THE MYTH OF LOSING TAIL ROTOR EFFECTIVENESS

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Abstract
The helicopter community has been plagued during the latest forty years by accidents due to unanticipated yaw, also called Loss of Tail rotor Effectiveness (LTE). How the problem was identified and what answers were given are first reconstructed from period documents and Airbus experience. A part of the mystery still remained and especially no clear explanation of the phenomenon was given. An analysis of accident databases existing in different countries is then presented. The figures are somewhat amazing and a yearly average exceeding 18 accidents was identified. Surprisingly three out of four accidents take place in the close vicinity of the ground where the recovery actions recommended in AC 90-95, the authoritative document about the topic, are not applicable. An explanation of the phenomenon is proposed, using the pedal curve as a tool. It allows understanding how and in what conditions unanticipated yaw occurs in the simplest case, hovering with wind. It also shows that recovery is affected by the modification of the pedal position at trim induced by the change in heading coming from the yaw rate, which makes the pilot feel the tail rotor to be ineffective. Accidents most probably occur because pilots do not use pedal corrections of sufficient amplitude during recovery. A more complex case is also analyzed, low speed turns to the right in ground reference with wind, as used during photographing or filming flights where unanticipated yaw often takes place. Such events are shown to occur when entering tailwind conditions, where the airspeed is reduced while a side wind component exists. A few myths grown on our poor understanding of the issue are then corrected, highlighting the unsafe way of flying helicopters with left wind, when performance is limited. The pedal curve provides a clear understanding of unanticipated yaw and gives an opportunity to solve that problem. This asks to build a unique, clear and consistent message toward pilots, appropriate to the low height conditions where the problem occurs, that shall be propagated by Authorities, Industry and Flight Schools.

1. INTRODUCTION

From time to time a single rotor helicopter operating at low speed starts spinning against the will of the pilot, who does not succeed to stop the rotation. It crashes while still yawing and this usually results in significant material damages and, too often, in fatalities or injuries. The following investigation shows that no failure was existing before the event : this is a typical unanticipated yaw accident, also designated as Loss of Tail rotor Effectiveness (LTE).

This problem was discovered by US Army in the end of the seventies after a series of accidents on the OH-58 Kiowa helicopter and was never fully explained. Remedies were defined and later urged to civil helicopters when it became obvious that they were also prone to such events. This did not solve the issue and many similar accidents still occur, as shown by an analysis of civil investigation reports, which mainly tells us that recovery actions recommended in AC 90-95, the authoritative guidance on that topic, are not applicable in 75% of the reported accidents. It is therefore worth having another look on that topic.

The pedal curve provides the yaw control trim position in hover with wind as a function of the wind heading. It will be shown to allow understanding most of the problem. How unanticipated yaw starts, why pedal effectiveness is felt to be so poor can be explained. Some convictions, shared on forums, can be shown to be only myths, the first one being that tail rotor may lose effectiveness.

The unanticipated yaw behavior depends on the main rotor sense of rotation. Similar results can be found in both cases, but the preferred yaw direction is changed. All comments and illustrations in this paper are given for helicopters which main rotor rotates counter-clockwise as seen from above (US sense of rotation).

2. A HISTORICAL VIEW

2.1. In the US Army

The first clear mention of a phenomenon involving an apparent loss of tail rotor effectiveness may be

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found in [1], reporting in 1977 a series of accidents on OH-58 helicopters that are not due to maintenance error, materiel failure or exceedance of an aircraft limitation. Although flights were planned and conducted according to Army aviation procedures, conditions were encountered where pedal inputs were unable to stop the right yaw rate that built. The proposed explanation is that full left pedal, added to the left wind component induced at the tail rotor level by the right yaw rate, make the blade angle of attack increase too much, leading to tail rotor stall. That explanation is the title of a reprint made about one year later [2].

In 1980 another paper [3] is written by a British exchange officer assigned to US Army Aviation Center of Fort Rucker. It provides a theory developed in the Empire Test Pilot School of Boscombe Down about this phenomenon that is named “tail rotor breakaway”. The issue had therefore already been found on other helicopters in Great Britain and tail rotor stall is also considered there as the cause. Four factors are deemed necessary to enter the problem : a high power, a decelerative attitude, slow airspeed and relative wind coming from the left.

In 1982 the “Loss of Tail rotor Effectiveness” designation appears [4], but “tail rotor spin” is also used [5]. At that time, the US Army has recorded 18 OH-58 accidents caused by that phenomenon since 1973, with an increasing rate (already 5 accidents in the current fiscal year). The tail rotor of the Kiowa helicopter is acknowledged as being marginal according to US Army criteria and this is seen as a contributing factor. The limited experience of the involved pilots is also pointed out but the difficulty of the mission of the OH-58, most often flown by a single pilot, shall not be underestimated.

Investigations are decided and the first results are published in 1983 in a Bell Operations Safety Notice sent to Bell 206 operators that can be found in [6], with also a complementary information letter issued the following year. The phenomenon is designated as unanticipated yaw and the first graphs showing in what wind azimuth conditions it may occur are provided, as well as a recommended recovery technique associating full opposite pedal, forward cyclic and, if altitude permits, power reduction. The information letter clearly utters that the tail rotor is not stalled and that the corrective pedal input shall always be opposite to the turn direction.

The reason for this statement is better understood when reading [7]. Published in 1984 this paper makes it clear that the previously recommended procedure in the US Army in case of a LTE event had been to remove some left pedal, most probably in the goal of cancelling the tail rotor stall condition that was thought to be the origin of the problem. The investigations that were made are summarized and a new procedure similar to that provided in Bell letters is recommended. Systematic investigation of combinations of control inputs had been made and the most effective was found to be full opposite pedal associated with forward cyclic. It was always possible to stop yaw rates as high as 115 degrees per second, not only with an improved tail rotor but even with the early OH-58A tail rotor considered as being marginal. Whether the forward cyclic was mandatory or only a way to make performance better is not clear. Improvements to the product aiming at decreasing the occurrence of LTE are announced, including a Power Droop Correction kit, the more powerful tail rotor and a Stability Control Augmentation System.

After 14 months without LTE accident, a new one occurs beginning of 1985 [8], providing an opportunity to recall what is LTE, in what conditions it may happen and how to recover.

A few months later it is necessary to state that all unexpected events are not LTE after a pilot applied the LTE recovery procedure following a gust lifting the tail of the helicopter, without significant yaw motion [9]. The obsessive fear of unanticipated yaw is such that people see that problem when it is not…

The Kiowa is not the only helicopter that encounters unanticipated yaw, as shown in a 1987 paper [10] covering a UH-1H accident. In altitude conditions, the crew made two approaches on what they thought to be the wreckage of another helicopter and entered twice in unanticipated yaw. Apparently the pilot knew how to recover but failed in the second occurrence. “Loss of heading control” is used to define the issue, not LTE.

Another occurrence is found in 1988 [11]. A Kiowa in left wind hover tends to yaw right. The copilot tries to escape by the right — another helicopter is on his left side — adding right pedal and some collective to transition to forward flight. The OH-58 enters unanticipated yaw. Full left pedal is said to have been applied but it does not stop the spinning and the helicopter crashes.

In September 1992, Flightfax celebrates its 20th anniversary and attempts to summarize those 20 years: “*Problems addressed in those early years included such things as mast bumping, dynamic rollover, and loss of tail rotor effectiveness (LTE). While there are still some accidents where pilots induce a dynamic rollover or fail to anticipate wind conditions and experience LTE, intensive training efforts and some aircraft redesign have greatly*

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reduced these kinds of accidents."

The status of the problem seems to be almost unchanged from that time. No big epidemic of helicopters spinning out of control exists but, from time to time, one case reported in Flightfax — not only on OH-58 but on any of the single rotor US Army helicopters — very much looks as an unanticipated yaw event, as far as it may be assessed from the initial description of an accident.

2.2. In the British Army

The US Army is not the only helicopter operator faced with the unanticipated yaw problem. In the 80s, British Gazelles suffer from a high accident rate due to losses of control in yaw. When hovering in wind, unanticipated left yaw builds — or yaw rate rapidly increases during left turns — that pilots do not succeed to stop. This often ends with substantial damage of the helicopter… This looks quite similar to the problems encountered by US Army with the OH-58, but on the left hand side because of the French sense of rotation of the Gazelle main rotor.

The issue is raised to the manufacturer, at that time Aerospatiale Helicopter Division that will later merge with the Helicopter Division of MBB into Eurocopter, now Airbus.

The strange point is that almost only the British Gazelles suffer from that problem. One or two accidents in the French Army present similar features, which is nothing compared to the number of accidents in the United Kingdom. An AAIB accident analysis [12] reports 15 losses of yaw control accidents or incidents in UK Armed Forces.

A tale was born there that the Fenestron® stalled when full pedal was applied. The official procedure at that time, in case of unanticipated left yaw, can still be found in a CAA analysis of tail rotor failures [13] : "*Recommended procedures for military operators following Fenestron® stall have included reducing right yaw pedal application until Fenestron® effectiveness is restored and then reapplying right pedal, attempting to shut down the engine, and lowering the collective lever and accepting a heavy landing."* It is quite similar to what US Army recommended some years earlier.

The unanticipated yaw is then not at all understood in Marignane and the tests focus on demonstrating that the recovery is not an issue, which is the experience Aerospatiale has with all their helicopters. The British Navy provides one of their Gazelle helicopters. It is equipped with a test installation and used to investigate whether any flight condition exists where yaw recovery might be a problem. Some flight hours are flown and yaw rates as high as 165 degrees per second demonstrated in different wind conditions. Applying full pedal always allows recovering from those extreme spot turns.

The results are presented to the British Army. Any reference to the Fenestron® stall is removed from documentation and full pedal application is requested in case of unanticipated yaw (designated as yaw divergence in the Royal Navy). The Ministry of Defence issues the Advance Information Leaflet 1/93, including the following information reported in [14] : "*In light wind conditions, an extremely rapid build-up of yaw rate can follow a relatively small left pedal application during low speed flight or in the hover, particularly with the ASE disengaged. In this event, immediate and positive application of right pedal, up to the maximum, should be applied and maintained to arrest the rate of yaw. Recovery action may be ineffective if the pedals are returned only to the hover position, and the yaw rate may initially continue to increase before deceleration and an eventual steady hover is established. Furthermore, if the pedals are not returned as far as the original hover position, a steady hover will never be achieved and the aircraft will stabilise at a particular rate of yaw which may be very high. Pilots may misinterpret this as a loss of yaw control. Be warned that any delay in applying corrective action will require progressively larger right pedal inputs to achieve a steady state hover and may lead the pilot to believe that he has lost control. Yaw rates of up to 165° per second to the left can rapidly be arrested by applying full right pedal without any discernable loss of fenestron performance*." This is a good summary of the Gazelle tests results and it apparently solves the problem : no complaint about the Gazelle yaw control is later received from the UK customer.

2.3. In the civil world

Unanticipated yaw is not exclusively linked to military missions. The civil usage of helicopters increasing, NTSB investigations identify that it is a contributing factor in several civil helicopter accidents. FAA issues then AC 90-95 [15].

It provides most of the material of Bell Information Letter, including the recommendations about recovery actions. AC 90-95 is still today the main source of information about what is called LTE and many accident investigation boards, after an event involving LTE, urge their Operational Authorities to make pilots aware of the content of the AC.

More than twenty years later, having observed that unanticipated yaw accidents still occur (55 identified between 2004 and 2014), NTSB issues

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a Safety Alert [16] to remind pilots of the issue, provide them with recommendations and give them some FAA references for further information, including AC 90-95.

3. DIGGING IN ACCIDENT DATABASES

Accident databases that exist on the web have been explored and losses of control on the yaw axis where no prior failure existed have been inventoried.

The search has been limited to the 2000-2016 period because more recent events might still be under investigation. In these 17 years, as many as 310 events have been found. This makes a bit more than 18 events per year and this is of course not comprehensive. It only concerns civil events that were investigated and reported in the considered databases. Some sites were identified but not further analyzed because of the language barrier. Some of the databases that were processed are quite recent and may not include the oldest events in the considered period.

Not all those losses of control are unanticipated yaw events. Spinning on the ground or immediately following take-off is most likely the indication of a poor mastering of the yaw axis by the pilot. Such events have been considered separately. They are represented in yellow in the figures of this chapter whereas accidents that seem to occur following an unanticipated yaw event are in orange. The latter category is from far the most numerous with about 5 out of 6 accidents.

Figure 1 shows the yearly distribution of the accidents that were found. Those figures should be better related to the number of hours flown but that information is not easily available !

No clear trend is visible. A 5-years sliding average seems to indicate a slight increase but this is not so obvious and could only be due to a higher completeness of the databases in recent events. In any case there is no decrease of the number of accidents. The problem is not improving and there is no reason, if nothing is done, not to record similar figures in the coming years.

About 90% of the unanticipated yaw accidents

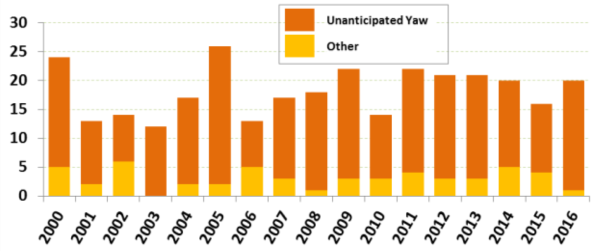

Figure 1: Yearly distribution of accidents

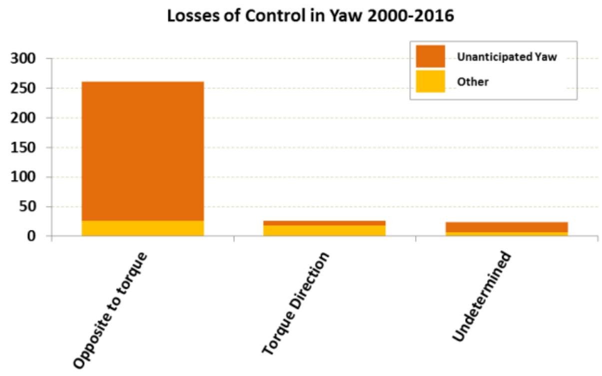

Figure 2: Yaw direction during the accident

take place opposite to the torque direction (rightwards with US rotors, leftwards with French rotors) and only 3% in the torque sense. The status is quite different for the other accidents, with 52% opposite to the torque direction and 35% in the torque direction. Summing both values does not lead to 100% as the spinning direction is not explicitly provided is some cases or is contradictorily reported (Figure 2).

35 of the 310 accidents (1 out of 9 accidents) resulted in at least one fatality, with an average of 1.7 fatalities per fatal accident. 77 accidents (1 out of 4 accidents) resulted in at least one serious injury, with an average of 1.6 serious injuries per accident. Losses of yaw control occur in the low speed range, usually close to the ground. The consequences are often limited, at least at human level. From a material point of view the helicopter is in most cases destroyed and otherwise badly damaged. A usual end to an unanticipated yaw accident is a helicopter lying on its side. Minor damages are recorded in only very few cases.

Figure 3 provides the country where the accident report was issued. Unsurprisingly the USA are far ahead. Just behind but at a much lower level is the United Kingdom, followed by Australia and South Africa. All others are well below one accident per year. Here again the comparison would be much more interesting if those figures could be compared to the level of helicopter operations in each country.

The next plot in *Figure 4* presents the missions that were flown when the accident occurred. Private flights come first. This may be linked to the pilot's experience, especially when considering that training is second. Almost half of the training accidents occur during solo flights that only represent 20-25% of syllabi. Accidents with an instructor aboard are however not exceptional, which shows that instructors are not much better prepared to deal with such an event than their student pilots. It is also significant that most of the losses of control that do not look as unanticipated

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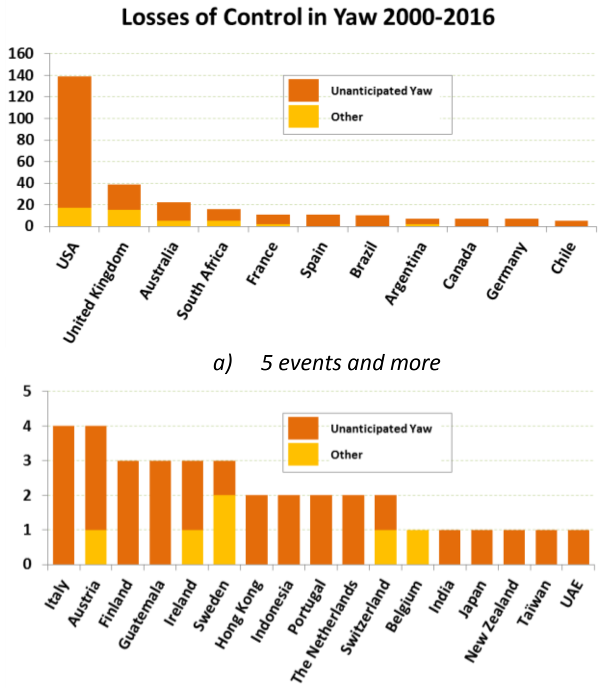
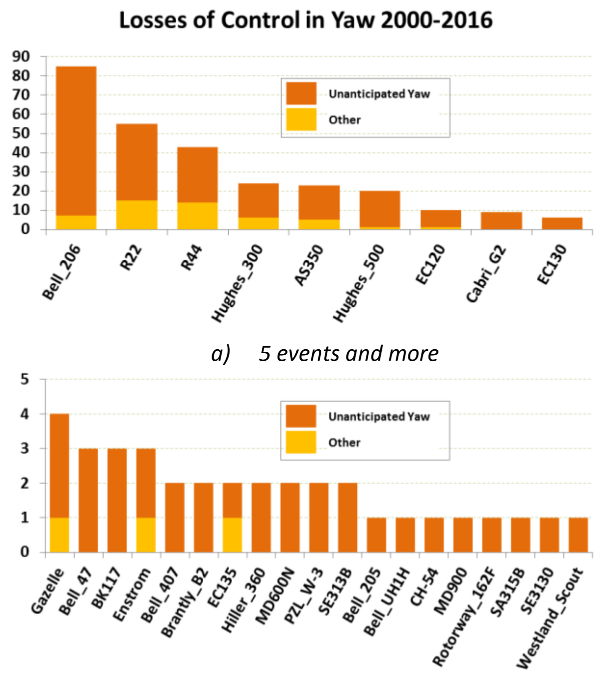


b) Less than 5 events

Figure 3: Origin of the accidents



b) Less than 5 events

Figure 5: Helicopters involved in the accidents

yaw also mainly occur during private and training flights.

Passengers' transportation/utility is at a level that is certainly not representative of the time spent in those helicopter operations. Flying low speed is there almost limited to take-off and landing and helicopters are thus not much exposed during these missions. All other missions require flying low speed in ground reference. Filming or photographing comes just after training, at the same level than passengers/utility flights but certainly with much less time spent in the mission. This will justify having a further look on this specific use in the paper.

The helicopter types that were involved in the accidents were grouped by family to allow plotting *Figure 5*. There is a clear predominance of light helicopters, which is consistent with putting forward private and training flights. There are even very few accidents on FAR/CS 29 helicopters, which demonstrates that commercial pilots having unanticipated yaw accidents are also mostly flying on light helicopters.

It may be noticed that all the involved helicopters have a skid landing gear, but the PZL W-3 and the CH-54. As a wheeled landing gear is only found on big helicopters, this is not new information. The real difference between skids and wheels is the way the helicopter is taxied. About 20 accidents occurred during hover-taxi on helicopters equipped with skids. Of course wheeled helicopters are not exposed to the unanticipated yaw threat when taxiing but it does not seem to be a primary factor.

Some people ensure in forums that the LTE problem is uniquely an issue of the OH-58/Bell 206 helicopter. This is clearly not the case : LTE accidents occur on many helicopters. Of course types that are more numerous, spend more time

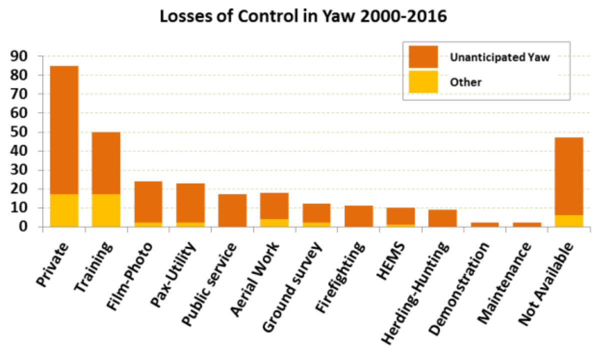


Figure 4: Mission flown when accident occurred

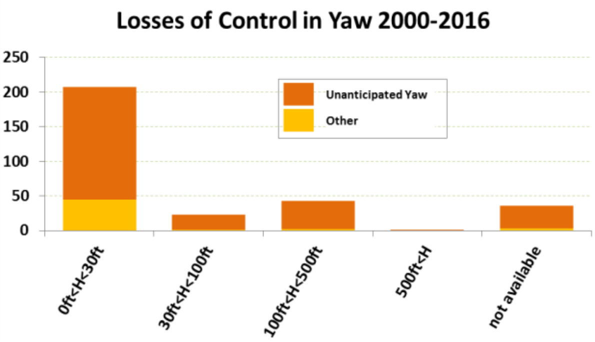


Figure 6: Starting height above the ground

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in the low speed range, are flown by less experienced pilots present a much higher risk of such events…

Helicopters with classical tail rotors, Fenestron® and even with NOTAR® are in the database.

Figure 6 shows the distribution of height above the ground at the time when the event starts. In 3 out of 4 accidents where information is available, it happens quite close to the ground, less than 30ft high and often much less. It was the feeling that came when reading many "LTE" accident reports and it is confirmed by this analysis. In the huge majority of the accidents, the height above the ground does not allow for transitioning the spinning helicopter to forward flight, as recommended in AC90-95 [15], which requires "*Apply full left pedal. Simultaneously, move cyclic forward to increase speed. If altitude permits, reduce power.*" The forward cyclic should be at least as optional as the collective reduction and equally be linked to height availability…

Summarizing the outputs of this analysis leads to the following points :

1) Each year many unanticipated yaw accidents are recorded, everywhere in the world, on many single rotor helicopters, without any trend towards reduction.
2) Light helicopters with low experience pilots are the preferred victims.
3) In 3 out of 4 accidents, the recovery recommended in AC90-95, the reference publication on unanticipated yaw, is not applicable due to the very low altitude where the event starts.

This gives at least one positive conclusion: there is room for improvement…

4. EXPLAINING UNANTICIPATED YAW BY THE PEDAL CURVE

A simple case is considered in this chapter, where the helicopter is making a hover spot turn in steady wind. It makes things easier to understand while being a real accident case. It can also enlighten more complex events.

The pedal curve is perfectly suited to this simple case and allows understanding how unanticipated yaw occurs and in what conditions. It also explains why the tail rotor is felt to be poorly effective during recovery and why a large amplitude pedal input is the only way to safely and quickly exit that uncomfortable phenomenon.

4.1. The pedal curve

It gives, for specified wind speed and WAT (Weight, Altitude, Temperature) conditions, the pedal position at trim in hover as a function of the wind azimuth.

Assuming a wind coming from the north, as in *Figure 7*, it comes to plotting the trim pedal position as a function of the helicopter heading. Zero heading, in the middle of *Figure 7*, corresponds thus to headwind, -90° heading is right wind, 90° is left wind, -180° and +180° are tailwind.

The data in *Figure 7* have been re-plotted from an Australian report [17] following tests on the Bell 206-B1 helicopter investigating the directional control of this aircraft after incidents were recorded.

The pedal curve is a kind of sinusoid with a minimum when the wind comes from the right hand side (critical azimuth) and a maximum when the wind comes from the left hand side.

As a first approximation it can be stated that, for a given wind speed, the main rotor torque is almost constant. Neglecting the airframe yawing moment, a constant anti-torque force, oriented to the right, must be provided by the tail rotor. A right wind component induces some inflow through the tail rotor that reduces the angle of attack on the blade and thus the tail rotor thrust. Maintaining the anti-torque level therefore asks for additional tail rotor collective pitch, i.e. more left pedal. The opposite occurs in a left wind condition where more right pedal is needed. The pedal curve therefore gives an indication of the thrust variations with heading. Increasing (i.e. more right) pedal position means that thrust at constant pitch is increasing.

A higher wind velocity makes the amplitude of the sinusoid increase. At some time the tail rotor performance limit may be reached. It can be seen in *Figure 7* that in the considered WAT conditions 40 kt is beyond this limit, the available tail rotor

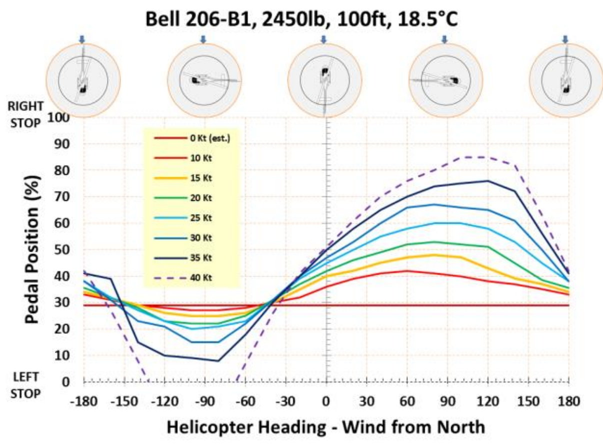

Figure 7: Pedal curves on a Bell 206-B1 with varying wind speed (data taken from [17]

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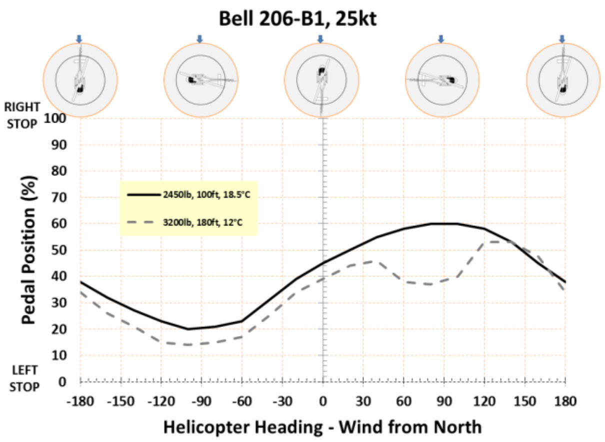

Figure 8: Pedal curves on a Bell 206-B1 with varying collective pitch (data taken from [17]

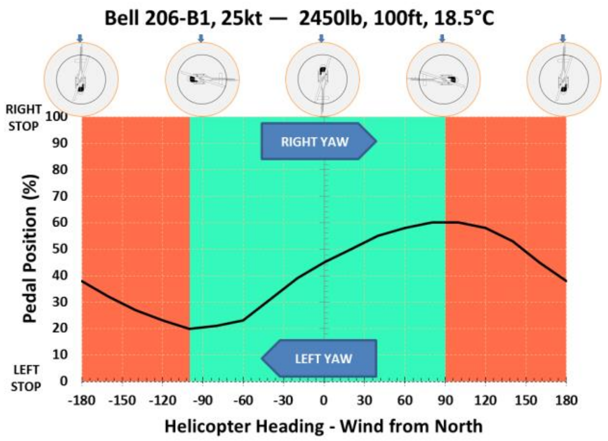

Figure 9: Stable (green) and unstable (red) ranges

pitch being insufficient in right wind.

Another effect is shown in *Figure 8* that is used further in this paper and is quite intuitive. Pedal curves for a unique wind speed and two different weights in almost Sea Level ISA conditions are plotted there. Increasing the weight (more precisely the referred weight, i.e. the weight divided by density, or the collective pitch) asks for more power, therefore more anti-toque, and shifts the pedal curve downwards.

This shift is more obvious on the left side of the figure than on the right side where a strange bump appears, which might be explained by the tail rotor VRS that occurs in 90° heading conditions and induces significant pedal activity, which is only a detail. Keep in mind that an increase of collective mainly makes the trim curve shift downwards.

In the following of chapter 4, the helicopter is making a hover turn in steady wind conditions. A unique curve is therefore only considered in *Figure 9* and is the basis of this analysis. 25 kt condition has been selected so that a significant pedal change with heading exists.

The helicopter may only be stopped on the black curve (zero yaw rate). When the current point (current pedal position, current heading) is brought below the curve, the pedal is more left than the trim position and the helicopter thus yaws to the left. When it is above that curve, the helicopter yaws rightwards. This is recalled by the two blue arrows in *Figure 9* and following.

The green area corresponds to the stable heading range and the red one to the unstable heading range. Stability and instability is driven by the slope of the pedal curve. The helicopter is stable with a headwind component and unstable with a tailwind component.

4.2. Starting unanticipated yaw

The existence of that unstable heading range provides an easy way to start yawing. Holding pedal fixed in unstable position leads the helicopter to depart from that heading. Pilots know the high pedal workload that is necessary to maintain tailwind conditions. Stopping controlling the yaw and blocking the pedal allows the heading to change in the direction of the initial disturbance until the helicopter reaches the stable point corresponding to the pedal position and stops there. This is not the "*uncommanded rapid yaw rate which does not subside of its own accord*" that is described in AC 90-95 [15] and therefore not unanticipated yaw. This behavior is predictable, even if the direction that is taken is random.

Start now in the stable range, in zero wind heading for example. A right pedal step is made (vertical red arrow in *Figure 10*) and leads above the trim curve. The helicopter therefore rotates to the right till it reaches the trim curve again and there it stops, being still in the stable range. In headwind conditions, pedal provides an attitude command : a control step mainly produces a heading step. A second right pedal step has a similar effect, leading to a second heading step, a bit larger due to the change in the slope of the pedal curve.

The third step takes us above the highest point of the pedal curve. This still means a nose-right rotation but the trim curve can no longer be reached — no trim condition exists with this control position — and the spinning does not stop as long as the pedal is not brought back sufficiently left. In this extreme point of the pedal curve, the nature of the response to the pedal control changes. The pilot might expect a step in heading and enters an endless spinning that he

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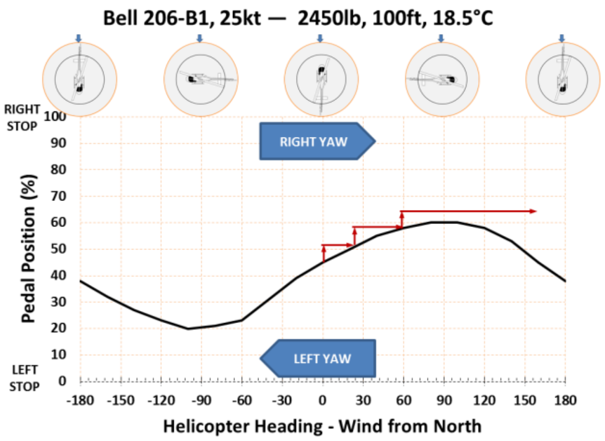

Figure 10: Starting unanticipated right yaw

may feel as not commanded. This fits with the unanticipated yaw description.

There is no wizardry. The helicopter is not yawing by its own accord and that response could be perfectly expected by a pilot who knows exactly the behavior of the helicopter and has a complete understanding of the wind conditions.

The same maneuver may as well be done in the opposite direction. Reaching a pedal position below the lowest point of the pedal curve will as well induce an endless spinning, this time towards the left.

There is no symmetry in the unanticipated yaw accidents. Most of them occur to the right with the US sense of rotation of the main rotor. There are however a few cases that occur in the opposite direction. The above explanation of how unanticipated yaw starts is therefore not invalidated and may as well address those rare left yaw occurrences.

It is however necessary to understand why so many accidents take place on one side, and so few on the other.

The pedal position when the unanticipated yaw starts may be an explanation. In the first case it was a comfortable almost centered position, not worrying at all. In the second case, it was extreme, not far from the left pedal stop and this provides a warning to the pilot. If he carefully monitors the yaw rate, nothing happens. He is more urged to do so it when he knows he is coming close to helicopter limits.

Perhaps more convincing, unanticipated right yaw may be wrongly perceived as a complete loss of tail rotor thrust, for example as it can exist after a tail rotor drive system failure. Sudden right yaw acceleration occurs in both cases and it is very unlikely that any pilot has sufficient experience of both phenomena to make a clear difference. When it occurs on the other side, left yaw is not the result of a loss of tail rotor thrust but of an excessive tail rotor thrust, which is not the result of a simple failure. It might come following a tail rotor servo-control commanding maximum pitch, which is certainly not what a pilot fears the most.

Eventually counteracting a right yaw asks for increasing the tail rotor pitch and boosts the power consumption. The pilot might be somewhat reluctant to do that, especially in performance limited conditions, and try to measure out his pedal input. A large pedal input on the opposite side has no detrimental consequence and should not be seen as a problem.

Unanticipated yaw may occur on both sides, at the limit between stable and unstable ranges. Accidents occur mainly following unanticipated right yaw and left wind conditions present thus the highest risk.

Left wind was one of the four factors driving the phenomenon identified in the Empire Test Pilot School. Well done ! The three other factors were low speed, high power and decelerative attitude. Low speed is necessary to have relative wind azimuth varying during a turn as a high speed turn is usually done in a limited sideslip range. High power and deceleration are not mandatory in our analysis. Both however shift the pedal curve downwards and may trigger unanticipated yaw when the pedal position is close to the maximum of the pedal curve. Even if a complete understanding of the problem was not reached in Boscombe Down — tail rotor stall was still seen as the cause of the problem — experimental investigations gave a quite accurate view of critical conditions.

4.3. Tail rotor is felt ineffective

Recovering from the unanticipated yaw at least requires coming back to the pedal curve. As the point where unanticipated yaw starts is the maximum of that curve, the trim position may only shift downwards when the heading changes.

Two different recovery maneuvers have been plotted in *Figure 11*, one in blue and a second — less abrupt — in yellow. A horizontal green dashed line has also been drawn that indicates the position of the pedal when the third step input was introduced, which is the reference the pilot may have in mind — or in the feet. In both maneuvers the amplitude of the pedal step that may stop the yaw is an order of magnitude larger than that used for starting. Most of that step aims at compensating the change in the trim condition, which is certainly not obvious to the pilot.

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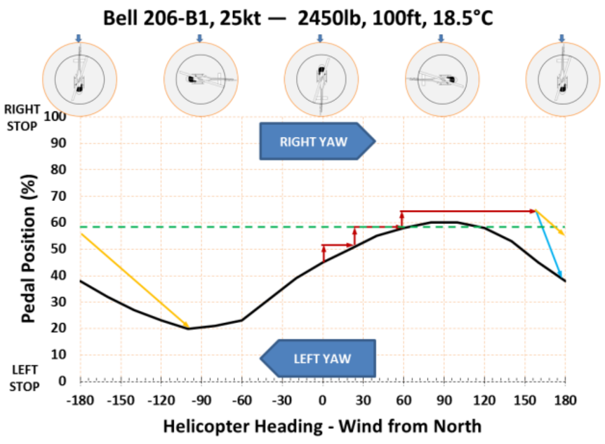

Figure 11: Large amplitude is mandatory for quick recovery

In most of the accident reports, the pilot states having counteracted unanticipated yaw by an opposite pedal input "*that had no effect*". The reason why the tail rotor seems to have no efficiency is there. Before being able to decrease the yaw rate, a huge step is first mandatory that only compensates for the trim change with heading. If the pilot fails to have a sufficient left pedal step, he still feels right yaw acceleration. Right yaw acceleration following a left pedal step is something aberrant and cannot make the pilot comfortable.

On a helicopter, controls at trim have large variations, almost from stop to stop. Control inputs by the pilot have two goals, keep or reach an average value representative of the expected trim condition and ensure control of the helicopter around that trim condition. When the trim change is slow, both components are in different frequency ranges, which may be easily managed by the pilot. This is the case of the longitudinal stick position that moves forward with speed. Speed variations are always quite slow and the change in stick position with speed does not interact with the longitudinal attitude control, which takes place at a much higher frequency.

For pedal in low speed conditions, this is a different story. It can be seen on *Figure 11* that a 40% change in pedal position may occur with a 180° heading change. With a 45 degrees per second yaw rate that does not seem excessive for an unanticipated yaw accident — and is still far from the 165 degrees per second demonstrated by a test pilot during the Gazelle tests — this makes a 10% change per second that needs to be compensated. In that case the pedal activity for control of the yaw axis and that induced by the heading change are clearly taking place in the same frequency range.

With a fly-by-wire system and a pure rate command control law, the problem does not exist. The control position is no longer linked to the tail rotor pitch but only to the commanded yaw rate and the pilot cannot be mistaken by the pedal at trim, which is always centered.

Unfortunately, it cannot be expected that fly-by-wire will be soon installed on all helicopters. The favorite victims of unanticipated yaw are small, cheap helicopters that cannot afford such a cost. Helicopter pilots have still to live with the unanticipated yaw issue in the near future.

4.4. Why is recovery failed ?

How unanticipated yaw starts is now understood. Why recovery pedal input may seem ineffective is equally clear. The remaining problem is to understand why so many accidents occur, during which the pilot does not succeed to stop the yaw.

As well on OH-58 as on Gazelle, test pilots were able to stop any yaw rate they could reach by applying full opposite pedal (and possibly some longitudinal cyclic input on OH-58). It was even shown during the Gazelle tests that coming back to the hover (headwind) position was enough to arrest the yaw, but the stop came quite late (270° after the unanticipated yaw occurrence, which can be understood using the pedal curve).

Pilot relating an event sometimes says that he used the amount of pedal he felt sufficient to stop the yaw. In that case the conclusion is quite easy : the pilot underestimated the mandatory input, certainly mistaken by the huge change in the trim conditions induced by the heading change.

In other cases, he ensures he reached the pedal stop. This is not consistent with the flight experience and would ask for some wizardry to cancel the tail rotor effectiveness…

Two accidents that were investigated occurred on helicopters that were equipped with a recorder. In those cases it is clear that the opposite pedal stop was never reached, and by far. In two other cases, the pilots claimed having used full pedal but it is possible to demonstrate that it was not true. In one of them a video was available and showed fully aligned pedals, largely after the start of the unanticipated yaw. The other is not in the database and happened on a military AS555N. On this helicopter the RPM is increased as soon as the pedal position is exceeding 75% and the recorded RPM value did not show any rise.

The most probable reason for the many unanticipated yaw accidents is that pilots use a too limited pedal input to counteract the yaw.

There are many accident reports relating more than one 360° turn. Such a full turn may only occur if the pedal is left in the initial position, or re-

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centered after a too limited attempt that proved to be inefficient. A large left pedal input would stop the helicopter after less than 360° rotation.

The initial lack of efficiency — that was explained — may be understood as a complete loss of tail rotor thrust. Very quick landing decision is sometimes taken that would be appropriate in case of complete loss of tail rotor thrust. The problem is that only a full pedal input without significant result may ascertain such a tail rotor failure.

An indirect confirmation of the missing or too limited pedal input during recovery may be found in some firefighting Skycrane helicopter incidents. Two unanticipated yaw videos could be seen on the web. The first one was on the US Forest Service site. The helicopter was first seen already yawing and dropping water. Control was regained after slightly more than 360° rotation. The second case happened in Greece and could be seen beyond a gas station. At the beginning of the recording the helicopter is already yawing and descending. After about 360°, very close to the ground, water is jettisoned and the helicopter comes again under control after 720°. In both cases it is clear that yaw was not stopped by pedal only but that the huge weight reduction was a major contributor.

A Skycrane accident was recorded. It occurred in Italy, in July 2001. After a missed water drop — the command was not armed — the helicopter was repositioned and, during a right turn, unanticipated yaw started. Cyclic and full left pedal are said to have been applied but water jettisoning was still unavailable and the helicopter crashed. The helicopter having yawed by more than 360° it is unlikely that any significant pedal input was made. The recovery that succeeded in the two above incidents was not possible here because the water dropping command was inoperative.

Unanticipated yaw accidents occur because pilots use a too small amplitude pedal input to stop the spinning helicopter. It is probable that they use what they feel necessary, based on their immediate experience in the stable heading range, do not perceive any significant deceleration and stop piloting the tail rotor. Exceeding 360° yaw means that the pedal was still close — or had been brought back — to the position that existed at the time unanticipated yaw started.

4.5. Unanticipated yaw when performance is limited

This is the most critical case but represents only a limited number of the accidents in the database. Most of them occur in low altitude condition, where performance is not an issue.

When operating close to the performance limit, applying a significant left pedal step, possibly to the stop, increases significantly the tail rotor power. If the engine is not able to provide this excess power the RPM droops, reducing the thrust of both rotors and thus making the helicopter descend while jeopardizing the recovery maneuver. To avoid the descent — remember that most often the event starts close to the ground — the pilot raises the collective stick, asking therefore for additional power and aggravating the problem.

This is a diverging situation and may only be solved by strongly reducing collective pitch. This needs to have a huge height margin with respect to obstacles. It is therefore of uttermost importance to avoid entering unanticipated yaw in performance limited conditions and a close control of yaw in that case is mandatory.

5. THE FILMING PROBLEM

A typical example of unanticipated yaw accident occurring when filming some point of interest on the ground from a helicopter may be found in [6].

The helicopter is turning around a ground point.

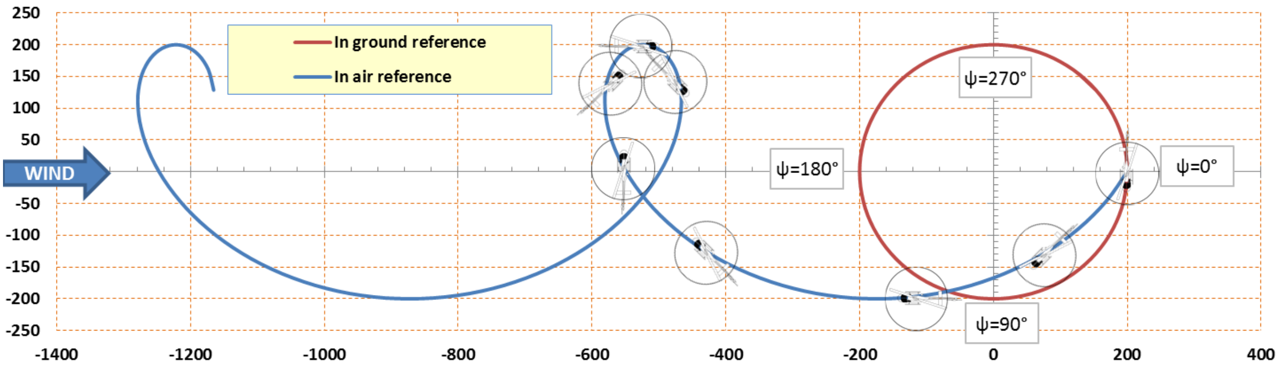

Figure 12: Flight path in ground and air reference during a ground reference turn (radius 200m, ground speed 45 kt, wind speed 25 kt)

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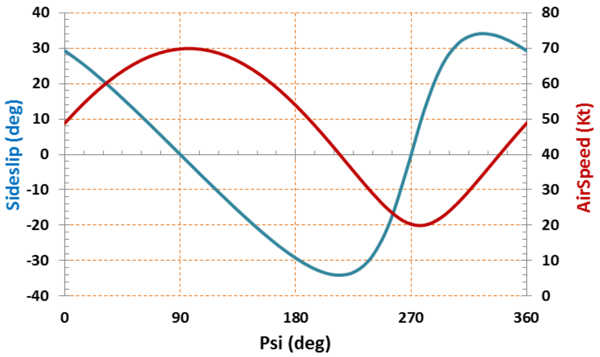

Figure 13: Airspeed and Sideslip during the maneuver of Figure 12

The goal is to have a smooth maneuver, with a constant ground speed, and ease the work of the cameraman by almost keeping the point of interest in a plane normal to the longitudinal axis of the helicopter. It is then possible to film with only corrections in elevation angle, without any in azimuth. This is obvious without wind and corresponds then to steady turn but becomes much more difficult when wind is added, which is the most probable condition.

In *Figure 12* are plotted in red the flight path with respect to the ground — a circle covered at a constant ground speed — and in blue the flight path with respect to air that allows reaching the expected result. This is no longer a circle, but a prolate cycloid, and the airspeed needs to be varied all along the maneuver.

Successive positions of the helicopter have been plotted on the blue curve. The heading of the helicopter is defined with respect to the red ground curve. In each location the helicopter is thus parallel to a tangent to the circle in the corresponding point. This makes that the helicopter axis is not tangent to the blue line, and indicates that the sideslip angle is also varying all along that curve.

Airspeed and sideslip angle during the maneuver are plotted in *Figure 13* assuming a 25 kt wind, a constant 45 kt ground speed and a 200m radius. The horizontal axis provides the position with respect to the circle as described in *Figure 12*. The sideslip angle varies between -35° and +35° and the airspeed between 20 and 70 kt (ground speed minus or plus the wind speed).

Slightly before reaching the tailwind condition (circa 230°-240°) the airspeed has been strongly reduced, asking for more torque, whereas there is a left sideslip component. The helicopter is coming close to the wind heading conditions where unanticipated yaw starts at the time when the collective pitch is significantly increased. A poor pedal compensation of that collective input or a too low airspeed may make the helicopter exceed that heading limit and enter unanticipated yaw.

Accident reports confirm that it is when coming into tailwind that spinning starts. This was the case in [6] even if the scenario was a bit different, the helicopter starting in hover in ψ=180° position and entering unanticipated yaw quite early in tailwind conditions. Before that, three similar orbits had been flown without any problem. A slight change in the conditions or in the pilot reaction can make the problem occur or not.

The same maneuver with a clockwise rotating rotor (French sense) would see the risk of entering unanticipated yaw taking place when the wind comes from the right, which occurs in the ψ=300° range, at which time the helicopter has started accelerating. A camera should thus be better installed on the left side of an American helicopter and films taken during left turn whereas it would be during right turns with a camera installed on the right side with French helicopters. In any case the pilot should keep aware of the wind direction and be especially careful when entering tailwind, mainly when the tail rotor pitch is much limited.

6. CRUSHING MYTHS

The pedal curve provides new understanding of unanticipated yaw phenomenon and may be used to kill some believes that can be found in pilots forums.

6.1. The tail rotor loses effectiveness

This one is the title of the paper and is first addressed. It seems to come mainly from a wording issue…

Bell Operation Safety Notice of 1983 reported in [6] only used “unanticipated yaw” to designate the problem. In the following year Information Letter, also reported in [6], that same wording is kept and it is only signaled that “Loss of Tail Rotor Effectiveness” was how US Army used to refer to the phenomenon, adding that it was misleading.

AC 90-95 [15] is entitled “Unanticipated right yaw in helicopters” but “unanticipated yaw” is found there 7 times against 3 times for “loss of tail rotor effectiveness” and 22 times for “LTE”. The warning about the confusing character of that designation has fully disappeared.

In the AC, both designations are first presented as synonyms : “*unanticipated right yaw or loss of tail rotor effectiveness*”. A bit further “*LTE is a critical, low speed aerodynamic flight characteristic, which can result in an uncommanded rapid yaw rate…*”

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is therefore disturbing. Is LTE unanticipated yaw or is it the cause of unanticipated yaw ? Note that "*uncommanded*" instead of "*unanticipated*" gives the feeling that the helicopter has taken the controls, whereas no external input is necessary to start unanticipated yaw. The pilot can do it by himself and in that case yaw is commanded, even if it was not anticipated.

No wonder if LTE is most commonly used to designate the phenomenon, but out of the AC 90-95 context, how can people imagine that it means unanticipated yaw, especially when translated into a foreign language ? People therefore think that tail rotor loses effectiveness.

"*Lack of Tail Rotor Effectiveness is when it doesn't matter what you do with the pedals, the aircraft is doing its own thing. It is not effective*" is an understanding of the problem found in a forum. The natural meaning of words cannot be ignored and the designation of a problem must take it into account.

"*It must be LTE, it is not the pilot's fault*" may also be found. Saying that the pilot cannot be responsible for an unanticipated yaw accident wrongly assumes that he has no means to exit the phenomenon and sends us back to the idea that the tail rotor became inefficient.

The problem is explained by the pedal curve. Who does justify the pedal position change with wind heading by tail rotor losing effectiveness? It must be made very clear that the tail rotor behaves as expected, that it keeps its effectiveness but that pilot may be mistaken by the huge change in trim pedal position induced by the heading change.

6.2. Unanticipated yaw is entering tail rotor Vortex Ring State (VRS)

Tail rotor VRS could as well be replaced by the main rotor vortices swallowed by the tail rotor described in AC 90-95. Both are local phenomena, occurring in a very limited heading range. They can explain a little kick that will vanish as quickly as it came. They cannot enlighten why pilots have difficulties to arrest the yaw.

The unstable range, the "*weathercock stability*" area as it is called in AC 90-95 is certainly a better explanation. The slope of the pedal curve there is the reason for the instability and it is the origin of the poor apparent effectiveness of the pedal control. In those conditions the trim pedal position moves leftwards with increasing heading. It means that during a right turn in tailwind conditions the anti-torque decreases and additional left pedal is mandatory to maintain the anti-torque level.

It must be noticed that the previous chapter is only written in terms of pedal position and anti-torque. Whatever the device used to provide that anti-torque, unanticipated yaw may occur as long as the shape of the pedal curve remains similar. A critical azimuth where the left pedal margin is minimal means that it is maximal in another azimuth and this is sufficient to ensure that a stable and an unstable range exist. If the amplitude of the pedal curve is large enough unanticipated yaw may occur if the pilot is a bit lazy in his yaw control.

It is therefore not surprising to find as well helicopters equipped with classical tail rotors, with Fenestron® and with NOTAR® in the accident records. All of them have a critical azimuth and may encounter unanticipated yaw. The explanation by the pedal curve is the same… even if one of them ignores VRS.

6.3. Unanticipated right yaw is running out of left pedal

The idea that being not able to provide enough anti-torque will make the helicopter enter right yaw that cannot be stopped may seem obvious. It is said differently in AC 90-95 or in Bell Operations Safety Notice : "*If considerable amount of left pedal is being maintained, a sufficient amount of left pedal may not be available to counteract an unanticipated right yaw*."

This happens when running out of pedal in pure hover. Certification requirements however do not allow it and FAR/CS 29.143 asks for having enough pedal margin to accommodate winds of at least 17 kt from any direction. Exceptions may exist in Category B certification that will be addressed later but take this 17 kt margin as granted in a first step — which is the case in the huge majority of the unanticipated yaw accidents.

Running out of pedal should therefore not happen in the flight envelope, or only as a transient, when maneuvering. In any case, coming close to the pedal limit should only occur in the vicinity of the critical azimuth, with the maximum wind speed.

Figure 14 allows showing what happens when running out of pedal. The pedal curve is plotted in limit 35 kt wind conditions (full line). From this position the torque is increased by two successive collective inputs, leading first to the dashed line, which minimum exactly corresponds to the left pedal stop, and then to the dotted line, which minimum is out of the pedal range.

The pilot starts in the critical azimuth❶. During the first collective increase he is able to compensate and comes on the left pedal stop in ❷. The following collective increase cannot be longer

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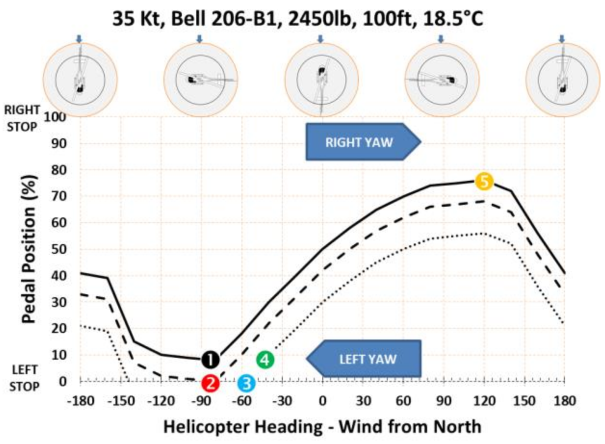

Figure 14: Running out of pedal

counteracted. The pedal curve moves from the dashed line to the dotted line but the pedal position remains on the stop, at 0%. The current point is therefore above the pedal curve and the helicopter yaws right until the dotted line is reached in ❸. The current point is now on the pedal curve, in the stable range, and the yaw motion stops there. Running out of pedal does not lead to endless spinning but only makes the helicopter nose come slightly into the wind.

Had the pilot not corrected at all the collective increase, he would have moved from ❶ to ❹. This is only a larger heading change, but in no case triggers unanticipated yaw.

The same collective increase, when starting in ❺, needs to be compensated and compensated without delay. The current point otherwise comes above the pedal curve, which starts unanticipated right yaw as it was shown previously.

Running out of pedal cannot produce unanticipated right yaw because it makes the helicopter come into the stable range. A helicopter spinning to the right with full left pedal is another myth. Only spinning to the left can be reached in such conditions. It might happen following a collective pitch reduction that is not counteracted with pedal, while in the critical azimuth range.

Wind from the opposite side is more robust to a collective reduction and unanticipated left yaw cannot start there. A very careful pedal compensation of any power increase is however mandatory in those conditions. This directly points out the next myth.

6.4. It is safer to fly with left wind when performance is limited

Some pilots advocate for choosing left wind conditions during approach, when performance is limited. It reduces the need for tail rotor pitch and therefore asks for a lower tail rotor power, making more power available on the main rotor.

From pure performance view, it obviously brings a slight improvement. It shall however also be considered from the unanticipated yaw standpoint.

Left wind is where unanticipated yaw starts. It was shown in the previous part that a collective increase in those conditions, when not fully counterbalanced with left pedal, was likely to trigger spinning of the helicopter. In response to such a yaw, a large left pedal input is the appropriate recovery.

Only a few kilowatts might be spared in left wind conditions on a light helicopter. If a large left pedal step is needed, many tens of kilowatts will be required. Is the small gain worth the risk ?

If it is only a question of over-torque, the risk might be taken as some maintenance actions are only at stake. If the engine is not able to provide the extra power that may be needed to recover from unanticipated yaw, this is much different. RPM droop and loss of control are not far away. Limit performance conditions may mean mountain flight, not easily allowing emergency landing. Unanticipated yaw risk cannot be ignored there.

6.5. Unanticipated yaw is a tail rotor sizing issue

It was already shown that unanticipated yaw starts in conditions far from full left pedal and tail rotor performance is therefore not the problem. The question may however be understood at the level of the ability to stop spinning.

The origin of the myth is certainly in the many accident reports stating that, despite full left pedal was applied, right yaw could not be stopped. If the existing rotor does not make it, a more powerful one should improve.

It has already been pointed out that it is very unlikely that full pedal is really applied. Manufacturers' tests on OH-58 and Gazelle had demonstrated that it was always possible to arrest any yaw rate. On the Gazelle it was even shown that using only the pedal position in headwind condition, i.e. much less than the pedal stop, was sufficient, even if the maneuver was stopped only late, after a significant heading change.

Of course such a limited tail rotor pitch range cannot allow stopping the yaw in the critical azimuth : the pitch at trim in those conditions is not available. Arresting the maneuver is however not an issue. It is possible, in Category B, to certify take-off and landing conditions without the 17 kt maneuverability of §29.143 in all directions. Flying in such conditions does not mean that

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unanticipated yaw cannot be stopped. It can however be stopped only in a limited wind azimuth range.

The question whether a better tail rotor may improve unanticipated yaw maneuver can be raised, especially when thinking that it was part of the modifications made on OH-58A to solve the problem.

A more powerful tail rotor used in the same flight envelope cannot be detrimental. In any case, the tail rotor sizing is not the cause of the unanticipated yaw and may thus only have a limited effect on the issue. The risk is to take benefit of this more powerful tail rotor to extend the flight envelope, for example increase the speed in lateral flight. This makes possible encountering larger amplitude pedal curves, possibly increasing the risk of starting unanticipated yaw.

The effect of a higher performance tail rotor on unanticipated yaw is not obvious and may seem psychological. It does not mean that a better tail rotor will not ease the life of a pilot but only that it cannot improve significantly unanticipated yaw.

7. CONCLUSION

Unanticipated yaw is a lasting problem that was not clearly understood. Whether the tail rotor was able to recover was questioned. The Loss of Tail Rotor Effectiveness wording but also the recommended recovery maneuver and the belief in endless spinning to the right with full left pedal are examples of the doubts raised about the tail rotor behavior, opening the door to interpretations more linked to wizardry than to science.

Using the pedal curve provides a better understanding of the issue. The problem is clearly where the trim pedal position is maximal, with left wind. There, a minute right pedal input or a poorly compensated collective increase may trigger unanticipated yaw. Pedal inputs necessary to stop the rotation are all the larger that the pilot reaction comes late. Accidents occur because of a too late, too limited response to unanticipated yaw.

This improved understanding of the phenomenon must now be transferred to pilots so that they are better aware of the problem and have a more appropriate reaction. Inaccurate or ambiguous elements, such as the Loss of Tail Rotor Effectiveness wording, shall be removed. Confidence in the tail rotor shall be restored and it must be made clear that, except in performance limited conditions, a large pedal input, till the stop if needed, will always stop the yaw.

Performance limited conditions are where the consequence of unanticipated yaw may be the worst. Special care shall be taken there to avoid entering into the phenomenon. Optimizing performance by a left wind component shall be clearly ranked as a risky behavior.

Up to now, unanticipated yaw was first encountered by a pilot in real conditions. Better understanding the problem might allow demonstrating it in flight. Facing an already seen phenomenon is much less disturbing than discovering it. The possibility to train all pilots if possible and at least instructors should be considered.

Authorities, Industry and Training Schools shall provide a unique message, really pilot-oriented. Inconsistencies and even opposite opinions are found in existing guidance on the subject. This contributes to the propagation of myths and shall be avoided.

8. ACKNOWLEDGEMENTS

The author would thank all the pilots sharing their experience in forums or blogs, providing different views of a problem.

He also thanks the aeronautical investigation boards that have developed easily accessible databases, making possible the analysis presented in chapter 3.

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