LEARNING FROM ALL OPERATIONS

Concept Note 6

Mechanism of Operational Resilience

Flight Safety Foundation

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FLIGHT SAFETY FOUNDATION

A note to the reader:

The goal of these Concept Notes is to provide a common framework and common language for talking about aviation safety. Such a new framework and language are needed because the existing language of safety is built around learning from failures and cannot easily express learning from success. Similarly, the existing frameworks of safety data collection and analysis are designed for incidents and accidents, and we want to learn from all operations.

As we expand our understanding of what constitutes a safety-relevant occurrence — an expansion that encompasses learning from all operations — we need a shared means of articulating what we are already learning that also allows discussion of new ways of learning. Positing a separate framework for describing safety successes, however, can create challenges for relating what can be learned from success to what has been learned from failure. Therefore, the goal is to describe a unitary framework for safety based on learning from all that happens, rather than separate frameworks for different "kinds" of safety. To achieve this goal, each of these concept notes establishes part of the necessary foundation, which is then integrated and translated into practical implications and applications in Concept Note 7.

1. Introduction

A system adapts when under pressure by changing its own states (Ackoff, 1971). At present, this adaptation is predominantly initiated by the system sharp end. The system adaptation can be seen, as described in Concept Note 4, through one of the five patterns of operational resilience or it may result in a loss event. Concept Note 4 answers the question: ***What* resilient behaviour happens?**

Concept Note 5 describes the three forces model of system adaptation, in which **resilience counterbalances the demand and efficiency pressures,** and the interplay of these three forces directs the system adaptation. Concept Note 5 answers the question: ***How* does resilient behaviour happen?**

But what shapes the capability of the system to counterbalance the pressures? What determines the capability for operational resilience? This concept note deals with these questions by outlining four operational resilience capabilities, describing them and providing some operational examples. This concept note is about the **mechanism of operational resilience** and answers the question: ***Why* does resilient behaviour happen?**

2. Four operational resilience capabilities

System resilient performance does not happen at random (Leveson, 2011). There are resilience potentials that shape the way a system can adapt when responding to pressures (Hollnagel, 2015). The resilience of an aviation operational system at the sharp end can be described with the help of four capabilities — plan, coordinate, adapt and learn (Figure 1). There are several examples in the literature and in operational communities intended to describe these capabilities (Hollnagel, 2015, American Airlines, 2020, American Airlines, 2021). There are overlaps across

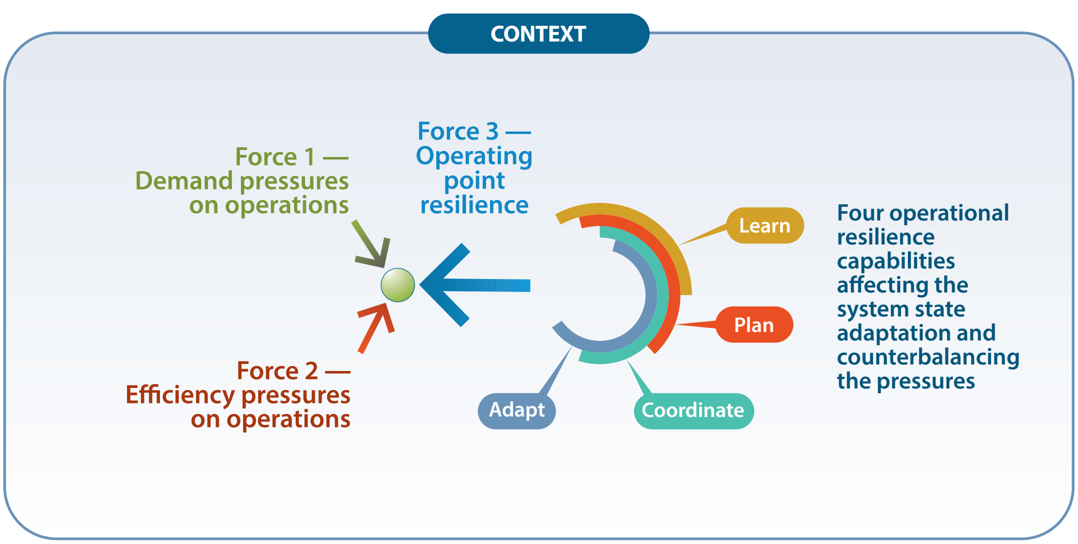

Figure 1: Operational resilience capabilities affecting the system state adaptation

these descriptions, but the focus of this note is not to compare and contrast these descriptions. Rather, we are choosing one of these descriptions to illustrate the Learning From All Operations concept. The resilience capabilities are synergetic — they do not follow in a simple sequence or in a loop, but are interconnected and reinforce each other. **Learning From All Operations promotes looking at the resilience capabilities that support system response to both expected and unexpected, both known and unknown, pressures.**

2.1 Capability to Plan

The operational resilience capability to plan is fostered by **anticipation:**

- Considering seasonal, local or situation probable scenarios and pressures — including but not restricted to operational threats;
- Anticipating the effect of pressures on the system;
- Anticipating the reactions of other actors;
- Anticipating the resultant system adaption in relation to safety envelopes and operational limits assumptions;
- Anticipating the effect of the pressures on the system environment and considering what-if scenarios; and,
- Anticipating gaps in knowledge (own and of another actor) and gaps in resources in general (for example, time, fuel, cognitive resources).

Anticipation typically triggers additional information gathering related to the pressures and the situation — for example, anticipating active runway change based on the weather forecast or anticipating a diversion to an alternate airport when hearing on the air traffic control (ATC) frequency that the crew of another aircraft approaching to the same airport just did so.

Anticipation is key for operational resilience, because identifying the characteristics of a rapidly developing situation based only on the feedback loop of monitoring may not provide sufficient time for reaction. Anticipation can be the result of insights, as we figure out how a system is going to act in a particular situation even though we have never experienced that exact situation before (Kauffman, 1980).

Building on anticipation, the essence of the plan capability is **preparation** for a course of action — for the system's response to pressures. For example, for a flight crew planning the taxi route, preparing and taking action in anticipation increases the operational resilience capability, but planning can also be done by responding to an evolving situation.

Preparation involves gathering information; accounting for the available system resources and getting them ready to be used; and scheduling and prioritising actions. For example, discussing what to do in case of encountering a specific pressure, such as landing on a contaminated runway or adding extra fuel in case of extended holding time at an airport with forecasted thunderstorms.

Preparation also includes setting an alternative plan and identifying conditions for triggering the plan — for example, diversion to an alternate airport. This is preparation in anticipation of an event by attempting to avoid the pressures. Preparing also involves establishing countermeasures like memory aids and reminders — for example, a tower air traffic controller's memory aid for an occupied runway (e.g., use of "Runway Occupied" strip in a dedicated strip holder of a different colour or "Runway Occupied" boxes placed on the flight strip board when a vehicle is authorised to enter the runway).

Anticipation and preparation are important not only for specific pressures but also for pressures in general — anticipating that some unexpected pressure would occur. No matter how well the anticipation works, it is still possible that some pressures may appear unexpectedly. In this case, the resilience capability to plan is for a general course of action — for example, a plan for going around from different altitudes, no matter the reason for going around. Additionally, performing drills and simulation exercises that include unexpected situations supports the system in being prepared to deal with surprise even if the exact nature of the surprise may not be known.

2.2 Capability to Coordinate

The operational resilience capability to coordinate promotes **alignment** between the people, the technology and the system environment. It includes:

- Coordinating the plan with relevant actors (e.g., flight crew to air traffic controllers);
- Building a shared mental model within the team;
- Configuring and setting the technological systems;
- Performing pre-briefings and discussing tactically the scenarios and the system reaction; and,
- Requesting support and cross-checking.

The resilience capability to coordinate applies to both expected and unexpected pressures. Maintaining common ground and developing mental or technology-based models of the situation allow the system to react better once something unexpected happens.

Timely and effective **communication** is an important enabler for the ability to coordinate.

2.3 Capability to Adapt

Planned or not, coordinated or not, action and adjustment are key for system resilient performance. Adaptation is assisted by **monitoring for, and correct recognition of, the situation**. Examples of monitoring for pressures are active listening, focused observation, visual scanning and pattern recognition. Monitoring at the system's sharp end involves proactively scanning for the routine pace of the operations and normal triggers but also for alarms, threats and anomalies. Apart from monitoring for expected pressures, the resilience potential includes **monitoring** for unexpected pressures, for the state of the system (including self-monitoring) and the environment. For example, the consequences of runway incursion situations could be mitigated by monitoring the air-ground communication frequency, the runway environment and the traffic-alert and collision avoidance system (TCAS) display that can help flight crews in identifying an actual or potential runway incursion.

Selection of response through decision-making is another element of adaptation. Deliberate response selection happens in the form of:

- Running the existing mental or technology-based models of the situation;
- Determining the amount of time available and amount of time needed;
- Assessing uncertainty and risk;
- Balancing competitive goals and trade-offs;
- Prioritising; and,
- Identifying leverage points on which to act.

Sometimes a response is selected before a problem is sufficiently understood. Flight crew reaction to smoke and fumes is an example of a situation in which the need for rapid action may not provide sufficient time to determine the source of the cues.

When the pressures are unknown, then the selection of a response happens through critical thinking. These are situations that are unique or rare, in which the nature of the problem is unclear and no efficient procedures are available for dealing with it. An example of an unknown pressure is the specific failure mode of a technological system for which there are no operational procedures or training. Even if the nature of the problem has been determined, no ready solutions are prescribed for some problems (Orasanu-Engel & Mosier, 2019).

The actual adaptation happens through **action and adjustment,** by deploying the existing resources and mobilising additional resources if needed — for example, managing team resources; following a check-list or procedure; changing automation levels, pace and sequence actions; managing taskload and workload; and adjusting the plan.

Action and adjustment also involve addressing pressures for which there is a scripted and trained response — for example, responding to a TCAS resolution advisory (RA). Some of these adjustments require quick decision and action in critical situations, such as take-off and landing (Orasanu, 1995).

The resilience capabilities do not manifest themselves in operations in a simple sequence but are highly iterative. This is specifically important for situation recognition and decision-making, because taking an action frequently changes the situation, thereby requiring a new decision (Orasanu, 1995).

2.4 Capability to Learn

Learning from everyday operational data and events can enhance safety management that is often based on a small subset of performance information, which may introduce avoidable but unrecognised consequences into the aviation system. Learning takes place at the system sharp end and at the system blunt end — at individual, team and organisational levels (Flight Safety Foundation, 2021). In this comprehensive scope, learning that starts at the system sharp end involves **recalling knowledge, learning in the moment, and reflecting and sharing knowledge.**

When needed, knowledge may be recalled from previous experience, procedures, regulations, company policies and guidance, or rules of thumb.

Learning in the moment happens by sense-making, seeking knowledge for learning and improvement, and asking for guidance. Learning in the moment is specifically an important resilience capability when the situation is unknown or underspecified.

Reflecting on and sharing what was experienced takes place through mental re-simulation, re-play, operational debrief, reporting, verbalising the experience, participating in formal learning and organisational debriefing. For example, even a short debriefing after each flight or each air traffic control duty shift is an opportunity to increase the professionals' capability for resilient performance by letting the operational team reflect on how they react to pressures (including threats) and adaptations and how they apply their competencies to keep sufficient margins of safety.

The blunt end system support for learning can take different forms. First and foremost, organisations can ensure psychological safety for the professionals to share experiences. Organisations can support individual learning by stimulating the reflection process — for example, by safety awareness, by providing rapid playback technical capabilities, by providing team processes for briefing and reflections. To achieve reliable learning, different forms of formal learning can be considered — learning by watching (e.g., observing virtual operational scenarios), learning by doing (e.g., simulation or on-the-job training) and learning by mental simulation (e.g., hangar flying).

If local adaptations are not shared, not communicated and not acknowledged upward and downward in an organisation, it could potentially harm the system (Rankin et al., 2014). Historical events are unique enough to make accumulating knowledge difficult. Each event is a single unrepeated data point, and accumulation requires pooling across diverse contexts (March, 1991). Sharing has another key benefit — it provides diversity of perspectives. Diversity of narrative can be seen as an enormous source of resilience (Dekker, Ciliers, & Hofmeyr, 2011). Additionally, sharing as a form of socialisation and externalisation enables the transfer of tacit knowledge and the transformation of tacit into explicit knowledge (Nonaka & Konno, 1998).

The Pilot Training Task Force (PTTF) of the International Air Transport Association (IATA) reports that in order to build resilience, the learning process for the sharp end professionals needs to develop two key elements — to raise the level of competence and to achieve the appropriate level of confidence (Airbus, 2021). Competence-based learning aims to support sharp end professionals in managing any situation, even situations that have not been specifically trained.

Additionally, being aware of how well someone performs in unpredictable situations can help them to develop their confidence and build their capability for resilient performance. It is therefore important for the reflecting and sharing process (e.g., briefings, discussions, formal training) to emphasise the positive aspects of behaviour. The IATA PTTF also reports that increasing resilience includes the principle of reinforcing confidence (Airbus, 2021). Highlighting the positive outcomes during a debriefing session is essential to this. Focussing on only the errors or inadequacies of the performance may have the unintended effect of decreasing the level of resilience (Airbus, 2021).

3. Examples of observed and reported resilience mechanisms

Some of the manifestations of the four resilience capabilities can be observed in operations. For example, in a line operations safety audit (LOSA) program, methodical observations of work are conducted. Many of the resilience mechanisms are observed during LOSA using the threat and error management (TEM) framework as an outcome measure. Still, they are not the primary focus. Since the beginnings of LOSA in 1996, its objective has been to leverage direct observations inside the cockpit to capture systemic and flight crew strengths and weaknesses as they relate to TEM performance (ICAO, 2002).

Concepts like anticipation, monitoring, and adapting are observed, but they are framed as performance moderators that can positively or negatively affect TEM performance. For example, if there is terrain at the destination that the crew needs to be aware of during their descent and approach, this is identified as a threat in LOSA, and observers are asked to capture how the crew managed this threat. During the management phase, perhaps the crew discusses terrain during the approach briefing, they ensure they have Terrain set on the Nav Display, and when descending, they call out the Minimum Safe Altitude (MSA) that contributes to a safe landing at their destination. Under the TEM framework, the threat of terrain was managed via anticipation and monitoring, which corresponds to the resilience mechanisms discussed in this note.

The American Airlines Learning and Improvement Team (LIT), adapted the Hollnagel Resilience Assessment Grid into its own language and model for data collection through three primary methods- normal flight observation, pilot interviews and surveys. LIT's language comprises four resilience potentials that are specified in terms of a subset of proficiencies (American Airlines, 2020; American Airlines, 2021).

However, some of the manifestations of the four resilience capabilities are less observable, and information about how they work in action can be gained by other methods — for example, by structured discussions with system front-end professionals.

Hereafter, we will provide some examples of observed resilience mechanisms — the actual manifestation in operations of the resilience capabilities that we created with information derived from a variety of sources. The capabilities represent a *potential* to act, so, cannot themselves be directly observed. But the actual adaptive processes that manifest as overt behaviours can be observed. For example, observing the coordination process in operations helps us to understand the system capability to coordinate. Similarly, the observed planning activities constitute an indicator for the system capability to plan. The examples illustrate multiple or single observations of operations.

3.1 Wind shear on final approach

The first example is described in Table 1. This example describes a specific airport where there is an elevated likelihood for wind shear on final approach to one of the airport's runways when the wind direction at the ground level is from the north. This local effect is the result of the runway's position with respect to the local terrain and is the specific pressure we study in the example. The question of interest for this particular example is restricted to the sharp-end operational system. The information in Table 1 describes the adaptive processes to counterbalance the identified pressure. The information is based on multiple observations and structured discussions with pilots.

Table 1: Observed and reported adaptive processes related to the pressure "wind shear on final approach"

System to be studied	
Approach to Airport X by specific flight crew at a specific time. *Note: Scope restricted to system sharp end.* *Note: The example is based on multiple observation points and structured discussions.*	
Pressures (potential or actual)	
Likelihood for wind shear on final runway (RWY) 09 when wind is from the north because of local orography.	
Learn	**Plan**
Recall knowledge — wind shear training, standard operating procedures (SOPs) and limits. Reflect by debriefing the approach, share Airport X wind shear phenomenon knowledge to air traffic control (ATC), aerodrome and company, refresh knowledge, if needed.	Anticipate based on own or other flight crewmembers' previous experience, airport specific information, actual weather report and weather forecast, operational flight plan (OFP) profile versus runway wind, preceding aircraft or ATC reports or visible cues. Prepare by considering extra fuel, go-around priming, what-if scenario, extended approach brief, recall wind shear training, SOPs and operational limits (prepare alternate runway or approach if available).
Adapt	**Coordinate**
Monitor cues (e.g., blow dust, ring dust, whirlwinds), weather radar, wind shear warning system, ask for wind update more frequently, use onboard information (flight management computer wind component and ground speed), pitch attitude, glide slope deviations, heading variations, unusual autothrust activity or throttle levers position. Adjust by considering optimum level of automation, consider early final configuration, apply recovery strategy, go-around if needed, use/follow flight director, aircraft operating manual/quick reference handbook Provide air report/pilot report .	Communicate with flight crew, cabin crew, ATC, company (possible diversion). Consider pilot monitoring's fitness and assertiveness for cross-check duties, consider pilot flying's proficiency, consider holding if needed for extended briefing, inform ATC on early final speed reduction.

3.2 Startle effect

The second example (Table 2, p. 7) involves a flight crew's startle response due to a combination of unexpected factors. For this example, startle and surprise were studied as two related but different phenomena. Startle was studied as a reflex that is the first response to a sudden, intense stimulus. It is a spontaneous and uncontrollable physiological and cognitive reaction. The startle response is accompanied by an emotional component and can lead to fear, panic and

Table 2: Observed and reported adaptive processes related to the pressure "startle effect"

<table>
<tr><th colspan="2">System to be studied</th></tr>
<tr><td colspan="2">Generic flight
Note: Scope includes both system sharp end and system blunt end within the organisation.
Note: The example is based on structured discussions.</td></tr>
<tr><th colspan="2">Pressures (potential or actual)</th></tr>
<tr><td colspan="2">Startle effect due to combination of unexpected factors (e.g., loud noise, electronic centralised aircraft monitor alert, lightning).
The trade-off between the need to "sit on the hands" for some time in order for the immediate startle effects to transition and the need for prompt reaction (e.g., some assumptions are for pilot response time within 5 seconds).</td></tr>
<tr><th>Learn</th><th>Plan</th></tr>
<tr><td>Reflect: Debrief and report via the safety management system if needed.
Practise personal control, breathing and scanning techniques.
Crew resource management (CRM) training on startle.
Upset recovery training.
Competence-based training.
Reinforce flight crew confidence.</td><td>There is no anticipation for this pressure as by definition the combination of factors was unexpected.
Prepare mentally or during briefing rehearse "black swan" events or foster crew discussion of a "plan of action" for both common non-normal events, and for the rare, "out of the ordinary" events — including pilot monitoring (PM) take over.
Plan support including unexpected critical or "black swan" scenarios in the CRM and simulator training and train for "manage surprise" competence. Regularly practice manual flying skills and provide pilots with surprise/startle related events from the industry.</td></tr>
<tr><th>Adapt</th><th>Coordinate</th></tr>
<tr><td>PM active monitoring of pilot flying (PF) — it is unlikely both pilots to be simultaneously seriously affected by startle effect. The effects of startle to be monitored include: precipitated reaction (quickly without thought), sudden backward movement, overreaction (excessive inputs); mini-freeze (no reaction, no communication, no response when there should have been one); scream or other emotional vocalisation; cues for stress and fear (breathing, pale face, sweating);
Flight crew recognise the unexpected pressures that led to startle.
Flight crew apply breathing and scanning techniques.
PF consider handing over control or PM consider taking control of the aircraft.</td><td>Communicate: Talk, call out observations, PF verbalise thoughts; PM use of standard call-outs. Use flight crew coordination, especially if there was unexpected reversion into manual flight. Inform air traffic control if unable to maintain clearance (level, heading, speed).
Align through instruments cross-checking. Assistive talk/call-outs by PM.</td></tr>
</table>

petrification. Apart from the observable effects, there is also the effect of visual focus to infinity — a lack of vision within two meters.

Surprise results from a difference between a person's expectations and what is actually perceived. As seen, surprise follows something unexpected. Startle also usually follows something unexpected but can also happen after an expected but strong stimulus — for example, seeing lightning yet having a startle response after the thunder. Another difference between surprise and startle is that surprise comes from the presence of something unexpected or the absence of something expected while startle only occurs after the presence of stimulus and not after the absence of a stimulus.

Fortunately, startle does not happen very often in aviation operations, which is why the source of the information for this example is predominantly based on structured discussions with front end professionals.

3.3 ATC scan of the aerodrome movement area

The third example, presented in Table 3, describes the observed and reported adaptive process for air traffic controllers providing tower ATC services at a specific airport. This example is a study of one specific task pressure — controller scanning the aerodrome movement area triggered by the call from traffic (e.g., a vehicle) on the movement area. The purpose of the task is for the controller to identify the position of the traffic, to mentally simulate the traffic movement from this position to the intended destination and to detect and resolve any potential

Table 3: Observed and reported adaptive process related to demand pressure "ATC scan of the aerodrome movement areas"

System to be studied	
Air traffic control (ATC) Tower X operations. *Note: Scope restricted to system sharp end. Note: The example is based on multiple observation points and structured discussions.*	
Pressures (potential or actual)	
Task pressure to scan the movement area in case of a call from traffic on the movement area. Task pressure to operate the automated ATC system head-down. Restriction of the field of view from the automated system terminal. Time pressures during morning rush-out.	
Learn	**Plan**
Reflect: Debrief and report via the safety management system, refresh knowledge, if needed, verbalise what was learnt. Use team resource management knowledge. Informal debriefings. Use of local 'safety ambassadors' that support local learning. Practice pressure recognition and reaction.	Anticipate traffic calls and typical traffic movement routes. Anticipate daily variations of traffic load. Informal local anticipation strategies in case of no adequate weather forecast, local events or traffic forecast — external information. Controller anticipate one own state. Anticipate impediments on the visual field of view from the tower cab. Prepare flight data traffic information based on plans. Pre-shift briefing regarding forecast traffic, traffic loads, team resource management and specific operational scenarios — for example taxi routings of different airport users (military, construction workers, business aviation, aircraft maintenance company). Consider traffic flow control measures.
Adapt	**Coordinate**
Cross-monitor tower (TWR) team work and state. Cross check traffic position visually and on the advanced surface movement guidance and control system. Adjust communication and use defensive controlling when under pressure. Support colleagues in the TWR when the workload or taskload is perceived high — specifically with safety critical tasks like conflict prevention. Open additional TWR working position. Let aircraft stop at the current position, if feasible. Prioritise and use personal strategies in case of pressure for multitasking and in case of information overload.	Communicate with the TWR team and supervisor when workload is high. Ask for assistance. Delegate tasks. Make inputs in the ATC automated system which aligns the automated system model of the situation with the actual situation. Verbalise intentions. Take an active position for coordination in case of doubt who shall initiate it. Use hand-over-take over of operational position strategies and check lists. Communicate the traffic flow measures.

conflicts or other operational implications that this movement may create. The study was triggered by a safety report submitted by a controller via safety management system (SMS) reporting process. The study team then decided to perform observations of operations and to organise structured discussions with the tower controllers. Apart from collecting information about the tower team adaptive processes, the study identified other repeatable pressures — task pressure for head-down operation of the automated ATC system that interrupts the visual observation of the movement area, restrictions of the movement area field of view from the tower cab and time pressure during morning typical rush-out operations at the airport.

The information in the above three examples is not an exhaustive account of how to manage a given pressure — it is only what has been observed and reported by professionals at the system sharp-end. If these observations extend over a variety of operational environments and multiple organisations, then this information can more closely represent practices for successful management of certain pressures. This is a way for the local adaptive processes to be known, shared and to benefit not only the team on a specific day but also to be shared widely within organisations and across the entire aviation industry.

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