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Crosscoupling: Its Effects On Helicopter Flight

Symmetry — or, better put, the lack of it in helicopters — is something pilots must be aware of when maneuvering, says the author.

by

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While airplanes are symmetrical, helicopters are not. So helicopter pilots must use somewhat different control strategies than their fixed-wing brethren when maneuvering.

Let us examine what happens in such a simple maneuver as going from straight forward flight into a coordinated turn — one without sideslip. Both airplanes and helicopters turn by banking so that their lift or thrust vectors have a horizontal component.

This horizontal component, known as "centripetal force" in high school physics, is what pulls the aircraft around, making it turn. This maneuver can be divided into three distinct phases: rolling acceleration, rolling velocity, and holding a steady bank.

Rolling Acceleration

To produce rolling acceleration, the airplane pilot deflects his ailerons with a sideways motion of the stick or wheel. This immediately produces a rolling moment by creating more lift on one wing than on the other.

The helicopter pilot does essentially the same thing in the cockpit, but the rotor, being only loosely connected to the rest of the aircraft, does its thing somewhat differently. It generates the required rolling moment by a sideward flapping of the rotor disc.

This produces the rolling moment in two ways: by tilting the thrust vector, and generating a moment at the top of the mast if the rotor has offset flapping hinges.

The lateral flapping comes from cyclic pitch applied approximately a quarter of a revolution ahead. This effect is in response to the sideward motion of the control stick. Just how close this is to a quarter of a main-rotor revolution depends on the type of rotor hub. If it is a teetering rotor, it is exactly a quarter. But if the rotor has hinge offset, the response is quicker. Figure 1 shows what the pilot and the control system must do to accelerate directly to the left.

With a teetering rotor, the motion is "pure," responding to the maximum change in up-cyclic pitch being applied right over the tail boom (for rotors turning counter-clockwise when viewed from the top). For the rotor with hinge offset and for the hingeless rotor, however, the pilot must use a little forward stick to avoid getting some nose-up pitching moment. This forward motion is a measurement of "acceleration crosscoupling."

Note that the type of rotor also influences the amount of

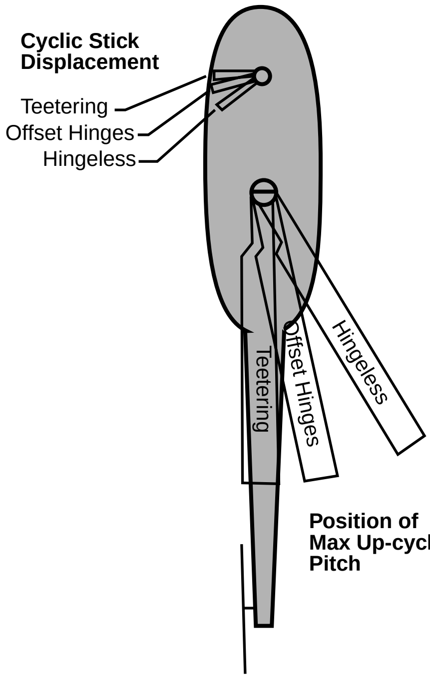


Figure 1

Control Displacement: Left Roll Acceration With Different Rotor Types

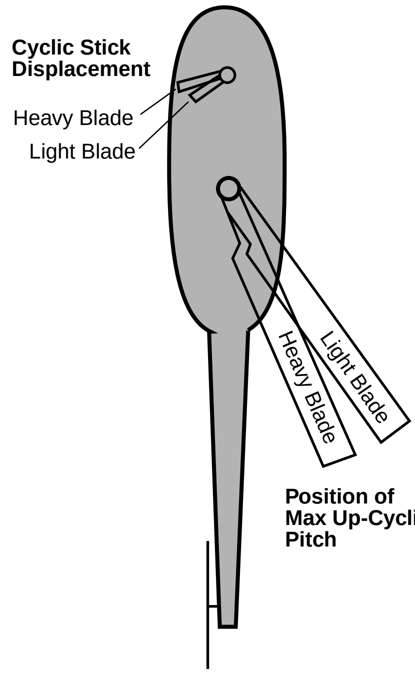


Figure 2

Control Displacement: Left Roll Velocity With Heavy and Light Blades

control motion needed. The higher the hinge offset, the more control moment is produced for the same flapping. This flapping is essentially equal to the change in cyclic pitch.

Rolling Velocity

To maintain a steady rolling velocity, the airplane pilot simply leaves his ailerons deflected and the wings "screw" themselves into the air after they have accelerated to the rate dictated by the wing design and the aileron deflection.

The rotor, however, is a device of another nature. It acts as a gyroscope and must be "precessed" to make it have a steady rate.

For the left roll, the maximum up-cyclic pitch must still be applied somewhere near the tail boom so the stick remains to the left, as it was to accelerate. But now, another effect has to be accounted for.

Since the blade on the left side is going down with respect to the air, its angle of attack and, therefore, its lift is increased compared to the blade on the right side. To avoid up-flapping over the tail and down-flapping over the nose, the pilot must hold some aft stick to compensate for these changes.

The amount of this "rate crosscoupling" does not depend on the type of rotor hub. If we ignore the damping in the aircraft's roll — a reasonable assumption for helicopters without long wings — we can say that, once the rolling velocity is steady, there is no need for a rolling moment from the rotor. We can also say there is no need for rotor tilt with respect to the mast, and thus no need for lateral flapping. If there is no flapping, it does not matter how the blades are fastened to the hub.

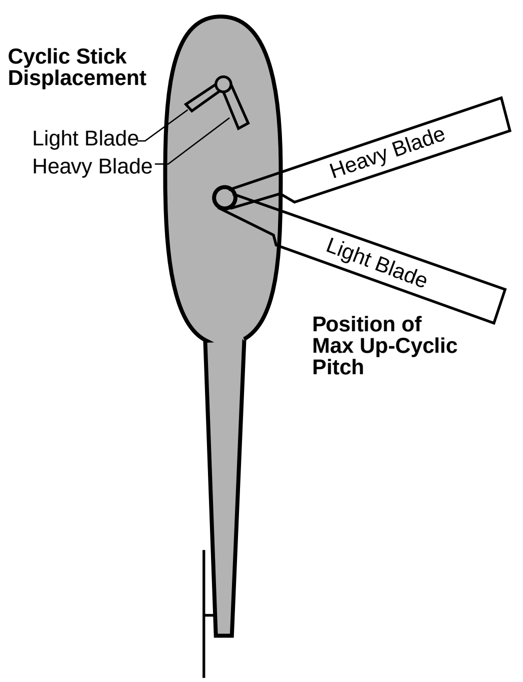
What does matter, however, is how heavy the blades are. The heavier the blades, the more lateral cyclic pitch is required to precess the rotor at a given rate. The **longitudinal** cyclic pitch required to balance the aerodynamics, however, will be the same for both light and heavy blades. Figure 2 illustrates the overall results when holding a steady left-roll rate with both light and heavy blades.

In this case, the distinction between light and heavy blades is one of relativity. The important factor is the ratio between the blade's aerodynamic and inertia characteristics. This ratio, called the Lock number, would be the same if the blades were built to the same design and used the same construction materials, no matter what their physical size.

In practice, we find single-engine helicopters, which have to possess good autorotative entry characteristics, have heavier blades than multiengine machines, where it is assumed that all engines will not stop simultaneously. Very heavy blades were a characteristic of helicopters with tip-jet engines that were in vogue during the 1950s.

Figure 3

Control Displacement: Steady Left Bank With Heavy and Light Blades



Holding the Bank

Getting to the desired bank angle is only part of the turn maneuver. To maintain the bank, the wing lift or the rotor thrust must be increased over that required just to maintain level flight. That is, the wing or rotor must produce more than one G.

The airplane pilot accomplishes this by holding aft stick to increase the wing's angle of attack. The helicopter pilot does it by increasing collective pitch.

Now, instead of having a rolling velocity, the helicopter has a pitching velocity (easy to see in a 90^o bank) and the rotor must be precessed nose-up, using aft stick.

Since this pitching velocity means the blade over the nose sees more air coming down than the blade over the tail, it might be expected that cyclic pitch, that is, right stick, must be used to prevent a rolling moment to the left. There is another and opposing effect, however, that might be stronger.

Since the thrust is higher than in level flight, coning is also higher. This effect makes the blade over the nose see more air coming up than the one over the tail. If this effect is stronger than the one due to the nose-up pitching velocity, the pilot might have to hold left stick instead of right.

This coning effect is again a function of blade weight, and is stronger on rotors with light blades. Figure 3 illustrates the difference in control positions required to hold a steady bank with both heavy and light blades.

What To Do About It

In an actual maneuver, of course, the acceleration, velocity, and steady crosscoupling effects phase in and out, and they may be accompanied by other effects, due to such things as inadvertent sideslip.

While it might be possible to eliminate one of these crosscouplings by biasing the linkages between the cockpit and the swashplate in the right way, it would be difficult to eliminate all of them. So control-system designers usually leave it up to the pilot to use his flying skills to compensate.

Perhaps in the future, some sophisticated fly-by-wire systems will make the helicopter respond purely to cockpit control motions with no "Kentucky Windage" corrections required of the pilot.♦

[This article is reprinted from Rotor & Wing International *in the interest of sharing safety information with the worldwide aviation community. — Ed.]*

Rotors and Feathers Don't Mix

Avoidance is the key to preventing in-flight encounters of the wrong kind.

Helicopters and birds share many flight characteristics but neither wins when they try to share airspace too close together.

Here are some tips to help avoid unpleasant bird-machine conflicts that apply to rotorcraft and fixed-wing aircraft alike:

• **Be visible.** When you cannot avoid bird areas, turn on all lights, when possible. Strobe lights, landing lights, rotating beacons and running lights are believed to be effective in alerting and dispersing birds from the flight path. In short, "light up" so that birds can see and detour away from your aircraft.

• **Avoid damage**. If areas of high bird concentration are encountered, turn on the windshield heat. It has been found that a warm windshield can better withstand bird impact forces because of its greater flexibility.

• **Reduce impact force.** Maintain lower safe air speeds in areas frequented by birds to minimize the potential for a bird strike and to reduce the impact forces should one occur.

• **Stay on top.** During cruise, watch for flocks of migratory birds. Attempt to climb above observed flocks. Birds have a tendency to dive when frightened, so the rule of thumb is to climb and allow the birds to pass below the aircraft.

• **If all else fails.** Should a bird strike occur during cruise, check all instruments immediately. Ingested birds sometimes cause problems that may not be readily detected unless the instrument readings are properly analyzed. Consider landing at the nearest airport.

Experience indicates that structural or engine damage is most probable when "loud-bang" strikes are encountered, even when no apparent damage is visible or "felt" from inside the aircraft.

Report all suspected or actual bird strikes as soon as possible to the nearest ATC facility. Such information is valuable for alerting and routing other aircraft in the area. ♦

What's Your Input?

Flight Safety Foundation welcomes articles and papers for publication. If you have an article proposal, a completed manuscript or a technical paper that may be appropriate for *Helicopter Safety*, please contact the Editor. Submitted materials are evaluated for

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