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The role of Pilots' monitoring strategies in flight performance

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Abstract. Since decades, the number of aircraft accidents is continuously decreasing thanks to support systems and the introduction of automation. However, a drawback of this trend is that crews tend to be "automation addict" due to pressure and fatigue, which mean that they practice less and less manual flying. Also, an over-confidence in the automation can promote the occurrence of a particularly prominent typology of error: the failure of the crew to properly monitor the flight instruments, which can be particularly hazardous during the final approach phase. This paper describes an experiment that was undertaken to study pilot's monitoring strategies thanks to eye tracking technology during manual approaches. We examined the relationship between visual patterns and flight performance (to find out if the approach was stabilized or not). The results show that gaze allocation of pilots who failed to stabilize their approach was sub-optimal. An analysis of the visual dispersion shows that they did not divide efficiently their visual attention compared to reference crew. Also, these pilots did not sufficiently gaze primary flight instruments requested to fly the approach (the attitude indicator, the localizer and the glide deviation scales). We assume that eye tracking may be a useful tool to improve pilots' monitoring strategies, for example gaze-training based on video clip showing experts' visual pattern could help novice pilots to adopt appropriate gaze strategies.

Keywords: Attention sharing, Eye Tracking, Individual Differences, Go Around, Visual Pattern

Introduction

Human error is classically seen as the major source of aviation accidents. The exact proportion varies over sources, but approximately 60 to 80 percent of aviation mishaps involve human factors (Shappell and al., 2006). Since decades, the number of accidents is continuously decreasing, in particular thanks to the introduction of automation. One of the expected benefits of automation is to reduce pilot's workload, increasing situation awareness when facing complex environments or technical problems and lower errors (e.g., Lee & Seppelt, 2012).

In flight operations, automation is mainly used to reduce workload in highly dynamic phases of the flight, and particularly during the critical approach segment, where the aircraft is flying at low altitude within busy traffic environment. Not surprisingly, according to Boeing's statistics (2010), from 2001 to 2010, 49 % of fatal accidents occurred during the approach phase. Particularly, unstabilized approaches are identified as a major cause of accident (runway overrun, tail strike...) and one of the significant contributors is probably the transition between automatic and manual flying.

During this last part of the flight, from an operational point of view, flight directors compute and display proper pitch and bank angles required to fly a selected path typically via an Instrument Landing System (ILS) approach. The ILS is a ground equipment based on two radio beams that together provide pilots with both vertical (Glide) and horizontal (Localizer) guidance during an approach to land. For example, if the aircraft is high on the glide path, the pitch bar will deflect downward and then, the pilot will only have to decrease pitch proportionally to pitch bar deflection. Once the proper pitch angle is reached to regain the correct path, the flight director bars will be centered with the current aircraft attitude until the next correction (if required). On fly by wire aircrafts, flight directors command the autopilot to fly requested trajectory and are typically used with the auto-thrust, which deals with appropriate thrust adjustment. As a consequence, flying with flight directors implies that the visual pattern is mainly focused on deviation bars and mental effort is reduced since pilots are not requested to adjust path and deviations according to thrust, pitch and bank: visual scanning requested to fly the aircraft is condensed to minimum. Besides, (Weir & Mc Ruer, 1972) have already suggested that pilot workload increase with instrument scanning requirement and task complexity.

Among unexpected consequences of automation, skill loss is observed when automation takes on the tasks previously assigned to the operator and its skills may atrophy as they go unexercised (Endsley & Kiris, 1995; Haslbeck & Hoermann, 2016). In flight deck operations, crews tend to be "automation addict", which means that they practice less and less manual flying.. A typical source of confusion for the crew is also the sudden breakdown of automation considering the lack of practice, hand skill flying and the ability to face unexpected situation, particularly during landing (e.g., Haslbeck and al., 2012). Another drawback of automation is that it can generate complacency effects (e.g., Parasuraman & Manzey, 2010), which can promote the occurrence of a particularly prominent typology of error, the failure of the crew to properly monitor the flight instruments. This lack of monitoring can be particularly hazardous during the final approach phase: a typical example is the flight crew's inadequate monitoring of airspeed in the Asiana Airlines Flight 214 crash at San Francisco.

The monitoring of the instruments can be materialised by the visual scanning pattern in the cockpit. A pilot scan can be described as an automatic and conditioned activity that is situation dependent using flying instruments. Moreover, scanning process can be disrupted by workload, level of automation and lack of scanning strategies. Analysis of visual pattern is a technique often used in human factor research to gather information about scanning strategy: (Sarter, Mumaw, & Wickens, 2007; Haslbeck, Schubert, Gontar, & Bengler, 2012; Haslbeck, & Bengler, 2016). Diaz et al. (2001) have already used this technique to study mode awareness of Boeing 747 pilots. Shapiro and Raymond (1989) have also demonstrated a correlation between efficient scanning techniques and performance.

In this work, we had several objectives. Firstly, we aimed at reaching a better representation of the automation levels used by airline crews during approaches phases. Secondly, we aimed at examining the potential relationship between flying performance (during manual approach phase) and pilots' monitoring strategies. We firstly hypothesized that a vast proportion of the pilots performs the majority of the approach with automation (flight director and auto-thrust engaged) confirming the global lack of manual flight training observed by aviation authorities. To examine this hypothesis, we conducted a survey among 120 professional pilots in order to reach a better understanding of their flying habitude, in particular regarding automation. We secondly hypothesized that the crews who demonstrate lower flying performance during the approach demonstrate sub-optimal visual scanning patterns in comparison to experts with higher flying performance. In particular, we assumed that crews with lower performance would show a weaker monitoring of the critical parameters such as relationship between pitch and thrust or localizer and glide slope deviation indicators. In order to validate this second hypothesis, pilots performed manual approaches in a full flight simulator while their ocular behavior was recorded with an eye tracking.

Method

The survey

Participants. All participants (112 males and 8 females) were qualified on Airbus A320, as Captain (38 %) and First Officer (62 %). They respectively totalized, on average, 9870 FH (sd = 980 FH) and 2730 FH (sd= 670 FH). All were volunteers and have not been rewarded. The survey has been conducted thanks to Google Forms editor and all pilots were contacted by a mailing list. The initial question was to identify which level of automation was used primarily during approaches in good weather conditions (with or without flight directors and associated auto-thrust): thus, pilots were requested to record, the level of automation that they will use during the next 100 landings. In order to understand the importance for them to better defining gaze allocation in the cockpit, participants were also asked if they think that manufacturer should publish detailed information regarding the required visual patterns during the various different phase of flights.

Flight simulator experiment

Participants. Twenty pilots were recruited (10 Captains and 10 First Officers) to perform the Flight simulator experiment (some of them took part in the survey). They were all qualified on Airbus A320. All pilots were male, with a mean age of 42 for Captains and 29 for First Officers, and a minimum of 1000 flying hours (FH). They respectively totalized, on average, 11 500 FH (sd = 1300 FH) and 3500 FH (sd = 340 FH). All were volunteers, signed a consent form and provided demographic information. They have not been rewarded for their participation. Participants were randomly assigned to compose a crew and were not informed about the purpose of the study. Pilots were only briefed with all relevant flight related paperwork, but they were not introduced to the scenario and purpose of research.

Apparatus. Experiments were conducted in a full flight simulator, manufactured by Thomson and used for regular training of flight crew. During approaches, we recorded three parameters: the speed (standard value = 138 kt), height above the runway threshold (standard value = 50 ft), and touchdown point (standard value = between 300 and 600 m). Two Head mounted Pertech eye have been used to record the visual patterns of the two pilots. All data were computed thanks to EyeTechMotion and EyeTechLab software. Video and audio have been also collected to analyse interactions between the pilot flying and the pilot monitoring. Several areas of interest on the cockpit were defined to study gaze allocation during the approach: airspeed indicator, attitude indicator, heading / localizer couple, vertical speed / glide / altitude couple, flight mode annunciator, the navigation display, the system display and the windows. Gaze allocation in % for each zone of interest represents the proportion of time looking at a particular display

Task. All pilots performed an approach at Toulouse airport on runway 32R, without automation, i.e. neither flight directors nor auto throttle engaged. The scenario began with a take-off from the runway threshold and crew were requested to climb 5000 ft, turn left and intercept the localizer and the glide slope at this altitude. Then, they were cleared to the approach and the scenario ended when the aircraft reached a full stop on the runway with the parking brake applied. Flight crews were required to fly the aircraft in compliance with flight crew operating manual and operator requirements regarding stabilization criteria. If stabilization was no more guaranteed during the approach, pilots had to make the decision to go around or not, according to them. All pilots performed this approach as pilot flying and as pilot monitoring, randomly. Approaches were flown with a runway visual range of 550 m and a crosswind of 15 kt for the purpose of evaluating visual pattern, frequency, type of gaze allocation and correction strategy to fly back correct ILS course and glide path. Terminal feedback was also provided to pilots in the form of a Precision Approach Path Indicator (PAPI) on the left side of the runway. During the approach, gaze allocation of pilots flying from 2500 ft on final up to 50 kt on roll out have been recorded. This choice has been made because the lower the altitude, the more accurate the ILS beams have to be flown and the more the visual attention is solicited.

Results

Survey

As expected, airline pilots declared that they performed a majority of their approaches with the highest level of automation above the decision height. More precisely, more than 50% of the airline pilots estimated that they perform 31 to 60% of their next 100 approaches with flight directors and auto-throttle (see Figure 1). Besides, According to participants' answers, fatigue is the most common reported cause of this decision at 89%. Moreover, pilots answered that during a visual approach on this aircraft, they preferred leaving the auto-thrust engaged to manage speed in order to be more available to monitor the trajectory and the environment.

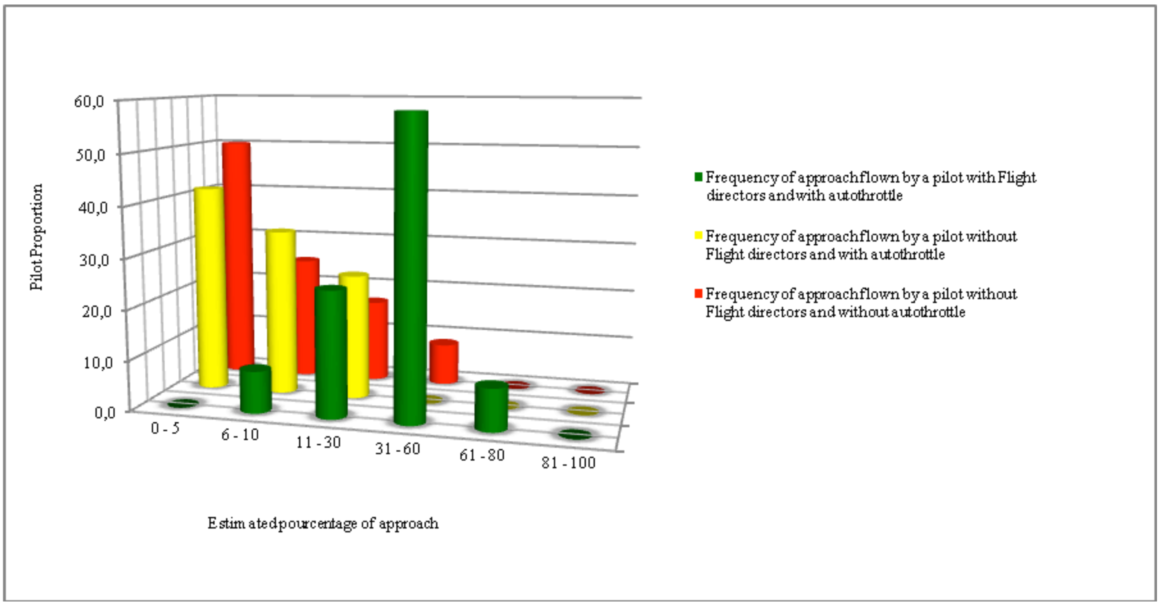

Figure 1. Reported automation levels used in adequate weather conditions (120 participants).

Besides, 75 % of pilots answered that a publication of detailed information regarding the required visual patterns for the different phases of flight (take off, approach etc.) could help them to include relevant flying instrument and develop efficient visual patterns.

Flight simulator experiment

Performance at landing

Considering all participants, 16 out of 20 pilots performed a stabilized approach: the 4 most precise pilots have been identified to constitute the most accurate group (based on the precision error on the localizer/glide couple and accuracy at touchdown), the others 11 pilots constituting the standard pilots group. However, 5 pilots that did not stabilized their approach and decided to go around at approximately 750 ft (which was an appropriate decision considering their trajectory). Figure 2 highlighted the high level of landing performance of the most accurate pilots compared to the 11 pilots whose approach was stabilized. Then, have be contrasted the visual scanning pattern and gaze allocation of the pilots who go around and those of the four most accurate .

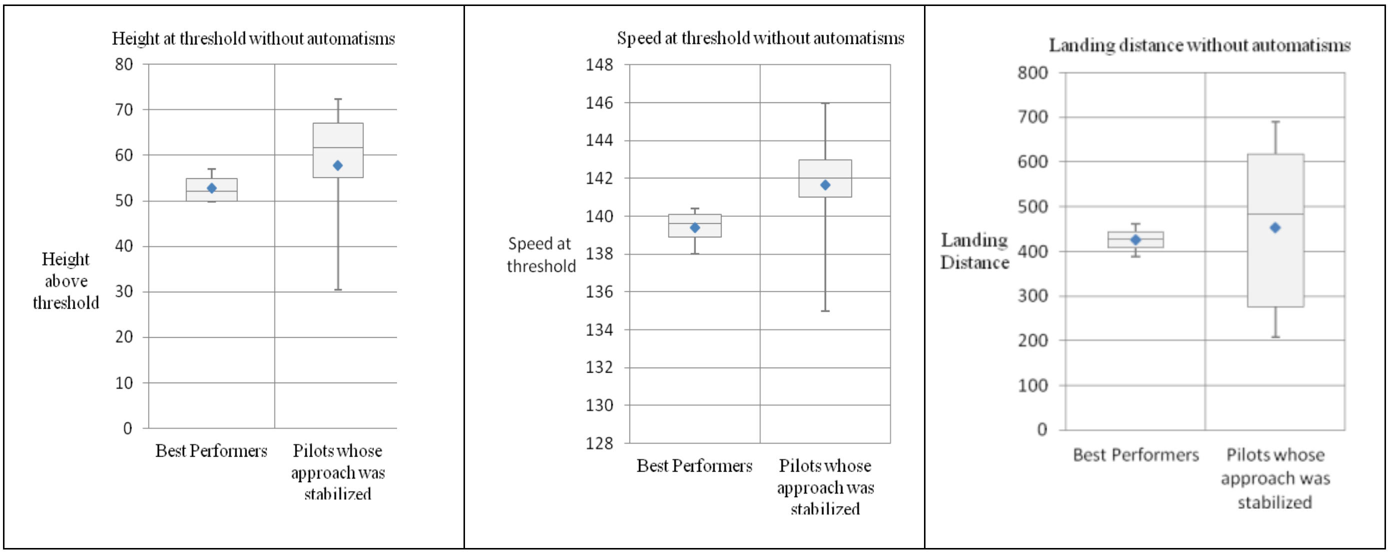

Figure 2. Height (left panel), Speed above threshold (middle panel) and landing distance (right panel) for the subgroup of most accurate performers (*n*=4) and the subgroup of standard stabilized approaches (*n*=11).

Visual scanning patterns

We identified an optimal gaze allocation to flying instrument based on the four most accurate pilots who performed the approach. For each zone of interest, we defined an interval for the optimal percentage of gaze allocation around the mean of the four most accurate pilots. The interval has been arbitrarily chosen at two standard deviations from this mean (see Figure 3). Thus, we considered that percentages of gaze allocation outside this interval indicated suboptimal visual scanning.

The pilots of the most accurate group spent most of their time gazing the attitude indicator, the localizer and the couple glide/vertical speed. This distribution can be explained because these zones are closely linked and they are the three main sources of information needed to maintain the aircraft path within the ILS beams. For example, to descend, pilots have to decrease pitch and associated thrust to keep a constant speed and reciprocally.

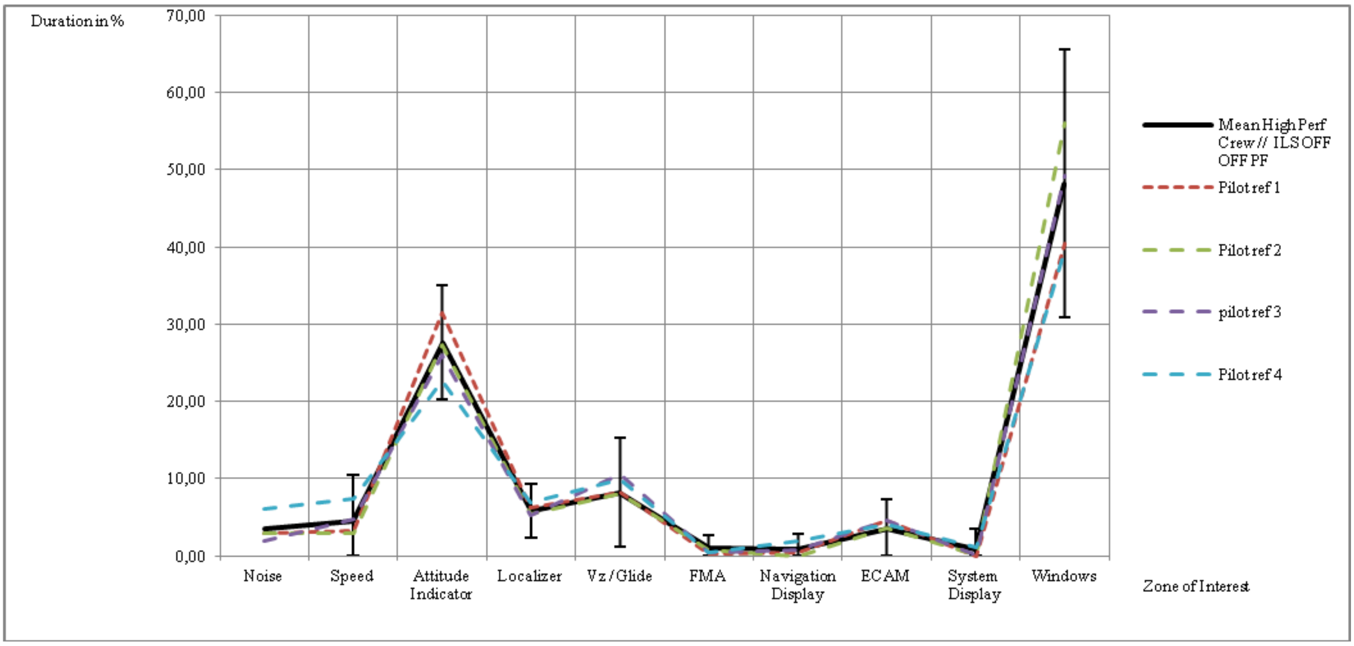

Figure 3. Percentages of gaze allocation for each zone of interest. The solid line represents the mean of the four most accurate pilots, dashed lines represent each of these four pilots and intervals represent two standard deviations from the mean of this subgroup.

The dispersion of the gaze was greater for the group of pilots who performed an unstabilized approach than for the other pilots (see Table 1). Indeed, standard deviations of percentage of gaze time in each of the three critical zones of interest are at least twice as large for unstabilized pilots (n=5) than for stabilized pilots (n=16) (sd = 26.3% vs 7.7% for the attitude indicator, sd = 7.9% vs 2.5% for the localizer, and sd = 9.5% vs 4.1% for the glide path).

Table 1. Percentage of time in main zones of interests without automation regarding pilot performances.

Zone of interest	Attitude Indicator	Localizer	Vz/Glide	ECAM	Windows
Mean percentage of dwell time (sd) for the most accurate pilots (*n*=4)	27.6 % (3.7)	5.8 % (1.8)	8.2 % (3.6)	3.5 % (1.8)	48.3 % (8.7)
Mean percentage of dwell time (sd) for standard pilots (*n*=11)	19.9 % (7.7)	5.2% (2.5)	7.3 % (4.1)	1.9 % (2.0)	53.9 % (12.0)
Mean percentage of dwell time (sd) for pilots who went around (*n*=5)	29 % (26.3)	7.7 % (7.9)	10 % (9.5)	1.8 % (1.5)	35.7 % (32.6)
Optimal dwell time interval associated to a stabilized approach.	[20.2 ; 35;0]	[2.2 ; 9.4]	[1.0 ; 15.4]	[0 ; 7.1]	[30.6 ; 65.7]

An analysis of each individual visual scanning pattern of the unstabilized pilots revealed that these pilots either over-focused or under-focused various critical zones (see Figure 4). In other words, the dwell time of at least one zone of interest differed by more than two standard deviation compare to the best performers. More precisely, (i) two pilots (FO2 and FO3) under-focused the attitude indicator and over-focused the localizer, (ii) one pilot (CDB1) over-focused both attitude indicator and glide path, (iii) one pilot (FO1) under-focused attitude indicator and localizer and (iv) one pilot (FO4) over-focused attitude indicator and under-focused localizer.

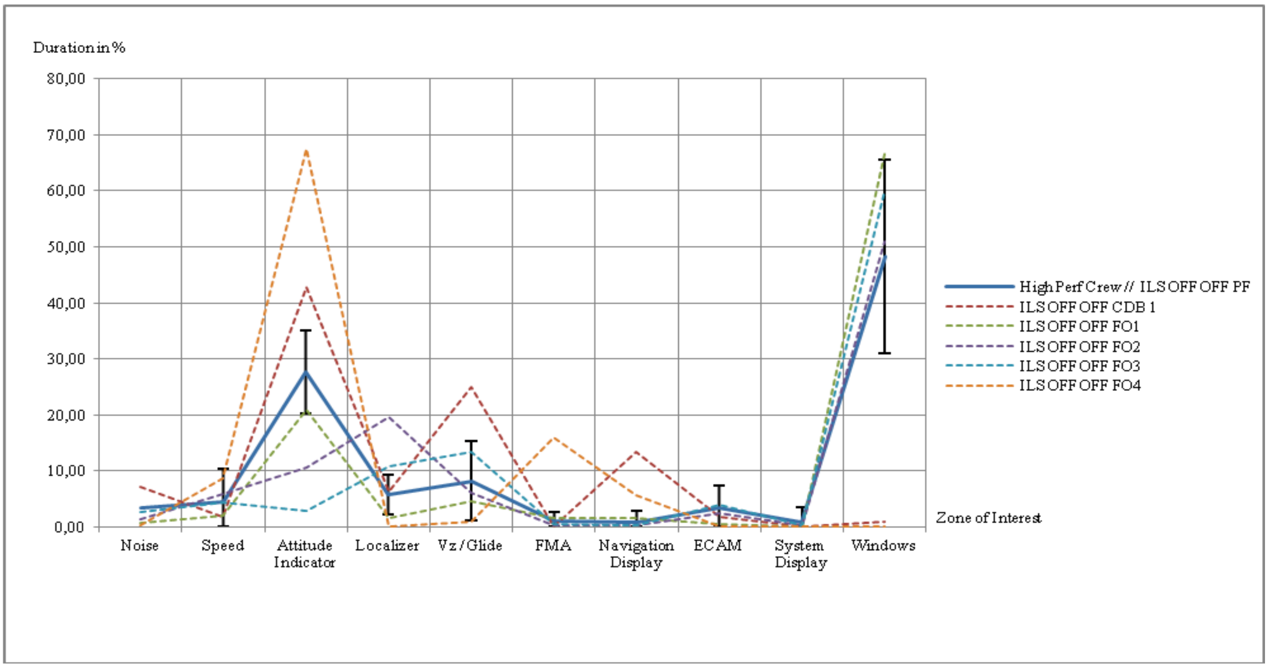

Figure 4. Percentages of gaze allocation for each zone of interest for each of the five pilots who ended in an unstabilized approach. The solid line represents the mean of the four most accurate pilots and the intervals represent two standard deviations from the mean of the most accurate pilots (i.e. the optimal visual scanning).

Finally, study of dwell time for each instruments allowed defining optimal gaze allocation and visual pattern associated to a stabilized approach. In fact, these intervals have been defined taking into consideration most accurate group of pilots and related standard deviation for primary flight instruments.

Discussion/Conclusions

Overall results

The objectives of this study were to analyse pilots' automation level during the approach and characterize visual patterns of pilots with eye tracking system during hand flying on the ILS. To this aim, operational pilots qualified on Airbus 320 have been recruited and took part to this program.

First of all, it has been suggested that pilots routinely use the highest level of automation up the minimum decision height due to fatigue regulation and to reduce their workload in order to increase their situation awareness. According to the survey, this hypothesis has been confirmed: in fact, in compliant weather, 31 to 60 % of pilots set the flight directors and the auto-throttle up to the decision altitude. Less than 10 % of these pilots fly without automation in adequate conditions.

As a consequence, we assumed that some crews could demonstrate lower flying performance during manual approach associated with suboptimal visual scanning pattern. To this respect, pilots performed approaches in full flight simulator without automatisms while their gaze behaviour was recorded. Among the 20 pilots (10 crews), 15 performed a stabilized approach and landed within stabilization requirements. The study of the gaze allocation of these pilots showed that the time spent on different instruments, and particularly the attitude indicator was similar to the proportion reported in the literature, namely between 15 to 59 % (Fitts and al., 1950; Weir & Klein, 1971; Pennington, 1979).

However, 5 out of 20 pilots flown an unstabilized approach and made the decision to go around. Study of gaze allocation of pilots who pulled up vs. the four most accurate revealed that gaze allocation of primary flying was is at least twice as large than for most accurate pilots. In fact, these pilots over and under-focus on different primary instruments to the detriment of others in this dynamic phase of the flight. Thought, it can be assumed that these pilots had not a visual pattern in accordance with the situation and were not sufficiently trained to perform manual approach: they did not divide sufficiently their visual attention to take information and process it at a sufficient rate to correct deviation.

Despite these remarks, interestingly 100 % of unstabilized approach induced a go around; the experiment did not record any “procedure violation”. In fact, continuation of an unstabilized approach is regularly observed (Causse and al., 2013) and has been found to be a casual factor in 40 % of all approach and landing fatal accidents (Flight Safety Foundation, 2009). So, our sample of pilots was really aware of stabilization requirement and did not hesitate to make the decision to pull up when necessary.

Furthermore, due to accuracy of the eye tracker, it was not possible to differentiate between the heading and the localizer and a similar statement has been made for the altitude which can not be differentiated from the couple glide / vertical speed but it can be hypothesized that radio altimeter keeps the pilot aware of the height of the aircraft above the runway so this differentiation was not essential for the study. However, it could have been interesting to differentiate between the vertical speed indicator and the glide to study relationship between these two parameters in case of deviation.

According to theses researches, it can be conclude that some crews (5 out of 20) demonstrate lower flying performance during manual approach due to the lack of training, as assumed. Pilots who performed unstabilized approaches have a gaze allocation at least twice as large than for the more precise pilots. Moreover, study of most accurate pilots allowed to define gaze allocation intervals to fly a stabilized approaches. However, it can not be concluded that pilots' monitoring strategies were clearly not sufficient to fly this type of aircraft without automatism for 5 pilots out of 20: it can be assume, that accuracy could be probably improved with a sufficient recurrent training. For example, gaze-training based on video clip showing experts’ visual pattern could help pilots to adopt appropriate gaze strategies.

Whereas visual patterns could be considered as suboptimal for pilots who performed an unstabilized approach, all pilots monitoring were particularly strict concerning ILS deviation: it could be assume that during recurrent training on line or in the simulator, outside this experimentation context, crew would take more in consideration the way the pilot fly back to the correct trajectory according to deviation, weather and height of the aircraft on the approach.

Perspectives of the study

In this research, after the simulator session, pilots were asked if they wish that the manufacturer publish visual patterns for a specific type of approach according to the level of automation: 75 % of pilots would approve this document because they consider that these patterns could help them to encompass all specific instruments which are request for the landing in the correct sequence, as taught in flying school. Moreover, some studies (Adam & Condette, 2013) also concluded that it should be necessary for manufacturer and operator to define together a visual scan that would optimize crew teamwork during some phase of the flight and particularly the go around procedure. These patterns could help pilots to manage time spend on each instruments during the approach and associated cinematic.

Another way to improve approach stabilization could be to use these eye tracking systems in recurrent training to increase consciousness of pilots in respect to their visual circuits. In fact, if the visual circuit of some pilots is suboptimal compared to most accurate, lack of training seems to be the reason considering the survey. According to this research, gaze allocation for each of fly instruments during the approach is constant for more accurate regarding pilots who performed unstabilized approaches. Moreover, for the most accurate pilots, there are " similar sequences " when flying without automatims: they are taking more in consideration the attitude indicator associated with thrust displays when flying the aircraft without auto-thrust, probably due to a better consideration of the couple pitch / thrust. Furthermore, these pilots take into consideration more all flight instruments with a dwell time different of other and mainly the one who go around. So, it can be hypothesised that, if less accurate pilots could take into consideration visual pattern of more accurate pilots group, they would probably develop their scanning strategy.

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