HELICOPTER AERODYNAMICS

CONING

The upward bending of the rotor blades caused by the combined forces of lift and centrifugal force. Coning is more pronounced with heavier loads and high density altitude. Lift decreases because it now has a horizontal component. The pilot should increase centrifugal force by lowering the collective and increasing RPM. Coning results in blade bending in a semi-rigid rotor; in an articulated rotor, the blades assume an upward angle through movement about the flapping hinges.

CORIOLIS EFFECT

The tendency of a rotor blade to increase or decrease velocity in the plane of rotation due to movement of the blades' center of mass. When the center of mass of a rotor blade moves closer to the axis of rotation, its rotational velocity will increase. As the advancing blade of a rotor disc flaps up, its center of mass moves closer to the axis of rotation, and its velocity increases. As it becomes the retreating blade it flaps down and its velocity decreases. Coriolis effect is also known as the conservation of angular momentum.

DISSYMMETRY OF LIFT

The unequal lift between the advancing and retreating blades created by forward movement of the helicopter, or wind during hovering flight.
FORWARD FLIGHT @ 100 mph:

- Rotor blade tip speed approximately 400 mph in a no wind hover
- Advancing blade airspeed will be 400 mph PLUS the 100 mph forward airspeed

- Retreating blade airspeed will be 400 mph MINUS the 100 mph forward airspeed

Since lift increases as the velocity of the airflow over the blades increases, the lift over the advancing blade is greater than the lift over the retreating blade. The helicopter would roll to the left. Dissymmetry of lift is compensated for by blade flapping and feathering. The increased lift on the advancing blade will cause the blade to flap up, decreasing the angle of attack because the relative wind will change from a horizontal direction to more of a downward direction. The decreased lift on the retreating blade will cause the blade to flap down, increasing the angle of attack because the relative wind changes from a horizontal direction to more of an upward direction. The combination of decreased angle of attack on the advancing blade and increased angle of attack on the retreating blade through the blade flapping action tends to equalize the lift over the two halves of the rotor disc. In the extreme case, there is not enough airflow over the retreating blade to generate lift and it stalls. This is called retreating blade stall, and the helicopter will experience low frequency vibrations, a pitch up, and a tendency to roll to the left. Turbulence and gusty winds can contribute to retreating blade stall.

RECOVERY:

- Reduce airspeed
- Reduce collective pitch, which will reduce the angle of attack throughout the disk and unstall the retreating side.

DYNAMIC ROLLOVER

A lateral rolling tendency which starts when the helicopter has one skid on the ground and it becomes a pivot point for lateral roll. Each helicopter has a critical rollover angle beyond which recovery is impossible. If the critical rollover angle is exceeded, the helicopter will roll over on its side regardless of cyclic corrections by the pilot. An upslope rolling motion results from excessive application of cyclic into the slope. A downslope rolling motion results from excessive application of collective. Application of collective pitch is more effective than lateral cyclic in controlling the rolling motion because it changes main rotor thrust. A smooth, moderate collective pitch reduction may be the most effective way to stop a rolling motion. Reducing collective too fast, however, may create a roll in the opposite direction. If collective reduction causes the downslope skid to hit the ground abruptly, the rate of motion may cause a roll or pivot about the downslope gear.

GROUND EFFECT

Increased efficiency of the rotor disc due to proximity of the ground. It usually occurs less than one rotor diameter (approx. 2/3 of the rotor diameter) above the surface. It is caused by the rotor downwash field being altered from its free air state by the presence of the surface. A helicopter will require a smaller angle of attack and less manifold air pressure to hover in ground effect than out of ground effect. Sloping ground will produce an uneven ground effect and will tend to produce a rolling movement to the downhill side.

GROUND RESONANCE

Hard contact with the ground which causes the blades to become out of balance. Ground resonance generally occurs only with three bladed, fully articulated rotor systems. Corrective action could be an immediate takeoff if RPM is in the proper range, or an immediate closing of the throttle and down collective if the RPM is low. Ground Resonance can also be caused by faulty drag dampers, which allow a certain amount of geometric imbalance to occur. Rotor blades that are not properly tracked or balanced can also start the chain reaction.

GYROSCOPIC PRECESSION aka PHASE LAG

When a force is applied to a rapidly spinning object, the reaction occurs 90 degrees away from the point that the force was applied, in the direction of rotation. The pitch change horn compensates for gyroscopic precession. The pitch change links are connected 90 degrees away from the appropriate blade.

MAST BUMPING

A low-G situation could cause the rotor shaft to violently strike the mast, possibly shearing off the main rotor. The low-G condition could be brought on by a climb followed by an abrupt push-over. Recovery from a low-G condition is accomplished by gentle application of aft cyclic to re-load the rotor.

SETTLING WITH POWER aka VORTEX RING STATE

In most regimes of powered flight, the rotor blades displace air downwards through the rotor disc. This airflow is sometimes called induced flow. Intense vortices form as a result of this process and produce wake turbulence. Helicopters, unlike airplanes, have the capability of entering their own wake. The vortices formed by the downwash will combine with the tip vortices present in all regimes of flight to produce very large thrust variations over the disc area. The high velocity airflows moving both upwards and downwards will produce stress on the blades and there will be an overall loss of lift. This results in vibration, buffeting, a temporary loss of cyclic authority and an accelerated rate of descent. An increase in collective pitch in this state will intensify the strength of the vortices and will aggravate the symptoms. Increasing power will therefore increase the rate of descent rather than overcome it. The helicopter is descending in turbulent air that has just been accelerated downward by the rotor. Reaction of this air on rotor blades at high angles of attack stalls the blades at the hub (center of the rotor) and the stall progresses outward along the blade as the rate of descent increases. The combination of conditions likely to cause settling with power:

- 10 knots airspeed or less
- 20% or more engine power
- 300 fpm or greater rate of descent

Vortex ring state is likely to occur during a steep approach, when at a high gross weight, high density altitude, in no wind or downwind conditions, or when hovering out of ground effect. A proper glidepath will avoid settling with power. Recovery may be accomplished by a reduction in power or by increasing airspeed to come out of the column of air and/or partially lowering the collective pitch or entering autorotation. Either way, there will be a considerable loss of height. By putting the aircraft into autorotation, the normal autorotative flow is restored. In this condition, the vortices leave the disc and form above where they are harmless.

TORQUE

Newton's third law of motion states, "To every action there is an equal and opposite reaction". As the main rotor of a helicopter turns in one direction, the fuselage tends to rotate in the opposite direction. Torque is counteracted by a tail rotor and pedals.

Since torque effect on the fuselage is a direct result of engine power supplied to the main rotor, any change in engine power brings about a corresponding change in torque effect. Since there is no engine power supplied to the main rotor during autorotation, there is no torque reaction.

TRANSLATING TENDENCY

The entire helicopter has a tendency to move in the direction of tail rotor thrust while hovering. Torque is also turning the helicopter to the right. This movement is sometimes referred to as "drift". To counteract this drift, the rotor mast in some helicopters is rigged slightly to the left side so that the tip path plane has a built in tilt to the left, thus producing a small sideward thrust.

TRANSLATIONAL LIFT

The additional lift obtained when the airspeed over the rotor disk is 15 mph or more. The rotor system becomes more efficient and produces more lift because the higher inflow velocity supplies the rotor disc with a greater mass of air per unit of time. The helicopter is also entering clean (undisturbed) air. Effective translational lift will be achieved when all of the air entering the rotor disk is new, and when the rotor tip vortices are separated from the rotor (when they trail behind).

TRANSVERSE FLOW EFFECT

A decreasing efficiency of the rear half of the rotor disc due to effects of air flow across the disc. In forward flight, air passing through the rear portion of the rotor disc has a higher downwash velocity than air passing through the forward portion. This is because the air passing through the rear portion has been accelerated for a longer period of time than the air passing through the forward portion. This increased downwash velocity at the rear of the disc decreases the angle of attack and blade lift, hence in combination with gyroscopic precession, causes the rotor disc to tilt to the right (the advancing side). The lift on the forward part of the rotor disc is greater than on the rearward part. Due to gyroscopic precession, the rotor blades will reach maximum upward deflection on the left side and maximum downward deflection on the right side. The pilot compensates for transverse flow effect with left cyclic.

WASHOUT

The rotational velocity of the rotor blade is greater at the tip than at the root. Since lift increases as the velocity of the airflow over the airfoil increases, there is an unequal distribution of lift over the rotor blade. This is compensated for by manufacturing the blade with a built in twist, called washout. Blade twist produces a higher pitch angle at the root where speed is low, and a lower pitch angle at the tip where the speed is high. Washout helps distribute the lift more evenly along the rotor blade.