Helicopter Control:

Vortex Ring State (VRS)

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What exactly is Vortex Ring State?

Much as a fixed wing aircraft experiences a stall, the equivalent in helicopters may be considered as Vortex Ring State. VRS is sometimes also referred to as "settling with power", which adequately describes the condition. In simple terms, this aerodynamic condition occurs when a helicopter descends at low forward airspeed during powered flight, into its own downwash created by the rotor blades. (Thus continuing to "settle" whilst "power" is being applied). VRS thus mostly occurs during landing, but may also occur during high hovers, downwind quickstops, formation flying in the turbulence of other machines or recovery from autorotation with low airspeed.

It is important to understand that three factors simultaneously need to be present in order for Vortex Ring State to occur. The first factor is a very low forward airspeed of less than 20-30 knots, the second factor is a descend rate exceeding 300 foot per second or more and the last factor is that the helicopter must be producing at least 20% or more of available power.

Symptoms of VRS:

The first symptoms of a helicopter experiencing VRS is an increasing sink rate with a decrease of cyclic authority (caused by the turbulence of the air entering the rotor system) together with a serious vibration of the main rotor system and/or juddering of the airframe. The extremely high descend rate may exceed 3000 feet per minute or more and simultaneously uncommanded yaw, pitch and roll of the machine may be experienced. Should the symptoms not be recognised early on by the pilot, recovery becomes impossible. The net result more than likely ends up as a seriously unscheduled landing. (A.k.a crash)

Minor Vortex ring state does occur in some form during helicopter operations but should not become an issue to maintain controlled flight. Most pilots are taught to avoid VRS by maintaining a vigilant watch on their rate of descent (not to exceed 300 fps) and forward airspeed to maintain 30 knots or more as mentioned before in order to maintain translational lift.

Getting to grips with VRS…

Let's take a step back for the moment in order to understand the phenomenon better. Helicopters use a set of spinning blades or rotors to produce lift by forcing the air downwards. In doing so, the blades get forced upwards with equal (but opposite) force according to Newton's third law of motion. We all know that the formula for lift is:

Where V is airspeed of the rotors, S is surface area of the blades and Cl (coefficient of lift) is effectively the angle of attack or pitch of the rotor blades. We'll ignore air density for the purpose of the article.

Consider the rotor hub of a helicopter to that of a rotating bicycle wheel. Obviously the hub of the bicycle wheel will rotate slower than the outside diameter of the tyre itself. In much the same way, a rotor blade rotates around an axis. Thus, the airspeed along the length of the rotor blade will differ according to the distance it is away from the centre of the rotor hub. Taking that argument further and understanding the lift formula, the rotor blade will generate different amounts of lift across its length.

Effectively, the further away we move from the centre of the hub (or the root of the blade), the higher the airspeed and thus the greater the amount of lift being produced. The increased lift translates into increased downwash or induced flow of air being pushed downwards. This is thus at its highest at the actual rotor tip itself. As explained in previous articles, dissymmetry of lift will thus occur. In this case, not between the advancing and retreating rotor blades of the helicopter, but rather between the inner and outer part of the actual rotor disc itself.

The effect itself is a direct result of the dissymmetry of lift between the inner and outer sections of the rotor disc. More air is thus forced downwards (at higher speed) by the outer portion of the blades than the inner part of the rotor disc.

Right, so let's take this argument a bit further and for the moment completely ignore the induced flow or downwash being created by different sections of the rotor disc. If the helicopter was descending at a rate of say 100 feet per minute, the air rushing upwards would meet the rotor disc at a relative velocity of 100 feet as well. So if we bring the issue of downwash back into the equation again…. then the relative velocity of total air "leaving" the rotor disc would effectively be the difference between the downwash "created" by the rotor disc and the velocity of the air flowing upwards to "meet" the rotor disc.

So let's take a theoretical example to demonstrate vortex ring state. Let's say that a helicopter was descending at 100 fpm, with the downwash being created by the root of the rotor disc at 200 fpm and the downwash being created by the rotor blade tip at 600 fpm. Now if the pilot increased the rate of descend to 300 fps (an increase of 200 fpm), the relative downwash created by the blade root has decreased to zero feet per second.

It is now easy to comprehend that if the machine further increased its rate of descent, the relative upward velocity of the air will at same stage exceed the downwash velocity being created by the blade root. Remember that the amount of lift being created is lowest at the blade root, owing to this part of the rotor moving slower through the air, as per our lift formula.

Eventually we decide to increase the rate of descent to 400 fpm. What occurs now, is that the root of the rotor blade has effectively stalled, seeing that the upward velocity of air now exceeds the downwash (or lift) being created by that part of the blade. This produces a secondary vortex ring in addition to the normal tip-vortices (common to all airfoils) created by spinning rotor blades. The secondary vortex ring is generated where the airflow changes from up to down as demonstrated in our example.

This rotor blade stall will spread out further along the length of the blade as the descent rate of the helicopter increases and the relative velocity of the upwards airflow exceeds the downwash velocity created by the rotor disc.