HELICOPTER TECHNIQUES - (NOT) FOR DUMMIES

News / Airlines

By Andreas Eissler

Some time after having served as a bush pilot and mechanic in the tropical rain forests of Borneo, as well as in the high mountain regions of Papua – Irian Jaya for a few years, I was asked to present a lecture to a symposium of the Christian Pilots Association CPV in Germany, to broach the issue of advantages and limitations of helicopter operations in mission aviation.

As – or even more than – in other parts of our lives, flying is bound to physical limitations. More than elsewhere, any technical solution is a compromise between goals and physical limitations. Thus technology opens vast capabilities to us, but is our main limiting factor at the same time.

rain forest runway

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Bush airplanes can land and takeoff in short distances, but they still need runways.

Certainly the most obvious advantage of helicopters is that they need very little space for takeoff and landing. Compared by payload, a Cessna 206 or a Cessna 210 requires roughly 1500 ft of runway, depending on density altitude of course, whereas a JetRanger or a LongRanger theoretically is able to take off and land even in confined areas with a diameter of not more than 50 ft (in due consideration of the pilot’s skills).

Therefore, the advantage in remote areas clearly is on the side of the helicopter.

This is actually the main reason for helicopter operations worldwide, including my job in western Papua ten years ago, where mountain ridges reach up to more than 16,000 ft. This, of course, holds quite some challenges and limitations. In many cases a standard profile cannot be performed, and a steep approach is required instead.

What does that mean? If we are approaching a landing site in confined areas, such as a wood glade, we basically have to aim our flare at a point slightly above the elevation of the tallest obstruction adjacent to our landing site, perform as much as a full stop right above it and lower down, stationary until touchdown. That sounds practicable, but in doing so, we are restricted by two essential factors:

1. Weight limitations for hover OGE (out of ground effect)
2. The danger of a vortex ring state

Dealing with these things is part of basic helicopter pilot training to a certain degree, and specifically part of mountain and other additional flight training.

A good pilot never stops learning, especially if relatively inexperienced and not very long on site. Over two and a half years, I have served several terms of about two month each in Wamena, West Papua, and during that time I took any chance for training with senior pilots by my side, mostly incorporated as part of our missions. Deadhead legs could provide such chances, and it was one of them that allowed me to train on landings into some of the most interesting confined areas I have approached, with the most senior and experienced pilot of our base as co- and safety pilot.

Not far, northeast from our base in Wamena, there were several large sink holes, caused by karsts below.

Helipad in rain forest

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Helicopters aren’t limited to runways – a big advantage in the jungle.

The relatively even surface had sunk each maybe between 20 ft and 60 ft deep, with diameters ranging from 20 to 100 yards, almost perfectly round craters with close to vertical sidewalls and even ground but covered with high grass and shrubs. They were a sight worth seeing, especially from the air. Well, we wanted to see them from inside. So we checked out some of them, the larger ones with some forward speed, hovering to one end and using the space available for forward takeoff, and the medium ones for vertical landing and takeoff.

I didn’t set down our LongRanger on the overgrown and potentially unstable ground, of course, but kept hovering at all times – we didn’t want to take the chance of becoming stuck in those holes. And we avoided the small ones: a vertical descent so close to solid walls all around would have provided almost a guarantee for vortex ring state without a way out.

To understand what this means we have to get into physics and aerodynamics a bit now.

Vortex Ring State

As aviators, we know about the wake turbulence of fixed wing aircraft. A helicopter’s rotor blade acts like a wing, with its tip cutting through the air at speeds comparable to those of business jets and airliners, even when hovering stationary, and therefore it produces wakes just the same way a fixed wing does.

Vortex ring state graphic

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Vortex ring state is a serious condition in a helicopter.

Wake turbulence sink down slowly, which means that a helicopter’s wake turbulence won’t interfere with its producer as long as he is level or moving at sufficient forward speed. Just like airplanes, we escape our own wakes, and the airstream through our rotor is relatively calm and straight (*picture 03)*.

Even in a stationary hover OGE (out of ground effect), our own wake turbulence is sinking away from us. The moment when we start to lower down at little or no forward speed is when it gets interesting. This has to be performed very carefully and at sink rates less than 300 ft/min, otherwise we might catch up with our own wake, which then is circling around our blade tips and hitting the blades from the top again. This leads to a reduction of lift, increasing our sink rate: vortex ring state is striking.

A knee-jerk reaction would be to pull the collective lever, in order to increase power and lift. Unfortunately, increasing power and the angle of attack on our rotor blades will result in stronger wake turbulence, so in effect we are going down even faster instead of slowing our sink rate. The only way to recover a vortex ring state is to escape our own wake by pushing the stick (especially carefully in a two-blader, don’t risk mast bumbing and low-q rollovers) and picking up forward speed, which requires sufficient altitude and some obstacle-free area ahead.

From this first example we can see already that a helicopter needs to be piloted with a great amount of anticipation and situational awareness.

Ground effect and translational lift

The other critical factor for steep approaches is the mass or weight limitations for hover OGE (out of ground effect) the higher the altitude of our landing site.

Even though the phenomenon of ground effect is not quite as noticeable for fixed wing pilots as it is for helicopter pilots, everybody who cares about good, soft landings understands the shift when ground effect is starting to take in during flare. This is the moment when the air supporting the wing cannot simply dodge away any more when close to the ground, so it builds an air cushion under our wings, which adds to our lift. With smaller aircraft, this occurs up to about 10 ft above the ground. In return, it means that our lift is less with the same power setting, and our helicopter needs more power, when out of ground effect.

When performing a standard landing profile in a helicopter, this is compensated by a phenomenon called translational lift. In hover, the air basically is shoveled through our rotor from top to bottom in a vertical airflow. 100% of our lift is produced directly by the engine(s) propelling the rotor.

Translational lift diagram

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Translational lift makes the rotor system more effective.

In a standard takeoff profile with a departure path free of obstacles, a helicopter is lowering its nose out of hover without changing the power setting much, to pick up speed in ground proximity, taking advantage of ground effect. At about 20-30 knots, translational lift is setting in. Physically it means that the additional kinetic energy is increasing the total lift of our rotor, and it can be described by a pilot scheme of the rotor area level acting similar to a fixed wing, in addition to its function as sort of a propeller pushing air downwards. The helicopter begins to climb all by itself without any change in its power setting (and it starts to yaw in the direction of the rotor turning more or less abruptly, which is anticipated by the experienced pilot beforehand and evened out by releasing opposite pedal just the same time).

During approach and landing, translational lift is vanishing during flaring out through about 30-20 knots, and power must be increased in order not to increase our sink rate, or not to plump down.

As a result, the transition to a hover requires more power than horizontal flight.

That’s why we prefer standard profiles, which provide takeoff out of ground effect right into translational lift, and landings out of kinetic/translational lift right into ground effect.

Away from airfields, conditions which allow a standard approach or departure are rather rare though, even in flat lands like the swamps in Central Kalimantan on Borneo, where my home base was located. Mountains started to rise no less than 45 flight minutes away, but most hamlet squares or wood glades in the rain forests wouldn’t provide enough space for standard profiles either, not to mention people on site.

Our most frequent destination here was the “helipad” of a bush clinic, which allowed our JetRanger’s main rotor about 3 ft distance to the trees in front, and our tail boom standing out over a downslope behind. In places like that something close to a CAT A takeoff is the only practical profile. Here, the helicopter lifts off vertically and slightly backwards up to the altitude of the TDP (takeoff decision point) before turning and accelerating, to keep the spot of departure in sight, and to increase the chances to reach the spot again in case of emergencies like engine failures.

The Dead Man’s Curve

When trying to land in confined areas, we are forced to land more or less vertically. This means that we have to establish a hover OGE, and then lower down from there. It is crucial to consider the increased power demand in our weight and balance calculation before takeoff for landing, when loading the helicopter.

Ignoring this could place us at the back side of the so-called “dead man’s curve” in no time (see photo at right).

Dead man's curve

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Will you have enough power to hover at the bottom of that approach?

Some people take the dead man’s curve to mean height-velocity-diagrams, which describe certain speeds in relation to certain altitudes out of which some emergency procedures cannot or only hardly be performed. But what actually is called the “dead man’s curve” is the power curve. The curve in the diagram shows that below about 50 kts translational lift is starting to diminish, and the power demand is increasing. That’s very different from fixed wing airplanes, where the relationship between speed and power are proportional constants until touchdown, and it is the reason why autorotation should be performed between 50 and 70 kts, even though it is possible outside those margins, but with a significantly higher rate of descent at slower forward speeds.

If I need to load up my helicopter, or to land in confined areas especially at high altitude, I must count in the necessary power reserves. Otherwise I won’t have enough power left to flare the aircraft out before ground, nor to speed up again for a go-around.

By the way, the backside of this curve is the speed range that must be avoided strictly in a gyrocopter, since it cannot add power directly to the main rotor.

Great advantages with great limitations

Naturally the performance limitations of helicopters are different from those of airplanes. The cruise speed of a helicopter is comparable to an airplane of similar size and weight – up to the aerodynamic limitations of helicopters in general: of course an Mi 26 can’t go as fast as a Boeing 737. The reason simply is that a helicopter’s rotor needs a minimum of rotational speed to produce enough lift at a safe angle of attack (just like an airplane needs forward speed), while airspeed is capped by the changing aerodynamic laws in sonic and supersonic (rotational) speeds at the same time. Even when moving forward in the direction of flight, none of the blade tips should reach or pass sonic speed, even when travelling at VMO.

Attempts to combine the advantages of both rotary wing and fixed wing concerning speed and takeoff/landing flexibility, while reducing their disadvantages, have resulted in hybrid aircraft like the V22 Osprey, or Eurocopter’s (now Airbus Helicopters’) X3, referred to as the fastest helicopter in the world.

One of the disadvantages of contemporary helicopters is a high fuel consumption and as a result a range less than comparable fixed wing aircraft. A JetRanger, for example, is able to carry about 90 gallons of fuel, but it consumes 26 gallons per hour, and more fuel also means less payload. So most helicopter missions require a compromise between payload and range. Additionally, a helicopter’s service ceiling depends largely on its actual payload.

The following tables show the great variation in service ceiling and maximum altitude for hover in and out of ground effect for a JetRanger B2 in relation to temperature, which is a crucial factor for helicopter operations as well as for fixed wings airplanes.

ISA	1179 kg	1361 kg	1451 kg
hover IGE	19600ft	15200ft	13200ft
hover OGE	14900ft	10300ft	5300ft
SC (MCP ?100ft/min)	20000ft	20000ft	13500ft

ISA +20°C	1179 kg	1361 kg	1451 kg
hover IGE	16800ft	12300ft	10200ft
hover OGE	11800ft	7200ft	3000ft
SC (MCP ?100ft/min)	20000ft+	18200ft	13500ft

IGE = in ground effect; OGE= out of ground effect; SC= service ceiling; MCP= maximum continuous power

Despite high costs, not only because of high fuel consumption but also due to high maintenance complexity, in many cases helicopters are the means of choice, in some cases simply because they are the only ones capable of doing a job. In other cases they are still even cheaper than alternate transportation methods. The gross fuel consumption and maintenance costs of trucks on remote tracks in a longer timespan, carrying the same payload, often pile bills up higher in the end than a quick helicopter mission.

Helicopter medevac

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Helicopters are the only practical option for remote medevac operations.

In the vast mountain areas of Irian Jaya, the most efficient way for medevacs over longer distances, especially when involving more than two patients at a time, or for the transportation of community development supplies and construction materials, often is the combined use of available air transportation.

In those cases we formed a transportation chain, in which planes like a Cessna Caravan or a Twin Otter would take payload to an airstrip close by, or pick up patients from there, while our helicopters’ responsibility was to cover the leg between the remote destination and the airstrip – taking multiple turns if necessary.

Sometimes this kind of teamwork with local operators of light aircraft, such as a Cessna 206, was used in a way to pattern daily flight schedules most efficiently for all those involved as well.

In the end, even though there seems to be just one advantage opposing a whole bunch of disadvantages, this one advantage of being able to hover and to vertically take off and land provides a variety of operational fields, some of which are medevacs, transportation to and from undisclosed areas or sling load missions. The latter don’t even require landings on site at all, and most helicopters are able to carry more payload by sling than in the cabin, since the load is located outside the aircraft structure.

Advantages and disadvantages are tied together even considering emergency situations. In case of a total engine failure, the sink rate of a helicopter is going to be higher than an airplane’s and thus its action radius and time left till touchdown will be less, but a helicopter doesn’t have to look out for a long strip; it can auto-rotate right into a relatively small spot.

Autorotation – the big mystery

Helicopter landing zone

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This would be a scary view from an airplane, but it could be an emergency landing spot for a helicopter.

Autorotation is a topic that sometimes confuses even helicopter technicians, pilots or instructors who do not really understand how it technically works. There are ideas circulating, starting from just the momentum of the rotor is kept up by setting the rotor to zero angle of attack, profiting from inertia and hoping the original altitude hasn’t been too high for the rotor to run out of energy before arriving at the ground.

This is obviously wrong, as much as the idea that during autorotation, a helicopter is in kind of a free fall, with the airstream keeping the rotor running, and using this rotation energy to slow the helicopter’s fall before impact. But even if it’s clear to us that such a fall would result in vertical speeds of several hundred miles per hour (if from sufficient altitude), impossible to be absorbed down to zero in a short bracing flare, how does autorotation actually work?

Even though it might sound complicated at first, it is actually simple. An autorotation is a kind of gliding flight (similar to an airplane after engine failure), in which one part of the rotor area is trading altitude for energy, which it absorbs to drive the rotor, while the other part is emitting the gained kinetic (movement) energy in terms of lift.

Autorotation airfoil

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During autorotation, air hits the rotor blade due to rotational movement and the downward glide, resulting in a modestly positive angle of attack.

After having established autorotation by instantly lowering the collective lever all the way down (and thus preventing our rotor from quickly loosing RPM by drag), we have a combination of two inflow directions at our rotor blade profile: horizontally from the front by the rotational movement of the rotor, and vertically from below by our sink rate. This results in an effective inflow from forward below, with the angle depending on the relation between the airspeeds from both inflow directions (see picture at right). In the outer area of our main rotor, the forward speed of the blade is quite high in relation to the vertical speed, which results in an effective direction of inflow at a flat but positive angle, just like in normal flight producing the lift needed to keep flying (i.e. gliding).

This makes it necessary to keep the rotor speed up, and the energy for that comes from the inner part of the rotor area. Here the rotational speed is relatively low due to the small radius of the inner part of the rotor blades, which results in a steeper angle of attack. Steep, but combined with the vertical speed of the sinking helicopter, at an inflow angle that produces thrust to this part of the rotor blade, just like the wind is speeding a traversing sailboat’s cruise, blowing from abeam (see picture at right).

Autorotation airfoil interior view

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Closer to the rotor hub, the angle of attack is much higher, due to slower rotational speed.

Crucial for the correct direction of inflow – and to prevent a rotor stall – is, as always, to keep up rotor speed within the respective limits. Main rotor controls are adjusted for a safe, constant autorotation RPM with the collective lever slightly above the lower stop, so the pilot is able even to speed up rotor RPM during autorotation.

Helicopter pilots usually don’t think much about it; they just use the effects and controls the way they have learned and trained – they’re doing their jobs to save their and their passengers lives. A mechanic’s job is to make sure that it all works the way it’s supposed to. Frequently checking and adjusting the flight controls and lower collective stop to ensure a safe autorotation RPM and its controllability is an integral part of my duties as a mechanic within my current occupation.

Aerodynamically an autorotation is considered the safest flight attitude of a helicopter, since it is the most stable one.

By the way, this is exactly how gyrocopters again are functioning, just with horizontal propulsion (and a rotor slightly tilted backwards) instead of a sink rate providing for the vertical airflow component. And it is exactly the way a maple seed is making its smooth way down from the tree – I have loved this one ever since I was a little boy.

03 MAY 2016

SOURCE: AIRFACTSJOURNAL
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