# FLEXIBLE PROCEDURES TO DEAL WITH COMPLEX UNEXPECTED EVENTS IN THE COCKPIT

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**Abstract**

Modern airliner operations consist of an environment with multiple detailed procedures to cover critical abnormal events and with systems that are automated and highly reliable. Complex and unexpected events are rare and may thus present a challenge to the crew to deal with, putting demands on the resilience of the crew. In the EU Man4Gen project a "flexible procedure" was developed as a strategy to assist flight crew in dealing with unexpected events where an existing procedure was not available. This procedure is intended to assist crews in adapting their response to the situation and be more flexible in their application of their procedures and training to increase the effectiveness of their response. This paper describes the procedure and its development within the project based on two sets of flight simulator experiments with operational flight crew. The resulting flexible procedure consists of steps to help crews manage time criticality, manage (un)certainty and finally to plan for contingencies and changes. This forms the basis of the discussion of how procedures can be a source of resilience in the cockpit, rather than forming a barrier to it.

## 1 INTRODUCTION

Modern flight crew operate in an environment with multiple detailed procedures to cover critical abnormal events, and with systems that are automated, and highly reliable. In this environment, complex and unexpected events without a clear procedure or systems solution (such as a systems reset) are rare, and may therefore present a challenge to the crew in knowing how to assess the situation and decide on a course of action (Casner, Geven & Williams, 2013; Dekker et al. 2008; Klein et al. 2004). Examples of such events are the engine explosion that occurred on Qantas Flight 32, leading to a multiple systems failure (ATSB, 2011). The Qantas Flight 32 accident exemplifies how an experienced flight crew initially try to apply procedures as required, but eventually need to adapt their response to the situation that they faced and be flexible in the application of the procedures.

The research team in the EU FP7 "Manual Operations of 4th Generation Airliners" project set out to investigate the strategies used by pilots in unexpected events through interviews (Rankin, Woltjer, & Field, 2016) and a set of exploratory simulator experiments. The results of these interviews and experiments were used to develop a strategy to assist flight crew in an unexpected event, in the form of a procedure that was flexible in its application. This paper describes the development of the procedure, the philosophy behind the different phases of the procedure and how it was validated in a follow-up experiment.

The aim of the research project was to investigate the ways in which flight crew handled the multiple failures, and environmental challenges, and the potential for assisting crew in responding to unexpected situations more effectively. In the already highly proceduralised environment of the modern airliner cockpit, the addition of a procedure is a solution that should be treated with care. While procedures form a key part of the safety process in the cockpit, there is also a risk associated with applying procedures without fully understanding their purpose. Procedures are usually developed to address a particular failure or situation, and a change in the particular situation can lead to the procedure no longer being appropriate. For example, in the situation of a complex or multiple failure, it can be difficult to identify the most appropriate procedure to apply because several procedures are applicable, and the priority of the different procedures is not easy to identify – for example where an engine failure causes multiple systems to fail. In order to avoid these potential limitations of a procedure we developed a strategy that could be used by flight crew to handle unexpected and complex situations that don't have a single "good" solution, but where multiple solutions could be effective. This strategy would have the structured elements of a procedure, but would also be generic and flexible enough to be able to cope with many different situations – a flexible procedure.

## 2 EXPERIMENT 1: EXPLORATORY EXPERIMENT

An initial set of experiments that was carried out in the Man4Gen project with 20 crews of line pilots identified that there was a potential for an unexpected or surprising situation to develop into a serious problem if the situation is not rapidly understood. The experiment scenarios included complex unexpected events, such as a bird strike that caused problems on multiple engines. The aim of these scenarios was to create a situation with multiple conceivable options for strategies of how to cope with a problem, where there was no single correct strategy based on normal operating procedures. In some cases the flight crew could take decisions and carry out actions that did not effectively manage the risks, or even increased the risk to the aircraft and flight.

The initial experiments in Man4Gen were carried out to identify the strategies that were applied by flight crew when faced with an unexpected, complex, situation (Field et al. 2016). These experiments identified not only the successful actions and decisions, but also the problems that were observed in the way that the crews responded to the situations. Across the results from the crews, there were three main areas that were identified for potential improvement in the development of the procedure:

1) Threat assessment – crews often experienced a high level of temporal stress and therefore expedited their decisions and actions without sufficient understanding of the situation at hand.

2) Problem solving structure – by improving the structure behind problem solving, crews are assisted in checking whether the procedures and actions suggested by the aircraft systems (e.g. the Electronic Centralised Aircraft Monitor, ECAM; or Engine Indicating and Crew Alerting System, EICAS) are applicable based on the information that they have.

3) Defining goals – identifying, comprehending and defining goals and an associated progress review would assist crews in deciding on an appropriate course of action and in checking how effective their actions are in achieving the goal.

### 2.1 Development of procedure

All three problems are intertwined, and the aim was to develop a flexible procedure that would assist crews in addressing all three. The concept behind the flexible procedure was to develop a strategy that would assist flight crew, in a format that would be familiar to them – the procedure – while not prescribing all of the actions to carry out in detail. A key element of the flexible procedure calls on the flight crew to "consider" carrying out the steps. In this way the flexible procedure requires the flight crew to actively develop their understanding of the situation and thereby guide them in assessing and carrying out actions appropriate to the situation. The strategy and flexible procedure was developed by a team consisting of human factors experts, operational flight crew, and operational experts from the industry. It was reviewed by representatives from the project members and tested using airline flight crew.

### 2.2 Procedure philosophy

The procedure combines the concepts of improving crew threat assessment and assisting their ability to manage uncertainties. This failure management procedure aims to assist crews in managing surprising, unexpected and diffuse situations where conventional training and published procedures may be insufficient. The procedure philosophy encompasses three concepts:

1) Manage time criticality
2) Manage uncertainty
3) Plan for contingencies and changes

The design parameters for the procedure are that it should be concise, logical and easy to remember. The steps in the procedure should be aligned to current operating principles and training, and supplement the existing manufacturer and operator's procedures. Flight crews should also be able to relate to the logic of the procedure so that the way it is presented aligns with their training. Furthermore, the procedure should be designed to limit the cognitive load on pilots at the start of the procedure (in consideration of stress and emotional responses), but as initial stabilisation of the situation may free crew cognitive capacity, the procedure should engage this increased capacity in higher level problem solving. The procedure also includes elements that can be applied depending on the situation that the crew faces in order to focus their decisions and actions on the most appropriate course.

### 2.3 Procedure phases

This philosophy was translated into a flexible procedure that consisted of six phases that covered the three concepts discussed above through a series of workshops with pilots and human factors experts. Phases 1, 2 and 3 were intended to manage the time criticality; Phases 4 and 5 manage the uncertainty; Phase 6 consists of the planning for contingencies and changes:

Phase 1: Stabilize flightpath

Phase 2: Mitigate immediate threats

Phase 3: Short term planning

Phase 4: Identify situation

Phase 5: Perform appropriate actions

Phase 6: Long term planning

Each of these phases consists of a number of reminder steps and suggestions for decisions and actions that could be taken by the crew to address the situation.

**Phase 1: Stabilize flight path**

The first phase is aligned with the crew response to an unintended deviation of the flight path, and includes the already likely memorised steps that can be performed immediately without specific reference to the procedure. It is included to highlight the importance of controlling the aircraft and flight path, and thereby regain composure in the situation. By including it as the first step, it also emphasises that subsequent steps in the procedure should not be carried out until sufficient aircraft control has been established. The phase is concluded with the division of Pilot Flying (PF) and Pilot Monitoring (PM) tasks between the crew in order to remind the crew to consider the options that are available to them and reinforce the active problem solving role of the monitoring pilot. We emphasize the division of these tasks for two reasons: 1) it prevents two crew members diagnosing the problem at the same time and forgetting to fly, and 2) it must reinforce the active problem solving role of the PM in this situation. In other words, who is best suited for which role in this particular situation?

**Phase 2: Mitigate immediate threats**

After Phase 1 guides immediate aircraft recovery with regards to flight control, Phase 2 guides immediate aircraft recovery with regards to aircraft/system integrity. At this point crews take care of the second most critical aspects, after controlling the aircraft; immediate threats. Immediate threats are those which may have a severe effect on aircraft integrity and/or controllability (Both internal and external events). Put plainly, mitigating immediate threats prevents the aircraft from falling from the sky (in conjunction with flight path control).This could be, for example, addressing a serious engine fire or flight controls failure and putting the aircraft back onto a stable flight path.

**Phase 3: Short term plan**

After Phases 1 and 2 are completed, the crew will have information telling them whether the aircraft will be out of their control in the immediate minutes, or not. If either Phase 1 or Phase 2 leaves many control issues/immediate threats remaining, then the crews may acknowledge that they do not have time and must land as soon as possible. However, provided they have control of the aircraft and the actions in phase 2 were effective in mitigating the immediate threats, they then must acknowledge that they have time to regain a better understanding of the situation, and resolve/prepare accordingly. Based on this "criticality acknowledgement", they must define a short term plan before continuing (especially considering a split cockpit situation). A short term plan describes the flight plan for the next 5, 15 or 30 minutes depending on the time available.

**Phase 4: Identify situation**

In Phase 4 the crew is tasked with understanding the nature of the situation (both failures and context), before proceeding to verify it and perform appropriate actions in Phase 5.

Usually in basic, single failure cases, the failure or situation may be non-complex and the process of problem identification is concise and intuitive. However, iIn the context of complex and ambiguous situations, familiar and rapid responses may be less effective or even detrimental, and may contribute to undesirable states and a (further) lack of understanding of the situation. In these situations it is particularly important to be aware whether the situation may be different than initially assumed or expected, and in which ways. In unclear situations, this phase may assist crews with steps geared to setting up a mental model of the situation at hand, which will support Phase 5 in determining what actions and procedures are most likely to be suitable/effective/safe given the situation.

**Phase 5: Perform appropriate actions**

In Phase 5 the crew will perform actions to further resolve the situation or reconfigure to a more desirable state.

Usually in basic, single failure cases, published and prescribed checklists will provide crews with the resolution required. However, complex and ambiguous situations may not be as clear cut. There may be situations where several procedures/checklists can be applied, and where it is not clear what the priorities are. In such situations, certain checklists may still assist a crew in developing understanding of the situation (e.g. troubleshooting checklists), but crews must acknowledge the limitations that these procedures have when encountering such complex, ambiguous situations.

In order to maximize rebuilding of the understanding of the situation, maximize checklist suitability and efficacy and, importantly, prevent inadvertent application of unsuitable checklists or checklist items, crews must acknowledge what they intend to do or learn with this checklist, and ensure that the procedure is safe to apply. In most cases such considerations are intuitive and part of a familiar process, but in complex and ambiguous situations, it may be a simple safeguard against undesirable states and a further loss of understanding of the situation.

**Phase 6: Long term planning**

Phase 6 is the final phase, in which the crews plan their flight continuation after managing the failure situation. This phase is twofold: first of all crews must ascertain what the effects of the failure(s) are. Second of all, crews must determine what the most suitable continuation plan is pertaining to other flight aspects such as weather, company considerations, and approach & landing considerations.

## 3 EXPERIMENT 2: PROCEDURE VALIDATION

A second set of experiments was conducted in the Man4Gen project to validate the flexible procedure. Similar to the initial experiment, a complex scenario was flown in the simulator that was intended to be challenging to the experienced crew who participated. A total of 15 crews (30 participants - captain and first officer) participated in the two flight simulator experiments (18 participants on a long-haul aircraft, 6 crews on a short-haul aircraft) to evaluate the procedures. The scenario in the experiment was a flight with a lightning strike after takeoff which affected the engine computers, a minor engine warning prior to the lightning strike added to the ambiguity of the situation.

The experiment results evaluating the procedure indicate that the crews identified that the procedure tended to assist in effective time management and reducing the temporal stress of the unexpected situation. The crews found the procedure intuitive and flexible, but rated the support for contingency planning neutrally. The results indicated that the crews that took more time for their decision making made more effective assessment of the situation which leads to a better performance in their choice of route after the lightning strike. The analysis of the results of this experiment is further described in Mohrmann et al (2017).

## 4 DISCUSSION & CONCLUSIONS

The results of the experiment indicate that the better performing crews in the scenario benefitted from the structured approach to the assessment of the situation. The crews that applied the structured approach were able to spend more time in the latter phases of the procedure – identifying the situation, performing the appropriate actions and formulating a long-term plan -– with respect to their route management and troubleshooting of the engine problems. The initial phases of the procedure were intended to cover the initial actions that the crew carry out to stabilise the situation and determine the severity of the situation. These initial actions include the immediate actions that crews are expected to carry out to stabilise the flight path, which would include the memory items for example. Many of the crews did not spend as much time on these initial phases, or actively verbalised the procedure during these phases, which could be explained by the crew's familiarity with these initial steps and the scenario design.

In the highly proceduralised environment of the modern airliner cockpit, with well-trained crews, extensive automation and extremely reliable systems, it is interesting to explore the potential benefits that a flexible procedure concept could have on the resilience. Despite the high level of safety, the aviation industry still strives to improve and resilience to cope with unanticipated, or multi-failure situations. The strategy that is described in this paper is a way of further assisting crews in applying their training and experience in order to effectively deal with an unexpected situation. The flexible procedure offers a method to assist the crew members in detecting potential mismatches between their understanding of the situation and better be able to identify whether immediate action is needed and how much time is available for decision making. In turn, the crews would then be better able to quickly re-frame and understand the situation following an unexpected event.


**Acknowledgements**

The authors would like to thank the organisations and participants involved in the experiments. This research was funded as part of the FP7 2012 Aeronautics and Air Transport programme under EC contract ACP2-GA-2012-314765-Man4Gen. The views and opinions expressed in this paper are those of the authors and are not intended to represent the position and opinions of the Man4Gen consortium and or any of the individual partner organisations.


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