RUNWAY CONFLICT ALERTING DURING TAKE-OFF AND LANDING: ADVISORY OR DIRECTIVE?

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Abstract

Runway incursions pose a significant threat to continued safety in commercial aviation. In recent years, stakeholders have initiated a number of programmes dealing with the issue of runway incursions, with the majority adopting traditional advisory alerting techniques. In contrast, this work proposes the use of directive cockpit alerting, which provides both an alert of the conflict as well as guidance on which manoeuvre to conduct to clear the conflict. This paper reports the findings of simulator trails designed for the assessment of the effectiveness and acceptability of the directive alerting strategy within the context of runway incursions. Statistical analysis performed on the quantitative measures taken from the evaluations have shown that the directive mode of alerting leads to a higher probability of the crew performing the correct action when faced with an alert. This, together with overall participant acceptance of the directive alerting concept, is a strong indicator that the technique has the potential of providing a complete solution to the problem of runway incursions.

1. Runway Conflict Alerting in the Cockpit

Direct cockpit alerting of a conflict to the aircraft in take-off or landing is an improvement over the current operational standard. However, the method of situational awareness, based on cockpit displays and aural alerts of the presence of the conflict as described in literature [1-16], is not ideal. The take-off and landing phases of flight impose, in their own right, high workload and operational pressures to the crew. Bad weather conditions, pressures to adhere to tight operational schedules and busy airfields also contribute to heightened workload. Consequently, an alert would be triggered when the crew are busy performing other critical tasks. For instance during the take-off run, the crew are focused on monitoring their speed and engine parameters. Therefore, they cannot be expected to also monitor the traffic display to maintain their situational awareness of other aircraft close to the runway as backup, in the rare event that a runway conflict occurs. Such action could be more hazardous, by distracting the crew from their primary task. This problem is in fact more pronounced in systems exercising two levels of alerting (caution followed by warning). An early cautionary alert in landing, for instance due to a procedural conflict, could distract the crew from their landing procedure. Whilst the procedural conflict constitutes a threat, it does not necessarily lead to a physical conflict, since, although an obstructing aircraft on the runway violates procedure, this aircraft could be decelerating after landing with the intention of vacating the runway shortly. Subsequently, announcing an alert in the cockpit as a result of this type of conflict may potentially make the situation more hazardous, by unnecessarily alarming the crew in a delicate part of their landing sequence.

When a runway conflict does occur, situations that may be hazardous to the safe continuation of the flight may develop very quickly and with little warning. This has shown to be the case in numerous runway conflict incidents and accidents, where a few seconds make the difference in the outcome of the scenario. In the typical conflict scenario of an aircraft encroaching onto an active runway from a taxiway, it is only after the conflicting aircraft crosses the hold-short bar that a conflict could be flagged, leaving very little time from when the alert is generated to the collision. To aggravate matters, human reaction times and decision-making capabilities are severely compromised when workloads are high and when threatening situations are announced without prior warning. Additionally, crew are usually inexperienced in handling these situations, since most pilots are only faced with an event of a runway conflict during simulator trials and follow very little recurrent training on the subject. If a runway conflict is announced, the crew are faced with an uncommon situation and with very little time for corrective action to be taken; factors making for a deadly combination.

Therefore there is the need for the design of a new alerting concept to address these issues. This is, however, challenging and requires careful consideration of several factors. Primarily, human interaction between the alerting system and the crew must be addressed, ensuring that the crew respond to the alert in the intended manner. Additionally, the operational environment has a large impact on the design of the alerting concept, with the high workload and time pressured events of take-off and landing adversely affecting the response of the crew to the alert. The physical environment of the cockpit also plays a significant role in the effectiveness of the alerting system, with some alerting technologies being more adequate than others in successfully interacting with the crew. Consequently this multidisciplinary problem requires an analysis of key aspects.

1.1. The Mental Process in Runway Conflict Mitigation

Following an alert of a conflict, crew are required to mentally follow the information processing procedure [17] and effectively take the following steps in order to successfully resolve the conflict:

- Perceive the threat,
- understand the dynamics of the situation,
- determine a manoeuvre that will successfully resolve the conflict,
- decide to execute the manoeuvre,
- execute the manoeuvre.

Performing these steps can take several seconds and need to be performed in an environment where time is of the essence in determining whether the conflict can be successfully resolved or not. Additionally, once the threat is understood by the crew, it may be very difficult for them to reliably and objectively determine what action to perform to mitigate the conflict. The mode of information transfer is also critical to this step, as it has the potential of introducing additional delays. For instance, for a conflict occurring during take-off, it may not be possible for the crew to identify very quickly from a graphical display (particularly in critical circumstances) whether it is better to abort the run and to stop before the conflict, or to continue the take-off and overfly it safely. In fact, crews only have their intuition and experience to go by in measuring the distance required to safely stop their aircraft or complete the run and become airborne. Considering the fact that crew typically operate different aircraft and in a large variety of operating conditions, it is impossible to objectively determine it mentally with confidence. Additionally, in the operational environment of take-off and landing, deciding to perform a manoeuvre can be demanding and is subject to hesitation or even erroneous conclusions. Studies have shown that whereas in clear-cut conditions a decision can be taken quickly, in marginal conditions humans tend to dither. Hesitation, in this circumstance, results in the changing of the situation that may no longer render the original decision on what manoeuvre to perform valid.

Therefore, the method of providing an informative (advisory)[1] alert of a conflict that requires the pilot to carry out the five previously mentioned steps could result in the conflict not being adequately resolved. The use of aural

[1] Although the alert is advisory in nature, the term *informative* is used herein to distinguish it from *advisory*, the latter often used to signify an alerting level.

informative alerts alone would take too long to convey the complex spatial and temporal information on the existence and position of the conflicting aircraft. Additionally, it is impractical for an aural informative alert to provide an indication of possible avoidance manoeuvres. On the other hand, the use of graphical information alone, through the use of, for instance, a moving-map, requires the crew to continuously monitor the display for the event that a rare runway conflict occurs, distracting them from other more routine tasks. If, however, such monitoring is not performed, conflicts may be missed (i.e. step 1 in the chain is missed). This could be mitigated through the use of an aural and/or visual attention grabber, to attract the crew's attention of the conflict. Following this, the crew could then make use of the display to continue the information processing procedure. However, this technique has the potential of introducing a delay associated with looking at the display and understanding what the problem really is, particularly when considering the complexity of a moving-map display with traffic overlay. In the context where crew cannot constantly look at a graphical display, the attention grabber would be the first indication of the conflict and the crew would therefore be unaware of its presence and threat, leading to a slow reaction. On the other hand, if the crew have a preconceived perception of the potential threat, through for instance having seen an aircraft approaching the runway visually, then, when the alert is triggered the pilot may inadvertently latch onto the wrong target on the display, where in actual fact the alert of incursion would be caused by another aircraft. These shortcomings may therefore suggest that the use of a moving-map for this application may be inappropriate.

In order to support a fast, reliable and repeatable crew response to a runway conflict, it would be advantageous to automate the first three steps in the chain. This will result in the crew mentally following a shorter route in the information processing procedure as shown in Figure 1, thereby eliminating the time required to assess the situation and take a decision. This approach also reduces the variability in the crew's response as a result of personal perception and rushed decisions, which potentially can be a significant improvement when considering the human (pilot) in the response chain.

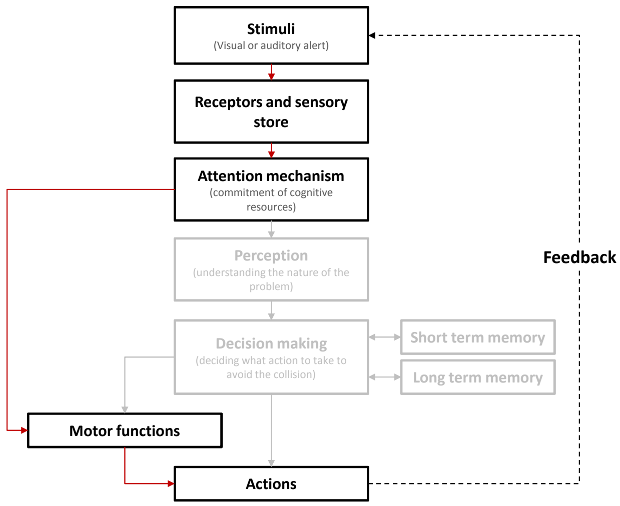

Figure 1 - Reducing reaction time delay through the bypass of processes in the human information processing chain. Adapted from [17].

1.2. Top Level Design Requirements

Following on these arguments, four design requirements were identified for a new alerting concept, namely:

1. The new alerting system *shall* integrate and harmonise with existing systems and operating procedures (SOPs) such that it does not detract the flight crew's attention from existing systems.
2. The alerts *shall* provide sufficient and non-resource-conflicting information such that the crew response occurs in a timely manner.
3. The alerts *shall* be clear such that they generate an immediate and correct action on behalf of the crew.
4. The new alerting system *should* make use of multiple channels to benefit from redundancy gains.

2. Proposed Alerting Technique

2.1. Conflict Alerting during Take-off and Landing

With the requirement for the new alerting system to provide the crew with directive aural alerts to instruct them on what action to take, a new alerting scheme has been developed to provide short, clear messages in the cockpit. Since the alerting system is designed to operate as a safety-net function, the alerts are generated only when traditional separation assurance methods fail. By definition, alerts generated by such a system are tactical in nature and require immediate crew attention and action. As a result, the context warrants that alerts are generated only at level 3 (warning), as level 2 (caution) and level 1 (advisory) alerts would constitute nuisance alerts during take-off and landing that can unnecessarily distract the crew from their primary tasks and could lead to unnecessary action.

Runway conflicts occurring during take-off can be mitigated in one of two ways; either by aborting the run and bringing the aircraft to a stop on the runway, or otherwise, continuing with the take-off and climbing over the conflicting aircraft. During landing, conflicts can be mitigated by either missing the approach and conducting a go-around, or otherwise, in the event that the conflict will resolve itself as the ownship approaches the runway, the aircraft can be allowed to continue with the landing. Determining which of the manoeuvres can be conducted safely requires an assessment of the aircraft's take-off and landing performance.

Therefore, in both take-off and landing, the pilot needs to be told to either abort the manoeuvre (rejected take-off (RTO) or go-around respectively), or otherwise continue with the manoeuvre. In the latter case, although a runway conflict has occurred, no action is required from the crew. Consequently, to remain in line with the 'Dark-and-Silent' cockpit philosophy, in which an alert should only represent a failure condition, the alerting system should remain quiet. For the aborted manoeuvre case, the wording 'STOP'[1] and 'GO-AROUND' are already used as formal phraseology in the cockpit to indicate an aborted take-off and missed approach respectively. Therefore, it is natural for these words to be adopted for the new alerting scheme. However, these words alone give no indication to the crew on the reason for the stop or go-around to be initiated and may be detrimental to the pilot's mental process of obeying the alert. Therefore, these have been appended with the word 'TRAFFIC', to indicate that the alert is being issued due to a traffic conflict, so that the overall adopted phraseology becomes 'STOP TRAFFIC' and 'GO-AROUND TRAFFIC'.

Since the cockpit environment could be noisy, the sounding of an alerting tone prior to the verbal alert has been be introduced to act as an attention grabber, reducing the problem of detectability. The alerting tone being proposed, described textually as 'WHOOP WHOOP', is similar in concept to that currently used for EGPWS alerts and is approximately 1s long. The full aural alert, is repeated periodically until mitigating action has been taken. The alerts are repeated with a 2.5s interval, allowing sufficient time for crew reaction whilst avoiding the problem of alert overload due to rapid repetition.

In the case of a rejected take-off, crew may still be unaware of how far the conflicting aircraft is, particularly in low visibility. Therefore, the alerting system has been designed to take up the resolution assessor role by providing the crew with distance-to-conflict call-outs in metres[2]. These are useful as they provide an indication of deceleration and closure rate and could be used by the crew in the event of an imminent collision, for taking the decision on whether or not to take unconventional action, such as a lateral excursion, to avoid the collision.

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[1] The phraseology 'ABORT' is also used by various operators. The exact wording of the alert itself is not critical to the scope of the study and could be adapted to suite manufacturer and operator convention.

[2] Distance call-outs may alternatively be made in feet, depending on airframer convention.

Once the conflict has been cleared, either through action on behalf of the crew in following the alert or through action on behalf of the other aircraft, an advisory alert to indicate that the critical situation has ended is given. In this case, a 'CLEAR OF CONFLICT' alert is issued, in line with the phraseology already used by TCAS.

The aural alert is also supported by a textual alert on the primary flight display. This takes advantage of redundancy gains by providing the alert through both the aural and visual channels.

2.2. Conflict Alerting during Taxi, Backtrack and Line-up

When the ownship is taxiing, backtracking or lining up for take-off on the runway, it could cause a runway conflict by incorrectly being on the runway whilst another aircraft is attempting to take-off or land. Since the ownship would probably be manoeuvring slowly or would be stationary, there are several situations where mitigating action on behalf of the third party is required to clear the conflict. In these cases, therefore, the crew cannot be directed into taking any evasive manoeuvre. Although these situations are not the direct focus of this work, they are being considered herein to be able to provide a complete alerting solution whilst the ownship is manoeuvring on the runway.

Since directive alerting is not possible in these cases, the use of informative alerts in conjunction with a moving-map display is being proposed. These are useful in enhancing the crew's situational awareness by making them aware about the situation and also prompting them to communicate the situation to ATC and take mitigating action when possible.

In the event of a traffic conflict during line-up (i.e. when the aircraft is stationary), a 'CAUTION TRAFFIC' alert is being proposed. In this case a cautionary alert, rather than a warning, is warranted since the ownship is stationary and is typically not in a position to take any evasive action. This phraseology alone, however, provides little information on the location of the other aircraft. Consequently, the terms 'BEHIND' and 'AHEAD' appended to the alert are being proposed, as these give an indication on the whereabouts of the other aircraft and provide added situational awareness to the crew. On the occurrence of such an event, the procedure will require the pilot in command to refer to the moving-map display, on which an auto pop-up showing the conflict would be displayed. The crew would then decide on any appropriate action that is to be taken.

In the event of a traffic conflict during taxiing or backtrack, a 'WARNING TRAFFIC AHEAD/BEHIND' alert is being proposed, since mitigating action by the ownship could indeed be possible in certain circumstances, by vacating the runway through the closest taxiway.

3. Evaluation of the Alerting Philosophy

In order as to evaluate the efficacy of the directive alerting philosophy, a series of simulator evaluations were carried out to qualify the alerting system to a Technology Readiness Level (TRL) of 4. The objectives of the evaluations were to:

- Assess the effectiveness and acceptability of the aural directive alert on the flight deck.
- Assess how well the system leads the crew to the correct (directed) response and to understand why crews reacted in the manner they did in the scenarios given.
- Assess the value of the preceding auditory tone and the use of a graphical display in conjunction with the aural alerts.
- Compare the directive aural alert philosophy with a typical advisory (or informative) mode of alerting.

3.1. Independent Variables

Since the directive alerting philosophy for runway conflicts is novel and its implications may be controversial in comparison with more traditional HMI strategies, there was an interest in comparing crew reaction to the directive and advisory (traditional) alert techniques. To achieve this, the alerting unit was modified to support three HMI output modes, namely:

Mode 1: Directive alerts with introductory tone. No traffic information available on the navigation display.

Mode 2: Directive alerting as in Mode 1 with introductory tone removed. Traffic information shown on a typical airport moving-map and a textual graphical alert to annunciate the directed manoeuvre.

Mode 3: Advisory alerting. The directive alerts were replaced by informative verbal alert 'RUNWAY INCURSION' without the introductory tone. Traffic information shown on a typical moving-map as in Mode 2.

The aim was to have participants complete the evaluation scenarios using one of the three modes. This alone, however, would not give each individual participant exposure to the various modes and therefore no direct comparison of which alerting technique is preferred could be obtained. Seen in isolation, either mode of alerting could be seen as an improvement over no alerting system. Therefore, midway during the trials, some participants were presented with scenarios in both Mode 2 and Mode 3. This allowed for qualitative comparison of the modes and instigated comments, criticism and recommendations. To compensate for the effect of preconditioning, some participants were presented with Mode 2 followed by Mode 3, whilst others were presented with Mode 3 followed by Mode 2.

3.2. Scenario Design

A total of 15 scenarios were designed to test the alerting system. These were chosen to simulate runway incursions during the take-off (including line-up), landing and taxi or backtrack on the runway, with seven scenarios involving conflicts during take-off, six during landing and two with the ownship in taxi or stationary on the runway.

Two aircraft were involved in each scenario: the ownship and the intruder. The ownship was the aircraft represented by the actual simulator equipped with the alerting system whilst the intruder was the aircraft coming in conflict with the ownship on the runway, typically causing a runway incursion by violating ATC instructions. Other aircraft movements were also simulated but only one intruder was selected during the scenarios. This assumption is valid due to the fact that it is highly improbable for more than one aircraft to be in runway conflict with the ownship at one time.

Due to the synthetic environment of the simulator, where the occurrence of a collision is harmless and the fact that the crew participating in the evaluations are preconditioned to expect a conflict to occur, generating realism is challenging. This is a similar problem to that encountered during line pilot proficiency checks, where pilots expect engine failures and pilot incapacitation during take-off. They are therefore more likely to successfully react to the failure, as the element of surprise is lost. To compensate for this problem, crew workload during take-off or landing was elevated to a higher level than that expected during normal operations. This was achieved by asking the participants to manually fly the aircraft (without the aid of the auto-pilot), as well as by adding moderate crosswinds and turbulence. With crews typically intent on flying the aircraft and landing properly, the increased workload was designed to distract the crew from the awareness of the test set-up and the expectancy of an alert. This strategy was found to be effective, to the extent that in one circumstance the pilot flying was so focussed on flying the aircraft that he missed one of the runway conflict alerts issued during landing, despite the loudness of the alert.

The majority of the scenarios (11 of 15) where set in low visibility. Although also useful in good visibility, it is expected that the alerting system will be most effective in low visibility conditions (and in the dark), where the crew would be otherwise unaware of the traffic conflict situation that would be developing and an alert would come as a surprise. Low visibility

conditions simulate the situation where the crew are unaware about the runway conflict well, therefore ensuring the element of surprise.
The remaining four scenarios were set in good visibility to allow the assessment of the crew's reaction to a directive alert when they have visual means to independently confirm the conflict situation. The scenarios were set in marginal conditions so that feedback on whether crews were inclined to overrule the aural directive alerts as a result of their independently formed understanding of the conflict scenario, or otherwise, could be obtained. Such scenarios can be considered to assess the limits of performance of the directive alerting strategy and were designed to provide valuable information on the crew's perception of and reliance on the alerting strategy.

3.2.1. The Scenarios

Scenarios 1 and 2 were designed to address taxiing and line-up manoeuvres on the runway. Although not the main focus of the evaluations, these scenarios were included to stimulate discussion on and support the investigation of the value of the alerting system in these situations. Scenario 1 was designed to simulate two aircraft backtracking after each other in very low visibility of 100m[1] with the ownship being the second aircraft slowly closing in on the aircraft ahead. The scope of the scenario is that of evaluating the crew's cautiousness to proceed in the situation and to identify whether the use of an alert to indicate a violation of minimum separation would be beneficial or a nuisance. The value of the moving-map display in such circumstances, when made available, was also assessed.

Scenario 2 was designed to simulate the situation where the ownship is lined up for take-off with another aircraft on final approach for landing on the same runway. This scenario was intended to depict the difficult situation where, in an environment where the ownship is the only aircraft equipped with the alerting system, a runway conflict occurring when the ownship is in a low energy state cannot easily be mitigated by ownship action alone. The scenario was intended to generate discussion on what sort of action the crew would feel comfortable in taking in such situations and whether the aural alert and graphical display are appropriate.

Scenarios 3 to 9 were designed to simulate conflicts during take-off, with conflicts occurring at different speeds ranging from the start of take-off to the decision speed V_1. Such a wide range was selected because the implications of aborting the manoeuvre vary significantly as the take-off manoeuvre progresses towards V_1 and this often results in preconditioned 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 3 was set with the conflicting aircraft already present on the runway, 400m ahead of the ownship, when the ownship commences the run, giving a time-to-latest-reaction (TTLR) of approximately 6s. Scenarios 4, 5, 6 and 7 were intended to generate alerts in the low-speed, medium-speed and high-speed regime. In these scenarios, the conflicting aircraft was made to enter the runway at distances of 400m, 800m, 1000m and 2000m from the runway threshold respectively, with a TTLR set at 3s. This corresponds to the conflicts being generated when the ownship is at approximately 40kts, 60kts, 80kts and 120kts respectively. The precise speed per run at which the alert is generated depends on the actual aircraft acceleration profile which is run-dependent (according to specific pilot handling). This, however, does not affect the scenario repeatability, as what needs to be repeatable is the TTLR for a particular speed regime. All the scenarios were set in low visibility so that the conflicting aircraft would not be visible before the alert was issued. In these scenarios, performing a RTO is the only correct manoeuvre and therefore an alert to abort the run is issued. Following the abort, the crew are presented with the distance-to-conflict

[1] Despite the fact that crew would typically not accept such a manoeuvre in such low visibility, the scenario is useful in evaluating the appropriateness of the alert. In these scenarios, participants were asked to taxi faster than they would normally feel comfortable with.

countdowns. Comparison of crew response in these scenarios enables the assessment of a number of issues such as, for example, whether there would be a tendency for crews to hesitate aborting at higher speeds and whether following a high speed rejection, there was any tendency to decrease braking if crews perceived that the aircraft was decelerating fast enough to stop before reaching the conflicting aircraft.

Scenario 8 was one of the good visibility scenarios designed to evaluate the crew's confidence in the system when independent conflict situational awareness can be obtained through visual contact. This scenario consisted of an intruding aircraft approaching the runway from a taxiway which, however, only crosses the runway after the ownship in take-off crosses the intersection point. Of course, the crew (and alerting system) would have detected the aircraft proceeding beyond the hold-short bar and approaching the runway, but the set-up allowed the ownship to pass the taxiway intersection point just as the intruder would be approaching the runway shoulder. In this case, therefore, the alerting system would not generate an alert, as the preferred option would be to continue the run. Indeed, the scenario was set such that aborting the run would allow more time until the ownship reaches the intersection point, thereby increasing the risk of collision as the intruder would proceed further forwards and eventually enter the runway. Visually, however, it would not be so easy to come to this correct conclusion, potentially concluding that it is better to stop. This scenario, therefore, offered an excellent opportunity to assess the confidence the crew can be expected to have in the system and how the two independent channels, namely that of the aural alert and the visual channel providing external cues, interact.

Scenario 9 was again designed to test the assertiveness of the alerting philosophy when visual impressions can conflict with the system’s intentions. In this case, the condition was set-up to test the assertiveness in the silent cockpit philosophy in continuing a take-off run. To this effect, the conflict conditions were designed so that an intruder causes a conflict at 135kts (just before V_1) such that the dynamics result in a can-go/cannot-stop condition. Accordingly, the system remains silent and no alert is generated. The velocity was set such that the intruder became visible in the reduced visibility conditions after the system detected the conflict, but just before or about V_1. In this way crew would become aware of the conflict at a critical time in a silent environment and the element of surprise would be significant. This scenario was particularly interesting as it also allowed the assessment of whether the lack of any call-out could be interpreted as a system failure.

Scenarios 10 to 15 addressed conflicts during landing. Here, three scenarios were designed to occur in good visibility (11, 13 and 14) in order to allow crews to form an independent opinion of the developing situation. In Scenario 10, the conflicting aircraft was lined-up for take-off on the same runway on which the ownship would be landing. In this case, the system remained silent until 15s to collision. With the ownship travelling at approximately 150kts, this corresponded to the alert being generated when the ownship would be approximately 1100m from the threshold. In this scenario, therefore, it was expected that crews would detect the conflict before the alert to go-around would be generated by the system and the intention was to assess whether crews tolerated the other aircraft on the runway and proceeded with the approach until the system issued the alert or whether they would initiate the missed approach earlier on their own initiative. In this way, the scenario supported the assessment of the appropriateness of the alerting threshold (i.e. the timeliness of the alert) and whether the silent behaviour of the system before the alert was triggered, caused any concern that the system had failed (thereby reducing the confidence in the system).

Scenario 11 was designed with the ownship number two in the landing sequence and the aircraft fails to vacate the runway. An alert to go-around is issued when the ownship comes within 10s of the runway threshold. With the conflict occurring in good visibility and the crew being in visual contact with the other aircraft, the scenario is intended to instigate discussion on the timeliness of the alert. Specifically, it was of interest to assess whether the alert comes too early and is of nuisance or whether the alert comes too late, making the crew feel uncomfortable with the situation and would prefer calling the go-around earlier. In the case where the alert is considered to be issued too early, it was relevant to assess whether the crew were ready to overrule the alert and knowingly continue the descent.

Scenario 12 was simulated in low visibility, with the conflicting aircraft entering laterally into the runway from a taxiway 800m from the threshold when the ownship would be 10s (750m) from touchdown. An alert is triggered immediately to instruct the crew to go-around. This scenario was designed with the intention of monitoring the crew's reaction to a go-around during the last seconds before touchdown.

Scenario 13 addresses the situation where the ownship is on final approach to land on a runway operated in mixed mode with an aircraft taking off ahead of it. The aircraft commences take-off and aborts the run. This scenario was set in good visibility so that the crew will be able to see the other aircraft stationary in the middle of the runway. The scenario is set so that the alert to go-around is once again triggered when the ownship is approximately 10s from the runway threshold. The scope of this scenario was as in Scenario 11, to evaluate the timeliness of the alert in the context.

Scenario 14 is similar to Scenario 11, but the aircraft just landed ahead will start to turn off to vacate the runway just before an alert on the ownship would be triggered. This scenario was designed to test the appropriateness of the alerting threshold in such circumstances. The scenario was set in good visibility to enable crew to be in visual contact with the aircraft ahead. This scenario also tested the crew’s confidence in the silent concept (i.e. whether they would doubt system failure) and allows corroboration of views with those obtained from Scenario 8 in take-off.

The last scenario, Scenario 15, addresses a conflict scenario occurring after the ownship will have touched down on landing. In this case, there will be little action the crew can take other than from applying maximum braking and full reverse thrust. In this scenario an alert is issued to direct the crew to apply maximum braking. As in the case of take-off, the distance call-outs are intended to provide situational awareness with respect to distance to the conflict and closure rates to the crew. In this scenario it was interesting to evaluate how the crew would react to the alert generated after touchdown as well as evaluate whether, in the case they would not be able to decelerate in time, the crew would consider a lateral manoeuvre.

3.3. The Participants

The crews chosen to participate held a full, fixed-wing, single-aisle, multi-engine rating with a range of experience, ranging from junior first officers to senior captains and training captains. Ages ranged from the mid-twenties to the mid-fifties, with a total flying experience ranging from 1,300 to 17,500 hours. Four participants had a B737 type rating with the remaining being current on the A320. Hours on type ranged from 1,000 to 11,500 hours. Most of the participants who flew the A320 had previously also flown the B737 (200 and/or 300/400 series aircraft) and some also flew the Avro RJ70. Such a wide sample range provided a representative sample of the whole population in terms of considerations such as age group, experience and training background. The sample, however was, due to the resources available, limited in terms of aircraft category (no pilots flew long range/twin-isle aircraft, small commuter aircraft or business jets) and airline culture. Nevertheless the sample chosen was not considered to distract from the scope of the evaluations. The mixture of experience between B737 and A320 aircraft is of relevance when considering HMI strategies, since the two airframers (Boeing and Airbus) tend to have somewhat divergent strategies in cockpit philosophies.

Twenty-three individuals were chosen on the basis of non-probabilistic convenience sampling[1]. The majority (91%) were male and 9% (two participants) were female. During the evaluations, participants were asked to follow typical company procedures, operating in crew of two in order to ensure representative operation (ecological validity). The more senior member was asked to act as the pilot in command.

3.4. Data Collection

Both qualitative and quantitative data were collected in the evaluations, with the former expected to capture the most indicative of results. Qualitative data were obtained from post-scenario questionnaires and semi-structured interviews to establish the participants' overall acceptance of the alerting system and the clarity of the alerts generated. Quantitative data were obtained through logging of flight simulator data, which, following processing were used to compare the efficiency of the evasive manoeuvre executed by participants.

3.5. Evaluation Results and Analysis

Twenty-two evaluation sessions using crew pairs were carried out for a total of 175 trials (scenario runs), with 76 in HMI Mode 1, 63 in Mode 2 and 36 in Mode 3. The scenarios selected for evaluating the HMI in Mode 3 (informative alerting) were mostly high-speed take-off scenarios and those during landing where a missed-approach could be avoided, as it is in these circumstances where the comparison between directive and informative alerting was expected to be most crucial.

3.5.1. Objectives 1 and 2

Although objectives 1 and 2 are distinct, their discussion is linked and they are consequently herein presented together.

All participants accepted the directive alerting concept and considered it an improvement when compared to the current operational environment. Likewise, all participants reported that the alerts were unambiguous and easy to understand, as the phraseology used was in line with phraseology currently used on the flight deck. Crews had no problem following the command to either abort the run during take-off or to perform a missed approach during landing. This, however, may not be surprising, as crew are typically accustomed to following commands. All of the participants felt that the directive nature of the alerts is in line with the philosophy employed in the cockpit, where currently a TCAS or EGPWS alert directs the crew into taking a manoeuvre. For this reason, the crew felt comfortable in following the alerts (T1.1-T1.3). Typical comments, which also relate the level of confidence expressed in the system, were:

T1.1: *"I would rely on it 100%"*
T1.2: *"It's the same for TCAS, same for EGPWS"*
T1.3: *"If the thing said stop, I'd stop!"*

However, age group and experience can be expected to have a potential impact on crew acceptability of and dependency on the new surveillance equipment and directive alerting. It is well known that more experienced pilots tend to be less accepting of new technology in the cockpit. Age group also appears to have an effect on the crew disposition to abort a run late in take-off, where senior pilots tend to be more reluctant to abort at high speeds than their younger counterparts, for fear of overrun. This tendency expresses itself in a lowering of the effective decision point to a few knots before V_1. Although this observation was not made in the context of runway collisions, its discussion is relevant in the present context because crews can be expected to relate the concept of decision speeds and scheduled performance with conflict mitigation, even though this would be incorrect as, from a performance perspective, the problem

[1] Subjects were selected because of their convenient accessibility with respect to location, availability and cost. Since the evaluations where held over a two-month period, the effect of convenience sampling due to crew schedules was not expected to have any impact on the validity of the evaluations and extrapolation of the results to the whole population.

is substantially different. If this is the case, then more senior pilots may be expected to be more reluctant to follow a stop alert close to V_1. A similar effect can be expected during landing, particularly in good visibility where the crews will have visual contact with the conflict. In such cases, the more senior pilots may be more inclined to ignore or override the alert in certain circumstances than younger pilots who will have less flying experience.

The responses given by the pilots during the evaluation appear to indicate that age does indeed influence disposition to blindly accept the directive alerts, but not to the extent of senior crew being averse to it or considering it inappropriate. All junior pilots appeared to be well disposed to blindly accepting and following the alerts. In comparison, the senior pilots were, whilst quite comfortable to follow the alert in situations where they perceived they had limited situational awareness (typically in low visibility), more inclined to overriding it when they considered the alert appropriate. This mainly referred to approaches in good visibility, where the pilots felt that, through their situational awareness and discretion, they could avoid unnecessary missed approaches. Indeed, the senior pilot who was most in favour of alert override in Scenario 13 (Trial 7), immediately aborted the take-off run close to V_1 in Scenario 7, despite the tendency for more senior pilots to be reluctant to abort at high speed.

The suggestion that pilots should have the authority to physically suppress or inhibit the alert despite following it in perceived difficult situations is interesting because, whilst it exhibits a level of scepticism expected in senior pilots, it effectively also strengthens the view that the directive alerting concept is indeed acceptable. The suggestion for overriding the alert here does not imply mistrust in the system but, rather, an acceptance of the alerts and a suggestion for pilot discretion to coexist with the system. This concept can be considered advantageous as it can reduce the impact of false warnings and, with pilot decision in the loop, could contribute to lower effective unnecessary aborts. Indeed, putting the pilot in the decision loop, where the human response is modulated by situational awareness, can significantly contribute towards the mitigation of any reduction in safety levels that may be inadvertently introduced by safety-net functions and Level-3 alerts through false or incorrect alerting.

The concept of authority to override, however, is delicate in nature because, whereas the suggestion of overriding the alert may appear reasonable in the context of well trained, proficient senior captains, the notion of authority to disregard a Level-3 alert is debatable, particularly in the context that such an alert needs to operate with the whole pilot population in different circumstances, and different operator cultures.

It is interesting to note that pilots approaching middle age, being experienced captains but not yet holding senior positions tended not to feel the need to have the authority of override the alert, exhibiting a tendency similar to that of junior pilots. This is perhaps understandable in the light that this generation of pilots will likely have had more exposure to computer technology in their upbringing then those who are senior captains today. Furthermore, it can also be expected that as one gains more experience in life, one would be more aware of the limitations of technology and its implications. If this is so, it appears that this category of pilots are still confident in automation and technology whilst being very aware of the infrastructure and procedural limitations in operation from experience gathered throughout their career. Indeed, typical comments by experienced pilots were:

T1.4: *"If you have a situation where it's telling you to go-around for example, ATC may tell you clear to land, then you say no I'm going around... ATC might have made a mistake"*
T1.5: *"I would rather trust a fresh computer than a busy controller"*

In terms of the value perceived by the applicants of the system in different visibility conditions, many participants felt that the directive alerts were useful in both good and poor visibility. In poor visibility, the advantages of the alerting system are obvious, as the crew would otherwise be unaware of the conflicting aircraft. In good visibility, the alerting system was also considered of value, with several crews voicing the opinion that they would still follow it (T1.6) and that in certain airfields where runway topography obscured views (such as undulated or crossed runways with obstacles such as buildings in between), the conflict aircraft may still not be visible (T1.7-T1.8). Operation at night may also offer significant challenges, as aircraft can be missed in the multitude of lighting normally associated with busy airports. Besides these circumstances, pilots considered the warning system of value even when they will be in visual contact with the conflict aircraft. However, not all crews were in agreement with the notion of blindly obeying the alert in good visibility conditions, with several suggesting that they should have the authority to overrule the alert in situations where they are sure that the threat is not sufficiently serious to warrant following the alert (T1.9).

T1.6: *"I would still want it, even when it's CAVOK"*
T1.7: *"The system is very handy both in low vis but even in VMC conditions especially where parts of the runway are hidden due to slopes etc."*
T1.8: *"In good visibility the warning system becomes a back up system. You are not going to see a light aircraft in the middle of the runway. There are some runways because of the topography you can't see the other side, like Manchester or Leeds"*
T1.9: *"Excellent, especially in IMC conditions. In VMC however, I would incline to let the pilot decide if the warning is appropriate. For example the 'go-around, traffic' could be triggered unnecessarily if visual separation is maintained."*

The merit of needing to override the alert in VMC is linked with the selection of thresholds. It is relevant to point out here that since the system does not differentiate between good and poor visibility conditions, thresholds need to be set conservatively to safeguard low visibility operations. It is understandable that this may lead to undesirable go-around alerts on approach (this will not happen in take-off) and in this context the view expressed in T1.9 is understandable. However, from a design perspective, it can be argued that, with correctly set thresholds, pilots would be exceeding limits of predefined safety when knowingly pushing limits. Of course, through visual contact, the safety limits are conceptually restored but whether this practice will be acceptable to the industry or otherwise is a matter of debate. The challenge that needs to be met is perhaps best captured by:

T1.10: *"I think that the most important thing is that the system gives enough time to react but is not too sensitive otherwise the use of the system in busy airports will be filtered... ignored... switched off by users!"*

It is reasonable to conclude from the discussion that no concern on the directive concept was voiced and that the alerting concept proposed in this work, therefore, should be very acceptable on the flight deck. The question of authority to override the alert in certain conditions has been voiced, but allowing crews to exercise discretion may be counter-productive in the global context and will need to be addressed further.

The discussion up to this point has effectively addressed the appropriateness of directive alerting concept. It is relevant to also address the individual attributes of the design of the alerting philosophy, namely:

- The appropriateness of the phraseology as an indicative, but not necessarily final, solution.
- The value of the distance call-outs.
- Suppression of the alert beyond V_1.
- Remaining silent when the solution to the conflict is to continue the manoeuvre.
- The alerting strategy during taxi/backtrack/line-up.

The effectiveness and appropriateness of the phraseology used for the alerts in terms of wording and duration is of interest because, in the design, a compromise was sought between length of the selected phrase and detail intended to be conveyed in the message. The chosen alert, therefore, was expected to have a potential impact on crew perception of the threat and reaction times. All of the participants were of the opinion that the alerts and phraseology used ('STOP TRAFFIC' and 'GO-AROUND TRAFFIC') are in line with what they are used to in the cockpit (in particular, through the mandatory presence of TCAS and EGPWS). They are effective and no evidence of distraction from or delay in the correct reaction required by the crew was noted. Indeed, T1.3 indicates the general mind-set observed in the evaluations in response to the alert 'STOP TRAFFIC' during take-off.

The distance call-outs during the braking phase in an aborted take-off or after landing proved to be effective and were perceived of value by the crew. Whereas, informally during the briefing sessions some pilots had reservations with respect to their expected value, once placed in the environment of emergency braking in low visibility due to a runway conflict, their views changed completely. The distance call-outs were found to be of great value to all crews when not in visual contact with the conflicting aircraft, as otherwise they would have had no objective indication of where the conflict might be. The effectiveness and value of the call-outs can perhaps be best portrayed by the occasion where, in Scenario 7, one crew elected to veer off the runway and onto the grass when it became obvious to them that they would not stop before hitting the aircraft. They did so just before visual contact with the conflicting aircraft. Although not tested for, the distance call-outs can conceptually also be used to reduce braking when the conflict aircraft is far away and it is evident that there is ample distance to safely bring the aircraft to a halt with reduced braking. The concept of reducing braking, however, is a matter of discussion, since this can be dangerous in conflicts where pilots may gain a false sense of security that they will stop in time.

Alerts were suppressed at V_1 on the basis that aborting beyond this point conflicts with current practice. Furthermore, there is serious concern on the risk of false alarms beyond V_1. It was therefore decided that no abort should be advised after V_1. This can be interpreted as the system not providing surveillance after V_1, which is acceptable, as it is quite reasonable to expect safety-net functions not to provide support in the most challenging of conditions. However, on closer analysis one can quickly conclude that if a runway conflict were to be detected after V_1, conflict dynamics will probably result in the more appropriate action being a CTO. In such events, the no call-out strategy in the event of a CTO fits in perfectly with the concept of inhibiting alerts at V_1. This narrows even further the window of conflict combinations where the system is unable to provide effective support.

Participants expressed concerns regarding the appropriateness of the directive mode in the high-speed regime of take-off (Scenarios 7 to 9). Many participants felt that alerts should be suppressed prior to V_1 (such as V_1 - 5s), expressing hesitation in aborting the take-off just before V_1.

T1.11: *"V_1 is a go-speed not a stop-speed. The pilot at V_1 has already decided to go. The pilots decide not to go at V_1 minus five seconds approximately."*

This issue highlights the problem of crew perception of the definition of V_1, which has long been identified by the aviation community [18]. This probably stems from fear of overrun, which is backed by the fact that only gross performance is allowed for, statistically indicating that there is indeed a 50% chance of overrun when aborting at V_1. There are also other effects, such as uncertainty in braking capability and a general lack of experience in emergency braking from V_1, but perhaps the most influential is the fact that the take-off distance required (TODR) of two-engined aircraft is limited by the one-engine inoperative (OEI) case and crew operating in field limited conditions will consequently benefit from additional margins in the normal (all-engines operative (AEO)) manoeuvre. This, coupled with their lack of experience in emergency braking tends to raise doubts in pilots' minds whether they would manage to stop in time on the short runway, even though scheduled performance would indicate that they are operating within regulation. As a result, pilots tend to be reluctant to abort close to V_1 and there is evidence that there may be preconditioning themselves to go a few seconds before V_1, despite the fact that this will not guarantee a successful CTO. As discussed earlier, the extent of this limit can be expected to worsen with pilot age. The net effect of this discussion is the probable translation of this informal crew mind-set to the context of the alerting system. It is important to emphasize the relevance, therefore, of crew training to follow the alert irrespective of any preconceived ideas if an RTO is advised by the alerting system just before V_1. This highlights the need of the introduction of procedures to cater for the alerting system, a subject that is further discussed later in this text. Indeed, the 'go-minded' mentality was openly acknowledged by the participants:

T1.12: *"We are 'go-minded'. Training should help with that."*

The tendency to be reluctant to abort take-offs at high speeds was also evidenced by one pilot who, despite following the alert to abort at high speed, commented:

T1.13: *"I think the warning should be inhibited at 100kts because if you get the warning, you should keep going. By the time you get it, you'd be past it at your speed."*

The alerting system does not take into account the possibility of an early rotation in critical conflict conditions, where the aircraft in take-off could rotate before reaching V_R and climb above the conflicting aircraft. Early rotation is a risky manoeuvre and it is not possible to successfully direct, in terms of an optimal flight trajectory, the crew to early rotation to ensure that the conflicting traffic is missed whilst not jeopardising the safe continuation of the flight. Likewise, other unconventional manoeuvres, such as increasing thrust when the take-off is being attempted at a derated setting[1] are not considered by the alerting system for reliability reasons. In these circumstances it is reasonable to rely on visual contact in conjunction with crew's discretion in the manoeuvre of choice with the alerting system not providing support.

The issue of the system remaining silent in the CTO case was raised by participants during the discussions. This was because whilst the merits of remaining silent can be appreciated as previously described, generating no alert, particularly in good visual conditions, could be perceived by pilots as a system failure, with the possibility that they would attempt to abort the run on their own initiative. This eventuality, of course, would not be desirable. The merit, therefore, was to consider whether it would be preferable to issue an alert such as 'CONTINUE TRAFFIC' in the case of a CTO. Whilst the advantage in good visual conditions is obvious, it is possible that in low visibility, where a conflict alert would surprise the crew, such an alert could be counter-productive. Here dichotomous views where recorded:

T1.14: *"Being quiet maintains the 'status-quo', you're going to continue doing what you're doing."*
T1.15: *"You need something to tell you that the system is actually working. So you don't think that it didn't give you the alert because the system isn't working!"*

Fifteen trials using Scenario 8 were held to simulate the marginal CTO case in a runway conflict in good visibility conditions, where usually, the impression could favour the crew to stop. Accordingly this scenario involved the conflict aircraft failing to stop at the hold-short bar whilst taxiing and approaching the runway shoulder as the ownship accelerated towards V_1. All participants correctly continued the take-off and successfully cleared the conflict. From the 20 participants, 15 were satisfied with the alert being suppressed, as they felt it would be congruent with the 'Dark-and-Silent' cockpit philosophy (T1.12, T1.14). Five participants felt that seeing an aircraft approaching the runway instilled in them the desire to stop, despite still following the SOPs and continued the run. These participants felt that the system should not remain quiet and should instead inform the crew of the incursion through some form of advisory (T1.15), even if only to provide

[1] Take-off is typically performed using derated thrust (for fuel efficiency, reduced wear and tear and noise abatement) allowing the crew an additional amount of power which could be applied in such a situation to rotate earlier.

additional confidence that the alerting system has not malfunctioned.

To conclude the discussion of the effectiveness of the directive alert concept it is appropriate to analyse the quantitative data recorded on the simulator. A total of 123 trials were conducted with the directive alert (HMI Modes 1 and 2), with 66 being conducted in the various take-off scenarios and 57 during landing. Of these, pilots reacted as intended by the system and successfully avoided the collision as desired in 122 of the occasions, with only one event being recorded where the pilot contradicted the alerting philosophy. This occurred in Scenario 9, where the pilot flying saw the conflicting aircraft and decided to stop when the system remained silent because the preferred decision was to continue. In this case the crew took a high-speed lateral manoeuvre to avoid the collision, which highlights the correct operation of the prediction algorithm design. However it also highlights the difficulty with the concept of remaining silent as, in this case, the pilot must have, possibly through fear of collision, concluded that a collision must have been imminent and that the system had failed. This is understandable because it is known that the human brain can make erroneous deductions under stressful conditions. It would not be unreasonable to conclude that a confirmation to continue the take-off would have probably led the pilot to continue the run. It is also relevant to point out that there were nine trials in this scenario, with the other eight continuing the run as expected and this suggests that the probability of doubting the system when remaining silent may be low.

Crews who were in favour of following the alert under all circumstances also commented that such an alerting system needs to be backed-up by clear SOPs to strictly dictate that the alert should always be followed.

T1.16: *"Procedure would dictate that you always obey the alert"*

The taxi/backtrack/line-up operation is not a core feature of the system but was introduced to provide a complete solution on the runway. In such conditions the design proposed informative alerts because there were few options considered conventional that could be taken by the ownship in these contexts. The scope of the evaluation was to consider difficult scenarios that could highlight whether the author's concerns in the appropriateness of informative alerts were founded or otherwise. To assess this, the two scenarios chosen involved the ownship closely following another aircraft along the runway and an aircraft approaching to land on the runway on which the ownship was lining up for take-off. As expected, these scenarios raised concerns on the clarity of the alert. In the situations, such as Scenario 1, where the ownship is actively involved in the runway conflict by taxiing too close and fast to the aircraft ahead, the crew appreciated the alert 'WARNING TRAFFIC AHEAD' and took action to reduce their closure rate. The context afforded the relatively long aural alert without compromising timeliness in reaction. However, in Scenario 2, with the alert 'CAUTION TRAFFIC BEHIND', crews raised concern there was little action they could take. This was not unexpected as in such situations, action by the other party is normally required to mitigate the conflict. In addition to this, the alert raised concerns with the participants, as they felt that the aural alert alone provided insufficient information as to exactly where and what manoeuvre, if any, the conflicting aircraft was performing (T1.17-T1.19). Participants commented that the alert itself does not indicate whether another aircraft is taxiing, taking off or landing behind them. It was generally felt that the aural alerts alone where inadequate. This again was expected and confirms that advising pilots of a threat without supporting them further towards taking mitigating action is ineffective.

T1.17: *"The problem is this: the aural warning doesn't tell you if someone is lining up behind you or somebody on the approach"*
T1.18: *"Is it four miles behind me, one mile behind me, I only know that it is just behind"*
T1.19: *"If you're not aware that there is somebody on the approach, the first reaction is to look at each other and say 'what'?"*

This clearly indicates the value of the display in such circumstances. The use of the display is also reasonable because crew workload during taxi/backtrack/line-up will not be high as in take-off and landing. Use of a moving-map display is, therefore, recommended for such manoeuvres. It is interesting, however, to note that several pilots commented that the aural alert alone (when not presented with the display in HMI Mode 1) was adequate because it prompted them to contact ATC (T1.20). Two participants attempted to vacate the runway from the closest taxiway. There were, however, concerns on the possibility of nuisance warnings caused in busy airfields. Whilst the crew felt that a minimum of 30s warning is adequate to avoid nuisance alerts, they still felt that, within this short time, it is not always possible for them to vacate the runway, particularly when the next exit taxiway is far from the threshold (T1.21). In such circumstances, participants commented that they would hesitate to take a lateral manoeuvre off the paved runway surface, as this is risky, and would prefer contacting ATC to instruct the other aircraft on the approach to go-around.

T1.20: *"It was good because it prompted me to ask ATC"*
T1.21: *"What can you do, it's too late. The most you can do is to tell ATC and he might tell the other guy to go-around. The engines take too long to spool up"*

This discussion suggests that an informative alert needs to be generated with sufficient time for crews to react either by contacting ATC or confirming the conflict with the moving-map beforehand, if available. A late warning would limit its value and the solution needs to be a compromise with the risk of generating unnecessary alerts. It should be considered, however, that nuisance advisory alerts in this context will have less of an impact on safety, operations and general acceptance than those generated by the directive contexts of take-off and landing.

3.5.2. Objective 3

Objective 3 was concerned with the value of the preceding auditory tone and the use of a graphical display. The literature [19-20] advises that verbal alerts issued in a noisy environment and when the crew are under high workload should be preceded by an attention grabbing auditory tone. Consequently, the verbal alerts were preceded by an introductory (whoop-whoop) tone. However, an introductory tone introduces an additional delay, which is not advantageous in the context of emergency alerting when the alert cannot be generated earlier to compensate for this delay. In general, crews can either be expected to wait for the completion of the tone and the alert to react, or else, react immediately on hearing of the tone. If they react on the tone alone before the verbal alert is issued, then they would be latching on the tone itself as the alert. This is not the intention of this tone, also because unless a unique tone is used, confusion on the meaning of the tone can result[1]. Furthermore, there is a limited number of specific tones that crews can be expected to memorise on the flight deck and, considering that a runway incursion alert is expected to be a rare event, it is quite possible, in this circumstance, that a specific tone could surprise or confuse the crew rather than lead them to immediate, correct action. It is for this reason that the merits of the preceding tone were considered through simulator evaluation. Both qualitative data in terms of participant opinion and quantitative data in terms of reaction times were used in this consideration.

The data collected gave no evidence that the preceding tone had any significant effect towards directing pilots to abort the manoeuvre and it can be concluded that the verbal alert on its own is sufficient. As shown in Table 1, 76 trials included the introductory tone (Mode 1) and 63 trials were conducted without the tone (Mode 2). All participants of the 76 trials commented that the tone (which was 1.22s long and followed by a 0.15s pause before the verbal alert) was too long. This delay was considered particularly significant during the medium and

[1] A specific case where a tone was misidentified was that of the Helios accident in 2005, where the aircraft involved used the same tone for take-off configuration warning and loss of cabin pressure. As the aircraft climbed through 12,000ft the cabin pressure warning horn sounded and the crew misidentified it as a take-off configuration warning.

high-speed take-off scenarios, where every second can affect the outcome of the situation.

T3.1: *"It was taking too long to get the actual message"*
T3.2: *"The 'whoop-whoop' causes a delay of about two seconds. Not happy with this."*

One of the comments (T3.3) actually confirmed that at least some pilots were waiting for the verbal alert following the preceding tone, as intended by design:

T3.3: *"In the 'whoop-whoop' phase you're still confused. 'Whoop-whoop' what? It's not just let's try out a rejected take-off and see what happens. You have to be 100% sure what's the warning"*

The question, therefore, is whether crews would prefer the inclusion of the tone or otherwise. Their reaction to the tone suggested eliminating it altogether:

T3.4: *"I feel the initial `whoop-whoop' is not needed"*
T3.5: *"I don't see the need for a horn, it wastes time"*

In this discussion, however, one must keep in mind the fact that the participants where in a simulated environment with the sole purpose of evaluating a runway collision avoidance function. This will surely have somewhat biased the arguments, because the simulated environment is quieter and more relaxed than can be expected in normal operations and participants would be preconditioned to expect a runway conflict and associated alert.

With the response indicating a preference for the tone removal, quantitative data in terms of response times to alerts with and without the preceding tone were assessed and are presented in Table 1. Whilst the details of the merits of these statistics are discussed further in this text, it is here appropriate to extract key inferences with respect to the discussion of the value of the preceding tone.

The removal of the preceding tone reduced the average response time by 0.8s during take-off and 0.3s during landing. Besides the fact that the landing results may be conditioned by the availability of the moving-map in some of the trials, it is reasonable to focus on the reduction in response time during take-off particularly because it is envisaged that conflicts in take-off will be more likely to require immediate reaction when compared to conflicts experienced on the approach. The reduction in response time of 1.37s due to the removal of the preceding tone led to a 0.8s reduction in average response time during take-off. This suggests that the preceding tone partially conditioned crews' reaction to the extent of reducing the effect of the delay in reacting to the verbal alert by approximately 0.6s. Nevertheless, the overall additional delay of 0.8s is considered more of a disadvantage, as it brings the crew's closer to, or possibly exceed, the TTLR point. A reduction in standard deviation in reaction time in take-off is also noted in Table 1. Although the reason for this cannot be ascertained, it is possible that the tone chosen may have startled the crew, which would understandably result in a larger spread in reaction time when compared to that without such a tone.

Table 1 - Statistics for crew reaction time in HMI Modes 1 and 2.

	Mode	μ	σ	# of samples
Take-off	1	2.61	0.51	24
	2	1.78	0.38	19
Landing	1	2.31	0.57	19
	2	2.02	0.86	20

It can, therefore, be concluded from this analysis that the removal of the preceding tone would be advantageous as it will contribute to reduce the reaction time in take-off at the expense of the unlikely event of crews missing the alert. If this risk is considered too high then a compromise can be found, whereby the tone is placed after the verbal alert preceding the repetition. This may be a solution that mitigates the risk of missing the alert, without compromising the reaction times.

Objective 3 also involved with assessment of the value of graphical displays to augment the aural alert. All participants presented with a textual alert on the primary flight display (Mode 2, 63 trials) agreed that the graphical alert was beneficial and this confirms the value of the concept of redundancy gains in the context of runway incursion alerting.

The value of the airport moving-map in runway conflict mitigation, however, is debatable. Airport moving-maps are already present on the flight decks and will most certainly become available on all commercial aircraft in the future. It is perhaps obvious to deduce that it will also be useful during taxi, back-track and line-up on the runway, as evidenced by transcripts T3.6-T3.7:

T3.6: *"The map is very, very useful, ignore the idea of traffic, just taxiing around is very useful... something essential I think, once you experience it, you don't want to stop using it"*
T3.7: *"Another big plus which we didn't really do today is taxi out in poor visibility for places like Charles De Gaulle, these places with complicated taxi routes"*

The question, therefore, is whether the use of an airport moving-map would be advantageous in conflict resolution during take-off and landing, when the crew will be concentrating on other tasks and reaction times may be low. All participants considered this not to be the case during take-off, with a few having strong views against its use.

T3.8: *"The aural alert is far more useful than a detailed map of the runway and the apron and the terminal buildings, which although is very pretty and good for taxiing out, it is not a mode I would choose for take-off"*
T3.9: *"If you get the auto-call to tell you to stop, you don't need the map"*
T3.10: *"There is no need to have it on display. You just need to hear something, stop/go/whatever, you won't be looking inside to see it"*
T3.11: *"In take-off if it says stop, I would stop because I heard the command and not because I made use of the display"*
T3.12: *"If something taxis onto that runway, no amount of maps, displays, pictures or photographs is going to change the fact that it is on the runway and you have to stop"*

This confirmed the intentions of the design, where, at the conceptual design phase, it was considered that there would be no value for crews to confirm a stop command via an airport moving-map during take-off. Not only would this distract from the authority (and intention) of the alert, but referring to the display would result in a further delay in response and a risk of potential replacement of objective assessment (by the system) with subjective interpretations of the conflict conditions deduced from the moving-map. This view is further confirmed by T3.13:

T3.13: *"In take-off it doesn't help, you definitely not going to look at the map. We're looking at other things, we don't have time, you're looking at the engines, looking at the speed, we have call-outs to do"*

The comment of other responsibilities and, specifically, that referring to call-outs is interesting. On one occasion in Scenario 9, the pilot not flying fixated on the conflict aircraft on the display and missed the rotation speed, calling for rotation 3s late. Besides the intrinsic concerns associated with late rotation, this delay actually brought the two aircraft in conflict closer together and resulted in a higher risk of collision.

T3.14: *"Having that information displayed on the map caused me to fixate on that display and as a result, I was late in giving the* V_R *rotate command which oddly enough could have caused us to hit that aircraft"*

Whereas it can be expected that an airport moving-map display could provide situational awareness prior to the dynamics resulting in a conflict (and the issuing of an alert), its availability can also act as a serious distraction, not least when considering that an airport moving-map display is comparatively complex and highly dynamic. It will therefore require more attention to extract the relevant information from it than, for example, that required when reading an engine instrument, where gauges are designed to allow quick observation of multiple instruments through the interpretation of relative needle position and colour coding. The effects of the complexity of the airport moving-map can be expected to have greatest impact on operations particularly in the early stages of system availability:

T3.15: *"I am pretty sure that the system [moving map] will initially result in quite a few unnecessary aborted take-offs... If I have new stuff on my screen, I have to do something about it, especially in low visibility"*

The value of knowing the relative position of the conflict aircraft to that of the ownship has already been highlighted through the concept of distance call-outs. It was therefore of interest to determine whether the airport moving-map would be useful for such information. One pilot was specifically asked the question, to which he replied:

T3.16: *"Personally I didn't need to look at the display. The distance call-outs were less intrusive"*

Furthermore it should be noted that the pilot flying should be looking out in such circumstances and there will be little value in the pilot not flying focussing his attention on a display to carry out a call-out function that can be automated through the distance call-out alerts.

All participants considered the map as an ineffective tool during landing. This could possibly have been due to the limitation of the implementation of the map, which only allowed the view of a fixed 800m range ahead of the ownship and therefore did not allow the full view of the runway for traffic monitoring. Despite this limitation, participants felt that the directive alert alone was sufficient as it led to the correct action.

T3.17: *"I don't think you need it in flight"*
T3.18: *"If it [the system] will give you a warning that there is traffic, you do not care if it is at the first intersection or second intersection, you go-around anyway."*
T3.19: *"In these cases the display is not very useful, it is more the aural alert we are reacting to"*

Two participants commented that once the go-around had been initiated, they made use of the display to confirm the threat on the runway. They did not, however, use the display as a means of conflict detection or mitigation.

T3.20: *"After the go-around I looked at it"*

3.5.3. Objective 4

Having established that directive alerting of runway conflicts will be acceptable on the flight deck, it was interesting to assess whether this strategy would be preferred over non-directive (informative) alerts informing of the presence of a conflict. This is because, seen in isolation, either system would be expected to foster positive response in trials, as both would be perceived as introducing an improvement in the safety levels achieved in current operation. However, it is important to attempt to select the better of the two strategies when considering implementation. Clearly, the algorithms associated with the non-directive alerting will be simpler, as no conflict resolution guidance would need to be provided. Crews would instead need to rely on an airport moving-map to identify the threat, as would be expected with technologies developed to date.

In order to be able to compare the two alerting strategies, two sets of trials were carried out. In the first, crews were exposed to and underwent trials with the directive alerting, followed by a further briefing and a set of trials with non-directive alerting. The second set had the sequence reversed with crews first being exposed only to and undergoing trials with the non-directive alerting, followed by briefing and trials with the directive alerting. This ensured that there would be no bias due to preconditioning in the results. In these experiments, Modes 2 and 3 were used and therefore both the directive alert set-up and the non-directive counterpart had the same airport moving-map available. The non-directive alerts where generated with the same algorithm, with the conflict mitigation and alert suppression algorithms disabled, so that the alert 'RUNWAY INCURSION' was generated for every conflict detected, leaving the crew to decide what action to take.
Seventy-two trials where carried out in this experiment using four sets of crews, equally split between the two sets. The two crews that experienced the non-directive alerting strategy first liked it, but on carrying out the trials with the directive alert immediately preferred the latter technique. The crews that ran the process in reverse disliked the non-directive alert, having seen the directive alerting beforehand. This outcome is very indicative that the

directive alerting approach is superior to informative alerting in the context of runway conflict alerting during take-off and landing. However, the finer merits of the views expressed by the participants should also be addressed.

A concern that was voiced by participants was that non-directive alerting required them to correctly identify the conflict dynamics from the airport moving-map and external cues and to then decide on the action to take, clearly requiring significant mental processing. Indeed, the scope of the directive alerting is to reduce the mental process to a simple reaction and this is a view endorsed by the participants in T4.1:

T4.1: *"The directive would be the only one I could live with. The informative just takes too much time to take the information in, process it and decide what you are going to do. By which time you have missed other things..."*

Indeed, in one particular instance on the approach (Scenario 13, with an aircraft aborting a take-off ahead on the runway), when the 'RUNWAY INCURSION' alert was sounded, the crew did not execute a missed approach. They continued to land despite being intentionally[1] not cleared to do so. Although the scenario did not result in a collision, the safety margins associated with the landing manoeuvre were seriously compromised. During the ensuing discussions, the crew admitted that from the moment the alert was issued until touchdown they were attempting to decide whether to perform a go-around or to land and apply full braking by following the airport moving-map. This additional workload caused the crew to miss the fact that they were not cleared to land (T4.7-T4.8). When the same scenario was exercised with the directive alerts, the same crew reacted immediately without having to take the decision on whether or not to perform the go-around.

T4.7: *"We are making the mistake of [being] the thinker and not the reactor."*

T4.8: *"Once you start thinking about it, then OK, I am weighting up the odds and trying to make a decision, there is the chance you make the wrong decision... and this is why SOPs are written. Once you hear the call you react immediately."*

All the participants were of the opinion that the directive mode of alerting is more compelling during landing and they would feel more inclined to following the alert immediately.

T4.9: *"If it tells you 'GO-AROUND', I would be more inclined to doing it"*

More seriously, participants elected for the manoeuvre that would not have been preferred by the system in six of the 17 take-off trials with non-directive alerting. This indicates a high probability of crews taking sub-optimal or inappropriate manoeuvres when only informative alerting is available. In the high speed conflict scenario (Scenario 7 in take-off, preferred manoeuvre to abort), two out of three elected to continue rather than abort. One of these hit the conflicting aircraft at high speed. In comparison, all ten trials of Scenario 7 using the directive alerting were completed with the preferred manoeuvre, all of which were successful. In Scenario 8, where the conflict dynamics, in good visibility, warranted continuing the take-off to pass the other aircraft before it actually entered the runway, the statistics were even worse. Four out of the five trials using informative alerting resulted in collisions following rejection of the run. Only one participant elected to continue and successfully avoided the conflict. In comparison 11 trials in this scenario were carried out using directive alerting, all of which were completed successfully.

The results of Scenario 8 are perhaps very indicative of the limitations of the informative alerting technique. With the conflict occurring at high speed and in good visibility, the 'RUNWAY INCURSION' alert may have preconditioned pilots to misjudge the conflict conditions, for it is natural to attempt to stop if one sees an aircraft approaching the runway. Crews were of the opinion that in such conditions, hearing the informative alert

[1] The pseudo ATCO intentionally did not clear the aircraft to land during the scenario, when he realised that the crew continued with the approach.

supported by the visual cues of an aircraft approaching the runway could cause them to take an instinctive reaction to stop.

T4.10: *"May prompt a rejected take-off because you think you have more time"*
T4.11: *"Just to hear something may trigger a reaction"*
T4.12: *"RUNWAY INCURSION at this stage would probably panic you"*

In contrast, in Scenario 7, which warranted the aircraft stopping from high speed (>100kts) in low visibility, participants indicated that, in the absence of directive alerting, they felt more confident in continuing the run and climb over the conflict, as they found it very difficult to judge the distance required to stop:

T4.13: *"It is very difficult to judge whether you will stop or not and its very difficult to gauge distance [from the display]"*

Whilst this comment is valid for all scenarios and particularly those in take-off, the non-assertiveness of the informative alert reinforces the argument that, due to the fact that the crew are `go-minded' at high speed (typically above 100kts), an alert which does not specifically indicate what action should be conducted, could lead to the crew to taking the incorrect decision. All participants who experienced the system with non-directive alerts were of the opinion that these must be supported with an airport moving-map, particularly in low visibility take-off conflicts. In these cases, the crew have otherwise no means of knowing where the conflicting aircraft is positioned and therefore cannot take an informed decision on whether to stop or continue the run.

T4.14: *"During the roll phase you want the function for the ground traffic information and for that you need some sort of map. One can't function without the other... how will you know where it [the conflicting aircraft] is?"*

However, during low visibility landing, the participants were of the opinion that once a runway incursion alert is generated, an immediate go-around should be performed and the use of the display in this case is, therefore, not required as they would not knowingly continue with their descent.

T4.15: *"In the take-off in ground phase I really like the map, but during an approach and in low vis, then no. You're not going to land anyway, you just go-around"*

A particular complication with the 'RUNWAY INCURSION' alert of Mode 3 (as compared to 'CAUTION TRAFFIC BEHIND' in Modes 1 and 2) is the case during taxi/back-track/line-up, where the alert does not advise whether the threat is approaching from ahead or behind the ownship. In these circumstances, several participants commented that the alert alone provides no indication on where and what action the conflicting aircraft is performing and they therefore cannot take any action. In these circumstances the crew felt that the alert alone provided no additional situational awareness and needed to be backed up by the airport moving-map.

T4.16: *"The call caught me off guard. With `RUNWAY INCURSION' I was looking down the runway, never assuming something was coming from behind"*

Quantitative analysis was performed to provide measures of success or failure of the evasive manoeuvres conducted during each scenario and to perform a comparison of the participant's response to the alerts using the different HMI modes. This analysis tested for any difference between HMI modes, in:

- Conducting the expected evasive manoeuvre.
- Collision rates.
- Crew reaction.

Comparison of the Expected Evasive Manoeuvre across Modes

The contingency table of Table 2 shows the frequency with which participants conducted the expected manoeuvres when provided with alerts in the different HMI modes. From this table it is evident that approximately 20% of the participants conducted an unexpected manoeuvre when provided with alerts in Mode 3, with the deviations occurring mostly (6 out of 7) in the high speed take-off scenarios (7, 8 and 9). This statistic is significantly larger when compared to its counterpart for Modes 1 and 2. However, this alone provides no insight into whether there is an association between crew action and the HMI mode, or whether the effect is simply due to chance.

Table 2 – Expected action contingency table.

Mode	Expected Action		Total
	Yes	No	
1	75 (98.7%)	1 (1.3%)	76 (100%)
2	63 (100%)	0 (0%)	63 (100%)
3	29 (80.6%)	7 (19.4%)	36 (100%)
Total	167 (95.4%)	8 (4.6%)	175 (100%)

A non-parametric test of differences was, therefore, conducted to determine whether an association indeed exists. The Pearson chi-square (χ^2) test of hypothesis with a 0.05 level of significance[1] was selected for the test. However, this test does not provide reliable results when the expected counts in the contingency table are low (with more than 20% of the frequencies being below 5). This can be corrected for through the application of Yate's correction for discontinuity, which however, is only possible for 2x2 contingency tables. Consequently, Modes 1 and 2 were grouped together to form a 2x2 contingency table as show in Table 3. Yate's corrected χ^2 was then computed[2] on this table. This resulted in a χ^2 statistic of 23 and a significance of p=0.000, therefore rejecting the null hypothesis H_0 that the association between the crew action and HMI mode is due to chance. As expected, the result indicates that there is a higher probability that the crew perform the expected action when given directive alerts (Mode 1 and 2) as against when given informative alerts (Mode 3). Performing the Yate's corrected χ^2 on Mode 1 and 2 alone gives a statistic of 0.66 with a significance of p=0.417. This indicates that the difference observed between the expected manoeuvres when the crew were presented with HMI Modes 1 and 2 is not significant.

Table 3 – Grouped expected action contingency table

Mode	Expected Action		Total
	Yes	No	
1&2	138 (99.3%)	1 (0.7%)	139 (100%)
3	29 (80.6%)	7 (19.4%)	36 (100%)
Total	167 (95.4%)	8 (4.6%)	175 (100%)

Comparison of Collision Rates across Modes

When comparing the relative success of each HMI mode, perhaps what is more important than determining whether participants conducted the expected action is whether a collision was avoided or not. In fact, during the 175 trials, six collisions occurred[3], five when exercising HMI Mode 3 and one when exercising HMI Mode 1. In fact these collisions occurred due to an incorrect action taken on behalf of the crew in mitigating the conflict during Scenarios 7, 8 and 9 (Table 4). During Scenario 7, one trial out of the three exercised using Mode 3, led into a collision close to rotation as the participants decided to continue the run, thinking that there was sufficient distance remaining. Similarly, out of the five trials held using Mode 3 for Scenario 8, four participants opted for a rejected take-off with three of them not decelerating in time to avoid having to take a lateral manoeuvre to avoid a medium speed collision. The one participant evaluating HMI Mode 1 violated the procedure of continuing the run when the system remains silent (Scenario 9), performing an abort close to V_1. In this case the crew veered off the runway at 104kts to avoid the collision.

Table 4 - Collision demographics

Scenario/Test	HMI Mode	Expected Action	Conducted Action	Collision or Lateral Excursion Velocity (*kts*)
7/18	3	RTO	CTO	146
8/17	3	CTO	RTO	53
8/20	3	CTO	RTO	53
8/23	3	CTO	RTO	26
8/25	3	CTO	RTO	59
9/11	1	CTO	RTO	104

[1] This ensures that there is only a 5% chance that the null hypothesis is wrongly rejected (Type I Error).
[2] Yate's corrected χ^2 was computed using the statistical software SPSS v17.

[3] These included the cases where a lateral excursion was attempted, as the response would have resulted in a collision if this action was not taken at the last moments before impact.

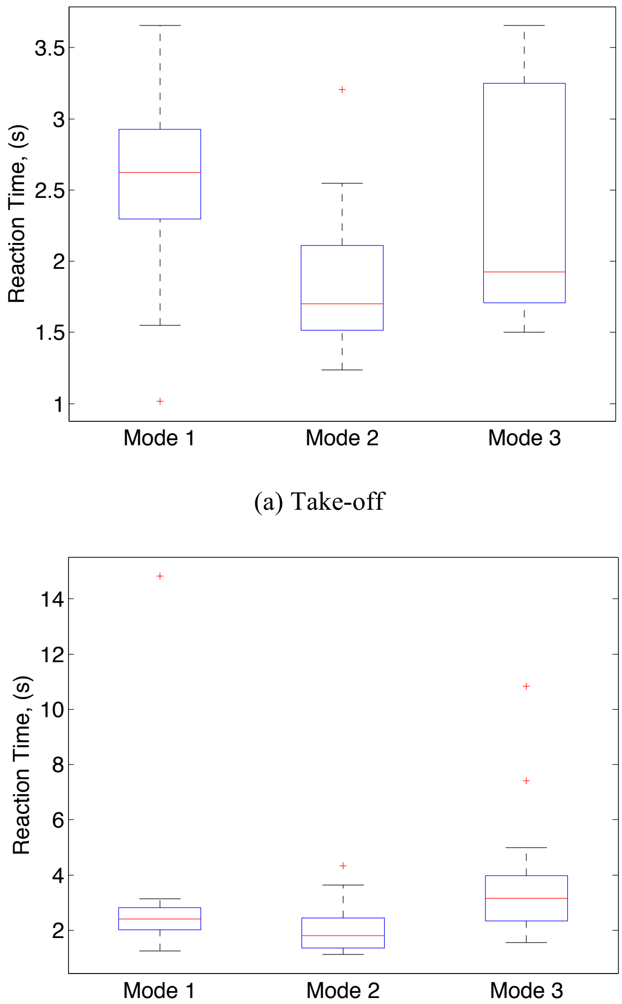
The statistics of Table 4 indicate that five collisions would have occurred in Mode 3 and one with Mode 1 if lateral manoeuvres where not conducted under the crew's initiative. This indicates that the failure rate, in terms of collisions or runway excursions, was recorded to be 15% for Mode 3 as against 0.8% for Modes 1 and 2. This suggests that directive alerting contributes significantly towards the outcome of a conflict when compared to non-directive techniques.

Comparison of Crew Reaction Time across Modes

In order to evaluate crew reaction to the various HMI modes, the reaction time was measured to establish whether there is any significant difference in crew reaction between the modes. The reaction time was taken as the time from the issue of the alert until mitigating action was taken. In the case of a RTO, this was taken to be the time from initiation of the alert until the thrust levers were retarded, whilst in the case of a missed approach the reaction time was taken to be the time from initiation of the alert until the thrust levers were advanced to TOGA.

The crew reaction time is a metric which can be grouped across a family of scenarios, such as those in take-off and those in landing. In this manner, the number of samples available is larger, allowing for more significance in the statistical analysis performed. For this analysis, Scenarios 3 to 7 where grouped for analysis of reaction time during take-off, whilst Scenarios 10 to 13 were grouped for analysis of reaction time during landing. Scenarios 1 and 2 were excluded from the analysis as these were only designed to obtain qualitative data. Scenarios 8, 9 and 14 had the alert suppressed in Modes 1 and 2 and therefore could not allow comparison in reaction time. Scenario 15 was not included in this analysis.

The data samples for reaction time are represented in the box-plot of Figure 2, where the central red mark is the median, the edges of the box represent the 25th and 75th percentiles and the whiskers extend to the most extreme data points, with the outliers plotted individually. Although, outliers are generally the cause of error in data collection or data entry and are often discarded, in this case they were not. The outliers above the median in the data gathered during the trials were actually caused by crew intentionally disregarding the alert when they were in visual contact with the intruder. These were of significance in indicating that the crew felt comfortable in continuing with the manoeuvre and were removed only for the statistical analysis, as they would otherwise bias the calculated crew reaction times. The single outlier below the median in take-off Mode 1 was probably caused by the crew being preconditioned to expect the alert and was therefore also excluded from the statistical analysis of reaction time.



(a) Take-off

(b) Landing

Figure 2 - Box-plot of crew reaction time across modes

Table 5 shows the mean μ and standard deviation σ, corrected for outliers, for the reaction time across the HMI modes for take-off and landing. The data distributions were tested for normality (i.e. exhibiting a Gaussian distribution) using the Kolmogorov-Smirnov (K-S) test with a 0.05 level of significance, with the null hypothesis signifying that the data are normally distributed (and the alternate hypothesis signifying that the data are non-normal). The last column in Table 5 shows the p-values for the K-S test. Since these are all much greater than 0.05, the null hypothesis is accepted, signifying that the data are normally distributed.

Table 5 - Statistics for crew reaction time across modes. K-S p-values greater than 0.05 indicate that the data are normally distributed.

	Mode	μ	σ	# of samples	K-S p-value
Take-off	1	2.61	0.51	24	0.922
	2	1.78	0.38	19	0.787
	3	2.33	0.91	7	0.599
Landing	1	2.31	0.57	19	0.965
	2	2.02	0.86	20	0.590
	3	2.93	0.95	11	0.977

From the statistical data, and particularly from the box-plot, there is evidence that the crew reaction time experienced during the trials may be statistically shown to be dependent of the HMI mode.

During take-off, particularly in Modes 1 and 2, the reaction time was found to have a low standard deviation, resulting in a small spread and therefore a correspondingly small box in the box-plot. From the box-plot it is also evident that the median in Mode 2 is significantly lower than that in Mode 1. In contrast, Mode 3 exhibits a larger spread in the data, which is biased towards larger values of reaction time. This is indeed confirmed by the K-S p-value, where for Mode 3 in take-off, a value of 0.599 was obtained. This indicates that whilst the data are approximately normally distributed, they are skewed towards larger reaction times. During landing the difference between Modes 1 and 2 is not so evident with the boxes in the figure occupying a similar region. Mode 2, however, still exhibits the lower median of the two. As in take-off, Mode 3 in landing exhibits the largest median and spread across the three modes.

To verify the inferences suggested by the box-plot, a one-way analysis of variance (ANOVA) with a 0.05 level of significance was conducted across the three modes; the null hypothesis signifying that there is no significant difference between reaction time across the three modes and the alternate hypothesis indicating that the difference is significant. The test revealed a significant difference between the modes both during take-off ($F(2,46)=11.80$; $p=0.000<0.05$) and landing ($F(2,47)=4.90$; $p=0.012<0.05$). However, as the ANOVA tests only for the presence of a significant difference between the three modes, it alone is insufficient to indicate where the difference lies between the different modes. For this, a post-hoc Tukey Honestly Significant Test (HSD) was conducted allowing the comparison between pairs of means.

This test confirmed that the difference in reaction times observed between Modes 1 and 2 during take-off ($p=0.000<0.05$) in Table 5 is indeed statistically significant. The reaction times to Mode 2 alerts were faster, exhibiting a mean difference of 0.83s from those associated with Mode 1. This result corroborates with the qualitative data obtained from the crews, where they voiced concern that the preceding tone during take-off introduces an undue delay in responding to the alert. However, no conclusions can be made on whether the significant difference in reaction time is due to the removal of the preceding tone or the introduction of the graphical display, which also has an effect on the overall situational awareness (even though crews claimed not to have used the display in their decision making process). The same test performed for the landing trials revealed that the difference in reaction times between Mode 1 and Mode 2 alerts is, in fact, not significant ($p=0.461>0.05$). What is observed is that Mode 2 has a slightly lower mean reaction time but a larger standard deviation. The difference, however, is also not considered significant in terms of impact on safety, primarily because go-around alerts in landing are not critical in timing down to the last seconds to avoid a conflict, as may be the case in take-off. From this argument it can be concluded that the two modes bear no significant impact on performance during landing.

Tukey's HSD test performed on Modes 2 and 3 during take-off revealed that the 0.55s difference in reaction times is marginally significant (p=0.048<0.05). However, what is probably more significant is the large difference in standard deviation between the two modes, as this suggests that the lack of directiveness in Mode 3 will introduce a spread in reaction times, which compromises the effectiveness of the alert in critical conditions.

In comparison, the test performed on the landing cases revealed that the difference between the two modes is statistically significant (p=0.008<0.05). Although there is no clear explanation for this observation, reaction times are probably affected by the fact that, during landing, runway conflicts tend to be less critical in terms of TTLR and this may result in a slight hesitation in pilot reaction if an alert is not assertive.

4. Conclusions

This work has demonstrated that directive alerting is a robust approach to mitigating runway conflicts, with pilots responding positively to the concept. The major findings of this work are:

- Aural directive alerting should be used in safety-net functions to mitigate runway conflicts.
- The aural alerts ‘STOP TRAFFIC’ and ‘GO-AROUND TRAFFIC’ repeated with a separation of 2.5s were found to be satisfactory.
- The aural alert should be augmented by a textual visual display confirming the alert.
- An introductory auditory tone is not preferred and its insertion before the alert repetition may be appropriate if the tone is to be retained.
- If the explicit command to stop or go-around are not preferred, then the alerts should be designed to be interpreted as instructions to stop or go-around and not to simply alert pilots of a conflict.
- Remaining silent in the continued case appears satisfactory but introduces the risk of being confused with system malfunction.
- Suppressing alerts at V_1 is in line with alerting strategies currently employed in the cockpit.
- Distance call-outs to the conflict are very useful and should be included.
- Clear instructions to follow the alert need to be enforced through SOPs. Authority to delay a go-around in good visual conditions where the conflict aircraft is positively identified visually may need to be considered.
- Use of the airport moving-map is not preferred, although the technology will be available on the aircraft.
- Conflict mitigation during taxi/back-track/line-up is challenging and needs further work to ensure effective alerting.

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