FLIGHT SAFETY FOUNDATION

LEARNING FROM ALL OPERATIONS

Concept Note 5

Three Forces Model of System Adaptation

MAY 2022

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

In Concept Note 4, we looked at the system's resilient behaviour, which introduced the learning dimension of operational resilience patterns. The five patterns of operational resilience (remaining within the prevention space, recovering from critical state, recovering from hazardous state, rebounding back within the safety control envelope and envelope expansion) are the observable system adaptive process to keep operations safe and prevent accidents. But what actually drives these resilient behaviours?

This note introduces the next important learning dimension of Learning From All Operations — the forces that drive the system adaptive process. Previously, we described the system operating point transitioning in the prevention, recovery and consequences mitigation spaces; here we focus on what pushes the system operating state in one direction or another.

This micro level of driving forces is an important learning dimension, because the forces are present all the time, and we can learn from their interplay during all operations without waiting for undesired events to happen.

2. Adaptation as a cumulative effect of three forces

Systems routinely adjust their performance to match operational conditions (Hollnagel, 2016). **The system context and conditions present various pressures on the system. System adaptation is the reaction of a system as a result of balancing pressures and resilience. In this way, it can be said that pressures and resilience are system performance shaping factors — they shape the likelihood of desired and undesired outcomes.** Figure 1 illustrates how resilience counterbalances the pressures to result in adaptive behaviour (Madni & Jackson, 2009). In this way, the system dynamics are determined by the cumulative effect of three forces (Rasmussen, 1997).

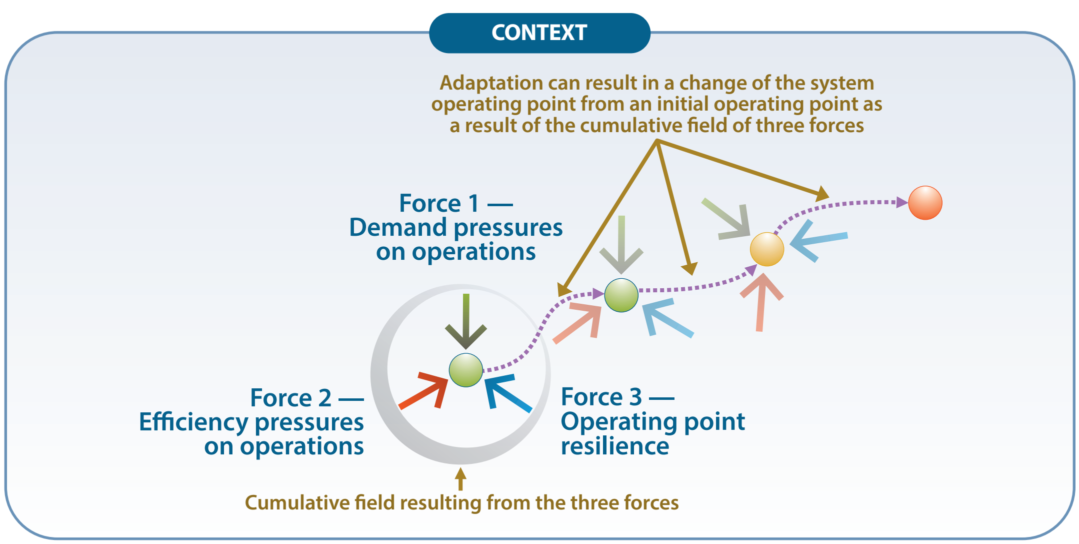

Figure 1: Three forces model of system adaptation

The first force comprises the **demand pressures on operations. This force includes demands on the system to do something.** The system exists to fulfil a purpose. System goals stem from the system purpose as well as from the need to achieve the purpose within a context and with constraints — for example, in an environmentally sustainable way. The goals originating from the system purpose and the goals originating from the system constraints and context impose demand pressures on operations. Moreover, additional pressures come from the fact that these objectives may conflict and the system will need to balance them and perform trade-offs (Orasanu, Fischer, & Davison, 2002). The need for aircraft energy management during descent and approach creates demand pressures for flight crews. Heavy traffic in the sector is an example of demand pressure on air traffic controllers.

The second force that drives the adaptation of the system operating point is **efficiency pressures on operations. These are the pressures to use fewer resources.** The resources are always finite, but even when they are in abundance, there are often pressures to "conserve" the resources.

Time is an important resource which may impose efficiency pressures on operations (Orasanu, 1995). The emphasis on fuel economy and on-time performance are examples of efficiency pressures on operations. An individual "least effort" attitude (the way requiring the least effort to finish tasks) can also be a source for efficiency pressures on operations. Often, time pressure will combine with a demand pressure to result in a cumulative pressure field. For example, a short taxi time from the gate to the runway can combine with the need to perform certain tasks and to respond to air traffic control (ATC) clearances during that time, and this may contribute to the cumulative pressure field on a flight crew.

The third force, the operating point resilience, aims to keep the system's operating point in equilibrium against the demand and efficiency pressures. If the system operating point is within prevention space, the system is stable — the operation is balanced. But as described in Concept Note 4, there is more that the operational resilience force does. 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. 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.** In this way, adaptation, in a wider sense, includes not only withstanding pressures but also a system steering response to both the magnitude and the duration of pressures.

The system might also anticipate an impending pressure, and initiate a resilient adaptation proactively (before the pressure actually manifests) rather than reactively (after the pressure manifests).

Successful adaptation occurs when the interplay of demand pressures, efficiency pressures, and resilience results in a desired outcome. It should be noted that both desired or undesired outcomes can occur by chance, and not because of the success of adaptation processes.

Operating point resilience potential will also be described in Concept Note 6. The next two sections describe the first two forces from the Foundation's Three Forces model of system adaptation and provide some examples of demand pressures and efficiency pressures on operations. **The description is not to be considered as a taxonomy or as a classification scheme. The description of pressures is intended more as a guide to practitioners — to aid in their examinations of what pressures affect the system's sharp end.**

The understanding of pressure used for Learning From All Operations incorporates all the internal or external for the system factors, both real or perceived, that require the use of system resources or require the use of fewer resources. It is to be noted that factors affecting system resources are common for both demand and efficiency pressures. In this way, the same resource, but affected differently, can be seen related to the demand pressures and related to efficiency pressures on operations. An example is time as a system resource. Temporal demand might refer to how much time it takes to accomplish some task/goal, whereas temporal efficiency would refer to a pressure to accomplish that task/goal in as little time as possible. The resilient adaptation of "buying time" refers to an attempt to relieve that temporal efficiency pressure — to extend the time available to accomplish the task.

3. Demand pressures

3.1 What are demand pressures?

Demand pressure is any event or condition that requires use of system resources — for example, physical, physiological, informational, cognitive or time resources. There are always demand pressures in operations. To understand Force 1 "demand pressure on operations," it is important to consider two aspects of demand:

- **Demand from what source:** What are the sources of these demand pressures? Where do they originate?
- **Demand for what resource:** What system resource is the demand affecting?

Demands may come from varying sources:

- From changes or disturbances, but also from opportunities;
- From the 'customers' of the system or from entities within the system;
- From the need to perform some nominal, planned tasks (e.g., standard operating procedures) or from the need to respond to failures or unplanned events.

Demands are not positive or negative per se — for example, performance may be optimal at certain levels, not necessarily the lowest levels, of task demand.

Some demand will be predictable and some demand will be less predictable. But, depending on resources, constraints, and the design of work, demand leads to pressures. Pressures, however, may also result from perceived and not real demand.

Demand pressures trigger the system to adjust, to adapt its operations. If demand pressures are not addressed in a timely fashion, more pressure may result, and total pressures may accumulate.

Demand pressures may not be independent but can interact and influence each other. Different demand pressures may become, or be perceived as, conflicting and may require trade-offs.

3.2 Sources of demand pressures

Sources of demand pressures in aviation operations include the following:

Demand pressures to achieve purpose and objectives:

- To fulfil the system purpose — for example, the purpose of ATC is to prevent aircraft collision;
- To deliver on system objectives (objectives stemming from the purpose or from controlling other emergent system properties like environmental protection or integrating in operations diverse airspace users); and,
- To perform a given (familiar or unfamiliar, procedure-defined or not) task — task pressure.

External threats and stressors:

- Threats — events or errors that occur beyond the influence of operational personnel, that increase operational complexity and that must be managed to maintain the margin of safety. Threats for flight crew and threats for air traffic controllers may be different. Flight crew threats can be high terrain, aircraft system malfunction, or controller actions. ATC threats can be poor sight lines for tower controllers, surveillance coverage, frequency congestion or aircraft deviation from clearances.

- Operational conditions — for example, operating a new aircraft type with different performance and control models, un-crewed aircraft systems integration in operations, environmental pressures on systems.
- Information quality pressures — ambiguous, missing, outdated, irrelevant, incorrect, non-timely, intermittent information.
- Demand to respond to variability — variable demand requires variably scaling up and down the resources and matching the requisite of demand with the requisite of the resources. The scaling up and down and requisite matching is a demand in itself. It can also affect some of the resources' activation (e.g., attention during underload and overload).

Professional and social pressures:

- Professional pressures related to career goals or job security;
- Social pressures related to how others judge one's behaviour, competence or skills; and,
- Team pressure and relationships and authority gradient.

Personal pressures:

- Confidence;
- Trust;
- Anxiety;
- Rest/fatigue;
- Work-related stress;
- Personal stress;
- Health;
- Workload; and,
- Expectation bias.

4. Efficiency pressures

Efficiency pressures on operations are linked to a perceived or actual pressure to use fewer resources. Similar to demand pressures, there are two aspects of efficiency pressures:

- **Efficiency pressure from what source** — What are the sources of the efficiency pressures?
- **Efficiency pressure on what system resource** — What system resource is the efficiency pressure affecting?

The sources of efficiency pressures can be seen as coming from different levels:

- Industry and societal pressures for efficiency — for example, pressures for noise reduction;
- Organisational pressure for efficiency — for example, pressures for cost savings;
- Team pressures for efficiency — for example, pressures to use less the shared team resources;
- Individual pressures for efficiency — for example, personal pressures, get-home-itis;

Here is an example description of generic system resources that may be affected by efficiency pressures:

- Technology — for example pressures to preserve technology resources, particularly when use cycles or use time are limited;

- Materials and supplies;
- Energy;
- Financial;
- Time;
- Physiological;
- Psychological;
- Competence; and,
- Knowledge — for example, using automation to perform a task so that a human doesn't have to be knowledgeable about that task.

Efficiency pressure has at least two effects on the system adaptive behaviour. The first one is a pressure for the effects on the system operating point to transition closer to critical and hazardous states. When operating closer to the safety prevention envelope, another unexpected/surprising pressure can easily push the system beyond the safety prevention space. An example is an aircraft that climbed earlier than recommended to an altitude that is at or near the maximum performance limited flight level because of efficiency pressure for less fuel consumption — for example, in order not to be blocked later by other traffic on the same route. In this situation (Figure 2) the system operating point gets closer to the safety prevention envelope (the boundary between the white and yellow space) and, in case of turbulence or significant temperature or wind change (for example, change from head to tail wind) leading to a stall warning activation, the system operating point can change into a critical state.

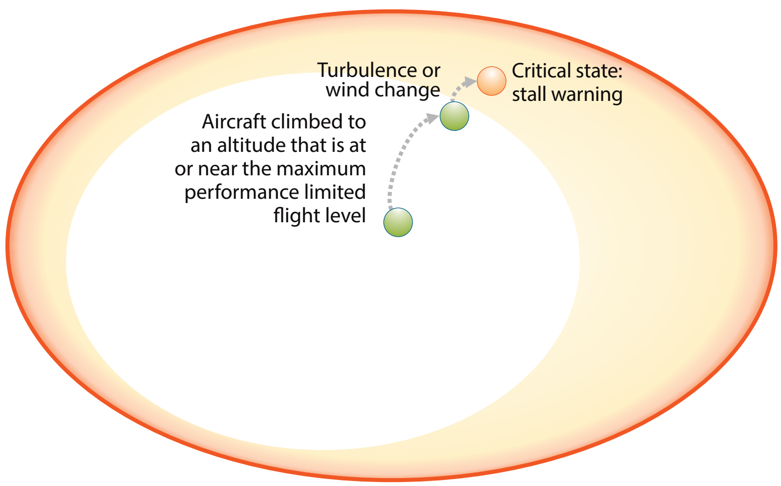

Figure 2: Efficiency pressures to operate closer to safety prevention envelope

The second effect of efficiency pressures is to keep the system resources at the levels that are needed for nominal operations without providing buffers. When system entities are closely interacting and their resources are at the limits, a small unexpected demand can affect one entity and rapidly propagate through the tightly connected network of entities. The tightly coupled system that is characterised by many small transitions of the system operating point may suddenly experience a large transition. In this situation, even if the system may initially operate away from the safety prevention envelope, the new pressure will have a disproportionately large effect on operating point transition. The system can experience one large transition bringing it far into critical and hazardous space.

An example (Figure 3) is a tight arrival and departure sequence for a single runway. The air traffic controller's plan may involve a sequence of the first aircraft landing, followed by an aircraft departure and then another aircraft landing. When looked at separately, the spacing between the first arrival and the departure and the spacing between the departing aircraft and the second arrival aircraft may be tight but manageable in a way that keeps the system operating point away from the critical and hazardous states, if nothing unexpected occurs. However, the first landing aircraft, impacted by a wind gust induced longer flare, may miss the exit taxiway that the air traffic controller expected it to take, leading to a longer than planned occupation of the runway, which in turn may delay the departing aircraft. When the air traffic controller issues a take-off clearance with minimum distance only, and the crew of the second arriving aircraft, observing an occupied runway, may decide to go around at the time when the departing aircraft is taking off, then the resultant situation is a hazardous simultaneous departing and low-level going around aircraft.

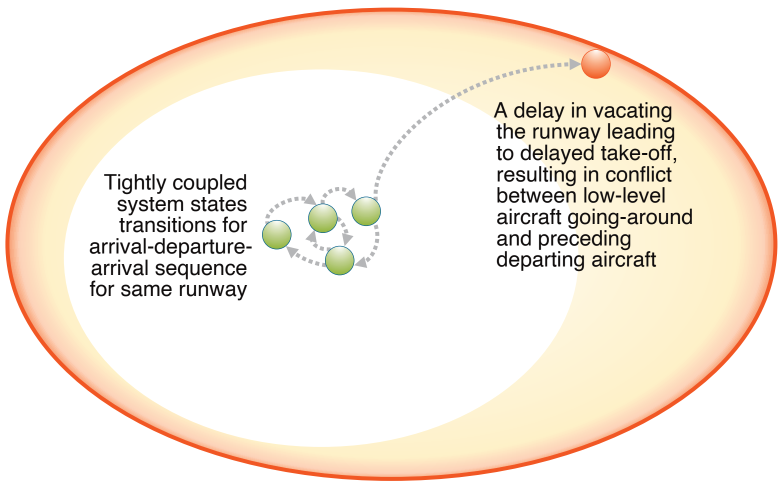

Figure 3: Efficiency pressures effect on tightly coupled system

For many situations, the transition of the system operating state into the critical and hazardous space is preventable. In the above example, there are at least two practical options to effectively simplify the situation. The first option is for the departing crew to decline the line-up and take-off clearance when separation is close to the margins — e.g., when they observe the close spacing on their traffic-alert and collision avoidance system display. The second option is for the approaching crew to keep traffic awareness and inform ATC sufficiently early if to go-around becomes probable. In general, counterbalancing the pressures is shaped by the system operating point resilience and will be described in more detail in Concept Note 6.

5. Example of pressures

The specific pressure on operations will be different for different operational systems. The pressures on a flight operation system will be different from the pressures on an airport operation system. Moreover, similar systems will experience different pressures and this will be very much context-dependent. **Learning From All Operations aims to understand what pressures are encountered during operations and how they affect system adaptation.** To facilitate this learning process, it may be useful for organisations to customise their specific description of pressure sources.

Here is an example of such a customised description of sources of pressures, as used in the context of the American Airlines Learning and Improvement Team (American Airlines, 2021).

The specific context of American Airlines Learning and Improvement Team led to a definition of pressure sources that are external from flight crew and that are observable:

- Aircraft mechanical;
- Airport;
- ATC;
- Automation;
- Cabin (flight attendants or passengers);
- Dispatch or paperwork;
- Environment (air or ground traffic, terrain);
- Ground or ramp — language barriers with push crews and included the clear area when taxiing into the gate;
- Maintenance;
- Ops pressures (gate agent, CS, operational changes); and,
- Weather impact (gusty winds, tail wind, convective activity, turbulence).

6. Acknowledgements

This work was funded under grant and cooperative agreement 80NSSC21M0187 from the National Aeronautics and Space Administration's System-Wide Safety Project, part of the Aeronautics Research Mission Directorate's Aviation Operations and Safety Program.

This note was drafted by Tzvetomir Blajev from Flight Safety Foundation and by Dr. Jon Holbrook from NASA. Thank you to Dr. Immanuel Barshi from NASA and to the members of Flight Safety Foundation's Learning From All Operations Working Group, who contributed to the ideas and clarity of this report: Valerie Stait, Cathay Pacific Airways; Capt. Tom Becker, TUI Fly; Capt. Max Butter, Lufthansa; Capt. Nick Peterson, American Airlines; Capt. Brian Teske, PhD., Delta Air Lines; Dr. James Klinect, LOSA Collaborative; George Hodgson, Southwest Airlines and Capt. Bertrand de Courville. Thank you to Darisha Vidrine, FSF intern, for organising the references used.

Suggested citation: Flight Safety Foundation. (2022). Learning From All Operations Concept Note 5: Three Forces Model of System Adaptation.

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