Aerodynamics guide and tips

This document will explain how to achieve diferent simulation styles and wings in Usim flight physics module.

Airfoils

Airfoils are bodies capable of generate lift. Lift is generated by the air passing trough the wing. The air stream hits the wing and it is splited in two. When the air passing below is slower than the air passing avobe a diferential pressure is generated pushing the wing upwards. This is called lift. Lift can change depending on the shape of the wing. Or better said, the profile of the wing.

In Usim airfoils use four data entries to comute lift. Wing area in ft squared, wing aspect ratio the lift coefficient in function of angle of attack and finally the efficiency factor that is how much drag proportional to lift generated.

The most important value that defines how the wing performs is the lift coefficient.

What is lift coefficient?

To understand this in a more practical way imagine the following scenario

You are in your car cruising trough the highway, stick your arm out of the window perpendicular to the car direction of travel with your hand facing down. You will notice that the air hits your hand and as said before the air stream gets splited. You can feel the air passing fast trough your hand. Our hand now is a wing. In this case a symetrical wing. That means that your hand splits the air evenly. The same amount of pressure is generated both up and down and your hand is kinda forced to stay at that position.

Now bearly rotate your hand so that the hand is angled a bit upwards. Now you will feel that theres a pressure building up on the bottom of your hand because the air is impacting more directly. You'll notice that your hand is being pushed upwards. This is because you hand is now generating lift due to the increase on the angle of attack.

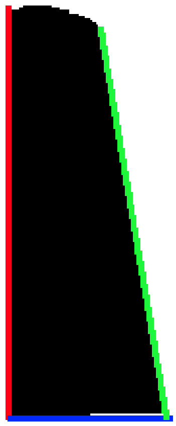
How much the upwards force increses when you rotate your hand is what we call Lift coefficient or coefficient of lift or just CL. The more angle the more lift is generated.

BUT rotate you hand a bit more and you'll notice that at some point your hand sudently lose the upward force that was holding your hand. This is called STALL. When the angle of attack is too high the air passing trough the upper part of your hand gets disturbed (blocked). The turbulent airflow produce an increase on the upper pressure of the wing making the diferential pressure to lower and making the wing loose lift capablitiy.

This is why a CL curve rises up to a certain angle and then starts to lower on higher angles of attack. How steep, how linear and how long the CL curve is, defines the performance of a wing.

We will now look at how the wing shape affects the curve and how curves looks like.

Before continue we need to know how to call the components of a wing shape.

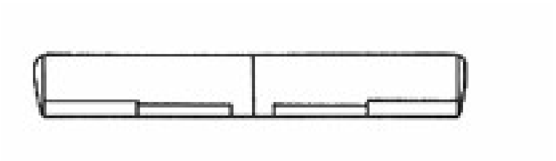


red: is the wing leading edge.

Green: is the trailing edge.

Blue: is the wing chord.

We will first take a look at the most comon wing found in most civilian small aircrafts.

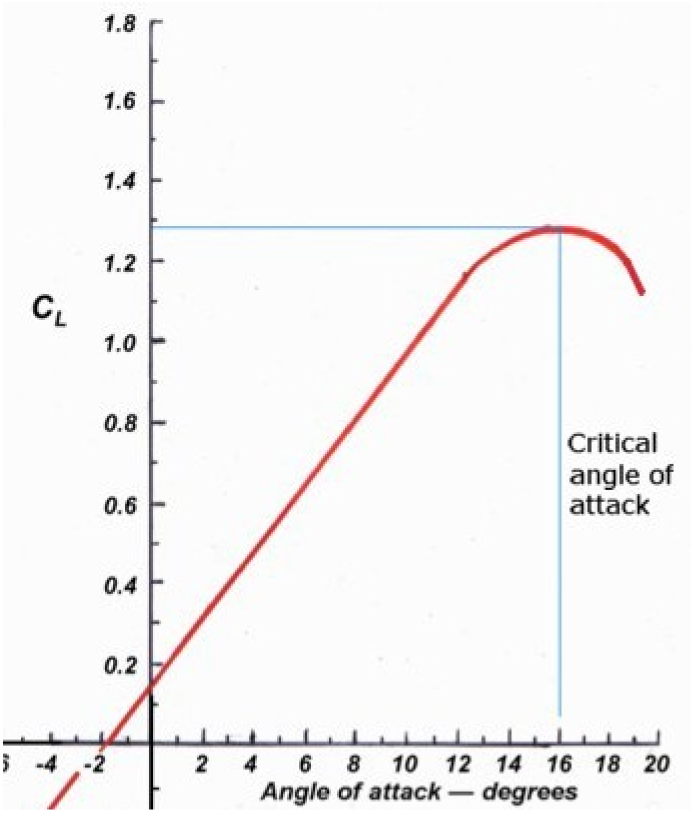


In this example the leading edge is straight angled at 90 degrees relative to the aircraft fuselage.

For straight Symetrical wings (remember our hand) the CL increase is of 0,1 per angle of attack. Meaning that at angle of attack 15 the wing produces 1.5 of CL.

But we also remember that a wing stalls at some point. The stall angle for a straight wing is defined by the curvature of the wing profile. The more curve the less the air gets diturbed. But all wings evetually stall no matter the shape. For most wings the critical angle of attack (at wich the max CL is generated) is about 15 to 20 degrees, this value varies due to the aspect ratio a low aspect ratio will have stall at a more angle attack, while high aspect ratio wing has the critical angle at a less angle of attack.

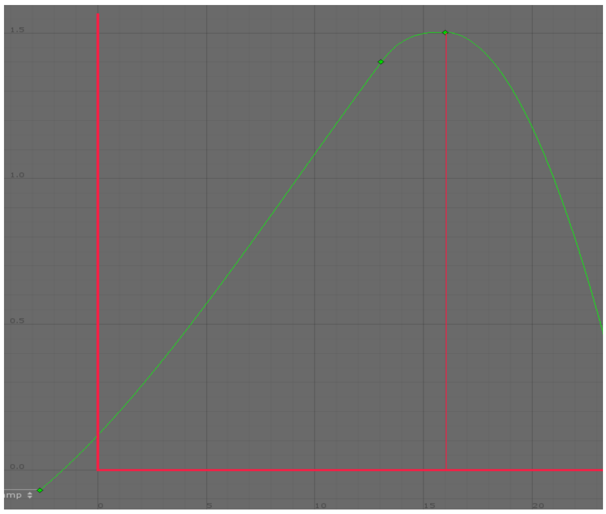
Example of straight wing CL curve.



As you can see the CL rises up to the critical angle of attack and then starts to drop fast.

If the wing was symetrical the CL at 0 angle of attack is 0. In this figure the CL at 0 angle is at about 0,15. This is because generally main wings are not symetrical since is more desirable to generate lift upwards rather than evenly. Symetrical airfoils are used mostly for auxiliarry airfoils present in the aircraft such as the horozintal stabilizator. Symetrical airfoils are also used for acrobatic aircrafts. To provide the same amount of lift when the aircraft is inverted.

This is how the CL curve looks in Usim.



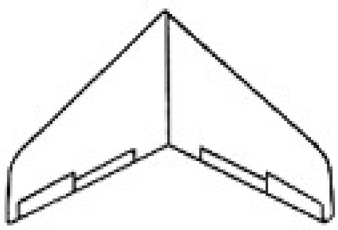
Swept wings

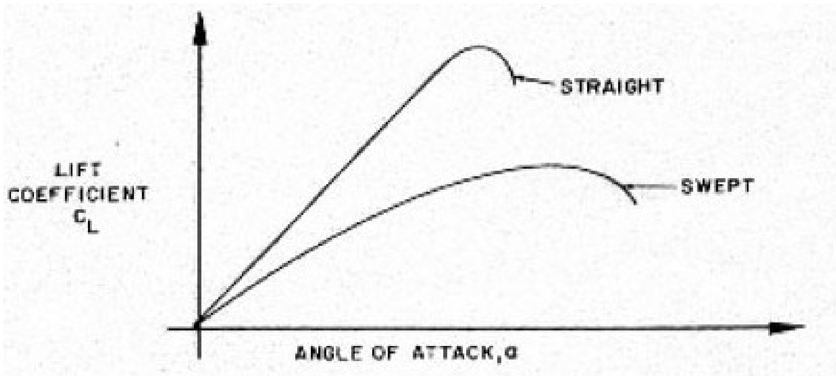
At high speeds the forces generated can be huge. So huge that it could rip the wing off in real life. During WWI fighters usualy break the main wing due to excess of speed during a dive or pulling off a dive. This is because wings were straight. And a straight wing at high speeds generate way to much lift even with a slight angle variation.

For fast flying aircraft swept wings were introduced. A swept wing is a wing wich leading edge is angled backwards like an arrow. This shape causes the CL curve to be progressive instead of linear as seen in straight wings. This allows a more smooth change in lift at high speeds. But it also meas that at low speed the wing needs more angle of attack to generate enough lift.

Swept wings are cleaner. Having a higher efficieny factor. Also the critial angle of attack (stall point) hapens at more angle that in a straight wing.

Let's see an example.





As you can see the swept wing produces less lift in proportion to the angle of attack but it streches providing a critical angle of attack at higher angles. Also notice that the curve isn't as steep as it is in straight wings. This allows the smooth lift changes at high speeds.

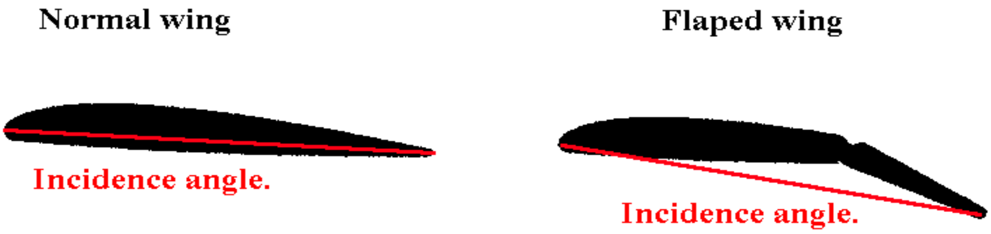
Now that we have understand the basics of lift in an airfoil we'll see what a high-lift device is and how it can affects lift generated in the airfoil.

High-lift devices

Usim simulates trailing edge high lift devices only, for now. Like Flaps.

Flaps are a moving portion of the trailing edge. It is used to change the shape of the airfoil profile by lowering the trailing edge. This slows the air passing below the wing so pressure rises and more lift is generated. How much lift can add a device depends on the airfoil more than the flap itself.

When the flap is deployed two things hapen CL is increased and wing incidence is increased. Incidence is the angle formed between the trailing edge and the leading edge. This is the direction the wing is actually pointing. Say Z local axis in Unity.



transform name	curve to use	Incidence change
flap_Aero	flap	-0.4
flap_Aero	flap	-0.4

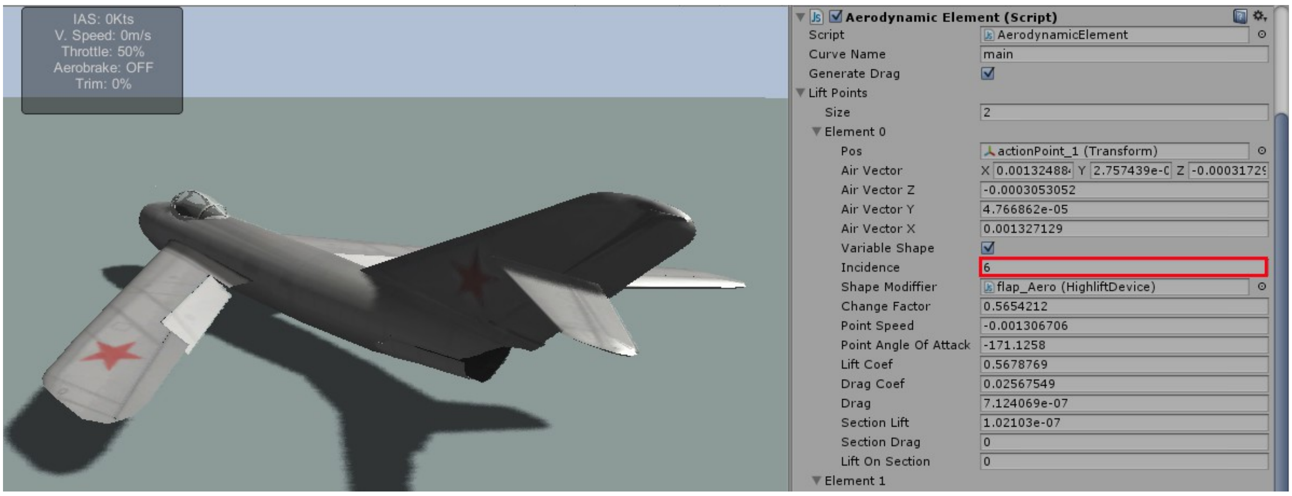
in Usim we configure the high-lift devices by asigning it a curve to use and an incidence change factor.

The curve defines how much CL is added to the wing CL in relation to angle of attack. Say that the flap fully deployed at 20 deg adds 1 unit of CL. So the curve will go from 0 at angle 0 to 1 at angle 20.

Incidence factor is a portion of the high-lift device rotation along the X axis. So for our flap at 20 degrees if we had an incidence change of 0,5 the resulting incidence will be of 10 degrees.

Ailerons and elevators can be setup in the same way. They are basically flaps that can rotate donwards and upwards but the effect is the same.

Allways check that incidence of the airfoil change as espected. To do that find your airfoil in the hierarchy and in the inspector you'll see the incidence field for the lift point. Like this.



Now we know how lift is produced, how shape affects lift and how a high-lift device can increase lift. Now we will see how to simulate and arcade style.

Arcade in Usim is an easy to fly, user frendly aircraft. It still uses the same basis as any other simulation style. But we tweek it in a way that is easy and stable to fly.

TIPS!

Use bigger wing areas. Making the wing bigger that it actually is can provide more lift even at low speeds preventing early stalls and making easier to perform landing and takeoffs. At high speeds the excess of lift due to a bigger wing provides the aircraft super manoeuvrability. To compensate if needed the CL can be smaller.

Make airfoils symetric. Having 0 CL at 0 angle of attack helps preventing the undesired pitch change with the increase of speed. Also makes the aircraft fly the same way inverted. This is usefull for aerobatics.

Add lot of damping. Adding damping using the aids/arcade settings in the main configuration tab helps to control the aircraft and hold it in the desired flight attitude after it was changed.

Set inertia tensors to 1. Inertia is not good if we want to have a simple simulation.

Less wheight. Depends on the aircraft it can help to achieve easier take-offs and landings.

Use aids/arcade forces to simulate controls. Instead of setting up high-lift devices you can use only aileron force and elevator force found in the main tab of the vehicle editor window.

The framework is very flexible. You can simulate it simple or realistic or a mix in between.

Remember that even for arcade styles the basic principles of flight are present. So if you are using it for a game i recomend introducing your gamer a bit about flying.

IMPORTANT:

Auto-trim. As said before if we have positive incidence in the main wing the aircraft will pitch up when speed starts to increase. Trim is used to mantain the aircraft in the desired pitch angle with out having to constantly correct with the elevator. In Usim the trim is just a constant elevator input. Is strongly recomended that users know about the trim and how it works. In real life aircraft are flown with trim NOT elevator. The elevator is used to perform manouvers like trurn, takeoff and final flare of the landing. After the manouver is done the flight is controled with bot trim and throttle.

The auto-trim feature let's you describe a curve in function of speed that will set the trim automatically. So a pilot don't have to worry about adjusting the trim. It can be hard to setup but this feature will be automatic in future versions.

Testing against real life data

There are some flight performance values found in internet for a specific aircraft that can help set up the flight dynamics to match the real aircraft.

Cruise speed. An aircraft is generally design in a way that at cruise speed there's the less drag possible to save on fuel. To achieve this the aircraft is trimed to be leveled at cruise speed.

Knowing this we can do the following test to see how much CL is needed for cruise flight and adjust the curve.

Set you aircraft to start at cuise speed in the air. To do this place your aircraft in the air and adjust the “speed” variable in the plane control script. When you press play the aircraft will start at the speed you specified.

With the auto-trim off and trim at 0, adjust throttle to stay at cruise speed. If the nose of the aircraft falls you need to shift the CL curve higher. If the nose pitches up then your wing CL is too high at 0 angle of attack.

Stall speed (power off). Remember that at high angles of attack stall may occur. If you reduce power while flying straight you will have to adjust pitch to maintain altitude. The angle keeps increasing until the aircraft is unable to mantain altitude and the nose drops. This is how stall manifests. At wich speed this occurs is what is called stall speed.

If your aircraft stalls at a higher speed than the desired stall speed then it means that the max CL value should be bigger or at a bigger angle of attack. This depends on the shape of the wing. If you have a straight wing and your max CL is say 1.5 at angle 18 and the stall speed is heigher than it should it means that the CL should be a bit higher than 1.5. Having the critical angle at a biger angle in this case is incorrect since we learned that only swept wings have high critical angle. Other reason could be incorrect wing area. Remember that aileron and flaps are also considered part of the wing.

Take-off speed. Once we have the previusly data set we can deduce how effective flaps are.

Take off speed usually is considered with the aircraft configured for take off. This is flaps deployed (a few degrees) and trim set.

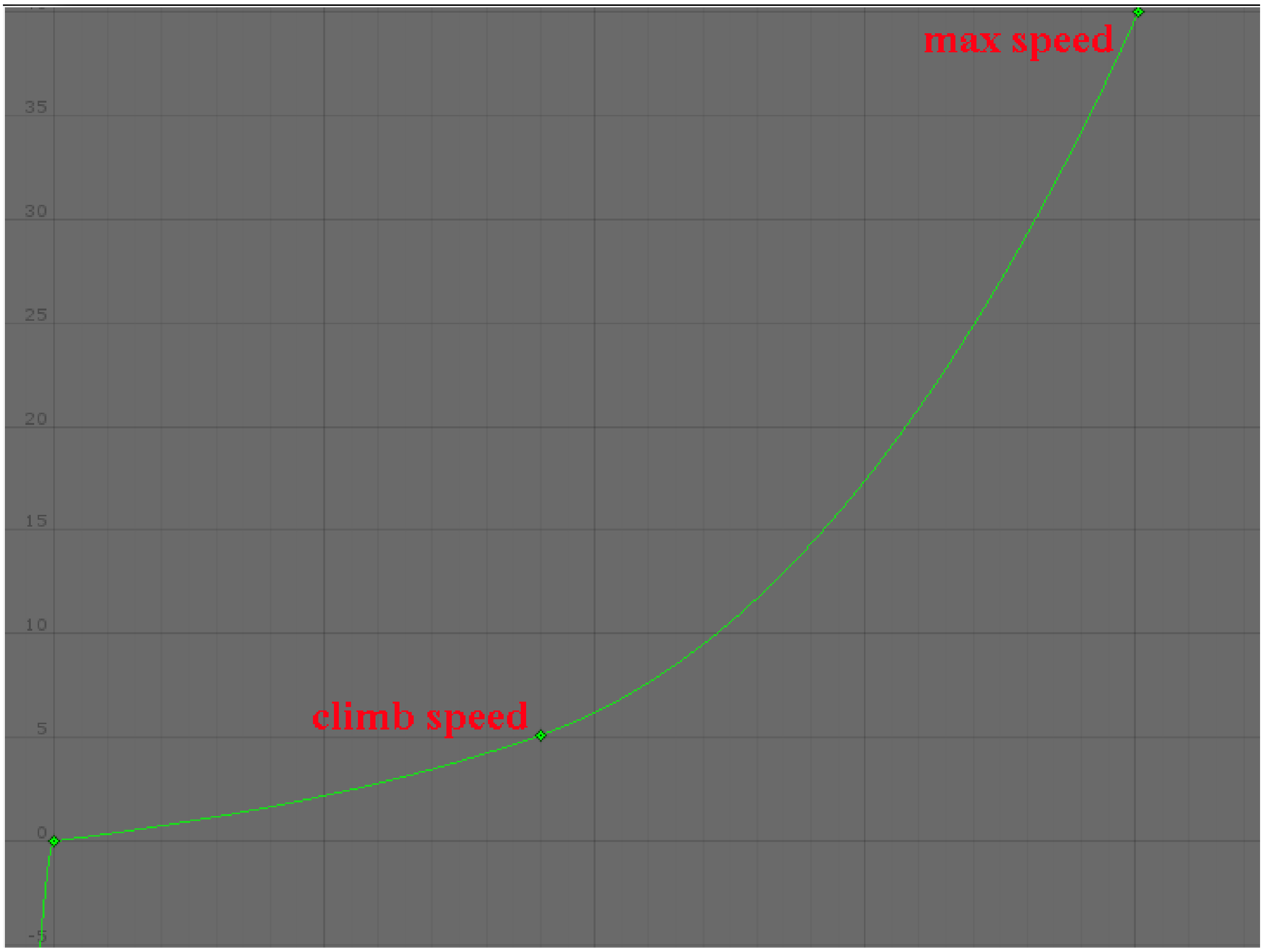
While rolling down the runway as speed increase when we are reaching the stall speed we should start having elevator control. The nose (or tail) should be able to rise even if the aircraft wount produce enough lift to take off. If you don't then you might be lacking lift generation at the horizontal stabilizator (the airfoil the elevator affects). If you have pich control keep nose up until the aircraft starts climbing. If the take-off speed was too high then you lack flap efficiency.

Seting the drag-power ratio right

Climb rate at climb speed. Mantaining climb speed we should have enough power to have a steady climb at some rate (vertical speed). If our vertical speed is higher we have too much power or less drag than it should. Two things can be adjusted to match climb rate. Wing efficiency factor or parasit drag.

Usim strongly recomend using engine power values found in internet in HP and adjust parasit drag of the aircraft to match the power to drag ratio. Once you have that ratio right the climb rate should be the one desired.

Max leveled speed. You can adjust parasit drag to match the aircraft max speed. And having the climb rate right we can guess how the drag curve looks like.



With this data that we can easily find in internet and knowing how to test it, Usim can help you model an aircraft fairly matching real life specifications.

Trial and error is part of the procces but is also fun.

For any questions

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