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Applying the Perceptual Cycle Model (PCM) over an Aircraft Approach and Landing Procedure

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Runway Overruns (ROs) are the result of an aircraft rolling beyond the end of a runway, being one of the accident's types that most frequently occurs on aviation. ROs usually happen in landing phase and are a consequence of adverse weather, unstable approaches, long touchdowns, poor runway surface conditions, deficiencies in aerodrome facilities and inadequate use of deceleration devices. As these precursors are correlated with decisions taken by the pilots during the approach and landing procedure, the current work aims to analyse their decision-making process with the addend of the Perceptual Cycle Model (PCM). Interviews with two (2) pilots were conducted to capture this process. A process that was analysed via the Schema Theory as incorporated in the PCM, providing adequate causal explanations for erroneous decisions and raising recommendations.

Keywords: Aviation, Runway Overrun, Naturalistic Decision Making, Perceptual Cycle Model.

1. Introduction

In December 2005, Southwest Airlines Flight 1248 overran the runway during landing at Chicago Midway International Airport (Fig. 1). The airplane rolled through an airport perimeter fence onto an adjacent roadway, where it collided with an automobile before coming to a stop. The airplane was substantially damaged. Of the 103 people aboard and 4 occupants of the automobile, 21 persons received minor injuries, and one was killed. The landing was performed in adverse weather conditions over a contaminated runway. The pilots failed to divert to another airport with more favourable landing conditions and to use available reverse thrust in a timely manner (FAA, 2022).

Fig. 1 - Photo of the Airplane after the Accident (FAA, 2022)

Events like that, characterized by the inability to stop the aircraft within the runway limit, are named Runway Overrun (RO). Most of them occurs in landing phase and are associated with adverse weather, unstable approaches, long touchdown, poor runway surface conditions, deficiencies in aerodrome facilities and inadequate use of deceleration devices (IATA, 2022).

Following unfavourable weather or runway surface condition, another airport or runway might be requested. Following an unstable approach, a go around might be performed. Following a long touchdown, the deceleration devices might be more aggressively applied. During approach and landing, the pilots make a series of decisions. They are the last barrier of the complex aviation system, but their situational awareness or overreliance may activate an inappropriate schema leading to a poor decision. In high workload circumstances, such as the approach and landing procedure, it is not uncommon to emerge problems in decision-making that potentially lead to an incident or accident.

This paper proposes the appliance of the Perceptual Cycle Model (PCM) in the analysis of naturalistic decision making of the approach and landing procedure. The PCM draws on Schema Theory to demonstrate how the environment and context surrounding the decision interact with the cognitive structures and actions of the decision maker (Plant & Stanton, 2017). Schemata are mental templates of knowledge clusters that are structured upon experiences similar in nature, driving future behaviours and being updated upon the exposure to new experiences. The paper explores, through the PCM, how the flight crew decision making processes during approach and landing precedes a normal landing and/or an overrun.

2. The Perceptual Cycle Model

The Naturalistic Decision Making (NDM) framework emerged as a manner to study how people make decisions and perform cognitively complex functions in demanding real-world situations. This includes situations characterized by limited time, uncertainty, high risk, organizational and team restrictions, unstable conditions and variables amounts of experience (Neisser, 1976).

The Perceptual Cycle Model (PCM) is a NDM model that presents a process-orientated approach to understand decision making by exploring the interaction between a person's cognitive schema, the actions they undertake and information available in the world. It has three key components: world, schema and action, which interact in a cyclic manner. The first one refers to the information provided by the world (W) and environment. The second characterizes the schema (S) that is activated by the information available. The third step resumes the actions (A) that may be taken, based on the individual and active schema (Plant & Stanton, 2012). The actions influence the world (Fig. 2).

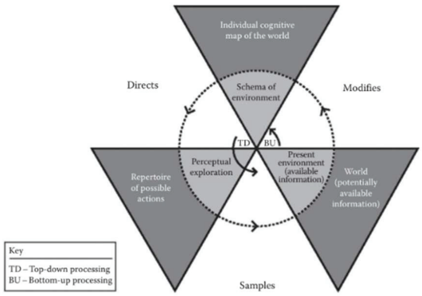

Fig. 2 - Perceptual Cycle Model (Plant & Stanton, 2017)

Lima et al. (2024) used the PCM as a framework for the evaluation of pilot recognition and response to failure conditions in the context of the Safety Assessment Process for aircraft development and certification. Da Silva et al. (2023) and Parnell et al. (2022) applied the PCM as a tool for accident investigation, providing a framework to explore pilot's interactions with the aircraft and the relations of those interactions with the accidents' causes. These studies resulted in insightful material for training and aircraft indications design improvements. The current study aims to achieve similar results but analysing the whole approach and landing procedure and identifying the schemas that may be activated in each decision-making step.

3. The Approach and Landing Procedure

During approach, the aircraft must follow the correct flight path, normally given by a three-degree approach track (FSF, 2009a). This path is usually indicated by the ILS (Instrument Landing System) or the GPS (Global Positioning System) Approach mode as well as by visual aids such as the PAPI (Precision Approach Path Indicator) and/or the runway surface markings. It typically results in a runway threshold crossing at a height of 50 feet and a touchdown point of 1,000 feet beyond the threshold.

The ILS is a precision runway approach support employing two radio beams to provide pilots with vertical and horizontal guidance during the approach. The localizer (LOC) provides azimuth guidance (Fig. 3), while the glideslope (GS) defines the correct vertical descent profile (Fig. 4). The GPS Approach mode is a non-precision approach defined by a series of waypoints and altitude restrictions that the pilot will follow to the runway threshold, free of conventional guidance such as the ILS.

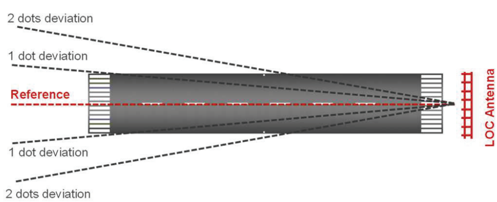

Fig. 3 - Localizer Representation (Reiser et al., 2024)

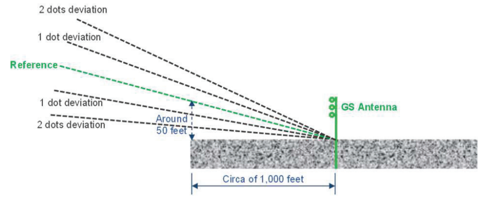

Fig. 4 – Glideslope Representation (Reiser et al., 2024)

The ILS and GPS Approach typically guide the flight crew until the Decision Altitude (DA) and Minimum Descent Altitude (MDA), respectively. After that, the flight crew performs a visual approach and uses the visual aids as references. The PAPI system is a set of lights that the flight crew can see during the final approach. The ratio of white to red lights seen is dependent on the angle of approach to the runway (Fig. 5). Above the designated glideslope a pilot will observe more white lights than red; at approaches below the ideal angle more red lights than white will be seen.

Fig. 5 – PAPI Lights (Reiser et al., 2024)

The approach should not be performed with an aircraft airspeed over the reference speed (v_{ref}) + 20 knots and not less than v_{ref} (FSF, 2009a). Still, it must be equal to v_{ref} at the runway threshold to ensure that the estimated Unfactored Landing Distance (ULD) will be achieved. ULD is the distance used by an aircraft in landing and braking to a complete stop (on a dry runway at sea level) after crossing the runway threshold at 50-feet Above Ground Level (AGL) with v_{ref} in landing configuration (FSF, 2009c). The ULD is determined from data obtained from aircraft certification campaign with maximum brake application and without the use of thrust reverser. Corrections for airport elevation, aircraft weight, wind and icing conditions are available at the manufacturer Aircraft Flight Manual (AFM).

Under 50 feet of height, the pilots are required to change the aircraft attitude in a few seconds for a safe and smooth touchdown in a manoeuvre called flare. They raise the aircraft nose to both land the aircraft on the main landing gear first and decrease the descent rate and vertical load. Nonetheless, a firm touchdown is recommended, particularly on wet or contaminated runways, to minimize the risk of aquaplaning (Eurocontrol & FSF, 2021). If not executed correctly, lasting too much time, the flare may result in a long touchdown.

The aircraft must touch the ground at the aiming point, which is usually 1,000 feet from the runway threshold. A long touchdown occurs when an aircraft touches the ground far ahead of this point.

After the touchdown, the flight crew must decelerate the aircraft using the available devices, such as Ground Spoilers, Wheel Brakes and Thrust Reverser Systems. The inadequate or late use of these devices as well as a poor runway surface condition may increase the distance required to stop the aircraft. Ground spoilers are panels mounted on the upper surface of the wing. When extended, they dump the lift raising the load on the wheels and thus improving the wheel-brake efficiency. They also increase aerodynamic drag contributing to aircraft deceleration. The spoilers usually deploy automatically (if armed) upon touchdown or upon thrust reverser's activation.

Wheel brakes are located on the wheels of the main landing gears. Braking action results from the friction force between the tires and the runway surface. It depends on aircraft speed, wheel speed (i.e., free rolling, skidding or locked), tire condition and pressure, runway surface condition and its friction coefficient, the load applied on the wheel, and the number of operative brakes. Normal brakes are applied through pedals and, sometimes, differential braking is necessary to control the aircraft laterally. Anti-skid systems prevent tire skidding and maximize brake efficiency according to the runway surface. Autobrake systems provide automatic braking at maximum deceleration rates, which varies according to runway surface conditions and its mode selection (e.g., Low, Medium, High). Emergency brakes may be used in case of normal brakes failure. In this case, the pilot must pull the handle carefully and slowly, modulating the braking action as there is no anti-skid protection (Reiser et al, 2024).

Thrust reverser systems, whose efficiency is higher at high speeds, must be selected as early as possible after touchdown. They provide a deceleration force that is independent of runway surface condition (FSF, 2009d).

3.1 *Applying the PCM*

As exhibited above, the approach and landing procedure is a sequence of observations, decisions and actions that are detailed through the PCMs in Fig. 6 and Fig. 7. Both models were based on the expertise of two pilots. The first one holds a commercial pilot license with multi engine and instrument ratings as well as E50P, E55P and E550 type ratings, accumulating a total of 1,600 Flight Hours (FH). The second holds a fixed wing commercial pilot license with single engine, multi engine, instrument and flight instructor ratings as well as an E145 and E550 type ratings, accumulating 350 FH. Both have practice as aircraft accident investigators.

The pilots were interviewed through a method similar to the Critical Decision Method (CDM), that is a retrospective interview strategy to evaluate the decision making during nonroutine incidents (Klein et al., 1989). In the current work, the pilots described the approach and landing procedure without interruption by the interviewer. After that, the procedure was reconstructed in the form of a timeline that stablished the sequence of actions and the information used to support these actions. During the timeline construction, the decision points (i.e., the moments that more than one course of action is possible) were identified. The decision points were then explored by questioning what the pilots are seeing and hearing at this moment, for example; what are the information that they use to make each decision; which are the possible courses of action as well as how these options are selected and/or rejected; and so on. Lastly, both pilots validated the PCMs.

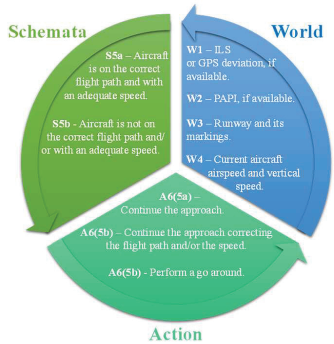

Fig. 6 - PCM of the Approach Procedure

During approach, the flight crew determine if the aircraft is on the correct flight path by observing the ILS and GPS deviation and/or the PAPI. When these aids are not available, they focus on the distance to the runway and use the vertical speed as a reference, flying based on their experience. The adequate speed is checked through a direct comparison between the aircraft airspeed and the reference one, estimated previously and briefed prior to the approach.

When a stable approach is identified (S5a), the flight crew continues the approach. Once an unstable approach is recognized (S5b), they may continue the approach correcting the flight path and/or the speed or they perform a go around.

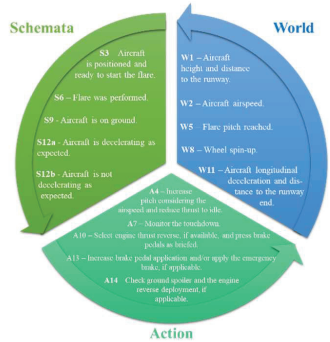

Fig. 7 - PCM of the Landing Procedure

The landing phase begins at 50-feet height and/or over the runway threshold. As soon as the flight crew identifies this condition, they start the flare by increasing the pitch and reducing the engine thrust reverse in order to lower the vertical speed. The pitch variation depends on the aircraft airspeed, as a small pitch in high-speed may result in floating the landing. Note that, in this moment, the pilot should not be looking at the instruments. Instead, his eyes must be looking out the window.

As soon as the flare pitch is reached, the flight crew start monitoring the touchdown or, more specifically, the wheel spin-up. It is worthy to mention that the aircraft is not necessarily with the weight on wheels after the wheel spin-up. In this condition, the deceleration may be initially low even with full-brake application, inducing the pilot to believe in a brake malfunction.

With the aircraft on ground, the pilot selects the engine thrust reverse, if available, and presses the brake pedal as briefed. The briefing is realized prior to the approach. Thus, the brake application profile considers the runway length and information regarding its surface condition, when presented. It does not necessarily take into consideration a high-speed nor a long touchdown (i.e., a critical landing).

The pilots then monitor the aircraft deceleration and the distance to the runway end to evaluate if it is necessary to increase the brake pedal application. Rarely, they also apply the emergency brake, even without any brake failure input. At last, the flight crew checks the ground spoiler and the engine reverse deployment, if applicable.

3.2 *Evaluating the PCM regarding Runway Overruns*

An unstable approach may result in an increased height or speed over the runway threshold. The certified ULDs, provided in the AFM, are determined based on the assumption that the landing gear is positioned 50-feet above the threshold. For every 10 feet above this standard, landing air distance (i.e., the distance between 50-feet and the touchdown point) will geometrically increase 200 feet (FSF, 2009c). An excessive speed over the runway threshold may also result in a long touchdown as well as a higher speed from which the pilot must stop the aircraft (FAA, 2016). A 10 percent increase in final approach speed results in a 20 percent increase in ULD, assuming a normal flare and touchdown (FSF, 2009c).

The long touchdown directly reduces the runway available for braking. When the crew does not identify a critical landing or is not aware of a real and unfavourable runway surface condition, they may start with a usual deceleration procedure (i.e., an inadequate one). For each second beyond 2 seconds of delay to employ the deceleration devices, 200 feet may be added to the braking distance (FSF, 2009c). Besides, less than maximum brake also impacts this distance.

Therefore, the risk of an overrun increases when more than one precursor is present as multiple hazards create a synergistic effect, as exemplified in Fig. 8.

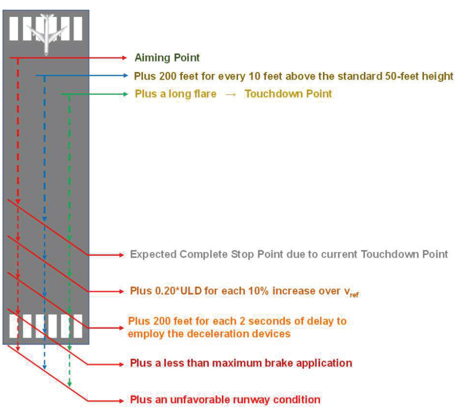

Fig. 8 - Summary of the Precursors that may Affect the Landing Distance (Reiser et al., 2024)

For each decision that the flight crew takes, there is a schema running in their minds, which is responsible for the human performance variability and may cause different outputs. For instance, the decision of performing a go around or even of correcting the flight path and/or speed during the approach is made only if an unstable approach is recognized. The adequate speed is easily identified, but the correct flight path is not so trivial in aircraft without the GPS Approach Mode and/or in runways without ILS and/or PAPI.

The recognition of a critical landing is also not simple. Flare variability is large, and it is also not easy to perceive a long touchdown, mainly when the aircraft floats the landing as the weight-on-wheels signal is not used as reference. Shortfalls in the accuracy and timeliness of runway surface conditions reporting, when available, are also identified as a contributing factor to many runway excursions. Consequently, the decision to apply the brake pedal aggressively should always be performed. The problem is that an aggressive brake profile is not comfortable.

To check the ground spoiler and the engine reverse deployment is the last action to be executed, justifying one of the "pilot's error" listed as a precursor of the Southwest Airlines Flight 1248 accident.

4. Case Study

The Southwest Airlines Flight 1248 accident occurred on the first leg of a scheduled three-day trip that originated in Baltimore. Its departure was delayed approximately two hours due to deteriorating weather conditions in the Chicago area. Once enroute, the flight crew received weather updates for the airport indicating that runway 31C would be the active runway instead of the 04R, and that braking action reports were mixed, reporting good or fair braking action for the first half of the runway and poor braking action for the last half (FAA, 2022). Runway 31C is slightly larger than the 04R.

Approximately 25 minutes prior to landing, while in a holding pattern, the first officer entered a few scenarios into the Onboard Performance Computer (OPC) using the reported wind conditions of 11 knots at 90º (i.e., 8 knots of tailwind) as well as both fair and poor braking action reports separately, as the OPC would not accommodate mixed reports. Based on his inputs, with fair braking action for the entire length of the runway, the airplane would come to a full stop 560 feet short of the departure end of the runway. Using poor braking action for the entire length yielded a stopping point 40 feet short of the departure end. Further discussion between the pilots also resulted in a decision to divert to an alternate airport if the tailwind component increased to above ten knots or if braking action reports indicated poor braking action for the entire runway length.

Upon receiving a landing clearance, the first officer was informed that the wind had decreased to 9 knots at 90º, and braking action continued to be reported as good for the first half of the runway and poor for the second one. The airplane touched down in the designated touchdown zone at a speed of 124 knots. The ground spoilers deployed and, within one second of touchdown, the automatic braking system began to operate. This flight was the first planned operational use of the automatic braking system, per a new Southwest Airlines policy. Neither the pilot nor the copilot had previously used the autobrake system.

Following touchdown, the captain stated that he attempted to deploy the thrust reversers but had difficulty moving the levers to the reverse thrust position. He felt the antiskid system begin cycling after touchdown, but that the cycling stopped, and the airplane seemed to accelerate. Then, he applied manual braking, disconnecting the automatic brakes, and did not continue with his attempt to deploy the thrust reversers. He later stated to investigators that he believed the use of the autobrakes distracted him from the thrust reversers after his initial attempt to deploy them.

The first officer also stated that he felt a reduction in the airplane's deceleration and began using manual braking. He subsequently saw that the thrust reverser levers were still in the stowed position, moved the captain's hand away from the levers, and initiated deployment of the reversers about 15 seconds after touchdown. The engines reached full reverse thrust about 18 seconds after touchdown, and approximately 500 feet from the end of the runway. The airplane ran off the departure end of the runway.

The decision-making errors listed by the NTSB as contributing factors of this accident are related to steps 10 to 14 of the Landing Procedure PCM. The flight crew concluded that the aircraft was not decelerating as expected (S12b) and reacted by pressing the brake pedal, even in a contaminated runway. The check of the engine reverse deployment was treated as a secondary task (i.e., the last one to be performed).

5. Discussion

The PCM starts with the initial event in the external environment and how it first presents itself to the decision maker (e.g., the aircraft airspeed on the cockpit instruments and the runway surface condition report). The interactional nature of the individual with the environment within the PCM means that it requires information to be accurate and up to date. Real-time information regarding the status of the landing would assist in reducing the ambiguity in the decision-making process. The PCM reinforce the relevance of functionalities that aim to increase the pilots' situational awareness by generating alerts when an excess of energy during approach is detected, the autobrake setting does not fit, and/or a more aggressive brake pedal application is necessary. Functionalities like that are called Runway Overrun Awareness and Alerting System (ROAAS) and they will become mandatory on Europe for every large airplane used in commercial air transport, whose first individual certificate of airworthiness will be issued on or after 1 January 2025 (EASA, 2020). The Airbus Runway Overrun Prevention System (ROPS) and the Embraer Phenom 300 Runway Overrun Awareness and Alerting System (ROAAS) are commercial examples of this kind of functionality (Jacob et al. 2009; Marques, 2019).

Another aid to increase the safety during landing is the accuracy of the information regarding the runway surface condition, which may be reported using several types of descriptive terms such as type and depth of contamination, readings from a runway friction measuring device, an aircraft braking action report, or an airport vehicle braking condition report. The lack of standardisation with concern to the assessment of the runway surface condition and braking action, the compilation of the conditions to end-users such as the flight crew (e.g., use of different terminology and format), and the use of the reported information by the pilots, influences the accuracy and timeliness of runway surface conditions reporting, which is cited as contributing factors to many runway excursions. The ICAO Global Reporting Format (GRF) methodology was proposed as a solution for this issue (Skybrary, 2024).

Basically, the GRF comprises an assessment by airport operations staff using a Runway Condition Assessment Matrix (RCAM) and the consequent assignment of a Runway Condition Code (RWYCC). The outcome of the assessment and associated RWYCC are transmitted using a uniform Runway Condition Report (RCR) forwarded to air traffic services and the aeronautical information services for dissemination to pilots. Pilots use the RWYCC to determine their aircraft's performance by correlating the code with performance data provided by their aircraft's manufacturer. This will help pilots to correctly carry out their landing and take-off performance calculations for wet or contaminated runways (Skybrary, 2024). The GRF is still not implemented in every country and/or runway (ICAO, 2024).

The PCM also confirms that general and executive aviation are more prone to runway overruns. These types of aviation use small airports without any infrastructure (e.g., ILS and PAPI) and with shorter runways. Pilots are usually less experienced, particularly with handling high-speed landings and the flare. Here, the safety may be increased mainly by reinforcing the training programs, that should specifically address proper landing techniques and the understanding of the aircraft performance limits.

6. Conclusions

The PCM accounts for the cognitive processing of the individual and the interaction of the wider systemic elements, being useful at presenting how a decision aid will be integrated within a certain scenario and how it will shape the experience of the individual, as well as their interactions with the environment. Therefore, this method is advocated in the review of a decision aid after its initial design to understand how it may interact within a system (Parnell et al., 2022). This could allow any unforeseen and unintentional interactions to be reviewed in the design process or reinforce the interactions in a system in operation.

Runway excursion is the type of aircraft accident that most frequently occurs, being composed by overruns and veer-offs and occurring predominantly during landing. Their precursors include operational deviations such as unstable approaches, long touchdowns and the inadequate use of deceleration devices. Significant attention to address these precursors are dedicated by the aviation industry and the novelty of this study remains in the application of the PCM to explore these precursors, which are also related to poor decisions.

The development of this present study allowed an analysis of the functions directly linked to the approach and landing procedure, improving the understanding of the complete scenario. The relevance of better runways infra-structure and of initiatives such as the ROAAS and GRF was pointed out.

The PCM also allowed to visualize how qualitative analysis can help to investigate variability present in the scenarios (e.g., the Southwest Airlines Flight 1248 accident) and thus, making it possible to create barriers to avoid possible risks. The PCM usage highlighted the flight crew behaviour and course of actions operating the thrust levers given the information received and the pilot's schema at that moment.

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