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The number of rotor blades, rotor rpm and rotor diameter have little effect on formation of the vortex ring state, but aircraft with higher disk loading and increased blade twist are more susceptible to it. *Photos courtesy of the U.S. Marine Corps, Airbus Helicopters (below, left) and Robinson Helicopter (below, right).*

NEED TO KNOW

Vortex ring state is one of three distinct working conditions for a helicopter's rotor.

The Vuichard Recovery uses tail rotor and bank to move the aircraft laterally out of the vortex ring.

At the end of this recovery technique, the aircraft is free of the vortex and is at climb power and attitude.

Flying Through the Vortex

A new technique allows pilots to fly out of vortex ring state in a powered climb.

By Tim Tucker

On Aug. 23, 2013, a Eurocopter AS332 with 18 persons on board was on the final stage of an instrument approach to Sumburgh Airport in the Shetland Islands.

As the aircraft neared the minimum descent altitude of 300 ft agl, nose-up pitch was 12 deg and airspeed was 43 kt. At about 240 ft, pitch had reached 20 deg nose-up, airspeed was 32 kt and the descent rate was 1,000 fpm and increasing.

As the Super Puma descended through 100 ft, the airspeed had dropped below the flight data recorder's lower limit of 30 kt, the engine torque had been increased to 115 percent and the rate of descent was about 1,800 fpm.

The aircraft hit the water 1.5 nm short of Runway 09, killing four passengers and seriously injuring three others and a pilot.

More than 10 years earlier, on March 4, 2003, a Robinson Helicopter R44 was the subject of a TV commercial being filmed in Jakarta, Indonesia. While the aircraft was making a steep approach with a 12- to 15-kt tailwind to a hotel's rooftop helipad, it developed a very high descent rate, which the pilot appeared never to arrest. The helicopter struck the helipad, bounced into the air, then rolled off the edge of the building and fell 15 stories into a third-story swimming pool. The two passengers on board were killed, as was the pilot.

Although the U.K. Air Accident Investigation Branch is still investigating the 2013 crash, both accidents appear to be classic examples of a pilot's failure to recover from the vortex ring state, sometimes called "settling with power." (See the sidebar.)

Traditionally pilots have been taught to lower the nose (forward cyclic), reduce power and, essentially, "fly out" of the condition. But there is a much better way, which I have dubbed the "Vuichard Recovery" after Claude Vuichard, a senior flight inspector/examiner for the Swiss Federal Office of Civil Aviation.

The vortex ring state is only one of three distinct working conditions for a helicopter's rotor.

In the common condition, airflow is directed downward through the rotor and the rotor disc moves in the direction of rotor thrust, as in a vertical climb. This is called the propeller working state, or sometimes the normal working state. Hovering is the static thrust condition in this state.

If the hovering helicopter descends at greater than 300 fpm, it enters the vortex ring state. Here, the rotor still directs the air downward, but some air below it is forced out radially and up outside the rotor disc. Some of this upward-flowing air is drawn in and back down through the rotor. This forms the large circulating pattern called the vortex ring state. (Smaller vortices are formed inboard on each blade near the rotor hub but are of little consequence.).

The vortex ring state also can be recognized when airspeed is less than effective translational lift and random yawing and pitching produces a wallowing effect and buffeting or shuddering of the aircraft. Classic examples include out-of-ground-effect hovering and steep approaches downwind.

The vortex acts perpendicular to the main rotor. If the pilot applies forward cyclic to recover, the tailwind blows the vortex in the same direction the aircraft is moving and delays recovery.

The third distinct rotor working condition—the windmill brake state—is encountered if the descent is allowed to continue to greater than 2,000 fpm. In this state, the flow of air is pushed entirely upward through the rotor. Rotor thrust is achieved by actually slowing this upward flow. The force generated by the rotor is equivalent to that produced by a parachute of the same diameter.

Interestingly, the boundary between the vortex ring state and the windmill brake state is the ideal autorotation condition.

George de Bothezat first recognized the vortex ring state in 1922 with his "flying octopus," a machine with four massive, six-bladed rotors (very similar to many drone designs we see today). Since then, numerous flight tests, wind tunnel experiments and mathematical modeling efforts have refined our understanding of the vortex ring state. It is understood that the number of rotor blades, rotor rpm and rotor diameter have little effect on the vortex ring formation, but helicopters with higher disk loading and increased blade twist are more susceptible to it.

"Settling With Power"

In the U.S., there seems to be a great deal of confusion on whether the vortex ring state should be properly or improperly referred to as "settling with power." The controversy stems from a condition completely different from the vortex ring state, in which engine power required exceeds engine power available.

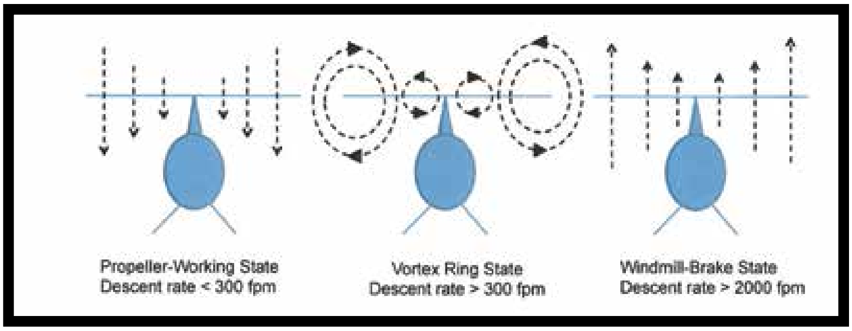
Over the years, various aviation organizations have used conflicting terminology in discussing these very different conditions.

In the 1950s, the U.S. Navy referred to the vortex ring state as "power settling" and used the term "settling with power" for the power-available-vs.-power-required situation. Not wanting to let the Navy set the standard, the U.S. Army reversed the terminology in the 1960s. Army pilots in Vietnam used the term "settling with power" to refer to the vortex ring state and "power settling" when they were trying to get out of a tight landing zone with too many troops onboard.

The FAA uses "settling with power" in its discussion of vortex ring state in both the Rotorcraft Flying Handbook and the Practical Test Standards (probably because there are more former Army pilots in the FAA than former Navy pilots).

Outside the U.S., the picture is much clearer; for the most part, the term used is "vortex ring state."

I say, let's call it what it is—the "vortex ring state," not some vague term that has different meanings to different pilots.—*Tim Tucker*



In the propeller working state, air moves down through the rotor. At a descent rate greater than 300 fpm, the vortex ring state begins; some downflow moves radially out under the rotor disc and is drawn up and into the rotor. In the windmill brake state, all air moves up through the rotor.
Illustrations by Tim Tucker

Now as for the "Vuichard Recovery," I was introduced to the technique while teaching a Robinson Pilot Safety Course in Neuchatel, Switzerland in June 2011. The previously mentioned Vuichard was one of the attendees. During the flight portion of the course, in a Robinson Helicopter R44, I went over the standard vortex ring state recovery technique that had been taught to pilots here in the U.S. for more than 60 years. Vuichard is a helicopter pilot of more than 35 years with more than 16,000 flight hours. This supposed student then asked me if he could demonstrate a recovery technique that he had developed over the years as a pilot conducting long-line operations in the Swiss Alps.

I'm normally fairly reluctant to heed such requests from a trainee who wants to "show me" one of his or her own techniques. This is especially true outside the U.S., where I'm not familiar with local standards and practices. But in this case, I hesitantly agreed.

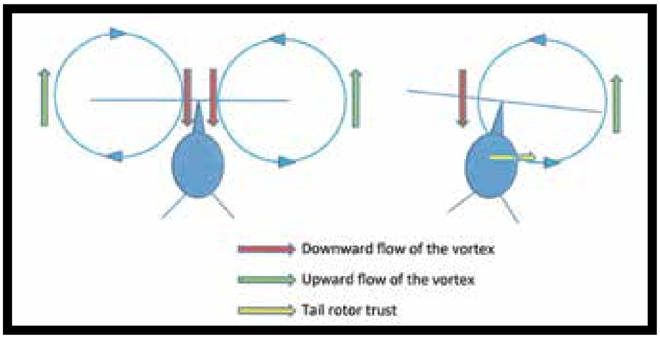
Rather than forward cyclic and reduce collective (as I have been teaching and evaluating for years), he actually increased the collective to climb power, added the appropriate left pedal to keep the nose straight and applied right cyclic. The combination of tail rotor thrust and right bank moved the aircraft to the right and almost immediately out of the vortex ring. I was amazed. After a little practice, I was making recoveries from a fully developed vortex ring state with only 20 to 30 ft of altitude loss.

For the past two years, we have been teaching the Vuichard Recovery with great success in the safety courses at Robinson's Torrance, Calif. plant and abroad. Additionally, I have included it in the maneuver guides for R22, R44 and R66. Pilots quickly see the recovery is accomplished more efficiently with much less altitude loss than the traditional method.

One common student error in the Vuichard technique is not coordinating enough left pedal with the increase in collective, allowing the nose to yaw to the right. Remember, it is the tail rotor thrust that helps move the helicopter to the right to enable the recovery, so the left pedal is essential. When teaching the recovery, I find it a little easier for pilots to break the procedure down into two steps. First, apply the right cyclic to establish a 10- to 20-deg bank angle, then increase the collective to climb power coordinated with the left pedal. Once the two-step process is mastered, it is quite easy to then progress to smooth, simultaneous control inputs.

As with the traditional method, I recommend practicing the Vuichard Recovery so that it can be completed above 1,000 feet agl. For demonstration purposes, I frequently allow a high descent rate to build prior to initiating the recovery to clearly show how efficient this new technique really is. However, in the real world, early recognition and initiation of the recovery is key to minimal altitude loss. Once proficiency with the technique is achieved, pilots should practice recovering from the vortex ring state as soon as the condition is recognized.

It is interesting to compare the two techniques at the point of exit from the vortex ring. Traditionally, when the aircraft is clear of the vortex, the helicopter is in a dive caused by the nose low attitude, power is reduced and the descent rate is high. For the entire time the pilot is correcting to a climb attitude and climb power, the aircraft is losing altitude. With the Vuichard Recovery, at the point the aircraft is clear of the vortex, climb power and attitude are already present so altitude loss is minimized.



In the Vuichard recovery, the pilot increases collective to takeoff power, adds appropriate pedal and applies right cyclic for a 10- to 20-deg bank. The recovery is complete when the rotor reaches the upward flow of the vortex.
Illustrations by Tim Tucker

I'm convinced the Vuichard Recovery is a tremendous improvement and can greatly improve the safety of operations close to the vortex ring boundaries. Instruction should begin at the student pilot level to build an instinctive, intuitive reaction and continue throughout one's training.

It is important for the FAA to include a specific discussion of the method in the Rotorcraft Flying Handbook and the Helicopter's Instructor's Handbook so that pilots and instructors could quickly exit from this potentially fatal condition.

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