How Aircraft Fly and are Controlled

—FORCES—

Motion for flight is reaction to applied forces. The direction of applied forces will often have reaction forces in different directions than the applied force. The forces acting on the machine then have the effect of two component-force reactions acting 90-degrees from each other.

The aerodynamic lift in level or climb flight attitudes is often slightly aft from vertical so has a large vertical component-lift and a small aft component-drag and in descent will have the large vertical component-lift with a sustaining gravity component-forward acting at the center of mass.

The aircraft travels with an angle-of-attack directing the engine thrust slightly above the forward direction of motion so acting at the engine has a large thrust component-forward and small thrust component-lift. In descent, with reduced or loss of engine thrust, gravity component-thrust maintains the sustaining thrust by descent.

The gravity force acts from the current center-of-mass directly toward the earth so in level or climb flight attitudes has a constant large gravity component-load toward the surface and a small gravity component-drag which, in descent, becomes sustaining gravity component-thrust.

Additionally there are different frictional forces from displacement and flow of the airmass by the aircraft motion causing a reactive drag force in the opposite direction of forward motion.

—BALANCE—

All forces have moments acting through their moment arms to a center-of-pressure, the effective center-of-load, point of rotation. Flight control is adjusting forces for the balance to cause desired motion.

Our example 2,000 lb, aircraft at its optimum Vy indicated-airspeed and 200 pounds of thrust will be in motion at an air-encountering angle of at least 6 degrees angle-of-attack, so will have a continuous 20 or more pounds of thrust component-lift (sine 6°= .1) acting at the engine contributing to the total lifting forces.

This engine-lift acts along the fuselage as its moment arm to the center of pressure. Engine-lift coordinated with the elevator aerodynamic loading, maintains the balance for a specific indicated-airspeed angle-of-attack.

The difference with ground and inflight balance in an aircraft is that there are additional airborne forces acting at their different fixed positions. On the ground, the only lifting forces are the landing gear and the only loading is gravity at the center of mass.

When airborne, engine lifting at the attachment of the engine, and the elevator and horizontal stabilizer aerodynamic loading are acting at their structural placement on the empennage. The center of mass (gravity) always acts at its current location.

Change of any one balance-control force in these locations causes a change of the fulcrum position, the center-of-pressure near the aerodynamic center of lift, moving slightly forward or aft as an effective center of gravity. Acting at their attachments, elevator aerodynamic lift/load forces combined and with engine thrust component-lift set the balance for a specific indicated-airspeed angle-of-attack.

The basis of static loading is the designed aerodynamic load/lift limits of the stabilizer and elevator controls to maintain required balance. Loading is critical and not maintaining the loading limits could lead to loss of aircraft control. Manufacturer published tables and charts enable loading an aircraft within its design balance limits.

—ENGINE THRUST—

A method to determine approximate engine thrust output can be by use of the sine of a six-degree angle (sine = .1). If in hands-off trimmed level flight at a 6-degree pitched longitudinal angle as the aircraft angle-of-attack, the sustaining thrust will be approximately 10 to 12 percent of the gross weight. The vertical thrust of gravity plus a small stabilizer aerodynamic loading is the load of the aircraft. The 2,000 lb. aircraft then requires the same amount of vertical lift.

Similarly, an engine out 6-degree descent will be using sustaining gravity component-thrust of one-tenth the gross weight. A 2,000-pound aircraft will require 200 pounds sustaining thrust. The 6-degree angle-of-attack level flight is close to Vx or Vy in most small aircraft.

At a 12-degree (sine = .2) longitudinal pitched aircraft angle-of-attack, sustained level flight will require thrust equal to two-tenth of the gross weight. The two-thousand pound aircraft will now require 400-pounds of sustaining thrust.

A six-degree aircraft angle-of-attack in a six-degree pitched climb will require 200-pounds sustaining thrust for the indicated-airspeed, plus 200-pounds excess thrust to sustain the six-degree climb angle.

—LIFT—

There are three sources of lift in an aircraft, large aerodynamic lifting acting outward from the top of the wings and fuselage, a small thrust component-lift acting outward at the engine attachment and a small aerodynamic load or lift at the stabilizer.

Aerodynamic lift is reaction to displacement of mass-of-the-air by an airfoil. It requires an equivalent mass-of-the-air displacement away to cause the opposite reactive force away lifting the aircraft load.

An aircraft **load** is the sum of all forces acting away from the bottom of the aircraft. This includes the mass weight of the aircraft always directed toward the surface from the center-of-mass plus any aerodynamic load from the stabilizer/elevator acting away from the bottom at their attachment, and centrifugal maneuvering **"g"** loading acting opposite the current center of pressure.

An aircraft engine turning a propeller accelerates by blasting airmass rearward, to which the reaction force called **thrust**, propels the aircraft forward in a direction of motion. Accelerating to a velocity at which the aircraft fuselage and airfoils displace sufficient mass-of-the-air away, there become reactive forces outward as **aerodynamic lift**, equal to the mass of the aircraft plus any aerodynamic load.

At the instant lift becomes equal to the aircraft mass plus any aerodynamic load, acceleration ceases. There now becomes a **sustaining** thrust maintaining the aircraft lift and any **excess** thrust at that moment becomes **climb,** motion angled away with increasing altitude and/or if leveling, acceleration.

Thrust component-lift occurs when elevator pitching moves the direction of engine thrust above the forward direction of motion. Thrust component-lift is equal to the current total engine thrust multiplied by the Sine of the angle of pitch so changes with thrust change. We call this pitched angle of the longitudinal axis above the direction of aircraft motion the **Angle-of-Attack.** It is causing the size of the frontal area of the machine that is encountering the airmass so determines the volume of deflected mass.

With use of the mass-of-the-air, aircraft **sustain** the lift for flight with as little as one-pound of thrust for 10-12 pounds of aircraft mass. Any potential thrust greater than current sustaining thrust is available as **excess** thrust for maneuvering. From level constant indicated-airspeed cruise, adding excess thrust will increase the thrust component-lift causing the nose to increase pitch while the added forward component of that excess thrust sustains the new direction of motion with increasing altitude, **climb**.

An aircraft with addition of sufficient excess thrust could continue pitching to an attitude that the nose would be as much as 90-degrees climb angle, climbing straight upward. At that time, the thrust would be equal or greater than the total aircraft load. This is an extreme example as few aircraft have sufficient thrust to fly in this manner. In this extreme situation, forward thrust would be zero and all motion would be vertically away. The power available in most aircraft will allow no more than 10 to 15 degrees climb angle at lower altitudes.

The pressure caused by impacting and displacing the airmass determines the reactive **lift forces**. Mathematically deducing the displacement pressures involves the load of the aircraft, the area of wing and fuselage bottom surfaces, and the frontal area displacing the air. A small aircraft at its Vy indicated-airspeed will have approximately one-pound per square inch encountering pressure and a resulting reactive aerodynamic lift pressure of approximately one-tenth pound per square inch. The wings have lots of square inches. (2 wings @ 14 ft. x 5 ft. ea. x 144 = 20,160 sq. in. x .1 lbs./sq.in. = 2,016 lbs., the aircraft weight)

—ANGLE-OF-ATTACK—

Change of thrust component-lift affects a**ircraft balance**. You may even consider engine thrust component-lift a fifth control as thrust change causes a pitch change and can significantly affect the aircraft balance.

Longitudinal balance of the aircraft is by coordination of stabilizer/elevator position and thrust component-lift. Normal loading of an aircraft places the static center of gravity forward of the center of aerodynamic lift. This allows dynamic stability of the aircraft but requires the stabilizer and elevator to cause negative aerodynamic lifting (loading) to maintain that balance for flight.

When properly coordinated with the thrust component-lift, the aircraft will attain a specific angle-of-attack attitude at which it encounters the mass-of-the-air. This angle of encounter results in a frontal area of the fuselage and wings thereby determining the volume of airmass displacement. A larger frontal area caused by a larger angle-of-attack displaces a greater volume of mass in a given time so requires less encountering pressure. This means at higher angles-of-attack, the aircraft can sustain its lift while traveling at a slower velocity. The opposite is also true, reduced angle-of-attack requires greater velocities to displace the required mass-of-the-air in a given time.

The elevator establishes angle-of-attack by coordination with a current thrust setting. The angle-of-attack determines the indicated-airspeed the aircraft is flying. Reducing the angle-of-attack **allows** acceleration and coordinated thrust increase and/or gravity component-thrust of descent **causes** acceleration. Increasing angle-of-attack **allows** deceleration and upward zoom against gravity or coordinated decreased thrust **causes** deceleration. Operation below Vme with its greatly increased induced drag will require coordinated increase of thrust after slowing.

The coordination of stabilizer and elevator position with the sustaining thrust component-lift determines angle-of-attack. Elevator trim setting can fix the angle of attack to a neutral position of the elevator control and acts similar to a cruise control. Any time releasing manual elevator input, the aircraft will resume close to that angle-of-attack originally set with elevator trim. Thrust increase causes added component-lift to cause climb angle and if reduced for descent, component-lift reduces the angle-of-attack.

Indicated-Airspeed is the reading from the aircraft speed indicator. The indicated-airspeed indicator sensing comes from an open-ended tube (pitot tube) mounted facing forward into the oncoming airmass. The small pressure of this encountering mass moves the indicator needle. The instrument is calibrated in miles-per-hour and/or nautical miles-per-hour.

Indicated-airspeed then is a pressure reading and does not indicate a velocity across the ground or velocity within the airmass. It is only indicating the frontal pressures affecting the aircraft. Calibration normally has areas delineated to show maximum, minimum, and different structural and operational indicated-airspeeds as pressure force limits.

Engine placement determines the effect of thrust component-lift. Engines placed aft of the center of lift push the aircraft while engines placed forward pull the aircraft. Thrust increase with aft engine attachment results in the nose pitching down while tractor-engine thrust increase pitches the nose upward.

Aft attached, **pusher-engines** have the elevator and thrust component-lifting aft of the center of lift so for constant angle-of-attack indicated-airspeed flight, if one changes the other must change in the opposite direction so requires continuous coordination of both controls.

Forward attached, **tractor-engine** aircraft have thrust component-lift acting forward of the center of lift and stabilizer/elevator load is aft of the center of lift. In this case, if in level constant indicated-airspeed flight, there will be a small thrust component-lift coordinated with an elevator load/lift causing the angle-of-attack balance.

An increase of tractor-engine thrust will add some thrust component-lift, which will cause the nose to lift changing the direction of thrust into a climb angle and sustains the climb in a new direction of motion. The elevator position has not changed so the original coordination of the thrust component-lift and elevator load remains the same. The aircraft climbs at the original indicated-airspeed.

A decrease of tractor-engine thrust from level is different. When reducing thrust from coordinated level flight, the thrust component-lift incorporated into the angle-of-attack balance reduces. This is a small reduction of both angle-of-attack and reduced sustaining engine thrust and results in descent with an associated increase of indicated-airspeed while gravity component-thrust adds to maintain the required sustaining thrust.

Now throughout all descent, just as with the pusher-engines, to maintain constant indicated-airspeed, the elevator must be coordinated with any thrust change until again maintaining level flight.

Vy is the most efficient indicated-airspeed for distance over time and Vme (loiter) is the most efficient for time airborne. This means it requires additional thrust to sustain a greater or lower Vme indicated-airspeed. It takes very little increased angle-of-attack to require a large thrust increase.

Aircraft design usually allows hands-off, full power, maximum nose-up elevator trim, flight without stall. Manually adding aft elevator in this slowed condition can easily attain the wing critical angle-of-attack…stall.

Vx is an indicated-airspeed that causes the greatest gain of altitude versus distance traveled and normally used for attaining obstacle clearance. Vx is slightly slower than Vy during lower altitude operations.

— VISUAL FLIGHT —

Visual flight is controlling the attitude of the aircraft toward sighted targets to make them unmoving relative a point on the windshield. This is flight by collision course. By maneuvering to cause a sighted object to be unmoving relative a point on the window the aircraft will eventually reach that object. I call this **directed-course** flight.

A point in the distance ahead or on the horizon held unmoving becomes a constant heading. The horizon held in a constant position across the windshield maintains a constant pitch attitude. The wingtips held equal distance above the horizon is a wings level attitude.

When approaching a destination area, as that sighted area moves down the windshield toward the lower center of the windshield, beginning descent and maintaining the area unmoving causes the aircraft to descend directly to that area. This procedure, as a visual approach, will have the aircraft at approximately 1,000 feet AGL when 1-2 miles out.

When flying an approach to landing, maneuvering to sight the approach end of the landing area as a targeted point, centered unmoving on the windscreen, will cause the aircraft to fly directly to that point allowing a controlled spot landing.

This approach procedure if always maneuvered to be on a standard glidepath results in every approach to landing being essentially the same.

— TURNING FLIGHT —

Flight maneuvering involves turning flight. A coordinated level, constant indicated-airspeed turn involves aileron attitude roll with coordinated rudder input to a desired bank angle. The instant leaving wings level flight, the aerodynamic lift becomes angled causing reduced vertical aerodynamic component-lift. All texts describing turns suggest pulling the control wheel to add vertical lift. The problem is, pulling the control wheel causes increased angle-of-attack and slowing.

Flight technique of always flying elevator trimmed to the desired indicated-airspeed will allow continuous hands-off flight. Light rudder input will maintain heading control.

We earlier learned we get added thrust component-lift with use of excess thrust. So now, in our turn, if we coordinate added thrust when rolling into the turn, we can cause the nose to track level along the horizon in the turn, without pulling the control wheel, a horizontal climb. We have a level, constant indicated-airspeed turn, without touching the elevator control.

This procedure works through all turns to a maximum bank angle at which the coordinated thrust has increased to maximum power. In most small aircraft, this is approximately 30-40 degrees bank angle.

A turn continued beyond that held level with maximum thrust will begin descent or alternatively, coordinated aft elevator with acceptance of reducing indicated-airspeed to maintain level flight.

Usual flight is at indicated-airspeeds greater than Vy, which allows speed variations during maneuvering flight. However, landing approach maneuvering is typically at or slightly below Vy and requires consideration before inputting aft elevator and its slowing.

High angle-of-attack level flight requires significant increased power, can quickly reach maximum thrust, and with any manual aft elevator input, quickly approaches the wing critical angle-of-attack and possible stall.

—INADVERTENT STALL—

It is difficult to see that in minimum indicated-airspeed descending flight, adding power can cause stall. The fact remains it can happen. In descent, there is a substantial reduction of thrust component-lift normally contributing to angle-of-attack. To compensate, for maintaining the constant indicated-airspeed, added aft-elevator control and/or nose-up elevator trim maintains the desired angle-of-attack.

If a slowed, hands-off level flight is operating at 12-degrees angle-of-attack, the corresponding thrust component-lift is contributing as much as 6-degrees to that angle.

Reducing to idle thrust removes 4-5 degrees of the angle-of-attack, so allows acceleration. It requires adding aft-elevator or nose-up elevator trim to maintain the original constant indicated-airspeed. Now in a descent, the stabilizer is contributing 10-11 degrees of the angle-of-attack.

Increasing thrust will add back the thrust component-lift causing immediate increase of angle-of-attack by more than 4-5 degrees so is now 16-17 degrees nose-up…possibly exceeding the wing critical angle-of-attack.

A common condition where this occurs is the base to final VFR approach when overshooting the extended centerline. A pilot already in the trimmed, low-powered, landing configured slow-flight tends to increase the bank attitude and simultaneously pull the elevator attempting to correct back toward the extended centerline.

The increased bank causes reduced vertical lift and any added aft elevator causes more slowing from the added angle-of-attack. At this point, a power increase adding those 4-5 degrees to the angle-of-attack can cause immediate low altitude stall with no altitude for recovery.

Low altitude, slow indicated-airspeed flight maneuvering must be with minimum or no manual elevator input. There must be anticipation of forward elevator input prior to adding thrust in this condition.

A pilot must understand how thrust component-lift affects flight. All flight instruction of level turns should be without elevator input but with coordination of added thrust for its thrust component-lift.

Descending turns use gravity component-thrust so will increase descent rate during the turn. It is impossible visually ascertaining a steep nose-up attitude when descending. Anytime using aft elevator, the increased angle-of-attack reduces indicated-airspeed.

In all flight, always trim to a hands-off condition with aircraft controls. "You will be surprised how the airplane just wants to do its thing without all the fussing with the control wheel."

—INADVERTENT IMC—

A common cause of fatal accidents in aviation is inadvertently becoming IMC. A non-instrument rated pilot can quickly lose control.

We have now learned when trimmed hands-off aircraft essentially fly by themselves. If practiced as normal flight, safe control when encountering inadvertent IMC is by simply turning loose the control wheel, watching and believing the turn-and-bank or attitude instrument. Steer with rudder to attain and hold a standard rate turn on the turn and bank or attitude instruments. Hold the attitude one minute, and then reverse the rudder to attain and hold zero turn and fly out of the condition.

With practice, a pilot will quickly learn satisfactory control to fly safely back to visual conditions.

When maneuvering in this manner, there will be some minimum descent while in the turn. If the encounter is weather related, a small descent often aids in exiting the conditions, however adding a small amount of power would maintain a level turn and if deemed necessary, even more power causing climb to assure terrain clearance.

If losing visual reference in night VFR, again by turning loose of the control wheel and maintain zero turn on the turn-and-bank instrument, it is probable using excess thrust for climb will aid attaining distant lights or references. At the same time, climbing increases terrain clearance. The flight continues with reference to the turn-and-bank or attitude indicator for maneuvering or turning back.

—CROSSWIND LANDING—

When encountering crosswinds for landing, we need to consider a few basic criteria. Determine the actual crosswind component. This is relatively easy. Any reported winds are subject to change so by the time you get to final approach, it may be different, and by the time you get to touchdown again different. You will be flying visually with a heading correction for tracking the extended centerline and can sense how close the reported information may be. With all winds, close is good enough. You just have to visually fly the airplane making the landing area unmoving.

If the wind direction is more than 50-60 degrees (sine 60 = .9) away from the runway heading, consider the total wind as crosswind. If the wind is 40-50 degrees (sine 45 =.7) away, three quarters (.75) of the reported wind is crosswind. A wind 20-40 degrees (sine 30 = .5) away, one-half of the reported wind is crosswind. Close is good enough.

Now maneuvering on final approach will require a heading correction turned into the wind. Your small aircraft approach speed minus any headwind component will have you in the vicinity of 60 knots…one mile per minute. Anticipate a heading correction of one degree for each knot of crosswind. Visually turn to stop any drift, whatever it takes.

Fly inbound and when on short final, you can begin rudder input for a sideslip maneuver to align the wheels parallel with the runway and simultaneously roll into a banked attitude toward the wind to cause the aircraft to track the runway extended centerline. This slipping maneuver can be input according to pilot technique. Some start the slip on short final others input the slip during roundout or flare.

In any case, in this banked attitude the airplane will touchdown with the upwind main gear first. The momentum of the airplane is trying to continue down the runway as the other main gear and nose wheel complete the landing. Immediately turn the control wheel into the wind and maintain directional control with rudder and nose-wheel steering.

In unusually strong winds, rudder control may be minimal and will decrease with slowing. Anticipate adding power for propeller-blast to allow continued rudder control while at the same time reducing the impact of the crosswind weathervaning the tail.

Handling extreme winds with up to full power landing and braking could be possible. Anytime not maintaining positive control of the aircraft, consider immediate full power for directional control and possible rolling takeoff and go-around.

Extreme winds result in much reduced groundspeed so if it becomes an emergency, find a runway, taxiway, road, or field aligned into the wind. With a 40-60 knot headwind, the landing groundspeed can be close to zero.

—OFF-FIELD LANDINGS—

An incident requiring immediate landing often requires touchdown into unprepared surfaces. Such an off-field landing can be into rocks, trees, gullies, and other kinds of obstacles. This may mean immediate dismantle of the aircraft at or shortly after touchdown and often the nose wheel will catch resulting in being upside down.

There is often little time to make decisions about what to do so it is imperative to have previously made a plan. This includes previous consideration of what it may look like and how you may feel when seeing probable obstacle encounter.

Continued flight to a spot touchdown is paramount. Seventy-five percent of off-field landings touchdown beyond midfield on the chosen landing area as pilots feel they don't want to be low or slow so end up high and fast. Visually fix the approach end of the chosen site centered and unmoving on the windshield and keep it there.

Do not let the aircraft stall. The aircraft is gliding sustained with gravity component-thrust and normal control at least until touchdown. At or shortly after touchdown you will recognize if you can no longer control the aircraft. At that time, you are likely experiencing rapid deceleration and possibly dismantle of the machine.

Upon recognizing loss of control, you will think "I'm now a passenger, I have to be conscious when this thing stops!" At that time, you will be leaning forward against the shoulder harness and use whatever means possible to protect your head…you must be conscious when stopped, and when stopped, immediately leave the aircraft while helping any passengers.

Thinking of this basic procedure in advance allows you a plan. Innovation and invention during an incident is too late. Things will be happening very rapidly but if aware, you will think it is all in slow motion.

How much time does it take to touchdown and stop in rocks and trees? Maybe two, three…five seconds. How long is that? Count, one thousand, two thousand, three thousand, four thousand, five thousand…see, that can be a lot of time. You can likely do a lot of things during that time. Most importantly, you want to be protecting your head!

—HIGH ALTITUDE FLIGHT—

The normal assumption as taught is that aircraft will not fly as well at high-density altitudes as at lower altitudes. This is a very broad generalization based on limited understanding of the physics involved. It is not just the air; it is engine power and propellers. The reduced availability of oxygen for burning affects all engines so in many situations there may not be sufficient excess thrust available for takeoff or safe maneuvering.

With low-density air, the engine cannot produce the maximum rated power and rpm limitation of the engine will not turn a fixed pitch propeller fast enough to cause the normally expected mass thrust. These are huge factors against attaining required acceleration for takeoff and performance when airborne.

With combinations of high elevation, high temperature and/or high humidity, and there being no visual reference of reduced thrust during ground operation and takeoff, it requires very careful planning and consideration of all factors related to the aircraft performance to assure any safe takeoff. An understanding of the atmospheric density and the factors related to engine power is essential.

—AIR DENSITY AND YOUR AIRCRAFT—

Maintaining a constant indicated-airspeed pressure, when climbing to higher altitudes into the gradual thinning air (reduced mass per volume of the air), requires that the velocity (true airspeed) within the airmass must gradually increase to maintain the mass encounter required for constant indicated-airspeed pressure.

We call this velocity within an airmass “true airspeed”. The increased velocity maintains a constant mass encounter for a constant sustained lift. The airplane flies at an indicated-airspeed pressure. The temperature, wind, and density altitude affect the current conditions of the air, but only the encountering air displacement pressures and related reactive forces affect the aircraft lift.

As long as indicated-airspeed pressure is at or above the required minimum, it continues to fly in the direction controlled. If your aircraft does not have the engine power to maintain a minimum indicated-airspeed pressure, it will continue to fly, but will descend adding gravity component-thrust to sustain the set elevator pitched indicated-airspeed.

In descent, supplemental gravity component-thrust will always add to maintain the sustaining thrust, until the engine power available is again capable of level flight…or contact with the earth’s surface.

In higher altitude, temperature, or humidity low air-density conditions, the engine cannot intake a mass of oxygen for burning enough fuel to produce its maximum rated power.

Though increased velocity compensates the effect of reduced density on the indicated-airspeed pressure, the fixed-sized intake ducting causes reduced availability of oxygen dramatically affecting the engine power possible. Higher altitudes, temperatures, and levels of humidity all mean reduction of oxygen intake for burning in the engine. In these conditions, the reduced excess power available dramatically affects maneuvering capability and may not be sufficient for flight.

Thrust available from an engine is dependent on the current density altitude. The power rating of a typical small aircraft engine/propeller combination may be 600-pounds thrust at sea level on a standard day. If it takes 200-pounds for sustaining Vy, then when becoming airborne, there will be 400-pounds excess thrust available for climb and maneuvering.

If this aircraft can fly only to 15,000 feet altitude, the engine will then be producing only 200-pounds thrust. This is a loss of 400-pounds thrust, 25-pounds per thousand feet altitude. This means at 5,000 feet there is 275-pounds excess thrust available and at 10,000 feet 150 pounds excess thrust.

How this affects normal flight operations is that you don’t have very much excess thrust for maneuvering at high-density altitudes. On a 5,000-foot elevation hot day, the density altitude can easily be 8-9,000 feet.

A landing in high density-altitude conditions will be normal but true airspeed and groundspeed will be significantly higher so requires longer rollout. The visual perspective of the ground when maneuvering low will show you are moving much faster. This is similar to the visual if landing with a tailwind.

How does this affect high altitude takeoff and maneuvering? You may have only 400 pounds thrust for takeoff with engine rpm limitations and reduced propeller efficiency; the acceleration will be slower requiring significantly more runway. Even with a long runway, it will be prudent to use short-field takeoff procedures. This means at liftoff, remain in ground-effect for acceleration, at least to Vy or greater. Obstacles that might exist require much consideration. Planning this low powered takeoff should include consideration of takeoff roll plus stopping distance for abort.

Reduced thrust in this example means there will be limitation to maneuvering. At lift-off, the potential 400 pounds of thrust immediately changes to 200 pounds sustaining thrust and only 200 pounds for maneuvering. At this time, climb rate will be much less and a level turn will be limited to a bank angle of less than 25-degrees.

From this, you can easily see that high-altitude maneuvering, often called mountain flying, requires consideration of the much reduced excess thrust available. At 10,000 feet, maximum level-turn bank angle is approximately 20-degrees and the 150-pounds excess thrust limits climb to less than 4-degrees climb pitch…not both at the same time. Operation at high-density altitudes quickly reduces the excess thrust and may require descent for maneuvering.

Remember, on a hot day, a 12,000-foot density altitude may occur at 9-10,000 feet and you will have only 75-pounds excess thrust. That means the maximum bank angle for a level turn is less than 15-degrees bank. Climb pitch will be less than 2-degrees, again, not both at the same time.