Design of Experiment for the Pilot Evaluation of an Airborne Runway Incursion Alerting System

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Abstract

Runway incursions pose a significant threat to the continued safety of commercial aviation. In response, the Runway Collision Avoidance Function (RCAF) was developed by the University of Malta and evaluated at Cranfield University as part of the European Programme FLYSAFE. This paper discusses the design of experiment developed in preparation of the said evaluations, addressing the objectives of the test programme and explains how these objectives were met.

1 Introduction

Despite several attempts at mitigating the threat of runway incursion through improvements in airport equipment and procedures, the industry still has no globally effective solution to the problem. Consequently, the elimination of the hazard of runway incursion is still listed as one of the most wanted items by the NTSB [1].

The model of accident causation proposed by James Reason [2] suggests that accidents occur as a result of a sequence of events; therefore measures should be taken to mitigate the risks at all stages. In response to the need to mitigate the risk of runway collision, various approaches have been considered to date. Amongst these are methods that alert the air traffic control officer (ATCO) and others that alert the flight crew directly. The authors are of the opinion that runway conflicts are best mitigated with direct alerting on the flight deck. The rationale for this essentially lies in the fact that it is the pilot who needs to take corrective or evasive action to avoid a conflict and alerting the ATCO would introduce an unnecessary delay to allow the relay of the alert to the pilot. Therefore, the Runway Collision Avoidance Function (RCAF) was designed by the University of Malta under the European Programme FLYSAFE as an airborne alerting system to directly alert the crew of a conflict.

Different strategies of alerting exist. Of major relevance to runway conflict alerting is the issue of whether the alert should be 'informative' or 'directive'. Informative alerts provide only information pertaining to the situation, whilst directive alerts contain information pertaining to the action that is required. Directive alerts have significant advantages over informative alerts in situations that need immediate reaction such as those of runway conflicts. This is because directive alerts reduce the reaction time by eliminating the mental processes where the pilot has to identify the alert, become situationally aware and then decide on the most appropriate course of action. Furthermore, all these steps introduce opportunity for human error and these are eliminated through the directive alerting approach. As a result, the RCAF was designed to generate directive alerts.

However, it is known that crews may prefer to take decisions themselves in certain situations. This includes runway conflict events, where it may be argued that it is pilots who should decide on the best course of action. A separate school of thought that was adopted in the development of the RCAF is that it is not possible for pilots to reliably determine the best course of action in demanding circumstances.

In essence, the RCAF is a safety-net function that provides an additional barrier to mitigate the risk of runway collisions. It provides surveillance of traffic movements within and in the vicinity of the runway and determines whether a conflict exits, generating timely alerts in the event of the risk of a collision. Directive alerts are provided on the flight deck using both the aural and visual channels.

The RCAF can be used in conjunction with other systems providing information pertaining to a runway conflict, such as a moving map showing the ownship position with respect to airport geographical layout and other traffic. This display would typically be presented on the cockpit's Navigational Display (ND). Such a system can provide visual information pertaining to the conflict that is independent of the RCAF and its alerting strategy.

Take-off and landing are two manoeuvres in which pilot workload is high and there is little time for reaction if an anomalous event occurs. Consequently, the effectiveness of an alerting system on the flight deck depends not only on the reliability of the alerts (that is, the reliability of the electronic system) but also on the design of the Human Machine Interface (HMI). These design considerations include alerting philosophy, timeliness of the alert, quantity and method of information transfer and the visual and aural component balance, amongst others.

To this effect, the alerting strategy adopted for the RCAF was tested through a series of pilot evaluations carried out at Cranfield University. This paper discusses the experiment design process in detail and is organised as follows: Section 2 explains the scope of the evaluation; Section 3 discusses the evaluation technique that was adopted and highlights some of the issues that were taken into account; Section 4 describes the simulator setup and Section 5 discusses the scenarios that were designed to test the RCAF; Section 6 describes the contents of the actual evaluation in chronological order and Section 7 presents the main conclusions.

2 Scope of Evaluation

The first step in the experiment design process was to clearly define the scope of the evaluation. Broadly, the evaluation was used to overall qualify the RCAF to a Technology Readiness Level (TRL) of 4.

In any system design, the user interface implications must also be considered and, in particular, it has been identified that new technologies and functional capability should only be introduced if they result in an operational advantage with no adverse effects [3]. In the phases of flight where the RCAF is applicable – primarily in take-off and landing – workload on the flight deck is already high. Therefore, it is vital that any new system does not detract the flight crew's attention from existing systems and responsibilities.

During take-off and landing, pilots are essentially required to scan several instruments and to maintain visual contact with the runway whilst controlling the aircraft. They also have to coordinate with air traffic control, keep a mental picture of the traffic situation around them (aided by monitoring voice radio communications) and monitor other systems to ensure the aircraft is capable of carrying out the manoeuvre. This essentially requires the crew to perform multiple tasks simultaneously. Such tasks clearly utilise the pilot's visual and mental resources. Multiple Resource Theory (MRT) provides an understanding of human performance limitations when attending to multiple tasks performed simultaneously and helps to design a system accordingly [4]. It identifies that an individual has a limited capacity for completing tasks, which can either be used to attend to one task or shared between tasks that do not compete with each other for processing resources at the different stages. Visual and spatial information, such as the position of the aircraft on the approach, occupies working memory's visual resources in the form of a spatial code. Consequently, a visual warning at this stage may be in direct conflict with the existing tasks, as these information processing resources are already occupied. Therefore, one or all the visual tasks involved may suffer from degradation in performance when the human brain is further loaded with visual tasks. However, introducing information through the auditory channel, such as, for example, using a verbal auditory warning, would not be in conflict with the information processing taking place. This is because the pilot will be able to maintain visual contact with the runway whilst simultaneously listening to the verbal alert. For this reason, the use of an auditory warning in a situation of high visual demand is normally preferable.

Consequently, a primary aim of the evaluation was to assess the effectiveness and acceptability of the aural directive alert on the flight deck and to compare it with visual and non-directive (or informative) modes of alerting.

A second important aim of the evaluation was to assess how well the RCAF leads the crew to the correct (directed) response and to understand why crews reacted in the manner they did in the scenarios they were given. Typically an alert informs the operator to a problem and the operator is required to respond in an appropriate way. The ultimate aim of the RCAF is to safely resolve a runway conflict and, with the pilot in the loop, it is important to validate the alerting strategy and pilot response together as a single step in the conflict resolution process.

A third important aim of the evaluation was to assess the response time of the pilot-in-the-loop system. In order to achieve timely response, the alert must be detected and the meaning must be clear. Detectability is a common problem, especially for speech-based auditory alerts, as it has been identified that the auditory channel is more prone to overload than the visual channel. Previous research in the area has highlighted that the use of an appropriately designed alerting tone is useful to enable the pilot to detect the alert in a noisy environment and when under high workload [5]. An alerting tone helps avoid forward masking as a result of the finite time required for attentional switching. It is well known that in stressful situations, aural and even visual alerts may be completely missed and an aural tone preceding a speech-based auditory alert mitigates this risk. Other considerations of the aural tone include amplitude assessment to ensure it is not masked by environmental noise whilst not being too loud to cause a startle reaction, and its uniqueness so that the meaning of the tone can be learnt and the response immediate.

Another concept considered in the RCAF alerting strategy is that of redundancy gains, which aims to reduce response time by presenting the flight crew with multiple presentations of the same information. This technique has been demonstrated to be successful in reducing response time [6]. In accordance with this theory, a time critical alert may wish to combine auditory and visual channels to increase the likelihood of the correct identification of the problem and help reduce response time.

Accordingly, it was an aim of the experiment to assess impact of a preceding auditory tone and the use of visual alerts in conjunction with speech-based alerts on the response of the crew.

Considering all the design issues, therefore, the pilot evaluation of the RCAF focussed on determining:

1. The validity, effectiveness and acceptance of the directive alerting philosophy on the flight deck from a human factors perspective.
2. Pilot reaction to the functional behaviour of the system in different operating conditions.
3. The impact of preceding auditory tones and the use of visual alerts in conjunction with speech-based alerts.
4. Strengths and weaknesses of the alerting technique and alerting system.

Once the scope was fully defined, the evaluation procedure was designed. This procedure was organised in three main sessions, namely the pre-evaluation briefing and simulator familiarisation session, the simulator session and the post-evaluation de-brief (Fig. 1). During the actual evaluations, these sessions were organised in two consecutive half-days, with the first half-day being dedicated to the pre-evaluation briefing and simulator familiarisation session. The evaluation procedure is addressed in Section 6.

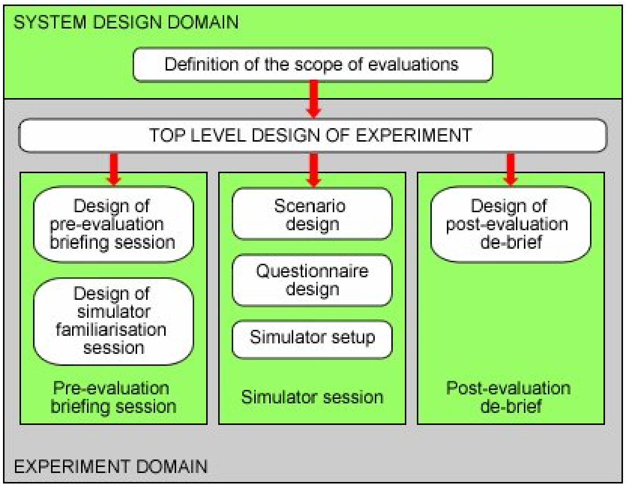

Fig. 1 The evaluation process

3 Evaluation Technique

3.1 Data Collection

The evaluation of the RCAF used both qualitative and quantitative data. Qualitative data were used to establish the participants' acceptance of the alerts presented and to establish the clarity of the alerts. Quantitative data were also obtained to compare the efficiency of the proposed evasive manoeuvre when executed by the participants.

3.2 Pilot Study

A pilot study using three participants was conducted to ensure the operational procedures involved in the use of the RCAF were clear and applicable. The participants were taken from the same population as that used in the main study to ensure validity. As a result of the pilot study, several amendments were made to ensure the objectives of the evaluation were met. These included altering the questions asked to participants, reducing the length of time each participant was needed in the simulator and refining some of the scenarios to ensure that they were as effective as intended and that a broad range of situations were covered.

3.3 Sample Characteristics

The sample was chosen to comprise of line pilots flying single-aisle large transport aircraft who held full, fixed-wing Air Transport Pilot's Licences with a multi-engine rating. Pilots with a range of experience, ranging from junior first officers to senior captains and training captains were targeted. These pilots were current on either the Boeing 737 or Airbus A320. Such a wide sample range not only provided a representative sample of the whole population, but also supported assessment of considerations such as the impact of age group, airframer HMI strategy, experience and training background on the alerting strategy.

3.4 Ethical Issues

Participants were given full information regarding the aims of the evaluation and how the data would be obtained and analysed. They were advised that all information obtained would be treated with the strictest confidence and that no personal details would appear in the final report. Participants were asked to sign an informed consent form and given the right to withdraw from the research at any time until the data were added to the analysis data pool.

3.5 Independent Variables

In order to assess the impact of the alerting philosophy of the RCAF, the alerting unit within the function was modified to support three HMI output modes, namely:

Mode 1: Standard RCAF alerting (directive alerts with introductory tone). No traffic information available on the ND.

Mode 2: Standard RCAF alerting as in Mode 1 but with the introductory tone removed. A moving map display with traffic overlay was made available on the ND.

Mode 3: Informative alerting. The standard RCAF alerts in this mode were replaced by informative speech-based auditory alerts. No introductory tone. The visual display was made available on the ND as for Mode 2.

Participants were asked to complete the evaluation scenarios using the RCAF with its output set to one of these three modes.

4 Evaluation Environment

4.1 Flight Deck Environment

The evaluations made use of Cranfield University's Large Aircraft Flight Simulator. The flight deck environment of this simulator is based on a Boeing 747-200 training device. The cockpit retains its original configuration, with standard control column, seats, central pedestal, windows, overhead panel structure and panelling. The flight engineer station has been replaced by an instructor station, from where the simulator and simulated environment are controlled.

The cockpit instruments of the original simulator have been replaced with LCD displays arranged in a five display configuration: the Primary Flight Display (PFD) and Navigation Display (ND) for each pilot and a central engines and systems display. The flight instrument and navigational display design is based on the Boeing 747-400 displays and symbology.

The simulator is also equipped with Airbus-style side-sticks and A320-style flight control unit and central pedestal controls for radio systems. This creates a physical environment that, whilst being generic and flexible to support research activities, is adequately representative of a typical large transport aircraft (Fig. 2).

The primary visuals are generated using Multigen-Paradigm Vega software running on an SGI Onyx II machine. This drives a SEOS display system based on 3 channels with collimated optics for critical depth of field cueing and excellent cross cockpit viewing. The optics afford a 180° horizontal and 40° vertical field of view. These qualities are fundamental in the support of the general immersive feel required of simulators used for such evaluation and research into human factors and crew activity on the flight deck.

Fig. 2 The Cranfield simulator

4.2 Simulation Environment

The Cranfield simulator architecture is based on a core of four networked computers (PCs) running the ownship model with an update rate of 50Hz and the instructor station (Fig. 3). These computers communicate with each other and with the primary image generator via Ethernet using the UDP protocol. The ownship model is based on the Boeing 747-200, providing the flight characteristics and handling qualities representative of the aircraft in question. The simulator also simulates several navigational aids including VOR, DME, marker beacons and ILS using a navigational aid database that is representative of the area in which the scenarios are set.

The primary image generator contains the visual database which represents Bristol Filton Airport (EGTG) surrounded by generic landscaping.

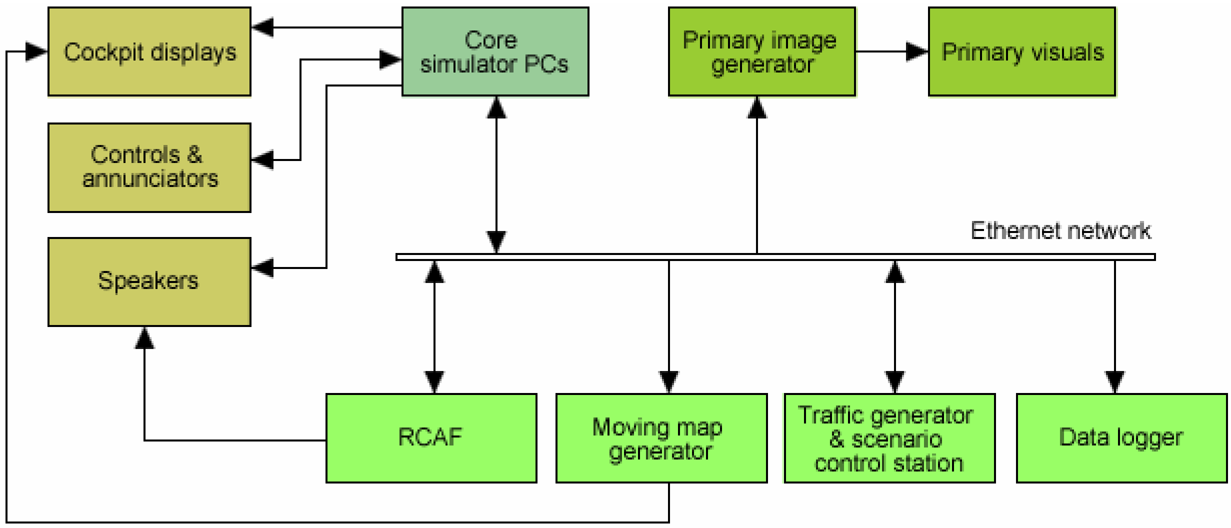

Fig. 3 Simulation environment

For the scope of the evaluations, the simulator was upgraded to provide the following functionalities:

- RCAF hosting. The RCAF needs to receive information about the ownship (such as flight management and air data information) and surrounding traffic in the form of simulated ADS-B messages. The RCAF also needs to send the auditory alerts to the simulator auditory system.
- Traffic generation and scenario control. The traffic generator and scenario control units were customised to simulate traffic movements and to create traffic conflict scenarios on the ground. This is further discussed in Section 5.
- Data logging. The simulator's data logger was customised to store all of the simulator parameters that were required for the quantitative analysis that followed.
- Moving map. A moving map generator was developed to represent a generic moving map displayed on the ND typical of products available on the market and other research programmes. This was designed to provide the pilots with the visual alerts of the conflict scenarios and to be used in conjunction with RCAF alerting to assess impact of the use of such a display as an additional, independent information channel. The graphical qualities of the moving map developed were not being assessed in the evaluation and consequently were not of major concern in the implementation of the moving map.

5 Scenario Design

5.1 Conflict Scenarios

A total of 14 scenarios were designed to test the RCAF (Table 1). These were chosen to simulate runway incursions during four specific runway manoeuvres: take-off, landing, line-up and backtrack.

Two aircraft were involved in each scenario: the 'ownship' and the 'target'. The ownship was the aircraft represented by the actual simulator in the evaluations and the target was the aircraft that was coming in conflict with the ownship on the runway, typically causing a runway incursion by violating ATC instructions. The ownship was flown manually by the volunteer pilots in order to increase workload to aid their distraction from the knowledge that they were in a simulated environment. Cross-winds and turbulence were also added for the same reason. The target was automatically generated and controlled by the simulated environment. Both aircraft broadcast

ADS-B messages but only the ownship was equipped with the RCAF. Other aircraft movements were also simulated but only one target was selected during the scenarios. This is because it is highly improbable that more than one aircraft would cause a runway incursion to the ownship at the same time.

The RCAF is a safety barrier aimed at providing protection where current procedures and systems fail. Consequently, it is expected that it will be most effective in low visibility conditions, where the crew of the ownship would be otherwise unaware of the traffic conflict situation that will be developing. For this reason, the majority of the scenarios were designed to be conducted in low visibility. This ensured that the crew did not have visual contact with the target aircraft before the incursion occurred and the alert was generated. In good visibility, runway incursions are not only less frequent, but are also more easily mitigated through visual detection by one of the parties involved (including the ATCO).

Table 1. Test scenarios

#	Ownship state	Target state	Alert generated	Expected pilot reaction	Visibility (m)
1	Backtrack	Taxiing in front of ownship at a slow closure rate	When separation is less than threshold and decreasing	Stop	100
2	Take-off	Taxiing in front of ownship at a slow closure rate	On setting thrust to take-off setting	Abort	100
3	Lineup	Approaching from behind	As soon as target enters protected zone[1]	Vacate runway	2000
4	Take-off	Lined up in front of ownship	On setting thrust to take-off setting	Abort	200
5	Take-off	Enters runway in front of ownship when ownship speed exceeds 45kts	As soon as target enters protected zone[1]	Abort	600
6	Take-off	Enters runway in front of ownship when ownship speed exceeds 70kts	As soon as target enters protected zone[1]	Abort	400
7	Take-off	Enters runway in front of ownship when ownship speed exceeds 108kts	As soon as target enters protected zone[1]	Abort	400
8	Take-off	Crosses hold-short bars to runway ahead of ownship at V_1	No alert generated[2]	Continue	10,000
9	Landing	Lined up	When ownship is approximately 1nm from touchdown	Go-around	900
10	Landing	Lands ahead of ownship but fails to vacate runway	When ownship approaches runway threshold	Go-around	10,000
11	Landing	Enters runway	As soon as target enters protected zone[1]	Go-around	900
12	Landing	Aborts take-off and stops far down the runway	When ownship approaches runway threshold	Go-around	10,000
13	Landing	Exits from the far end of the runway	No alert generated[2]	Continue	10,000
14	Landed	Enters runway in front of ownship	As soon as target enters protected zone[1]	Stop	500

[1] The ‘protected zone’ is a zone defined by the RCAF that includes the runway and its environs. The protected zone is exclusively reserved for the ownship during a take-off or landing.

[2] The RCAF generates no alert when it identifies that it is preferable to continue the manoeuvre. This is in line with the dark and silent cockpit concept.

Accordingly, although radio communications with air traffic control were simulated to include other traffic, care was taken to ensure that pilots were unaware of conflict aircraft during the actual experiment. This required the incursion to be caused by a simulated target aircraft piloting error.

The scenarios were chosen to simulate runway incursions at specific moments in the take-off and landing manoeuvres. Accordingly, scenarios 2, 4, 5, 6, 7 and 8 have been designed with the incursion occurring at specific speeds ranging from start of take-off to the decision speed V_1 (140kts). This was done because the implications of aborting the manoeuvre vary significantly along the take-off manoeuvre as V_1 is approached and this often results in pre-conditioned mind-sets that influence the crew's decision in such circumstances. Consequently, it was desirable to consider the effect of take-off progress on the pilot's reactions to the alerts.

Scenario 8 visibility is set so that the crew can visually detect the target aircraft crossing the hold-short bars and approaching the runway. The desired response is for the crew to continue the run, for in this scenario, the ownship will clear the conflict by continuing the take-off and if the run is aborted, the risk of collision increases. In such circumstances the RCAF does not generate an alert, in line with the dark and silent cockpit concept. It was desirable to assess pilot confidence in the RCAF by allowing a separate information channel (their vision and independent detection of the target) to lead them to an independent and possibly different conclusion. It is also evident that this scenario would have no value in low visibility conditions as the crew would have had no means of otherwise detecting the conflict (without a moving map).

Scenarios 9 – 14 address conflicts during landing. Here again, three scenarios (10, 12 and 13) were designed with good visibility to allow the crew to form an independent opinion as they would in such circumstances. The RCAF does not discriminate between good and low visibility conditions and therefore will provide alerts in either condition. Scenarios 10, 12 and 13 were designed to investigate how pilots would handle situations where an aircraft is still on the runway as they are approaching to land. In particular, the extent to which the crew would continue the approach and whether they would either abort before the RCAF alert would be generated or knowingly continue even after an alert, is of significant interest.

Certain scenarios were chosen to test the RCAF at the edges of its performance envelope. These include high speed take-off scenarios (e.g. Scenario 7) and landing scenarios where the ownship is given a land-after instruction (Scenario 10). In these scenarios, the decision taken by the RCAF is not straightforward. If an incursion occurs when the ownship is at a high speed during take-off, for example, the RCAF considers the implications of the continued run and aborted run cases to determine a preferred manoeuvre and generate an appropriate alert. In landing, it is common for an aircraft to have minimal separation from the aircraft in front of it and the RCAF is required not to issue nuisance alerts. Such conditions clearly test the capabilities of the RCAF concept and system and are of great interest to all stake-holders. They also stimulate debate with participating pilots and support investigation into HMI, procedural and crew issues that may be involved in such critical situations.

Scenarios 1 and 3 were designed to cater for operation at just before and after the take-off and landing manoeuvre. Although not the main focus of the RCAF and its evaluation programme, these scenarios were included to stimulate discussion on and support the investigation of the value of the RCAF in these situations.

5.2 Conflict Simulation Software

In order to create the traffic conflict scenarios described in Table 1, a rapid prototyping tool was developed [7]. This tool consists of a software package comprising three main blocks, namely the:

(1) Target Motion Generator: This was used to simulate typical targets in manoeuvres such as taxi, take-off and landing.
(2) Scenario Definition and Control Unit: This was used to define a runway traffic conflict scenario. The user can specify from a number of variables (such as ownship position and speed) the condition or moment at which the incursion will occur.
(3) Dynamic Target Control Unit: This feature enables the speed of the target to be dynamically controlled in response to the independent movement of the ownship. In this way, the exact moment the runway incursion occurs is controlled to meet the specifications defined by the Scenario Definition and Control Unit, so that reaction time available to the pilots in the event of a conflict is controlled in a repeatable manner. As in each scenario run the pilots had complete freedom in aircraft handling (eg. whether they conducted a rolling take-off or not, etc.) this unit allowed each run to create the same conflict conditions through dynamic control of the target.

This tool was designed to be flexible and easy to use and allowed the user to create realistic and repeatable conflict scenarios.

6 Evaluation Procedure

6.1 Briefing

Crews were not provided with any briefing material prior to their arrival for the evaluation trials. This strategy was selected to control the level of understanding of the system, as otherwise it would have been subject to the interest of the individual on the subject and his initiative. The briefing session was carefully designed to provide an understanding of the operation of the alerting system that was typical of what is expected of competent line pilots, taking into account the novel aspects of the system.

Consequently, the briefing session carried out upon the pilots' arrival at Cranfield University included the following:

- Welcome address and Company Presentations – This gave participants an overview of housekeeping and health and safety issues to consider whilst on site and an introduction of the universities and the departments involved in the RCAF development and evaluation.

- FLYSAFE Overview – This presentation provided a context to the evaluations, outlining the structure, activities and goals of FLYSAFE.

- RCAF Overview – This presentation focused on describing the problem of runway incursion, outlining the functionality to be evaluated and the rationale underlying its operating logic and parameters.

- Scope of the Evaluation – Participants were given the aims of the evaluation as well as the intended methods of data collection and analysis.

- The Cranfield Simulator – Participants were given an overview of the functioning of the simulator prior to the opportunity to familiarise themselves with its operation. The pilots were also briefed on the simulated operation (departure and arrival at Bristol Airport) and provided with the relevant Bristol airfield charts, as they would in normal operational briefings.

6.2 Familiarisation Session

All participants had the opportunity to familiarise themselves with the Cranfield simulator after the briefing session. The aim of this session was to introduce the pilots to the simulated environment on the first day prior to the evaluations the next morning.

During this session the pilots operated in pairs as a crew and flew a number of circuits in various wind and visibility conditions.

Particular attention was given to familiarising them with the following:

- Cockpit layout – Since the simulator is mainly used for research and has a combination of components which are characteristic of Airbus and Boeing aircraft, type-rated crews required familiarisation with the cockpit environment and HMI.
- Aircraft handling – Crews were given the opportunity to become familiar with the simulator's handling qualities, particularly during landing. The control column was used to 'fly' the simulator throughout the evaluations and this gave Airbus type-rated crews the opportunity to familiarise themselves with this method of control.
- Reference speeds – Crews were given the opportunity to be briefed on key reference speeds (such as V_1, V_R and approach speeds) and the flap-speed schedule.
- ILS approaches in low visibility.
- Moving map display – Crews would not have seen the moving map prior to the familiarisation session.
- Standard Operating Procedures (SOPs) – The pilots were told to follow standard procedures and radio communication with a pseudo-ATCO over the intercom.

During this session the RCAF was disabled and no conflict scenarios were simulated. However, the alerts they would be expected to hear in the event of a conflict were triggered to allow them to familiarise themselves with the specific messages, voice and tones. The familiarisation session lasted for approximately one hour.

6.3 Experiment

Participants were required to complete all scenarios, avoiding the other aircraft and following company SOPs. Participants operated in crews of two to ensure ecological validity, with the more senior member acting as the pilot in command (PIC). Where two first officers were working together, the pilot flying (PF) acted as the PIC. The 14 scenarios were presented to the crews in random order generated by the simulator. For half of the scenarios, the PIC acted at the PF and the other pilot acted as the pilot not flying (PNF). For the remaining scenarios, the PIC would act as the PNF and the other pilot would act as the PF.

The scenarios were divided into three main categories: backtrack/lineup, take-off and landing manoeuvres. To ensure that the participants were fully immersed in the simulation, all take-off, backtrack and lineup scenarios began at the ramp whereas the landing scenarios began at eight nautical miles from the runway threshold. This also provided the pilots with sufficient time to achieve a stabilised approach. Participants were required to give all ATC calls as they would be expected to under normal operating conditions and other aircraft chatter was generated though the pseudo-ATCO to give them an opportunity to maintain situational awareness as they would do in their working environment.

All scenarios were pre-recorded in the simulator so each of the crews was presented with the same scenarios. However, all ATC and other radio communications were created in real-time to support live interaction with the ownship's crew.

6.4 Post-Scenario Questionnaire

After each scenario, pilots were asked a number of questions from a post-scenario questionnaire specifically designed to capture the reactions of the crew during and after the scenario was conducted. This allowed specific details pertaining to each scenario condition to be captured for later qualitative analysis.

The interviewer administered the questions and noted the answers, as the pilots remained seated in the cockpit seats for this interview. The questions were of an open, semi-structured format to allow participants to give their views on the proceedings of the scenario just completed. The questionnaire also used closed and scaled questions to allow for quantification and comparison.

6.5 De-Briefing

At the end of the simulator session, participants were given a thorough de-brief. This gave participants an opportunity to reflect on the session, summarise their main thoughts and ask any final questions. The de-briefing session included group discussions as well as a self-completed questionnaire.

6.6 Data Collection

Following each evaluation session, the data pertaining to each scenario was retrieved from the data logging device for quantitative analysis.

6.7 Measures

The quantitative measures taken from the simulator were the following:

1. The closest point of approach (CPOA)
2. Whether a collision occurred and, if so,
    a. Ownship speed at the time of the collision
    b. Target speed at the time of the collision
3. Time from the start of the alert to action effected
    a. For aborted take-off, time to zero thrust setting
    b. For go-around, time to TOGA thrust setting

The qualitative data analysis used data collected in the post-scenario questionnaire and the de-briefing session. In order to obtain participants' views on the alerting strategy, the directive and non-directive modes of alerting were discussed. The participants were given the opportunity to share their experience after the scenarios and comment on and compare the perceived effectiveness of these alerting strategies in the scenarios experienced.

All the qualitative data was gathered by the same researcher to ensure consistency and reliability in the data gathered. The data were recorded and recurrent themes from the discussions were extracted and highlighted.

7 Conclusion

The experiment described in this paper was designed to meet the aims of the RCAF evaluation programme using line pilots and Cranfield University's Large Aircraft Flight Simulator. Accordingly, the experiment was structured around 14 carefully designed scenarios. Pre-evaluation briefing and familiarisation sessions supported the smooth and successful execution of these scenarios, with the post-scenario questionnaire, de-briefing session and recorded data retrieved from the simulator providing the qualitative and quantitative data required for eventual analysis.

The broad range of conflict combinations covered by the 14 test scenarios was designed to enable the assessment of RCAF operation in conflicts typically encountered in real operation. In this way, the experiment further enabled the evaluation programme to provide an indication of the expected impact of the RCAF on runway safety.

The experiment was used in the evaluations that were carried out at Cranfield University and the results from the evaluations provided sufficient material to successfully assess the RCAF performance and suitability in the cockpit.

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