LEARNING FROM ALL OPERATIONS

Concept Note 7

Pressures, Adaptations and Manifestations Framework

Flight Safety Foundation

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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

Flight Safety Foundation's goal with the set of seven Concept Notes is to outline a novel, unitary framework for safety based on Learning From All Operations (Flight Safety Foundation, Concept Note 1, 2022). With the aim to connect the understanding of resilience and adaptation to the understanding of risks and hazards, the conceptual framework uses a learning approach that considers operations as a system (Concept Note 2) and describes the following important learning dimensions:

- Monitoring aviation operations and learning from the difference between limits of safety control (safety control envelope) and limits as defined (operational limits assumptions) — Concept Note 3;
- Learning from three forces that drive the system adaptive process (demand pressures, efficiency pressures and operational resilience) — Concept Note 5;
- Learning from four resilience capabilities (plan, coordinate, adapt and learn) that support system response to expected and unexpected, known and unknown, pressures — Concept Note 6; and,
- Learning from five patterns of operational resilience — Concept Note 4.

2. Pressures and Adaptation Management

The overall Learning From All Operations framework is centred around the idea of using resilience capabilities to manage system pressures (including threats) and to manage the resultant adaptive process. In short, the framework can be defined as a pressures and adaptation management framework (Figure 1).

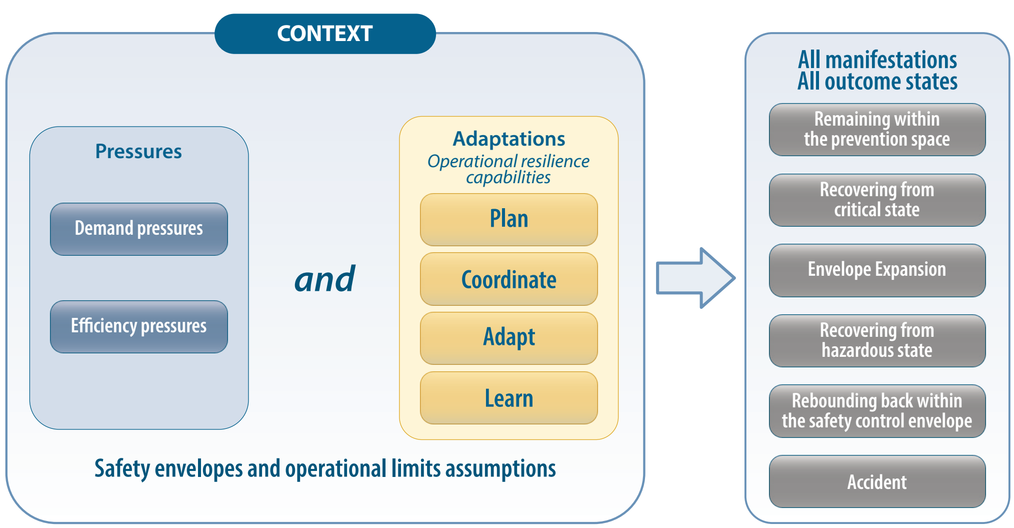


Figure 1: Pressures, Adaptations, Manifestations Framework

The first element, pressures, includes threats but also includes all types of demand (from changes or disturbances, but also from opportunities) and efficiency pressures described in Concept Note 5. The second element, adaptation, includes all types of system adaptive behaviour. In hindsight, some behaviours can be seen as errors, but Learning From All Operations uses an extended understanding of system behaviour that includes all types of adaptations, independent of their outcome. The third element of the framework describes the outcomes of system adaptation. The adaptive process can result in many types of outcomes, including desired and undesired system (e.g., aircraft) states. States, which can be undesired, can themselves be pressures that still need to be managed with adaptive behaviours. Finally, pressures and adaptations occur in a context. Understanding the system context, and specifically the limits of safety control and limits as defined, is necessary to connect all the other learning dimensions. The four learning dimensions are described in the next sections.

2.1 Safety Envelopes and Operational Limits Assumptions

The first learning dimension is about the performance space in which the system operates (Flight Safety Foundation, Concept Note 3, 2022). The system operating point transitions in this performance space and can enter in different areas. There are two boundaries that define the performance space.

The first boundary is the **safety control envelope,** which defines the actual boundaries of what is safely recoverable in operations by preventive or recovery measures (outside this boundary, the safety control becomes marginal to non-existent). The safety control envelope is determined by the available capabilities to control flight safety, to enforce safety constraints and to control the transition of the system operating point. Learning From All Operations aims to understand how the system responds to pressures and whether, in this process, the system migrates to states of higher risk. The system response to pressures can lead to a system state that is either stable or unstable. In this way, the concept of controlling flight safety is connected to the concept of system stability. The concept of system stability and system control can be illustrated with a ball-in-cup analogy. In this representation, the state of the system is represented as the position of a ball rolling on a surface.

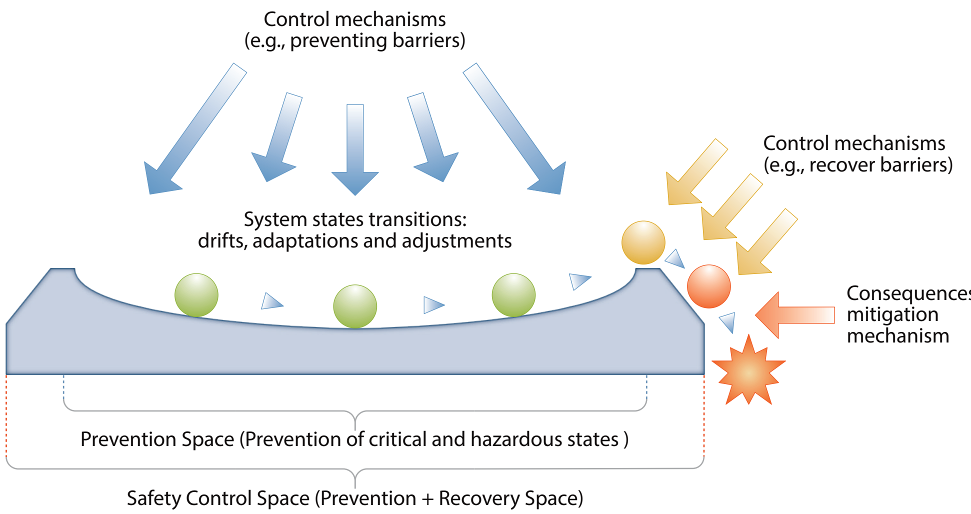
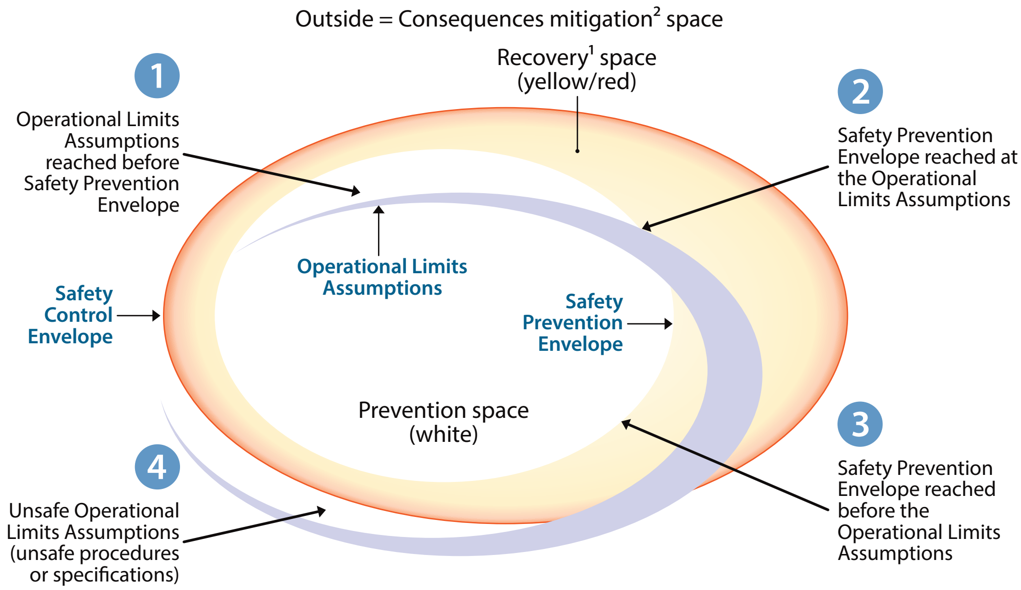


Figure 2: Visualising System Stability and System Control

When the system migrates to states with higher risk, there is a tipping point at which the system becomes unstable, represented in Figure 2 by the colour of the ball becoming yellow. **This is a system critical state.** When the system is in a critical state, there is a need for a recovery action. In the absence of such recovery action, the ball will roll downhill — in other words, the system will transition to a **hazardous state with marginal control on safety and a prompt need for recovery action to keep the system within the safety control envelope,** represented in Figure 2 by the ball becoming red.

Figure 3 provides a view from above the ball-in-cup metaphorical diagram in Figure 2 (p. 2) and the second boundary, operational limits assumptions, is overlayed on it.



Notes:

1. Recovery is possible also outside the safety control envelope, but it is mostly by chance.
2. Consequences mitigation — mitigating consequences of the system passing beyond the safety control envelope and mitigating accident consequences (e.g., engineered materials arresting system, survivability, evacuation)

Figure 3: Operational Limits and Safety Envelope Misalignment

In the middle of the envelope is the white area—the safety prevention envelope. Within this space, the system is adapting, coming closer or moving away from the critical thresholds. The yellow (system critical states space) and red (system hazardous states space) areas represent the recovery space. The system state transition through yellow and red space indicates growing closeness to the safety control envelope. If the recovery action does not bring the system back into the prevention space, the operating point of the system may pass through the safety control envelope boundary. The space outside the red area illustrates a situation outside the safety control envelope. Passing through the safety control envelope does not always mean an accident is certain to occur. There may be some mitigating factors to reduce that likelihood, including luck. But passing through the safety control envelope is associated with a significant loss of control over flight safety, with only marginal safety control, if any, available.

The second boundary that defines the system performance space is described by the **operational limits assumptions** — the imagined boundaries for operations (normative — rules, procedures, prescriptions or the subjective assumptions about where these boundaries are). Limits and the assumptions of the different actors about the limits can vary, and sometimes the limits are not fully defined (missing limits).

Ideally, the operational limits will neatly protect system operations from breaching the safety control envelope. **But in reality, limits of control and limits as defined have a more complex relationship** (for a detailed discussion of this relationship see section 4 from Concept Note 3). These and other reasons for misalignment of the operational limits and safety envelope result in generic patterns of their relationship — as illustrated in Figure 3.

The illustration and study of the relative position and the patterns of misalignment of the safety envelope and operational assumptions are important elements of the Learning From All Operations concept. The concepts of the safety control envelope and operational limits assumptions are part of the larger picture of charting the distance between operations as they actually exist and operations as they are imagined in the minds of managers or rule-makers. This distance is a critical component in understanding an organisation's resilience, the models of risk currently applied, and how well calibrated they are.

2.2 Three Forces — System Pressures

The second learning dimension involves understand the pressures that a system faces or could face (Flight Safety Foundation, Concept Note 5, 2022). System adaptation is a system's reaction to balancing pressures and resilience. Pressures and resilience are system performance-shaping factors — they shape the likelihood of desired and undesired outcomes. Figure 4 illustrates how resilience counteracts the pressures to result in adaptive behaviour. Pressures can be surprising, and sufficient resilience counter-pressure may not be immediately available. This can result in the system operating point transitioning toward critical and hazardous states (as shown in Figure 4). This transition is a result of the joint effect across the cumulative field of the three forces. During this transition, the resilience force can still help "steer" the adaptation trajectory for sustained adaptation, rebound or recovery to preserve or reacquire a safe state or avoid an accident.

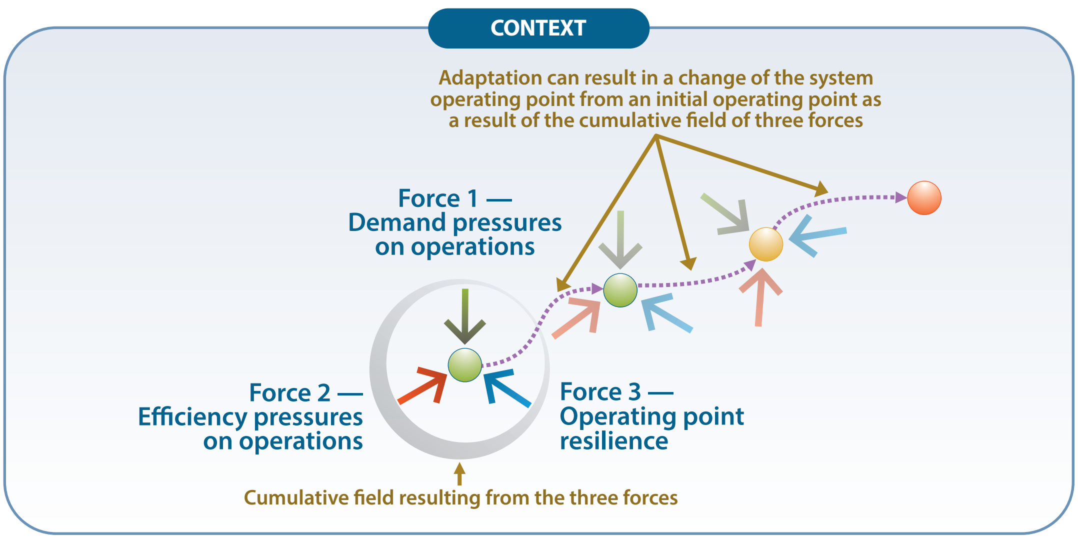


Figure 4: Three Forces Model of System Adaptation

Understanding the pressures that can act to change the system operating point provides insights into system behaviour, whether those pressures were expected or unexpected at the time of influence. Pressures include, but are not restricted to, operational threats — as a Learning From All Operations concept, pressures are broader in definition. Pressures can be categorised into two large groups — demand pressures (demand on the system to do something) and efficiency pressures (pressures to use fewer system resources). For example, personal pressures affecting professionals at the sharp end can be powerful shaping factors for system resilience performance. We can learn about pressures in various ways — we can observe everyday operations and discuss them with operational teams; analyse information from safety reporting and occurrence investigations; or learn from other organisations. The drift of the system operating point towards the boundaries of the safety envelope can be facilitated by the lack of knowledge of the position of safety envelopes and of the forces driving the system operating point. This is why

Learning From All Operations promotes learning about the demand pressures, efficiency pressures and the counteracting operational resilience that result in system adaptation relative to the safety envelopes.

2.3 Four Resilience Capabilities

The third learning dimension describes system resilience capabilities (Flight Safety Foundation, Concept Note 6, 2022). The system can counterbalance the demand and efficiency pressures. In the three forces model of system adaptation, the counteracting force is operational resilience. This force may contribute to a successful outcome, but it is not guaranteed. The other pressures might overwhelm the resilience action, or some additional factor outside of these forces (i.e., spurious events outside the sphere of influence of the system that we attribute to "chance") can also impact outcomes. Resilience is a process specifically intended to counter the demand and efficiency pressures for the purpose of preserving or reacquiring a state of (safe) equilibrium.

Operational resilience can be conceptualised in terms of four resilience capabilities — plan, coordinate, adapt, and learn (Figure 5). These resilience capabilities influence the way the system adapts when responding to pressures. The Learning From All Operations framework expands the scope of the inquiry to include all types of adaptive processes, irrespective of their outcome.

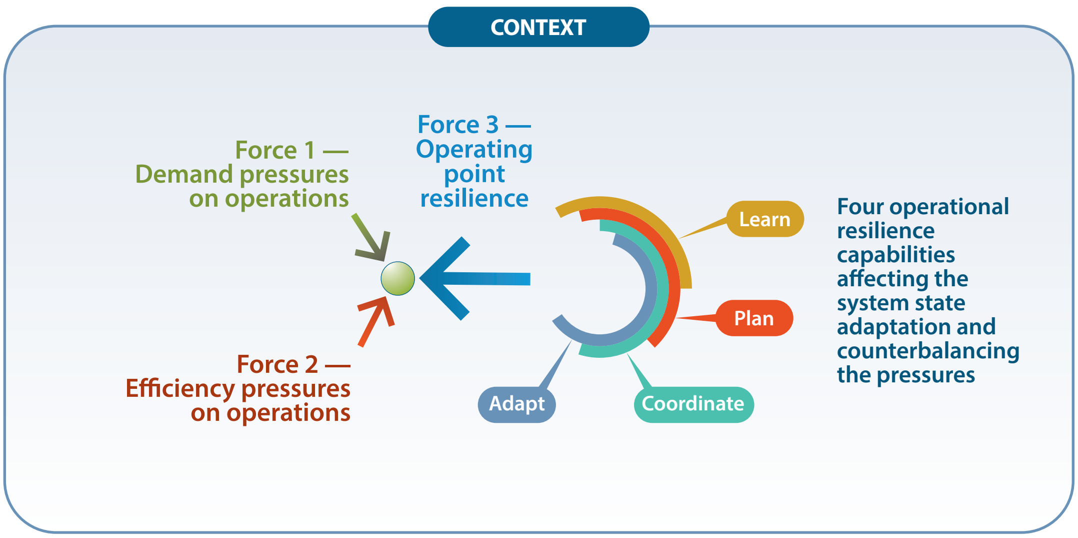


Figure 5: Operational Resilience Capabilities v Affecting the System State Adaptation

Resilience capabilities are synergetic — they do not follow in a simple sequence, in a loop, but instead are interconnected and reinforce each other. They are oftentimes emergent phenomena — a result of existing resources coupled in novel ways. Learning From All Operations promotes looking at the resilience capabilities that support system response to both expected and unexpected, both known and unknown, pressures.

2.4 Five Patterns of Operational Resilience

The fourth learning dimension promoted by Learning From All Operations is outcome of the adaptive process. The outcome involves resilience manifestation — the patterns of operational resilience that can be observed in operations (Flight Safety Foundation, Concept Note 4, 2022). The description of resilience used for Learning From All Operations from the safety point of view focusses on the different adaptive processes, with the aim of sustaining purposeful operations under varying conditions and pressures, while maximising the likelihood of an accident-free outcome and minimising the undesired consequences of a potential or actual adverse event. The adaptive process may not always be successful in preventing an accident, for example, due to overwhelming pressures.

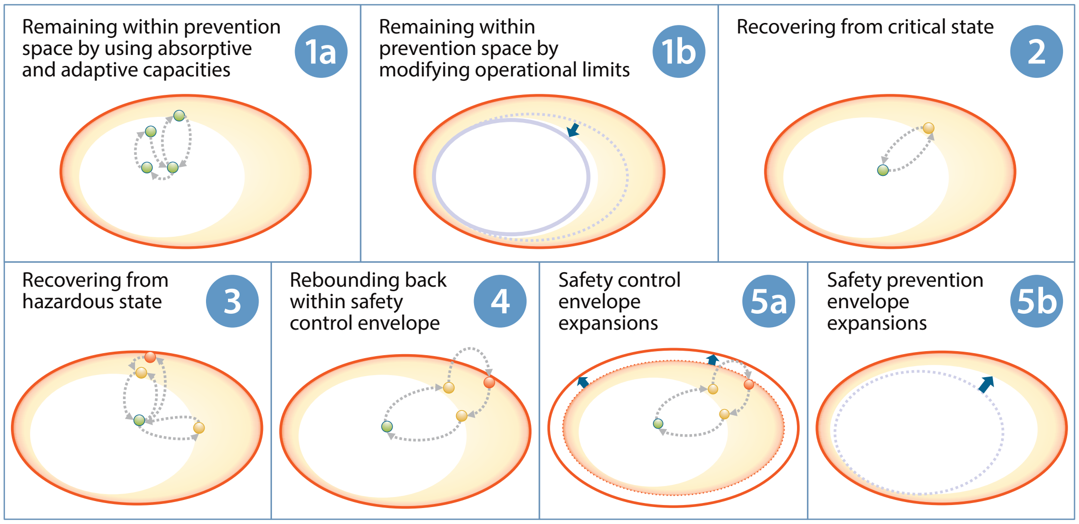


Figure 6: Five Patterns of Operational Resilience

The actual adaptation, as a result of the interaction of the pressures and operational resilience, can be observed in operations and understood through the lens of five patterns of operational resilience (described in Concept Note 4) — illustrated with the help of performance-space diagrams in Figure 6:

1) **Remaining within the prevention space** — prevent, avoid or withstand pressures to stay within the safety prevention envelope. This pattern of operational resilience includes, but is not restricted to, system robustness. An important system capability is not only what happens after a surprise or a disruption (expected or unexpected) that affects the ability to recover but also what proactive and preventive capabilities are present before the unexpected event that can be deployed or mobilised to deal with it safely;
2) **Recovering from critical state** — the system operating point transitions through the safety prevention envelope to and back from a critical state. Here, for some time, the system becomes unstable in terms of safety control and then the system recovers back to the prevention space;
3) **Recovering from hazardous state** — the system operating point transitions through the safety prevention envelope via critical states and to hazardous states but recovers back to the prevention space;
4) **Rebounding back within the safety control envelope** — the system operating point passes beyond the safety control envelope in a controlled safe manner and returns back to the safety control envelope; and,
5) **Expanding envelopes** — safety control and/or prevention envelopes are expanded based on applying critical thinking regarding operational limits within that operational context.

3. Margins

One way to monitor and measure the manifestation of operational resilience is by using a margin diagram. Here, as shown in the performance space diagram in Figure 7, margin refers to a distance in the system performance space that characterises the existing safety buffers; for example:

A. The distance between the system operating point and safety prevention envelope;

B. The distance between the operational limits and the safety control envelope;

C. The distance between the system operating point and safety control envelope;

D. The distance between the operational limits and the loss point (accident); and,

E. The distance between the system operating point and the loss point (accident).

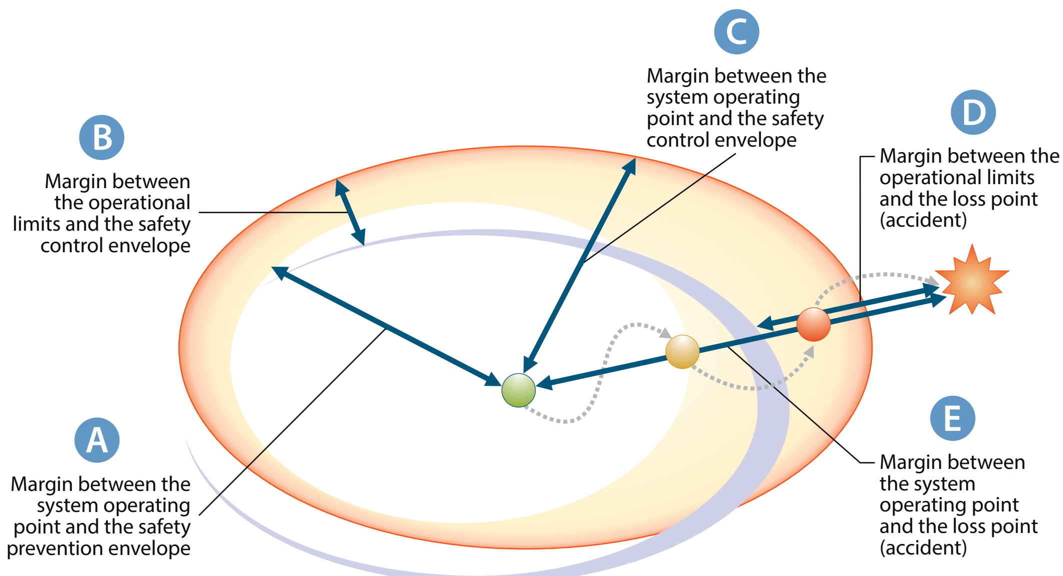
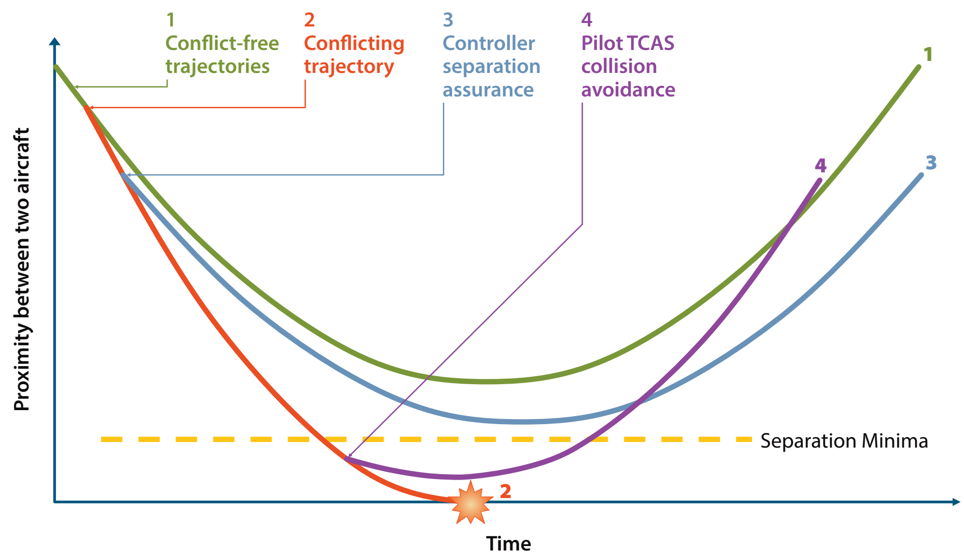


Figure 7: Margins

Studying the margins is important because operational resilience is a function of the system operating point resilience relative to the pressures (defining the system manoeuvring capacity) and the available margins (defining the available system space for manoeuvre). The margin diagram presents the time series of the margin values. While a performance space diagram is a conceptual tool, the margin diagram is also a mathematically correct tool. Examples of margin diagrams are shown in Figure 8. In these examples, the monitored margin is the proximity between two aircraft. This margin is an example of margin E from Figure 7 — the distance between the system operating point and the loss point (accident).

Figure 8 (p. 8) illustrates four different scenarios for margin diagrams. Scenario 1 (illustrated in green) is a margin diagram for the scenario of two aircraft in conflict free trajectories. The distance between the two aircraft is reduced, reaches the closest point of the approach, which is larger than the separation minima, and then gradually increases.

Scenario 2 (illustrated in red) is a margin diagram for the scenario of conflicting trajectories. For example, the conflict can be initiated by the controller overlooking a potentially conflicting aircraft when clearing an aircraft to climb after a pilot request due to turbulence. In the worst case, the conflicting trajectory can result in an accident.



TCAS = traffic-alert and collision avoidance system

Figure 8: Example of Margin Diagrams

Scenario 3 (illustrated in blue) is a margin diagram for the scenario of controller separation assurance. For example, the controller can detect the potential conflict and instruct crews of one or both aircraft to change headings, and the required separation could be maintained.

Scenario 4 (illustrated in purple) is a margin diagram for a scenario in which a traffic-alert and collision avoidance system (TCAS) helps pilots avoid a collision. For example, both pilots of the conflicting aircraft receive and correctly follow TCAS resolution advisories (RAs).

Margin diagrams can also be used to build and monitor margin distributions — a representation of the frequency by which a value of a given margin (often the minimum value of the margin for an event) has been observed in operations (Figure 9). Monitoring margin distributions across the entire range of values of a margin is an important element of Learning From All Operations. Indeed, there is a lot of information beyond the outliers representing system failures and key parameters exceedances. For example, using the entire range of the distribution can help identify shifts in the distributions representing early warnings for potential safety issues.

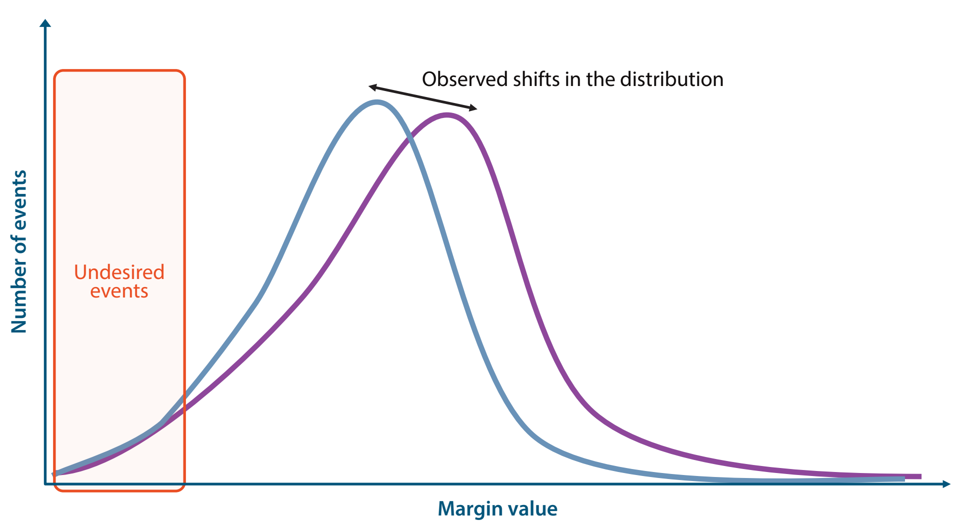


Figure 9: Margin Distributions

Knowing the tools of performance space diagram, margin diagram and margin distribution, the next legitimate question is what is a good process for how these tools can be used in practice. The next section provides some suggestions for how to implement the Learning From All Operations framework in practice.

4. Implementing Learning From All Operations

4.1 Leveraging Existing Safety Management Processes

Learning from all operations may help to further evolve existing safety management systems. It does not require a wholesale replacement of processes, practices and tools in an organisation (Flight Safety Foundation, 2021). But it does require the willingness to expand one's perspective or mindset starting from top management — as a complement to what is already in place. Most aviation organisations are already well positioned to collect, analyse, manage and disseminate safety data and insights. Organisations can leverage existing processes in manageable ways to expand those insights and translate them into action, through policies, procedures, training and equipment design. Here are examples of methods to support the Learning From All Operations concept. These methods build upon or complement approaches that are already used to collect and analyse safety data:

- **Observations of work —** studying how work, both routine and non-routine, takes place is an important basic method for understanding everyday work. Observations can have a single or broad focus, use a variety of recording technologies, and be continuous or selective. The focus should be on work as a whole rather than limited to specific unwanted outcomes or negative elements of work.
- **Event investigation —** event investigations conventionally focus on what went wrong, but the same methods can also be applied to what goes well. Even in the context of adverse event investigations, questions can be asked about what went right during the event, how things usually go well, and why things sometimes go exceptionally well.
- **Surveys and audits —** surveys and audits traditionally focus on problems and on negative aspects of group-based values, beliefs, attitudes and behaviour. But they can easily be applied with a focus on strengths and everyday work practices.
- **Expanded use of system data —** Data analysis, and specifically digital surveillance data, flight data analysis and flight operational quality assurance, have been historically focused on 'exceedance events'. These data sources can be expanded to support learning across the performance distributions. System data can also be used to support a post-ops replay or re-simulation capability to enhance the effectiveness of sharp end professionals' debriefing and to facilitate their self-learning. Organisations' qualitative safety reports also offer a rich source of information as it pertains to understanding situations where workers came close to safety margins, but were able to recover.

4.2 A Generalised Learning Process

As described previously, there are various methods for leveraging the existing safety management processes to Learn From All Operations. Each of the methods will follow its own logic and will have its own specificities. Although there will not be one process to fit all types of implementations, there are some elements that will be common to any inquiry involving Learning From All Operations. These elements stem from the conceptual framework described by the seven Conceptual Notes and will answer the following questions:

- **What is the subject to be studied?**
  - Is the inquiry on learning from 'what went right' in addition to 'what went wrong'?

- Is the inquiry triggered by a specific subject or it is a routine safety monitoring process?
- How did the subject of the study become known?
- What initial analysis and discussion took place and what assumptions were made — is it a systemic rather than occasional issue, and where and when does the operational expertise suggest the issue should be expected?
- What is the industry knowledge about the subject to be studied?

- **What is the operational system to be studied?**
  - What are the system boundaries?
  - Does the inquiry study only the sharp end system or does it include elements from the blunt end system (e.g., training, procedures design, original equipment manufacturers (OEMs), regulators, certification authorities)?
  - What is the studied period and why?

- **What is the adopted learning approach?**
  - A top-down learning approach, starting from an undesired aircraft state and inquiring backwards to normal operations.
  - A bottom-up learning approach, starting from observed or reported pressures or adaptations to certain pressures and inquiring forward to potential undesired aircraft states.
  - A combination of a top-down and bottom-up learning approach.

- **What is the information scope on which learning is based?**
  - Based on flight data — exceedances and/or distributions.
  - Based on expertise elicited from sharp end professionals — discussions, workshops.
  - Based on observations of operations and/or observations of training sessions.
  - A combination of above.

- **What are the key learning parameters?**
  - What are the parameters that define the safety prevention and safety control envelopes — for example, separation between two aircraft in the air, separation between an aircraft and the terrain, runway end crossing height, remaining distance to runway end, aircraft lateral and longitudinal acceleration, aircraft pitch attitude.

- **What are the safety envelopes?**
  - What are the values of the key learning parameters that define the safety prevention envelope and safety critical envelope?

- **What are the operational limit assumptions?**
  - How do system design and procedures define the operational limits?
  - Are there varying operational limits and why do they vary?
  - Are different actors assuming different operational limits and why?
  - Are there missing operational limits — a segment from the performance space where procedures do not define a limit?

- **How do operational limits assumptions relate to safety prevention and safety control envelopes?**
  - Operational limits reached before safety prevention envelope;

- Safety prevention envelope reached at the operational limits assumptions;
- Safety prevention envelope reached before the operational limits assumptions; and,
- Safety control envelope reached before operational limits assumptions — unsafe operational limits assumptions, unsafe procedures or system design.

- **How should the information collection be organised?**
  - How should information be collected about the system demand and system efficiency pressures?
  - How should information be collected about the adaptive behaviours driven by the four resilience capabilities (learn, plan, coordinate and adapt)?
  - How should information be collected about the five patterns of operational resilience manifestations (remaining within the prevention space; recovering from critical state; recovering from hazardous state; rebounding back within the safety control envelope; and envelope expansion)?

- **How should the collected information be analysed and how should a decision be made?**
  - What combination of quantitate and qualitative information analysis should be adopted?
  - Who will make a decision about the system risk and resilience?
  - What process and criteria will be used to decide about the risk and resilience implementation activities? How will this be balanced with the other system objectives — e.g., efficiency, environment protection, security and quality?
  - What monitoring of the implementation activities and of the affected system performance will be needed and how this will be organised?

- **How will the lessons learned be promoted and shared?**
  - How will what has been learnt be preserved and promoted?
  - How will what has been learnt be forwarded to system design, training, procedures development and to the relevant actors in the aviation industry?

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