft is to be able to overcome it with the lift. If an aircraft had a mass of 2 tonnes* (2000 kg), it would have a weight of 19620N. This is the figure that we need to surpass to be able to lift our aeroplane off the ground.[1]

Without going into too much detail, the ways in which we can generate this lift are governed by the equation of lift:

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

Looks like a somewhat complicated formula, but it is really easy once broken down. L is the lift, rho (ρ) is the density of air (how much air there is in a fixed area), V is the velocity (speed) of the aeroplane, S is the area (because A was taken), and C_l is the coefficient of lift. This is determined by the shape of the aerofoil, which we touched upon earlier on.

Hopefully, looking at that equation has started giving you ideas as to why aircraft are not only designed how they are, but require speed to be able to fly. Velocity forms an integral part of generating lift. Without it, there is no lift. In addition, density is a key factor in lift. The denser the air, the more lift that can be generated. Of course, the equation also references the size of a wing. The larger a wing, or lifting surface, the more lift can be generated. So why not just have massive wings? Well, the problem with larger wings is that the bigger you make them, the more the weigh. So, at some point you are just making matters worse for yourself.

[1] *Do not confuse tonne with ton. A ton (UK - Long Ton) is 1016.047kg (2240 lbs), whilst a ton (US - Short Ton) is 906kg (2000 lbs)*

In addition to that, you have to take into account what will happen to that wing in flight. How do you keep a massive wing connected to an aeroplane at high speed?

The last part of the equation, the lift coefficient, is a little bit more complicated. Thankfully, however, we do not have to worry about that, as aerofoils come tested with graphs showing lift coefficients at different angles of attack - this is the angle at which the wing is compared to the air. I will not go too deep into this, as it can get very complicated very quickly. As a reference, our aircraft has a coefficient of lift at 10 degrees on the wing of around 1.04, without flaps. Normally a wing is already pitched upwards slightly a few degrees, to help an aeroplane take off without having to pitch up the nose massively. So, if we assume that the aircraft has a 2.5 degree pitch on the wing already, we need to pitch our nose up 7.5 degrees more to get out 10 degrees on the wing.

The wing area of our aircraft is 14.2 metres squared. Let's assume we want to take off and it has a mass of 1000kg. That means the weight is 9810N. For our density, we will use a standard figure, which is called 'standard atmospheric pressure' - this is important. That figure is 1.225 kg/m^3. From this, we can work out what speed (in metres per second) we need our aircraft to be at to take off. Let's look for 10000N of lift.

Rearranging the formula leaves us with:

$$V = \sqrt{\frac{2L}{\rho S C_l}}$$

Throw in the numbers, and we have a speed of approximately 36.5m/s. Converting that to knots (which is the unit of speed for an aircraft, a nautical mile), we have a takeoff speed of 71kts. Believe it or not, that is actually almost exactly what one of the best speeds are in the aircraft operating book!

With that, you now have a basic understanding of how lift works. Now we need to consider just how to get to that speed to take off!

1.2.2 - THURST AND DRAG

Thrust is the useful component that we need to generate from an engine to get us moving. There are many complicated equations that govern the thrust generated by a propeller, or jet turbine, but those will be beyond the scope of this lesson, and for the most part this entire series. Just to quickly go over it, the thrust force produced by a propeller depends on a whole bunch of factors, including the pitch of the propeller (more on this in another lesson), the size of the propeller, the rotation speed of the propeller, the speed of the aircraft and more. The equations in and of themselves are fairly large, and you need to be fairly confident in mathematics and conversion factors to be able to apply them correctly.

What we will look at however, is how thrust and drag are related. Imagine an aircraft sitting on a runway, with no wind at all around it. If we were to place a force on it to move it forward, we would expect some force in the opposite direction. We call this force, drag.

Depending on the situation, drag is either a help or a hindrance. On takeoff, it is certainly a hindrance! The equation for drag is as follows:

$$D = \frac{1}{2}\rho V^2 S C_d$$

Most of this looks the same as the lift equation, except that we now have D for drag force and Cd for the coefficient of drag. What is clear though, is that as the speed increases, the drag increases. This is one of the key factors that prevents an aircraft of passing certain speeds, along with the construction of the aircraft, and not wanting it to fly apart. Taking a simplified example, let's assume this aircraft can produce 3000N of thrust from the propeller. Let's take the drag coefficient to be 0.1, which is fairly reasonable for this situation.

Let me explain where this number has come from. The coefficient of drag is actually two components added together. We have the friction of the aircraft skin (the bodywork) taken from the area that is being hit by the wind. So, in a straight line this would be the front of the aircraft. For an aircraft like this, we are probably looking at 0.07 or 0.08 as that coefficient. The other coefficient comes about from the following formula:

$$C_{di} = \frac{{C_l}^2}{\pi \, AR \, e}$$

AR is the Aspect Ratio of the wing - this is the wingspan squared divided by the wing area. The other values are pi, which for this equation I will approximate to 3.14, and e - which is eccentricity of the wing. For our aircraft, this is around 0.8. For an elliptical wing (as seen in the wing section), this would be 1.0, which would be theoretically the perfect wing for drag efficiency. This is why the shape of a propeller blade is elliptical, and not straight. Calculating this drag, which we call 'induced drag', gives us a value of around 0.02. Add the two together, and our total drag is approximated to be 0.1.

The area, S, this time will be taken from the front of the aircraft, not the top. We will approximate 8 metres squared for this. Rho shall once again be 1.225 kg/m^3. To have the aircraft no longer able to accelerate, the drag, D must equal the thrust, T. So D is going to be 3000N.

Rearranging the main drag equation once again, we have:

$$V = \sqrt{\frac{2D}{\rho S C_d}}$$

Throw in the numbers, and we have a speed of 86 m/s. Converting that to knots, and we have approximately 167 kts, which is the fastest the aircraft will be able to go at maximum thrust. The only way it will be able to go faster will be to use gravity to provide an additional force by tilting the nose down. This is why when you pitch the aircraft nose down, you need to reduce the thrust. We will cover this more when we look at control the altitude of aircraft.

In short, the theoretical maximum speed of an aircraft is limited by the size of the frontal area of the aircraft, the thrust that can be produced by the engine, the density of air, and the given coefficient of drag. Though massively simplified, the coefficient of drag actually is changing constantly as the aircraft is moving. This is something that I will not be going into in this lesson, but if you are curious, feel free to ask me on Discord.

With that, you have just taken your first steps into the world of aviation and engineering! Lesson two will be taking a break from the equations, and looking at the six pack of instruments inside the cockpit of our aircraft.