Man4Gen: Manual Operation of 4th Generation Airliners

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Abstract. Aviation has achieved a high level of safety as a result of decades of improvements to systems, procedures and the increased use of automation in the flight deck. Unfortunately, when an unexpected event occurs, recent history has shown that pilots are not always able to take control and manage safe flight. Research undertaken by the Man4Gen project addresses the ability of the pilot to utilize manual control in a safe manner in modern automated aircraft. Man4Gen focusses on understanding the breakdown of situation awareness, which can result from the occurrence of unexpected and challenging situations in 4th generation aircraft. Specifically, the role of effective flight-path and system monitoring, decision-making and sudden reversions to manual control are being considered.

Keywords: Safety, Situation Awareness, Cognitive Systems Engineering

Introduction

During the evolution of commercial airliners, the aviation industry has developed a system that is the safest mode of transportation. Accident rates are reduced to the lowest level in history. However, these rates have levelled off over recent years, and further improvements have proved difficult to achieve. Upstream of accidents and incidents are factors such as mismanagement of threats, crew errors and lack of situation awareness. While aviation is an extremely safe mode of transport, accidents will continue to occur if the crew lacks the skills to remain in control of the 4th generation aircraft in abnormal situations. In such situations, the crew should have the proper skills to manually control the aircraft, manage the automation systems effectively, and always maintain an acceptable level of situation awareness.

The rate of 4th generation airliner hull losses is already lower than that for 3rd generation aircraft. This is shown in Figure 1. This improvement, while rapid at first, has now levelled off and it has become a focus for the industry to improve this. This is evidenced by the efforts that the aviation industry continue to make to improve the safety of operations, through the number of different initiatives at all levels of the industry – from initial pilot training, to line operations, from airlines, to airframe manufacturers, from researchers to regulators. This includes efforts to reduce loss of control accidents, runway excursions, controlled flight into terrain, and unsafe go-arounds to name a few.

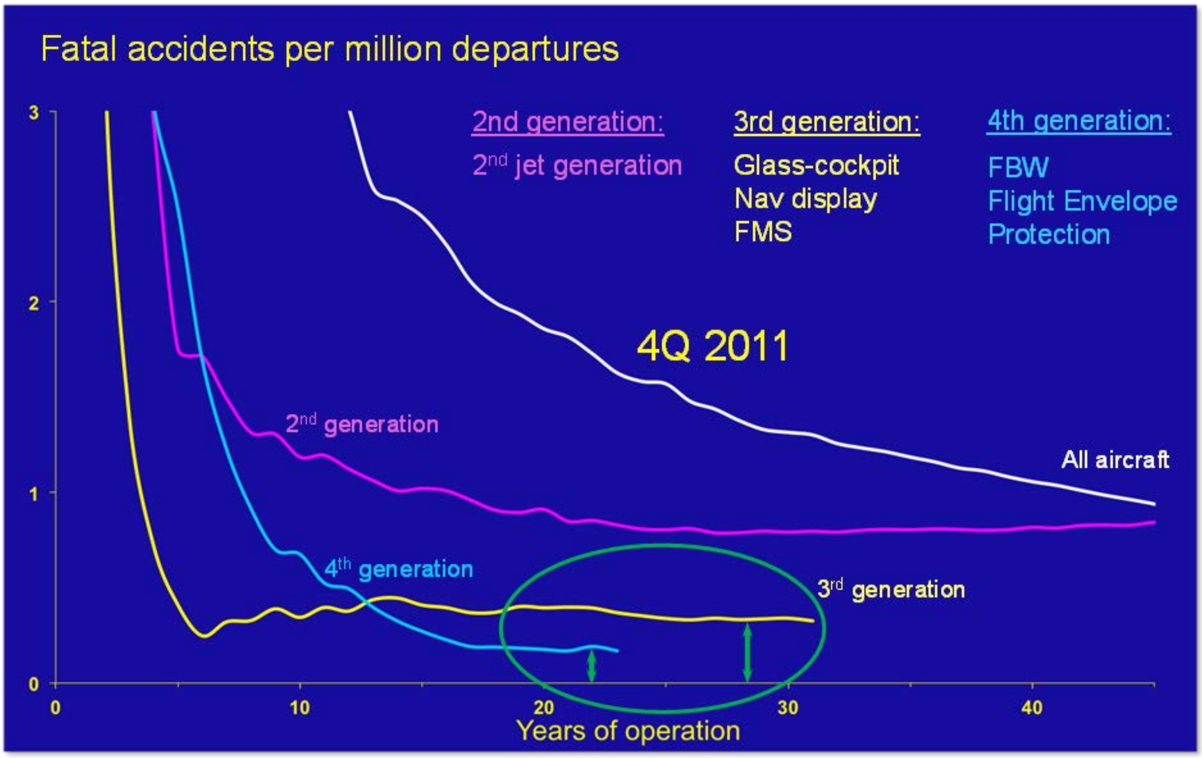

Figure 1: Fatal accidents per million departures per generation aircraft (Ascend, Airbus 2011)

Examining the accident rates in further detail, a comparison can be made between different categories of accidents (see Figure 2). While there is a difference made between fatal and non-fatal accidents, the primary accident categories remain runway safety related accidents, Loss Of Control In-flight (LOC-I) and controlled flight into terrain (ICAO, 2013). The accident rates used in the EASA safety analysis indicate that while the number of accidents was small, LOC-I is responsible for most fatal accidents in the period 2002-2011, while the highest number of non-fatal accidents was also related to runway safety – including those related to unstable approaches (EASA, 2012).

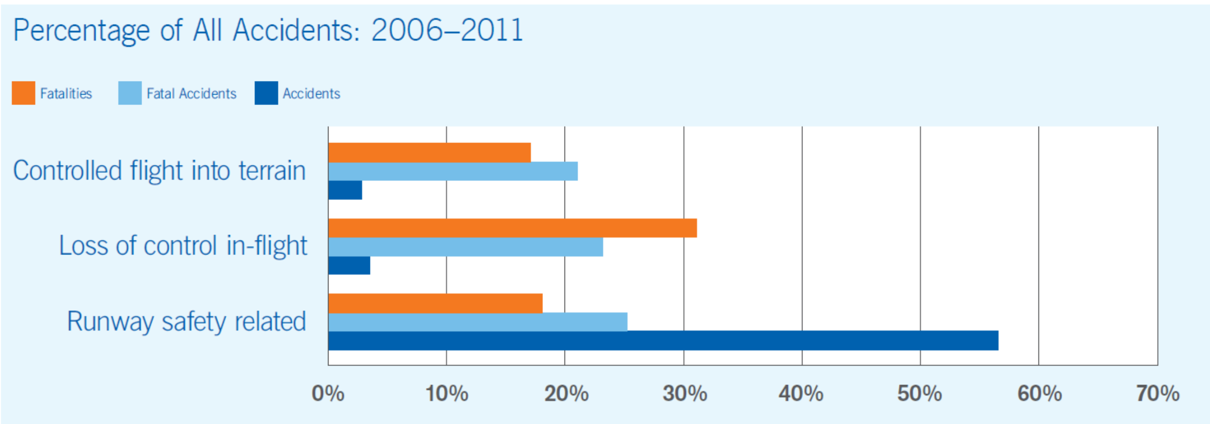

Figure 2: Percentage of all accidents (ICAO, 2013)

During the chain of events that leads to the accident in a LOC-I situation for example, the pilot is unable to maintain control of the aircraft by applying manual operation skills to prevent or recover from the situation that lead to the LOC-I. Such instances have occurred in the highly automated 4th generation aircraft, as well as conventional aircraft, and with experienced pilots fully trained to current standards. Accidents such as these can be due to a combination of the crew not managing the aircraft systems effectively after an unexpected event, and being unable to apply appropriate manual handling skills. Due to increased safety requirements, efficiency of commercial operations, environment and technology, the pilot's task in modern airliners has transitioned from flying the aircraft by means of manual control inputs, to increased programming of automation and monitoring of the cockpit systems and information during most phases of the flight. Hence, the pilot has become more of a system manager than a closed-loop controller. However, this can influence the pilot's ability to understand and effectively control the same aircraft systems, particularly when return to manual operation is required. A study by the UK Civil Aviation Authority (CAA) in 2004 highlighted the growing dependence of flight crews on automation (Wood, 2004). It is also consistently reported that there is a reduction in manual flying skills that correlates with the increasing use of automation (Roessingh et al., 1998; Wood, 2004).

Despite automation, airplane upsets may be induced due to environmental conditions, system error or human inputs. When in an in-flight upset condition, the pilot may be forced to disengage the autopilot and take over manual control. However, if the crew is not fully aware of all contributing factors, this can lead to inappropriate actions, an aggravating of the upset condition and eventually to loss of control. Additionally, if the automation of flight control systems fails, the crew is expected to resume manual operation of the aircraft immediately. The crew may need to fly the aircraft manually, or may modify the automation mode and use the flight controls in a degraded mode. It has been shown that flight crew can have difficulty understanding the automation concepts and how to correctly use the automation (Mumaw et al., 2001).

The Man4Gen project aims to identify the common thread behind the events that lead to these airplane upsets and accidents, and to recommend short-term changes to operational procedures, training and aircraft systems technology in order to mitigate this threat to aviation safety. Man4Gen is a European study funded as part of the European FP7 2012 Aeronautics and Air Transport programme. In the Man4Gen consortium the following partners work together: NLR (coordinator), DLR, IDT, Linköping University, Boeing R&T, University of Vienna, Medical University of Vienna, Global Training Aviation, Airbus Operations and Airbus. The project started in 2012 and will run till the end of 2015.

In this paper the approach of the Man4Gen project and its research methods are outlined.

The Man4Gen Approach

As a starting block of Man4Gen, a literature overview was performed to identify the existing studies and material that are available in the areas applicable to the project and offers an overview of academic studies, reports from aviation regulators, research institutes and accident investigation agencies. This review was used to identify the roadmap for the project based on existing knowledge and related activities taking place worldwide. The review and analysis is summarised in the following problem statement:

> *"Despite the substantial and proven safety benefits of automation systems in 3rd and 4th generation aircraft, evidence indicates that when faced with unexpected and challenging situations, pilots sometimes have difficulty in quickly and effectively responding to situations which require a rapid transition in their activity from monitors of very reliable systems, to active and authoritative decision-makers exercising manual control over the aircraft."*

To gain insights into issues with automation in modern aircraft, a more directed literature study was performed. Additionally, interviews with pilots and instructors were carried out. The main objective of the interviews was to get an operational perspective on the themes highlighted by the literature report and in the previous analyses, to gain contextual knowledge by collecting examples of situations which can be used to improve training scenario development and, finally, to increase the understanding of the operational environment.

In addition to the existing data that is available to us from previous research, industry study groups and accident and incident analysis, the project includes study to examine and model the response of crew to unexpected events. The aim of this research is to understand the underlying factors behind the decisions, actions and events that ultimately lead to incidents or accidents. Two research perspectives have been applied within the project that complement each other and enable a more complete understanding to be built – Cognitive Science, and Cognitive Systems Engineering.

Research methods to investigate how crews and aircraft successfully handle unexpected events from a Cognitive Systems Engineering (CSE), or sensemaking, perspective have been developed throughout the first year of the project. Models have been developed that can be used to describe how the crew (and aircraft) as part of the joint system handle events, and consequently where it may go wrong. The CSE models have been used to:

1. Describe the crew-aircraft system,
2. Identify areas of interests for further investigation (e.g. automation issue analysis, interview topics and experiment requirements), and
3. Support the analysis of experimental results.

In addition to CSE, the project applies research methods from a Cognitive Science and Neuroergonomics perspective. This research method focuses on studying the impact of unexpected events on the flight crew's Situation(al) Awareness (SA). The SA research has focused on:

1. Identifying a sound working definition of SA for Man4Gen,
2. Evaluating existing qualitative and quantitative SA measurement tools, and
3. Highlighting issues associated with SA to propose SA dependent variables and measurement tools for the experiments to be carried out in the evaluation exercises.

Primary research (expert interviews) and secondary research (literature overview) have been carried out for this task. To identify the most critical issues of SA in the Man4Gen project a review of human factors in cockpit was performed. A study to link the concept of egocentricity and stress has been carried out to identify plausible hypothesis for the simulation experiments.

These two research perspectives are applied in the analysis data from operational experiments that are being carried out within the project. To investigate the research conclusions, a number of operational evaluation experiments will be executed in two phases. In the first experimental phase, several experiment settings were determined to identify the processes that lead to confusion of loss of SA when using automation. Two high-fidelity, flexible flight simulators have been used to run experiments to explore the common threads behind the events that lead to airplane upsets, incidents and accidents. The data from these experiments will be used as input for the sensemaking and SA research models on one side and on the other side will be analysed by the industrial aviation partners to identify behavioural patterns associated with decision making in unexpected situations.

The second experimental phase of the project will, based on the results of the first phase, determine mitigation strategies to guide the future development of operations procedures, training and cockpit design with respect to 4th generation airliners. The aim is to provide guidance solutions to assist the pilot, in preventing the loss of aircraft state awareness and to enable potential rapid transition to assume full and affective manual aircraft control. Other findings of the first phase might also lead to recommendation for modification of the cockpit system design, procedures or training methods that will reduce the risk of the crew losing the awareness of the situation or system state.

In the remainder of this paper we will have a more detailed look at these two different research perspectives, and how they are applied within the project.

Cognitive Systems Engineering Research Method

Research methods to investigate how crew and aircraft successfully handle unexpected events from a CSE perspective have been used throughout the first year of the project. During the first phase of the research mindmapping was used to converge on the main areas to investigate: surprise, confusion, system knowledge, communication, procedures and manual control. The crew-aircraft contextual control model (see Figure 3) has been drawn to sketch the main cognitive processes (Rankin et al., 2013). Sensemaking loops have been identified in the models and the theoretical models have been adjusted to the crew-aircraft context. The Extended Control Model (ECOM) (Hollnagel, 2005) has been applied to elaborate the crew-aircraft model in order to use the model for examining the distribution of tasks and roles across the crew members and the aircraft system.

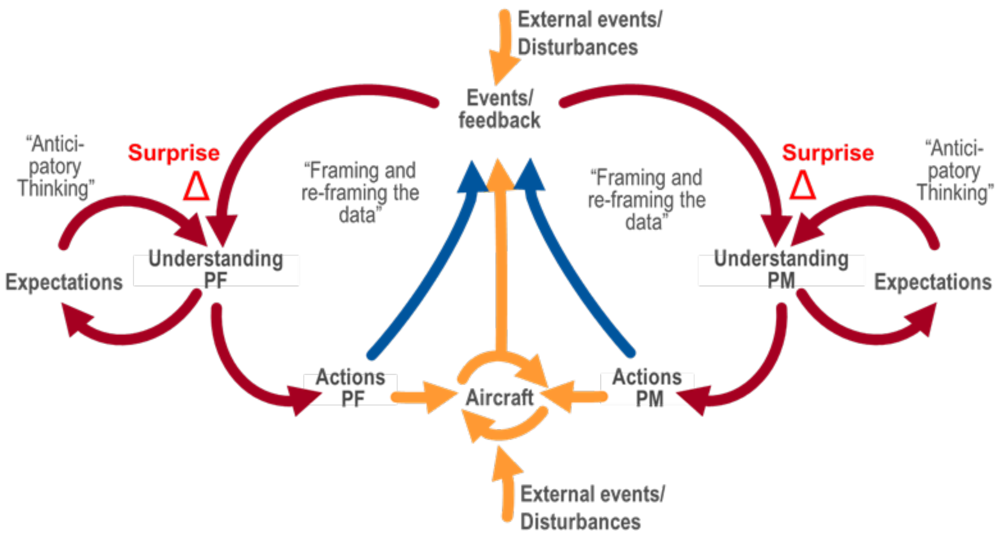

Figure 3: The crew-aircraft contextual control model (Rankin et al., 2013)

The ECOM can be used to identify what to observe during the experiments in the test scenarios. The models describe how the system handles and adapts to different situations. By taking scenarios where a crew is challenged, the models aid operational experts in examining the interactions between the crew and the aircraft system and identifying the critical strategies and processes that a crew is expected to exhibit when handling an unexpected situation. In turn the models and analysis serves as a link between what is observed in the experiment and the underlying theories from a CSE perspective. By carrying out the ECOM analysis on the crew's performance the differences between crew's performances can be identified and examined in detail. This offers a description of the state of the crew-aircraft system at a particular moment in time and the distribution of tasks and roles as well as the trajectory of control. It is also interesting to investigate the change in control architecture, identification of anticipatory and reactive control in response of a disturbance, and determination of how the control architecture changes between the different levels of control. The research is examining methods for analyzing and mapping this.

Experiments are carried out on full-flight research simulators in an operational cockpit environment. In these experiments flight crews are confronted with surprising or confusing situations they are unfamiliar with. These situations require analysis and decision making that are outside the normal system or procedural response. The research methods that have been identified in this CSE analysis capture the strategies applied by the crews, and identify the information and process required to handle these situations. A number of methods will be used to capture the outcome of the experiments that will be applied with the models:

- **Observation.** The central method of evaluation will be through expert observation of the experiments. This is both real-time evaluation during the experiment as well as post-experiment evaluation. Due to the nature of the scenarios the interpretation of the flight crew performance is assessed by operational experts.
- **Eye-tracking.** Eye-tracking methods are applied to track the key areas visually monitored by the flight crew during the experimental scenarios. The aim of the eye-tracking will be to capture and analyse the information that is being used by the flight crew in response to events and changes to the aircraft state.
- **Debriefing.** The debriefing will consist of several parts to capture a set of complementary information to be triangulated during the analysis, including the observation data, the individual pilot's perspectives (initial individual de-brief followed by individual self-rating questionnaires) and the crew perspective (video-play back).
- **Simulation data.** The flight simulators are set up to capture the data from the simulated aircraft, and crew interactions with the aircraft systems. The key aircraft parameters are recorded to capture the state of the aircraft. Similarly the autopilot modes are recorded for reference to the modes engaged, armed, and transitions between modes. Crew interactions with the aircraft are recorded and time-stamped and referenced against the observation data.

The models bring together different elements of CSE that are relevant to this project, and apply them to the central problem area – enabling pilots to respond appropriately to situations where they must be effective decision makers controlling the aircraft. The models that have been developed in this project represent the crew-aircraft system in its operational environment, and are used to visualise and describe how the system handles and adapts to different situations. The theoretical models have been adapted and fitted to the crew-aircraft context to help describe the control structure, and the levels of control for the performance of the crew and aircraft in operations. The models have helped to define the observations that are required during the experiments, and identify the potential critical points in the scenario. The models will further be used as part of the analysis work following the experiments.

Analysis using the models has further helped to identify the research requirements for the experiments and define the basis for the experimental and scenario design. The analysis within this task has also emphasised the importance of including certain elements within the experiment scenarios to test and examine the behaviour of crews in response to unexpected events.

Cognitive Science Research Method

The SA research has aimed to establish a thorough understanding of SA for the Man4Gen problem statement – focusing on the ability of crew to be able to effectively switch between different levels of automated and manual control. Similarly to the CSE approach, the aim has also been to establish the variables and measurement tools to be able to evaluate SA during the operational experiments. This task has been carried out through both primary research, interviewing experts and a laboratory experiment, and secondary research with an analysis of existing literature. The first aspect of the primary research was a set of problem centred expert interviews with 14 operational experts investigating the definition of SA, its measurement, and how SA is trained. The second aspect was a social cognition experiment addressing stress, and egocentricity, which may play a relevant role within the socio-technical environment.

SA is a term which is widely used in different branches and contexts but for which there is not a single, codified definition. As within Man4Gen industrial, aviation and academic partners are working together, it was important to share a common understanding regarding what we are talking about when speaking of SA in the context of the problem definition.

As Endsley's definition of SA (Endsley, 1995) is the most commonly used definition both in general and in the aviation industry, we used this definition as a baseline. Expert interviews were carried out to collect opinions from an operational environment and find tendencies how a possible Man4Gen definition could be formulated. The interview results show that SA in aviation is not a standardized term but rather a container term that refers to a competence in training, a state in accident and incident reports and serves as a theory in experimental settings investigating crew-aircraft issues. Based on our research, we have come up with the following proposal for the Man4Gen SA working definition:

> *SA in an aircraft cockpit includes the recurrent and continuous perceiving, comprehending and projecting of the state of the aircraft and its systems: where the aircraft is and its environment, time and fuel states, possible threats to the safety of the aircraft, the people and their states involved in the operation including passengers as well as developing "what-if" scenarios for contingencies.*

This definition very much corresponds with the ICAO definition of SA (ICAO, 2006). It is still general and we suggest refining it for individual purposes. This means for example further breaking down the generic definition in an experimental setting where for each scenario and its events SA and its emphasis should be detailed to a micro level (e.g., mode awareness).

Crucial factors associated with SA have been identified through the analysis of literature, and focusing on the relevant aspects highlighted by the interviews. We distinguished between human factors that are relevant for single pilots from those relevant in crew settings. In this analysis, attention arose as one of the main human factors affecting SA in the cockpit. This is particularly relevant when considering the operational environment where a high level of automation is present in normal operations, thus affecting the type of task the crew carries out. In the crew aircraft environment, there is a large amount of different information competing for attention, or in some cases conflicting information, which can make it difficult to identify the relevant information. This is especially true in unexpected situations, which can be ambiguous, surprising or even confusing. In order to deal with these simultaneous sources of information, pilots apply systematic scans, or information sampling strategies. This scanning behavior can be adversely impacted in unexpected situations and can lead to attention narrowing. The most common breakdown of SA occurs when all of the information required to understand the situation is available, and perhaps being presented, but is not perceived, or attended to by the pilot.

When pilots monitor the aircraft systems, the data is interpreted, and applied to build an understanding of the current state of the system. This is also referred to as a mental model. This understanding of the current state is compared to the expectations of the crew, the expected state of the system. Surprise arises when the current understanding and the expectations do not match. This mismatch can arise due to a misunderstanding of the current state – misinterpretation of information, or missing information for example – or incorrect expectations of the system. In order to prevent a mismatch arising, the crew continuously adjusts their understanding and expectations, and anticipates the consequences of the changing states.

Based on the findings of the SA research carried out thus far in the project, the main objectives of the SA analysis in the operational experiments has been to investigate issues and processes involved in maintaining or losing SA with a focus on display/system design, procedures and training. Considering the main focus of Man4Gen's problem definition and the factors mentioned above, the following tools, methods and SA related variables were identified as most appropriate for the simulator experiments (see Table 1).

Table 1. SA related variables and research methods

SA related variables	Tools/methods
Pilot attention / perception	Expert observation
	Eye tracking / gaze tracking
Pilot functional state	Heart rate
	Questionnaires
Pilot performance	Expert observation
	Video analysis
	Simulator logging data
Pilot self-reported SA and workload	Questionnaires
Pilot communication	Expert observation
	Video analysis

Next to the simulator experiments and methods mentioned in Table 1, fMRI experiments were carried out to investigate SA on a fundamental neuronal level. fMRI is a non-invasive neuroimaging method for studying the human brain in vivo. The experiments tackle fundamental aspects of SA that are highlighted as being important in the problem statement and investigate the neurobiological correlates that can be considered central to piloting and monitoring an aircraft.

The eventual development of appropriate recommendations for training, cockpit displays or procedures requires the identification of the SA levels (perception, comprehension or projection (Endsley et al., 2003; Endsley, 1995, 2001) at which the lack of SA may arise. Additionally, possible break downs in SA after surprising and/or confusing events while operating 4th generation airliners will be analyzed.

Experimental Preparations

The aim of the first set of operational evaluation experiments is to investigate the conclusions of the theoretical analysis in an operational setting. To prepare for these experiments, several experiment settings were determined that could be used to identify the processes that lead to confusion or loss of SA when using automation. Usage of high fidelity, flexible flight simulators is proposed to validate results of previous research and the analysis in a realistic environment.

The objective of these experiments is to develop a better understanding of the processes that influence flight crew SA and hence operational decision-making. Two scenarios were developed: one for the DLR research simulator AVES, one for the NLR simulator GRACE. Both scenarios followed a common baseline structure while taking into consideration the differences between the simulators. To ensure traceability with regards to relevance and objective of the scenario elements the process of the scenario development starts from the agreed problem statement of Man4Gen and ends with relating the necessary flight crew actions to a behavioural marker system. The latter also facilitated the appropriate selection of measurement and observation methods to be used to objectively and subjectively evaluate pilot behaviour during the simulator tests. The flight crew actions which are investigated by means of these scenarios are related to key pilot competencies or behavioural markers. See Figure 5 for a graphical overview of the process followed by the scenario development team within the project.

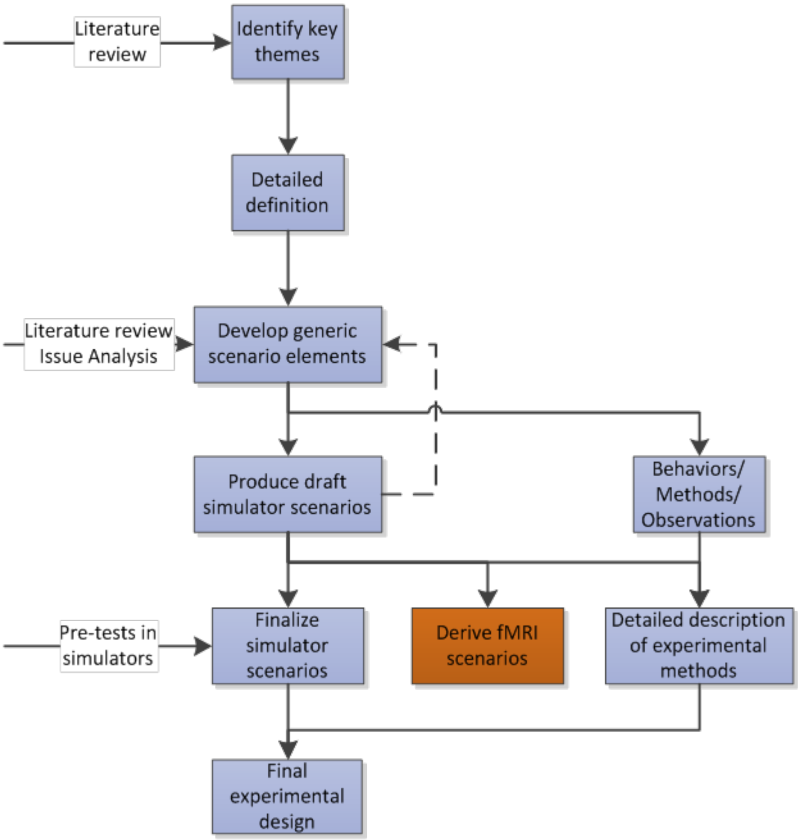

Figure 5: Process followed to arrive at the final experimental design

Final Remarks

The Man4Gen project is investigating whether there is a common thread behind the most common accident and incident causes, and how this could be addressed in order to improve safety. The focus of this research is the role of the flight crew within the crew-aircraft system in a highly automated and highly proceduralised environment. There is a wealth of data available on operations, incidents and accidents, which are often reduced to causes and contributing factors. By carrying out experiments in an operational environment, with operational flight crew, the intention is to better understand the situations behind this data, and the processes that lead to the situation.

The intent behind the application of two leading research perspectives in the field of psychology is to be able to understand the crew-aircraft system from different angles: from a Sensemaking, or CSE perspective, as well as from a SA, or Cognitive Science perspective. In this way we are able to combine research that examines the behavioural patterns of the crew, with a perspective that looks at the crew-aircraft system as a whole.

The experiments were completed earlier this year, and the analysis is ongoing. The results from our experiments, as well as the analysis methods, will be reported later in the project.

Acknowledgements and Contact Information

The Man4Gen research is 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 do not necessarily represent the position and opinions of the Man4Gen consortium and or any of the individual partner organisations. If you have any questions regarding the Man4Gen project, please contact man4gen@nlr.nl.

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