INVESTIGATING PILOT'S DECISION MAKING WHEN FACING AN UNSTABILIZED APPROACH: AN EYE-TRACKING STUDY

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Unstabilized approach has been identified to be a major causal factor of approach-and-landing accidents (e.g. off-runway touchdowns, hard landing, tail-strikes, etc). We conducted an experiment in order to analyze pilots' performance during such approaches. Ten type-rated, commercial pilots flew each in a B737 full-flight simulator during an unstabilized approach at Hamburg airport. The Pilot Flyings' (PF) eye gazes were collected. The results revealed that half of the pilots persisted in an erroneous landing decision. These latter pilots had higher dwell time on the attitude indicator/flight director whereas the group of pilots who perfomed the go-around exhibited more fixations on the navigation display prior to their final decision. These findings indicate that the decision whether to land or to go-around is taken considerably long before the respective task is executed, and that the use of heuristics impair pilot's performance.

Introduction

Unstabilized approaches have been identified to be a major causal factor of approach-and-landing accidents. Poor pilot performance in aircraft handling, system control or crew resource management during approach and landing reveal that, from the years 2001 to 2010, 49% of all fatal accidents worldwide occurred during the initial approach, final approach, or in the landing phase (Boeing, 2010). To approach and land safely, pilots are required to follow approach profiles fulfilling predetermined stabilization criteria based on flight parameters defined by the authorities, such as vertical speed, airspeed, or landing configuration in relation to the height above ground (ICAO, 2006; Airbus, 2006). If the criteria for stabilized approach are not met at the stabilization height (e.g. 1000 feet), a go-around is mandatory. However, continuation of an unstabilized approach has been found to be a causal factor in 40% of all approach. Combined with a system philosophy based on a master (human)-slave (machine) relation (Tessier & Dehais, 2012), today's flight deck automation has a significant negative impact on this demanding flight phase. Mode confusion or improper system state awareness significantly contribute to approach destabilization (Sarter & Woods, 1995). The aerodynamic characteristics of modern aircraft wings aggravate the competing physical interplay of altitude loss, deceleration, (vertical) speed restrictions and airplane configuration. This always creates added complexity in the pilot's decision-making process leading to high workload situation (Dehais et al., 2012) and thus promoting perseveration to land at all cost (Causse et al., 2013; Curtis & Smith, 2013).

One promising approach to better understand pilot's performance during unstabilized approach is to measure their eye movements. For instance, several accidents analyses pointed out that poor monitoring was a contributive factor involved in many accidents during the approach (Spangler & Park, 2010; National Transportation Safety Board, 2014a; National Transportation Safety Board, 2014b; Dutch Safety Board, 2010; Civil Aviation Authority, 2013). Little is known on how pilots actually supervise the flight deck during critical phases such as the approach. Interestingly enough, several studies revealed the suitability of the eye tracking technique for understanding attentional vulnerabilities of pilots (Dehais, Causse, & Pastor, 2008; Huettig, 1999; Kasarskis et al., 2001; Mumaw, Sarter, & Wickens, 2001; Sarter, Mumaw, & Wickens, 2007; Wickens, et al., 2008; Dehais et al., 2015).

In order to better understand why trained pilots may fail to adequately monitor flight parameters, the DGAC/DSAC [1] initiated the Pilot Vision project that aimed at analyzing eye tracking data collected during more

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than 100 approaches by ISAE-SUPAERO. A first study was conducted over 32 stabilized approaches and revealed that both Pilot Monitoring (PM) and Pilot Flying (PF) exhibited a high percentage of dwell time out of the window during the short final. For PMs this was to the detriment of the monitoring of the speed indicator (Reynal, Colineaux, Vernay, & Dehais, 2016). In the present study, we focused our analyses on an eye tracking dataset collected with 10 pilots facing unstabilized approach at the Hamburg airport. The approach was segregated in two major sequences to investigate pilots' decision making. The first sequence started from around 3000 feet to 2500 feet (*Approach Initiation* sequence), and the second one (*Decision* sequence) started from 2500 feet point until the Missed Approach Point (MAPt). The 2500 feet FL was somewhat arbitrary, but meant to initiate a time during which the instability of the approach should begin to be noticeable. As some pilots continued with the unstable approach beyond decisoin height, our intention was to compare the ocular scanning strategy between those who did, and those who did not. These data were then compared with another eye tracking dataset collected during a stabilized approach to identify potential different ocular strategy.

Material and Method

Participants

Ten airline Captains, including one female, volunteered to partipate to the experiment. They all endorsed the role of Pilot Flying. Their mean age was 44.45 years old (*SD* = 17.91; *min* = 23; *max* = 71) with a mean flight experience of 11372.73 hours (*SD* = 11899; *min* = 1500; *max* = 33000). On Boeing 737 NG, this group had a mean flight experience of 4402.55 hours (*SD* = 3558.54; *min* = 64; *max* = 9000). A confederate pilot was involved as PM to play a particular role during the flight, but their data are not included in the analyzed group as they are part of the experimental protocol.

Flight simulator and scenarios

The experiments were conducted on a Boeing 737 NG full-flight simulator of the CAE 600 series. It has a hydrostatic motion system with six degrees of freedom (6DOF), a Rockwell Suprawide Vision System and is certified as Level D/Zero Flight Time—this means that the simulator reflects the aircraft so realistically that operator training can be accomplished without the necessity to do further training on the real aircraft before the trainee pilot is allowed to fly with passengers on board.

The scenario consisted of an approach to Hamburg and began approximatively 50NM south of the field at Flight Level (FL) 150 (15,000 feet). The tailwind component of the descent profile was stronger and the cloud layer with freezing conditions was thicker than forecast. The latter required the use of the engines' Thermal Anti-Ice system (TAI). The resulting, higher bleed demand drives the Full Authority Digital Engine Control (FADEC) system to schedule higher idle thrust in order to ensure sufficient air flow within the engines. Tailwind and high idle thrust had an impact on the descent profile such that the aircraft was approximatively 3,000 feet high on path. Immediately after the start of the scenario, a runway change was announced that shortened the distance to touchdown by 25NM. Altogether, the aircraft ended up being approximatively 10,000 feet high on path. The crews had full auto-flight system function available (autopilots, flight director, and auto-thrust).

Eye-tracker and Areas of Interest

Eye tracking data were collected with a Pertech eye-tracker (0.25° – 0.5° of accuracy). Head movements were corrected by an alignment of three infra-red emitters to map participants' fixations on an image of reference. The 10 following areas of interest (AOI) were created (see Figure 1): 1) Heading (HDG), 2) Attitude Indicator (AI), 3) Airspeed (Speed), 4) Flight Mode Anounciator (FMA), 5) External view (Ext.), 6) Flight Control Unit (FCU), 7) landing gears panel (Gears), 8) Engine-Indicating and Crew-Alerting System (EICAS), 9) Navigation Display (ND), 10) Altitude indicator (Alt.), and the two subsidiaries 11) No AOI, which is for all what is being viewed but does not correspond to any AOI, and 12) Uncaptured, which includes all the data that was not captured by the device (i.e. this is not an AOI but a non-captured quantity of data).

Eye-tracking and data analysis

Each approach was segregated into two sequences (see Figure 2), namely *Approach Initiation* (from the beginning of the recording to 2500 feet), and *Decision* (from 2500 feet to the decision to land or to go-around). As the temporal milestones that define the *Decision* sequence do not vary from one subject to another, this study is mainly focusing on this *Decision* sequence.

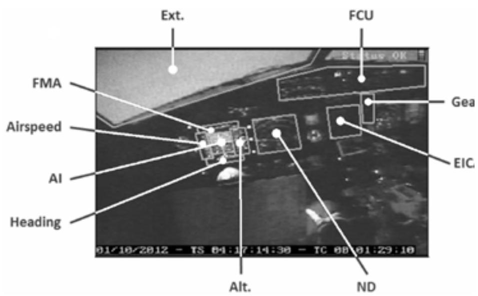

Figure 1. The different Areas of Interest (AOIs) in a Boeing 737 NG cockpit as they were drawn for the experiment.

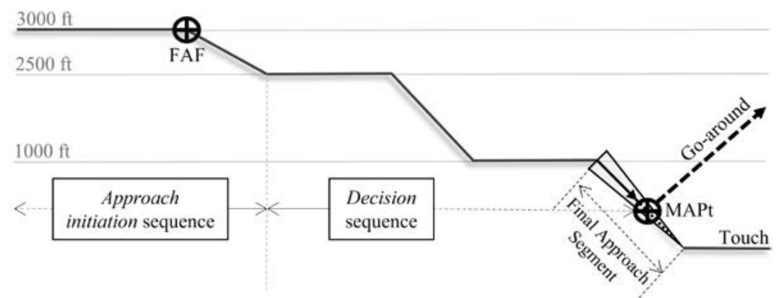

Figure 2. Schematization of a standard approach profile (FAF stands for Final Approach Fix; MAPt stands for Missed Approach Point, which is the point were the go-around procedure is effectively started after a go-around decision).

Behavioral and eye-tracking results

Our behavioral results disclosed that five pilots decided to make a go-around (GA group) and the five other persisted in an erroneous landing decision (Landing group). Therefore, we focused our eye tracking study on the comparison between the GA group and the Landing group to identify potential different ocular strategies that would characterize them.

The descriptive results for the study of pilots' ocular behavior (in terms of dwell time percentages per AOI during the *Decision* sequence on the D3CoS data) are shown on Figure 3. While 10 different AOIs were measured in the data analysis (see Figure 1), we focused our analysis on the seven that received the majority of scans. Therefore, only Airspeed, Attitude Indicator, Altitude, ND and External view AOIs were taken into account. The average percentage of dwell times on the different AOIs and for *Approach Initiation* and *Decision* sequences were plotted to reveal the differences in each AOI, between the cases of go-arounds and landings. As these descriptive results suggested, it appears that pilots who continued landing ganced at the AI more (M = 27 vs M = 11; t = -1.64) and at the ND less (M = 9.6 vs M = 23; t = 1.49) compared to those who correctly executed the go-around.

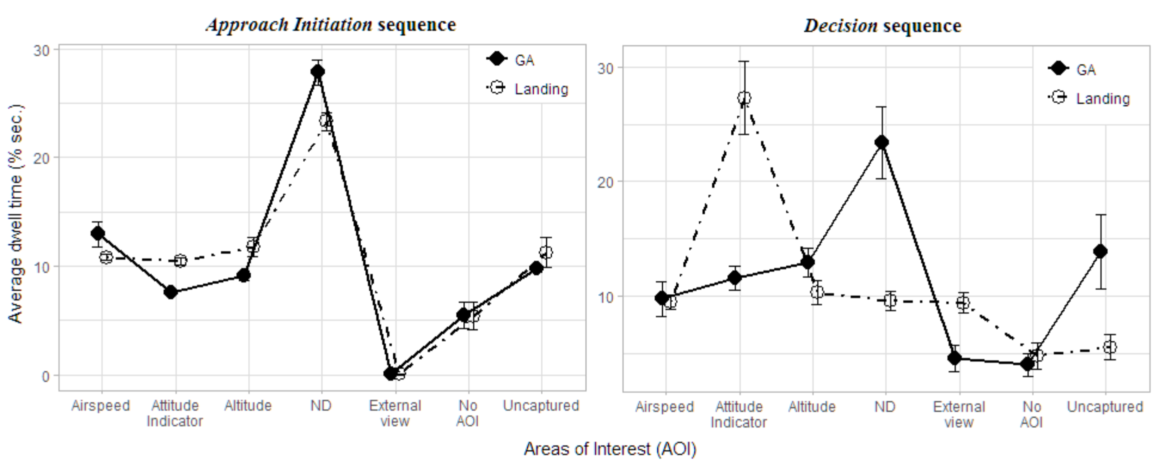

Figure 3. Average dwell time percentages centered standard error bars (in seconds; *y* axis) per AOI (*x* axis), for *Approach Initiation* sequence (on the left), and *Decision* sequence (on the right) during Hambourg approach (breakthrough in clouds), for GA (closed circles) and Landing (open circles) groups.

In order to identify ocular behaviors specific to unstabilized approach, we compared these eye tracking data with a previous one collected during a stabilized approach at Saint-Exupéry Lyon airport in Boeing 777 and Airbus A330 full-flight simulators (please report to Reynal, Colineaux, Vernay, & Dehais, 2016). Though the scenario and aircrafts were different from the ones that we used in this experiment, glide characteristics, level of automation and user interfaces were similar, thus allowing us for such comparisons. As the number of pilots were not similar (*n* = 8), we randomly removed 2 pilots from our unstabilized approach dataset. The descriptive results are shown on Figure 4. As in the previous graphs, the set of AOIs have been reduced. We conducted a second 7 x 2 ANOVA (AOIs [Indicator, Altitude, ND, External view, No AOI, Uncaptured] x Approach types [Stabilized, Unstabilized]), with AOIs implemented as within factor and Approach types implemented as between factor. This analysis disclosed a significant Approach types x AOIs interaction [$F(1, 14) = 4.52$, $p < .001$, $\eta^2_p = .18$]. Tukey's HSD post-hoc analysis revealed that the pilots who faced a stabilized approach glanced more at the External view ($p < .05$) and the Attitude Indicator ($p < .05$) than the ones who experienced unstabilized approach. The data also reveal a trend toward less scanning on te ND for the stablized group.

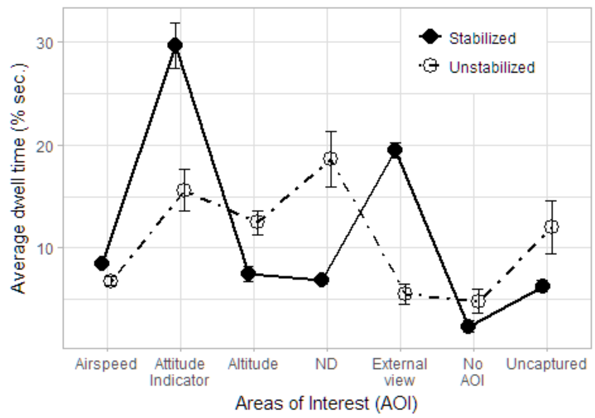

Figure 4. Average dwell time percentages centered on standard error bars (in seconds; *y* axis) per AOI (*x* axis), starting from 2500 feets until the decision to go-around or to land (i.e. *Decision* sequence), for stabilized approaches (closed circles) and unstabilized ones (open circles).

Discussion

The objective of this paper was to better understand pilot's ocular and behavioral performance when facing an unstabilized approach. To the authors' knowledge, this study was the first to measure the PF's eye movements during such kind of approach. The scenario was designed in such a way that the aircraft would never become stabilized at the 1000 feet-gate. Our behavioral results, shown that half of the crew persisted in an erroneous landing decision while the other half decided to go-around. Interestingly enough, these qualitative eye tracking findings disclosed that these two groups of pilots exhibited different ocular behaviors. This was particularly true during the *Decision* sequence as pilots from Landing group focused more on the Attitude Indicator whilst pilots from GA group glanced more at the ND (see Figure 3). The Attitude Indicator displayed the flight director behavior thus indicating the flightpath for landing whereas the ND provided information of the current position of the aircraft and of future trajectory (i.e. missed approach segment). This finding may indicate that pilots from the Landing group summoned up all their cognitive resources on supervising the landing trajectory to the detriment of the monitoring of other parameters related to alternative strategies (i.e. go-around). On the contrary, pilots from the GA group seemed to have a better management and anticipation of alternative strategies.It is important to note that the two groups did not differ in their scanning during the *Approach Initiation* sequence, indicating that there was nothing maladaptive about the landing group's overall visual performance. The difference between the two groups therefore seems to lie in the ability to notice specific cues regarding the instabilitiy, or in the decision criterion (e.g., acceptance of risk).

In the experiment, the flight profile changed as dynamical as the environmental conditions. Thus, the decision whether and how to re-stabilize the aircraft had to be constantly challenged and re-taken by the pilots. There are navigational rules that enable pilots to compute the vertical path of a trajectory. However, the closer the final approach, the least the cognitive resources are available to correctly calculate and follow such algorithms (Lacko, Osterloh, & Dehais, 2013). Instead, algorithms are replaced by heuristics, being built upon experience and recency, which make corrective actions to path divergence less trustworthy (Wickens, 2003). The eye-tracking results imply that the decision whether to land or to go-around is taken considerably long before the respective task is executed, and that heuristics aggravate the perseveration being observed in this study. This is well in line with statistical data, which show that still 97 percent of all unstabilized approaches end up with a decision to land (Curtis & Smith, 2013) thus exhibiting "perseveration" behavior (Causse et al., 2009; 2013, Dehais et al, 2012). Eventually the comparison of these eye tracking data with a previous ocular dataset collected during stabilized approach seemed to support that unstabilized approach also impacted pilots' gaze behavior. Hence, we finally compared our "unstabilized" dataset with a previous one collected during stabilized approaches. The statistical findings indicated that stabilized and unstabilized approaches induced different gaze patterns. Indeed, stabilized approaches makes pilots more confident to land and thus allow them to more focus on PFD and also integrate visual cues for a transition from instrument flight to the (always) visual landing manoeuvre. This is in line with training recommendations in the Flight Crew Training Manuals (FCTMs). However, it is interesting to note that pilots from the Landing group, in our unstabilized scenario, qualitatively exhibited similar pattern, especially on the PFD. Thus, traces of perseveration can be identified in that group as this gaze behavior doesn't justify otherwise.

We believe that these analyses demonstrate the potential of eye tracking studies to analyze PF's eye movements during critical phases such as unstabilized approach. These first descriptive results, with other (Reynal, Colineaux, Vernay, & Dehais, 2016), show that there is a need to establish standards on visual scanning pattern with regards to eye tracking to be consistent with SOPs during landing. These eye tracking results support recent recommendation by the Federal Aviation Administration (FAA), stated that "by March 2019, air carriers must include specific training pertaining to improve monitoring". However, one has to consider our study has several limitations that need to be considered as our sample was composed of only 10 pilots in simulated conditions, and the accuracy of eye tracking techniques still remains a challenge, especially in ecological conditions.

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