The Takeoff demystified (Tim Brill ATP/CFI)

When the lift created by your airplane's wings exceeds its weight, your airplane will takeoff and climb. Conversely, when the weight exceeds the lift, your airplane will descend and eventually land. Pretty basic!

This is a two part article. Part 1 discusses the takeoff. Part 2 discusses the landing.

A Reminder about Airplane Energy

Remember, your airplane needs a minimum amount of energy, call it airspeed, to generate the lift necessary to fly. If you have too much airspeed, you may begin to pull parts off your airplane because you have exceeded its structural limits. This is why your maneuvering speed is so important. Your airplane's "pressure relief valve" is its ability to stall. Anyway, this defines your airplane's flight envelope, (minimum energy to fly and maximum energy that doesn't exceed the structural strength of the airplane) and as long as you stay within the flight envelope everything the airplane does it was designed to do, including stall and spin! Your only real "job" as pilot in command is to stay within your airplane's flight envelope.

The Angle of Attack

Lets first review the Bernoulli Principle, named after the Swiss Daniel Bernoulli. He realised that a shaped object moving through a fluid, be it water or air, exhibits certain predictable results. Let's look at an airplane wing. The "front" edge is called the leading edge. The "back" edge is called the trailing edge. A line drawn from the leading edge to the trailing edge is called the chord line. A line drawn perpendicular from the chord line to the upper and lower surface of the wing is the camber. An airplane wing has a greater camber on the top side of the wing than the bottom side of the wing. Meaning the wing has more of a curve on the top than the bottom. All airplane wings are designed basically the same. They are more technically known as an airfoil. So according to Bernoulli, as this airfoil moves through the fluid called air, the air is forced to travel around our wing. Because of the greater camber, or curve, on the upper section of the wing, the air has a farther distance to travel over the top of the wing, then it does under the bottom of the wing. Here is where Bernoulli's genius comes into play. As a result of the greater distance traveled, the air flows faster over the top of our wing and as a consequence the top of the wing creates a slightly lower pressure area than does the bottom of the wing, creating a lifting force towards the lower pressure area. This and a bit of Sir Isaac Newton's Second Law of Motion, "for every action there is an equal and opposite reaction," and you have the ingredients for flight. Well, there are a few more important considerations to create an airplane, but you do have an airfoil.

Now, as our intrepid airfoil moves forward through the fluid of air, it creates in the air a relative wind that is equal in velocity but opposite in direction of the movement of the wing. It also creates drag as a by-product of generating lift. Remember Isaac Newton? Pilot's know this as induced drag, which among other things reduces our wings efficiency. If we were to draw the chord line of our wing, and draw a line that represents the relative wind, that angle formed by those two lines is called the angle of attack of the wing. As the angle of attack increases, initially so does both lift and drag, lift increasing faster than drag. At a point these trends switch and now the wing generates drag (induced drag) faster than lift. This point is called the critical angle of attack. Exceeding the critical angle of attack will result in the wing to “stall,” meaning it naturally wants to go to a lower angle of attack and resume “normal” flight.

As a pilot you have control over the angle of attack with your elevator. The elevator, of course, moves the nose of the airplane from the pilot's head to the pilot's foot. (Not to be confused with the ailerons that move the nose of the airplane from the pilots head to the pilots hip, or the rudder that moves the nose of the airplane from the pilots ear to ear. All 3 of our airplanes' control surfaces intersect at the center of gravity of the airplane).

The Lift Formula (My thanks to NASA)

An aircraft's lift capabilities can be measured from the following formula:

$L = (1/2)\ d\ v^2\ s\ CL$

- L = Lift, which must equal the airplane's weight in pounds
- d = density of the air. This will change due to altitude. These values can be found in a I.C.A.O. Standard Atmosphere Table.
- v = velocity of an aircraft expressed in feet per second
- s = the wing area of an aircraft in square feet
- CL = Coefficient of lift , which is determined by the type of airfoil and angle of attack.

So, let's say your airplane weighs 1800 lbs. How much total lift do you need to lift an 1800 lb airplane into the air, a bit more than 1800 pounds. If we assume the air density is constant, the area of your wing is constant and you cannot exceed the critical angle of attack, really the only variable you have left is velocity. If we maintain a constant angle of attack, at a certain airspeed you will takeoff. Simple.

OK, How Do We Control the Takeoff?

Our first step in any takeoff process is to ensure we have an adequate runway surface. Is it long enough, is it wide enough, what about the wind? What is my abort point? What is my plan if I have an engine failure after takeoff?

A word on an aborted takeoff. I would recommend that if you do not have at least 70% of your necessary takeoff speed 50% down your runway, abort. You will most likely run out of runway! Also, if your engine sputters or quits, immediately lower your nose and land straight ahead. Even if you run into things, it is more survivable than attempting a low level turn back to the runway and ultimately landing like a lawn dart.

Finally, a word on the runway “center line.” Good technique and airplane handling will have you on the runway centerline. But perhaps even more important is to go in a straight line (especially in a tailwheel airplane). Sometimes in a strong Cross wind I will go in a straight, but slight diagonal across the runway, takeoff roll to cut down a bit on the effect of the crosswind. I use the same technique on landings as well. Of course, on floats, skis and tundra tires, you can takeoff by accelerating in a slight “turn.”

Forces during a takeoff roll - the Torque Roll

We are on our runway and ready to go, so what happens now?

As you add power you generate a “torque roll” effect. In other words, as the engine crankshaft, and your propeller, rotates clockwise, the airplane counter rotates slightly counter clockwise. In doing so it adds a bit more pressure on your left main tire, which means it adds a bit of drag. Ever notice why your left main tire wears out more quickly than your right main tire. This is your torque roll. In a tricycle gear airplane, this torque roll effect is typically not powerful enough to drag the nosewheel across the runway surface. But in a tailwheel airplane, add power and the nose moves to the left. The “slower” you add the power, the less noticeable is the torque roll effect, but then do you still have enough runway for your takeoff? Always a trade off.

Forces during a takeoff roll - gyroscopic precession

Gyroscopic precession occurs when you make a pitch or yaw control input. Basically the gyroscopic precession force is (1) in the same direction as the force is applied and (2) 90 degrees off set. Ok, let's think about this a bit. Let's say you are in a Super Decathlon with its control stick (A control yolk does exactly the same). You can push the stick forward, or pull it back (elevator). Now, let's imagine you also have your propeller oriented vertically, just like your "stick." Now imagine you grab the very top tip of your propeller. You can push forward, or pull back, "In the direction as the force is applied." Now don't forget gyroscopic precession is also 90 degrees off set. So now we rotate our prop clockwise 90 degrees to see the effect of the gyroscopic precession. When we "push" on the elevator, gyroscopic precession moves, or yaws, the nose of the airplane to the left. Conversely, when we pull on the stick, the nose yaws to the right.

Again not as noticable in a tricycle gear airplane, but very noticeable in a tailwheel airplane. Try to "lift" your tailwheel with an abrupt forward elevator pressure, and your airplane will yaw left. Do this in conjunction with the torque roll effect, and your airplane will really yaw to the left!

A few points here to consider. First, the torque roll and gyroscopic precession forces do happen. You can "minimize" them by making the inputs that cause those forces "slower" and "softer." Seperate the inputs if you are able. Slowly add power, then softly nudge the stick forward.

Also, since making a pitch input causes a secondary gyroscopic precession yaw effect, making a yaw input causes a secondary gyroscopic precession pitch effect. Left rudder and the nose pitches towards the pilot's head. Right rudder and the nose pitches towards the pilot's feet. For you aerobatic pilots, how many times have you ended up "on your back" in the pivot of a hammerhead turn because you ignored the gyroscopic precession pitch effect when you "kicked '' left rudder?

Rotation and the left turning tendencies

We have managed to control the torque roll and gyroscopic precession effects and are now at takeoff speed. So a bit of elevator back pressure and we are flying, maintaining our recommended airspeed of Vy or Vx.

But notice what happens now. Propeller slipstream, P Factor and torque all combine into the "left turning tendencies" of your aircraft. Even the tricycle gear airplane will notice this effect. Solution, add right rudder pressure and keep that "ball" centered. The "steeper" your climb, the more noticable the left turning tendencies effects.

You can see there is a lot actually happening during a takeoff, all of which are predictable and manageable. The solution, don't be afraid to use your rudder to go straight.

Special Takeoffs - Soft Field

Our discussion so far is pretty much the typical “normal” takeoff process. So now let's look at some differences in soft field, short field and cross wind takeoff procedures.

Earlier In this discussion, I mentioned the lift formula and said let's assume the air density and wing area are constant. But what would happen if they could somehow increase the air density for our takeoff? With the same angle of attack and an increase in air density we can achieve the lift required for takeoff at a slightly lower airspeed. This is the basis of your soft field takeoff technique. By holding a slight back elevator pressure you can “nudge” the airplane into the air a bit earlier than “normal.” Now you need to “lower” the nose slightly and accelerate within a wingspan of the ground. What you have done is to create a “cushion” of air under you, which has the result of increasing the air density below you. Result, you are now in the air at a lower airspeed than “normal,” allowing you to move away from your soft, rough runway surface. But, the caveat. Do not attempt to continue to climb until you attain your “normal” takeoff speed, less that cushion of air disappears and you smack down on the ground because you now do not have enough lift to stay in the air. On some aircraft, partial flaps may also be recommended.

Special Takeoffs - Short Field (Confined Space)

This is your maximum performance takeoff. Assuming you do not want to accelerate in a circle (it can actually be done), First, review your runway environment, surface, slope, elevation, length, obstacles, density altitude, and what happens after you takeoff. You may takeoff on a very short runway but if then you immediately have to climb a mountain, hmmm, good luck! Also, make sure you have a well defined (marked) abort point and stick with that decision.

Next, use all the available runway. Over my years of flying I’ve heard two schools of thought. One says full breaks, full power, release the breaks and roll. The other says do a rolling takeoff, in other words, taxi onto the full runway and immediately add power. Use your taxi speed to add to your required airspeed. Be real careful if your engine fails using this technique. Alternatively, expect maximum torque roll and gyroscopic precession if you go from the full stop.   On some aircraft, partial flaps may also be recommended at lower density altitudes, so read the POH.

Either way, when you rotate at the recommended airspeed and climb at your Vx airspeed, it is a very steep climb. Then, when over your obstacle, you gently lower your nose and continue your climb out at your recommended Vy airspeed. This will also allow for better visibility and engine cooling.

Special Takeoffs - Cross Wind

The cross wind may affect your ability to maintain directional control of your airplane. Remember, directional control is basically your rudder. If you exceed your airplane's maximum, or demonstrated, crosswind component (that combination of wind speed and wind angle) you will lose directional control. So find another runway better suited to your airplane, or just wait until the wind decreases. Keep in mind the gust factor, which may momentarily place you in that realm of no control.

Otherwise, the only real difference is in the use of your ailerons to keep the wind from “lifting” the wing closest to the wind direction. At low speed, use full aileron deflection into the wind. As your ground speed increases. You can release some of the aileron deflection.

Once in the air, use the crab method to maintain the extended runway centerline on climbout.

Conclusion

Your takeoff is a process and should not be rushed. Your airplane will takeoff when it’s ready to do so, and not before. Don’t be in a rush. Be aware of the forces acting on your airplane and “separate” when practicable. Remember, the airplane will only do what you tell it to do, it's not magic! Plan your flight and then fly your plan.

Resources

https://www.grc.nasa.gov/www/k-12/WindTunnel/Activities/lift_formula.html

https://www.grc.nasa.gov/www/k-12/airplane/lifteq.html#:~:text=The%20lift%20equation%20states%20that,times%20the%20wing%20area%20A.&text=For%20given%20air%20conditions%2C%20shape,Cl%20to%20determine%20the%20lift.

https://www.flyingmag.com/minimizing-takeoff-risks/