DESIGN AND PRELIMINARY PILOT ASSESSMENT OF A DIRECTIVE RUNWAY CONFLICT ALERTING AND RESOLUTION SYSTEM

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Abstract

As runway incursions continue to occur, a radical change is required in the technique used for runway conflict mitigation. This paper presents the concept of an airborne runway conflict alerting and resolution system that generates directive alerts to the crew in order to instruct them on the action that should be taken to resolve the conflict. The system proposed utilises aircraft performance calculations to evaluate the viability of potential escape manoeuvres that could avert a collision as the basis of directing the crew into taking the safest action. A preliminary pilot assessment of the directive alerting philosophy has been carried out to qualitatively assess crew acceptance of this novel alerting philosophy in runway conflict mitigation.

1 Introduction

During runway operations, aircraft are constantly operating in close proximity of other aircraft and other vehicles. Separation from such hazards, therefore, is of prime importance in assuring the safe continuation of the manoeuvre. In controlled airfields, the ATCO is responsible for the control of traffic in and around the airfield and it is the ATCO who provides clearances for aircraft to enter a runway, take-off or land. It is therefore the ATCO who ensures that any movements are well clear of the particular aircraft in take-off or landing. In essence, the ATCO reserves the runway (or a portion of it) for the exclusive use of this aircraft and procedures are rigorously followed in order to ensure safe separation from other aircraft and vehicles. Nevertheless, it is good airmanship for pilots to independently ensure that they are cleared to enter a runway, land on it or take-off, that the approaches of a runway are indeed clear before entering it and, before taking off or landing, that the runway itself is clear. Such actions are, of course, more effective in situations of good visibility and in reduced visibility and bad weather, pilots and ATCOs are more careful to ensure that separation is indeed maintained. In fact, reduced visibility operations are subject to more stringent separation rules, where separation between aircraft is intentionally increased and certain manoeuvres are not allowed. Therefore, whereas the procedure dictates that the ATCO is responsible for traffic separation, the pilot also plays an active role in ensuring that the required separation is indeed preserved. The pilot also plays a critical role in restoring this separation when it is lost and this role is essential for the mitigation of the risk of collision.

However, notwithstanding rigorous procedure, training and good practice, the current procedural method of maintaining separation is prone to failure. This repeatedly results in aircraft and vehicles coming in conflict with one another on the runway. Indeed, in the US alone, during the period 2004 to 2007, 1353 runway incursions have been reported[1] [1].

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[1] Based on the FAA definition of a runway incursion prior to 2008. Definition: *any occurrence in the airport runway environment involving an aircraft, vehicle, person or object on the ground that creates a collision hazard or results in a loss of*

Current procedure, therefore, can be considered inadequate to ensure runway safety and thus needs to be complemented by a means that monitors traffic in the vicinity and warns the pilot accordingly. In a way, a sort of 'electronic-eyes' are required in order to substitute the human eyes of the pilot (or ATCO) when he or she fails to see or detect the conflict.

1.1 Runway Collision Avoidance Systems

A number of solutions have been proposed in an attempt to mitigate the risk of runway collisions. These can conceptually be divided into two philosophies, namely ground-based systems that are installed in an airport and airborne solutions that are installed on board aircraft (and therefore are independent of equipment installed in airports).

Several airports have already been equipped with ground based systems capable of advising ATC in the case of a runway incursion and these have shown to be effective in a number of conflict cases. However, the very nature of ground based systems introduces delays between the time the conflict is detected at the ATC station and the time the crew of the aircraft concerned take evasive action to mitigate the conflict. This is inadequate in certain circumstances, since reaction time may be critical for the safe avoidance of the collision. A further limitation is that ground-based systems depend on the ATCO transmitting the correct instruction in a timely, efficient and unambiguous manner over the radio. In critical situations, this may be a demanding task and indeed may even not be managed successfully. For these reasons, therefore, ground based systems can only provide a partial solution to the problem of runway traffic conflicts.

This suggests that an airborne system is required to effectively mitigate the hazards associated with runway incursion, with the scope of reducing the time between system alert and pilot reaction. Ideally, crews should be alerted of a potential runway incursion before it develops. Various approaches can be adopted, such as alerting the crew that a particular runway is being approached. However, due to human error, this technique may not completely resolve the problem and a method that alerts the pilot of an error or conflict once committed will still be required as a last-resort safety net. This, however, requires the system to be aware of the clearances given to the crew, possibly via Controller Pilot Datalink Communications (CPDLC). However, CPDLC is known to potentially have a latency of up to several tens of seconds and this renders the application useless as a means of reliably alerting the occurrence of a runway incursion.

An alternative strategy to clearance monitoring is to provide traffic surveillance to determine whether a potential physical conflict with another aircraft or vehicle on the runway exists. Whilst such a system does not protect against the violation of clearances, it can provide independent, robust and complete protection against runway conflicts and thus mitigate the risk of collision.

Providing on-board alerting in the event of a conflict in take-off or landing is an improvement over the current operational standard. However, in providing advisory alerts via the visual and/or auditory channels that only advise the crew of the existence of a conflict situation, the crew are essentially tasked with the problem of identifying what action should be taken. Besides introducing the problem of correctly interpreting the conflict scenario – which is critical in the decisions that need to be taken to resolve the conflict, such alerting may add significant workload to crew in critical moments of the take-off or landing. Indeed, following the annunciation of an alert, the crew must perform four sequential mental and physical processes to resolve the conflict. First, they must identify the conflict and its position in relation to that of their own aircraft (referred to as the ownship aircraft). Then they must identify a manoeuvre that will successfully resolve the conflict. Next they must decide to

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required separation with an aircraft taking off, intending to take off, landing or intending to land.

execute this manoeuvre and finally actually execute it.

These four steps can take several seconds to complete, even under normal working conditions. The high workload environment during take-off or landing and the inexperience of crew in handling such situations further compounds the problem, thereby increasing the chances of the crew hesitating in taking the correct action and may even lead to an incorrect decision in the circumstances. Indeed, human decision-making capabilities and reaction times are heavily compromised under high workloads and when threatening situations are announced without prior warnings. As a result, the chances of the crew erring in any of the four named steps, thereby breaking the path to successful conflict mitigation, is significant.

Consequently, this work is aimed at tackling these exact problems through the design of an onboard system that, apart from being capable of monitoring the traffic movements in the vicinity of the ownship or its intended path and determining whether a conflict or potential conflict exists, it is capable of determining an escape manoeuvre that will successfully resolve the conflict, thereby relieving the crew of three of the above four steps and consequently significantly simplifying the human processes involved in conflict mitigation. Logically, this requires the design and implementation of an appropriate cockpit alerting scheme to reliably support the transfer of information to the crew in a timely manner through the auditory and visual channels.

2 The Runway Collision Avoidance Function (RCAF)

The system being proposed, referred to as the RCAF, has an architecture based on the traffic management model described in [2]. It incorporates the three basic functional requirements of traffic surveillance, conflict detection and conflict resolution. The surveillance and conflict detection module performs the necessary operations to monitor the aircraft surroundings for intruding traffic and generates a conflict flag once a physical conflict is detected. The role of the conflict mitigation module is to then select the most appropriate manoeuvre to avoid the collision. Figure 1 shows the high level functional blocks of the RCAF and its interaction with the environment.

When an aircraft is cleared to make use of a runway for take-off or landing, the designated runway is essentially reserved for sole use by that aircraft. Any other aircraft or vehicle entering this reserved area results in a runway conflict. For this reason, it is natural to design a conflict detection algorithm based on this concept. This is similar to the concept of a `protected zone' or no transgression zone (NTZ) surrounding an aircraft whilst airborne, which defines a region into which no other entity must enter to ensure safety of the flight [3,4].

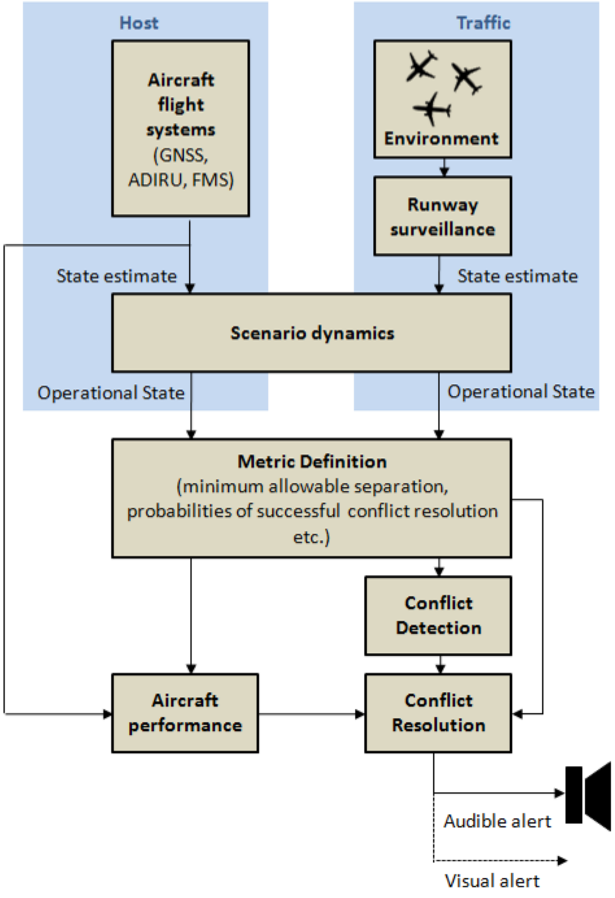


Figure 1 – The RCAF Architecture

The protected zone of an aircraft during runway manoeuvres can be defined as the entirety of the runway [5], extended in length and width by some fixed amounts (Figure 2). Although a procedural conflict is caused whenever traffic enters the protected zone assigned to the ownship, this does not always result in a physical conflict or a risk of collision. For example, the entry of a vehicle or aircraft on the runway behind the ownship during take-off constitutes a runway incursion from a procedural perspective but poses no particular risk of collision. In such circumstances, it is considered inappropriate to alert the crew of the runway incursion, as this would distract them unnecessarily from the manoeuvre they are conducting, thereby inadvertently increasing the risk of accident. This and other such considerations have resulted in the identification of the need to develop a generic conflict detection algorithm based on a set of rules that are functions of the kinematic states of the movements involved as well as the dynamics of the scenario. Overall, it is the quality of these rules that determines how nuisance alerts are suppressed or avoided. Although the design of the conflict detection algorithm is a critical consideration in the whole design of the solution, it is not the subject of this paper, as it is already available in the literature [6, 7].

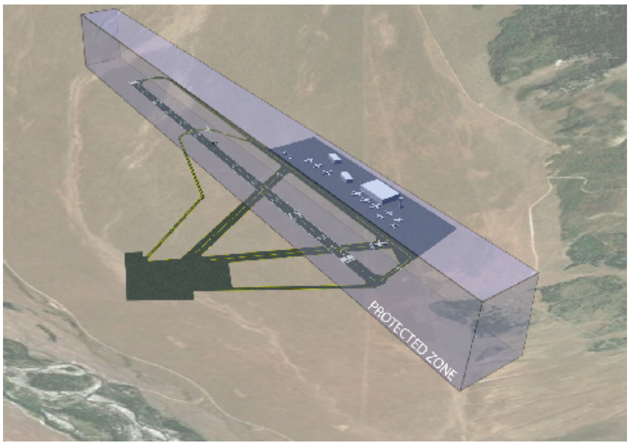


Figure 2 - Definition of the Protected Zone (in blue)

Once the RCAF detects a runway conflict, the conflict resolution engine is required to determine an escape manoeuvre that will successfully resolve the conflict. Determining a feasible escape manoeuvre during a runway operation requires the consideration of the performance capability of the aircraft.

2.1 Conflict Mitigation During Takeoff

To maintain compliance with standard operating procedures, runway conflict avoidance manoeuvres for an aircraft in take-off are reduced to one of two: continue take-off or rejected take-off. Naturally, the selection of one manoeuvre over the other depends on which solution is the most advantageous, resulting in the least possible danger to human life and aircraft damage. Therefore, mitigating a runway conflict during take-off requires an assessment of the aircraft's take-off performance. In this manner, it would be possible to predict the distance required for the aircraft in take-off to become airborne and reach the screen height. Similarly, in the case of an aborted take-off at any speed below V_1, it would be possible to predict the position on the runway where the aircraft would come to a halt. As a result, in the situation where a runway conflict does occur, an assessment could be done on what action (continued or aborted take-off) is best suited to reduce the probability of collision.

EASA Part 25 regulations [8] define the take-off distance required (TODR) as being the distance required for an aircraft to reach the screen height from brake-release. Regulations also define the distance required from brake-release to lift-off and this is referred to as the take-off run required (TORR). The distance required for an aircraft to a halt after an abort at the most critical moment (V_1) is called the accelerate-stop distance required (ASDR) or emergency distance required (EDR). TODR, TORR and ASDR are depicted graphically in Figure 3. These lengths are dependent on aircraft type, as well as environmental and operational conditions such as ambient temperature, pressure and humidity, wind conditions, runway slope, aircraft weight and thrust settings, and flap configuration. Consequently, operators calculate the expected (scheduled) distances required for each take-off prior to dispatch, taking into consideration many of the factors to ensure that the runway distances available (defined as TODA, TORA and ASDA) accommodate those required. Regulations also specify that an aircraft must be capable of continuing safe flight even if one engine fails during any phase of the journey, including take-off. Therefore scheduled distances (TODR, TORR and ASDR) are based on the occurrence of one engine failure at the most critical point during take-off.

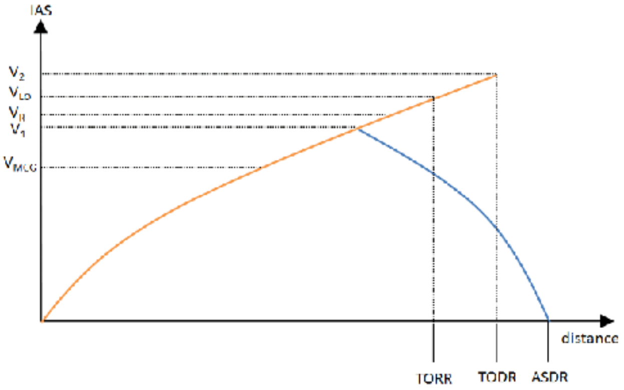
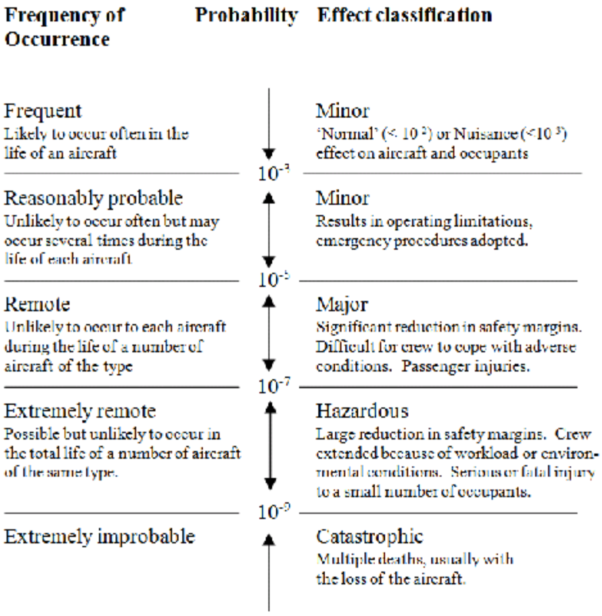


Figure 3 - Take-off Performance Schedule

The regulations also define gross and net performance. Gross performance refers to the average expected performance of an aircraft in the scheduled (planned) manoeuvre. Hence, gross performance essentially defines distances that, statistically, an aircraft is expected to have a 50% chance of exceeding. For this reason a leeway is introduced in TODR and TORR for the AEO case, to reduce the probability of exceeding these distances to a level of 10^{-7}. Statistically, this requires an addition of 5 standard deviations (5σ) to the average (gross) distances, resulting in what is referred to as net performance distances. Since σ is about 3% [9], the addition of a 15% leeway to TODR and TORR is adequate to ensure that all but 1 in 10^{-7} take-off runs will not exceed these allowances.

In the case of rejected take-off (RTO) the distance of interest is that required to bring the aircraft to a halt. The distance travelled during the transition phase of a RTO (the aircraft motion as the crew commence the abort by reducing thrust and applying speedbrakes and braking devices) cannot be quantified analytically and can only by estimated by allowing for the regulated quantity of time (typically 2s [16]) for the crew to reduce thrust and deploy maximum braking. However, whereas in the acceleration phase, the reliable prediction of distance is possible through the accurate modelling the acceleration profile, this is not the case during deceleration, where the frictional coefficient is highly dependent on the braking capacity, tyre wear and actual runway surface condition.

Table 1 - Classification of Failure Condition. Adapted from CS-25 [8]



Frequency of Occurrence	Probability	Effect classification
Frequent Likely to occur often in the life of an aircraft	↓ 10^{-3}	Minor 'Normal' ($< 10^{-2}$) or Nuisance ($<10^{-3}$) effect on aircraft and occupants
Reasonably probable Unlikely to occur often but may occur several times during the life of each aircraft	↕ 10^{-5}	Minor Results in operating limitations, emergency procedures adopted.
Remote Unlikely to occur to each aircraft during the life of a number of aircraft of the type	↕ 10^{-7}	Major Significant reduction in safety margins. Difficult for crew to cope with adverse conditions. Passenger injuries.
Extremely remote Possible but unlikely to occur in the total life of a number of aircraft of the same type.	↕ 10^{-9}	Hazardous Large reduction in safety margins. Crew extended because of workload or environmental conditions. Serious or fatal injury to a small number of occupants.
Extremely improbable	↑	Catastrophic Multiple deaths, usually with the loss of the aircraft.

The distance required from break release to a full stop (ASDR) is scheduled as a gross distance by regulation, and this again results in only a 50% chance of successfully reaching a halt in the allowed distance (assuming the run is aborted at V_1). This implies that, when using scheduled performance as the basis of collision avoidance, an additional leeway needs to be added to allow for a higher probability of stopping in the allocated distance.

The distance required for the aircraft to be brought to a halt after aborting a run at any speed $V_X < V_1$ is likewise known a priori, through scheduled performance calculations. The total distance from break release to a halt after aborting a take-off at V_X is herein termed

$ASDR_X$. The distance-velocity graph for various abort initiation velocities is as shown in Figure 4 allowing for a 2 second reaction time at V_X.

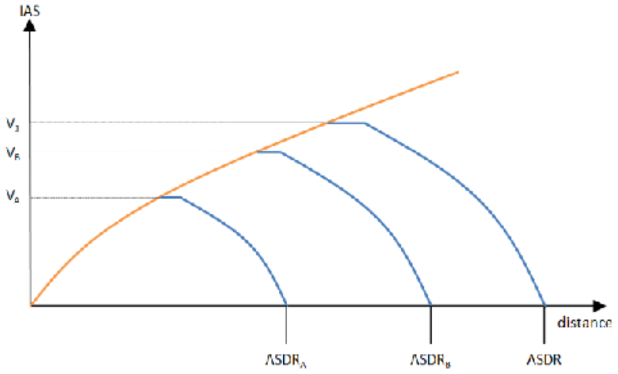


Figure 4 - ASDR factored for various abort initiation velocities

In general, the deceleration characteristic of an aircraft during braking is dependent on the braking force and idle thrust characteristics, with the former being of larger influence. For large aircraft, braking force and thrust are generally related to speed by quadratic polynomials [10-13]. Thrust polynomial coefficients depend on several atmospheric parameters including pressure and temperature. The braking force polynomial coefficients are highly dependent on the frictional coefficient between the aircraft tyres and the runway surface. Scheduled braking distances cater for atmospheric variations by compensating for airport altitude and temperature and cater for surface condition by tabulating gross distance variations with runway friction index (RFI). In a joint study [10] by NASA, Transport Canada and the FAA on business jets, medium and large aircraft, the frictional coefficient μ was experimentally found to be approximately constant with airspeed with a slight drop in μ at higher speeds and approximately linearly related to the RFI. Rather than using a best linear fit through the experimental data points of RFI versus μ, a minimum performance fit is taken such that only 5% of the data points fall below the fit. In this manner, the linear fit provides a 95% confidence when tabulating the aircraft braking coefficient with RFI, leading to the same confidence limit in the scheduled braking distance required.

In the event of a runway conflict occurring during take-off, the scheduled TODR and $ASDR_X$ could be used to assess whether a continued or aborted take-off (stop or go) would be the more beneficial in the circumstances. Since regulations defines TODR as the take-off distance required to reach the 35ft screen height, an additional distance to the net TODR is required to ensure sufficient vertical clearance between the ownship and the intruder. As a first approximation, this additional distance Δ can be calculated assuming the regulatory minimum first-segment climb gradient tabulated in the aircraft flight manual (AFM).

Consider a runway conflict as depicted in Figure 5, where the intruder enters the protected zone far down the runway such that there is sufficient runway distance left for the ownship to continue the take-off and clear the intruder as well as a sufficient distance to abort the run and bring the aircraft to a halt before reaching the intruder. In this case, although a continued take-off is possible and leads to the least economic impact, a runway conflict has indeed occurred and crew are procedurally required to abort the run. In a similar situation where the intruder is positioned outside the ownship's $ASDR_X$ but within the ownship's TODR, then the only viable manoeuvre for conflict mitigation is that of performing a RTO.

In the situation depicted in Figure 6, the intruder's position is such that the ownship can successfully complete the take-off in the distance remaining but however cannot successfully come to a halt in the case of a RTO. In this case, continuing the take-off and flying over the intruder safely is clearly the preferred solution.

The third combination considered is when the intruder enters the runway such that there is insufficient distance remaining for the ownship to safely fly over the intruder and also insufficient distance for the ownship to perform a RTO and come safely to a halt prior to reaching the intruder (Figure 7). In such a case attempting to continue the take-off normally or rotate earlier is not an accepted option, as this could readily result in a high speed collision with the ownship either still on the ground or having just become airborne before it will have reached sufficient height to clear the intruder. For this reason, the consequences of performing a RTO outweigh those of the continued take-off case. By initiating braking, the aircraft's energy is being dissipated, improving the chances for the crew to take a lateral evasive manoeuvre to avoid the collision or at worst be involved in a low speed collision.

2.1.1 Operation at the stop/go boundaries

In the case where the decision to go or stop is marginal, any uncertainty in aircraft performance or aircraft position can significantly impact the outcome of the decision. Both the ownship's and intruder's reported position suffer from measurement error. The ownship's position, derived from GPS data, has a scatter following a bivariate Gaussian distribution in the order of 3m-9m dRMS horizontally[2]. The intruder's reported position is derived from ADS-B which in turn is also supplied with GPS data for reporting. ADS-B packaging of data suffers from quantisation errors, which however are not significant, compared to the accuracy of GPS. Consequently, the overall intruder reported position is also bivariate Gaussian distributed with typical accuracy in the order of 3m-9m dRMS. Whilst the distribution of GPS derived errors follows an elliptical distribution in the horizontal direction, it can be very well approximated as circular owing to good unobstructed satellite coverage and hence low HDOP values. Working with this approximation, dRMS defines the 1.41σ (63%) containment circle of reported positions. To ease analysis, the error in reported position of the ownship could be reflected onto the intruder (or vice-versa), with the ownship then being represented as error free. Consequently, the additive reported error for both mobiles is in the order of 4m-13m dRMS. When both mobiles are subscribed to a differential GPS service, accuracy is improved, typically between 0.4m-1m dRMS for the ownship and 1m-1.4m dRMS for the intruder due to ADS-B quantisation error[3]. The additive reported error for both mobiles is then between 1m-1.7m dRMS.

The uncertainty in the range to the intruder and its associated probability density function can be used in conjunction with the theoretical probability density function associated with gross performance to estimate the probability of the stop and go decisions being successful in avoiding the conflict. This will require intensive numerical computation, which is not appropriate for the application. Consequently, simplified rules can be implemented to provide an estimate of the probability of a go or stop action would be successful. The final decision taken would then be based on these probabilities and, potentially, on the implications of the outcome being unsuccessful. For illustrative purposes, consider a scenario where the ownship has an equal probability of successfully overflying an intruder (if the take-off is continued) and of coming to a stop before it (if the take-off is aborted). The implications of failure of the two manoeuvres would not be the same, as the former would most certainly result in a high speed collision, whilst the latter would have a lower collision speed and therefore probably result in less injury or death.

Such a consideration, however, is a point of major debate and potential controversy. Firstly, this approach would complicate certification. Secondly, the method needs to be acceptable to the pilot community. Furthermore, liability issues and legal interpretation may influence acceptance by operators. Consequently, this issue needs to be addressed further before implementation.

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[2] The variation in accuracy is mainly dependent on the satellite coverage and geometry, quantified by horizontal dilution of precision (HDOP). At the 99.9th percentile, HDOP is less than 1.77 worldwide for unobstructed view.

[3] Assuming a 2.4m uniform quantiser, being the worst case quantiser for MODE-S, UAT and VDL-4 datalinks.

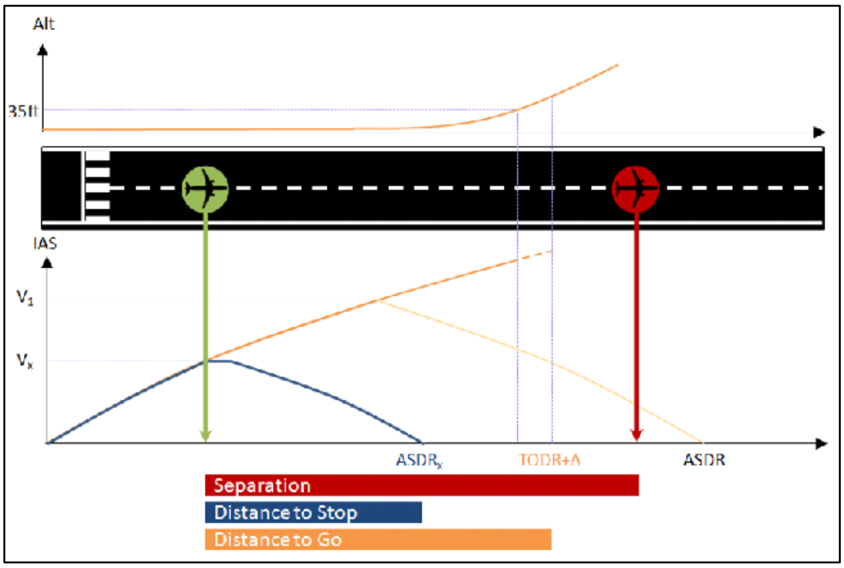

Figure 5 - Runway Conflict during Take-off - Can go, Can Stop

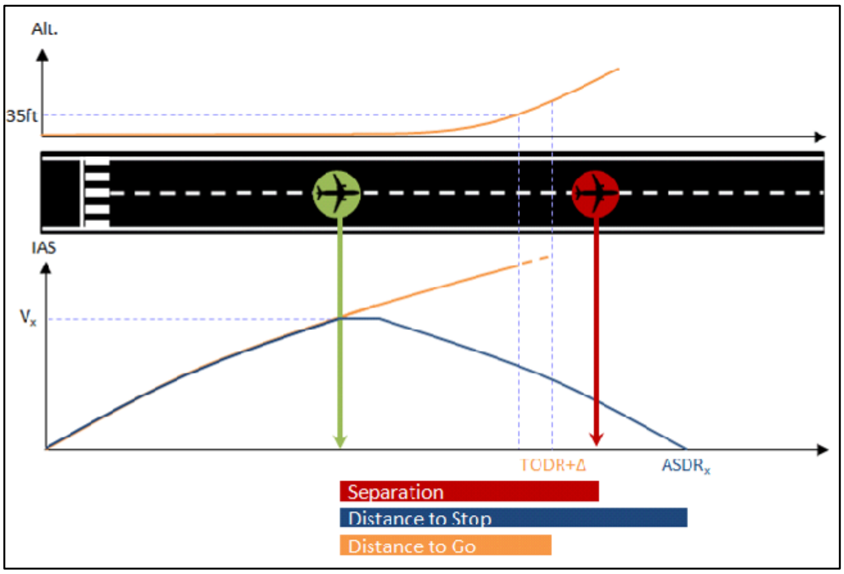

Figure 6 - Runway Conflict during Take-off – Can go, Cannot stop

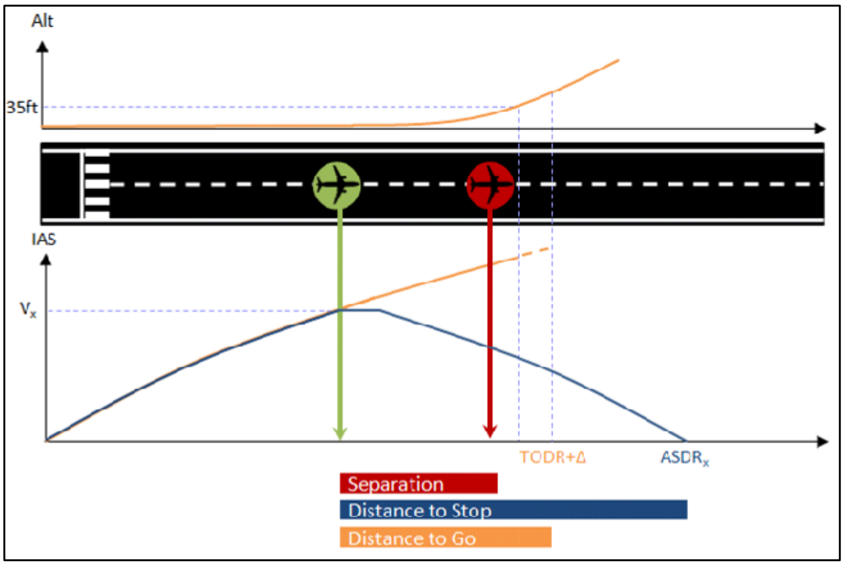

Figure 7 - Runway Conflict during Take-off - Cannot go, Cannot Stop

2.2 Conflict Mitigation During Landing

Runway conflicts occurring with the ownship in final approach are relatively easily mitigated by initiating a missed approach. However, the generation of unnecessary missed approaches needs to be mitigated. Such false alerts would certainly reduce confidence in the system and may have safety implications in situations where the ownship is low on fuel or in the case of bad weather. The risk is especially of note in busy airports, where it is normal for traffic to be present on the runway (albeit perhaps vacating) whilst the ownship is approaching the airfield to land. Consequently, to avoid the generation of nuisance warnings, the location of any conflicting traffic on the runway with respect to the ownship's expected landing distance requirements (LDR) is considered.

Regulations define the landing distance as the sum of the airborne distance from the screen height over the threshold to touchdown and the ground distance from touchdown to when the aircraft is brought to standstill. The ground run is calculated based on a dry runway using maximum braking, with a one second delay for deployment of automatic brakes. Credit for the use of thrust reverse is not considered. The landing distance of a particular aircraft is demonstrated during certification flight tests and the average is termed the unfactored or actual landing distance (ALD).

In practice, however, there are various operational factors that affect the repeatability of the landing distance. The most significant is piloting technique, where the flare and touch-down manoeuvre have a significant impact on the overall ALD. Naturally, automatic landings such as those associated with Category IIIB operations[4], should result in higher repeatability than manual landings. In fact, auto-land dispersion is found to exhibit a normal distribution [14,15]. Manual landings, in comparison, can be expected to exhibit a larger variation that may not be normally distributed. As in the rejected take-off case, the deceleration distance during landing is highly dependent on the frictional coefficient and cannot be modelled accurately, particularly on wet or contaminated runways without precise knowledge of the braking coefficient.

Part 25 regulations state that the certified ALD must be factored by 1.67 for dry runways to compensate for these variations and an extra 15% (resulting in an overall factor of 1.92) for wet runways. The factored ALD is called the landing distance required (LDR). This means that for a dry runway an aircraft should land within 60% of its scheduled LDR, allowing 40% margin. However, when operating on a wet runway, the 1.92 factor is based on the dry runway certified landing distance. Whilst this provides no insight to the available margin of error [8,16], these allowances were assumed to constitute 5 standard deviations of a normally distributed density function characterising the distribution of landing distance.

When the ownship is in the approach for landing and has still not crossed the runway threshold, the threat posed by third party aircraft manoeuvring on the runway surface depends on its position on the extended runway centreline. For instance, an aircraft taxing at the far end of the runway outside the ownship's LDR, possibly with the intention of vacating shortly, could be of little threat to the safety of the ownship. In such circumstances, delaying the generation of an alert until the situation develops further would not mpact safety whilst being beneficial in avoiding the execution of a missed approach that could be avoided. In such circumstances, suppression of the alert is maintained until the ownship reaches the 50ft screen height. If traffic is still present on the runway, albeit being beyond the ownship's LDR and the ownship reaches the screen height, a missed approach is considered to be the safest and preferred option in accordance with current procedures. In the case of Land and Hold Short (LAHSO) operations, the effective runway length and associated protection zone are based

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[4] Precision instrument approach and landing which could be used in low visibility with runway visual ranges down to 75m. The autopilot is used until taxi-speed

on the length of runway associated with the landing manoeuvre.

In comparison, a conflict event such as that involving an aircraft lined up for take-off on the runway on which the ownship intends to land poses a much higher safety risk and thus requires earlier action with the ownship initiating a missed approach. Nevertheless, the generation of such an alert still needs to be delayed until it is evident that the conflict will not be resolved without ownship intervention, in order to avoid unnecessary missed approaches. Thus, the timing of the generation of the alert on the ownship is based on the ownship's performance and the need to maintain a minimum safe separation with the intruder under conflict conditions.

From this discussion it is evident that the logic for alerting during landing is partitioned into two phases; that prior to the ownship reaching the threshold and that once the ownship surpasses the threshold. A runway conflict occurring with the ownship on or beyond the threshold requires immediate alerting to direct the crew into conducting a missed approach. However, prior to reaching the threshold, the intruder's position on the runway determines whether the alert is issued or not. If the intruder is within the ownship's LDR, the alert is issued as late as possible whilst assuring that the missed approach is performed safely. If the intruder is beyond the LDR, then the alert is suppressed until the ownship reaches the threshold, when the conditions of conflict are assessed again prior to the generation of any alert.

3 Alerting Scheme

Due consideration was given to the Human-Machine Interface (HMI) of the system. The RCAF makes use of the aural channel for providing the directive alerts as this is the fastest way of attracting the crew's attention without added head-down time. However, aural alerts cannot provide information relating to which aircraft is in conflict and where it is situated on the airfield. The merits of having such additional information in the cockpit were left to simulator assessment and evaluation and consequently. In order to support this, the RCAF was given the capability of driving an airport moving map display, which, in the case of an alert would highlight the conflicting traffic.

3.1 Alerting During Take-off

During normal operation, the RCAF is silent and generates no alerts, having no effect on normal take-off procedures.

In the event of a runway conflict, where the algorithm determines the safest evasive manoeuvre as being a RTO, a *'WHOOP WHOOP - STOP-TRAFFIC'* alert is generated[5]. The 'Whoop Whoop' lasts 1 second and is similar in principle to current GPWS 'Pull-Up' alerts. It is intended as an attention grabber prior to the verbal instruction. The verbal instruction first advises the crew on the manoeuvre that needs to be executed immediately, followed by the rationale behind the instruction. This alert state is sustained and the completed alert repeated periodically every 4.5 seconds until the crew initiate the abort by retarding the thrust levers or initiating braking. On the generation of such an alert, operating procedures will require the crew to immediately follow the directive alert and initiate the RTO sequence. During deceleration, distance call-outs to the intruder are generated to give the crew an indication of the separation left in metres[6] between the ownship and the intruder as well as indicating closure rate as the callouts are generated sequentially (eg. *'900...800...700'*). Once the conflict is resolved, a *'CONFLICT CLEAR'* alert is generated.

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[5] The exact wording of the alert itself is not critical to scope of the study and could be modified to suite manufacturer/operator convention.

[6] Distance call-outs may alternatively be made in feet, depending on airline operating procedures.

In the event of a runway conflict where the safest option being a continued the take-off, the RCAF remains silent and the crew are expected to continue the takeoff by following Standard Operating Procedures (SOPs).

The logic driving the directive alerts during take-off is depicted in Figure 8.

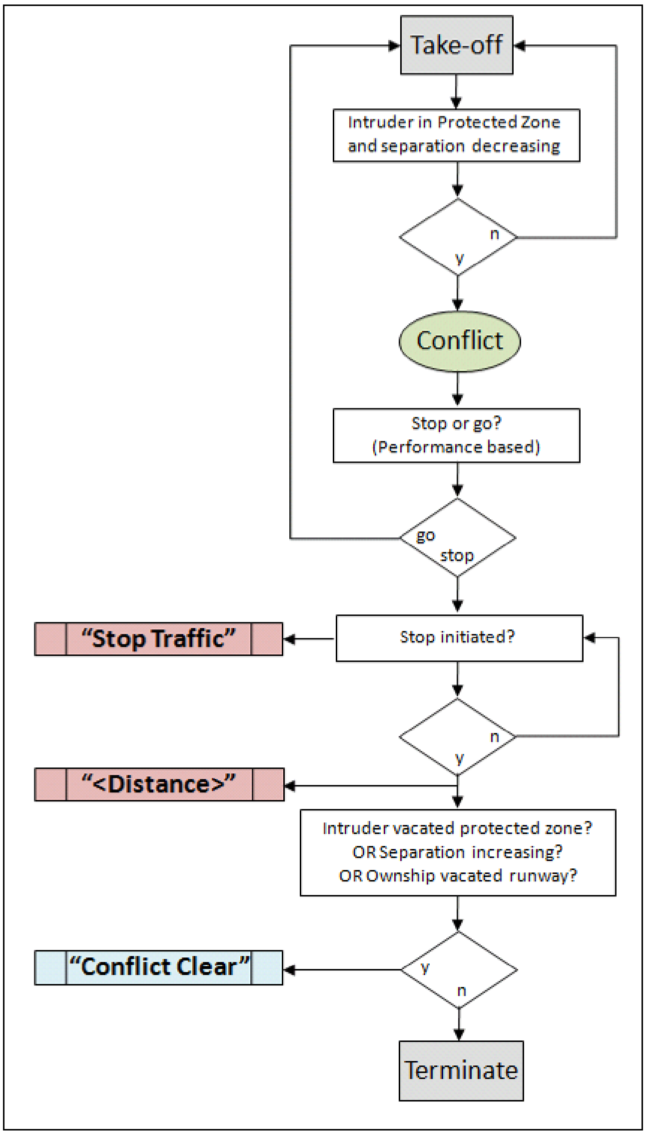

Figure 8 - Logic Diagram for alerting during Take-off

3.2 Alerting During Landing

As in the take-off case, no alerts are generated during normal operation and the RCAF has no effect on SOPs for normal conditions.

In the event of a runway conflict, the crew will be instructed to perform a missed approach with the alert 'WHOOP WHOOP - *GO-AROUND, TRAFFIC*'. As in the case for take-off, the alert starts with an attention grabber and is repeated every 4.5 seconds until the crew initiate the missed approach procedure, detected by the appropriate re-setting of the thrust levers. Once again, procedures would require the crew to immediately react to the alert and conduct the directed manoeuvre. As in the take-off case, a '*CONFLICT-CLEAR'* alert is generated once the conflict is resolved.

If a runway conflict occurs after the ownship has touched down and is decelerating, then the aircraft is committed to continue to landing manoeuvre. In this case, the scenario is similar to rejecting the take-off in the event of a conflict during take-off. The algorithm likewise issues a single 'WHOOP WHOOP - *STOP-TRAFFIC*' alert followed by distance call-outs.

In the case of a suppressed alert (or delayed with the intention of reducing nuisance alerts), the RCAF remains silent, indicating that the crew is expected to continue their approach by following SOPs.

The logic driving the directive alerts during landing is depicted in Figure 9.

4 Preliminary Pilot Assessment

A preliminary assessment of the RCAF's novel alerting methodology was conducted on Cranfield University's Large Aircraft Flight Simulator. This simulator provides an immersive environment typical of a large transport category aircraft. The cockpit environment is based on that of a Boeing 747, with a mix of Airbus and Boeing cockpit features being introduced, rendering the environment generic (Figure 10). The simulator has collimated optics to allow for realistic cross-cockpit viewing. This is an important feature in the current study.

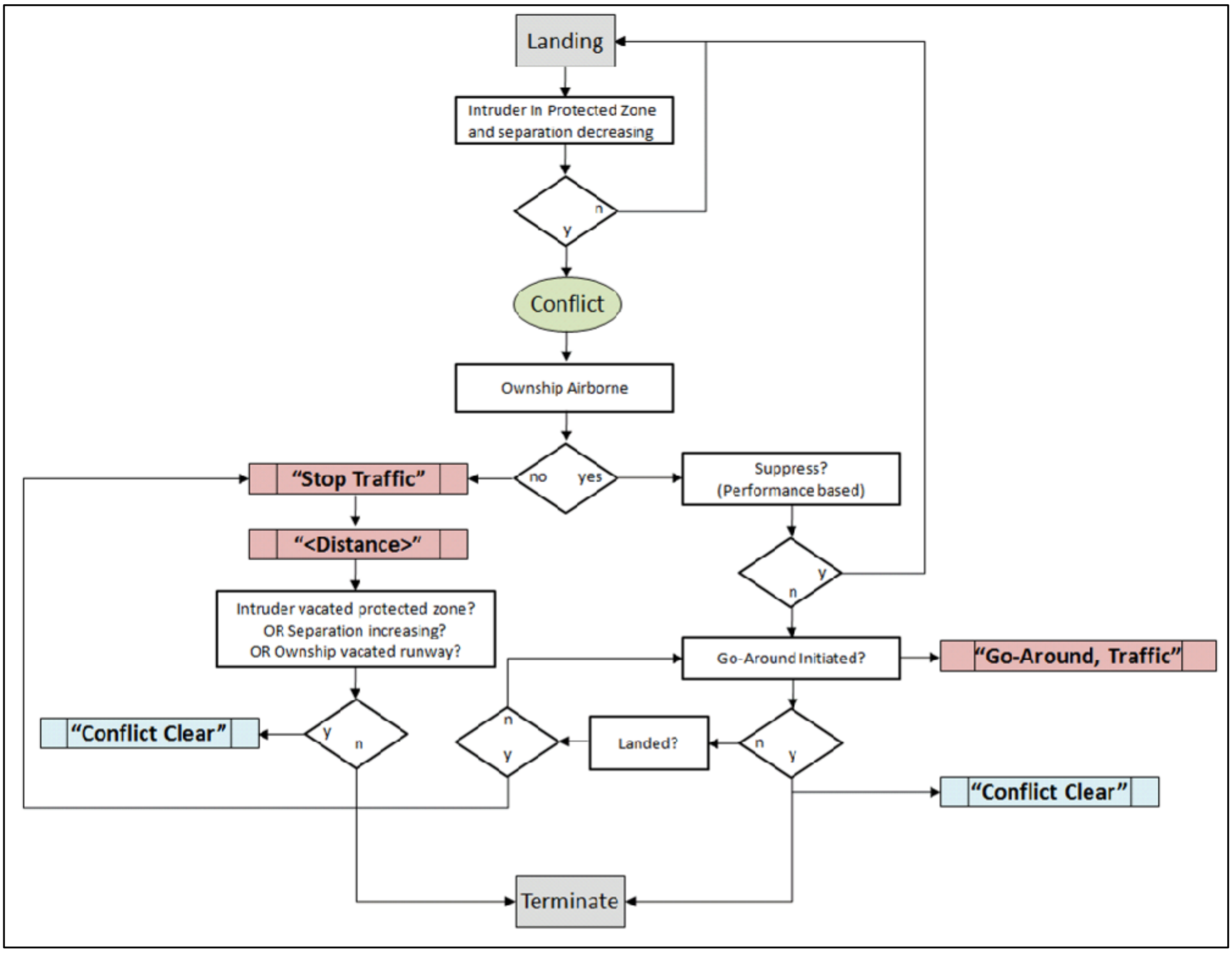

Figure 9 - Logic Diagram for Alerting during Landing

4.1 Scope and Assessment Procedure

The scope of the preliminary assessment was to assess the general validity and effectiveness of the alerting scheme prior to full pilot evaluation. This provided the opportunity to test the general qualitative attributes of the alerting at an early stage, thus allowing the authors to introduce any improvements that may be necessary prior to finalisation of the alerting scheme. In this way, the value of the pilot evaluation exercise could be maximised.

A group of 2 crew sets (4 pilots) was selected to participate in the preliminary pilot assessment. The two crews were taken from pool of respondents aged between 24 years and 50 years. Both Captains and senior First Officers took part and all were type rated and current on the Airbus A320. The participants were asked to participate in the experiments designed for the eventual pilot assessment [17]. The specific scenarios used for the eventual pilot evaluation are presented in Table 2. These were designed to cover different phases of the take-off and landing manoeuvres, thus providing for a comprehensive assessment of the alerting philosophy. All except for scenarios 1 and 3 were used in the preliminary pilot assessment described herein. Of these, only Scenario 8 was not set in low visibility conditions. Low visibility was intended to preclude the crew from seeing the intruder by the time an alert is generated. Scenario 8 was designed to test the impact of crews seeing the intruder, thereby effectively providing two independent channels of information relating to the conflict (the visual channel and the alerting channel). Each of the selected 12 scenarios was operated in crews of two ensuring ecological validity, with the more senior member acting as the pilot in command (PIC). After performing half the scenarios, the role of the pilot flying (PF) and pilot not flying (PNF) was swapped with the intention of reducing the element of learning, with regards to the generation of alerts.

Figure 10 - The Cranfield Simulator

The scenarios were designed to exercise the algorithm in typical runway conflict situations. Seven scenarios were targeted to test the algorithm with the ownship in take-off. During these scenarios, the runway conflict was generated at various ownship speeds (low, medium, high and at V_1) and with various visibility conditions, with the scope of monitoring the crew reaction and compliance to the alerts.

The assessment exercise involved asking questions to the participants after each scenario in order to capture their impressions before moving on to the next scenario. This allowed the gathering of qualitative information that was intended to address the following attributes:

1. The acceptance of the directive alerting concept for runway incursion alerting
2. The clarity of the alerts
3. The value of the whooping tone preceding the verbal instruction.

4.2 Results and Discussion

4.2.1 Acceptance of the Alerting Concept

The crews responded positively to the alerting concept, claiming that they are ‘happy with it’ and that they did not hesitate to follow the instruction on all occasions (all scenarios). This indicated that the philosophy should be acceptable on the flight deck. However, it must be kept in mind that, although all crews had flown the Boeing 737 (classic series), they were, at the time, flying the Airbus A320. The two major airframers have divergent cockpit philosophies and as a result, the response cannot be considered to reflect pilots flying Boeing aircraft.

The generation of no alert in the case of continuing a manoeuvre was also received positively, despite the authors’ concern that it could be interpreted as a failure of the system. The crews’ view was confirmed with their response in Scenario 8. In this setup, the intruder was programmed so that it crossed the hold short bar and proceeded to enter the runway such that if the take-off were to be aborted, a collision would occur, whilst if the take-off were to be continued, the intruder would be avoided. The target aircraft could be easily seen and the pilots did not hesitate to continue the take-off with the RCAF generating no alert. Furthermore, they reported that this did not lead them to suspect that the system had failed and thus did not compromise their confidence in the system, as they are used to this philosophy of cockpit alerting.

The crews also had no hesitation to follow the directive alert in all manoeuvres and considered it to be ‘very good’.

Furthermore, the distance call-outs were also considered very useful, particularly in low visibility conditions. They were also considered a very good aid to assess the deceleration rate being achieved.

Table 2 - The Test Scenarios

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

4.2.2 Clarity of the Alert

The alerts were considered to be clear as the crews had no difficulty with immediately reacting as instructed.

4.2.3 Value of the Whooping Tone

The crews did not respond favourably to the whooping tone. Mainly this was because they felt it delayed the generation of the verbal instruction and that distracted from their timely reaction to the threat and therefore compromised the effectiveness of the system. Indeed, a one second can make all the difference in critical circumstances, with an aircraft travelling at 100kts covering 50m in this time. It was also mentioned that on the ground, the tone could instinctively lead to an abort manoeuvre (stop) if crews did not wait for the tone to terminate before reacting and then this diluted the value of the verbal instruction. As a result, all pilots preferred the verbal directive alert (instruction) without the whooping tone preceding it.

5 Conclusion

A runway conflict alerting and resolution system that generates directive alerts to the crew in order to instruct them on the action that should be taken to avoid a collision has been

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

described. Such a system needs to use aircraft performance to predict which particular manoeuvre – that is, whether to continue or abort – would successfully lead to the avoidance of a collision. The appropriate alert would then be generated. The value of directive alerting is in the quick, objective decision-making, relieving the crew of the task that may be difficult to perform in challenging conditions. When a continued manoeuvre is suggested, the system does not generate an alert, in compliance with the dark and silent cockpit philosophy. When an abort is required, the instruction 'STOP – TRAFFIC' or 'GO-AROUND, TRAFFIC' is generated, depending on the type of manoeuvre being carried out. These verbal instructions are preceded by a 'Whoop Whoop' intended to act as an attention grabber. Furthermore, whilst the aircraft is braking, distance call-outs are generated.

This system has been tested in several simulated take-off and landing scenarios depicting conflicts at various stages of the manoeuvres. A small number of pilots and an immersive simulation environment were used to obtain a preliminary assessment of the alerting technique. The outcome of the assessment suggests that the technique will be acceptable in the cockpit and can have high value in averting a collision on the runway. An attention grabber, however, may not be favoured. These attributes will need to be confirmed in more rigorous pilot evaluations that follow this preliminary assessment.

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