WHAT CAN WE LEARN FROM RESILIENT PILOT BEHAVIORS? THE CASE OF ENERGY MANAGEMENT WHILE FLYING A STAR

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Recently, there has been increased interest in documenting flightcrew behaviors that contribute to safe operations. Instead of only capturing errors, new efforts are attempting to understand how pilots manage complexity and variability in the operational environment to ensure a safe mission. This approach highlights pilot responses to events and conditions that fall outside typical TEM threats; e.g., revised ATC clearances. This approach presents a two-sided coin: characterize flightcrew resilience /or/ generate insights regarding complexity in the operational environment that is not adequately managed by current flight deck interface designs, procedures, and training. To capture operational complexity, we have been analyzing flight path management tied to flying an RNAV STAR. Because ATC often requests revisions—e.g., descend late—and because RNAV STARs may not align with airplane performance limits, flightcrews need to monitor, anticipate threats to RNAV STAR compliance, and devise ways to accommodate unexpected challenges. In this paper, we identify general strategies that can support response adaptation and explore methods to facilitate training these strategies.

The Emergence of Safety II and Resilience

Operational safety in aviation (and other domains) has long been framed in terms of probabilistic risk assessment (PRA) in which risk is associated with airplane system failures, upsets, or erroneous flightcrew actions that need to be managed or mitigated. In this framework, flightcrew performance is judged by the flightcrew's ability to recognize and manage failures and upsets. When an unsafe outcome occurs, the event is typically described in terms of a flightcrew failure; e.g., loss of situation awareness, misdiagnosis, inappropriate control actions. Thus, the primary markers of safety within the PRA framework—accidents and incidents—are described as events in which flightcrew performance falls short of the prescribed decisions and actions. This approach has led to an investment in error classification schemes (e.g., Wiegmann & Shappell, 1997) to capture and understand the types of errors that flightcrews are most likely to make.

In the last 15 years, however, a complementary perspective on flightcrew performance and operational safety has emerged that focuses on the flightcrew's ability to manage the normal variability and complexity in the operational environment that is not adequately managed by current flight deck interface designs, procedures, and training. This perspective has been referred to as Safety II (Hollnagel, 2014).

Similarly, there has long been an emphasis in aviation on adherence to standard operating procedures (SOP) for the flightcrew, but careful analysis reveals that SOPs fall short in describing the full range of necessary flightcrew actions. According to this perspective, to understand operational safety, it is important to capture how operators identify and respond to unexpected or atypical operational demands. It is rare that a commercial transport flight, especially in the US, proceeds exactly as specified in the flight plan. Air Traffic Control (ATC) responds to weather and traffic patterns and other disruptions in the National Airspace System (NAS) by revising the flight path of aircraft in the NAS; examples are changes to routing, airspeed, or altitude. For example, as an airplane is descending to an airport and cleared to land on a specific runway, the winds shift considerably, and ATC asks approaching airplanes to re-route to a different approach and runway. The flightcrew makes changes to flight plan restrictions to force the airplane down earlier, which is a bit of creative problem-solving.

Hollnagel and others (e.g., Hollnagel et al., 2006) have developed a language around these system behaviors that focuses on "resilience." According to Hollnagel (2019), "*A system is resilient if it can adjust its functioning prior to, during, or following events (changes, disturbances, and opportunities), and thereby sustain required operations under both expected and unexpected conditions.*"

Thus, as a complement to traditional safety practices that attempt to reduce or mitigate flightcrew errors and establish strong SOPs, the ideas behind Safety II and resilience are acknowledging that an effective flightcrew plays a significant role in anticipating and managing the variability and complexity in the operational environment.

Two Views: Resilience vs Operational Complexity

This emerging perspective on positive flightcrew contributions to operational safety has generated a strong interest in capturing and documenting resilient flightcrew behaviors. Analysts have largely borrowed the Hollnagel framework—monitor, anticipate, respond, and learn—for categorizing these behaviors. From Hollnagel (2011):

- <u>The ability to anticipate.</u> Knowing what to expect or being able to anticipate developments further into the future, such as potential disruptions, novel demands or constraints, new opportunities, or changing operating conditions.
- <u>The ability to monitor</u>. Knowing what to look for or being able to monitor that which is or could seriously affect the system's performance in the near term – positively or negatively. The monitoring must cover the system's own performance as well as what happens in the environment.
- <u>The ability to respond</u>. Knowing what to do or being able to respond to regular and irregular changes, disturbances, and opportunities by activating prepared actions or by adjusting current mode of functioning.

- The ability to learn. Knowing what has happened, or being able to learn from experience, in particular to learn the right lessons from the right experience.

Clearly, there is value in documenting that resilient flightcrew behaviors occur routinely; this work furthers our understanding of the limitations of SOP (broadly defined). On the other side of the coin—opposite resilient behaviors—is the variability and complexity in the operational environment. We believe that there is equal (if not greater) value in understanding the drivers of resilient behaviors. Specifically, how is the operational environment creating situations that require the flightcrew to adapt and use resources outside SOP and training. Understanding complexity in the operational environment is important because it forces us to acknowledge that the larger system—airplane design, ATC procedures and clearances, pilot training, etc.—needs to evolve to reduce the need for unsupported flightcrew performance. These insights can potentially lead to changes in interface design, training, or other system characteristics.

Case Study: Monitoring for Flight Path Management

In an exploration of monitoring (Mumaw et al., 2020), we documented knowledge, skills, and strategies that experienced pilots use for flight path management during descents; specifically, in flying Area Navigation (RNAV) Standard Arrival Routes (STARs) to the approach. While RNAV STARs are designed to account for a certain degree of adverse conditions, such as a tailwind, there can be considerable complexity and variability introduced by ATC revisions. There is a range of conditions in which a flight can be forced off the RNAV STAR. For example, ATC's traffic load can require them to slow a flight earlier than planned or to take it off its planned lateral path. The revised ATC clearance may still require that the flightcrew meet waypoint airspeed and altitude restrictions, and the flightcrew needs to understand how to revise some element of the clearance and still comply with waypoint restrictions. In these cases, the flight management system (FMS) predictions likely become invalid, and the flightcrew is required to reason through the changes to intervene effectively.

When we discussed these situations with experienced pilots, it became clear that there is no formal/explicit training on how to

- anticipate potential threats to flight path compliance,
- monitor indications to determine how likely the airplane is to comply with the clearance,
- respond/intervene through FMS flight plan modifications or actions on the flight controls.

However, despite the lack of explicit training, these pilots had developed methods for dealing with the "normal" variability and complexity that can be encountered on the majority of flights. These methods offer a clear illustration of resilient performance.

Having uncovered this demand for adaptive responding from the operational environment, the challenge then becomes how to improve flightcrew performance, especially for less-experienced pilots. We chose to develop targeted training to fill the current gap. Although the situations that flightcrews can face can vary considerably—across RNAV STARs, airports, wind conditions, and air frames (to name a few factors)—we were able to articulate the knowledge, skills, and strategies for managing descents (discovered in our work) and convert them into a training module to support resilient performance. An initial question is how to select a level for describing and training this resilient performance. At one end of the continuum, training could focus on general energy-management principles for all airplanes, or could even attempt to introduce principles of "resilient responding" more abstractly. At the other end, training could separate out the specifics of airplane performance, runway layouts, local airport customs, etc. We chose instead a middle ground that would give pilots a set of general problem-solving skills around a small number of problem types. We believe this formulation can serve as a model for training skills foundational to resilient flightcrew performance.

The Problem Space and Training Approach

The problem space, as we first encountered it, was large: managing compliance to an RNAV STAR in the face of shifting winds, weather, ATC needs, airplane performance limits, etc. To identify anchors for training, we sought representative problem types. By filtering Aviation Safety Reporting System (ASRS) reports for missed crossing restrictions during descent and discussing operational practices with experienced line pilots, we

- collected a set of cases where crews reported violations of altitude or airspeed constraints along RNAV STARs, and
- identified knowledge, skills, and strategies pilots used to manage these successfully.

From these data, we observed poor outcomes with these two characteristics:

- crews found themselves higher than originally planned (too much energy), often violating the constraints and,
- the situation could have been anticipated and prevented through early control action or FMC flight plan changes

We were able to also identify three problem types, which are connected to three types of ATC clearance revisions[1]:

1. <u>Held high</u>, meaning prevented from descending at the anticipated point along the arrival,
2. <u>Slowed early</u>, causing the crew to shallow their descent gradient to accomplish the deceleration, and
3. <u>Loss of track miles</u>; a change that substantially reduces required track miles.

Further, each of these problem types can occur for different reasons; for example, loss of track miles can occur when ATC gives a "direct to" clearance that eliminates intermediate waypoints, or when there is a need to land on a closer runway. Together, these problem types capture the range of energy-management / flight path management situations, and each type represents common ATC practices for managing traffic and environmental conditions. More importantly, these types of clearance revisions commonly lead to flight path management difficulties in line operations, and they are issues that SOPs may not directly address.

Our approach to training attempts to use diverse operational scenarios to illustrate strategies for anticipating, monitoring, and responding to manage each problem type. We believe it is possible to use this approach to aid pilots in seeing specific operational cues for action and to provide problem-solving skills for each problem type. The goal is to both support performance

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[1] A few other problem types could be called out, but we believe the three specified here provide adequate grounding for training the necessary knowledge and skills.

on specific problems and also to facilitate transfer across a wide range of operational variability and complexity.

We are also combining training on flight path management skills—anticipating, monitoring, controlling—with important principles about flightcrew communication. When one pilot becomes concerned about potential threats or inadequate performance, it is critical to share those concerns/expectations with the other pilot. More specifically, we are emphasizing several types of communication: identifying potential concerns and jointly planning how to monitor for them; sharing expectations about flight path and how it will be managed; and updating information about status. Updates may include positive information (e.g., potential threats resolved), as well as notification of developing concerns. A subtext of this material is an elevation of the role of the Pilot Monitoring (PM). Traditionally, the PM is trained and evaluated largely to identify and call out deviations from current flight path targets; e.g., airspeed is 6 kts too fast. In our training module, the PM is given broader responsibilities to develop a view of downstream flight path constraints to aid in anticipating potential threats to compliance[2]. Finally, we believe that the identification and training of "resilience" needs to be grounded in specific operations; that is, solving operational problems within a specific domain. This grounding allows pilots to understand that the operational environment demands working "beyond SOPs" and highlights specific knowledge and skills to address that need.

We are currently planning a flight simulator-based study to determine if this training can improve flightcrew performance when flying challenging RNAV STARs. In early reviews of our training module, reviewers recognized the relevance of the skills for addressing the current gaps in training. Looking forward, another potential use of this training is to facilitate transfer to the full range of operational situations. Indeed, we have discussed whether these flight path management skills could be generalized to operational problems around fuel management or other aspects of mission monitoring. Our approach is to start with a grounding in one operational area and then create awareness of the applicability of these skills to other operational needs.

Summary and Conclusions

We identified an area—flight path management along RNAV STARs—in which experienced pilots revealed knowledge, skills, and strategies that allowed them to perform successfully but were not formally trained. We developed a training module intended to improve flightcrew performance. The basic tenets behind our training module are that training

- should reveal common features of the variability and complexity in the operational environment; that is, classes of operational situations which can be addressed using relevant strategies
- needs to be grounded in realistic operational examples.
- should use realistic problem solving and frequent opportunities for trainee interaction
- should build supporting skills, such as crew communications, for integration back into the flight deck setting
- provide principles that support generalization to novel situations

[2] Note that this framing is different from current Threat and Error Management (TEM) notions. For our training, a potential threat to fight path management can be a reduction in track miles, which is unlikely to be treated as a threat in TEM.

An upcoming evaluation study will assess the impact of our training module on understanding and performing in both practiced and novel flight path management situations. It will also inform us of strengths and weakness of the module and about directions for improvement.

Acknowledgments

The work reported here was funded by NASA's System-Wide Safety Project, part of the Aeronautics Research Mission Directorate's Aviation Operations and Safety Program.

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