OPERATIONS

FLIGHT IN TURBULENT AIR

Does a helicopter behave any differently than an airplane when flying through turbulence? Yes and no.

A direct comparison

An airplane and a helicopter are flying in formation in gusty air. In which would you rather be a passenger? If you said the helicopter you would agree with most people who have had the chance to make the comparison.

The National Advisory Committee for Aeronautics (NACA) made a classic comparison years ago by flying two aircraft of about the same size in formation: a Sikorsky S-51 and a Cessna Airmaster. The recording instrumentation showed that the helicopter had a smoother ride. There are two reasons for the difference: one aerodynamic and the other dynamic.

The explanation

When an airplane encounters a vertical gust, the gust velocity divided by the forward speed defines the change of angle of attack on the wing. But the dynamic pressure, which determines the increase in lift, is proportional to the square of the forward speed. Thus the increment in wing lift is directly proportional to the first power of the forward speed.

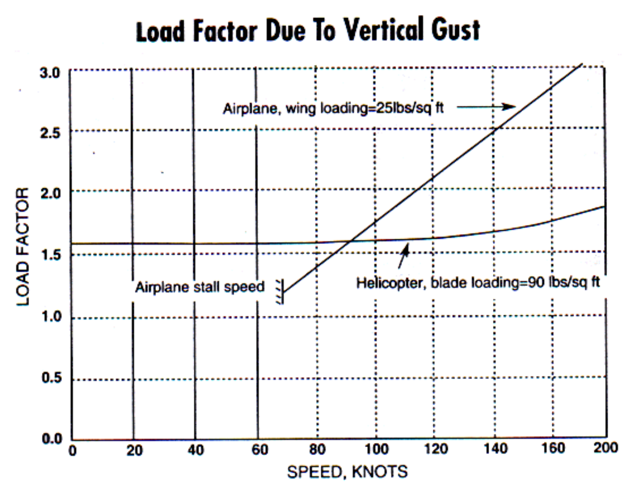
The situation is different with the helicopter. The gust velocity divided by the local velocity of a blade element defines the change in angle of attack, and also fixes the local dynamic pressure. Although the conditions at a blade element are changing around the azimuth, the simultaneous changes in angle of attack and dynamic pressure almost compensate for each other, with the result that the gust-generated increase in rotor thrust is only slightly more in forward flight than it is in hover.

A major difference between the airplane and the helicopter is how much wing or blade area is available to produce this increment in lift. An airplane designer will choose a value of wing loading that defines a minimum stall speed. The lower the wing loading, the lower the stall speed. A wing loading of 25 lbs/sq ft assures a flaps-up stall speed in the neighborhood of 70 knots.

A helicopter designer will choose a value of blade loading that defines the speed at which the aircraft will encounter retreating blade stall. The lower the blade loading, the higher this speed will be. A typical value for today's designs is 90 lbs/sq ft. For the same gross weight, a helicopter compared to an airplane will have less than 25% of the area to generate additional lift.

No relief for airplanes

The effect of increased lift/thrust may be reflected as an increment in load factor in encountering a gust, and it is solely dependent on wing/blade loading. The figure shows the effect of a 20 ft/sec "sharp-edged" gust for two aircraft as a function of forward speed. This chart indicates that, for reasonable cruise speeds, the helicopter responds less than the airplane.



Inertial relief

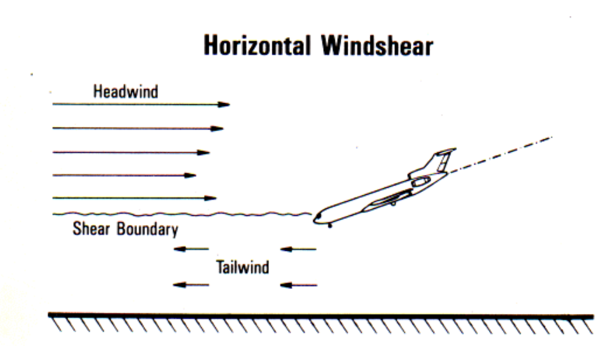
The dynamic effect is due to the fact that the blades are attached to the helicopter airframe through flapping hinges--or flexible blade roots. Thus when they are suddenly subjected to additional lift, the blades respond by coning. This means that there is an “inertial relief” as some of the force is expended in accelerating the blades upwards before they can exert a force on the airframe. Most airplanes get no such relief.

The only exceptions are large jet airplanes whose wings do have some flexibility. Nervous passengers readily notice this during a takeoff roll on in flight, in turbulent air.

For a single sharp-edged gust the relief is short-lived since the coning will be complete in a fraction of a second. However, it might be significant in “choppy” air where, the gusts are coming up and down rapidly. In this case, the rotor actually will act as a vibration absorber.

Wind shear

While making a landing approach, an airplane is particularly vulnerable to horizontal wind shear, especially if the headwind that it was depending on for airspeed suddenly quits or even momentarily becomes a tail wind.



If this reduces the speed of the air over the wing to less than the stall speed, a crash landing is the probable result, and several well-reported examples have occurred involving commercial airliners. Strong wind shears are usually connected with thunderstorm activity.

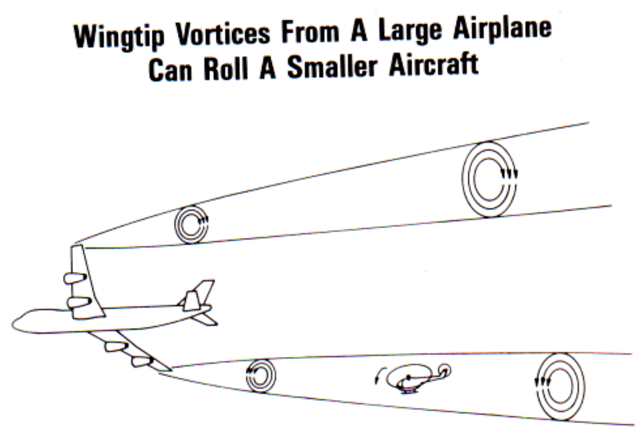
For a helicopter, the existence of horizontal wind shear is inherently less dangerous. However, if the horizontal shear were also accompanied by a strong downflow, a low-flying helicopter might be driven into the ground before the pilot could react. I have heard of at least one accident where this might have been the case.

Wind shift

The same local meteorological phenomena that produce changes in wind with altitude can also cause a change with time. Thus a wind reported to be out of the north a few minutes ago may now be out of the south, and if the direction is important in making piloting decisions, the pilot may be now making the wrong one.

Wing tip vortices

Flying into a vortex left by the wingtip of a large airplane can upset a helicopter just as easily as an airplane.



One of these invisible whirlpools can persist for several minutes before becoming unstable and self-destructing. Up until then, it is strong enough to roll any small-or medium-sized helicopter or airplane unfortunate enough to try to fly down its center--or even close to it.

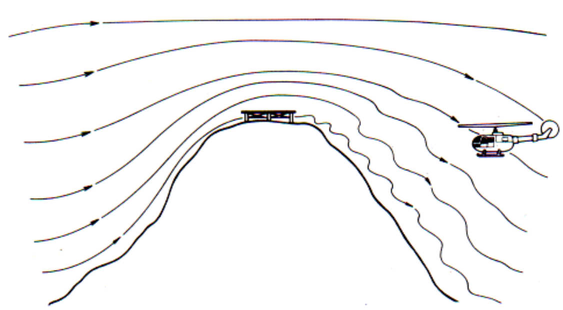
Some people have said that a helicopter rotor will destroy the vortex by chopping it up. Don’t you believe it!! Even if it were true, the destruction would come too late.

The vortex pattern left by helicopters has, on occasion, been blamed for upsetting small aircraft. However, the more likely culprit was the downwash in the immediate vicinity of the rotor. Inherently much less stable than a wing-tip vortex, the complex pattern of rotor-tip vortices contains the seeds of their own rapid conversion into unorganized turbulence that quickly dissipates.

Mountain flying

Wind blowing over mountain ridges and peaks generates flow patterns that can surprise an inexperienced helicopter pilot. For instance, approaching a landing site by flying upwind is usually good advice--but if that site is on the top of a mountain ridge, the approach is through air that is tumbling down into the valley below so the helicopter has to climb just to maintain altitude.

An Upwind Approach To A Pinnacle Landing Site



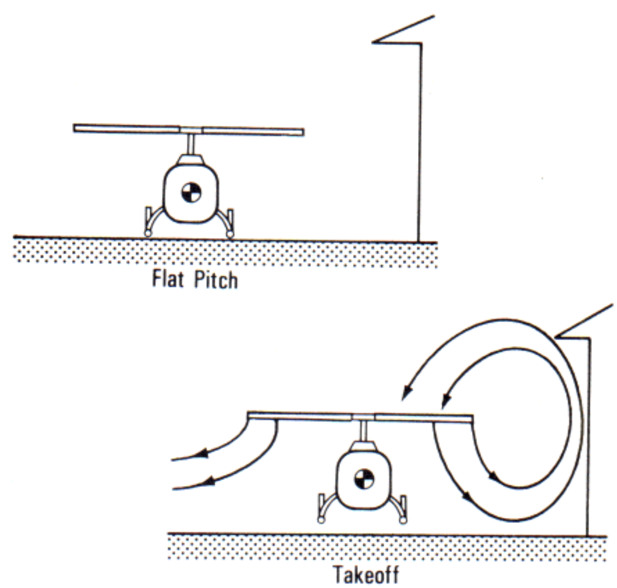
If the power available is marginal, as it often is in hot-and-high conditions, the landing might be in jeopardy. Experienced mountain fliers cautiously approach such spots along a crosswind path over the upwind side of the ridge, turning into the wind just at touchdown.

Operation near obstructions

A white-water boatman can see the currents and rough stuff that might upset him, but a helicopter pilot very seldom gets such clues. It is bad enough that the ambient wind gets distorted by nearby obstructions--producing unseen currents and rough air, but the helicopter, being a wind machine, can add to the confusion with recirculation of its own rotor wake.

The figure below shows one of the most noticeable effects that can occur when taking off near an obstacle.

Wake Recirculation



The recirculating wake produces an increase in the non-uniform inflow pattern at the rotor disc as thrust is increased to lift off. This will require a non-standard hover cyclic stick position that might come as a surprise to the unsuspecting pilot.

For example, if, because of recirculation, the downflow is stronger on the left side, the helicopter will tend to mover backwards because of the 90^o lag in flapping. Not only is the cyclic pitch affected but the increased downflow looks like a climb condition--which requires more power to the main rotor and therefore to the tail rotor also. This represents a decrease in ground effect and might keep a heavily-loaded helicopter grounded.

Distortions of the inflow distribution also occur whenever the helicopter is maneuvered into a region of disturbed wind--such as around a rooftop landing pad, mountain ridge, drilling platform, or ship's deck. In these cases, inflow changes might be either up or down but will generally come on suddenly during a takeoff or landing. To minimize the surprise when landing, some pilots recommend a slow cross-wind approach which gives the best chance of reversing the decision if things get too rough.

The ground vortex

Let's imagine a wind tunnel test of a helicopter model in both hover and forward flight using smoke to determine the characteristics of the flow. In hover, you will see the flow impinging on the test section floor and then going both up and down the tunnel.

When the tunnel fan is running at low speed you will see a different pattern. The rotor is pushing air upstream along the floor, but everywhere else the flow is downstream. At the point on the floor upstream where the wake flow is overcome by the tunnel flow, the flow will curl up on itself like a breaking wave at the beach. This is called the "ground vortex."

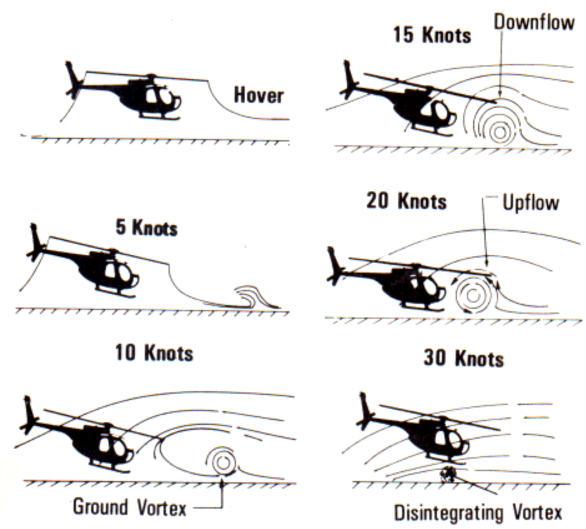
You can actually see this from a helicopter that is flying low and slow over a dusty field. Somewhere ahead will be a distinct horseshoe-shaped ground vortex.

Running off the ground cushion

The presence of the ground vortex can explain the occasional report by helicopter pilots that, "I ran off the ground cushion."

The helicopter normally benefits from the reduction of power when flying in ground effect both in hover and in forward flight. The sudden loss of this benefit can be traced to running over the ground vortex at some forward speed as shown below.

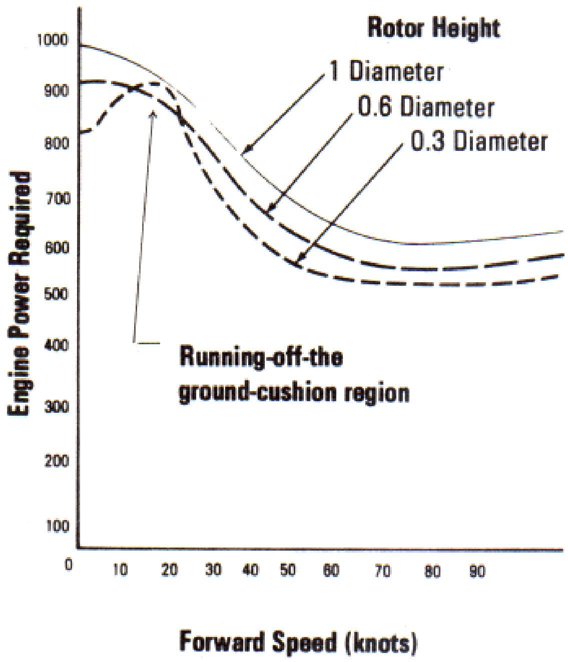
Effect of Ground Vortex on Inflow Patterns

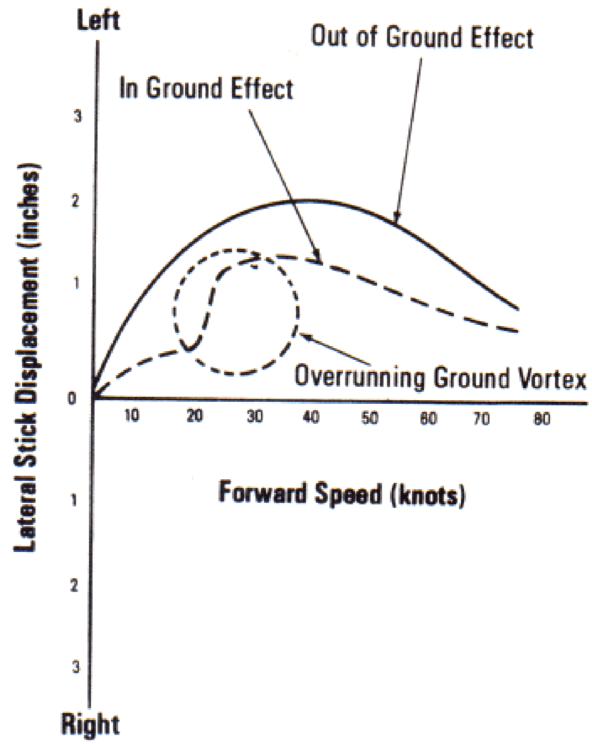


Note how the vortex develops and influences the conditions at the rotor. In the speed range of 10 to 20 knots, the effect of the ground vortex is to increase the downwash through the leading portion of the rotor disc as if it were in a climb. Until the vortex is overrun, this effect causes the power required to increase, rather than decrease as the ground effect would normally indicate. Since the vortex stays close to the ground, its effects are most significant at low rotor heights. For high rotor heights, the vortex is overrun at lower speeds but its overall effects are less.

The figure on the next page shows the power required as a typical helicopter goes into forward flight at three rotor heights. The height of 30% of the diameter is good for hover but does show a rise that the pilot would quickly discover if his available power had been just enough to hover in the first place.

Ground Effect In Forward Flight





In practice, this type of takeoff is accomplished by doing it as quickly as possible and sacrificing a few feet of altitude. The FAA recognizes this technique when they establish the maximum gross weight for certification of single-engine helicopters. They require that the helicopter must be capable of hovering in ground effect (IGE) at a landing gear height that permits transition into forward flight at a fixed collective pitch without touching the ground. Most helicopters require a skid height of three to five feet to accomplish this maneuver.

Stick to the left

As illustrated, the change in inflow through the rotor not only affects the power required but the lateral trim as well. Normally, at low speeds, the downflow through the front part of the rotor is lower than through the rear part, causing the rotor to want to flap up to the left--unless the pilot holds it down with left stick.

The effect of the ground vortex is to increase the downflow through the front part of the disc, making the flow more uniform and reducing the requirement for left stick. This condition applies only until the vortex gets under the leading edge of the disc, producing a strong upflow and a sudden requirement for substantial left stick that may take the pilot by surprise.

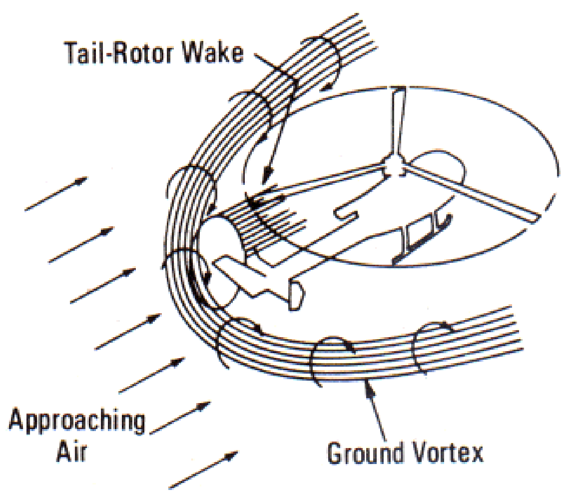
Although the figures indicate more-or-less steady flow induced by the vortex, this is mostly artistic license. The flow actually has much random turbulence, especially as the vortex passes under the rotor, so that besides the average effects on power and trim, the pilot must also contend with erratic trim changes.

Since velocities are relative, it does not matter whether the helicopter is moving over the ground on a calm day or hovering over a spot on a windy day; the effect of the ground vortex is the same. This leads to the conjecture that the observed hover performance of a given helicopter may seem worse with a 10-to-20 knot wind than it is on a calm day. I have never heard a pilot complain on this, but I am listening.

What the tail rotor sees

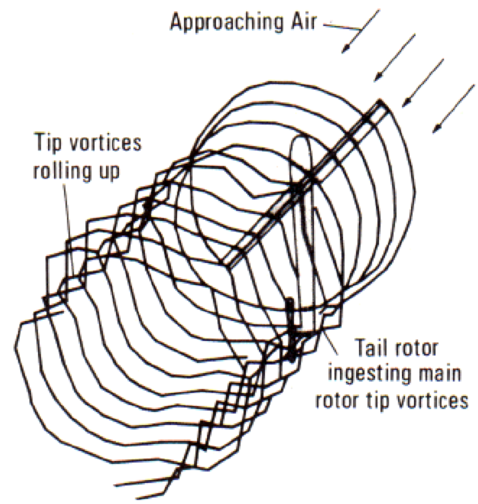
If the helicopter is in rearward flight or is hovering over a spot in a tail wind, the ground vortex is behind it, but that is where the tail rotor is. If the two are coincident, as in the figure below, there may be problems with holding a precise heading.

Ground Vortex Interference In Rearward Flight



It is not only the ground vortex that can effect tail rotor performance. Some helicopters have run out of directional control when flying slowly with the wind coming from the right front. In this case, the disturbing factor is the wad of tip vortices coming from the advancing edge of the main rotor and being ingested into the tail rotor as shown below.

Conditions in Right Quartering Flight



Some helicopters run out of pedal in this condition, which is called, "flying in the slot." This was a big problem with Bell UHs and AHs before the tail rotor was moved from the left side to the right side of the vertical stabilizer. The resulting reversal in the direction of tail rotor rotation (tail-rotor blade closest to the main rotor going up) significantly improves the controllability in this flight condition.

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