Precession

Precession refers to a change in the direction of the axis of a rotating object. In physics, there are two types of precession, torque-free and torque-induced, the latter being discussed here in more detail. In certain contexts, "precession" may refer to the precession that the Earth experiences, the effects of this type of precession on astronomical observation, or to the precession of orbital objects.

Torque-free precession

Only moving objects can be in torque-free precession. For example, when a plate is thrown, the plate may have some rotation around an axis that is not its axis of symmetry. When the object is not perfectly solid, internal vortices will tend to damp torque-free precession.

Torque-induced precession

Torque-induced precession (**gyroscopic precession**) is the phenomenon by which the axis of a spinning object (e.g. a part of a gyroscope) "wobbles" when a torque is applied to it. The phenomenon is commonly seen in a spinning toy top, but all rotating objects can undergo precession. If the speed of the rotation and the magnitude of the torque are constant the axis will describe a cone, its movement at any instant being at right angles to the direction of the torque. In the case of a toy top, if the axis is not perfectly vertical the torque is applied by the force of gravity trying to tip it over. A rolling wheel will tend to remain upright due to precession. When the wheel tilts to one side, the particles at the top are pushed to one side and the particles at the bottom are pushed the other way. However, since the wheel is rotating, these particles eventually switch places and cancel one another out. Precession or gyroscopic considerations have an effect on bicycle performance at high speed. Precession is also the mechanism behind gyrocompasses.

This concept is easier to understand by examining the effects of inertia, which is often stated by the phrase "A body in motion tends to stay in motion." In this case the "motion" of a rotating body is in its rotation. If an external force pushes upon the rotating body, the body will resist the force by pushing back against it, but the reaction is delayed.

Gyroscopic precession also plays a large role in the flight controls on helicopters. Since the driving force behind helicopters is the rotor head (which rotates), gyroscopic precession comes into play. If the rotor head is tilted to the right, its counter-clockwise movement forces the aircraft to fly forward. To ensure the pilot's inputs are correct the aircraft has corrective linkages which tilt the rotor head to the right when the pilots push the "cyclic stick" forward, or to the left when the stick is pulled to the back.

The physics of precession

Precession is the resultant of the angular velocity of rotation and the angular velocity produced by the torque. It is an angular velocity about a line which makes an angle with the permanent rotation axis, and this angle lies in a plane at right angles to the plane of the couple producing the torque. The permanent axis must turn towards this line, since the body cannot continue to rotate about any line which is not a principal axis of maximum moment of inertia; that is, the permanent axis turns in a direction at right angles to that in which the torque might be expected to turn it. If the rotating body is symmetrical and its motion unconstrained, and if the torque on the spin axis is at right angles to that axis, the axis of precession will be perpendicular to both the spin axis and torque axis. Under these circumstances the period of precession is given by:

$$T_p = \frac{4\pi^2 I_s}{Q T_s}$$

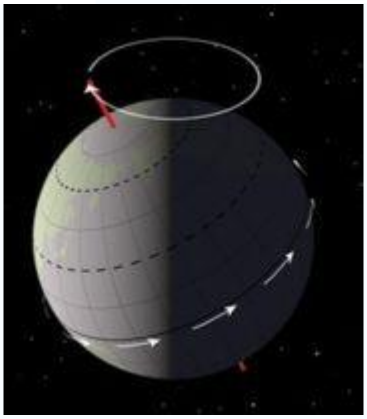
In which I_s is the moment of inertia, T_s is the period of spin about the spin axis, and Q is the torque. In general the problem is more complicated than this, however.

For a layman's explanation of Precession: we will have to imagine the wheel of a gyroscope as a group of particles that are being forced to move in circle. Remember the particles want to move in a straight line. In order for the particles to move in a curved line there must be a force. This force is provided by the structure of the wheel holding the particles within the wheel.

Now let's see what happens to our accelerating particles when a torque is applied to the spinning wheel. Assume the axis of rotation created by the torque is through the center of the wheel at 90 degrees to the primary rotation of the wheel. Let's look at a particle that is on this axis of rotation. Since the particle is on the axis of rotation there is no direct motion applied to the particle at the instant of the applied torque. But let's look at what will need to happen at the next moment in time. The particle is now going to be forced to curve again. This time in the direction of the curve so as to accommodate the tilt of the wheel. Now we have a particle that is already moving and it wants to keep moving in a straight line. So the particle will exert a force on the wheel. If you look at a particle on the other side of the wheel you will see that the force of the second particle is in the opposite direction of the first particle. That pair of unmatched forced is what causes the precession torque that is 90 degrees to the applied torque.

Precession of the equinoxes

Main article: Precession of the equinoxes



Precessional movement.

The Earth goes through one complete **precession** cycle in a period of approximately 25,800 years, during which the positions of stars as measured in the equatorial coordinate system will slowly change; the change is actually due to the change of the coordinates. Over this cycle the Earth's north axial pole moves from where it is now, within 1° of Polaris, in a circle around the ecliptic pole, with an angular radius of 23 degrees 27 arcminutes [1], or about 23.5 degrees. The shift is 1 degree in 180 years (the angle is taken from the observer, not from the center of the circle).

The explanation of this is: The axis of the Earth undergoes precession due to a combination of the Earth's nonspherical shape (it is an oblate spheroid, bulging outward at the equator) and the gravitational tidal forces of the Moon and Sun applying torque as they attempt to pull the equatorial bulge into the plane of the ecliptic. The portion of the precession due to the combined action of the Sun and the Moon is called **lunisolar precession**.

Precession of planetary orbits

Precession of the perihelion (very exaggerated)

The revolution of a planet in its orbit around the Sun is also a form of rotary motion. (In this case, the combined system of Earth and Sun is rotating.) So the axis of a planet's orbital plane will also precess over time.

The major axis of each planet's elliptical orbit also precesses within its orbital plane, in response to perturbations in the form of the changing gravitational forces exerted by other planets. This is called **perihelion precession**. Discrepancies between the observed perihelion precession rate of the planet Mercury and that predicted by classical mechanics were prominent among the forms of experimental evidence leading to the acceptance of Einstein's Theory of Relativity, which predicted the anomalies accurately.[2]

It is generally understood that the gravitational pulls of the Sun and the Moon cause the precession of the Earth's orbit which operate on cycles of 23,000 and 19,000 years. These periodic changes of the orbital parameters, as well as that of the inclination of the Earth's axis on its orbit, are an important part of the astronomical theory of ice ages.

Precession is also an important consideration in the dynamics of atoms and molecules.

Understanding Gyroscopic Precession

Have you ever held a gyroscope in your hand and played with the way it resists movement? If not, perhaps you should, it may help your understanding of what we will discuss here. When this phenomenon is applied to helicopters, the only thing that is usually taught or mentioned are the issues of control rigging. Here I will show that where helicopters are concerned, Gyroscopic Precession is much more significant and important than you can imagine, and your understanding of this will help your flying tremendously.

Most helicopter pilots including flight instructors do not fully understand the affects of gyroscopic precession as it applies to helicopters. This lack of knowledge complicates the training process significantly as the helicopter does things that the pilot did not intend for it to do, and consequently does know why the events occurred. As it is, most students or pilots have either been taught about the control rigging issue talked about below, or they have read about it. After that they learn to fly the helicopter, and without being aware of it, eventually they just overcome the difficulties associated with gyroscopic precession.

Gyroscopic precession is a phenomenon that resists movement when a force is applied to *any* rotating body. The result of the outside force will occur approximately 90 degrees later in the plane of rotation. It is not exactly 90 degrees later, but that is close enough for what we are concerned.

What you probably already know is the fact that with regard to helicopters, the controls are rigged is such a way that when forward cyclic is applied, the helicopter moves forward, likewise for aft, etc. To accomplish this, the pitch link is offset 90º to the rotor blade. The swash plate still tilts in the direction of cyclic input, but due to the rotor pitch link location, the input to the blade occurs 90º earlier in the plane of rotation.

To view the control rigging, turn the rotor so that one blade is to the left of the cockpit, and input forward cyclic. Note that the swash plate tilts forward, but the control link is over the aft portion of the swash plate, increasing the angle of attack on the left blade. When the rotor is in motion, the reaction to this increase in the angle of attack on the left side will result in a climbing blade that will reach maximum upward defection when the blade is in the aft position, the blade on the right side will feather, decreasing the angle of attack as it moves forward reaching minimum deflection when it is in the forward position and the disk will be tilted forward.

First, one must understand that relative to the helicopter there are both *effects*, and *tendencies* of gyroscopic precession, and that *any* change in [1]*any* control position will affect the rotor disk with these complications of gyroscopic precession. This means that if the pilot moves either the collective or the cyclic, the helicopter will respond with the effects and/or tendencies of gyroscopic precession. Pedal inputs alone *do not* have any gyroscopic precession effect on the main rotor, however there is no such thing as pedal inputs alone. If you input pedal, this directly effects torque and consequently other control inputs must be made which *do* have gyroscopic precession complications.

As the cyclic is moved *gently* forward to initiate a departure from a hover, there is little noticeable effect of gyroscopic precession, but as the cyclic is input forward to counter the climbing tendencies of effective translational lift, the helicopter will roll slightly to the left, and the pilot must input slight right cyclic to over come this left turning *tendency*. Most will notice this as the helicopter leads to the left of the runway rather than to track the centerline. Student pilots will allow this to happen, and that is because they are letting the helicopter fly them rather then them flying the helicopter.

More significantly however, During the final phase of the approach while the cyclic is aft for deceleration, and the pilot is increasing the collective to reduce the rate of descent, the helicopter will drift to the right unless a significant left cyclic input is made. This right drift is more significant as the collective is more aggressively increased to terminate the approach to the hover.

These drifting tendencies as described in the above two paragraphs are a direct result of gyroscopic precession. This is easily understandable as the cyclic directly inputs tilting forces on the rotor disk. Think about it, as you move the cyclic forward, the rigging causes the rotor to tilt forward, but the follow through effect of gyroscopic precession causes the left rolling tendency. And likewise to the right when aft cyclic inputs are made.

Gyroscopic precession also acts on the helicopter when a turn is entered in either direction (left or right) from straight and level level flight. When the helicopter is rolled into a right turn, the disk is tilted to the right through cyclic rigging, but the disk will have a further tendency to tilt forward and the nose of the helicopter will drop. When a turn to the left is entered, the disk will have a further tendency to tilt aft, and the nose will climb. This is why all students will notice an increasing airspeed when they bank right, and a decreasing airspeed when they bank left.

In the next couple of paragraphs, we will explain the gyroscopic effects of the collective on the rotor and why. First we must understand that it is physically impossible for the collective to have any effect of gyroscopic precession by itself. This is due to the fact that the collective does not move the rotor in its plane of rotation. However, due to the fact that the collective directly changes the size of the bite of air that the rotor blades take, the collective produces a noticeable difference in the tendencies of gyroscopic precession due to cyclic inputs.

The effects of gyroscopic precession from collective can be demonstrated from level flight; as the collective is lowered, the angle of attack is decreased on all blades collectively (at the same time), and the helicopter will roll to the left. Remember that the disk is already tilted forward through cyclic input for forward flight, and this tends to follow through in the direction of rotor rotation when the collective is decreased resulting in a left turning tendency.

The affect of collective inputs on the rotor are also very noticeable in the termination of the approach to a hover when the helicopter rolls aggressively to the right. The right roll is caused by the rotor disk being tilted aft, but more so by the aggressive raising of the collective to terminate in a hover, and the follow through affect of gyroscopic precession. There is a secondary affect which is the result of "Translating Tendency" during this phase of the approach as well. This is due to the fact that as the collective is more aggressively increased for the termination, left pedal is also applied rather aggressively.

Eventually students will just learn to overcome these tendencies, but often they will not know how or why. Remember that the laws of gyroscopic precession say that when a force is applied to any rotating body, the affect will take place 90 degrees later in the plane of rotation. What is little understood is the fact that although the helicopter rotor is rigged in such a way that the controls work properly, there are still gyroscopic tendencies effected by control inputs that the pilot must overcome.

Flying the Disk

Helicopter pilots must learn to understand that a helicopter rotor is a disk once it is turning; they must not think of it as blades. Pilots must also be aware that the helicopter hangs on the mast like a pendulum from the main rotor disk. With this knowledge, perhaps it would easier to understand how the helicopter reacts to control inputs effecting the rotor disk.

The controls

The collective increases the pitch, or the angle of attack of all main rotor blades equally and at the same time regardless of the blade position in the plane of rotation (collectively). This action on the main rotor blades provides the thrust.

The cyclic changes the pitch of a given main rotor blade in its cycle of rotation. If the cyclic is moved forward, the pitch is increased on the blade that is left of the fuselage, and the blade that is right of the fuselage **feathers (pitch is decreased automatically). Due to gyroscopic precession, this action takes effect 90 degrees later, and the disk tilts forward. This tilting of the main rotor controls the direction of main rotor thrust.

The pedals control the tail rotor blades in the same way that the collective controls the main rotor blades, but rather than lift the helicopter, the tail rotor counters the torque on the fuselage caused by the engine driving the main rotor (Newton's third law of motion – for every action there is an equal and opposite reaction).

Action

When a cyclic input is made, there will be a time delay before the helicopter reacts to this input. The time delay is partly a result of gyroscopic precession, and partly due to the pendulum action of the fuselage hanging on the disk. The duration of this time delay will be relative to the speed that the rotor is turning, and also relative to fuselage weight. Consider a high-speed small diameter rotor like the R-22 with a tip speed of 672 feet per second, and compare that to a Bell 47 with a tip speed of 600 feet per second. Then consider the max gross weight difference of 1480 lbs (2850 – 1370). Obviously the reaction time of the R-22 will be much quicker than the bell 47.

When flying a helicopter you have to learn to anticipate what is going to happen, and you must react with the proper control inputs in advance. This is one of the reasons for a distant focus; you can sense a movement of the helicopter much quicker when you are focused on the distant horizon using your peripheral vision around the helicopter. You can see a doorframe raise or lower laterally, while fore and aft movements can be detected by movements in the instrument panel against the horizon, or perhaps the compass, this is the attitude of the aircraft relative to the horizon, i.e. attitude flying.

Although I discourage this in most cases, I have had students where it helped... When you are taking your first flight lessons in a helicopter, it may help to make a couple of marks on the windshield with a dry erase marker. There should be no need for more than 2 marks, perhaps one for the hover attitude and one for the departure acceleration attitude. Other attitude references can be made to these marks. For example, the cruise attitude may be 1 or 2 inches above or below one of the marks. You should not look at these marks but rather look through them to the distant horizon. After a little time has passed these marks should be erased so that the student learns to fly without this handicap.

When you are *flying the disk*, you make a control input and then wait for a reaction, if it was to much, then adjust accordingly; if it was to little, then make a little more. These inputs should be small, and once an input is made, you must hold it and wait for the helicopter to react. In reality, only micro-seconds elapse after the input is made, but it is enough time that students think their input was ineffective, and then they add more. Just about the time they add more, the helicopter reacts to the first input, which by now is extremely excessive, and a counter input must be made. Now cyclic chasing has begun, and it accelerates until the helicopter is swinging wildly like a ball on a rope, and the instructor must take the controls and get the helicopter back into a stable hover and give it to the student again for another attempt.

Knowing that the rotors are disks, it should be obvious that the effect of the wind on these disks will be similar to that as if you were carrying a large flat object in the wind. If you were carrying this object over your head, and you let the wind get under it, the wind would tilt it in that direction so you must tilt this object into the wind to prevent it from blowing you around. Likewise if you were carrying this object (a large piece of plywood for example) vertically, the wind would blow you sideways accordingly. The effect of the wind on the rotor disks is the same, and your inputs must counter this effect (see figure 15).

There is a tendency for the helicopter to descend when a right turn is entered, and climb when a left turn is entered. This tendency is a result of gyroscopic precession, and must be anticipated, and countered accordingly. To understand why this takes place, you must first understand that the mechanical action on the blade to tilt the disk in the desired direction is different than the occurrence that causes the climbing or descending tendency. The rotation of the main rotor is in a counterclockwise direction, so when the rotor is titled to the right during the turn, the tendency of the disk will be to follow through with a forward tilt causing the descending tendency. Likewise, when the left turn is entered with a disk tilt to the left, the rotor will follow through with a slight aft tilt causing the climbing tendency.

As you learn to fly, and throughout your career, just remember that the rotors become disks once they are in rotation, and not blades. Anticipate the action of the wind on these disks, and learn to stay ahead of the aircraft. The helicopter will only do what you let it do, or what you tell it to do through control inputs, but it will always follow the disk.

Note that a small helicopter such as the R-22, which has a relatively small tail rotor, still has a 42-inch disk on a 172-inch lever. That is a lever over 14-feet long measured from the mast centerline to the tail rotor centerline.

UNDERSTANDING TRANSLATIONAL LIFT and TRANSVERSE FLOW EFFECT

Translational lift

Translational lift is commonly misunderstood and often thought to mean only effective translational lift (ETL). They are often thought to be one and the same, and clearly they are not. Translational lift is obtained by any amount of clean air through the rotor system. Even 1 knot of air introduced into the rotor system from either wind or forward speed provides translational lift which improves the efficiency of the rotor system. The benefits of translational lift improve infinitely and continuously as airspeed increases, however the negative effects of induced drag negate any further benefits of translational lift above about 45 knots of airspeed. This is to say that increasing the airspeed increases translational lift and thereby improves the flight characteristics of a helicopter through about 45 knots of airspeed. Note that this airspeed may vary slightly from one helicopter make/model to another.

Effective translational lift is translational lift advanced to the point where all air flowing through the rotor system of a helicopter is fresh or undisturbed air. That is air that has not already passed through the rotor system while the helicopter speed is slow or when it is in a hover.

Effective translational lift can be recognized by the sudden tendency of the helicopter to climb as it passes through about 16 – 20 knots of airspeed; this airspeed will vary slightly from one helicopter make or model to another. Some pilots also refer to the result of effective translational lift as “blowback.” Passing through effective translational lift (ETL) while on approach can be identified by the sudden tendency of the helicopter to sink when an increase of collective pitch becomes necessary to maintain a continuous sink rate.

While in a hover in any wind there will be some translational lift, and in a strong enough wind you can even have effective translational lift while in a stationary hover. This wind can be blowing from any direction creating enough airflow through the main rotor to maintain ETL, or gusts of wind causing the helicopter to pass in and out of ETL. Airflow inducing translational lift does not have to be from the front of the helicopter as often thought, and taught.

An increase in translational lift will reduce the amount of power required to sustain flight in a given profile, therefore as translational lift varies by the wind while hovering, it will be necessary to work the collective pitch to maintain a given hover height. The collective workload will obviously be relative to the variance of translational lift. This will also be true during takeoff or landing when the winds are gusty.

Pilots should understand that the benefit of translational lift might not be noticeable in all hover conditions. With wind conditions from approximately 330° to 120° (clockwise, and relative to the nose of the helicopter from the pilots seat) the benefits will be noticeable whether in a stationary hover, while taxing, or while in low speed forward flight.

In wind conditions from 120° to 330° (clockwise), the benefits will be diminished due to the increased workload caused by the decrease in tail rotor effectiveness (see figures 1 – 3).

While in a downwind hover taxi the rotor downwash can be retained in the rotor system by the combination of forward flight and the tail wind. As a result, any benefit of translational lift will be reduced and the power demand may be extremely high. This condition is similar to that of settling with power, and in fact without the benefit of ground effect (a high altitude hover), it could develop into settling with power.

Transverse flow effect

Transverse flow effect is a vibration of the main rotor caused by a lift imbalance. This imbalance of lift is caused by the flow of air through the rotor while the rotor is tilted into the wind. The air on the low side of the rotor disk is somewhat recirculated due to ground effect which causes a higher angle of attack, while the air on the high side of the disk passes through and is accelerated clear of the disk with a resulting reduced angle of attack. This vibration and imbalance of lift occurs at about 12 – 15 knots of airspeed and can be induced by forward flight or from the wind while in a hover.

The airspeed of occurrence is relative to the helicopter being flown but is always slightly less than the airspeed where effective translational lift will occur.

Transverse flow effect can occur from any direction of flight, or any wind direction while in a hover just as translational lift can also occur from any direction. However due to the fact that the aircraft is generally faced into the wind most text on these phenomenon usually refer to forward flight only. As a result, figures depict transverse flow effect and translational lift only from the front and likewise the references are made to the fore and aft portion of the disk (see figure 17).

Many pilots confuse the vibration of transverse flow effect with effective translational lift and as a result, these pilots will state that they are passing through effective translational lift when they feel this vibration on approach. The fact is that the rotor vibration caused by transverse flow effect occurs at an airspeed slightly slower than effective translational lift so any pilot using this vibration as a sign that they are passing through effective translational lift while on approach has already passed through ETL before he or she felt the vibration.

It is important that pilot's understand the difference in these two conditions to prevent the possibility of entering into settling-with-power inadvertently while using the wrong factor to determine the passing of effective translational lift. It is far better to use a safe minimum airspeed of 20-30 knots to stay above ETL. ☺

YOUR FIRST HELICOPTER LESSON

What to expect

Relative to population very few people are pilots (only 1/3 of 1 percent), even fewer are helicopter pilots (about 1 in 25), and fewer still ever master the machine. The helicopter is not forgiving if you exceed its limitations and even less forgiving if you exceed your limitations

The success of a pilots training and ultimately his or her career often depends greatly upon the drive; a pilot who is out to impress others usually does not do as well as a pilot who is motivated by a sincere desire to learn to fly and to succeed as an excellent pilot.

During your first lesson the helicopter is going to demonstrate to you what seems like a complete refusal to do anything that you want it to do. In reality however it is going to do everything just as you tell it to whether you meant to or not. You must learn that it is a very responsive machine sensitive to even the slightest control inputs.

Control anticipation

You must learn to anticipate the helicopters reaction to your control inputs. You have to learn to stay one step ahead of the helicopter at all times. Each time you make a control input you must adjust all other controls accordingly. If you are going to increase the collective pitch (manifold pressure), you must be aware that you are going to have to lead that input with throttle, and due to the increased torque you will have to counter a right yaw with left pedal. Likewise if you are going to input left pedal you will have to lead with a throttle increase as well.

You must learn to view the tachometer as a trend meter and at the same time you must learn to maintain the rpm always in the top 50 percent of the green arc.

Think about the sequence of events if you fail to lead the other controls when you make a simple left pedal input: You input left pedal, the energy comes from the main rotor, and this results in lower rotor and engine rpm which consequently reduces lift, and the helicopter settles toward the ground.

Death grips and frozen legs

The single most important factor that will inhibit your ability to control the helicopter is your *inability* to relax. All of the controls move easily and respond the best to relaxed and decisive but small inputs.

The collective/throttle grip should be a light one as both controls mover very easily. If you are flying a governed helicopter such as the R-22, you can easily over-ride governor inputs thereby causing associated rpm problems if you maintain a white-knuckle grip on the throttle.

Pedal inputs are easy when you relax. If you need to input left pedal, you must relax your right foot or better still, lift it slightly so that the left pedal input is possible. If the pedal is hard to push it is for 1 of 2 reasons; either it is because you are pushing against the instructor, or it is much more likely that you are pushing against your other tense foot. In either case you are doing the wrong thing and you need to make the appropriate correction.

In your early stages of flying you should grip the cyclic lightly with your fingers only. Your forearm should be rested on your right leg and there should be no movement of your elbow. Do not try to take the cyclic grip fully in your hand; that will come later, at this point it will only hinder your controlling ability. You have all the movement necessary to control the cyclic in your fingers and your wrist.

Manifold pressure and tachometer correlation

The manifold pressure and tachometer are directly related. This is difficult to learn at first but as you do control manipulation becomes easier. Increasing the throttle also increases manifold pressure, and decreasing the throttle decreases manifold pressure.

If you notice for example that while in a hover your altitude is low, and an instrument check shows low manifold pressure and also low rpm, all three conditions can be corrected by simply increasing the throttle. A slight increase and then wait for the effect, there will be a delay as the engine picks up the speed of the heavy rotor system.

If you notice in your instrument scan that manifold pressure is low and your rpm is high, you can raise the collective increasing manifold pressure and this will in turn pull down the rpm. It should be noted however that your ears should be tuned to the tone of the engine in the top of the green arc (rpm), and any change of tone should bring you to scan the instruments. This will all come in time.

Attitude flying

Learning to fly by attitude and engine tone is very important in progressing with your helicopter training. You must learn to focus on the distant horizon or tree line, do not focus down near the helicopter. You must learn to use your peripheral vision for those things around you and for your position over the ground.

As you make a pedal turn in the hover you must keep your focus on the distant area letting your eyes sweep with the turn always looking straight ahead. This is not to say that you can never look down. Actually quite the opposite you should look down periodically to make sure that you are where you want to be, but then return your focus straight ahead and distant.

The instructor and you

If the instructor says, “I have the aircraft”, relinquish control immediately. You should follow that statement with, “you have the aircraft.”

Never argue with the instructor, the instructor is always right, even when he or she is wrong. So are examiners etc. If you disagree with your instructor take it up later not in the aircraft.

Never make excuses about the wind causing your problems or any other factors that will remain constant throughout your flying career. If the wind is causing you problems it is because you have not yet developed the skill to deal with the winds.

If the instructor says you are tense on the controls and you need to relax; you are tense on the controls and you need to relax; don't deny this, it won't help you.

Do not concern yourself with whether it is you or the instructor flying the aircraft. Just try to do your best at all times. If you are concerning yourself about who is doing the flying, you are not doing your job.

The controls of the helicopter are very easy to manipulate. If you feel resistance in the controls it is the instructor you are feeling most of the time and it is because you are doing the wrong thing. Never fight the instructor, if you feel this resistance you should relax and think about the situation.

If you constantly try to do your best flying, in time everything will fall into place and you will be doing what you have dreamed of.

Cowboy attitude

You must resist the temptation to show-off throughout your career. Those things you have seen in the movies are often camera tricks and they will get you in trouble. Once you make a mistake in a helicopter there is no going back, and you may even live to regret it. A pilot must understand that anyone who knows anything about aviation knows that it takes greater skill to fly responsibly and intelligently than to fly sloppy and show off. The only person that is truly impressed by macho piloting is the pilot himself.

Regardless of whether you are flying an airplane or a helicopter, you must realize your own limitations and never exceed them. It is the failure to do this that kills most pilots who find themselves in an irrecoverable situation. Usually it was the pilot's abilities that were exceeded, not the aircrafts. Even if the aircraft limitations were exceeded it was because the pilot failed to do his or her job.

Before every flight a pilot must analyze all of the factors that will affect the flight as a whole; take into consideration all of the risk factors involved, and his or her particular skill level. The pilot must then decide whether to make the flight or not, and with all of these things considered if the pilot chooses to depart then he or she must not exceed any of the limitations involved, especially his or her own capabilities.

Learning to scan

During flight training the student must learn to complete a visual scan frequently. This scanning process includes both inside and outside of the cockpit. The student should make the instructor aware that they are accomplishing this scan by announcing so. The student should also be well aware that it is unsafe for an instructor to solo a student who does not complete and announce these scans.

The student must always clear the area left and right before commencing any turns, and he or she must state that it is clear following the visual check. Many students state that it is clear without making a legitimate visual check. A quick snap of the head left and right while announcing clear is not an acceptable check for traffic and will not be accepted by the instructor or the examiner. Proper examples:

"Clear left, clear right", or "traffic two o'clock high", etc.

"RPM ok, manifold pressure correcting, airspeed ok", "Carb temperature ok, correcting airspeed", Etc.

Mastering the machine takes time

Students often become frustrated when they cannot achieve the desired results immediately. Many students are of the incorrect assumption that they will be able to hover a helicopter in the first hour. When they cannot accomplish this they often think their performance is substandard and this is not true. The instructor must make students aware that no one can hover a helicopter in less than 5-hours and anyone who says otherwise is full of something, usually themselves. Each student has their own level of understanding, but there may be an occasional student who will master the anticipation factor quicker than others enabling steady state flight sooner but this is absolutely no indication of who will be a better pilot

Control confusion

During the first 20 hours or so of flying student pilots will most certainly confuse the controls. This is especially noticeable between the pedals and the cyclic. When these student pilots want the helicopter to go left, they often input left pedal which introduces a yaw while the helicopter maintains its position over the ground. What was needed was a left cyclic input because the cyclic controls the helicopters ground position while the pedals control only the heading.

Some training materials will state that the collective controls speed while taxiing, and this is confusing to students. What determines speed is always a combination of cyclic and collective inputs. If the pilot inputs a collective increase while maintaining a constant cyclic position the helicopter is going to climb, not go faster. To increase speed, the increase in collective pitch must be accompanied by a forward cyclic input (a very small input, but an input just the same). Likewise to slow down, if a constant cyclic position is maintained and the collective is reduced the helicopter will sink while maintaining the same speed. A small aft cyclic input must accompany this decrease of the collective pitch.

When learning to hover students must think of the cyclic as the control that makes the helicopter go where you want it to go. The cyclic controls ground position and it works like a joystick. Think of the collective as the control that maintains your height above ground. The pedals are the control that points the helicopter in the direction that you want it to point, always true with the direction that the helicopter is moving unless your instructor tells you otherwise.

WEIGHT & BALANCE and FUEL BURN

The factors concerning weight and balance are: the datum, weight, arm, moment, and CG (center of gravity). As fuel is burned, the CG (center of gravity) moves forward, so fuel burn is quite relative to weight & balance data. Furthermore landing weight is significant in many weight & balance calculations. Although most modern weight and balance data are calculated using a graph, many pilots prefer to use the manual calculation method.

Datum

The datum is an imaginary line from which all components on an aircraft are measured. The datum can be a number of inches in front of the aircraft, or it could be the most forward point of the aircraft, or even some point in the middle of the aircraft. All components located aft of the datum are positive (+), and all components located forward of the datum are negative (–). For lateral weight & balance, the datum is the centerline of the aircraft. All components left of center are negative (–), and all components right of center are positive (+). The datum is also known, or referred to as, “station 0.”

Weight

Weight is the weight of the aircraft or the weight of any item such as fuel, oil, passengers, baggage or cargo that will be placed within the aircraft. The weight of articles should be accurate, not just guessed. 100LL fuel weighs 6 lbs per gallon, and oil weighs 7.5 lbs per gallon.

Arm

The arm is the distance from the datum that any component is located. The arm is also the CG of that specific item. The fuel is a given distance from datum as is the oil, the passengers, etc. The weight of any relative object is multiplied by the arm, to find the moment.

Moment

The moment is the result of the weight of an object multiplied by the arm. The total moment is then divided by the total weight to find the CG.

CG (Center of Gravity)

The CG is ultimately the balance point of the aircraft. It must be located within specifications for the controllability of the aircraft. If the CG is located aft, the controls will be limited in forward movements, and likewise if the CG is forward, the controls will be centered aft. In helicopters, many times lateral CG is critical for lateral control centering. In that case, the CG should be as near center as possible.

Calculating the CG

It is helpful to have a worksheet for calculating weight and balance (see figures 7a and 7b). After locating the weight and balance data for the aircraft you are going to fly, fill in the worksheet with the necessary information. Example:

Problem data:

Pilot	175#
Passenger	180#
Oil	8 qts.
Fuel	41 gal.

Actual weight and balance data from an aircraft:

WEIGHT AND BALANCE DATA

BELL 47 G-2 - N6746D - S/N 2250

Maximum gross weight for this helicopter is 2450 lbs.

All calculations based on weights recorded per Saliaka Aviation on Oct. 11, 1992, and calculated per Maverick Helicopters, with battery installed in aft location.

ITEM	**WEIGHT**	**ARM**	**MOMENT**
BASIC EMPTY WEIGHT			
Less oil and usable fuel	1,676.90	+7.05	11,832.00
CALCULATED MOST FORWARD CG			
Basic empty weight	1,676.90	+7.05	+11,832.00
Pilot and 2 Passengers (170 # ea.)	510.00	- 30.00	-15,300.00
Oil (8 qts @ 7.5 lbs gal.)	15.00	+26.50	+397.50
Fuel (5.0 Gal. 20 min. reserve)	30.00	+4.95	+148.50
Totals	2,231.90	-1.31	2,992.00
CALCULATED MOST AFT CG			
Basic empty weight	1,676.90	+7.05	+11,832.00
Pilot	170.00	-30.00	-5,100.00
Oil (8 qts. @ 7.5 lbs gal.)	15.00	+26.50	+397.50
Fuel (41 gal.)	246.00	+4.95	+1,217.70
Totals	2,107.90	+3.96*	+8,347.20

*Note: Although the calculated most aft CG is within limitations, a ballast must be placed in the cabin in single pilot operations of sufficient weight to move the CG forward to center the cyclic, and to prevent a tail strike on approach. The CG limitations are –3.0 to +4.0. Station 0 is approximately 2 inches forward of the mast centerline.

Using this problem data, calculate the weight and balance of the aircraft and determine if it is within CG (see figures 7a and 7b). Filled in a form, it should look like this:

ITEM	WEIGHT	ARM	MOMENT
N6746D	1,676.90	+7.03	11.832.00
Pilot	175	-30.0	-5,250.00
Passenger	180	-30.0	-5,400.00
Oil	15	+26.50	+397.50
Fuel	246	+4.95	+1,217.70
Totals	2,292.9		+2,797.2

CG = +1.22

Notice in this problem, there are both negative and positive arms. This is due to the fact that the datum (station 0) is just forward of the mast centerline.

In an aircraft where there is a lateral arm specified, for example in this case if the empty aircraft had a lateral CG of .02 with a range of +0.2 to –0.2 specified, the lateral moment and CG are found the same way as the longitudinal moment and CG. So with a pilot (right seat position) lateral arm of +12.5, and a passenger lateral arm of –13.3 specified, when you calculate the lateral CG it would look like this:

Item	Weight/Arm/Moment	
Aircraft	1676.9 x .02 = 33.538	
Pilot	175 x +12.5 = +2187.5	
Passenger	180 x –13.3 = –2394.0	
Totals	2031.9	–172.96

Total lateral moment (–172.96) divided by total weight (2031.9) = CG –0.08

Moving the CG (weight shift)

If you calculated the CG and found it to be out of range, you could move baggage from one point to another, to move the CG within allowable limits. The formula for recalculating the CG is very simple: Weight (of object) x distance moved ÷ gross weight = change in CG.

If in the above example the passenger were moved 2 inches forward, we could put the formula to work: 180 x 2 = 360 ÷ 2,292.9 = 0.15. If the weight change is forward, then the change is subtracted from the previous CG. The previous CG of 1.22 – 0.15 (Change in CG) = a new CG of +1.07. If the weight change were aft, the change in the CG would be added to the previous CG.

Weight Change

This formula is effective for calculating the new CG after a fuel burn. It is still a simple formula, and first you must know the CG before the fuel burn. Using the above example, the CG was found to be +1.22. The CG of the fuel is (fuel arm) +4.95, calculate the distance between the two, +4.95 – +1.22 = +3.73. Next calculate the new gross weight using a fuel burn of 125 lbs. Subtract the weight of the fuel burned (125 lbs) from the previous gross weight (2,292.9) = 2,167.9 (new gross weight). Having consumed 125 lbs of fuel, the formula is: 125 (fuel burned) x 3.73 (difference of CG) ÷ 2167.9 (new total weight) = +0.21 (the change in CG). The weight shift is forward so the change in CG is subtracted from the old CG. The new CG is +1.22 – 0.21 = A new CG of + 1.01

Fuel burn

Information on the fuel burn characteristics of an aircraft are not found in the operator's handbook. This information must come either from personal experience, or from someone else who is familiar with the aircraft. The fuel burn can vary significantly between different aircraft with similar engines, but it will remain close on the same make and model of aircraft using the same engines. The best way to determine fuel burn accurately is to land and refuel with a large safety margin during the first leg, and then you can make accurate calculations for the aircraft after that.

Never rely on fuel level indicators, always make a visual check of the fuel level regardless of how difficult it might be. An effective way to do this is to purchase a piece of doweling from your local hardware store and keep it with you for all flights regardless of the aircraft you will be flying. Become familiar with what level of fuel is equivalent to how many gallons or pounds of fuel in a given aircraft. Even those plastic calibrated indicators available from various sources are only an estimation of the actual fuel level.

One good method is to calculate the fuel burn per minute of any aircraft flown, and then use the following formula for fuel burns enroute. For this example, using a burn rate of 15 gallons per hour. (Gallons per hour burned) 15 x 6 (weight of fuel per gallon) = 90 (pounds per hour) ÷ 60 (minutes) = 1.5 (pounds per minute). Then for the minutes flown calculate the fuel burned, 90 (minutes) x 1.5 (pounds per minute) = 135 (pounds of fuel burned) or 22.5 gallons.

Although the above example may seem complicated, it is very effective when it is necessary to calculate a new weight and balance for every departure, when you do not have to take on fuel.

It is just as easy to calculate only gallons per hour burn rates when that is your only concern for flight planning. The formula is: Time (in minutes) ÷ 60 x GPH = fuel burned. For time remaining subtract the gallons burned from the initial quantity and divide gallons remaining by rate of burn (GPH). 15 (gallons remaining) ÷ 5.5 (gallons per hour burn rate) = 2.7 (hours remaining). For hours and minutes remaining, multiply .7 x 60 = 42 (2 hours 42 minutes remaining). ☺