

4RESCUE 4RESEARCH

4RESEARCH is the regular scientific attachment to 4RESCUE. In this edition you find the description and findings of the DLR (German Aerospace Center) project on the use of active sidesticks in helicopters.

We would like to call on you to send in your manuscripts for review and publication. The size should not exceed 15,000 characters (including spaces). For the next issue, please send an abstract of your paper until February 5, 2010.



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Active Sidesticks

Using active sidesticks to cue the pilot for vortex ring state avoidance

The risk of VRS

In the world of rotorcraft, the overall safety record is not quite as good as that of fixed wing aviation. Studies on rotorcraft safety repeatedly point to the fundamental problem of pilot workload saturation. The helicopter pilot often finds himself in a situation where too many things simultaneously require his attention. Even if the next event is of a dangerous nature, he may not be able to cope up efficiently to all demands and may neglect to act upon certain events. The consequences can be catastrophic. One example of such a potentially dangerous situation is the vortex ring state (VRS) which happens when a helicopter descends too fast at low forward airspeed. Figure 1 shows a smoke visualization of a helicopter model in VRS. It is characterized by a strong recirculation through the rotor, which causes loss of thrust and leads to even higher rates of descent and poor controllability. Although helicopter pilots are trained to avoid the VRS, accidents are happening. Many of these occur at altitudes below 200 feet and at low forward speed, typically in the late phase of landings where little altitude remains for evasive actions. In many cases, pilots did



Figure 1: A wind tunnel model helicopter in vortex ring state. Picture copied from: J Meijer Drees, W.P Hendal, Airflow patterns in the neighbourhood of helicopter rotors. Aircraft Engineering and Aerospace Technology, 1951 vol. 23 (4) pp. 107-111

not recognize the situation as VRS and made matters worse by pulling up on the collective stick to arrest the sink rate, thereby increasing the rate of descent further. This is the crux of the VRS: it often happens at low altitude and leads to a rapid loss of altitude. Escaping the VRS requires altitude, which then may not any longer be at hand. Therefore, the best way to handle the VRS is to avoid it.

Therefore, the German Aerospace Center (DLR) has started a project to

develop a tactile cueing function for pilot assistance that ultimately is to be test flown on the DLRs Flying Helicopter Simulator (FHS), shown in figure 2. This is a unique research platform due to its experimental variable stability control system. DLR's French partner ONERA (Office National d'Études et de Recherches Aéropatiales) has brought an important input to this project in the form of a model for predicting the closeness to the VRS. This model has been developed over the years based on real flight tests into the VRS and has the advantage that it delivers a real time estimate of the closeness to and risk of VRS.

Using active sidesticks

With the FHS, the DLR develops advanced flight controls, tactile cueing, envelope protection, and handling qualities. For this purpose, the FHS is equipped with a fly-by-wire/fly-by-light control system which is capable of testing experimental algorithms and features active sidesticks, a sort of highly refined force-feedback sticks, replacing the conventional cyclic and collective control inceptors. The active sidesticks can generate warning hints and cues felt by the pilot as if an un-tiring helper was sitting next to him for assistance in difficult

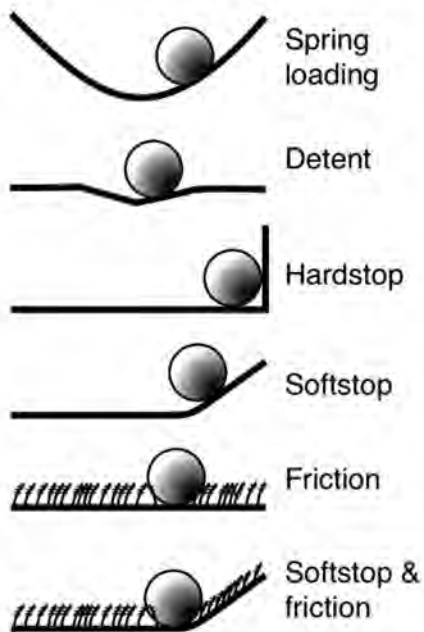


Figure 3: The active sidestick is capable of generating a wide range of artificial force feels, here visualized as a ball on different shaped surfaces.



Figure 2: DLRs Flying Helicopter Simulator

situations. The active sticks are capable of generating a wide variety of force cues as shown in figure 3. These different force cues can be combined as well as moved relative to each other and the stick position. This makes them ideal giving warnings at discrete points of stick deflection. Another advantage of the active stick is that it can adapt its control force feel across the flight envelope so that the pilot always has the best possible control force gradient.

For the VRS-avoidance function, a combination of softstop and friction is used. The friction emulates the normal friction brake known from helicopters. The onset point of the softstop is continuously recalculated so that it is felt at a position that corresponds to the maximum allowable sink rate. In order to fly at this maximum rate of descend, the pilot simply pushes the collective stick to the softstop and knows that he is being guided. In this situation, he knows that he needs not any longer to monitor the vertical airspeed indicator, thereby relieving him to better monitor the outside world and avoid obstacles. Should the pilot find it necessary override the limitation, he no longer needs to push and deactivate any buttons. He simply pushes the stick through the softstop, which is limited to a force of around 20 N (approx 4 lbs). This gives the pilot the best of both worlds: a flight envelope protection that still allows the pilot to use the full potential of the helicopter.

Where to expect VRS?

Every helicopter pilot learns that he has to avoid high rates of descent at low forward airspeeds. Generally, a rule of thumb such as: "never descend faster than 500 ft/min at forward airspeeds lower than 30 kts" is used. Using such fixed rules has the disadvantage that they disregard parameters such as helicopter mass and air density. In this work, the cooperation with ONERA has allowed the use of a prediction model that continuously takes into account these parameters as well as the forward and vertical airspeed. It is called the "epsilon" model and is based on real flight tests into the VRS. To establish the model, test pilots repeatedly flew into the VRS at different combinations of airspeeds, mass, and air densities. The result is a



Figure 4: Active cyclic and collective stick in the cockpit of the FHS

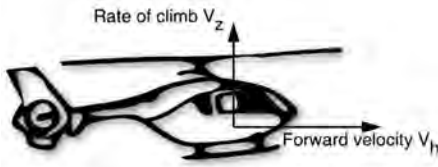
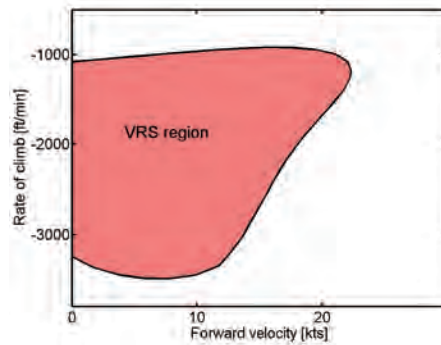


Figure 5: The epsilon model predicts the onset of the real VRS at combinations of forward airspeed and sink rates as shown by the inner region of the figure.



model that calculates a value for the single parameter ϵ , which expresses the immediate danger of VRS. The cueing system uses this parameter as input and calculates the softstop onset point on the collective stick in a way so that, by following it, the pilot knows that he is kept clear of the VRS.

Simulator tests

A first step in assessing the cueing function was to test it thoroughly in the ground based FHS system simulator which is a hardware-and-software-in-the-loop simulator of the FHS. The experimental hardware in the simulator is an exact duplicate of the flying experimental system, allowing the researcher to simply transfer the developed software to the FHS by means of a flash-memory card. The objectives of the simulator trials were to test and ensure stable, correct, and predictable handling of the cueing function. Also important was to test that the cueing function works well for various tasks. Finally, the amount of workload reduction in VRS-related situations was evaluated. For this purpose, the NASA Task Load Index (NASA-TLX) was used. To measure the workload, the pilots are asked to return ratings for 6 different factors after having performed the task. These are 1) mental demand, 2) physical demand, 3) temporal demand, 4) performance, 5) effort and 6) frustration. The pilot is also asked to rate these factors against each other, thereby giving an idea, of what factors influence workload the most. In the end, the ratings are combined to single number that defines the weighted workload for the task as experienced by the pilot.

In general, several different tasks are used for flight handling evalua-

tions but most of these are designed to stay within a safe flight envelope with respect to VRS. Therefore, to evaluate the workload reduction by using the VRS-avoidance-function, new task had to be designed, that drive the operational condition closer to the VRS regime. Two task elements were used: a vertical remark (bob-up-down), and a flight along a downhill slope.

Vertical remark

This task was taken from a handling qualities design guide (the ADS-33E) which, among other parts, contain a catalogue of flight test maneuvers used for handling qualities evaluations. The task is called „vertical remark“, also known as bob-up/bob-down, shown in figure 6. In its original form, it aims at testing the ability to „accomplish an aggressive vertical descent close to the ground“. It also

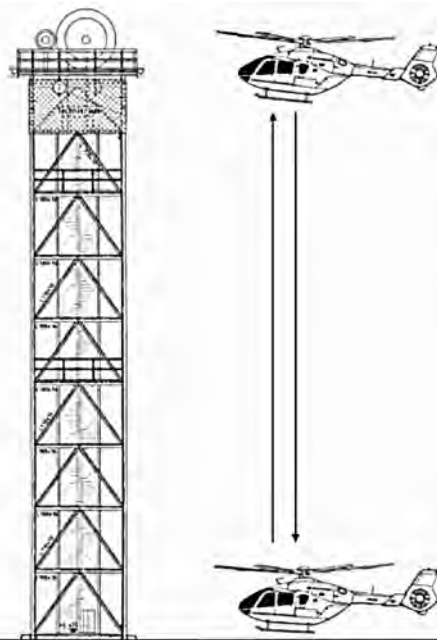


Figure 6: Vertical remark, or bob-up-down, is a task that pushes the pilot to attain high rates of climb and descent

tests the ability to combine vertical and lateral aggressive maneuvering. In its application to testing the VRS-avoidance function in this paper, mainly the first of the objectives was tested. A telemetry tower was used as maneuver reference. For the task, pilots started from a stabilized low hover aside the telemetry tower. They then climbed to the top of the tower, stabilized a few seconds and descended to the original hover position. Contrary to the original maneuver as defined in ADS-33E, no requirements were made as to how well or how long the pilot has to hold the upper hover position since only maintaining safe rates of descent was of interest in terms of VRS. The pilots quickly familiarized with the cueing function. Using it as a guide for finding the targeted rate of descent was easy, as one pilot stated:

You put down the stick [to the soft-stop].

You reach the max rate of descend, you go down,

and at the end of the maneuver, you stop. That is it!

Pilot A

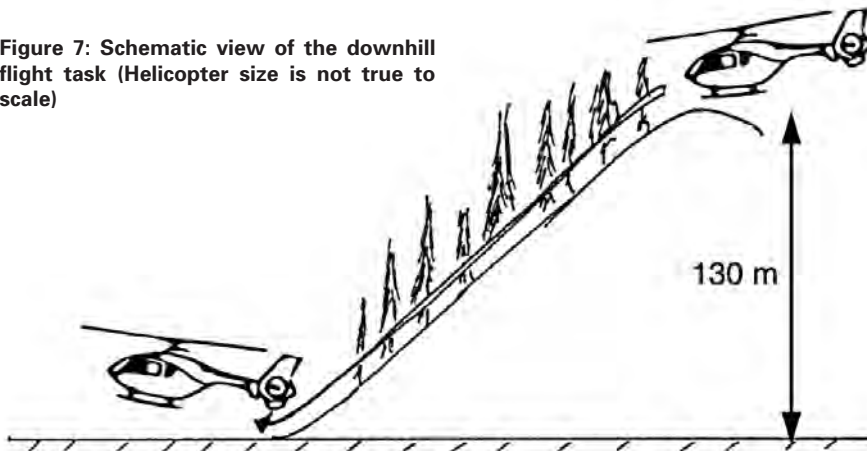
Downhill flight

In order to better study the effects of using the cueing function for periods > 10 seconds, a somewhat extended task was developed. It consisted of flying down along a hill of 130 m height over the surrounding area and covered with trees as shown in figure 7. Through the trees, an S-shaped track approximately 3 rotor diameters wide was made. Orange traffic cones were placed in the middle of the track for the pilot to follow as shown in figure 8. A tailwind of 10 kts was added to increase the pilot workload during the task. The task was constructed to contain elements similar to those experienced when making a steep approach for landing into a confined area.

The pilots were to perform the tasks within a safe flight envelope, but also as fast as possible. Nevertheless, as in a simulator no risk of life is involved, and since the fixed base prevents the pilots from feeling acceleration and speed, it was very important to stress that the task was

to be flown with the same caution as in a real helicopter. In this task, the pilots were asked to perform the following steps:

Figure 7: Schematic view of the downhill flight task (Helicopter size is not true to scale)



1. Start in a hover immediately above the ridgeline of the hill
2. Target and reach a rate of descent as high as you would feel comfortable with in real flight
3. Fly and remain below treetops
4. Follow s-shaped track marked by cones down along the slope
5. Stop to hover or land at the foot of the hill

Overall, the task was found difficult due to a high obstacle density and the required manoeuvring accuracy. This required the pilot to focus outside the cockpit, preventing him from monitoring the rate of descent on instruments. A contributing factor is also the simulator itself. The old simulation problem of lacking visual cues such as moving grass or other microtextures degrades the perception of motion for the pilot. Despite this, they found the tactile cueing on the collective very helpful for main-

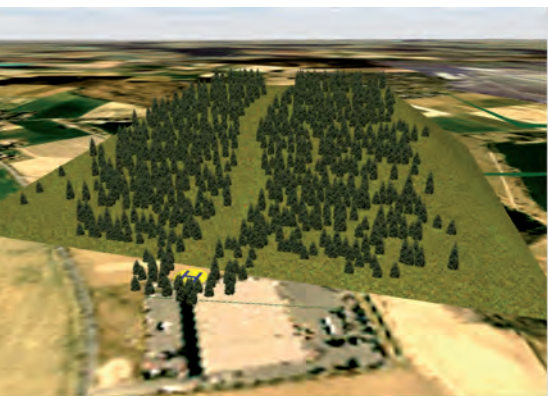


Figure 8: The hill with its S-shaped track through the trees. Yellow traffic cones are placed along the middle of the track, for the pilot to follow.

taining a safe rate of descent without having to monitor instruments thoroughly. Without cueing, the task was still flyable but pilots had to

concentrate more on maintaining a safe rate of descent, which ultimately increased the workload and risk of accidents. A significantly higher workload compared with the vertical remask was noted and it was concluded that the task was well suited for workload rating.

By adding cueing, an immediate difference was seen in the activity on the collective stick. Without cueing, the pilot would make numerous corrections and constantly have to monitor the vertical speed indicator and adjust the rate of descent. With cueing, the pilot could use the soft-stop as guide and the activity was much lower. The pilot no longer needed to make continuous corrections and a more steady control behaviour was observed. Speaking in numbers, adding cueing reduced the number of collective inputs by 40% to 80% depending on the pilot. The corresponding values of which denote the closeness to VRS would stay at safe level throughout the task. Also, the cue helped in quickly attaining and maintaining the targeted rate of descent and an overall reduction in task duration could be seen: without cueing, the test run would take roughly 70 s, whereas adding cueing reduced this time by around 20 s!

In general, the cueing-function has been rated very positively. Typically, the rating of the „physical demand“, „temporal demand“, and „effort“ showed the biggest improvements. The „temporal demand“

was rated as relatively unimportant. This is related to the way the cueing effectively indicates a limit for the rate of descent. The pilots knew that descending faster was not an option. As a consequence, they did not care about the duration of the task.

Two out of three pilots experienced significant overall workload reductions with clear improvements in all rating dimension when the cueing function was used. Expressed as overall weighted ratings, these pilots experienced drops from 0.9 0.52 for pilot A and 0.99 0.64 for pilot C. Pilot B returned moderately improved ratings of 0.84 0.8. This pilot noticed that cueing did reduce the workload on the collective stick but also led to an increase of workload on the cyclic stick in order to control flight path angle. Furthermore, he noted that the cueing required a re-learning that may take time for experienced pilots. This behaviour was not observed with the other pilots.

NASA TLX Workload	Pilot A	Pilot B	Pilot C
No cueing	0.9	0.84	0.99
With cueing	0.52	0.8	0.64

Next steps

The excellent results gathered so far in DLR's simulator, encourages DLR to do the next steps and continue with flight tests on the FHS. Of course, there are some engineering hurdles to overcome, among these a general ruggedization of the cueing system software. These have been met and next step is to test the cueing function in flight onboard the FHS which will take part in 2010. The emphasis of the flight tests will be on demonstrating the cueing function under real flight conditions with all their aspects. The key is to show that cueing functions help the pilots to lower workload while not limiting their choice of actions.

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