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Airport Traffic Conflict Detection and Resolution Algorithm Evaluation

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Acronyms and Symbols

α	Alpha, probability of Type 1 error
ADS-B	Automatic Dependent Surveillance-Broadcast
AFE	Above Field Elevation
AGL	Above Ground Level
ATC	Air Traffic Control
ATCAM	Airport Traffic Collision Avoidance Monitor
C	Collision
CA	Caution Alert
CD&R	Conflict Detection and Resolution
CDTI	Cockpit Display of Traffic Information
CG	Center-of-gravity
CPA	Closest Point of Approach
EPU	Estimated Position Uncertainty
FAA	Federal Aviation Administration
FY	Fiscal Year
GPS	Global Positioning System
IA	Indication and Alert
IC	Initial Condition
JPDO	Joint Planning and Development Office
KORD	Chicago O'Hare International Airport
LACM	Low Altitude Conflict Monitor
NACp	Navigation Accuracy Category for Position
NASA	National Aeronautics and Space Administration
NC	Near Collision
NextGen	Next Generation Air Transportation System
NTSB	National Transportation Safety Board
RSI	Runway Status Indication
RSM	Runway Safety Monitor
RTCA	Radio Technical Commission for Aeronautics
Rwy	Runway
SD	Standard Deviation
SPR	Safety, Performance, and Interoperability Requirements
SURF IA	Enhanced Traffic Situational Awareness on the Airport Surface with Indications and Alerts
TCAS	Traffic Alert and Collision Avoidance System
TCM	Taxi Conflict Monitor
TI	Traffic Indication
TMA	Terminal Maneuvering Area
TMX	Traffic Manager
WA	Warning Alert

1 Abstract

Two conflict detection and resolution (CD&R) algorithms for the terminal maneuvering area (TMA) were evaluated in a fast-time batch simulation study at the National Aeronautics and Space Administration (NASA) Langley Research Center. One CD&R algorithm, developed at NASA, was designed to enhance surface situation awareness and provide cockpit alerts of potential conflicts during runway, taxi, and low altitude air-to-air operations. The second algorithm, Enhanced Traffic Situation Awareness on the Airport Surface with Indications and Alerts (SURF IA), was designed to increase flight crew awareness of the runway environment and facilitate an appropriate and timely response to potential conflict situations. The purpose of the study was to evaluate the performance of the aircraft-based CD&R algorithms during various runway, taxiway, and low altitude scenarios, multiple levels of CD&R system equipage, and various levels of horizontal position accuracy. Algorithm performance was assessed through various metrics including the collision rate, nuisance and missed alert rate, and alert toggling rate. The data suggests that, in general, alert toggling, nuisance and missed alerts, and unnecessary maneuvering occurred more frequently as the position accuracy was reduced. Collision avoidance was more effective when all of the aircraft were equipped with CD&R and maneuvered to avoid a collision after an alert was issued. In order to reduce the number of unwanted (nuisance) alerts when taxiing across a runway, a buffer is needed between the hold line and the alerting zone so alerts are not generated when an aircraft is behind the hold line. All of the results support RTCA horizontal position accuracy requirements for performing a CD&R function to reduce the likelihood and severity of runway incursions and collisions.

2 Introduction

The Next Generation Air Transportation System (NextGen) concept for the year 2025 and beyond envisions the movement of large numbers of people and goods in a safe, efficient, and reliable manner [JPDO, 2010a]. NextGen will remove many constraints of the current air transportation system, support a wider range of operations, and provide an overall system capacity up to three times that of current operating levels. Emerging NextGen operational concepts [JPDO, 2010b], such as four-dimensional trajectory based airborne and surface operations, equivalent visual operations, and super density arrival and departure operations, require a different approach to air traffic management and as a result, a dramatic shift in the tasks, roles, and responsibilities for the flight deck and air traffic control (ATC) to ensure a safe, sustainable air transportation system.

The worst aviation accident on record resulted in 583 fatalities and was caused by a runway incursion when two fully loaded 747 airplanes operating in low visibility collided on a runway at Tenerife airport in 1977. Airport surface safety, including runway incursion prevention, is a serious concern of the National Transportation Safety Board (NTSB) [NTSB, 2012], Federal Aviation Administration (FAA), and National Aeronautics and Space Administration (NASA). The FAA is committed to reducing the severity and rate of runway incursions by implementing a combination of guidance, education, outreach, training, technology, infrastructure, and risk identification and mitigation initiatives [FAA, 2011]. Progress has been made in reducing the number of serious incursions, from a high of 67 in Fiscal Year (FY) 2000 to 6 in FY 2010; however, that number is again on the rise with 18 serious incursions in FY 2012, 11 in FY 2013, and 14 in 2014. The rate of all incursions has risen steadily over recent years – from a rate of 12.3 incursions per million operations in FY 2005 to a rate of 24.8 incursions per million operations in FY 2013 [FAA, 2011; FAA, 2007; FAA, 2009a; FAA, 2012; and FAA, 2015]. Without proactive counter-measures, the increase in air traffic forecasted under NextGen could potentially result in corresponding increases in runway incursion accidents.

NASA is conducting research to develop technologies, data, and guidelines to enable aircraft-based conflict detection and resolution (CD&R) in the terminal maneuvering area (TMA) under current and emerging NextGen operating concepts, providing an additional, protective safety layer for NextGen operations in the event that the tactical or strategic situation awareness is not sufficient or human errors or blunders occur. The CD&R concepts use cockpit display designs to promote surface situation awareness

and associated flight deck alerting concepts for safety assurance. The concepts employ continual ownship and traffic data monitoring and algorithms to detect conflicts on the runway, at low altitudes near the airport, and during taxi and ramp operations for multiple classes of aircraft and surface vehicles. Alerts are generated as necessary and appropriate when traffic could affect runway safety or other TMA operational conditions that may require flight crew response. Although substantial NASA research and testing has been conducted in the areas of surface operations situation awareness and runway incursion CD&R [Jones, et al, 2001; Jones, 2002; Jones, 2005; Jones and Prinzel, 2006], much of this research has been conducted with a human-in-the-loop and has not included the effect of navigation accuracy and CD&R system equipage levels on CD&R performance.

The Enhanced Traffic Situational Awareness on the Airport Surface with Indications and Alerts (SURF IA) application has been established by RTCA Special Committee 186 to reduce the likelihood and severity of runway incursions and collisions. Safety, performance, and interoperability requirements (SPR) [RTCA, 2010] have been developed for SURF IA to increase flight crew situation awareness of the runway environment and facilitate an appropriate and timely response to potential conflict situations. The SURF IA application utilizes cockpit display of traffic information (CDTI) to promote surface situation awareness and associated flight deck indication and alerting concepts for safety assurance. The application employs continuous ownship and traffic data monitoring and algorithms to detect potential conflicts on the runway. Several human-in-the-loop studies have been conducted to evaluate the SURF IA concept [Moertl and McGarry, 2011a; McGarry and Helleberg, 2011; and Moertl and McGarry, 2011b].

A fast-time batch simulation study was conducted to evaluate the performance of the aircraft-based CD&R algorithms in the TMA, with variations in surveillance accuracy. The algorithms were evaluated under various runway, taxiway, and low altitude scenarios, multiple levels of CD&R system equipage, and various levels of horizontal position accuracy. Algorithm performance was assessed through various metrics including the collision rate, nuisance and missed alert rate, and alert toggling rate. This paper presents an overview of the CD&R concepts, description of the test method, and study results.

3 System Description

3.1 Simulation Tool

A simulation tool, known as Traffic Manager (TMX), was utilized for this study. TMX is a desktop simulation application designed for interaction studies of aircraft in present or future Air Traffic Management environments [Bussink et al, 2005]. TMX can serve as a stand-alone traffic simulator, scenario generator, scenario editor, experiment control station, data recording tool, and rapid prototyping environment and can operate in real-time or fast-time mode. For this study, TMX was used in fast-time mode simulating various approach, departure, and taxi scenarios at the Chicago O'Hare International (KORD) airport. Although TMX is capable of simulating up to 2,000 aircraft simultaneously, only two aircraft per scenario were simulated. Each aircraft used a six-degree-of-freedom dynamics model. The TMX user interface is shown in Figure 1.

Some modifications were made to TMX for this study. These included: 1) an updated database for the KORD airport; 2) creation of a Global Positioning System (GPS) sensor model for position accuracy; 3) creation of an interface to the CD&R algorithms; 4) expansion of the pilot model to handle the required taxi, runway, and low altitude maneuvers; and various other minor modifications.

Figure 1. Traffic Manager User Interface.

3.2 Surveillance Data

The quality and accuracy of reported traffic surveillance data are critical to the integrity of the CD&R capability. For this study, it was assumed that Automatic Dependent Surveillance – Broadcast (ADS-B) will be used as the means for transmitting (ADS-B Out) and receiving (ADS-B In) aircraft surveillance data. ADS-B transmissions were modeled according to RTCA DO-242A specifications [RTCA, 2002]; however, latency effects, transmission line-of-sight, and bandwidth blockage were not modeled to minimize computational overhead. For state-vector messages, a one hertz data transmission rate was used. The traffic position accuracy was simulated as dependent upon the GPS measurement errors. A Gauss-Markov process modeled the time correlation between successive position measurement errors [Mohleji and Wang, 2010].

Navigation Accuracy Category for Position (NACp) describes the accuracy of positional information. NACp values range from 0 to 11 [RTCA, 2002]. The horizontal Estimated Position Uncertainty (EPU) values for NACp categories of 8 and higher are listed in Table 1.

Table 1. NACp Categories.

NACp	95% Horizontal Accuracy Bound (EPU)
8	EPU < 92.6 m (0.05 NM, 305.6 ft)
9	EPU < 30 m (99 ft)
10	EPU < 10 m (33 ft)
11	EPU < 3 m (9.9 ft)

The FAA has issued an ADS-B Out Final Rule [FAA, 2010a] which includes performance standards for ADS-B Out. The rule states that EPU must be less than 0.05 nautical miles (NM), which is equivalent to NACp 8.

The SURF IA SPR has proposed horizontal position accuracy requirements [RTCA, 2010] for the SURF IA function. Through analysis, the SPR identified that to meet safety requirements, horizontal position accuracy when on the airport surface may vary from NACp 9 at the largest airports to NACp 11 at

the smaller airports. The airborne horizontal position accuracy requirement is NACp 7 for single runways and parallel runways not closely spaced. NACp 10 is required for surface vehicles.

To span the ADS-B Out Final Rule and SURF IA requirements, traffic position accuracy equivalent to levels NACp 8, 9, 10, and 11 were evaluated for this study. Truth data, with no accuracy errors, was also evaluated to determine the effect of error free data in relation to the various NACp levels.

3.3 Conflict Detection

Two CD&R algorithms, Airport Traffic Collision Avoidance Monitor (ATCAM) and SURF IA, were evaluated during the simulation study.

3.3.1 Airport Traffic Collision Avoidance Monitor

ATCAM was designed to identify potential traffic conflicts at low altitudes near the airport, on the runway, and during taxi and ramp operations for multiple classes of aircraft and surface vehicles and generate alerts (defined below) for display to the flight crew. An initial implementation of directive alerting was also developed. Directive alerting specifies the action to take to resolve a conflict situation.

ATCAM is comprised of three separate aircraft-based algorithms that rely on traffic state information obtained from ADS-B In.

1. The Runway Safety Monitor (RSM) [Green, 2006] is designed to detect and alert for runway conflicts. RSM monitors ownship and traffic located in a three-dimensional virtual zone around the relevant runway using ownship and traffic state data and separation and closure rate to determine whether an alert should be generated.
2. The Low Altitude Conflict Monitor (LACM) is designed to detect and alert for air-to-air conflicts near the airport at altitudes below 1,000 ft to not conflict with the Traffic Alert and Collision Avoidance System (TCAS). LACM computes closing speed, time to closest point of approach (CPA), time to co-altitude, and other data between ownship and approaching aircraft to determine if criteria and thresholds have been met for issuing alerts, similar to the TCAS approach.
3. The Taxi Conflict Monitor (TCM) is designed to detect and alert for ground taxi conflicts in the airport movement areas. The TCM design is similar to that of LACM and computes distances between ownship and traffic, closing speeds, time to CPA and other parameters.

The three algorithms are independent but are integrated and share data to increase the probability of detection for all possible conflicts during airport TMA operations. RSM has been through extensive testing [Jones, et al, 2001; Jones, 2002; Jones, 2005; Jones and Prinzel, 2006]. LACM and TCM are less mature but have been evaluated in simulation studies [Jones, et al, 2009; Jones, et al, 2010]. Otero et al, 2013 provides a detailed description of ATCAM including alerting criteria.

3.3.2 Enhanced Traffic Situational Awareness on the Airport Surface with Indications and Alerts

SURF IA identifies potential runway conflicts that involve aircraft or vehicles in the airport maneuvering area and within 3 NM of the runway threshold and 1,000 ft above field elevation (AFE). SURF IA generates both indications and alerts (IAs) (defined below) for a CDTI. SURF IA utilizes traffic surveillance information obtained from ADS-B In and generates IAs based on the aircraft/vehicle states during same runway, very closely spaced parallel runway, and intersecting runway operating configurations. Six types of aircraft operational states are defined: 1) taxiing on a taxiway toward a hold line or stopped at a hold line; 2) entering or crossing a runway (not lined up with runway); 3) takeoff; 4) approach; 5) after landing roll-out on runway (e.g., less than or equal to 40 kts); and 6) stopped or taxiing along a runway. To prevent inappropriate crew responses during departure, IAs are inhibited above 80 kts. The SURF IA application does not currently address taxiway or low altitude air-to-air conflicts, directive alerting, and is not intended for use on helicopters or vehicles. A complete description of the SURF IA application can be found in RTCA, 2010.

3.4 Indications and Alerts

Indications and alerts notify the flight crew of potentially hazardous situations and are presented to the flight crew on a CDTI [RTCA, 2010].

3.4.1 Indications

Indications are intended to generate pilot awareness and situation assessment by highlighting the runway and traffic status as relevant to ownship operations. Indications identify operational conditions that are generally normal, yet relevant for runway safety and could be a precursor to a non-normal situation. Only visual annunciations are required and used for indications. Indications are only issued for runway conflict situations. Two types of indications are defined.

A *traffic indication* (TI) highlights a potential runway traffic collision/hazard that could emerge in the near future. TIs are intended to increase the flight crews' awareness of the relevant runway traffic. The flight crew could proceed with the intended operation after a brief assessment of the situation and if appropriately cleared. An example of a TI displayed on an electronic surface map is shown in Figure 2. The relevant traffic is highlighted by an enlarged traffic symbol surrounded by a dashed circle in the same color and an identification tag showing flight identification and ground speed in knots. A status message ("Traffic") is displayed.at the bottom of the surface map along with the estimated distance to the traffic in nautical miles until below 0.1 NM (600 ft), then displayed in feet.

A *runway status indication* (RSI) identifies whether the runway that the ownship is approaching or using is in-use by other traffic and is not suitable for entering, takeoff, or landing. Before proceeding, the crew should ensure they have the appropriate clearance and the indicated traffic is not a factor. An RSI is displayed on an electronic surface map in the same manner as a TI with the addition of a solid blue line outlining the relevant runway (Figure 3).

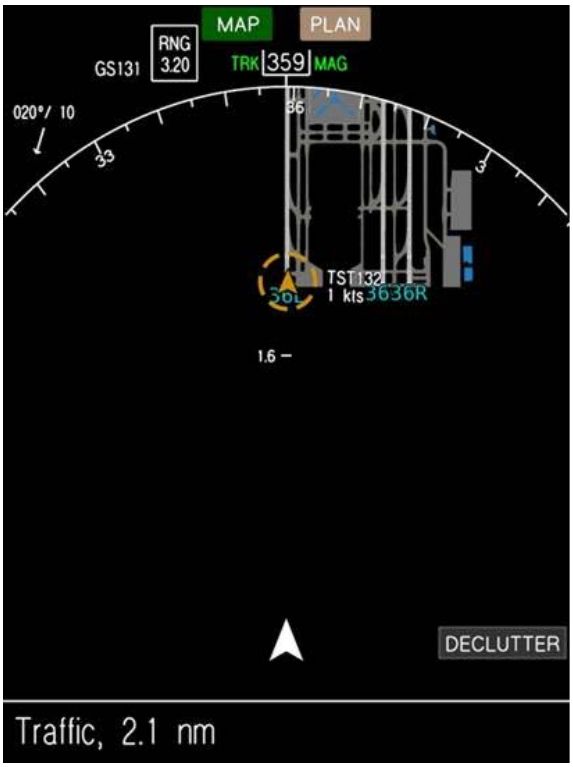

Figure 2. Traffic Indication.

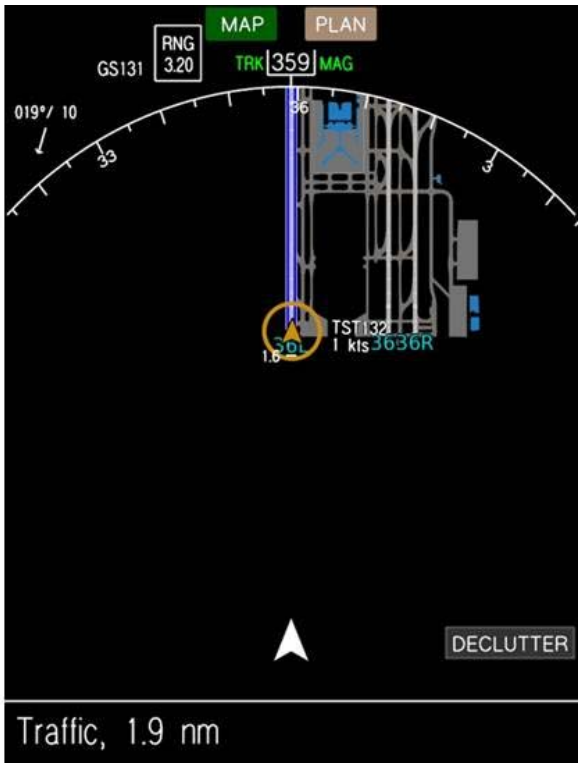

Figure 3. Runway Status Indication.

3.4.2 Alerts

Alerts identify potential collision hazards which require immediate flight crew awareness and may require timely action or response to avoid a collision. Alerts have priority over indications and are issued for both runway and taxi conflict situations. Auditory and visual annunciations are required. A two-level alerting scheme is defined.

Caution alerts (CAs) are generated for conditions that require immediate flight crew awareness and subsequent flight crew response. An example CA displayed on a surface map is shown in Figure 4. The relevant traffic is highlighted by an enlarged yellow traffic symbol surrounded by a yellow circle, an identification tag that shows flight identification and ground speed in knots, and a yellow line around the relevant runway, if applicable. An alert message ("Caution, Traffic") is displayed at the bottom of the surface map in yellow text along with the estimated distance to the traffic. An audible annunciation is also made ("Caution, Traffic, Caution, Traffic").

Warning alerts (WAs) are generated for conditions that require immediate flight crew awareness and immediate flight crew response. WAs could occur without preceding CAs. A WA is displayed in the same manner as a CA, except the WA is associated with the color red, a square is used to surround the traffic symbol, and the alert message is "Warning, Traffic, Warning, Traffic" (Figure 5).

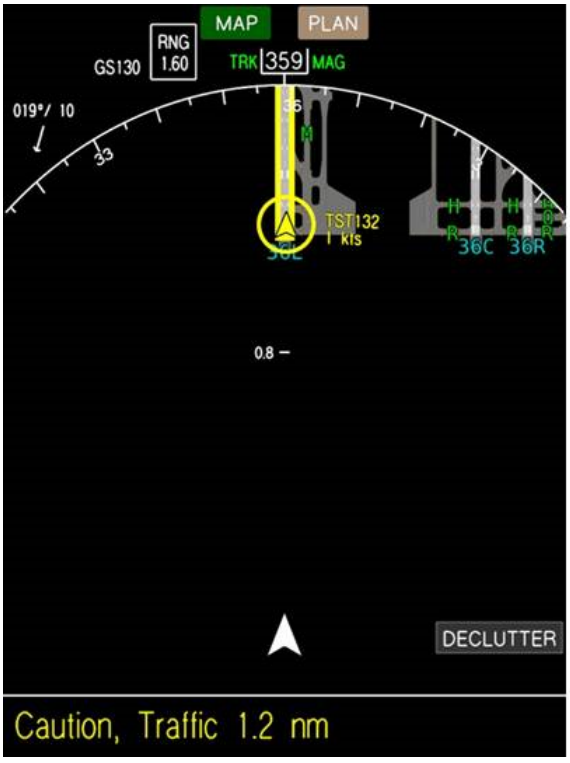

Figure 4. Caution Alert.

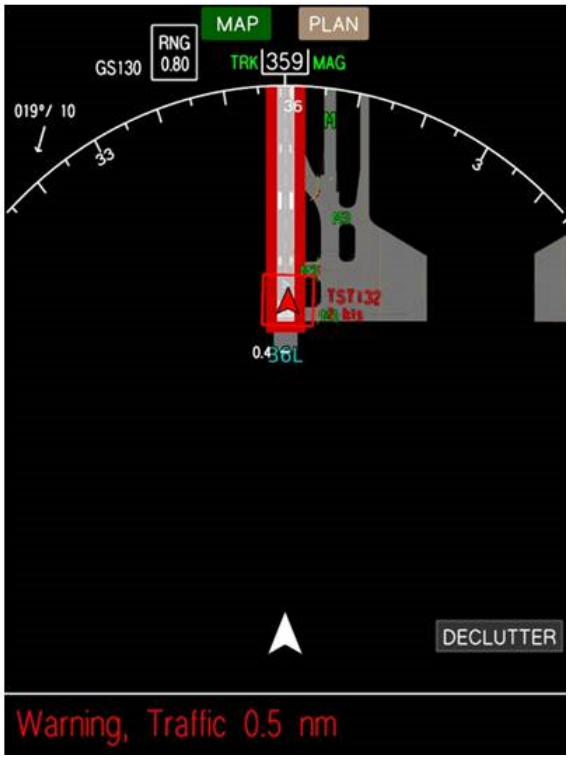

Figure 5. Warning Alert.

3.4.3 Directive Alerting

Directive alerting specifies the action to take to resolve a conflict situation in lieu of providing a generic WA. The directive issued depends on the conflict situation. Examples of directive alerts are as follows: "go-around" when on approach, "abort" when departing, "stop" when taxiing or rolling-out, and "climb" when air-to-air conflict on approach. The directive alerts can be displayed in the cockpit visually and audibly, similar to the method used for WAs.

4 Test Method

Data collection occurred for runway, taxi, and low altitude air-to-air conflict scenarios. Only two aircraft were included in each scenario to limit the interaction in this initial fast-time study. For ease of discussion, the aircraft will be referred to as Aircraft A and Aircraft B.

4.1 CD&R Equipage

Various levels of CD&R system equipage were simulated for this study: a) both aircraft equipped; b) neither aircraft equipped; or, c) one or the other aircraft equipped.

When an aircraft was not equipped, it would follow its planned flight path to the end of the test run. When an aircraft was equipped, it would take action after a WA was generated by following an appropriate maneuver (e.g. go-around, abort, stop), depending on the operational phase. The maneuver was based on the relative location of the aircraft at the projected CPA.

4.2 Test Scenarios

Seven runway, three taxiway, and two low altitude air-to-air scenarios were developed. Variability was introduced into the scenarios by varying the location of the aircraft, speed of the aircraft, and/or time when the aircraft started to proceed along its predefined route (Appendix B). As a result, not every test run resulted in a conflict or collision. The runway scenarios were selected based on the most common types of runway incursions according to RTCA, 2010 and Cardosi et al, 2010.

4.2.1 Runway Scenario – Arrival with taxi crossing

This scenario evaluated the situation where an aircraft was on approach as another aircraft taxied perpendicularly across the runway.

The initial condition (IC) for Aircraft A was at 3.5 NM prior to the threshold at 1,110 ft AFE at an indicated airspeed of 142 kts. Aircraft A flew at a constant altitude to intercept the glideslope at 3.3 NM from the threshold and then descended on a 3 degree glide-path for a straight-in approach to Runway 10. For the nominal flight plan, Aircraft A landed, decelerated at 8.2 ft/s^2, taxied down the runway at 30 kts, and then slowed to exit the runway at Taxiway M7 at 3 kts. Aircraft B started at various locations around Runway 10 and taxied across starting from a complete stop and accelerating at 3.3 ft/s^2 to 15 kts. The actual taxiways for KORD were not used in this study. Instead, Aircraft B's initial position was placed at 14 different locations along the length of Runway 10 (0, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 6000, 7500, 9000, and 10,000 feet from the approach runway threshold) simulating various taxiway entry points and at 18 locations away from the runway (300, 320, 340, 360, 380, 400, 450, 500, 550, 600, 650, 700, 800, 900, 1000, 1200, 1400, and 1600 feet from the runway centerline) (Figure 6) (Appendix B.1). Aircraft B (red chevron, Figure 6) began to taxi when Aircraft A (blue chevron, Figure 6) was at various points in its approach and rollout (from 3.5 NM to the runway threshold, at 0.5 NM intervals, crossing the runway threshold, glide-path aim-point (1,000 ft), and 3,400 ft, 5,400 ft, 7,000 ft, 9,000 ft, and 9,800 ft past the threshold). If maneuvering were required based on a CD&R WA being triggered in an appropriately equipped aircraft, Aircraft A would conduct a go-around if above 70 ft AFE; otherwise, it would continue to land and stop on the runway. Aircraft B, if equipped, would stop if its nose had not reached the runway shoulder (greater than 100 ft from the runway centerline) at the projected stopping point; otherwise, it would continue to taxi across the runway. When conducting an emergency stop by either aircraft, a 13.1 ft/s^2 deceleration rate was used.

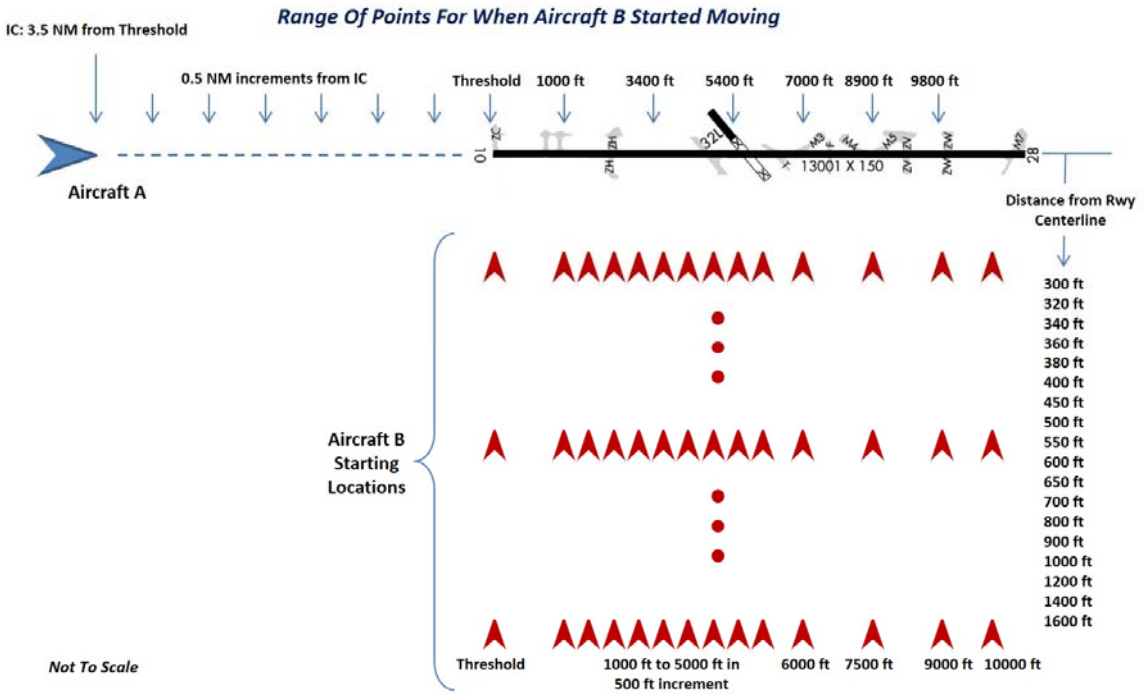

Figure 6. Arrival with Taxi Crossing Scenario Initial Conditions.

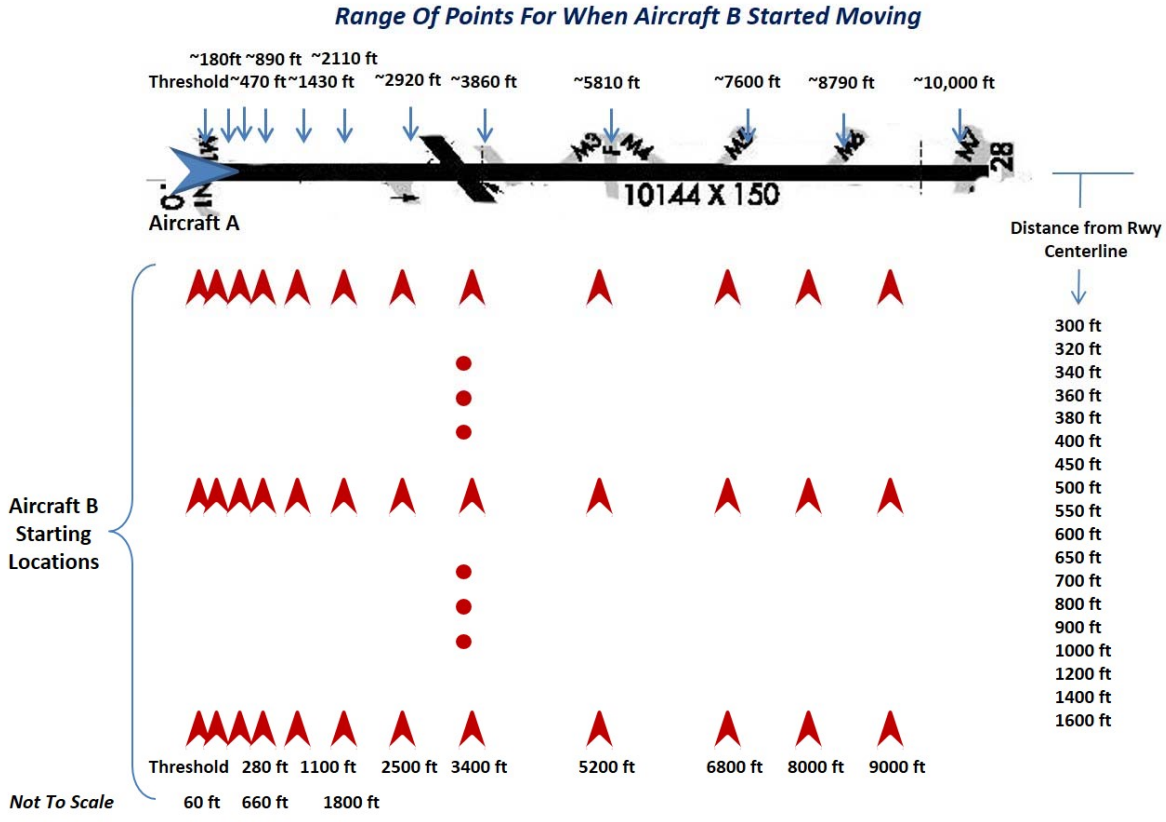

Figure 7. Departure with Taxi Crossing Scenario Initial Conditions.

4.2.2 Runway Scenario – Departure with taxi crossing

This scenario tested the situation where an aircraft was on departure as another aircraft taxied perpendicularly across the runway.

The configuration for this scenario was similar to the arrival with taxi crossing scenario, except the IC for Aircraft A was in position on Runway 10 for departure. Aircraft B's IC was placed at 12 different locations along the length of Runway 10 (0, 60, 280, 660, 1100, 1800, 2500, 3400, 5200, 6800, 8000, and 9000 feet from the runway threshold) simulating various taxiway entry points and at the same 18 locations away from the runway as in the previous scenario (Figure 7) (Appendix B.2). Aircraft B began to taxi when Aircraft A was at various locations along its departure and climb out (0 ft, 180 ft, 470 ft, 890 ft, 1,430 ft, 2,100 ft, 2,920 ft, 3,860 ft, 5,810 ft, 7,600 ft, 8,790 ft, and 10,000 ft from the runway threshold). If maneuvering were required based on a WA being triggered in an appropriately equipped aircraft, Aircraft A would abort departure if below takeoff decision speed (131 kts) and stop on the runway; otherwise it would continue departure. Aircraft B, if equipped, would maneuver as described in the previous scenario.

4.2.3 Runway Scenario – Arrival with departure from same runway

This scenario evaluated the situation where an aircraft was on approach and another aircraft was departing on the same runway in the same direction.

The IC for Aircraft A was at 3.5 NM prior to the threshold at 1,110 ft AFE at an indicted airspeed of 142 kts. Aircraft A flew at a constant altitude to intercept the glideslope at 3.3 NM from the threshold and then descended on a 3 degree glide-path for a straight-in approach to Runway 10. For the nominal flight plan, Aircraft A landed, decelerated at 8.2 ft/s^2, taxied down the runway at 30 kts, and then slowed to exit the runway at Taxiway M7 at 3 kts. Aircraft B's IC was in position on Runway 10 for departure (Figure 8). Aircraft B began its departure when Aircraft A was at various locations along its approach path (from 3.5 NM to the runway threshold, at 0.5 NM intervals, crossing the runway threshold, and glide-path aim-point (1,000 ft)) (Appendix B.3). If maneuvering were required based on a CD&R WA being triggered in an appropriately equipped aircraft, Aircraft A would conduct a go-around if above 70 ft AFE; otherwise, it would continue to land and stop on the runway. If Aircraft B were in position and holding on the runway for departure, no maneuvering action would be taken. If departure roll had begun, Aircraft B would abort departure if below takeoff decision speed (131 kts) and exit the runway; otherwise, it would continue departure.

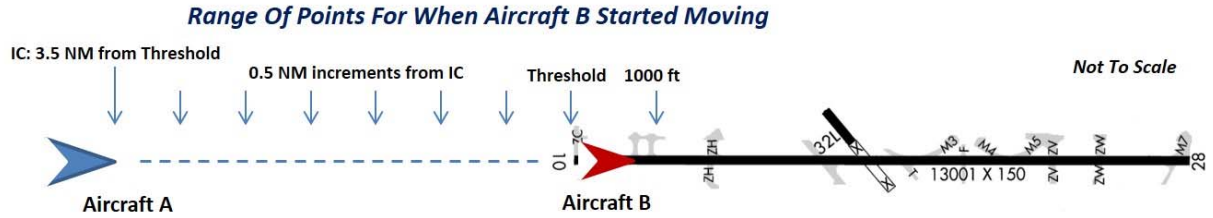

Figure 8. Arrival with Departure from Same Runway Scenario Initial Conditions.

4.2.4 Runway Scenario – Departures from intersecting runways

This scenario tested the situation where aircraft were departing on intersecting runways, heading toward the runway intersection.

Aircraft A's IC was in position on Runway 14L for departure. Aircraft B's IC was in position on Runway 22R for departure. Aircraft A began its departure when Aircraft B was at various speeds along its departure path (at the Runway 22R threshold (0 kts), 20 kts, 40 kts, 60 kts, 80 kts, 100 kts, and at the runway intersection (120 kts)). Conversely, Aircraft B began its departure when Aircraft A was at various speeds and locations along its departure path (at the Runway 14L threshold (0 kts), 30 kts, 50 kts, 70 kts, 90 kts, 110 kts, 130 kts, 150 kts, 170 kts, and at the runway intersection (just lifted off)) (Figure 9) (Appendix B.4). If maneuvering were required based on a CD&R WA being triggered in an appropriately equipped aircraft,

the aircraft would abort departure if below takeoff decision speed (131 kts) and stop on the runway; otherwise, it would continue departure.

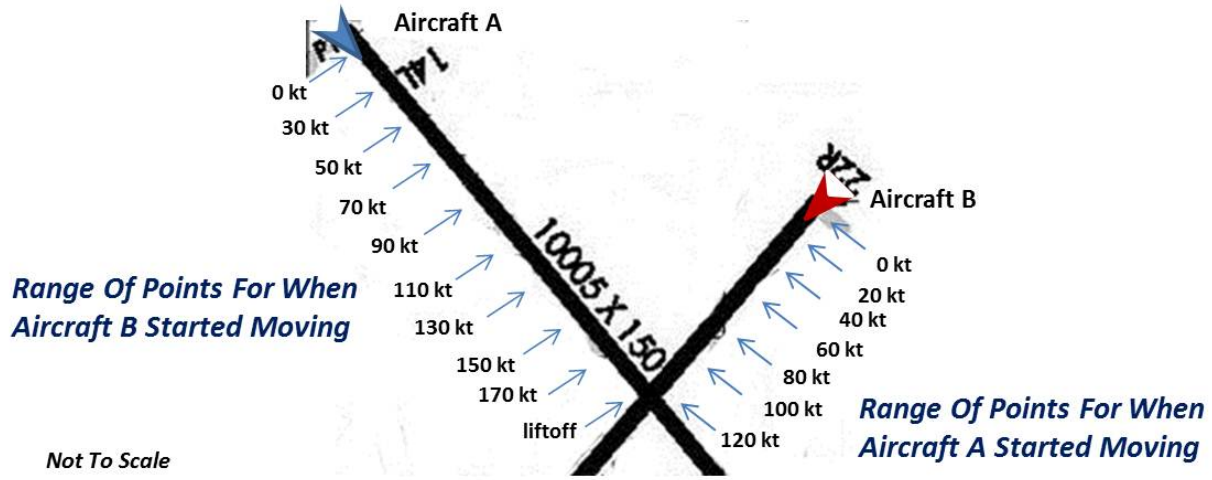

Figure 9. Departures from Intersecting Runways Scenario Initial Conditions.

4.2.5 Runway Scenario – Arrival and departure from intersecting runways

This scenario tested the situation where an aircraft was on approach and another aircraft was departing on an intersecting runway.

The IC for Aircraft A was at 3.5 NM prior to the threshold at 1,110 ft AFE at an indicted airspeed of 142 kts. Aircraft A flew at a constant altitude to intercept the glideslope at 3.3 NM from the threshold and then descended on a 3 degree glide-path for a straight-in approach to Runway 14L. For the nominal flight plan, Aircraft A landed, decelerated at 8.2 ft/s, taxied down the runway at 30 kts, and then slowed to exit the runway at Taxiway P4 at 3 kts. Aircraft B's IC was in position on Runway 22R for departure. Aircraft B began its departure roll when Aircraft A was at various locations along its approach and rollout (from 3.5 NM to the threshold, at 0.5 NM intervals, and 630 ft, 0.25 NM, 0.5 NM, 0.8 NM, and 1 NM from the runway threshold)) (Figure 10) (Appendix B.5). If maneuvering were required based on a CD&R WA being triggered in an appropriately equipped aircraft, Aircraft A would conduct a go-around if above 70 ft AFE; otherwise, it would continue to land and stop on the runway. Aircraft B would abort departure if below takeoff decision speed (131 kts) and stop on the runway; otherwise, it would continue departure.

4.2.6 Runway Scenario – Head-on arrivals

This scenario evaluated the situation where two aircraft were approaching a runway from opposite directions.

The IC for Aircraft A was at 3.5 NM prior to the threshold at 1,110 ft AFE at an indicted airspeed of 142 kts. Aircraft A flew at a constant altitude to intercept the glideslope at 3.3 NM from the threshold and then descended on a 3 degree glide-path for a straight-in approach to Runway 10. Aircraft B's IC and approach was similar but to Runway 28. For the nominal flight plan of both aircraft, the aircraft landed, decelerated at 8.2 ft/s, taxied down the runway at 30 kts, and then slowed to exit the runway (Aircraft A at Taxiway M7, Aircraft B at Taxiway K) at 3 kts. Aircraft B began its approach when Aircraft A was at various locations along its approach and rollout (0.5 NM intervals beginning 3.5 NM prior to the threshold, crossing the runway threshold, and 1400 ft, 3700 ft, 5500 ft, 7100 ft, 9,000 ft, and 9,800 ft past the threshold)) (Figure 11) (Appendix B.6). If maneuvering were required based on a CD&R WA being triggered in an appropriately equipped aircraft, a go-around would be conducted if above 70 ft AFE; otherwise, the aircraft would land and exit the runway at a taxiway.

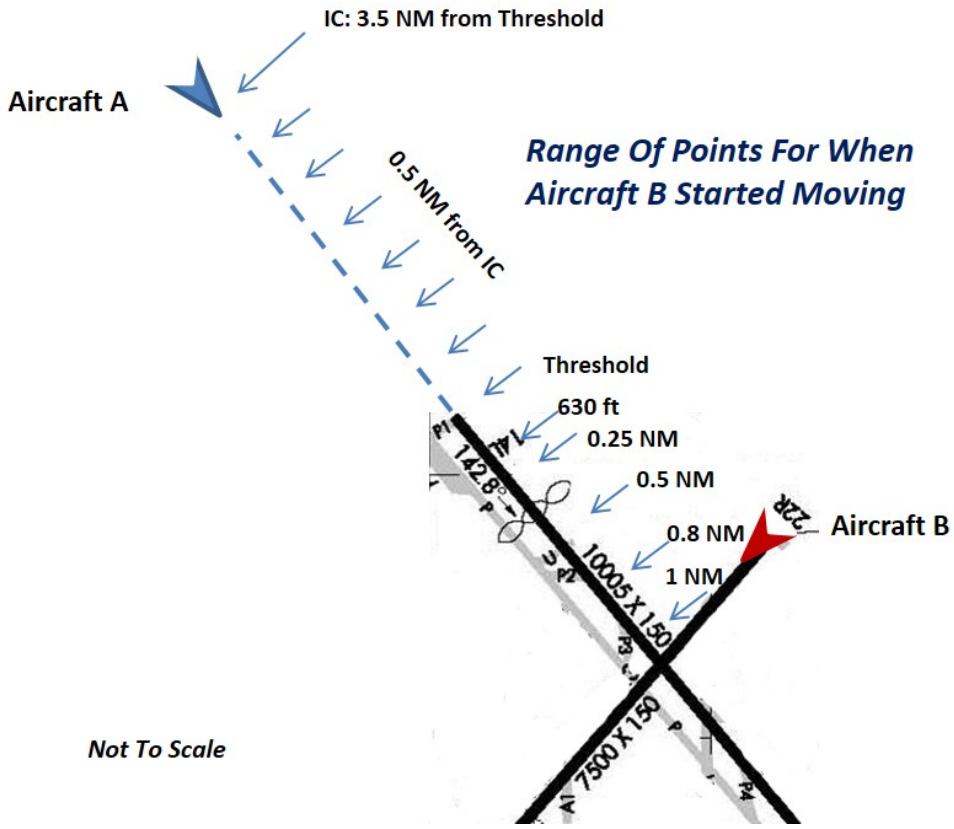

Figure 10. Arrival and Departure from Intersecting Runways Scenario Initial Conditions.

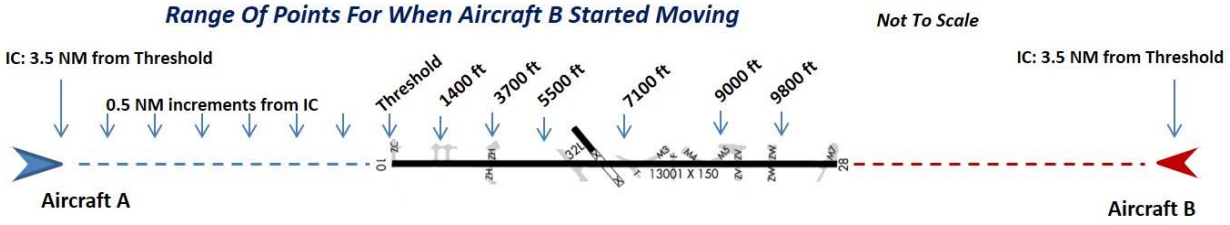

Figure 11. Head-on Arrivals Scenario Initial Conditions.

4.2.7 Runway Scenario – Arrivals to intersecting runways

This scenario evaluated the situation where two aircraft were arriving on intersecting runways.

The IC for Aircraft A was at 3.5 NM prior to the threshold at 1,110 ft AFE at an indicted airspeed of 142 kts. Aircraft A flew at a constant altitude to intercept the glideslope at 3.3 NM from the threshold and then descended on a 3 degree glide-path for a straight-in approach to Runway 14L. Aircraft B's IC and approach was similar but to Runway 22R. For the nominal flight plan of both aircraft, the aircraft landed, decelerated at 8.2 ft/s, taxied down the runway at 30 kts, and then slowed to exit the runway (Aircraft A at Taxiway P4, Aircraft B at Taxiway E) at 3 kts. Aircraft B began its approach when Aircraft A was at various locations along its approach and rollout (from 3.5 NM to the threshold, at 0.5 NM intervals, crossing the runway threshold, 1,100 ft, 2,000 ft, 3,800 ft, 5,300 ft, and 1 NM from the runway threshold) (Figure 12) (Appendix B.7). If maneuvering were required based on a CD&R WA being triggered in an appropriately equipped aircraft, a go-around would be conducted if above 70 ft AFE; otherwise, the aircraft would land and stop on the runway.

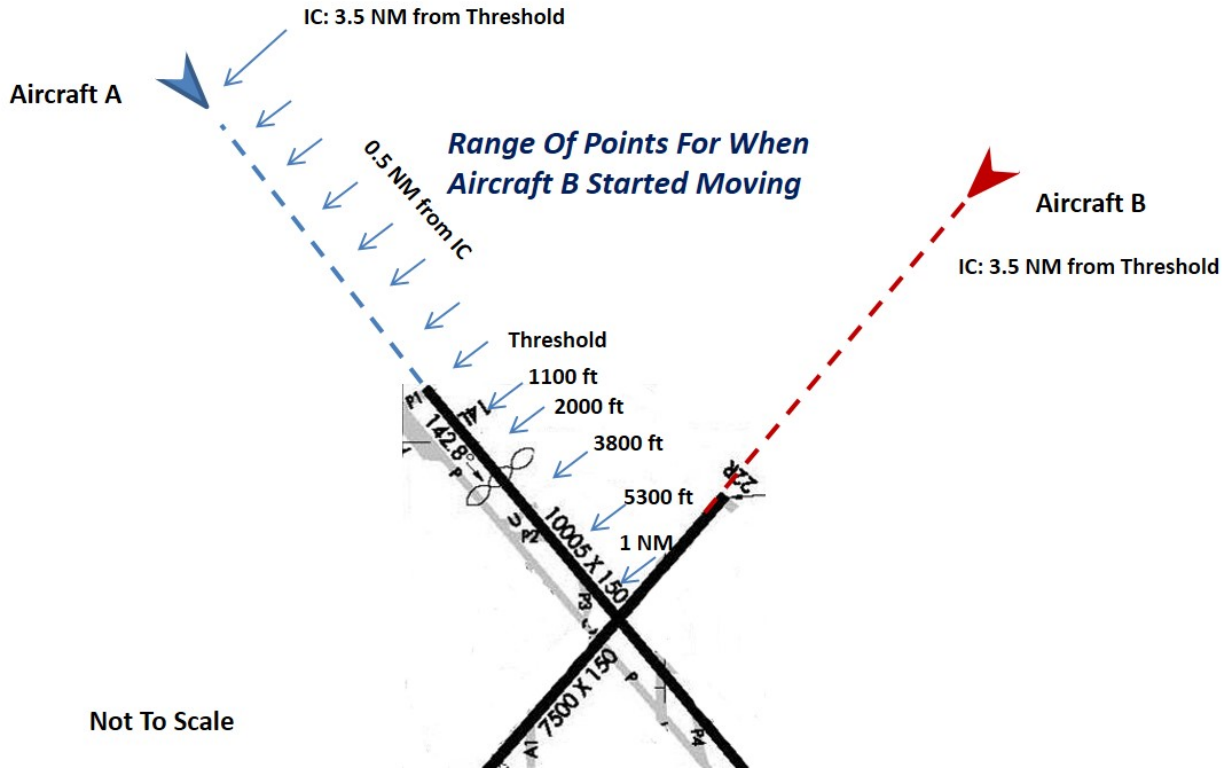

Figure 12. Arrivals to Intersecting Runways Scenario Initial Conditions.

4.2.8 Taxi Scenario – Taxi following

This scenario tested the situation where a taxiing aircraft exhibits excessive closure on traffic from behind.

Aircraft A taxied at a constant speed (between 12 and 24 kts, at 2 kts intervals) on Taxiway M toward Runway 10. Aircraft B also taxied on Taxiway M toward Runway 10, ahead of Aircraft A, at a 10 kts (Figure 13) (Appendix B.8). If maneuvering were required based on a CD&R WA being triggered in an appropriately equipped aircraft, Aircraft A would decrease taxi speed to 8 kts and Aircraft B would increase taxi speed to 25 kts.

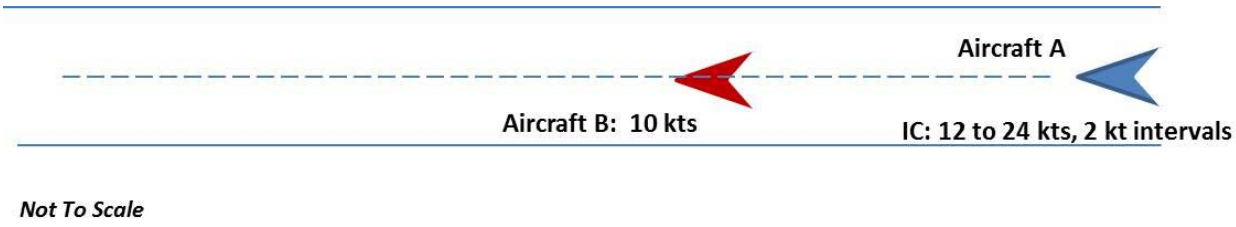

Figure 13. Taxi Following Scenario Initial Conditions.

4.2.9 Taxi Scenario – Taxi intersection

This scenario tested the situation where aircraft conflict at a perpendicular taxiway intersection.

Aircraft A began taxi at 15 kts. Aircraft B taxied across the taxiway, starting from a complete stop and accelerating to 15 kts at 3.3 ft/s^2. Aircraft B's initial position was placed at 4 different locations along Aircraft A's taxiway (400, 600, 800, and 1,000 feet ahead of Aircraft A) simulating various taxiway crossing points and at 5 locations away from the taxiway (260, 410, 560, 710, and 860 feet from taxiway centerline) (Figure 14) (Appendix B.9). Aircraft B began to taxi when Aircraft A was at various locations

along the taxiway (0, 150, 300, 450, and 600 ft from its starting position). If maneuvering were required based on a CD&R WA being triggered in an appropriately equipped aircraft, the aircraft would stop at an accelerated rate (13.1 ft/s^2) provided it could be determined that the aircraft's nose location was greater than 100 ft from the intersecting taxiway centerline at the projected stopping point; otherwise, it would continue to taxi across the taxiway.

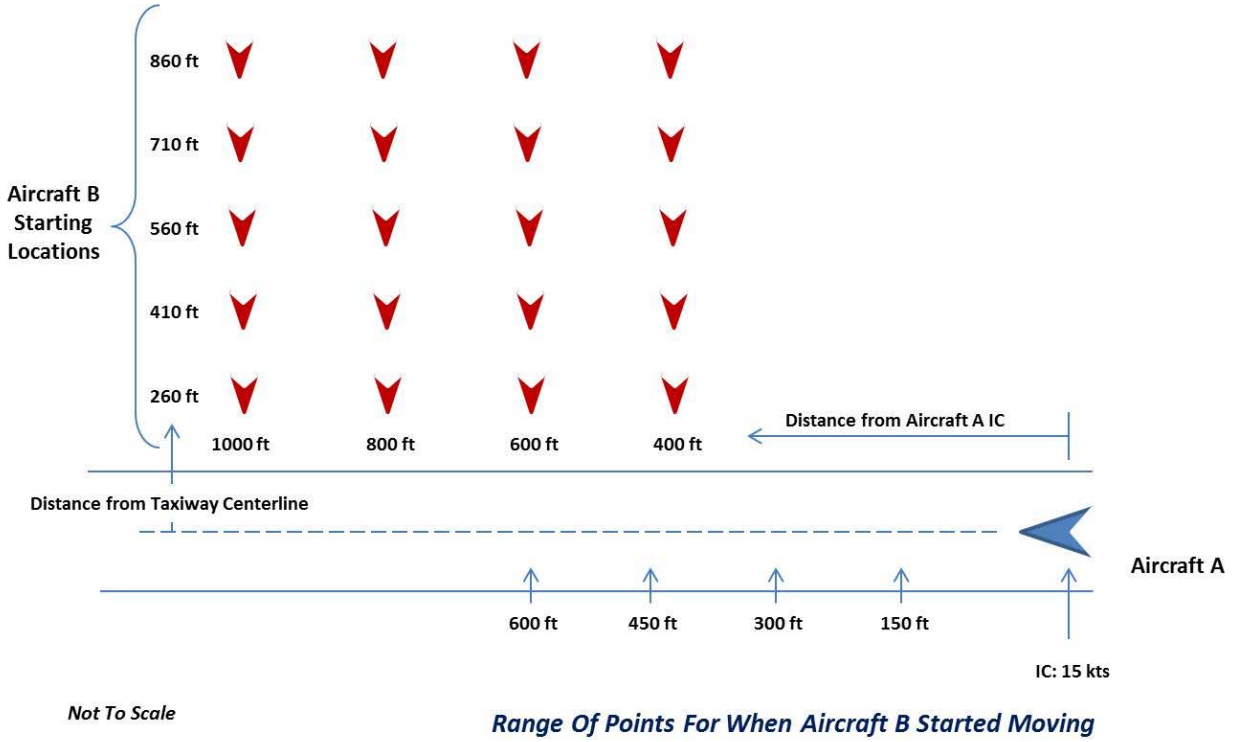

Figure 14. Taxi Intersection Scenario Initial Conditions.

4.2.10 Taxi Scenario – Taxi head-on

This scenario tested the situation where two aircraft conflict head-on on a taxiway.

Aircraft A began taxi on Taxiway M at M2, traveling toward Runway 10 at 15 kts, taking a right turn onto Taxiway T. Aircraft B began taxi on Taxiway T at T1 traveling toward Taxiway M at 15 kts. For some test runs, Aircraft A began to taxi when Aircraft B was at various points along it's taxi route (at Taxiway T1, 1,600 ft, 3,200 ft, 4,800 ft, 6,400 ft, 8,000 ft, and 9,600 ft (crossing Taxiway M) from T1). For additional test runs, Aircraft B began to taxi when Aircraft A was at various points along its taxi route (at M2, 9,500 ft, 7,900 ft, 6,300 ft, 4,700 ft, 3,100 ft, and 1,500 ft from T1) (Figure 15) (Appendix B.10). If maneuvering were required based on a CD&R WA being triggered in an appropriately equipped aircraft, the aircraft would exit at a taxiway or stop if a taxiway could not be reached before reaching the other aircraft.

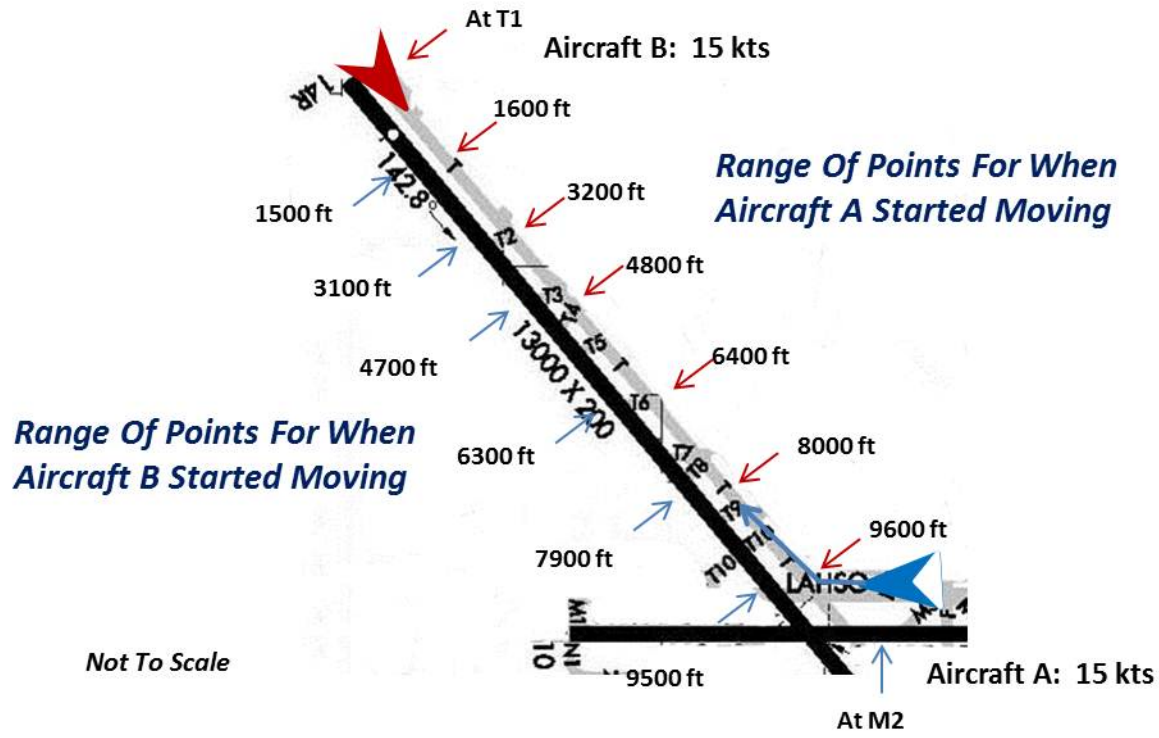

Figure 15. Taxi Head-on Scenario Initial Conditions.

4.2.11 Air-to-Air Scenario – Arrival with crossing airborne traffic

This scenario tested the situation where traffic crossed the path of an aircraft on final approach.

The IC for Aircraft A was at 4 NM prior to the threshold at 1,270 ft AFE at an indicted airspeed of 142 kts. Aircraft A flew at a constant altitude to intercept the glideslope at 3.3 NM from the threshold and then descended on a 3 degree glide-path for a straight-in approach to Runway 10. Aircraft B (a helicopter) traveled perpendicularly across Aircraft A's flight path, flying level at an indicated airspeed of 50 kts. Aircraft B's initial position was placed at 7 different locations along Aircraft A's approach path at 0.5 NM intervals beginning 3 NM prior to the runway threshold, at 4 locations away from Aircraft A's approach path (2,195, 4,445, 6,695, and 8,945 feet from the extended runway centerline), and at 7 different altitudes (100, 250, 400, 550, 700, 850, and 1,000 ft AFE). Aircraft B began to fly forward when Aircraft A was at various distances from the runway threshold (from 4 NM to 1 NM to the threshold, at 0.5 NM intervals) (Figure 16) (Appendix B.11). If maneuvering were required based on a CD&R WA being triggered in an appropriately equipped aircraft, Aircraft A would conduct a go-around if Aircraft B was at the same altitude or lower at projected CPA; otherwise, Aircraft A would continue to descend. Aircraft B would climb if at or above Aircraft A's altitude or descend if below Aircraft A's altitude at projected CPA.

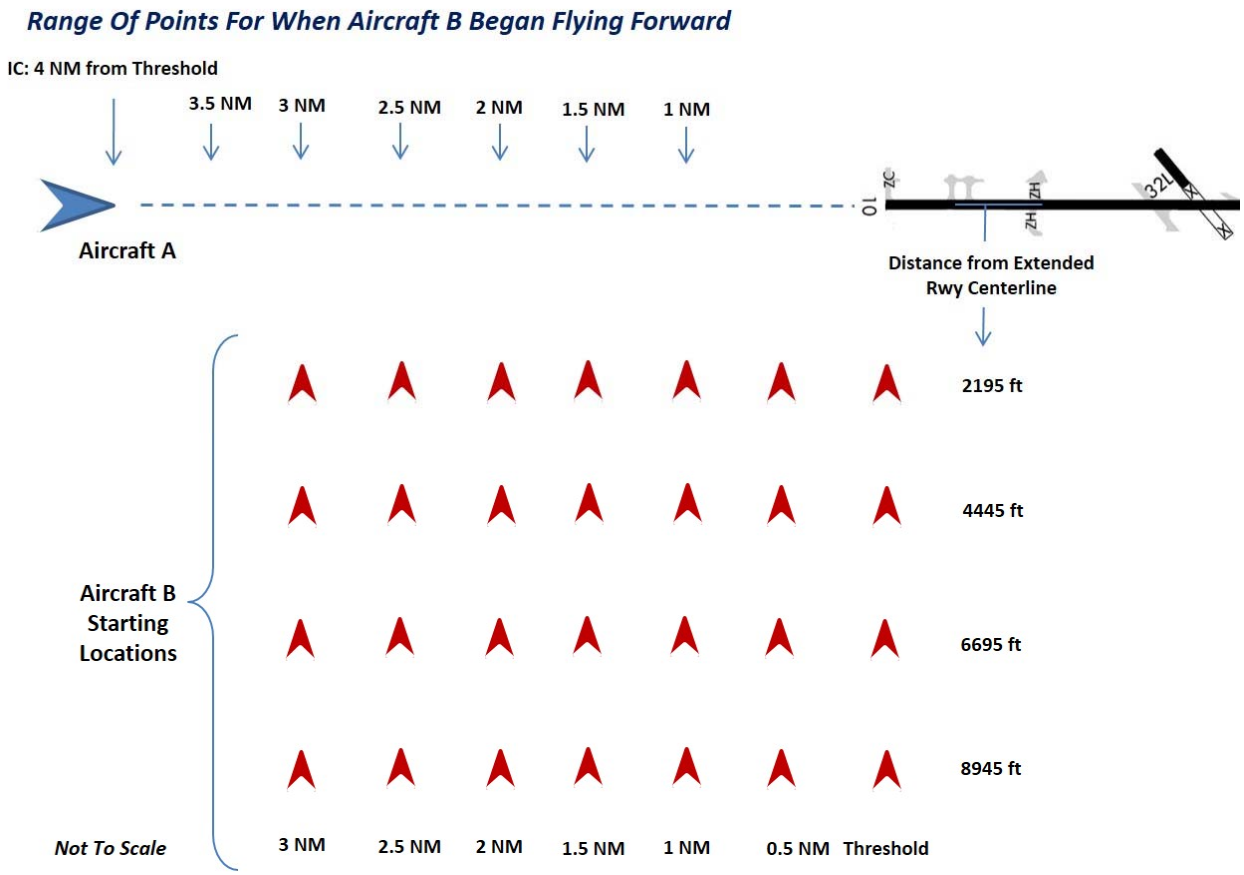

Figure 16. Arrival with Crossing Traffic Air-to-Air Scenario Initial Conditions.

4.2.12 Air-to-Air Scenario – Departure climb-out with crossing airborne traffic

This scenario tested the situation where traffic crossed the flight path of a departing aircraft.

The configuration for this scenario was similar to the arrival air-to-air scenario, except the IC for Aircraft A was in position on Runway 10 for departure. Aircraft B (a helicopter) traveled across the path of the departing aircraft once airborne, flying level at heading 000 and at an indicated airspeed of 50 kts. Aircraft B's initial position was placed at 7 different locations along Aircraft A's departure path (from 5,000 to 11,000 ft from the runway threshold, at 1,000 ft increments), at 3 locations away from the runway (3100, 3950, and 4800 feet from the runway centerline), and at 7 different altitudes (100, 250, 400, 550, 700, 850, and 1000 ft AFE). Aircraft B began to fly forward when Aircraft A passed various distances along the runway (approximately at the runway threshold, and 115 ft, 355 ft, 620 ft, 960 ft, 1,385 ft, and 1,875 ft from the runway threshold) (Figure 17) (Appendix B.12). If maneuvering were required based on a CD&R WA being triggered in an appropriately equipped aircraft, Aircraft A would level off if Aircraft B was projected to be at a higher altitude at CPA; otherwise, it would continue departure climb. Aircraft B would climb if projected to be at or above Aircraft A's altitude or descend if below Aircraft A's altitude at CPA.

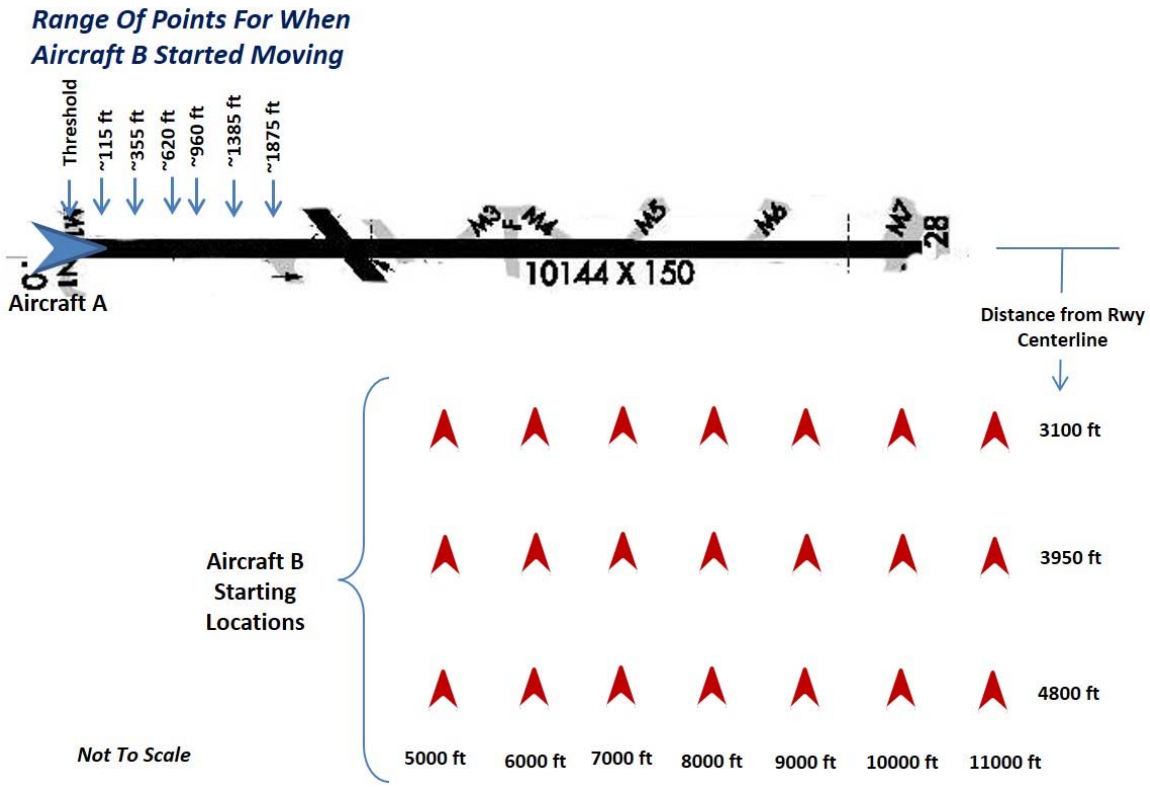

Figure 17. Departure Climb-out with Crossing Traffic Air-to-Air Scenario Initial Conditions.

4.3 Pilot Reaction Delay

A delay was incorporated to simulate the reaction time from when a pilot would receive a WA until action was taken to resolve the situation. The following delay times were used for this study: 5 seconds (sec) when aircraft was on approach, 3 sec when aircraft was rolling out, 2 sec during taxi, 2 sec during departure, and 3 sec for air-to-air maneuvers. These delay times were selected based on reaction delays experienced during previous simulation and flight testing [Jones, 2005; Jones and Prinzel, 2006; Jones et al, 2010]

4.4 Test Matrix

Algorithm performance was evaluated for the 12 conflict scenarios described above using the ATCAM CD&R algorithm and for the 7 runway scenarios using the SURF IA algorithm, for five levels of surveillance accuracy (NACp 8, 9, 10, 11, and truth), and four levels of CD&R system equipage (Neither aircraft equipped, only Aircraft A equipped, only Aircraft B equipped, and Both aircraft equipped) (Appendix A). Thus, 20 cases were examined for each of the scenarios. A total of 240 cases were evaluated for ATCAM and 140 cases for SURF IA.

Directive alerting was evaluated for three scenarios (two runway and one taxiway), two levels of surveillance accuracy (NACp 10 and truth), and three levels of CD&R system equipage (only Aircraft A equipped, only Aircraft B equipped, and Both aircraft equipped), for a total of 18 cases (Appendix A). These three scenarios were selected because the directive alert generated by ATCAM could have a different outcome from the standard maneuvering conducted for the other test cases. Truth surveillance accuracy was evaluated to obtain results of directive alerting with accurate data. NACp 10 surveillance accuracy was selected for evaluation based on the SURF IA requirements for large airports [RTCA, 2010]. There was no need to evaluate the condition where neither aircraft take action since directive alerting results in action.

The number of replicates for each treatment combination varied by the level of surveillance accuracy. As shown in Table 2, more replicates were conducted for the lower NACp values in order to increase the level of precision for estimating the true location of the aircraft. Initial testing was conducted to provide an estimate of the variance across NACp values. This estimate was used to confirm that the number of replicates listed in Table 2 provided a reasonable level of accuracy based on subject-matter expertise, while staying within the resource constraints.

Table 2. Number of Replicates.

NACp	Number of Replicates
8	7
9	6
10	4
11	3
Truth	1

Some of the test conditions for some of the scenarios, in which a conflict would obviously not occur, were omitted in order to reduce the size of the test matrix.

The number of test runs per scenario and NACp level is shown in Table 3. A full factorial design was used. The standard number of runs per scenario is multiplied by the appropriate number of replicates (Table 2) and by four for the four levels of CD&R system equipage. As a result, data were collected for 504,504 test runs with the ATCAM CD&R algorithm and for 294,756 test runs with the SURF IA CD&R algorithm.

As described above, directive alerting data were only collected for selected scenarios, two levels of surveillance accuracy, and three levels of CD&R system equipage. Therefore, data were collected for 1,545 test runs for the directive alerting evaluation.

Data were collected for the test runs in random order by scenario. For data manageability of the scenarios that required a large number of test runs, data were collected randomly grouped by level of surveillance accuracy and CD&R system equipage due to limitations on computer storage and for ease of data collection and processing. Based on subject-matter expertise, it was determined that this grouping should not have any impact on the results.

Table 3. Number of Test Runs.

Scenario	Standard Number of Runs	Number NACp 8 Runs	Number NACp 9 Runs	Number NACp 10 Runs	Number NACp 11 Runs	Number Truth Runs	Total number Runs
Runway Scenarios:							
Arrival Taxi Crossing	2,367	66,276	56,808	37,872	28,404	9,468	198,828
Departure Taxi Crossing	1,077	30,156	25,848	17,232	12,924	4,308	90,468
Arrival Departure Same Runway	9	252	216	144	108	36	756
Departures Intersecting	16	448	384	256	192	64	1,344
Arrival Departure Intersecting	13	364	312	208	156	52	1,092
Head-On Arrivals	14	392	336	224	168	56	1,176
Arrivals Intersecting	13	364	312	208	156	52	1,092
Taxi Scenarios:							
Taxi Following	7	196	168	112	84	28	588
Taxi Intersection	76	2,128	1,824	1,216	912	304	6,384
Taxi Head-On	13	364	312	208	156	52	1,092
Air-To-Air Scenarios:							
Arrival Crossing Traffic	1,372	38,416	32,928	21,952	16,464	5,488	115,248
Departure Climb-Out Crossing Traffic	1,029	28,812	24,696	16,464	12,348	4,116	86,436

4.5 Test Metrics

Some of the metrics utilized for this study are defined in this section. All data is referenced from the aircraft center-of-gravity (CG), unless noted otherwise.

4.5.1 Near Collision / Collision

For runway conflicts, a near collision was counted if the CG of the two aircraft were < 300 ft apart laterally and vertical separation was < 200 ft. A collision was counted if the aircraft were < 150 ft apart laterally and vertical separation was < 100 ft (Figure 18). The 150 ft collision separation corresponds to large aircraft with a wingspan and fuselage length of approximately 150 ft (which was used for this study). The 150 ft value also corresponds to the width of the simulated runway. Also, aircraft that are between the hold line and runway edge (150 ft distance for this study) are considered hazards and classified as near collisions.

For the taxiway conflicts, a near collision was counted if the aircraft CG's were < 185 ft apart laterally. A collision was counted if the aircraft CG's were < 150 ft apart laterally.

For mid-air conflicts, a near collision was counted if the aircraft CG's were < 500 ft apart laterally and vertically [FAA, 2014]. A collision was counted if the aircraft CG's were < 150 ft apart laterally and vertical separation was < 100 ft.

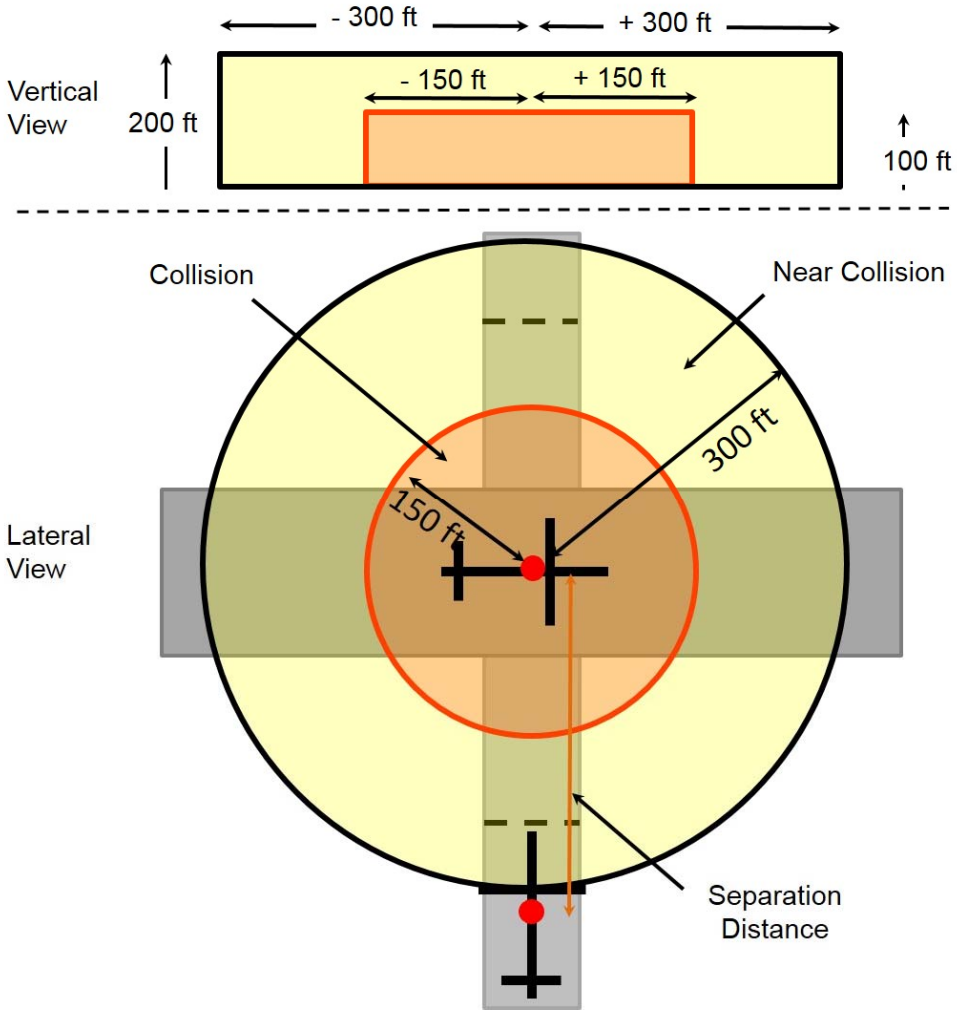

Figure 18. Near Collision / Collision Definition for Runway Scenarios.

4.5.2 Nuisance / Missed Indications and Alerts

According to the SURF IA SPR [RTCA, 2010], a nuisance indication or alert is defined as any indication or alert generated by a properly functioning CD&R system that is inappropriate or unnecessary for the particular situation. Nuisance IAs could distract the flight crew unnecessarily, reduce confidence in the system, and negatively affect safety and operational effectiveness. Repeated nuisance IAs could decrease the use of CD&R and reduce expeditious flight crew response to true IAs.

A missed indication or alert is defined as a failure to provide an indication or alert when it is necessary provided ownship and traffic are adequately equipped [RTCA, 2010]. Missed IAs represent a reduction in CD&R benefits and result in operations that are similar to today's operations where IAs are not provided.

The SURF IA SPR definitions of nuisance and missed boundaries were applied. Horizontal position error was the only source of error modeled. Other sources of error, such as vertical position error, airport database error, and flight technical error were not included.

When an aircraft was on approach, an approach corridor as defined in the SURF IA SPR for NACp 8 with a probability of missed alert of 0.01 was used since NACp 8 and higher was being evaluated (Figure 19). The corridor width was +/- 321.5 ft at the runway threshold and linearly increased to +/- 964.6 ft at 3 NM away from the runway threshold. The nuisance boundary condition occurred when the true aircraft position was outside the approach corridor, but the detected position was within the approach corridor. The missed boundary condition occurred when the aircraft's true position was within the approach corridor, but the detected position was outside the approach corridor. Since the true position of the approach aircraft tracked the extended runway centerline and was never outside of the approach corridor, the aircraft could never enter the nuisance boundary.

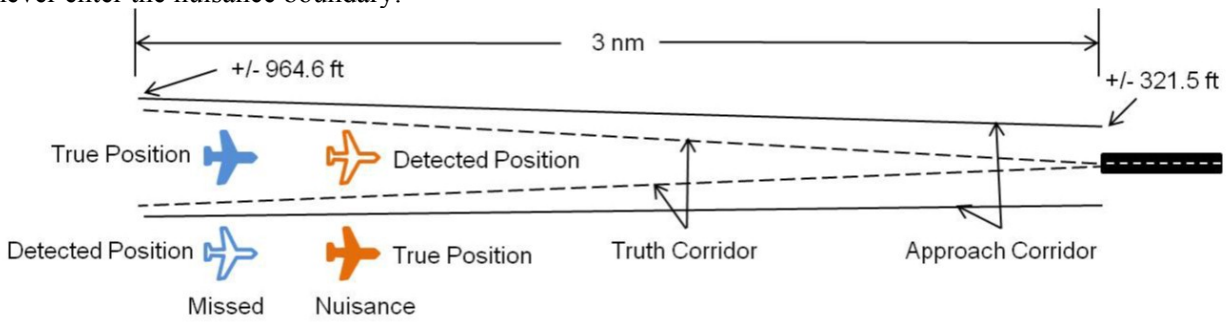

Figure 19. Missed/Nuisance Alert Definition When On Approach.

When an aircraft had crossed the runway threshold on landing or was traveling along a runway (Figure 20), the nuisance boundary condition occurred when the aircraft's true position was farther than one runway width (150 ft) from the runway centerline, but the detected position was within one runway width of the centerline. A missed boundary condition occurred when the aircraft's true position was within one runway width of the runway centerline, but the detected position was greater than one runway width from the centerline.

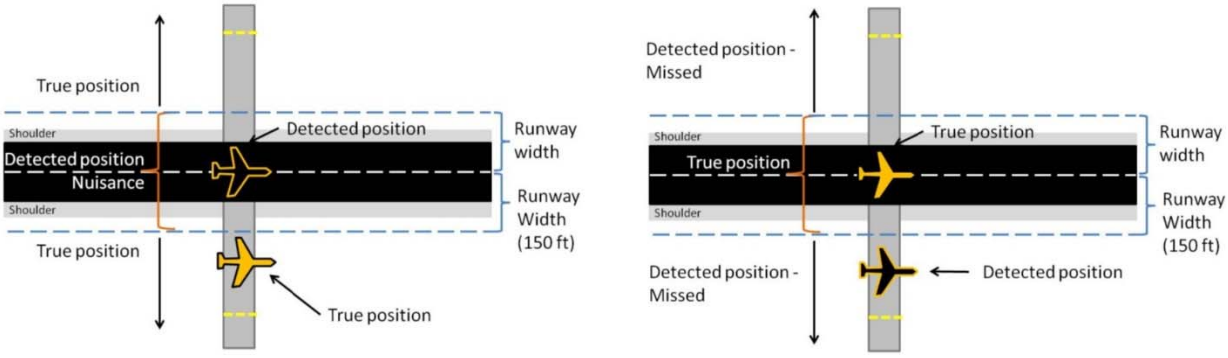

Figure 20. Nuisance/Missed Alert Definition When Traveling Along a Runway.

When an aircraft was taxiing across a runway, the nuisance boundary condition occurred when the true position of the aircraft's nose (when entering) or tail (when exiting) was at or behind the hold line, but any part of the detected aircraft (from nose to tail) was between the runway shoulder edges (Figure 21). The missed boundary condition occurred when the true position of any part of the aircraft was between the runway shoulder edges, but the detected nose position (when entering) or tail position (when exiting) was outside of the runway shoulder edges. A shoulder width of 7.5 m (24.6 ft), as defined in the SURF IA SPR for Aerodrome code 4, was used. A 150 ft wide runway was assumed; therefore, the distance between shoulder edges was approximately 200 ft. The hold line was located 225 ft from the runway centerline.

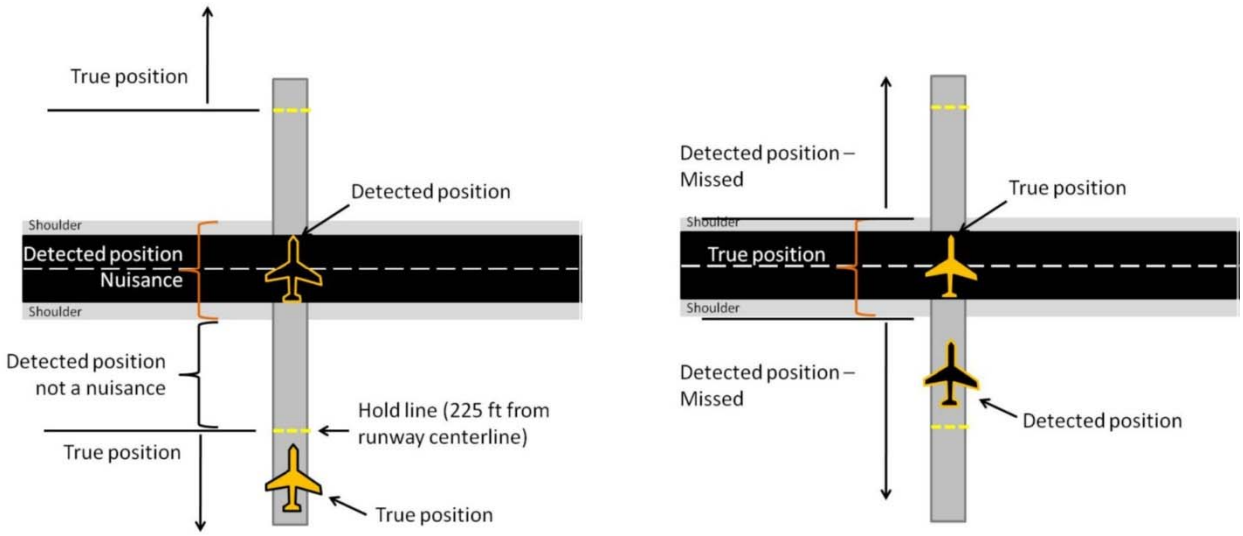

Figure 21. Nuisance/Missed Alert Definition When Taxiing Across a Runway.

When an aircraft was traveling along a taxiway, the nuisance boundary condition occurred when the true position was farther than one taxiway width (75 ft) from the taxiway centerline, but the detected position was within one taxiway width of the taxiway centerline. The missed boundary condition occurred when the true position was within one taxiway width of the taxiway centerline, but the detected position was greater than one taxiway width from the taxiway centerline. Since the true position of both aircraft during taxi tracked their respective taxiway centerlines, the aircraft could never enter the nuisance boundary.

When an aircraft was crossing at a taxiway intersection, the nuisance boundary condition occurred when the true position of the nose (when entering) or tail (when exiting) was at or behind the taxiway holding position (assumed for this study to be 129.5 ft from crossing taxiway centerline [FAA, 2009b]), but any part of the detected aircraft (from nose to tail) was determined to be between the taxiway shoulder edges. A shoulder width of 24.6 ft was used [FAA, 2010b]. The missed boundary condition occurred when the true position of any part of the aircraft was determined to be between the taxiway shoulder edges, but the detected nose position (when entering) or tail position (when exiting) was outside of the taxiway shoulder edges.

When an airborne aircraft was crossing the path of an approaching aircraft, the nuisance boundary condition occurred when the true position of the crossing aircraft was outside of the approach corridor defined above and the detected position was within the approach corridor. The missed boundary condition occurred when the true position of the crossing aircraft was within the approach corridor and the detected position was outside of the approach corridor.

An IA was considered to be a nuisance if the IA was generated when the aircraft was within a nuisance boundary, based on the definitions above.

A straight-forward corollary for a missed IA definition does not exist. If the aircraft was within the missed boundary, based on the definitions above, and an IA was not generated, that did not necessarily mean that an IA should have been generated. Even though one of the aircraft was in the missed boundary,

the geometry of the aircrafts' trajectory may not be on a collision path. Therefore, an algorithm dependent definition was developed. If an IA was generated when transmitting truth data but an IA was not generated at the same instance when transmitting NACp data, then a missed IA was counted.

4.5.3 Unnecessary Maneuver

Previous research has shown that pilots instinctively react upon receiving airport traffic WAs in the flight deck [Jones et al, 2010] without necessarily confirming with secondary or additional information first. It is critical that alerting only occurs when needed; otherwise, these unnecessary maneuvers can cause delays, equipment wear, and other costs to airlines.

Each occurrence of a maneuver (go-around, accelerated braking, rejected take-off, climb, descend, accelerate during taxi, and decelerate during taxi) was evaluated to determine if the maneuver was necessary. Maneuvering was considered unnecessary if made based on a WA issued when the aircraft were broadcasting NACp accuracy, but for the same test conditions, a WA was not issued when broadcasting true position data. This measure quantifies untimely nuisance alerts using an algorithm-dependent methodology. Only the test runs in which maneuvering was possible were evaluated for unnecessary maneuvers. Therefore, for Aircraft A, unnecessary maneuvering was only evaluated when Aircraft A or both aircraft were equipped with CD&R. Likewise, for Aircraft B, unnecessary maneuvering was only evaluated when Aircraft B or both aircraft were equipped.

4.5.4 Unwanted Alert

This metric was developed as an effort to determine how far an alert zone should be from the hold line so unwanted (i.e., nuisance) alerts do not occur when an aircraft is preparing to cross the runway but is still behind the hold line. The edge of the alert zone was placed at the same location as the hold line (225 ft from the runway centerline) so an alert would be generated the moment the aircraft crossed the hold line. An alert was considered unwanted if the true aircraft position was behind the hold line but the detected position indicated the aircraft to be over the hold line, causing an alert (Figure 22). If an unwanted alert was triggered, the maximum distance the detected aircraft nose crossed over the hold line was recorded, thus approximating the distance the alert zone should be from the hold line.

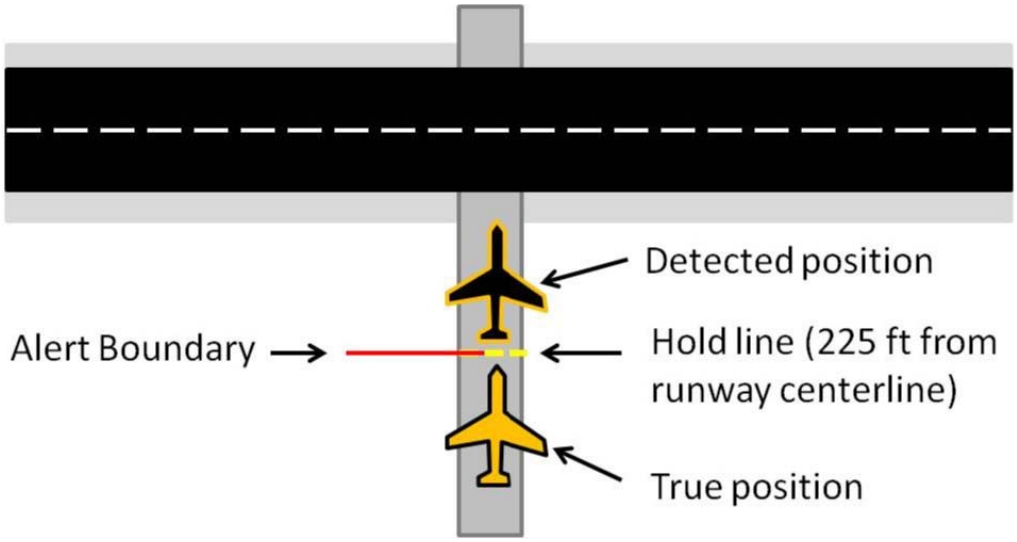

Figure 22. Unwanted Alert Definition.

5 Results

A summary of quantitative results is presented. All data is referenced from the aircraft CG, unless noted otherwise. For the aircraft used in this study, the nose position was 72.8 ft from the CG and the tail position was 82 ft from the CG.

For each scenario, the data analysis was limited to the area of interest, i.e., until the aircraft reached the CPA or until 10 seconds after a WA terminated, whichever was later. Also, both aircraft broadcast the same level of positional accuracy for each test run.

Pearson's Chi-Square Test [Agresti, 2002] was utilized to evaluate relationships between position accuracy or CD&R equipage levels and the test metrics. The null hypothesis tested the independence between the five position accuracy levels or four CD&R equipage levels and the associated test metric, meaning that changing the position accuracy level or CD&R equipage level was not associated with more collisions, for example. This hypothesis was rejected in favor of the alternative hypothesis, that position accuracy level or CD&R equipage level was not independent of the test metric if the p-value fell below a significance threshold of $\alpha = .05/2 = .025$. This threshold was specified to account for the fact that two aircraft contributed to the same data set but were tested separately. Reducing α in this way reduced the risk of false positives, or concluding there was a relationship between position accuracy or equipage level and a test metric when there was really no such relationship. If the null hypothesis was rejected, suggesting that a test metric was in some way dependent on the position accuracy or CD&R equipage level, the nature of that relationship was inferred from standardized residuals. Position accuracy or equipage levels with positive residuals indicate the levels are different from the rest and have more reported events than would happen by chance.

Some test metrics with infrequent events may produce sparse data that would violate the assumptions of the Chi-square test. In these cases, the data table was systematically condensed to either fit the assumptions or be tested using Fisher's Exact test [Agresti, 2002] with the same hypotheses as above. If the null hypothesis was rejected, the table itself was used to draw conclusions about which position accuracy or equipage levels reported more events than would happen by chance.

5.1 ATCAM Algorithm Results

5.1.1 Position Data Analysis

An analysis was conducted to determine the difference between the true aircraft position and the detected aircraft position for each position accuracy category for all test runs conducted during the ATCAM algorithm evaluation (Table 4) in order to validate the surveillance simulation against the NACp 95 percent (%) horizontal accuracy bounds specifications (Table 1). The prediction interval is an estimate of an interval in which future observations will fall, with a certain probability, given what has already been observed. The 95% prediction interval means there is a 95% probability that a future observation will be contained within the prediction interval. These values fall within the defined NACp 95% horizontal accuracy bounds.

Table 4. Position Data Analysis During ATCAM Evaluation.

NACp	Mean (ft)	Standard Deviation (ft)	95% Upper Prediction Interval (ft)
8	144.7	78.2	298.0
9	46.9	25.4	96.6
10	15.7	8.5	32.4
11	4.7	2.6	9.9

5.1.2 Runway Scenario – Arrival with Taxi Crossing

For each of the 20 cases in this scenario, 2,367 combinations of the initiation delay and initial position for Aircraft B (taxiing aircraft) were evaluated, for a total of 198,828 test runs.

Algorithm performance – CAs were issued on 43% to 58% of the runs for the taxiing aircraft (Aircraft B) but only 16% to 30% of the time for the approach aircraft (Aircraft A) (Table 5). WAs were generated on approximately 44% to 50% of the runs for either aircraft. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which CAs and WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

When analyzing alerts that occurred when transmitting truth position data, CAs were issued on approach when the aircraft was approximately 1.3 NM to 1.0 NM prior to the runway threshold. During a higher percentage of test runs, the alerting criteria was not met until the aircraft was less than 1.0 NM prior to the runway threshold on approach or on the runway after landing, within the WA zone. For this study, the runway was 150 ft wide and the runway hold line was 225 ft from the runway centerline. For the taxiing aircraft, CAs occurred approximately 570 ft before reaching the runway centerline (345 ft before the runway hold line) until approximately 310 ft past the runway centerline (235 ft past the runway edge). WAs occurred from approximately 470 ft before reaching the runway center line (245 ft before the runway hold line) until 305 ft past the runway centerline (230 ft past the runway edge).

Table 5. ATCAM Alert Statistics for All Evasive Actions by NACp for Arrival with Taxi Crossing Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
8	66,276	19,783, 29.9	2,557, 3.9	33,476, 50.5	10,432, 15.7
9	56,808	11,291, 19.9	626, 1.1	25,870, 45.5	2,008, 3.5
10	37,872	6,144, 16.2	4, 0.0	16,793, 44.3	432, 1.1
11	28,404	4,596, 16.2	2, 0.0	12,506, 44.0	141, 0.5
Truth	9,468	1,528, 16.1	0, 0.0	4,161, 44.0	0, 0.0
Aircraft B (Taxi)					
8	66,276	38,276, 57.8	12,890, 19.4	29,397, 44.4	11,691, 17.6
9	56,808	26,237, 46.2	1,675, 3.0	27,513, 48.4	3,158, 5.6
10	37,872	16,415, 43.3	685, 1.8	18,009, 47.5	820, 2.2
11	28,404	12,236, 43.1	545, 1.9	13,534, 47.6	481, 1.7
Truth	9,468	4,076, 43.0	186, 2.0	4,515, 47.7	128, 1.4

Alert toggling occurred when multiple instances of CAs and WAs were generated during a test run (Table 5). Alert toggling is undesirable (i.e., it is a distraction to the flight crew and would cause mistrust in the technology). As the position accuracy was reduced, alert toggling occurred more frequently, particularly for NACp 8 accuracy. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which multiple CAs and multiple WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The alert toggling included gaps between alerts in many instances. In addition to position accuracy, the toggling can also be a result of aircraft maneuvering. It should be noted that for Aircraft B, toggling occurred when truth position data was transmitted, which was not expected. It was determined that these multiple alerts were generated after Aircraft B had crossed Runway 10 and was entering a nearby runway. Alerts should not have been generated in this situation because there was no traffic threat on the nearby runway.

When analyzing by CD&R equipage level (Table 6), CAs were issued on approximately 22% of the runs for Aircraft A and on approximately 49% of the runs for Aircraft B for all equipage levels. WAs were generated on 42% to 51% of the runs for Aircraft A, depending on the equipage level, and on approximately 47% of the runs for all equipage levels for Aircraft B. For Aircraft A, there was a significant difference (p

< 0.001) in the number of runs in which CAs and WAs were generated between Aircraft B and Both aircraft equipped vs. Neither aircraft and Aircraft A equipped. For Aircraft B, there was a significant difference (p = 0.004) in the number of runs in which CAs were generated between Both aircraft equipped vs. Neither aircraft, Aircraft A, and Aircraft B equipped. There was not a significant difference (p = 0.411) in the number of runs in which WAs were generated between equipage levels.

Alert toggling occurred more frequently when Aircraft B was equipped with CD&R (Table 6). For Aircraft A, there was a significant difference (p < 0.001) in the number of runs in which multiple CAs and multiple WAs were generated between Aircraft B equipped vs. Neither aircraft, Aircraft A, and Both aircraft equipped. For Aircraft B, there was a significant difference in the number of runs in which multiple CAs (p = 0.009) and multiple WAs (p < 0.001) were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Table 6. ATCAM Alert Statistics for All NACp by Evasive Action for Arrival with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	49,707	10,436, 21.0	617, 1.2	25,423, 51.1	3,011, 6.1
Aircraft A	49,707	10,248, 20.6	479, 1.0	25,441, 51.2	2,604, 5.2
Aircraft B	49,707	11,763, 23.7	1,302, 2.6	20,959, 42.2	4,410, 8.9
Both	49,707	10,895, 21.9	791, 1.6	20,983, 42.2	2,988, 6.0
Aircraft B (Taxi)					
Neither	49,707	24,497, 49.3	4,069, 8.2	23,154, 46.6	4,200, 8.4
Aircraft A	49,707	24,348, 49.0	3,948, 7.9	23,319, 46.9	3,970, 8.0
Aircraft B	49,707	24,425, 49.1	4,113, 8.3	23,143, 46.6	4,394, 8.8
Both	49,707	23,970, 48.2	3,851, 7.8	23,352, 47.0	3,714, 7.5

Table 7. ATCAM Alert Statistics When Transmitting Truth Position Data for Arrival with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	49,707	8,029, 16.1	1, 0.0	25,347, 51.0	0, 0.0
Aircraft A	49,707	8,070, 16.2	1, 0.0	24,978, 50.2	0, 0.0
Aircraft B	49,707	8,005, 16.1	3, 0.0	18,706, 37.6	0, 0.0
Both	49,707	8,031, 16.2	1, 0.0	18,402, 37.0	1, 0.0
Aircraft B (Taxi)					
Neither	49,707	21,437, 43.1	946, 1.9	23,483, 47.2	819, 1.6
Aircraft A	49,707	21,279, 42.8	946, 1.9	23,509, 47.3	781, 1.6
Aircraft B	49,707	21,325, 42.9	948, 1.9	22,344, 45.0	557, 1.1
Both	49,707	21,200, 42.6	946, 1.9	22,396, 45.1	637, 1.3

In order to demonstrate the effect of accurate position data on the occurrence of alert and multiple alert generation, alert statistics were also compiled by CD&R equipage level when truth position data was transmitted (Table 7). CAs were issued on approximately 16% of the runs for Aircraft A for all equipage levels and on approximately 43% of the runs for Aircraft B. WAs were generated on 37% to 51% of the runs for Aircraft A depending on equipage level and on approximately 46% of the runs for Aircraft B for all equipage levels. There were very few multiple alerts when Aircraft A was equipped with CD&R and less than 2% of the runs had multiple alerts for Aircraft B. For Aircraft A, there was no significant difference in the number of runs in which CAs (p = 0.956), multiple CAs (p = 0.169), and multiple WAs (p

= 0.250) were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which WAs were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which CAs ($p = 0.491$) and multiple CAs ($p = 1.0$) were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which WAs and multiple WAs were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped.

Missed and nuisance alerts – The number of runs in which the aircraft entered the defined missed and nuisance boundaries increased as the position accuracy decreased, as shown in Table 8. Aircraft can cross into the missed and nuisance boundary multiple times throughout a test run, for varying lengths of time. The number of times (count) and amount of time (duration and percentage of run length) that the aircraft were within the boundaries was greater when transmitting less accurate data. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies and when it entered the nuisance boundary between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies and when it entered the nuisance boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 8. ATCAM Missed and Nuisance Boundary Statistics for Arrival with Taxi Crossing Scenario.

	Entered Missed Boundary				Entered Nuisance Boundary			
NACp	# Runs, % Runs	Count (weighted mean, SD*)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Arrival)								
8	53,828, 81.2	6.6, 5.7	11.5, 11.9	7.9	371, 0.6	1.1, 0.2	0.6, 0.2	0.2
9	655, 1.1	1.6, 1.2	1.5, 1.6	0.8	333, 0.6	1.0, 0.1	0.6, 0.2	0.2
10	148, 0.4	1.0, 0.1	0.5, 0.3	0.2	136, 0.4	1.0, 0.0	0.4, 0.2	0.2
11	63, 0.2	1.0, 0.0	0.2, 0.1	0.1	64, 0.2	1.0, 0.0	0.2, 0.1	0.1
Truth	0, 0.0	0.0, 0.0	0, 0.0	0.0	0, 0.0	0.0, 0.0	0, 0.0	0.0
Aircraft B (Taxi)								
8	47,889, 72.3	2.0, 1.2	4.1, 2.9	3.6	19,798, 29.9	3.6, 3.8	6.5, 9.6	5.6
9	34,834, 61.3	1.3, 0.6	1.5, 1.2	1.3	87, 0.2	1.7, 1.4	1.3, 1.8	1.1
10	20,840, 55.0	1.1, 0.3	0.6, 0.3	0.5	0, 0.0	0.0, 0.0	0, 0.0	0.0
11	10,079, 35.5	1.1, 0.2	0.3, 0.1	0.2	0, 0.0	0.0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0, 0.0	0.0	0, 0.0	0.0, 0.0	0, 0.0	0.0

*SD = Standard Deviation

For the approach Aircraft A, the majority of occurrences of entering the missed boundary was after the aircraft had crossed the runway threshold for landing. The aircraft only entered the missed boundary while on approach before crossing the runway threshold during 2.8% of the test runs when the aircraft were transmitting data with NACp 8 accuracy. Since Aircraft A tracked the extended centerline on approach and centerline after landing, the nuisance boundary was entered as the aircraft was exiting the runway.

The taxiing Aircraft B entered the missed boundary at least once for a high percentage of the test runs for accuracy levels of NACp 8 to 11. This was due to the criteria for entering the missed boundary. The aircraft was counted as entering the missed boundary when the true position of any part of the aircraft was determined to be between the runway shoulder edges, but the detected nose position when entering or tail position when exiting was outside of the runway shoulder edges. As such, there was no buffer between when the aircraft was inside or outside the missed boundary so a measurable difference between the true and detected position could cause a missed boundary to be counted.

The number of test runs that contained missed and nuisance alerts was relatively low, overall, as shown in Table 9. However, missed and nuisance alerts for both aircraft were highest with NACp 8 accuracy. The

missed alert definition, as noted earlier, is algorithm dependent. For both aircraft, there was a significant difference in the number of runs in which missed CAs, missed WAs, nuisance CAs, and nuisance WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies ($p < 0.001$ for all except Aircraft A nuisance CAs $p = 0.004$).

Table 9. ATCAM Missed and Nuisance Alert Statistics for All Evasive Actions by NACp for Arrival with Taxi Crossing Scenario.

NACp	Total # Runs	Missed CA (#, Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival)					
8	66,276	1,525, 2.3	4,868, 7.3	5, 0.0	24, 0.0
9	56,808	470, 0.8	1,354, 2.4	0, 0.0	5, 0.0
10	37,872	169, 0.4	133, 0.4	0, 0.0	0, 0.0
11	28,404	68, 0.2	54, 0.2	0, 0.0	0, 0.0
Truth	9,468	1, 0.0	3, 0.0	0, 0.0	0, 0.0
Aircraft B (Taxi)					
8	66,276	2,239, 3.4	5,655, 8.5	2,231, 3.4	1,896, 2.9
9	56,808	864, 1.5	1,169, 2.1	0, 0.0	1, 0.0
10	37,872	142, 0.4	239, 0.6	0, 0.0	0, 0.0
11	28,404	36, 0.1	61, 0.2	0, 0.0	0, 0.0
Truth	9,468	2, 0.0	2, 0.0	0, 0.0	0, 0.0

Both aircraft experienced missed alerts when transmitting truth position data. These unexpected events occurred because even though the aircraft were broadcasting truth position data, the ADS-B transmission model was still being used. The transmission model resulted in a slight delay between one aircraft's position at the time of transmitting the ADS-B message and the position at the time of reception of the ADS-B message by the other aircraft. This delay was present in all scenarios, but this position difference was negligible compared to the NACp position uncertainty error. In these scenarios, one aircraft did not detect a conflict with the other aircraft based on the broadcast position, but if instantaneous position information were used, a conflict would have been detected. The small error introduced by the movement of the aircraft between transmission and reception of the ADS-B message resulted in just enough difference in relation to the other aircraft's position to result in the missed alerts. For Aircraft A, the missed CA should have occurred when the aircraft was exiting the runway while Aircraft B was located 10,015 ft down the runway near Aircraft A's exit. The missed WAs should have occurred after the aircraft landed and was at 71 kt and Aircraft B was 276 ft from the runway centerline. For Aircraft B, the missed CAs should have occurred when the aircraft was 286 ft from the runway centerline and Aircraft A had landed and was at 104 kt. The missed WAs should have occurred when the aircraft was on the runway and Aircraft A was on final approach, approximately 2500 ft prior to the threshold and 208 ft AGL.

An alert was considered a nuisance if it was generated at the same time the aircraft was determined to be within the nuisance boundary. Therefore, nuisance alerts for Aircraft A only occurred as the aircraft was exiting the runway (see explanation above).

When analyzing by CD&R equipage level (Table 10), missed alerts occurred for less than 4% of the runs and nuisance alerts occurred for 1.2% or less of the runs for all equipage levels for both aircraft. For Aircraft A, there was no significant difference in the number of runs in which missed CAs ($p = 0.203$), missed WAs ($p = 0.777$), and nuisance CAs ($p = 0.604$) occurred between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which nuisance WAs occurred between Aircraft B equipped vs. Neither aircraft, Aircraft A, and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which missed CAs ($p = 0.641$), missed WAs ($p = 0.127$), and nuisance CAs ($p = 0.162$) occurred between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which nuisance WAs occurred between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped.

Table 10. ATCAM Missed and Nuisance Alert Statistics for All NACp by Evasive Action for Arrival with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	49,707	526, 1.1	1,596, 3.2	1, 0.0	4, 0.0
Aircraft A	49,707	588, 1.2	1,609, 3.2	2, 0.0	4, 0.0
Aircraft B	49,707	542, 1.1	1,632, 3.3	1, 0.0	19, 0.0
Both	49,707	577, 1.2	1,575, 3.2	1, 0.0	2, 0.0
Aircraft B (Taxi)					
Neither	49,707	839, 1.7	1,768, 3.6	557, 1.1	415, 0.8
Aircraft A	49,707	810, 1.6	1,862, 3.7	525, 1.1	429, 0.9
Aircraft B	49,707	796, 1.6	1,727, 3.5	599, 1.2	531, 1.1
Both	49,707	838, 1.7	1,769, 3.6	550, 1.1	522, 1.1

Unnecessary maneuvering - As described in Section 4.5.3, each occurrence of a maneuver was evaluated to determine if the maneuver was necessary. Maneuvering was considered unnecessary if made based on a WA issued when the aircraft were broadcasting NACp accuracy, but for the same test conditions, a WA was not issued when broadcasting truth position data. Only the test runs in which maneuvering was possible were evaluated for unnecessary maneuvers. For Aircraft A, unnecessary maneuvering was only evaluated when Aircraft A or Both aircraft were equipped with CD&R. For Aircraft B, unnecessary maneuvering was evaluated when Aircraft B or Both aircraft were equipped. This measure quantifies untimely nuisance alerts using an algorithm-dependent methodology.

For this scenario, the percentage of test runs in which the aircraft maneuvered unnecessarily is shown in Table 11. As the position accuracy decreased, the frequency of occurrences of unnecessary maneuvers increased. With a NACp value of 8, approximately 11% of the maneuvers were unnecessary for Aircraft A and 3% of the maneuvers were unnecessary for Aircraft B. With a NACp value of 11, approximately 0.1% or 1 of 1,000 maneuvers were unnecessary for Aircraft A and 0.3% or 3 out of 1,000 maneuvers were unnecessary for Aircraft B. There was a significant difference ($p < 0.001$) in the number of runs in which unnecessary maneuvers occurred for Aircraft A between NACp 8 vs. NACp 9, 10, 11, and truth accuracies and in the number of runs in which unnecessary maneuvers occurred for Aircraft B between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies.

There were some unnecessary maneuvers for Aircraft B when transmitting data with truth accuracy. For these 10 runs, Aircraft B was located 10,015 ft from the runway threshold and 268 ft to 450 ft from the runway centerline, traveling toward the runway. Aircraft A was approximately 2,070 ft past the runway threshold with 129 kts ground speed.

Table 11. Unnecessary Maneuvers for All Evasive Actions by NACp Using ATCAM During Arrival with Taxi Crossing Scenario.

NACp	Total # Runs	Aircraft A (Arrival) (# Runs, % Runs)	Aircraft B (Taxi) (# Runs, % Runs)
8	33,138	3,657, 11.0	1,134, 3.4
9	28,404	1,076, 3.8	532, 1.9
10	18,936	81, 0.4	80, 0.4
11	14,202	19, 0.1	39, 0.3
Truth	4,734	0, 0.0	10, 0.2

The number and percentage of test runs in which the aircraft maneuvered unnecessarily based on the CD&R equipage level is shown in Table 12. A slightly higher percentage of unnecessary maneuvers occurred onboard Aircraft A when Both aircraft were equipped. For Aircraft A, there was a significant

difference ($p < 0.001$) in the number of runs in which unnecessary maneuvers occurred between Both aircraft equipped vs. Aircraft A equipped. There was no significant difference ($p = 0.536$) between equipage levels for Aircraft B.

Table 12. Unnecessary Maneuvers for All NACp by Evasive Action Using ATCAM During Arrival with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	Aircraft A (Arrival) (# Runs, % Runs)	Aircraft B (Taxi) (# Runs, % Runs)
Neither	49,707	N/A	N/A
Aircraft A	49,707	2,080, 4.2	N/A
Aircraft B	49,707	N/A	884, 1.8
Both	49,707	2,753, 5.5	911, 1.8

Collision avoidance – By the design of the scenarios, in the absence of CD&R, approximately 20% of the runs resulted in a near collision (NC) and approximately 10% resulted in collisions (C), as shown in Table 13. Collision avoidance was affected by the CD&R system equipage level. The most collisions were avoided when Both aircraft were equipped with CD&R. In some instances, CD&R was more effective depending on which aircraft was equipped. For this scenario, more collisions were avoided when the crossing Aircraft B was equipped. However, when only the approach Aircraft A was equipped, collision avoidance was less effective, but better than when Neither aircraft were equipped. When Neither aircraft was equipped with CD&R, there was no significant difference ($p = 1.0$) in the number of runs in which near collisions and collisions occurred between position accuracy levels. When only Aircraft A were equipped with CD&R, there was no significant difference in the number of runs in which near collisions ($p = 0.029$) and collisions ($p = 0.106$) occurred between position accuracy levels. When Aircraft B was equipped, there was a significant difference ($p = 0.003$) in the number of runs in which near collisions occurred between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies. There was also a significant difference ($p < 0.001$) in number of runs in which collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. When Both aircraft were equipped with CD&R, there was a significant difference ($p = 0.007$) in the number of runs in which near collisions occurred between NACp 9 vs. NACp 8, 10, 11, and truth accuracies. There was also a significant difference ($p < 0.001$) in the number of runs in which collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 13. Number/Percentage of Near Collisions (NC) and Collisions (C) Using ATCAM for Equipage Combinations for Arrival with Taxi Crossing Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	16,569	3,194, 19.3	1,540, 9.3	2,522, 15.2	1,065, 6.4	2,616, 15.8	519, 3.1	1,745, 10.5	432, 2.6
9	14,202	2,741, 19.3	1,319, 9.3	2,314, 16.3	992, 7.0	2,360, 16.6	114, 0.8	1,334, 9.4	75, 0.5
10	9,468	1,828, 19.3	880, 9.3	1,552, 16.4	676, 7.1	1,629, 17.2	53, 0.6	963, 10.2	18, 0.2
11	7,101	1,367, 19.3	660, 9.3	1,166, 16.4	506, 7.1	1,245, 17.5	21, 0.3	752, 10.6	5, 0.1
Truth	2,367	456, 19.3	220, 9.3	390, 16.5	171, 7.2	414, 17.5	6, 0.3	256, 10.8	0, 0.0

A more detailed investigation was conducted for the collisions that occurred when transmitting truth position data. The initial location of Aircraft A and Aircraft B for each run that resulted in a collision are indicated in Figures 23, 24, and 25. For example, in Figure 23, collisions resulted when Aircraft A was on approach and 2.5 NM prior to the runway threshold when Aircraft B began to taxi toward the runway from two different locations, (1) 1,600 ft back from the runway centerline and in line with the runway threshold (0 ft from the runway threshold) and (2) 1,600 ft back from the runway centerline and 1,000 ft from the runway threshold.

Many collisions were unavoidable for the approach aircraft. The most frequent causes were the WA occurred during high speed rollout or when the aircraft was too low to go around. Other times the collision occurred after the maneuver was initiated, but before aircraft climb, during climb-out, or during runway taxi. In some instances, the approach aircraft came to a full stop after clearing the runway, but then was hit by the taxiing aircraft.

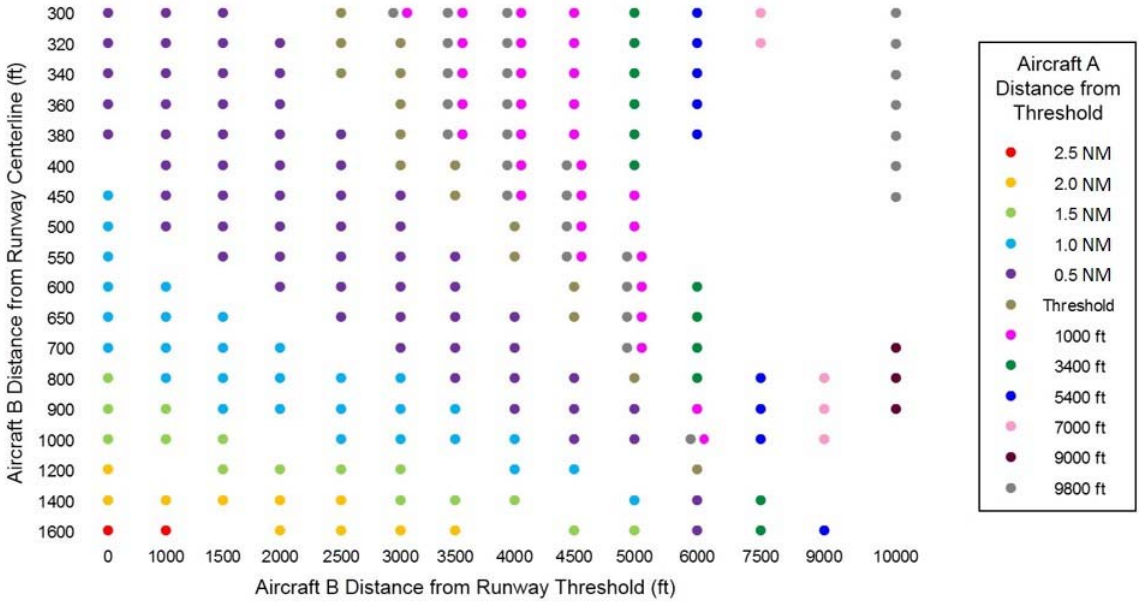

Figure 23. Aircraft Starting Locations for Collision Runs When Transmitting Truth Position Data When Neither Aircraft Maneuvers For Arrival with Taxi Crossing Scenario.

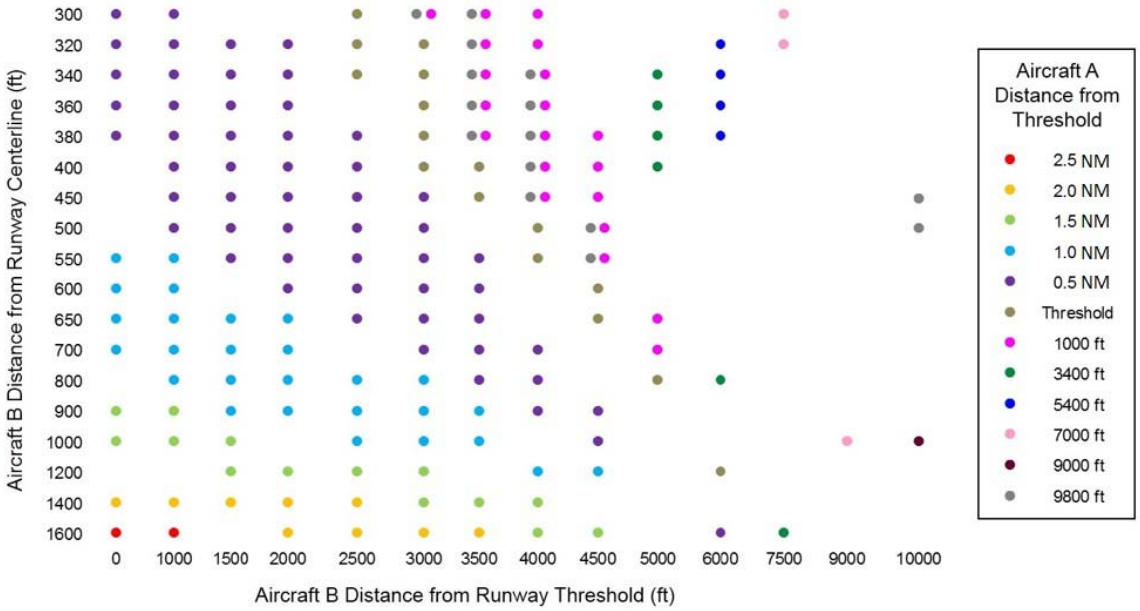

Figure 24. Aircraft Starting Locations for Collision Runs When Transmitting Truth Position Data When Only Aircraft A Maneuvers For Arrival with Taxi Crossing Scenario.

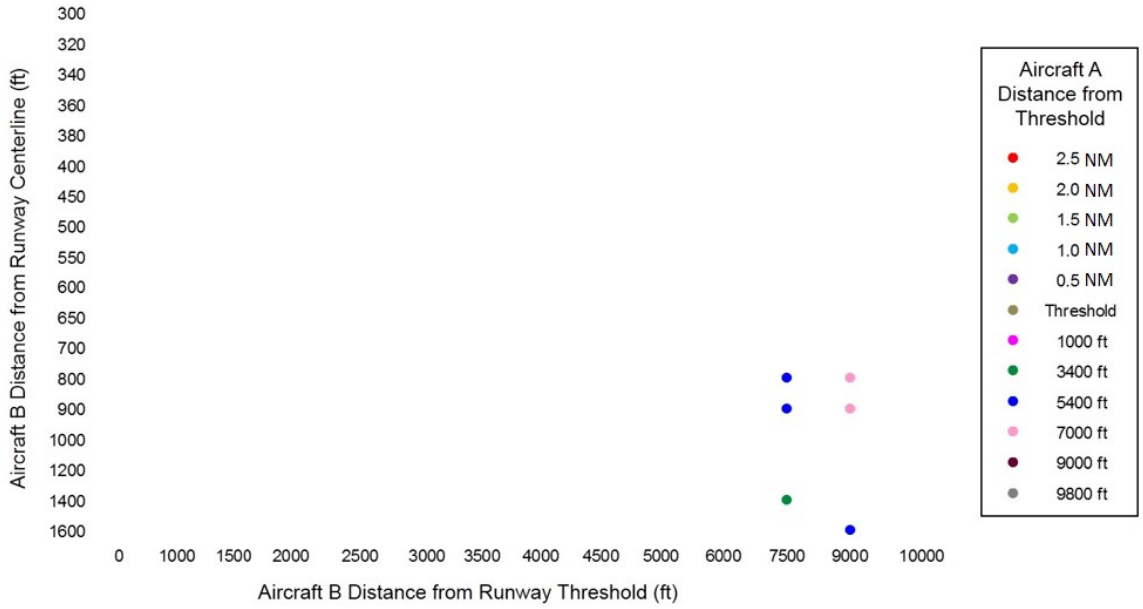

Figure 25. Aircraft Starting Locations for Collision Runs When Transmitting Truth Position Data When Only Aircraft B Maneuvers For Arrival with Taxi Crossing Scenario.

Unwanted alert – As defined above (Section 4.5.4), an alert was considered unwanted if the true position of Aircraft B was behind the hold line but the detected position indicated that the aircraft was over the hold line. The frequency of unwanted alerts increased as the position accuracy decreased, particularly with NACp 8 accuracy, as shown in Table 14. Also, a larger buffer between the hold line and alerting zone is required as the position accuracy decreases in order to reduce the number of unwanted alerts. For the arrival with taxi crossing scenario, 99% of unwanted alerts could have been avoided by placing the alert zone 390 ft past the hold line for NACp 8 accuracy, 135 ft past the hold line for NACp 9 accuracy, and 55 ft past the hold line for NACp 10 accuracy. The maximum standard for separation between the hold line and runway centerline is 280 ft [FAA, 2009b] to accommodate the largest aircraft. A 390 ft alerting zone buffer is not practical for even the largest airports.

Table 14. Unwanted Alert Data Using ATCAM for Arrival with Taxi Crossing Scenario.

		Unwanted CA		Unwanted WA	
NACp	Total # Runs	# Runs, % Runs	Max Distance Nose Over Hold Line (ft) (mean, SD)	# Runs, % Runs	Max Distance Nose Over Hold Line (ft) (mean, SD)
8	66,276	5,909, 8.9	126.4, 75.3	11,506, 17.4	147.5, 80.7
9	56,808	1,169, 2.1	50.5, 26.4	3,809, 6.7	55.4, 26.0
10	37,872	12, 0.1	16.6, 11.2	134, 0.4	24.7, 9.5
11	28,404	0, 0.0	0.0, 0.0	0, 0.0	0.0, 0.0
Truth	9,468	0, 0.0	0.0, 0.0	0, 0.0	0.0, 0.0

5.1.3 Runway Scenario – Departure with Taxi Crossing

For each of the 20 cases in this scenario, 1,077 combinations of the initiation delay and initial position for Aircraft B (taxiing aircraft) were evaluated, for a total of 90,468 test runs.

Algorithm performance – For both aircraft, CAs were generated on approximately 12% of the runs when transmitting data with NACp 8 accuracy, but were issued on 3% or less of the runs for accuracy levels of NACp 9 and higher (Table 15). For Aircraft A (departing aircraft), WAs were generated on approximately 53% of the runs when transmitting data with NACp 8 accuracy, but were issued on

approximately 40% of the runs for accuracy levels of NACp 9 and higher. For Aircraft B (taxiing aircraft), WAs were generated on approximately 58% of the runs when transmitting data with NACp 8 accuracy, but were issued on approximately 62% of the runs for accuracy levels of NACp 9 and higher. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which CAs and WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

When analyzing alerts that occurred when transmitting truth position data, all the CAs that were issued onboard the departing aircraft occurred after the aircraft had received a WA and aborted the departure. WAs were issued onboard the departing aircraft from when the aircraft was approximately 38 ft from the runway threshold and 15 kt until it was approximately 8,490 ft from the threshold and 360 ft AGL. The aircraft lifted off when it was approximately 5,070 ft from the threshold. For the taxiing aircraft, CAs occurred approximately 470 ft before reaching the runway centerline (245 ft before the runway hold line) until approximately 125 ft before the runway centerline (100 ft over the runway hold line). WAs occurred from approximately 470 ft before reaching the runway centerline (245 ft before the runway hold line) until approximately 185 ft before the runway centerline (40 ft over the runway hold line).

Toggling of CAs occurred on less than 1% of the runs for both aircraft for all position accuracy levels. For the WAs, as the position accuracy was reduced, the toggling occurred more frequently, particularly for NACp 8 accuracy (Table 15). For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which multiple CAs and multiple WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 15. ATCAM Alert Statistics for All Evasive Actions by NACp for Departure with Taxi Crossing Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Departure)					
8	30,156	3,392, 11.2	130, 0.4	15,862, 52.6	3,548, 11.8
9	25,848	233, 0.9	11, 0.0	10,806, 41.8	821, 3.2
10	17,232	40, 0.2	0, 0.0	6,915, 40.1	233, 1.4
11	12,924	28, 0.2	0, 0.0	5,164, 40.0	74, 0.6
Truth	4,308	10, 0.2	0, 0.0	1,730, 40.2	5, 0.1
Aircraft B (Taxi)					
8	30,156	3,799, 12.6	264, 0.9	17,469, 57.9	4,575, 15.2
9	25,848	804, 3.1	28, 0.1	16,144, 62.5	1,129, 4.4
10	17,232	300, 1.7	10, 0.1	10,676, 62.0	190, 1.1
11	12,924	190, 1.5	11, 0.1	7,974, 61.7	49, 0.4
Truth	4,308	67, 1.6	4, 0.1	2,655, 61.6	3, 0.1

The alert toggling included gaps between alerts when transmitting data with lower position accuracy (NACp 8 and 9). Multiple alerts also occurred as a result of aircraft maneuvering, Aircraft A conducting a rejected takeoff and Aircraft B accelerated braking. For both aircraft, alert toggling occurred when truth position data was transmitted. For Aircraft B, a multiple CA occurred after Aircraft A rejected the takeoff and was close to stopping. For Aircraft A and B, a multiple WA occurred after Aircraft A rejected the takeoff and was almost at a complete stop.

When analyzing by CD&R equipage level (Table 16), CAs were issued on approximately 4% of the runs for Aircraft A and on approximately 6% of the runs for Aircraft B for all equipage levels. WAs were generated on approximately 37% or 53% of the runs for Aircraft A, depending on the equipage level, and on approximately 60% of the runs for all equipage levels for Aircraft B. For Aircraft A, there was no significant difference ($p = 0.132$) in the number of runs in which CAs were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which WAs were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped. For Aircraft B, there was a significant difference ($p = 0.011$) in the number of runs in which CAs were generated between

Neither aircraft equipped vs. Aircraft A, Aircraft B, and Both aircraft equipped. There was also a significant difference ($p < 0.001$) in the number of runs in which WAs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

The rate of alert toggling for CAs was low (less than 1%) for both aircraft for all equipage levels. Alert toggling occurred more frequently for WAs for both aircraft (Table 16). For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which multiple CAs were generated between Both aircraft equipped vs. Neither aircraft, Aircraft A, and Aircraft B equipped and in the number of runs in which multiple WAs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which multiple CAs and multiple WAs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Table 16. ATCAM Alert Statistics for All NACp by Evasive Action for Departure with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Departure)					
Neither	22,617	975, 4.3	22, 0.1	11,931, 52.8	1,272, 5.6
Aircraft A	22,617	877, 3.9	32, 0.1	11,907, 52.6	716, 3.2
Aircraft B	22,617	916, 4.0	23, 0.1	8,312, 36.8	1,701, 7.5
Both	22,617	935, 4.1	64, 0.3	8,327, 36.8	992, 4.4
Aircraft B (Taxi)					
Neither	22,617	1,386, 6.1	31, 0.1	13,941, 61.6	1,686, 7.5
Aircraft A	22,617	1,273, 5.6	120, 0.5	13,523, 59.8	1,163, 5.1
Aircraft B	22,617	1,273, 5.6	38, 0.2	13,973, 61.8	1,909, 8.4
Both	22,617	1,228, 5.4	128, 0.6	13,481, 59.6	1,188, 5.2

Alert statistics were also compiled by CD&R equipage level when truth position data was transmitted (Table 17). CAs were issued on 0.5% or less of the runs for Aircraft A and on less than 2% of the runs for Aircraft B depending on the equipage level. WAs were generated on approximately 30% or 50% of the runs for Aircraft A depending on the equipage level and on approximately 60% of the runs for Aircraft B for all equipage levels. The rate of multiple alerts was very low for both aircraft and only occurred when either Aircraft A or Both aircraft were equipped. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which CAs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped, in the number of runs in which WAs were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped, and in the number of runs in which multiple WAs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped. For Aircraft B, there was a significant difference in the number of runs in which CAs ($p = 0.006$), multiple CAs ($p < 0.001$), and multiple WAs ($p < 0.001$) were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped. There was also a significant difference ($p < 0.001$) in the number of runs in which WAs were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped.

The SURF IA SPR [RTCA, 2010] specifies that IAs must be inhibited above 80 kts. As currently implemented, the ATCAM algorithm calculates alerts throughout the departure when the aircraft ground speed is greater than 80 kts (the mean ground speed when a WA was generated on Aircraft A was 108 kts, standard deviation 47.5 kts for truth accuracy). These data were included in the analyses even though these alerts would not be displayed in the cockpit as per the SPR. For the test runs in which the departing aircraft was to take action (Aircraft A only and Both equipped), WAs were generated when the aircraft's ground speed was less than 80 kts in 13% to 30% of the test runs; without this restriction, WAs were generated on 40% to 64% of the test runs (Table 18). More research is necessary to determine the collision avoidance

benefits of providing alerts to the flight crew after reaching 80 kts versus the risk of pilots making inappropriate responses at high speed.

Table 17. ATCAM Alert Statistics When Transmitting Truth Position Data for Departure with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Departure)					
Neither	22,617	0, 0.0	0, 0.0	11,532, 51.0	0, 0.0
Aircraft A	22,617	123, 0.5	0, 0.0	11,125, 49.2	42, 0.2
Aircraft B	22,617	0, 0.0	0, 0.0	6,990, 30.9	0, 0.0
Both	22,617	79, 0.4	0, 0.0	6,819, 30.1	24, 0.1
Aircraft B (Taxi)					
Neither	22,617	315, 1.4	0, 0.0	13,983, 61.8	0, 0.0
Aircraft A	22,617	390, 1.7	10, 0.0	13,598, 60.1	30, 0.1
Aircraft B	22,617	309, 1.4	0, 0.0	13,236, 58.5	0, 0.0
Both	22,617	352, 1.6	29, 0.1	13,129, 58.0	14, 0.1

Table 18. SURF IA WA Alert Data for Departure Aircraft.

NACp	Total # Runs	WA (# Runs, % Runs)	WAs when < 80 kts (# Runs, % Runs)
8	15,078	9,594, 63.6	4,509, 29.9
9	12,924	5,797, 44.9	2,105, 16.3
10	8,616	3,553, 41.2	1,191, 13.8
11	6,462	2,616, 40.5	863, 13.4
Truth	2,154	871, 40.4	288, 13.4

Missed and nuisance alerts – The number of runs in which the aircraft entered the defined missed and nuisance boundaries varied greatly based on the position accuracy level transmitted, as shown in Table 19. The number of times (count) and amount of time (duration and percentage of run length) that the aircraft were within the boundaries was greater when transmitting less accurate data (Table 19). For the departing Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs the aircraft entered the missed boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For the taxiing Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs the aircraft entered the missed boundary between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies and the number of runs in which the aircraft entered the nuisance boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The departing aircraft entered the missed boundary along its entire departure path. Since the aircraft tracked the runway centerline on departure and after liftoff, it was not possible for it to enter the nuisance boundary.

The taxiing aircraft entered the missed boundary at least once for a high percentage of the test runs for NACp 8 to 11. This was due to the criteria for entering the missed boundary. The aircraft was counted as entering the missed boundary when the true position of any part of the aircraft was determined to be between the runway shoulder edges, but the detected nose position when entering or tail position when exiting was outside of the runway shoulder edges. As such, there was no buffer between when the aircraft was inside or outside the missed boundary so a measurable difference between the true and detected position could cause a missed boundary to be counted.

Table 19. ATCAM Missed and Nuisance Boundary Statistics for Departure with Taxi Crossing Scenario.

NACp	Entered Missed Boundary				Entered Nuisance Boundary			
	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Departure)								
8	22,639, 75.1	4.0, 2.9	8.3, 8.6	23.8	0, 0.0	0, 0.0	0, 0.0	0.0
9	41, 0.2	1.8, 1.3	1.7, 2.0	4.3	0, 0.0	0, 0.0	0, 0.0	0.0
10	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
11	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Aircraft B (Taxi)								
8	10,230, 33.9	1.7, 1.0	3.8, 3.1	10.5	5,286, 17.5	2.5, 2.1	4.4, 6.0	12.6
9	6,094, 23.6	1.2, 0.5	1.5, 1.9	4.2	7, 0.0	1.1, 0.4	0.6, 0.7	1.8
10	3,343, 19.4	1.1, 0.4	0.7, 1.5	1.9	0, 0.0	0, 0.0	0, 0.0	0.0
11	1,504, 11.6	1.1, 0.4	0.4, 1.5	1.1	0, 0.0	0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0

Missed alerts occurred for most position accuracy levels for both aircraft, as shown in Table 20. Nuisance alerts did not occur for Aircraft A and only occurred when transmitting NACp 8 data for Aircraft B. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which missed CAs and missed WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which missed CAs occurred between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies and in the number of runs in which missed WAs, nuisance CAs, and nuisance WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Both aircraft experienced missed WAs when transmitting truth position data. This was due to the transmission delay of the ADS-B model as described in Section 5.1.2. For Aircraft A, four of the missed WAs should have occurred when the aircraft was 284 ft from the threshold and 40 kts and four should have occurred when the aircraft was 623 ft from the threshold and 60 kts. For Aircraft B, the 11 missed WAs should have occurred when the aircraft was 280 ft from the runway threshold and 291 ft to 387 ft from the runway centerline.

Table 20. ATCAM Missed and Nuisance Alert Statistics for All Evasive Actions by NACp for Departure with Taxi Crossing Scenario.

NACp	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Departure)					
8	30,156	51, 0.2	2,444, 8.1	0, 0.0	0, 0.0
9	25,848	11, 0.0	661, 2.6	0, 0.0	0, 0.0
10	17,232	5, 0.0	185, 1.1	0, 0.0	0, 0.0
11	12,924	0, 0.0	67, 0.5	0, 0.0	0, 0.0
Truth	4,308	0, 0.0	8, 0.2	0, 0.0	0, 0.0
Aircraft B (Taxi)					
8	30,156	140, 0.5	3,245, 10.8	167, 0.6	892, 3.0
9	25,848	82, 0.3	504, 1.9	0, 0.0	0, 0.0
10	17,232	32, 0.2	114, 0.7	0, 0.0	0, 0.0
11	12,924	16, 0.1	49, 0.4	0, 0.0	0, 0.0
Truth	4,308	0, 0.0	11, 0.3	0, 0.0	0, 0.0

When analyzing by CD&R equipage level (Table 21), for Aircraft A, missed CAs only occurred when Aircraft A or Both aircraft were equipped with CD&R. Missed CAs occurred at similar rates across equipage levels for Aircraft B. Missed WAs occurred on approximately 4% of the runs for all equipage levels. The rate of nuisance alerts was also similar across equipage levels for Aircraft B. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which missed CAs occurred between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped and the number of runs in which missed WAs occurred between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which missed CAs ($p = 0.041$) and nuisance CAs ($p = 0.919$) occurred between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which missed WAs and nuisance WAs occurred between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Table 21. ATCAM Missed and Nuisance Alert Statistics for All NACp by Evasive Action for Departure with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Departure)					
Neither	22,617	0, 0.0	768, 3.4	0, 0.0	0, 0.0
Aircraft A	22,617	47, 0.2	779, 3.4	0, 0.0	0, 0.0
Aircraft B	22,617	0, 0.0	905, 4.0	0, 0.0	0, 0.0
Both	22,617	20, 0.1	913, 4.0	0, 0.0	0, 0.0
Aircraft B (Taxi)					
Neither	22,617	68, 0.3	915, 4.0	42, 0.2	264, 1.2
Aircraft A	22,617	86, 0.4	1,069, 4.7	43, 0.2	164, 0.7
Aircraft B	22,617	54, 0.2	878, 3.9	38, 0.2	277, 1.2
Both	22,617	62, 0.3	1,061, 4.7	44, 0.2	187, 0.8

Unnecessary maneuvering - The percentage of test runs in which the aircraft maneuvered unnecessarily when transmitting data with various accuracy levels is shown in Table 22. Only the test runs in which maneuvering was possible were evaluated for unnecessary maneuvers. For Aircraft A, unnecessary maneuvering was only evaluated when Aircraft A or Both aircraft were equipped with CD&R. For Aircraft B, unnecessary maneuvering was evaluated when Aircraft B or Both aircraft were equipped. There were no unnecessary maneuvers for the departing aircraft (Aircraft A). As the accuracy decreased, the frequency of occurrences of unnecessary maneuvers increased for the taxiing aircraft (Aircraft B). With NACp 8, 5.4% of the maneuvers were unnecessary. With NACp 11, there was only 1 occurrence of an unnecessary maneuver. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which unnecessary maneuvers occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 22. Unnecessary Maneuvers Using ATCAM During Departure with Taxi Crossing Scenario.

NACp	Total # Runs	Aircraft A (Departure) (# Runs, % Runs)	Aircraft B (Taxi) (# Runs, % Runs)
8	15,078	0, 0.0	808, 5.4
9	12,924	0, 0.0	333, 2.6
10	8,616	0, 0.0	35, 0.4
11	6,462	0, 0.0	1, 0.0
Truth	2,154	0, 0.0	0, 0.0

When evaluating by CD&R equipage level, during 614 (2.7%) test runs Aircraft B maneuvered unnecessarily when only Aircraft B was equipped with CD&R. When Both aircraft were equipped,

unnecessary maneuvers occurred on 563 (2.5%) of the test runs. There was no significant difference ($p = 0.140$) in the number of runs in which unnecessary maneuvers occurred between equipage levels.

Collision avoidance –Approximately 31% of the runs resulted in a near collision and approximately 15% resulted in collisions in the absence of CD&R, as shown in Table 23. Collision avoidance was affected by the CD&R system equipage level. The most collisions were avoided when Both aircraft were equipped with CD&R. In some instances, CD&R was more effective depending on which aircraft was equipped. For this scenario, more collisions were avoided when the crossing Aircraft B was equipped. However, when only the departing Aircraft A was equipped, collision avoidance was less effective, but better than when neither aircraft were equipped. When neither aircraft were equipped, there was no significant difference ($p = 1.0$) in the number of runs in which near collisions and collisions occurred between position accuracy levels. When Aircraft A was equipped, there was no significant difference ($p = 0.179$) in the number of runs in which near collisions occurred between position accuracy levels. There was a significant difference ($p < 0.001$) in the number of runs in which collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. When Aircraft B was equipped, there was no significant difference ($p = 0.643$) in the number of runs in which near collisions occurred between position accuracy levels. There was a significant difference ($p < 0.001$) in the number of runs in which collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. When Both aircraft were equipped with CD&R, there was a significant difference ($p < 0.001$) in the number of runs in which near collisions and collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 23. Number/Percentage Of Near Collisions (NC) and Collisions (C) Using ATCAM for Equipage Combinations for Departure with Taxi Crossing Scenario.

	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
NACp		NC	C	NC	C	NC	C	NC	C
8	7,539	2,349, 31.2	1,088, 14.4	1,739, 23.1	771, 10.2	1,908, 25.3	547, 7.3	1,447, 19.2	431, 5.7
9	6,462	2,013, 31.1	931, 14.4	1,391, 21.5	524, 8.1	1,564, 24.2	98, 1.5	939, 14.5	43, 0.7
10	4,308	1,341, 31.1	622, 14.4	936, 21.7	344, 8.0	1,074, 24.9	8, 0.2	639, 14.8	5, 0.1
11	3,231	1,007, 31.2	467, 14.4	698, 21.6	257, 8.0	813, 25.2	1, 0.0	481, 14.9	3, 0.1
Truth	1,077	335, 31.1	156, 14.5	233, 21.6	85, 7.9	271, 25.2	0, 0.0	163, 15.1	1, 0.1

A more detailed investigation was conducted for the collisions that occurred when transmitting truth position data. The initial location of Aircraft A and Aircraft B for each run that resulted in a collision when neither aircraft was equipped with CD&R and when only Aircraft A was equipped with CD&R are indicated in Figures 26 and 27. For example, in Figure 26, a collision resulted when Aircraft A was at the runway threshold, initiating departure, when Aircraft B began to taxi toward the runway from a starting position 1,000 ft back from the runway centerline and 6,800 ft from the runway threshold. There were no collisions when transmitting accurate position data and only Aircraft B was equipped with CD&R. There was one collision, however, when Both aircraft were equipped. This collision occurred when Aircraft A was at the threshold and Aircraft B was located 300 ft back from the runway centerline and 60 ft from the runway threshold at the start of the run. For this run, both aircraft received WAs, however, not soon enough for Aircraft B to stop before reaching the runway. As defined previously, a collision was counted if the aircraft CGs were < 150 ft apart laterally and vertical separation was < 100 ft. By the time Aircraft A was 8,000 ft from the runway threshold, it had lifted off and was over 260 ft AGL, well above the defined collision vertical separation bound. Therefore, no collisions occurred when Aircraft B was located 8,000 ft or 9,000 ft from the runway threshold. If a WA was issued onboard the departing aircraft, the departure would be aborted provided the ground speed was below the takeoff decision speed of 131 kts, otherwise the departure would continue. For the 85 collisions that occurred when only the departing aircraft (Aircraft A) was equipped with CD&R (Figure 27), WAs were issued on all of these runs. On 46 of the runs, the WA was issued when the aircraft's ground speed was 135 kts or higher, therefore, the departure was not aborted, resulting in collision. The departure was aborted on 39 of the runs. The departing aircraft came to a stop

on five of the runs but was within the 150 ft lateral criteria of a collision. On the other 34 runs, there was not enough time for the aircraft to stop before the collision.

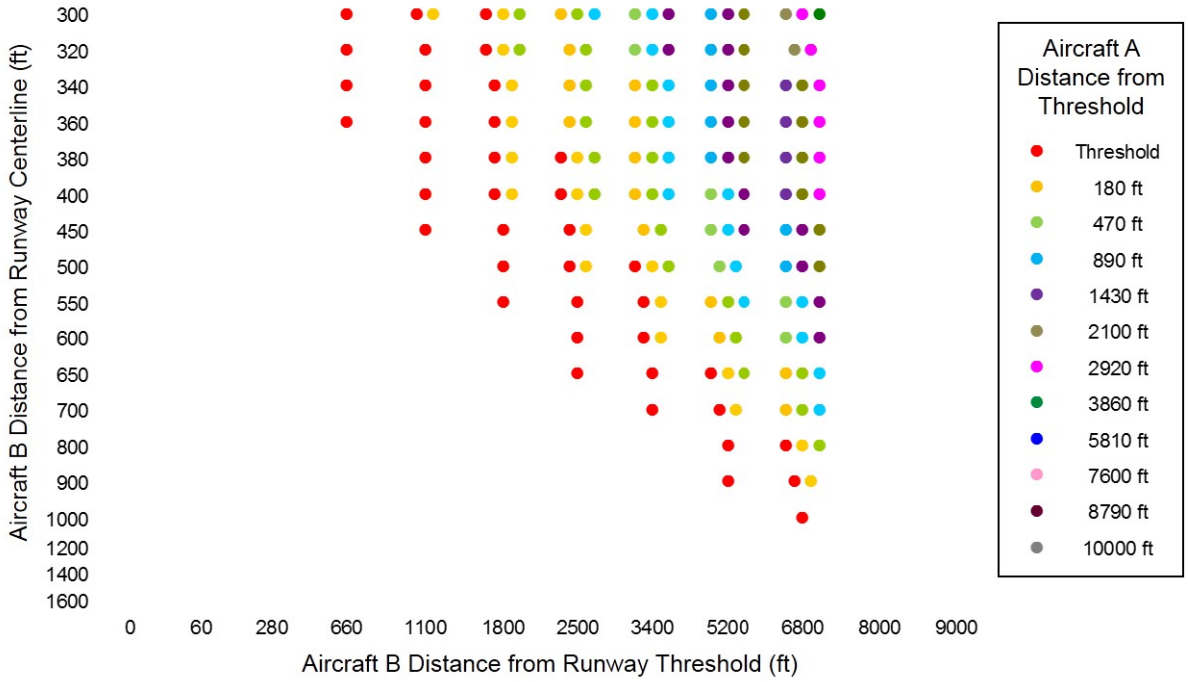

Figure 26. Aircraft Starting Locations for Collision Runs When Transmitting Truth Position Data When Neither Aircraft Maneuvers For Departure with Taxi Crossing Scenario.

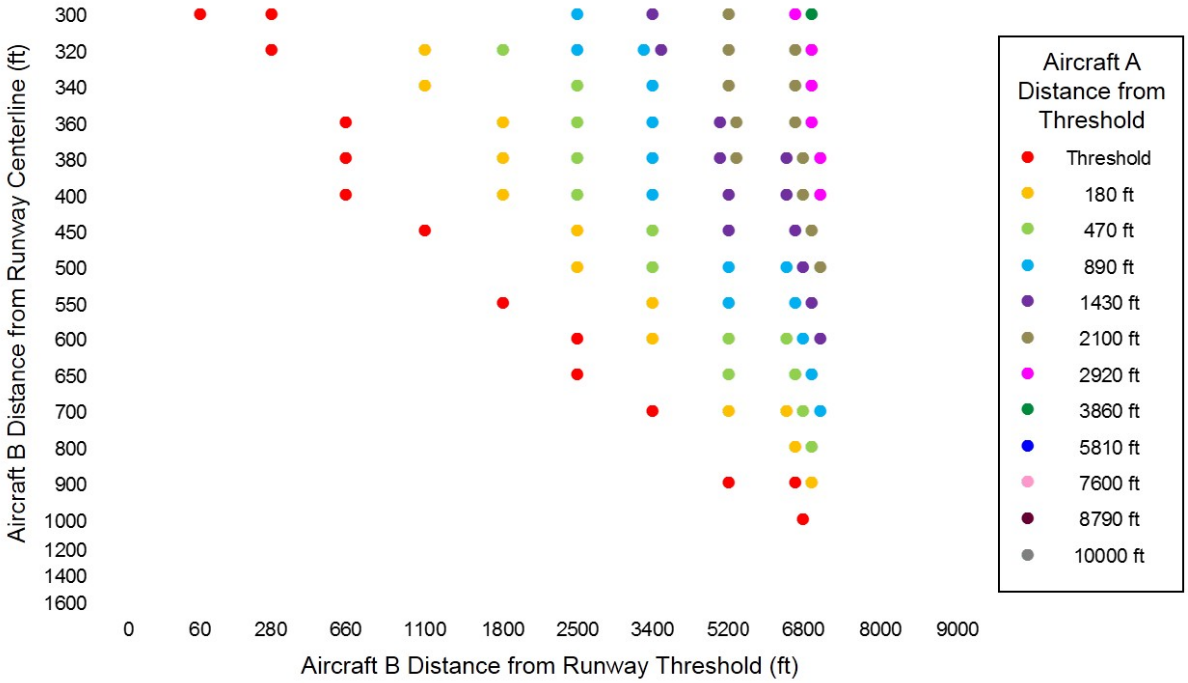

Figure 27. Aircraft Starting Locations for Collision Runs When Transmitting Truth Position Data When Only Aircraft A Maneuvers For Departure with Taxi Crossing Scenario.

Unwanted alert – As defined above, an alert was considered unwanted if the true position of Aircraft B was behind the hold line but the detected position indicated that the aircraft was over the hold line, causing an alert. The frequency of unwanted alerts increased as the position accuracy decreased, particularly when transmitting data with NACp 8 accuracy, as shown in Table 24. Also, a larger buffer between the hold line and alerting zone is required as the position accuracy decreases in order to reduce the number of unwanted alerts. For the departure with taxi crossing scenario, 99% of unwanted alerts could have been avoided by placing the alert zone 328 ft past the hold line for NACp 8 accuracy, 118 ft past the hold line for NACp 9 accuracy, and 48 ft past the hold line for NACp 10 accuracy. The maximum standard for separation between the hold line and runway centerline is 280 ft [FAA, 2009b] to accommodate the largest aircraft. A 328 ft alerting zone buffer is not practical for even the largest airports.

Table 24. Unwanted Alert Data Using ATCAM for Departure with Taxi Crossing Scenario.

NACp	Total # Runs	Unwanted CA		Unwanted WA	
		# Runs, % Runs	Max Distance Nose Over Hold Line (ft) (mean, SD)	# Runs, % Runs	Max Distance Nose Over Hold Line (ft) (mean, SD)
8	30,156	869, 2.9	79.5, 66.6	7,675, 25.5	124.5, 67.9
9	25,848	44, 0.2	29.0, 18.3	2,174, 8.4	52.1, 22.0
10	17,232	0, 0.0	0.0, 0.0	62, 0.4	22.9, 8.2
11	12,924	0, 0.0	0.0, 0.0	0, 0.0	0.0, 0.0
Truth	4,308	0, 0.0	0.0, 0.0	0, 0.0	0.0, 0.0

5.1.4 Runway Scenario – Arrival with Departure from Same Runway

For each of the 20 cases in this scenario, an initiation delay on Aircraft B (departure aircraft) was evaluated at 9 levels, for a total of 756 test runs.

Algorithm performance –For the approach aircraft (Aircraft A), CAs were issued on approximately 55% of the runs almost independent of the position accuracy levels (Table 25). For the departure aircraft (Aircraft B), CAs were generated on 78% to 84% of the runs, depending on the position accuracy level. WAs were generated on 44% to approximately 53% of the runs for both aircraft. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 0.984$) and WAs ($p = 0.590$) were generated between position accuracy levels. For Aircraft B, there was also no significant difference in the number of runs in which CAs ($p = 0.481$) and WAs ($p = 0.375$) were generated between position accuracy levels.

When analyzing alerts that occurred when transmitting truth position data, CAs were issued on approach when the aircraft was approximately 8,000 ft to 7,700 ft prior to the runway threshold and 454 ft to 439 ft AGL. WAs were issued when the aircraft was approximately 5,850 ft prior to the threshold and 343 ft AGL. For the departing aircraft, on 24 runs the CA occurred while the aircraft was still in position and holding; on four of the runs the CA occurred when the aircraft was 63 ft from the runway threshold and 19 kt. All of the WAs occurred while the aircraft was in position and holding.

As the position accuracy was reduced, alert toggling occurred more frequently, particularly when transmitting data with NACp 8 accuracy. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which multiple CAs and multiple WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The toggling included gaps between alerts when transmitting less accurate position data (NACp 8 and 9). In addition to position accuracy, the toggling was also a result of aircraft maneuvering. Sometimes multiple alerts occurred after Aircraft A conducted a go-around maneuver and after Aircraft B began its takeoff roll or aborted the takeoff. For both aircraft when truth position data was transmitted, WA toggling occurred after Aircraft A had conducted a go-around and then Aircraft B began its takeoff roll.

Table 25. ATCAM Alert Statistics for All Evasive Actions by NACp for Arrival with Departure from Same Runway Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
8	252	134, 53.2	30, 11.9	131, 52.0	71, 28.2
9	216	120, 55.6	4, 1.8	105, 48.6	12, 5.6
10	144	80, 55.6	0, 0.0	65, 45.1	8, 5.6
11	108	60, 55.6	0, 0.0	48, 44.4	6, 5.6
Truth	36	20, 55.6	0, 0.0	16, 44.4	2, 5.6
Aircraft B (Departure)					
8	252	212, 84.1	121, 48.0	135, 53.6	108, 42.9
9	216	174, 80.6	12, 5.6	108, 50.0	13, 6.0
10	144	112, 77.8	0, 0.0	65, 45.1	8, 5.6
11	108	84, 77.8	0, 0.0	48, 44.4	6, 5.6
Truth	36	28, 77.8	0, 0.0	16, 44.4	2, 5.6

When analyzing by CD&R equipage level (Table 26), for both aircraft, CAs were issued on a similar number of runs almost independent of the equipage level and WAs were generated on approximately 49% of the runs. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 0.991$) and WAs ($p = 0.894$) were generated between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which CAs ($p = 0.992$) and WAs ($p = 0.998$) were generated between equipage levels.

WA toggling occurred more frequently when Aircraft A was equipped with CD&R (Table 26). There was no significant difference in the number of runs in which multiple CAs occurred between equipage levels for Aircraft A ($p = 0.893$) and Aircraft B ($p = 0.860$). There was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs occurred between Aircraft A equipped vs. Neither aircraft, Aircraft B, and Both aircraft equipped.

Table 26. ATCAM Alert Statistics for All NACp by Evasive Action for Arrival with Departure from Same Runway Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	189	103, 54.5	8, 4.2	91, 48.1	15, 7.9
Aircraft A	189	102, 54.0	10, 5.3	87, 46.0	51, 27.0
Aircraft B	189	104, 55.0	7, 3.7	94, 49.7	16, 8.5
Both	189	105, 55.6	9, 4.8	93, 49.2	17, 9.0
Aircraft B (Departure)					
Neither	189	152, 80.4	31, 16.4	93, 49.2	28, 14.8
Aircraft A	189	152, 80.4	31, 16.4	92, 48.7	54, 28.6
Aircraft B	189	154, 81.5	35, 18.5	94, 49.7	29, 15.3
Both	189	152, 80.4	36, 19.1	93, 49.2	26, 13.8

Alert statistics were also compiled by CD&R equipage level when truth position data was transmitted (Table 27). The frequency of alert generation was similar to that which occurred across all position accuracy levels (Table 26). In contrast, however, no multiple CAs occurred while transmitting truth position data. Multiple WAs mostly occurred when only Aircraft A was equipped with CD&R. For both aircraft, there was no significant difference in the number of runs in which CAs ($p = 1.0$) and WAs ($p = 0.632$) were generated between the equipage levels. There was a significant difference ($p < 0.001$) in the

number of runs in which multiple WAs were generated between Aircraft A equipped vs. Neither aircraft, Aircraft B, and Both aircraft equipped.

Table 27. ATCAM Alert Statistics When Transmitting Truth Position Data for Arrival with Departure from Same Runway Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	189	105, 55.6	0, 0.0	84, 44.4	1, 0.5
Aircraft A	189	105, 55.6	0, 0.0	84, 44.4	40, 21.2
Aircraft B	189	105, 55.6	0, 0.0	93, 49.2	0, 0.0
Both	189	105, 55.6	0, 0.0	93, 49.2	0, 0.0
Aircraft B (Departure)					
Neither	189	147, 77.8	0, 0.0	84, 44.4	1, 0.5
Aircraft A	189	147, 77.8	0, 0.0	84, 44.4	33, 17.5
Aircraft B	189	147, 77.8	0, 0.0	93, 49.2	0, 0.0
Both	189	147, 77.8	0, 0.0	93, 49.2	0, 0.0

Missed and nuisance boundary count – The aircraft entered the defined missed boundary mainly when transmitting data with NACp 8 position accuracy, as shown in Table 28. Only the departing Aircraft B entered the nuisance boundary. The number of times (count) and amount of time (duration and percentage of run length) that the aircraft were within the boundaries was greater when transmitting less accurate data (Table 28). There was a significant difference ($p < 0.001$) in the number of runs that the aircraft entered the missed boundary for both Aircraft A and Aircraft B between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. There was no significant difference ($p = 0.027$) in the number of runs that the aircraft entered the nuisance boundary for Aircraft B.

For the approach Aircraft A, the majority of occurrences of entering the missed boundary was after the aircraft had crossed the runway threshold for landing. The aircraft only entered the missed boundary while on approach before crossing the runway threshold during 1.2% of the test runs when transmitting data with NACp 8 accuracy. Since Aircraft A tracked the extended centerline on approach and centerline after landing, the nuisance boundary was not entered.

The departing Aircraft B entered the missed boundary at least once for 97% of the test runs when transmitting data with NACp 8 accuracy. This was due to the criteria for entering the missed boundary. The aircraft was counted as entering the missed boundary when the aircraft's true position was within one runway width of the runway centerline, but the detected position was greater than one runway width from the centerline. As such, there was no buffer between when the aircraft was inside or outside the missed boundary so a measurable difference between the true and detected position could cause a missed boundary to be counted.

The number of test runs that contained missed and nuisance alerts was low for both aircraft, and mainly occurred when transmitting data with NACp 8 position accuracy, as shown in Table 29. There was a significant difference in the number of runs in which missed CAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies for Aircraft A ($p = 0.001$) and Aircraft B ($p < 0.001$). There was no significant difference in the number of runs in which missed WAs occurred for Aircraft A ($p = 0.125$), but there was a significant difference for Aircraft B ($p = 0.002$) between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. There was no significant difference in the number of runs in which nuisance CAs ($p = 0.333$) and nuisance WAs ($p = 0.111$) occurred for Aircraft B.

Table 28. ATCAM Missed and Nuisance Boundary Statistics for Arrival with Departure from Same Runway Scenario.

NACp	Entered Missed Boundary				Entered Nuisance Boundary			
	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Arrival)								
8	78, 30.9	3.6, 2.6	5.4, 4.9	5.0	0, 0.0	0, 0.0	0, 0.0	0.0
9	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
10	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
11	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Aircraft B (Departure)								
8	245, 97.2	8.8, 5.8	18.2, 14.3	25.5	4, 1.6	3.0, 2.7	5.4, 2.6	5.0
9	2, 0.9	5.5, 3.5	2.6, 2.5	2.4	4, 1.8	1.0, 0.0	1.6, 0.9	1.4
10	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
11	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0

Table 29. ATCAM Missed and Nuisance Alert Statistics for All Evasive Actions by NACp for Arrival with Departure from Same Runway Scenario.

NACp	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival)					
8	252	6, 2.4	5, 2.0	0, 0.0	0, 0.0
9	216	0, 0.0	2, 0.9	0, 0.0	0, 0.0
10	144	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	108	0, 0.0	1, 0.9	0, 0.0	0, 0.0
Truth	36	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Departure)					
8	252	10, 4.0	7, 2.8	1, 0.4	2, 0.8
9	216	0, 0.0	0, 0.0	0, 0.0	0, 0.0
10	144	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	108	0, 0.0	1, 0.9	0, 0.0	0, 0.0
Truth	36	0, 0.0	0, 0.0	0, 0.0	0, 0.0

For Aircraft A, all of the missed CAs should have occurred when the aircraft was on approach and approximately 1.3 NM prior to the runway threshold. All of the missed WAs should have occurred after the aircraft conducted a missed approach and the departing aircraft had begun its takeoff roll, except for one run. When the aircraft was transmitting data with NACp 11 position accuracy, the missed WA would have happened after a collision occurred, but the aircraft was to continue the departure since this was the condition when neither aircraft were to take action. For Aircraft B, two of the missed CAs should have occurred after the aircraft had begun its takeoff roll. The remaining missed CAs should have occurred while the aircraft was still in position and holding. Six of the missed WAs should have occurred while in position and holding, one should have occurred after Aircraft A had conducted a missed approach and Aircraft B had begun its departure roll, and the NACp 11 occurrence was on the same run as describe above for Aircraft A. All of the nuisance alerts occurred as the aircraft was exiting the runway, after rejecting the departure.

When analyzing by CD&R equipage level (Table 30), missed CAs occurred when Neither aircraft, Aircraft A, and Aircraft B were equipped. For Aircraft A, missed WAs occurred when Neither aircraft and Aircraft A were equipped. For Aircraft B, missed WAs occurred for all CD&R equipage levels. Nuisance alerts only occurred for Aircraft B, when Aircraft B was equipped with CD&R. There was no significant difference in the number of runs in which missed CAs occurred between equipage levels for Aircraft A ($p = 0.217$) and Aircraft B ($p = 0.074$). For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which missed WAs occurred between Aircraft A equipped vs. Neither aircraft, Aircraft B, and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which missed WAs ($p = 0.420$), nuisance CAs ($p = 0.250$), and nuisance WAs ($p = 0.062$) occurred between the equipage levels.

Table 30. ATCAM Missed and Nuisance Alert Statistics for All NACp by Evasive Action for Arrival with Departure from Same Runway Scenario.

CD&R Equipage	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	189	2, 1.1	1, 0.5	0, 0.0	0, 0.0
Aircraft A	189	3, 1.6	7, 3.7	0, 0.0	0, 0.0
Aircraft B	189	1, 0.5	0, 0.0	0, 0.0	0, 0.0
Both	189	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Departure)					
Neither	189	3, 1.6	3, 1.6	0, 0.0	0, 0.0
Aircraft A	189	3, 1.6	1, 0.5	0, 0.0	0, 0.0
Aircraft B	189	4, 2.1	2, 1.1	1, 0.5	2, 1.1
Both	189	0, 0.0	2, 1.1	0, 0.0	0, 0.0

Unnecessary maneuvering - The number and percentage of test runs in which the aircraft maneuvered unnecessarily when transmitting data with various levels of position accuracy is shown in Table 31. As the accuracy decreased, the frequency of occurrences of unnecessary maneuvers increased. With NACp 8, approximately 2% of the maneuvers were unnecessary for Aircraft A and 10% for Aircraft B. There were no unnecessary maneuvers with NACp 11 and truth accuracies. There was no significant difference in the number of runs in which unnecessary maneuvers occurred for Aircraft A ($p = 0.291$), but there was a significant difference between NACp 8 vs. NACp 9, 10, 11, and truth accuracies for Aircraft B ($p = 0.003$).

Table 31. Unnecessary Maneuvers for All Evasive Actions by NACp Using ATCAM During Arrival with Departure from Same Runway Scenario.

NACp	Total # Runs	Aircraft A (Arrival) (# Runs, % Runs)	Aircraft B (Departure) (# Runs, % Runs)
8	126	2, 1.6	12, 9.5
9	108	1, 0.9	5, 4.6
10	72	0, 0.0	1, 1.4
11	54	0, 0.0	0, 0.0
Truth	18	0, 0.0	0, 0.0

The number and percentage of test runs in which the aircraft maneuvered unnecessarily based on the CD&R equipage level is shown in Table 32. There was no significant difference ($p = 1.0$) in the number of runs in which unnecessary maneuvers occurred for Aircraft A and Aircraft B between equipage levels.

Table 32. Unnecessary Maneuvers for All NACp by Evasive Action Using ATCAM During Arrival with Departure from Same Runway Scenario.

CD&R Equipage	Total # Runs	Aircraft A (Arrival) (# Runs, % Runs)	Aircraft B (Departure) (# Runs, % Runs)
Neither	189	N/A	N/A
Aircraft A	189	2, 1.1	N/A
Aircraft B	189	N/A	9, 4.8
Both	189	1, 0.5	9, 4.8

Collision avoidance – The rate of near collisions and collisions was highest (44% to 52% over all position accuracy levels) when only the departing Aircraft B was equipped with CD&R. The rate was also high (33% for all position accuracy levels) when Neither aircraft was equipped (Table 33). Collision avoidance was very effective when Aircraft A and Both aircraft were equipped. For all CD&R equipage levels, there was no significant difference in the number of runs in which near collisions and collisions occurred between the position accuracy levels:

- Neither aircraft equipped: near collisions ($p = 1.0$) and collisions ($p = 1.0$),
- Aircraft A equipped: near collisions ($p = 0.036$) and collisions ($p = 0.333$),
- Aircraft B equipped: near collisions ($p = 0.924$) and collisions ($p = 0.954$), and
- Both aircraft equipped: near collisions ($p = 0.036$) and collisions ($p = 0.110$).

Table 33. Number/Percentage Of Near Collisions (NC) and Collisions (C) Using ATCAM for Equipage Combinations for Arrival with Departure from Same Runway Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	63	21, 33.3	21, 33.3	3, 4.8	1, 1.6	33, 52.4	32, 50.8	3, 4.8	2, 3.2
9	54	18, 33.3	18, 33.3	0, 0.0	0, 0.0	25, 46.3	24, 44.4	0, 0.0	0, 0.0
10	36	12, 33.3	12, 33.3	0, 0.0	0, 0.0	16, 44.4	16, 44.4	0, 0.0	0, 0.0
11	27	9, 33.3	9, 33.3	0, 0.0	0, 0.0	12, 44.4	12, 44.4	0, 0.0	0, 0.0
Truth	9	3, 33.3	3, 33.3	0, 0.0	0, 0.0	4, 44.4	4, 44.4	0, 0.0	0, 0.0

For the 154 runs in which a collision occurred, the approach aircraft was either 1.5 NM (3.2% of collision runs), 1.0 NM (14.3%), or 0.5 NM (27.3%) prior to the runway threshold, at the threshold (27.3%), or at the glide-path aim-point (1,000 ft past threshold) (27.9%) when the other aircraft began its departure. Many of the collisions occurred when the approach aircraft was landing, before the departure aircraft started its takeoff. Other times the departure aircraft had begun its roll but the approach aircraft landed and overtook the departing aircraft. When the departing aircraft was equipped with CD&R, the collision was sometimes caused by the aircraft aborting the departure, as was the case for the two collisions when Both aircraft were equipped. In practice, a pilot would most likely continue the departure under these conditions.

For the condition when truth position data was used and neither aircraft maneuvered, the scenario was designed such that a collision occurred when Aircraft A (arrival aircraft) was located 0.5 NM prior to the runway threshold, crossing the threshold, and 1,000 ft past the threshold when Aircraft B began its departure roll. For one collision, Aircraft A had landed and Aircraft B had begun its departure roll. For the other two collisions, Aircraft B was still holding in position.

For the one collision when Aircraft A was equipped, the aircraft received a WA but too late to take action before the collision. For the 88 collisions that occurred when Aircraft B was equipped, the aircraft received a WA but was in position and holding on 82 (93.2%) of these runs and did not take any action. On six (6.8%) of the runs, the departing aircraft aborted its departure but since the arrival aircraft continued its landing, collisions occurred. When Both aircraft were equipped, on one run both aircraft maneuvered

and the collision occurred as the approach aircraft began to climb out. On the other collision run, the departure aircraft aborted but the approach aircraft continued its landing and the aircraft collided.

5.1.5 Runway Scenario – Departures from Intersecting Runways

For each of the 20 cases in this scenario, an initiation delay on either Aircraft A or B was evaluated at 16 levels, for a total of 1,344 test runs.

Algorithm performance – For both aircraft, CAs were generated on less than 2% of the runs when transmitting data with NACp 8 accuracy only (Table 34). CAs are generally inhibited during departure since the workload is high and the flight crew does not have time for assessment. WAs were generated on approximately 36% to 39% of the runs when traffic was transmitting less accurate NACp 8 data, but were issued on approximately 60% of the runs when transmitting data with NACp 9 accuracy and higher. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which CAs and WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth position accuracies.

Table 34. ATCAM Alert Statistics for All Evasive Actions by NACp for Departures from Intersecting Runways Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Departure 14L)					
8	448	8, 1.8	0, 0.0	178, 39.7	43, 9.6
9	384	0, 0.0	0, 0.0	230, 59.9	24, 6.2
10	256	0, 0.0	0, 0.0	159, 62.1	0, 0.0
11	192	0, 0.0	0, 0.0	120, 62.5	0, 0.0
Truth	64	0, 0.0	0, 0.0	40, 62.5	0, 0.0
Aircraft B (Departure 22R))					
8	448	7, 1.6	0, 0.0	160, 35.7	37, 8.3
9	384	0, 0.0	0, 0.0	226, 58.9	18, 4.7
10	256	0, 0.0	0, 0.0	159, 62.1	0, 0.0
11	192	0, 0.0	0, 0.0	120, 62.5	0, 0.0
Truth	64	0, 0.0	0, 0.0	40, 62.5	0, 0.0

Alert toggling did not occur for CAs for either aircraft. For WAs, alert toggling only occurred when transmitting data with NACp 8 and 9 accuracies. There was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs occurred between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies for Aircraft A and Aircraft B.

The toggling included gaps between alerts. In addition to position accuracy, the toggling was also a result of aircraft maneuvering. Most multiple WAs occurred after both aircraft had initiated their takeoffs. Sometimes multiple alerts occurred after either aircraft aborted the takeoff.

The minimum and maximum distance from the runway threshold and ground speed when a WA was issued when transmitting truth position data is presented in Table 35. For Aircraft A, WAs were generated after the aircraft began its takeoff roll when the aircraft was approximately 10 ft to 436 ft from the runway threshold when Aircraft B was equipped with CD&R; however, the alert range was 10 ft to approximately 5,355 ft from the runway threshold (5 ft AGL) when Aircraft B was not equipped. For Aircraft B, WAs were generated when the aircraft was 4 ft to 280 ft from the runway threshold when Aircraft A was equipped with CD&R; however, the alert range was 4 ft to approximately 1,066 ft from the runway threshold when Aircraft A was not equipped.

Table 35. Aircraft Location When WA Issued When Transmitting Truth Position Accuracy Using ATCAM for Departures from Intersecting Runways Scenario.

CD&R Equipage	Aircraft A				Aircraft B			
	Minimum		Maximum		Minimum		Maximum	
	Distance from Threshold (ft)	GS (kt)	Distance from Threshold (ft)	GS (kt)	Distance from Threshold (ft)	GS (kt)	Distance from Threshold (ft)	GS (kt)
Neither	10	7	5358	140	4	7	1066	78
Aircraft A	10	7	5353	172	4	7	280	40
Aircraft B	10	7	436	50	4	7	1067	78
Both	10	7	437	50	4	7	280	40

When analyzing by CD&R equipage level (Table 36), for both aircraft, CA generation was low regardless of the equipage level. For Aircraft A, WAs were generated on approximately 68% of the runs when Neither aircraft or Aircraft A were equipped and on approximately 40% of the runs when Aircraft B or Both aircraft were equipped. For Aircraft B, WAs were generated on approximately 47% to 57% of the runs depending on the equipage level. For Aircraft A, there was no significant difference ($p = 0.288$) in the number of runs in which CAs were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which WAs were generated between Neither and Aircraft A equipped vs. Aircraft B and Both equipped. For Aircraft B, there was no significant difference ($p = 0.376$) in the number of runs in which CAs were generated between equipage levels. There was a significant difference ($p = 0.021$) in the number of runs in which WAs were generated between Neither and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Table 36. ATCAM Alert Statistics for All NACp by Evasive Action for Departures from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Departure 14L)					
Neither	336	3, 0.9	0, 0.0	229, 68.2	37, 11.0
Aircraft A	336	3, 0.9	0, 0.0	225, 67.0	14, 4.2
Aircraft B	336	1, 0.3	0, 0.0	134, 39.9	11, 3.3
Both	336	1, 0.3	0, 0.0	139, 41.4	5, 1.5
Aircraft B (Departure 22R)					
Neither	336	3, 0.9	0, 0.0	193, 57.4	23, 6.8
Aircraft A	336	1, 0.3	0, 0.0	158, 47.0	17, 5.1
Aircraft B	336	2, 0.6	0, 0.0	187, 55.6	8, 2.4
Both	336	1, 0.3	0, 0.0	167, 49.7	7, 2.1

CA toggling did not occur for either aircraft. WA toggling occurred more frequently when Neither aircraft was equipped with CD&R (Table 36). For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs were generated between Neither aircraft equipped vs. Aircraft A, Aircraft B, and Both aircraft equipped. For Aircraft B, there was a significant difference ($p = 0.004$) in the number of runs in which multiple WAs were generated between Neither and Aircraft A equipped vs. Aircraft B and Both aircraft equipped.

Alert statistics were also compiled by CD&R equipage level when truth position data was transmitted (Table 37). CAs were not generated when transmitting accurate data. The frequency of WA generation was higher than that which occurred across all position accuracy levels (Table 36); however, there were no multiple WAs when transmitting data with truth position accuracy. For Aircraft A, there was a significant difference ($p = 0.002$) in the number of runs in which WAs were generated between Neither aircraft and

Aircraft A equipped vs. Aircraft B and Both aircraft equipped. For Aircraft B, there was no significant difference ($p = 1.0$) in the number of runs in which WAs were generated between equipage levels.

Table 37. ATCAM Alert Statistics When Transmitting Truth Position Data for Departures from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Departure 14L)					
Neither	336	0, 0.0	0, 0.0	273, 81.2	0, 0.0
Aircraft A	336	0, 0.0	0, 0.0	273, 81.2	0, 0.0
Aircraft B	336	0, 0.0	0, 0.0	244, 72.6	0, 0.0
Both	336	0, 0.0	0, 0.0	242, 72.0	0, 0.0
Aircraft B (Departure 22R)					
Neither	336	0, 0.0	0, 0.0	231, 68.8	0, 0.0
Aircraft A	336	0, 0.0	0, 0.0	231, 68.8	0, 0.0
Aircraft B	336	0, 0.0	0, 0.0	231, 68.8	0, 0.0
Both	336	0, 0.0	0, 0.0	231, 68.8	0, 0.0

Missed and nuisance alerts – The aircraft entered the defined missed boundary mainly when transmitting NACp 8 position data, as shown in Table 38. There was a significant difference ($p < 0.001$) in the number of runs the aircraft entered the missed boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies for both aircraft. The nuisance boundary was never entered for this scenario because the aircraft tracked the runway centerline.

The aircraft entered the missed boundary for a high percentage of the test runs when transmitting NACp 8 data. This was due to the criteria for entering the missed boundary. The aircraft was counted as entering the missed boundary when the aircraft's true position was within one runway width of the runway centerline, but the detected position was greater than one runway width from the centerline. As such, there was no buffer between when the aircraft was inside or outside the missed boundary so a measurable difference between the true and detected position could cause a missed boundary to be counted.

Table 38. ATCAM Missed and Nuisance Boundary Statistics for Departures from Intersecting Runways Scenario.

	Entered Missed Boundary				Entered Nuisance Boundary			
NACp	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Departure 14L)								
8	339, 75.7	3.8, 2.4	6.9, 6.6	22.2	0, 0.0	0, 0.0	0, 0.0	0.0
9	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
10	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
11	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Aircraft B (Departure 22R)								
8	273, 60.9	2.9, 1.9	5.4, 5.8	17.6	0, 0.0	0, 0.0	0, 0.0	0.0
9	1, 0.3	1.0, 0.0	0.3, 0.0	0.8	0, 0.0	0, 0.0	0, 0.0	0.0
10	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
11	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0

Missed CAs did not occur during any test runs (Table 39). Missed WAs occurred for all position accuracy levels. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in

which missed WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. No nuisance alerts occurred for this scenario.

When analyzing missed WAs that occurred when transmitting truth position data, for both aircraft, an alert should have been issued onboard the aircraft as the other aircraft aborted its departure. For these 12 runs, no alerts were issued. The missed alerts were due to the transmission delay of the ADS-B model as described in Section 5.1.2.

Table 39. ATCAM Missed and Nuisance Alert Statistics for All Evasive Actions by NACp for Departures from Intersecting Runways Scenario.

NACp	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Departure 14L)					
8	448	0, 0.0	181, 40.4	0, 0.0	0, 0.0
9	384	0, 0.0	59, 15.4	0, 0.0	0, 0.0
10	256	0, 0.0	33, 12.9	0, 0.0	0, 0.0
11	192	0, 0.0	24, 12.5	0, 0.0	0, 0.0
Truth	64	0, 0.0	8, 12.5	0, 0.0	0, 0.0
Aircraft B (Departure 22R)					
8	448	0, 0.0	148, 33.0	0, 0.0	0, 0.0
9	384	0, 0.0	38, 9.9	0, 0.0	0, 0.0
10	256	0, 0.0	17, 6.6	0, 0.0	0, 0.0
11	192	0, 0.0	12, 6.2	0, 0.0	0, 0.0
Truth	64	0, 0.0	4, 6.2	0, 0.0	0, 0.0

When analyzing by CD&R equipage level (Table 40), for Aircraft A, the most missed WAs occurred when Aircraft B and Both aircraft were equipped. For Aircraft B, the most missed WAs occurred when Aircraft A and Both aircraft were equipped. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which missed WAs occurred between Aircraft B and Both aircraft equipped vs. Neither aircraft and Aircraft A aircraft equipped. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which missed WAs occurred between Aircraft A and Both aircraft equipped vs. Neither aircraft and Aircraft B equipped.

Table 40. ATCAM Missed and Nuisance Alert Statistics for All NACp by Evasive Action for Departures from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Departure 14L)					
Neither	336	0, 0.0	44, 13.1	0, 0.0	0, 0.0
Aircraft A	336	0, 0.0	48, 14.3	0, 0.0	0, 0.0
Aircraft B	336	0, 0.0	110, 32.7	0, 0.0	0, 0.0
Both	336	0, 0.0	103, 30.7	0, 0.0	0, 0.0
Aircraft B (Departure 22R)					
Neither	336	0, 0.0	38, 11.3	0, 0.0	0, 0.0
Aircraft A	336	0, 0.0	73, 21.7	0, 0.0	0, 0.0
Aircraft B	336	0, 0.0	44, 13.1	0, 0.0	0, 0.0
Both	336	0, 0.0	64, 19.0	0, 0.0	0, 0.0

Unnecessary maneuvering – No unnecessary maneuvers occurred for this scenario.

Collision avoidance – The highest rate of near collisions and collisions occurred in the absence of CD&R, approximately 6% of the runs, as shown in Table 41. The addition of CD&R eliminated near collisions and collisions when transmitting data with NACp 10, 11, and truth position accuracies and

reduced the occurrence when transmitting data with NACp 8 and 9 accuracies (less than 5% of the runs). When neither aircraft was equipped, there was no significant difference (p = 1.0) in the number of runs in which near collisions and collisions occurred between accuracy levels. When Aircraft A was equipped, there was no significant difference in the number of runs in which near collisions (p = 0.086) and collisions (p = 0.044) occurred between accuracy levels. When Aircraft B was equipped with CD&R, there was a significant difference (p = 0.004) in the number of runs in which near collisions and collisions occurred between NACp 8 vs. NACp 9, 10, 11 and truth accuracies. When Both aircraft were equipped, there was no significant difference in the number of runs in which near collisions (p = 0.044) and collisions occurred (p = 0.036) between accuracy levels.

Table 41. Number/Percentage Of Near Collisions (NC) and Collisions (C) Using ATCAM for Equipage Combinations for Departures from Intersecting Runways Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	112	7, 6.2	7, 6.2	4, 3.6	4, 3.6	5, 4.5	5, 4.5	4, 3.6	3, 2.7
9	96	6, 6.2	6, 6.2	2, 2.1	1, 1.0	0, 0.0	0, 0.0	1, 1.0	0, 0.0
10	64	4, 6.2	4, 6.2	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	48	3, 6.2	3, 6.2	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	16	1, 6.2	1, 6.2	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0

For the 34 runs in which a collision occurred, except one, Aircraft A's (departing Runway 14L) ground speed was approximately 50 kts when Aircraft B began its departure from Runway 22R. For the other run, Aircraft A's ground speed was approximately 70 kts when Aircraft B began its departure. Most of the collisions occurred when Aircraft A had just lifted off and Aircraft B was on departure roll at approximately 125 kts.

There were five collisions that occurred when Aircraft A was equipped, one where no WA was generated and the aircraft did not take action, one where the aircraft received a WA and took delayed action but did not have time to avoid the collision, and three where WAs were issued too late to take action before the collision. Five collisions occurred when Aircraft B was equipped. No action was taken on two runs because no WA was issued. On the other three runs, WAs were issued too late for the aircraft to maneuver. Three collisions occurred when Both aircraft were equipped. Aircraft A did not make any maneuvers because the WAs were issued too late. For Aircraft B, the WA was issued too late on two runs to be effective. On the other run, the WA was issued 24 seconds before the collision but no maneuvering was initiated.

5.1.6 Runway Scenario – Arrival and Departure from Intersecting Runways

For each of the 20 cases in this scenario, an initiation delay on Aircraft B was evaluated at 13 levels, for a total of 1,092 test runs.

Algorithm performance – CAs were generated on a higher percentage of runs when the aircraft were transmitting data with NACp 8 accuracy (Aircraft A, approximately 7%; Aircraft B, approximately 14%) (Table 42). WAs were generated on 23% to 30% of the runs for Aircraft A and on 54% of runs when transmitting NACp 8 data and 69% of runs for each of the other position accuracy levels for Aircraft B. For Aircraft A, there was no significant difference in the number of runs in which CAs (p = 0.199) and WAs (p = 0.369) were generated between accuracy levels. For Aircraft B, there was a significant difference (p < 0.001) in the number of runs in which CAs and WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 42. ATCAM Alert Statistics for All Evasive Actions by NACp for Arrival and Departure from Intersecting Runways Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
8	364	27, 7.4	2, 0.6	108, 29.7	29, 8.0
9	312	13, 4.2	1, 0.3	80, 25.6	19, 6.1
10	208	8, 3.8	0, 0.0	49, 23.6	4, 1.9
11	156	6, 3.8	0, 0.0	36, 23.1	3, 1.9
Truth	52	2, 3.8	0, 0.0	12, 23.1	1, 1.9
Aircraft B (Departure)					
8	364	52, 14.3	0, 0.0	198, 54.4	65, 17.9
9	312	3, 1.0	0, 0.0	216, 69.2	25, 8.0
10	208	0, 0.0	0, 0.0	144, 69.2	0, 0.0
11	156	0, 0.0	0, 0.0	108, 69.2	0, 0.0
Truth	52	0, 0.0	0, 0.0	36, 69.2	0, 0.0

When analyzing alerts that occurred when transmitting truth position data, only two CAs were issued onboard the approach aircraft when approximately 1,320 ft prior to the runway threshold and 106 ft AGL. WAs were issued when the aircraft was between approximately 190 ft prior to the runway threshold and 47 ft AGL until approximately 4,090 ft past the runway threshold after landing with a ground speed of 71 kts. For the departing aircraft, WAs were issued when 4 ft from the runway threshold and 7 kts until 141 ft from the threshold and 29 kts.

CA toggling did not occur for Aircraft B and occurred on 0.6% of the runs and less when transmitting data with NACp 8 and 9 accuracies for Aircraft A. WA toggling occurred more frequently when transmitting data with NACp 8 and 9 accuracies for both aircraft. For Aircraft A, there was no significant difference ($p = 0.291$) in the number of runs in which multiple CAs were generated but there was a significant difference ($p = 0.004$) in the number of runs in which multiple WAs were generated between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The toggling included gaps between alerts when transmitting lower position accuracy (NACp 8 and 9). In addition to position accuracy, the toggling was also a result of aircraft maneuvering. Multiple alerts mainly occurred after Aircraft B began its takeoff roll. Occasionally multiple alerts occurred after Aircraft A had landed and conducted accelerated braking and after Aircraft B aborted the takeoff. For Aircraft A, WA toggling occurred on one run when truth position data was transmitted. It was determined that this multiple alert was generated after Aircraft A had landed and was taxiing down the runway and was already past the intersecting runway. Aircraft B was in its takeoff roll and was located in the intersection. In this case, an alert should not have occurred onboard Aircraft A since it had passed and was taxiing away from the intersection.

When analyzing by CD&R equipage level (Table 43), for Aircraft A, alert generation was higher when Neither aircraft or Aircraft A were equipped. The rate of alert generation was more evenly distributed across equipage levels for Aircraft B. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which CAs and WAs were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which CAs ($p = 0.340$) and WAs ($p = 0.992$) were generated between equipage levels.

The CA toggling rate was low for Aircraft A and did not occur for Aircraft B. WA toggling occurred more frequently when Neither aircraft was equipped with CD&R (Table 43). For Aircraft A, there was no significant difference ($p = 0.249$) in the number of runs in which multiple CAs were generated but there was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs were generated between Neither aircraft equipped vs. Aircraft A, Aircraft B, and Both aircraft equipped. For Aircraft B,

there was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped.

Table 43. ATCAM Alert Statistics for All NACp by Evasive Action for Arrival and Departure from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	273	21, 7.7	2, 0.7	117, 42.9	37, 13.6
Aircraft A	273	22, 8.1	1, 0.4	114, 41.8	10, 3.7
Aircraft B	273	4, 1.5	0, 0.0	26, 9.5	5, 1.8
Both	273	9, 3.3	0, 0.0	28, 10.3	4, 1.5
Aircraft B (Departure)					
Neither	273	18, 6.6	0, 0.0	176, 64.5	42, 15.4
Aircraft A	273	16, 5.9	0, 0.0	174, 63.7	28, 10.3
Aircraft B	273	11, 4.0	0, 0.0	177, 64.8	11, 4.0
Both	273	10, 3.7	0, 0.0	175, 64.1	9, 3.3

Alert statistics were also compiled by CD&R equipage level when truth position data was transmitted (Table 44). The CA rate for Aircraft A was similar to that which occurred when transmitting data of various position accuracy levels (Table 43). CAs were not generated for the departing aircraft (Aircraft B) when transmitting accurate data. The frequency of WA generation was higher than that which occurred when transmitting data of various position accuracy levels. Multiple WAs only occurred for Aircraft A when transmitting data with truth position accuracy. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which CAs and WAs were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped and in the number of runs in which multiple WAs were generated between Neither aircraft equipped vs. Aircraft A, Aircraft B, and Both aircraft equipped. For Aircraft B, there was no significant difference ($p = 0.997$) in the number of runs in which WAs were generated between equipage levels.

Table 44. ATCAM Alert Statistics When Transmitting Truth Position Data for Arrival and Departure from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	273	21, 7.7	0, 0.0	126, 46.1	21, 7.7
Aircraft A	273	21, 7.7	0, 0.0	126, 46.1	3, 1.1
Aircraft B	273	4, 1.5	0, 0.0	93, 34.1	2, 0.7
Both	273	4, 1.5	0, 0.0	91, 33.3	3, 1.1
Aircraft B (Departure)					
Neither	273	0, 0.0	0, 0.0	189, 69.2	0, 0.0
Aircraft A	273	0, 0.0	0, 0.0	189, 69.2	0, 0.0
Aircraft B	273	0, 0.0	0, 0.0	189, 69.2	0, 0.0
Both	273	0, 0.0	0, 0.0	189, 69.2	0, 0.0

Missed and nuisance alerts – The arrival Aircraft A entered the missed boundary only when transmitting data with NACp 8 and 9 position accuracy and did not enter the nuisance boundary during any of the runs (Table 45). The departure Aircraft B entered the missed and nuisance boundary when transmitting data for all position accuracy levels except truth, with more occurrences as the position accuracy was reduced. The number of times (count) and amount of time (duration and percentage of run length) that the aircraft were within the boundaries was greater when transmitting less accurate data (Table

45). For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was a significant difference in the number of runs in which the aircraft entered the missed boundary ($p < 0.001$) between NACp 8 vs. NACp 9, 10, 11, and truth accuracies and entered the nuisance boundary ($p = 0.009$) between NACp 8 and 10 accuracies vs. NACp 9, 11, and truth accuracies.

For the approach aircraft (Aircraft A), the majority of occurrences of entering the missed boundary was after the aircraft had crossed the runway threshold for landing. The aircraft only entered the missed boundary while on approach before crossing the runway threshold during 1.9% of the test runs when transmitting NACp 8 data. Since Aircraft A tracked the extended centerline on approach and centerline after landing, the nuisance boundary was not entered.

The departing aircraft (Aircraft B) entered the missed boundary for a high percentage of the test runs when transmitting data with NACp 8 accuracy. This was due to the criteria for entering the missed boundary. The aircraft was counted as entering the missed boundary when the aircraft's true position was within one runway width of the runway centerline, but the detected position was greater than one runway width from the centerline. As such, there was no buffer between when the aircraft was inside or outside the missed boundary so a measurable difference between the true and detected position could cause a missed boundary to be counted. After the aircraft lifted off and was over 600 ft AGL, the aircraft started drifting from the runway centerline. Since there was no buffer between when the aircraft was inside or outside the nuisance boundary, a measurable difference between the true and detected position near the boundary could cause a nuisance boundary to be counted.

Table 45. ATCAM Missed and Nuisance Boundary Statistics for Arrival and Departure from Intersecting Runways Scenario.

	Entered Missed Boundary				Entered Nuisance Boundary			
NACp	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Arrival)								
8	234, 64.3	4.4, 2.9	7.0, 6.7	6.1	0, 0.0	0, 0.0	0, 0.0	0.0
9	1, 0.3	1.0, 0.0	6.2, 0.0	5.4	0, 0.0	0, 0.0	0, 0.0	0.0
10	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
11	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Aircraft B (Departure)								
8	305, 83.8	5.7, 4.0	11.5, 10.8	14.2	38, 10.4	1.3, 0.6	3.1, 2.5	6.1
9	36, 11.5	1.0, 0.2	1.6, 1.1	3.0	21, 6.7	1.3, 0.5	1.8, 1.2	3.5
10	14, 6.7	1.1, 0.3	0.8, 0.4	1.4	18, 8.7	1.1, 0.2	0.7, 0.4	1.4
11	9, 5.8	1.0, 0.0	0.3, 0.1	0.7	5, 3.2	1.0, 0.0	0.3, 0.0	0.5
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0

The number of test runs that contained missed CAs was low, as shown in Table 46. The rate of missed WAs was approximately 15% for Aircraft A at all position accuracy levels and for Aircraft B when transmitting data with NACp 8 accuracy. Nuisance alerts did not occur during this scenario. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which missed CAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. There was no significant difference ($p = 0.963$) in the number of runs in which missed WAs occurred between accuracy levels. For Aircraft B, there was a significant difference in ($p < 0.001$) the number of runs in which missed WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

When analyzing missed WAs that occurred when transmitting truth position data, for Aircraft A, an alert should have been issued onboard the aircraft as the other aircraft aborted its departure. The missed alerts were due to the transmission delay of the ADS-B model as described in Section 5.1.2.

Table 46. ATCAM Missed and Nuisance Alert Statistics for All Evasive Actions by NACp Arrival and Departure from Intersecting Runways Scenario.

NACp	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival)					
8	364	11, 3.0	52, 14.3	0, 0.0	0, 0.0
9	312	0, 0.0	41, 13.1	0, 0.0	0, 0.0
10	208	0, 0.0	31, 14.9	0, 0.0	0, 0.0
11	156	0, 0.0	24, 15.4	0, 0.0	0, 0.0
Truth	52	0, 0.0	8, 15.4	0, 0.0	0, 0.0
Aircraft B (Departure)					
8	364	0, 0.0	54, 14.8	0, 0.0	0, 0.0
9	312	0, 0.0	0, 0.0	0, 0.0	0, 0.0
10	208	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	156	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	52	0, 0.0	0, 0.0	0, 0.0	0, 0.0

When analyzing by CD&R equipage level (Table 47), for Aircraft A, the missed CAs occurred fairly evenly across equipage levels; however, missed WAs occurred much more often when Aircraft B and Both aircraft were equipped. For Aircraft B, slightly more missed WAs occurred when Aircraft A and Both aircraft were equipped. For Aircraft A, there was no significant difference ($p = 0.544$) in the number of runs in which missed CAs occurred but there was a significant difference ($p < 0.001$) in the number of runs in which missed WAs occurred between Aircraft B and Both aircraft equipped vs. Neither aircraft and Aircraft A equipped. For Aircraft B, there was no significant difference ($p = 0.942$) in the number of runs in which missed WAs occurred between equipage levels.

Table 47. ATCAM Missed and Nuisance Alert Statistics for All NACp by Evasive Action for Arrival and Departure from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	273	4, 1.5	12, 4.4	0, 0.0	0, 0.0
Aircraft A	273	2, 0.7	12, 4.4	0, 0.0	0, 0.0
Aircraft B	273	3, 1.1	67, 24.5	0, 0.0	0, 0.0
Both	273	2, 0.7	65, 23.8	0, 0.0	0, 0.0
Aircraft B (Departure)					
Neither	273	0, 0.0	13, 4.8	0, 0.0	0, 0.0
Aircraft A	273	0, 0.0	15, 5.5	0, 0.0	0, 0.0
Aircraft B	273	0, 0.0	12, 4.4	0, 0.0	0, 0.0
Both	273	0, 0.0	14, 5.1	0, 0.0	0, 0.0

Unnecessary maneuvering – No unnecessary maneuvers occurred for this scenario.

Collision avoidance – The rate of near collisions and collisions was relatively low for this scenario (Table 48). Approximately 8% of the runs resulted in near collisions and collisions in the absence of CD&R. When Both aircraft were equipped, the rate was cut in half when transmitting data with NACp 8 accuracy and near collisions and collisions were eliminated when transmitting data with NACp 9 and higher accuracy. When neither aircraft were equipped, there was no significant difference ($p = 0.999$) in the number of runs in which near collisions and collisions occurred between accuracy levels. When only Aircraft A was equipped, there was no significant difference ($p = 0.095$) in the number of runs in which near collisions occurred but there was a significant difference ($p = 0.001$) in the number of runs in which collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. When only Aircraft B was

equipped, there was a significant difference (p = 0.016) in the number of runs in which near collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies but there was no significant difference (p = 0.042) in the number of runs in which collisions occurred between equipage levels. When Both aircraft were equipped, there was a significant difference (p = 0.011) in the number of runs in which near collisions and collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

All of the collisions occurred on runs in which the arrival Aircraft A landed and was approximately 0.25 NM past the runway threshold when the departing Aircraft B began its takeoff roll. Six collisions occurred when Aircraft A was equipped. One of the collisions occurred because a WA was not issued and the aircraft did not take action to avoid the collision. For the other five collisions, Aircraft A did receive a WA but too late to take action before the collision. For the four collisions that occurred when Aircraft B was equipped and the traffic was transmitting data with NACp 8 accuracy, WAs were issued too late for maneuvering to be effective. For the one collision that occurred when the traffic was transmitting data with NACp 9 accuracy, the aircraft received a WA 13 seconds before the collision but did not take action until 1 second before the collision. For the four collisions that occurred when Both aircraft were equipped, no action was taken by either aircraft because either no WAs were issued or any WAs that were issued were too late for maneuvering to occur before the collision.

Table 48. Number/Percentage of Near Collisions (NC) and Collisions (C) Using ATCAM for Equipage Combinations for Arrival and Departure from Intersecting Runways Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	91	7, 7.7	7, 7.7	6, 6.6	6, 6.6	5, 5.5	4, 4.4	4, 4.4	4, 4.4
9	78	6, 7.7	6, 7.7	3, 3.8	0, 0.0	1, 1.3	1, 1.3	0, 0.0	0, 0.0
10	52	4, 7.7	4, 7.7	1, 1.9	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	39	3, 7.7	3, 7.7	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	13	1, 7.7	1, 7.7	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0

5.1.7 Runway Scenario – Head-On Arrivals

For each of the 20 cases in this scenario, an initiation delay on Aircraft B was evaluated at 14 levels, for a total of 1,176 test runs.

Algorithm performance – For Aircraft A, CAs were generated on 21% of the runs when transmitting data with NACp 10, 11, and truth accuracies, while the percentage of CAs generated increased when transmitting data with NACp 8 (84%) and 9 (33%) accuracies (Table 49). For Aircraft B, CAs were generated on 50% to 70% of the runs, with a higher percentage of CAs generated when transmitting less accurate position accuracy. WAs were generated on approximately 86% of the runs for either aircraft, almost independent of the position accuracy levels. For Aircraft A, there was a significant difference (p < 0.001) in the number of runs in which CAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. There was no significant difference (p = 0.908) in the number of runs in which WAs were generated between accuracy levels. For Aircraft B, there was a significant difference (p < 0.001) in the number of runs in which CAs were generated between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies. There was no significant difference (p = 0.878) in the number of runs in which WAs were generated between accuracy levels.

When analyzing alerts that occurred when transmitting truth position data, CAs were issued onboard Aircraft A when approximately 2,680 ft prior to the runway threshold and 177 ft AGL, 1,325 ft prior to the threshold and 106 ft AGL, or 9,848 ft past the threshold after landing and 5 kts. WAs were issued when approximately 870 ft prior to the runway threshold and 82 ft AGL until approximately 8,565 ft past the threshold after landing and 30 kts. For Aircraft B, six of the CAs occurred after the aircraft had conducted a go-around maneuver. The remainder of the CAs occurred when the aircraft was between 7,768 ft and 2,680 ft prior to the runway threshold and 443 ft and 177 ft AGL. WAs occurred when the aircraft was 2.3 NM prior to the runway threshold and 764 ft AGL and 872 ft prior to the threshold and 82 ft AGL.

Table 49. ATCAM Alert Statistics for All Evasive Actions by NACp for Head-On Arrivals Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
8	392	328, 83.7	206, 52.5	345, 88.0	249, 63.5
9	336	111, 33.0	8, 2.4	288, 85.7	29, 8.6
10	224	48, 21.4	2, 0.9	192, 85.7	8, 3.6
11	168	36, 21.4	0, 0.0	144, 85.7	5, 3.0
Truth	56	12, 21.4	0, 0.0	48, 85.7	2, 3.6
Aircraft B (Arrival Runway 28)					
8	392	273, 69.6	38, 9.7	354, 90.3	246, 62.8
9	336	207, 61.6	5, 1.5	283, 84.2	117, 34.8
10	224	121, 54.0	2, 0.9	192, 85.7	43, 19.2
11	168	83, 49.4	0, 0.0	144, 85.7	24, 14.3
Truth	56	28, 50.0	0, 0.0	48, 85.7	8, 14.3

CA toggling was prevalent for both aircraft when transmitting data with NACp 8 accuracy. For Aircraft B, CA toggling occurred on 10% or less of the runs. WA toggling occurred on 63% or less of the runs, with toggling occurring on 14% of the runs when transmitting data with NACp 11 and truth accuracies for Aircraft B. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which multiple CAs and multiple WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The toggling included gaps between alerts when transmitting data with lower position accuracy (NACp 8 and 9). In addition to position accuracy, the toggling was also a result of aircraft maneuvering. Multiple alerts occurred after Aircraft B conducted a go-around maneuver, when both aircraft conducted accelerated braking, and when they exited the runway. WA toggling occurred for both aircraft when transmitting truth position data. For Aircraft A, these multiple alerts occurred after aircraft landing while taxiing down the runway and when the aircraft had exited the runway after Aircraft B had conducted a go-around maneuver. For Aircraft B while transmitting accurate position data, all of the multiple alerts occurred after Aircraft A had exited the runway.

When analyzing by CD&R equipage level (Table 50), for both aircraft, alert generation was similar across all equipage levels. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 0.936$) and WAs ($p = 0.934$) were generated between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which CAs ($p = 0.306$) and WAs ($p = 0.694$) were generated between equipage levels.

Table 50. ATCAM Alert Statistics for All NACp by Evasive Action for Head-On Arrivals Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
Neither	294	135, 45.9	54, 18.4	255, 86.7	72, 24.5
Aircraft A	294	135, 45.9	66, 22.4	257, 87.4	68, 23.1
Aircraft B	294	129, 43.9	51, 17.4	252, 85.7	88, 29.9
Both	294	136, 46.3	45, 15.3	253, 86.0	65, 22.1
Aircraft B (Arrival Runway 28)					
Neither	294	174, 59.2	6, 2.0	260, 88.4	93, 31.6
Aircraft A	294	187, 63.6	9, 3.1	257, 87.4	140, 47.6
Aircraft B	294	167, 56.8	19, 6.5	253, 86.0	95, 32.3
Both	294	184, 62.6	11, 3.7	251, 85.4	110, 37.4

The CA toggling rate was between 15% and 22% for Aircraft A and between 2% and 7% for Aircraft B (Table 50). The WA toggling rate was high for all equipage levels for both aircraft. For Aircraft A, there was no significant difference in the number of runs in which multiple CAs ($p = 0.151$) and multiple WAs ($p = 0.126$) were generated between equipage levels. For Aircraft B, there was no significant difference ($p = 0.036$) in the number of runs in which multiple CAs were generated but there was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs were generated between Neither and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Alert statistics were also compiled by CD&R equipage level when truth position accuracy was transmitted (Table 51). The CA rate was lower when transmitting accurate data, but the WA rate was similar to the rate of generation when transmitting data with various accuracy levels (Table 50). The rate of multiple alerts was low when transmitting truth position data, except for the rate of multiple WAs onboard Aircraft B when Aircraft A and Both aircraft were equipped. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 1.0$), WAs ($p = 1.0$), and multiple CAs ($p = 0.250$) were generated between equipage levels. There was a significant difference ($p = 0.016$) in the number of runs in which multiple WAs were generated between Both aircraft equipped vs. Neither aircraft, Aircraft A, and Aircraft B equipped. For Aircraft B, there was no significant difference in the number of runs in which WAs ($p = 1.0$) and multiple CAs ($p = 0.250$) were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which CAs and multiple WAs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Table 51. ATCAM Alert Statistics When Transmitting Truth Position Data for Head-On Arrivals Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
Neither	294	63, 21.4	0, 0.0	252, 85.7	0, 0.0
Aircraft A	294	64, 21.8	0, 0.0	252, 85.7	0, 0.0
Aircraft B	294	63, 21.4	0, 0.0	252, 85.7	0, 0.0
Both	294	63, 21.4	1, 0.3	252, 85.7	3, 1.0
Aircraft B (Arrival Runway 28)					
Neither	294	126, 42.9	0, 0.0	252, 85.7	0, 0.0
Aircraft A	294	167, 56.8	0, 0.0	252, 85.7	78, 26.5
Aircraft B	294	126, 42.9	0, 0.0	252, 85.7	0, 0.0
Both	294	167, 56.8	1, 0.3	252, 85.7	60, 20.4

Missed and nuisance alerts – The number of runs in which the aircraft entered the defined missed and nuisance boundaries generally increased as the position accuracy decreased, as shown in Table 52. The number of times (count) and amount of time (duration and percentage of run length) that the aircraft were within the boundaries was greater when transmitting less accurate data (Table 52). For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs the aircraft entered the missed boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs the aircraft entered the nuisance boundary between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies. For Aircraft B there was no significant difference ($p = 1.0$) in the number of runs the aircraft entered the nuisance boundary between accuracy levels.

The majority of occurrences of entering the missed boundary was after the aircraft had crossed the runway threshold for landing. The aircraft only entered the missed boundary while on approach before crossing the runway threshold during 1.3% of the test runs for Aircraft A and 3.8% of the test runs for Aircraft B when transmitting NACp 8 data. Since the aircraft tracked the extended centerline on approach and centerline after landing, the nuisance boundary was entered as the aircraft exited the runway.

Table 52. ATCAM Missed and Nuisance Boundary Statistics for Head-On Arrivals Scenario.

NACp	Entered Missed Boundary				Entered Nuisance Boundary			
	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Arrival Runway 10)								
8	382, 97.5	8.4, 5.1	15.9, 12.1	15.5	120, 30.6	2.5, 2.2	5.1, 7.7	5.2
9	90, 26.8	1.2, 0.6	1.6, 1.3	1.6	102, 30.4	1.1, 0.4	1.3, 1.1	1.2
10	68, 30.4	1.0, 0.0	0.6, 0.4	0.6	50, 22.3	1.0, 0.0	0.5, 0.3	0.5
11	34, 20.2	1.0, 0.0	0.3, 0.1	0.2	22, 13.1	1.0, 0.0	0.2, 0.1	0.2
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Aircraft B (Arrival Runway 28)								
8	276, 70.4	3.6, 2.6	6.6, 6.4	5.8	7, 1.8	2.1, 1.2	4.4, 2.2	3.1
9	11, 3.3	1.2, 0.4	1.6, 2.0	1.2	4, 1.2	1.0, 0.0	2.5, 2.6	1.7
10	3, 1.3	1.0, 0.0	0.7, 0.3	0.5	3, 1.3	1.0, 0.0	0.7, 0.6	0.5
11	1, 0.6	1.0, 0.0	0.4, 0.0	0.3	3, 1.8	1.0, 0.0	0.3, 0.1	0.2
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0

The number of test runs that contained missed and nuisance alerts was low and mainly occurred when transmitting NACp 8 data, as shown in Table 53. For Aircraft B, there were no nuisance CAs or WAs. For Aircraft A, there was no significant difference in the number of runs in which missed CAs ($p = 0.111$) and missed WAs ($p = 0.037$) occurred between accuracy levels. There was a significant difference ($p < 0.001$) in the number of runs in which nuisance CAs and nuisance WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was no significant difference ($p = 0.051$) in the number of runs in which missed CAs occurred but there was a significant difference ($p = 0.003$) in the number of runs in which missed WAs occurred between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies.

For Aircraft A, the missed CAs should have occurred after the aircraft landed and exited the runway. The missed WAs should have occurred after the aircraft landed and was taxiing down the runway at 30 kts. For Aircraft B, all of the missed alerts should have occurred while on approach, prior to crossing the runway threshold. An alert was considered a nuisance if it was generated at the same time the aircraft was determined to be within the nuisance boundary. Therefore, nuisance alerts for Aircraft A only occurred after the aircraft landed and exited the runway.

Table 53. ATCAM Missed and Nuisance Alert Statistics for All Evasive Actions by NACp for Head-On Arrivals Scenario.

NACp	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
8	392	2, 0.5	3, 0.8	20, 5.1	18, 4.6
9	336	0, 0.0	0, 0.0	0, 0.0	1, 0.3
10	224	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	168	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	56	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Arrival Runway 28)					
8	392	3, 0.8	10, 2.6	0, 0.0	0, 0.0
9	336	0, 0.0	9, 2.7	0, 0.0	0, 0.0
10	224	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	168	1, 0.6	0, 0.0	0, 0.0	0, 0.0
Truth	56	0, 0.0	0, 0.0	0, 0.0	0, 0.0

When analyzing by CD&R equipage level (Table 54), in general, more missed alerts occurred when Both aircraft were equipped with CD&R. Nuisance alerts occurred more often when only Aircraft A was equipped. For Aircraft A, there was no significant difference in the number of runs in which missed CAs ($p = 0.50$), missed WAs ($p = 0.156$), and nuisance CAs ($p = 0.30$) occurred between equipage levels. There was a significant difference ($p = 0.006$) in the number of runs in which nuisance WAs occurred between Aircraft A and Both aircraft equipped vs. Neither aircraft and Aircraft B equipped. For Aircraft B, there was a significant difference in the number of runs in which missed CAs ($p = 0.004$) occurred between Both aircraft equipped vs. Neither aircraft, Aircraft A, and Aircraft B equipped and in the number of runs in which missed WAs ($p < 0.001$) occurred between Aircraft A and Both aircraft equipped vs. Neither aircraft and Aircraft B equipped.

Table 54. ATCAM Missed and Nuisance Alert Statistics for All NACp by Evasive Action for Head-On Arrivals Scenario.

CD&R Equipage	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
Neither	294	0, 0.0	1, 0.3	3, 1.0	3, 1.0
Aircraft A	294	0, 0.0	0, 0.0	8, 2.7	10, 3.4
Aircraft B	294	1, 0.3	0, 0.0	3, 1.0	0, 0.0
Both	294	1, 0.3	2, 0.7	6, 2.0	6, 2.0
Aircraft B (Arrival Runway 28)					
Neither	294	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft A	294	0, 0.0	8, 2.7	0, 0.0	0, 0.0
Aircraft B	294	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Both	294	4, 1.4	11, 3.7	0, 0.0	0, 0.0

Unnecessary maneuvering - The percentage of test runs in which the aircraft maneuvered unnecessarily when transmitting data with the various accuracy levels is shown in Table 55. Unnecessary maneuvers only occurred when transmitting NACp 8 data on less than 2% of the test runs. There were no unnecessary maneuvers when transmitting data with NACp 9, 10, 11, and truth accuracies. There was no significant difference in the number of runs in which unnecessary maneuvers occurred between accuracy levels for Aircraft A ($p = 0.037$) and Aircraft B ($p= 0.111$).

Table 55. Unnecessary Maneuvers for All Evasive Actions by NACp Using ATCAM During Head-On Arrivals Scenario.

NACp	Total # Runs	Aircraft A (Arrival Runway 10) (# Runs, % Runs)	Aircraft B (Arrival Runway 28) (# Runs, % Runs)
8	196	3, 1.5	2, 1.0
9	168	0, 0.0	0, 0.0
10	112	0, 0.0	0, 0.0
11	84	0, 0.0	0, 0.0
Truth	28	0, 0.0	0, 0.0

The number and percentage of test runs in which the aircraft maneuvered unnecessarily based on the CD&R equipage level is shown in Table 56. There were no significant differences in the number of runs in which unnecessary maneuvers occurred between equipage levels for Aircraft A ($p= 0.249$) and Aircraft B ($p = 0.499$).

Table 56. Unnecessary Maneuvers for All NACp by Evasive Action Using ATCAM During Head-On Arrivals Scenario.

CD&R Equipage	Total # Runs	Aircraft A (Arrival Runway 10) (# Runs, % Runs)	Aircraft B (Arrival Runway 28) (# Runs, % Runs)
Neither	294	N/A	N/A
Aircraft A	294	3, 1.0	N/A
Aircraft B	294	N/A	0, 0.0
Both	294	0, 0.0	2, 0.7

Collision avoidance – When neither aircraft was equipped with CD&R, 100% of the runs resulted in a near collision and approximately 79% resulted in collisions, as shown in Table 57. The addition of CD&R eliminated collisions when transmitting data with NACp 9, 10, 11, and truth position accuracy levels and reduced the occurrence when transmitting data with NACp 8 accuracy (3% of the runs). Collision avoidance was affected by the CD&R system equipage level. In some instances, CD&R was more effective depending on which aircraft was equipped. For this scenario, more collisions were avoided when Aircraft B was equipped. When Aircraft A was equipped, collision avoidance was less effective, but better than when neither aircraft were equipped. When neither aircraft was equipped with CD&R, there was no significant difference in the number of runs in which near collisions (near collisions on all test runs) and collisions ($p = 1.0$) occurred between accuracy levels. When Aircraft A was equipped, there was a significant difference ($p < 0.001$) in the number of runs in which near collisions and collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. When Aircraft B was equipped, there was no significant difference ($p = 0.675$) in the number of runs in which near collisions occurred but there was a significant difference ($p < 0.001$) in the number of runs in which collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. When Both aircraft were equipped, there was no significant difference in the number of runs in which near collisions ($p = 0.663$) and collisions ($p = 0.036$) occurred between accuracy levels.

When truth position data was used and neither aircraft took action, 11 collisions occurred. The scenario was designed such that when Aircraft B began its approach to Runway 28, 3.5 NM prior to the runway threshold, a collision occurred when Aircraft A (arrival to Runway 10) was located from 3.5 NM to the threshold, at 0.5 NM intervals, crossing the runway threshold, and 1,400 ft, 3,700 ft, and 5,500 ft past the threshold. For nine of these collisions, both aircraft had landed and were decelerating or taxiing down the runway when the collision occurred. For one collision, Aircraft A was taxiing down the runway and Aircraft B was just about to touchdown. For one collision, Aircraft A was exiting the runway as Aircraft B was about to touchdown.

Table 57. Number/Percentage Of Near Collisions (NC) and Collisions (C) Using ATCAM for Equipage Combinations for Head-On Arrivals Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	98	98, 100	77, 78.6	58, 59.2	34, 34.7	36, 36.7	16, 16.3	21, 21.4	3, 3.1
9	84	84, 100	66, 78.6	26, 30.9	3, 3.6	23, 27.4	0, 0.0	12, 14.3	0, 0.0
10	56	56, 100	44, 78.6	12, 21.4	0, 0.0	16, 28.6	0, 0.0	8, 14.3	0, 0.0
11	42	42, 100	33, 78.6	9, 21.4	0, 0.0	12, 28.6	0, 0.0	6, 14.3	0, 0.0
Truth	14	14, 100	11, 78.6	3, 21.4	0, 0.0	4, 28.6	0, 0.0	2, 14.3	0, 0.0

For all runs resulting in collision, WAs were issued and occurred just prior to touchdown, during high speed rollout, or when the aircraft was taxiing down the runway. When equipped with CD&R, maneuvering, which consisted of accelerated braking to exit the runway, was conducted on all but six runs. For the 37 collisions that occurred when Aircraft A was equipped, one occurred when both aircraft were

taxiing on the runway; four occurred when Aircraft A was taxiing on the runway and Aircraft B had just touched down; seven occurred when Aircraft A was taxiing on the runway and Aircraft B was just prior to touchdown; 11 occurred when Aircraft A was exiting the runway; nine occurred when Aircraft A had exited the runway; and five occurred when Aircraft A had exited the runway and stopped. These last five collisions may not have occurred if the scenario was designed such that the aircraft taxied further from the runway before it came to a complete stop. For the 16 collisions that occurred when Aircraft B was equipped, nine occurred when both aircraft were taxiing on the runway; five occurred when Aircraft B was exiting the runway; and two occurred when Aircraft B had exited the runway and stopped. For the three collisions that occurred when Both aircraft were equipped, two occurred when Aircraft A was taxiing on the runway and Aircraft B was just about to touch down and one occurred when Aircraft A was exiting the runway.

5.1.8 Runway Scenario – Arrivals to Intersecting Runways

For each of the 20 cases in this scenario, an initiation delay on Aircraft B was evaluated at 13 levels, for a total of 1,092 test runs.

Algorithm performance – The data (Table 58) shows that, for Aircraft A, CAs were generated on 23% to 43% of the runs and WAs were generated on 56% to 71% of the runs. For Aircraft B, CAs were generated on approximately 38% of the runs and WAs were generated on approximately 32% of runs, almost independent of the position accuracy levels. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which CAs and WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was no significant difference in the number of runs in which CAs ($p = 0.946$) and WAs ($p = 0.707$) were generated between accuracy levels.

When analyzing alerts that occurred when transmitting truth position data, CAs were issued onboard Aircraft A when 1.3 NM prior to the runway threshold and 454 ft AGL. WAs were issued when Aircraft A was on approach from 5,937 ft to 5,767 ft prior to the runway threshold and 348 ft to 339 ft AGL and then again when crossing Aircraft B's runway, from 2,060 ft to 5,245 ft past the threshold and 129 kts to 40 kts. For Aircraft B, CAs occurred when the aircraft was between approximately 7,967 ft to 7,757 ft prior to the runway threshold and 454 ft to 443 ft AGL. WAs occurred when the aircraft was 5,942 ft prior to the runway threshold and 348 ft AGL and approximately 5,490 ft prior to the threshold and 324 ft AGL.

Alert toggling occurred similarly for both aircraft, with toggling occurring mainly when transmitting data with NACp 8 and 9 accuracies, with a much higher percentage occurring when transmitting data with NACp 8 accuracy. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which multiple CAs and multiple WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 58. ATCAM Alert Statistics for All Evasive Actions by NACp for Arrivals to Intersecting Runways Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
8	364	155, 42.6	39, 10.7	203, 55.8	100, 27.5
9	312	77, 24.7	2, 0.6	222, 71.2	18, 5.8
10	208	48, 23.1	0, 0.0	146, 70.2	1, 0.5
11	156	36, 23.1	0, 0.0	108, 69.2	0, 0.0
Truth	52	12, 23.1	0, 0.0	36, 69.2	0, 0.0
Aircraft B (Arrival Runway 22R)					
8	364	135, 37.1	17, 4.7	132, 36.3	78, 21.4
9	312	125, 40.1	3, 1.0	105, 33.6	16, 5.1
10	208	80, 38.5	0, 0.0	66, 31.7	0, 0.0
11	156	60, 38.5	0, 0.0	48, 30.8	0, 0.0
Truth	52	20, 38.5	0, 0.0	16, 30.8	0, 0.0

The toggling included gaps between alerts when transmitting data with NACp 8 and 9 accuracies. In addition to position accuracy, the toggling was also a result of aircraft maneuvering. Multiple alerts occurred after Aircraft A or Aircraft B conducted a go-around maneuver, when Aircraft A conducted accelerated braking, and when the aircraft stopped on the runway. Sometimes a multiple alert occurred onboard Aircraft A after the aircraft was past the intersecting runway, which is not necessary since the aircraft is moving away from the intersection.

When analyzing by CD&R equipage level (Table 59), for Aircraft A, alert generation was similar across all equipage levels. For Aircraft B, more alerts were generated when Neither aircraft and only Aircraft B was equipped with CD&R. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 0.951$) and WAs ($p = 0.919$) were generated between equipage levels. For Aircraft B, there was a significant difference in the number of runs in which CAs ($p = 0.002$) and WAs ($p = 0.013$) were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

The CA toggling rate was similar between equipage levels for both aircraft (Table 59). The WA toggling rate was high for all equipage levels for both aircraft. For Aircraft A, there was no significant difference ($p = 0.683$) in the number of runs in which multiple CAs were generated but there was a significant difference ($p = 0.013$) in the number of runs in which multiple WAs were generated between Neither aircraft equipped vs. Aircraft A, Aircraft B, and Both aircraft equipped. For Aircraft B, there was no significant difference ($p = 0.565$) in the number of runs in which multiple CAs were generated but there was a significant difference ($p = 0.011$) in the number of runs in which multiple WAs were generated between Neither and Aircraft B equipped vs Aircraft A and Both aircraft equipped.

Table 59. ATCAM Alert Statistics for All NACp by Evasive Action for Arrivals to Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
Neither	273	83, 30.4	9, 3.3	180, 65.9	44, 16.1
Aircraft A	273	79, 28.9	8, 2.9	181, 66.3	26, 9.5
Aircraft B	273	85, 31.1	11, 4.0	174, 63.7	27, 9.9
Both	273	81, 29.7	13, 4.8	180, 65.9	22, 8.1
Aircraft B (Arrival Runway 22R)					
Neither	273	120, 44.0	3, 1.1	104, 38.1	32, 11.7
Aircraft A	273	92, 33.7	6, 2.2	78, 28.6	21, 7.7
Aircraft B	273	121, 44.3	4, 1.5	105, 38.5	29, 10.6
Both	273	87, 31.9	7, 2.6	80, 29.3	12, 4.4

Alert statistics were also compiled by CD&R equipage level when truth position data was transmitted (Table 60). The CA rate was lower for Aircraft A when transmitting accurate data, but the WA rate was slightly higher. For Aircraft B, the alerts rates were similar to the rate of generation when transmitting data with various accuracy levels (Table 59). The multiple alerts occurred mainly when transmitting NACp 8 data for Aircraft A. For Aircraft A, there was no significant difference ($p = 1.0$) in the number of runs in which CAs and WAs were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs were generated between Neither aircraft equipped vs. Aircraft A, Aircraft B, and Both aircraft equipped. For Aircraft B, there was a significant difference in the number of runs in which CAs ($p = 0.003$) and WAs ($p = 0.014$) were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Table 60. ATCAM Alert Statistics When Transmitting Truth Position Data for Arrivals to Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
Neither	273	63, 23.1	0, 0.0	189, 69.2	10, 3.7
Aircraft A	273	63, 23.1	0, 0.0	189, 69.2	0, 0.0
Aircraft B	273	63, 23.1	0, 0.0	189, 69.2	1, 0.4
Both	273	63, 23.1	0, 0.0	189, 69.2	0, 0.0
Aircraft B (Arrival Runway 22R)					
Neither	273	126, 46.1	0, 0.0	105, 38.5	0, 0.0
Aircraft A	273	96, 35.2	0, 0.0	79, 28.9	0, 0.0
Aircraft B	273	126, 46.1	0, 0.0	105, 38.5	0, 0.0
Both	273	96, 35.2	0, 0.0	80, 29.3	0, 0.0

Missed and nuisance alerts – The number of runs in which the aircraft entered the defined missed and nuisance boundaries increased as the position accuracy decreased, as shown in Table 61. The number of times (count) and amount of time (duration and percentage of run length) that the aircraft were within the boundaries was greater when transmitting less accurate data (Table 61). For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary and nuisance boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. The nuisance boundary was not entered with Aircraft B.

The majority of occurrences of entering the missed boundary was after the aircraft had crossed the runway threshold for landing. The aircraft only entered the missed boundary while on approach before crossing the runway threshold during 1.9% of the test runs for Aircraft A and 3.0% of the test runs for Aircraft B when transmitting NACp 8 data. Since the aircraft tracked the extended centerline on approach and centerline after landing, the nuisance boundary was entered as the aircraft exited the runway.

Table 61. ATCAM Missed and Nuisance Boundary Statistics for Arrivals to Intersecting Runways Scenario.

	Entered Missed Boundary				Entered Nuisance Boundary			
NACp	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Arrival Runway 14L)								
8	356, 97.8	7.8, 4.7	14.3, 10.8	13.3	135, 37.1	4.0, 3.1	6.7, 6.4	6.1
9	84, 26.9	1.3, 0.6	1.4, 1.1	1.3	77, 24.7	1.2, 0.4	1.6, 1.1	1.4
10	52, 25.0	1.0, 0.0	0.6, 0.4	0.6	37, 17.8	1.0, 0.0	0.6, 0.4	0.5
11	28, 17.9	1.0, 0.0	0.3, 0.1	0.2	21, 13.5	1.0, 0.0	0.3, 0.1	0.2
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Aircraft B (Arrival Runway 22R)								
8	276, 75.8	3.4, 2.2	5.3, 4.7	4.9	0, 0.0	0, 0.0	0, 0.0	0.0
9	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
10	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
11	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0

The number of test runs that contained missed and nuisance alerts was low, in general, as shown in Table 62. There were no missed CAs for Aircraft A and no nuisance alerts for either aircraft. For Aircraft

A, there was a significant difference ($p < 0.001$) in the number of runs in which missed WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was a significant difference in the number of runs in which missed CAs ($p < 0.001$) and missed WAs ($p = 0.004$) occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

For Aircraft A, all of the missed WAs should have occurred after the aircraft landed. For Aircraft B, all of the missed CAs and missed WAs should have occurred when the aircraft was on approach.

Table 62. ATCAM Missed and Nuisance Alert Statistics for All Evasive Actions by NACp for Arrivals to Intersecting Runways Scenario.

NACp	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
8	364	0, 0.0	52, 14.3	0, 0.0	0, 0.0
9	312	0, 0.0	5, 1.6	0, 0.0	0, 0.0
10	208	0, 0.0	1, 0.5	0, 0.0	0, 0.0
11	156	0, 0.0	2, 1.3	0, 0.0	0, 0.0
Truth	52	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Arrival Runway 22R)					
8	364	23, 6.3	5, 1.4	0, 0.0	0, 0.0
9	312	2, 0.6	0, 0.0	0, 0.0	0, 0.0
10	208	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	156	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	52	0, 0.0	0, 0.0	0, 0.0	0, 0.0

When analyzing by CD&R equipage level (Table 63), the rate of missed WAs was highest for Aircraft A, when only Aircraft B was equipped with CD&R. For Aircraft B, the missed CA rate was highest when Both aircraft were equipped; while the missed WA rate was very low. Nuisance alerts did not occur for either aircraft. For Aircraft A, there was no significant difference ($p = 0.283$) in the number of runs in which missed WAs occurred between equipage levels. For Aircraft B, there was no significant difference in the number of runs in which missed CAs ($p = 0.334$) and missed WAs ($p = 0.604$) occurred between equipage levels.

Table 63. ATCAM Missed and Nuisance Alert Statistics for All NACp by Evasive Action for Arrivals to Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
Neither	273	0, 0.0	17, 6.2	0, 0.0	0, 0.0
Aircraft A	273	0, 0.0	11, 4.0	0, 0.0	0, 0.0
Aircraft B	273	0, 0.0	20, 7.3	0, 0.0	0, 0.0
Both	273	0, 0.0	12, 4.4	0, 0.0	0, 0.0
Aircraft B (Arrival Runway 22R)					
Neither	273	6, 2.2	1, 0.4	0, 0.0	0, 0.0
Aircraft A	273	4, 1.5	2, 0.7	0, 0.0	0, 0.0
Aircraft B	273	5, 1.8	1, 0.4	0, 0.0	0, 0.0
Both	273	10, 3.7	1, 0.4	0, 0.0	0, 0.0

Unnecessary maneuvering – No unnecessary maneuvers occurred for this scenario.

Collision avoidance – There were no collisions for this scenario. The rate of near collisions was low (Table 64) and were affected by the CD&R equipage level. Interestingly, near collisions occurred when Both aircraft and only one aircraft (either A or B) were equipped but not when CD&R was absent. When

Aircraft B was equipped, the near collisions occurred after Aircraft B initiated a go-around maneuver. In all other instances, the near collision occurred after Aircraft A received a WA, maneuvered, and stopped on the runway. When Aircraft A was equipped, there was a significant difference ($p = 0.007$) in the number of runs in which near collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. When Aircraft B was equipped, there was no significant difference ($p = 0.036$) in the number of runs in which near collisions occurred between accuracy levels. When Both aircraft were equipped, there was a significant difference ($p = 0.025$) in the number of runs in which near collisions occurred between NACp 9 vs. NACp 8, 10, 11, and truth accuracies.

Table 64. Number/Percentage Of Near Collisions (NC) and Collisions (C) Using ATCAM for Equipage Combinations for Arrivals to Intersecting Runways Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	91	0, 0.0	0, 0.0	7, 7.7	0, 0.0	3, 3.3	0, 0.0	1, 1.1	0, 0.0
9	78	0, 0.0	0, 0.0	2, 2.6	0, 0.0	0, 0.0	0, 0.0	4, 5.1	0, 0.0
10	52	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	39	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	13	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0

5.1.9 Taxi Scenario – Taxi Following

For each of the 20 cases in this scenario, Aircraft A taxi speed was evaluated at 7 levels, for a total of 588 test runs.

Algorithm performance – For both aircraft, CAs were generated on 86% to 100% of the test runs and WAs were generated on 96% to 100% of the runs, with a lower percentage of alerts being generated when transmitting data with NACp 8 accuracy (Table 65). For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which CAs and WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was a significant difference in the number of runs in which CAs ($p < 0.001$) were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies and the number of runs in which WAs ($p = 0.016$) were generated between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies.

Table 65. ATCAM Alert Statistics for All Evasive Actions by NACp for Taxi Following Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Taxi behind)					
8	196	173, 88.3	83, 42.4	188, 95.9	66, 33.7
9	168	166, 98.8	58, 34.5	168, 100.0	37, 22.0
10	112	112, 100.0	22, 19.6	112, 100.0	7, 6.3
11	84	84, 100.0	2, 2.4	84, 100.0	0, 0.0
Truth	28	28, 100.0	0, 0.0	28, 100.0	0, 0.0
Aircraft B (Taxi ahead)					
8	196	168, 85.7	89, 45.4	189, 96.4	74, 37.8
9	168	166, 98.8	57, 33.9	165, 98.2	37, 22.0
10	112	112, 100.0	25, 22.3	112, 100.0	6, 5.4
11	84	84, 100.0	1, 1.2	84, 100.0	1, 1.2
Truth	28	28, 100.0	0, 0.0	28, 100.0	0, 0.0

When analyzing alerts that occurred when transmitting truth position data, alerts were issued sooner, with more distance between the aircraft, the faster Aircraft A was taxiing. This would give the flight crew more time to react when traveling at faster speeds. CAs were issued onboard both aircraft when the aircraft were approximately 597 ft apart (Aircraft A 24 kts) until they were 385 ft apart (Aircraft A 12 kts) (Table

66). WAs were issued onboard both aircraft when they were approximately 473 apart until they were approximately 322 ft apart. Aircraft B was always taxiing at 10 kts.

Table 66. Distance Between Aircraft at Alert Generation for Taxi Following Scenario.

Aircraft A (Taxi Behind) Ground Speed (kts)	Distance Between Aircraft When CA Generated (ft) (mean, SD)	Distance Between Aircraft When WA Generated (ft) (mean, SD)
24	597.2, 0.0	472.5, 0.9
22	562.9, 1.0	453.5, 1.9
20	538.4, 0.9	430.8, 0.9
18	495.2, 0.0	399.3, 0.9
16	461.8, 1.5	374.7, 4.3
14	422.9, 0.0	346.8, 0.0
12	385.3, 1.0	321.8, 1.9

As the position accuracy was reduced, alert toggling occurred more frequently, especially when transmitting data with NACp 8 and 9 accuracies (Table 65). For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which multiple CAs and multiple WAs were generated between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies.

The toggling included gaps between alerts and was mainly the result of the effect of position accuracy. For this scenario, the aircraft did not stop taxiing in the event that criteria for a collision was met; the run continued until the aircraft reached their closest point of approach, which was after a defined collision (on those runs that resulted in collision). Alerts and alert multiples were generated after the criteria for a collision was met, particularly when transmitting data with NACp 8 position accuracy; these alerts are included in Table 65.

When analyzing by CD&R equipage level (Table 67), for both aircraft, CAs were issued on approximately 95% of the runs and WAs were issued on over 95% of the runs for all equipage levels. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 0.928$) and WAs ($p = 0.026$) were generated between equipage levels. For Aircraft B, there was no significant difference ($p = 0.672$) in the number of runs in which CAs were generated but there was a significant difference ($p = 0.003$) in the number of runs in which WAs were generated between Both aircraft equipped vs. Neither aircraft, Aircraft A, and Aircraft B equipped.

Table 67. ATCAM Alert Statistics for All NACp by Evasive Action for Taxi Following Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Taxi behind)					
Neither	147	142, 96.6	53, 36.0	146, 99.3	68, 46.3
Aircraft A	147	141, 95.9	43, 29.2	147, 100.0	12, 8.2
Aircraft B	147	140, 95.2	41, 27.9	145, 98.6	25, 17.0
Both	147	140, 95.2	28, 19.1	142, 96.6	5, 3.4
Aircraft B (Taxi ahead)					
Neither	147	142, 96.6	53, 36.0	146, 99.3	69, 46.9
Aircraft A	147	138, 93.9	45, 30.6	145, 98.6	22, 15.0
Aircraft B	147	140, 95.2	38, 25.9	147, 100.0	18, 12.2
Both	147	138, 93.9	36, 24.5	140, 95.2	9, 6.1

The rate of alert toggling was high for CAs (greater than 19%) for all equipage levels. WA toggling occurred more frequently when Neither aircraft were equipped with CD&R (Table 67). For Aircraft A, there was a significant difference ($p = 0.014$) in the number of runs in which multiple CAs were generated

between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped. There was also a significant difference ($p < 0.001$) in the number of runs in which multiple WAs were generated between Neither aircraft equipped vs. Aircraft A, Aircraft B, and Both aircraft equipped. For Aircraft B, there was no significant difference ($p = 0.119$) in the number of runs in which multiple CAs were generated but there was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs were generated between Neither aircraft equipped vs. Aircraft A, Aircraft B, and Both aircraft equipped.

Alert statistics were compiled by CD&R equipage level when truth position accuracy was transmitted (Table 68). Alerts were issued at a slightly lower rate than when transmitting data with various accuracy levels (Table 67). No multiple alerts occurred when transmitting truth data. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which CAs and WAs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Table 68. ATCAM Alert Statistics When Transmitting Truth Position Data for Taxi Following Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Taxi behind)					
Neither	147	147, 100.0	0, 0.0	147, 100.0	0, 0.0
Aircraft A	147	129, 87.8	0, 0.0	110, 74.8	0, 0.0
Aircraft B	147	134, 91.2	0, 0.0	123, 83.7	0, 0.0
Both	147	122, 83.0	0, 0.0	110, 74.8	0, 0.0
Aircraft B (Taxi ahead)					
Neither	147	147, 100.0	0, 0.0	147, 100.0	0, 0.0
Aircraft A	147	129, 87.8	0, 0.0	110, 74.8	0, 0.0
Aircraft B	147	134, 91.2	0, 0.0	123, 83.7	0, 0.0
Both	147	122, 83.0	0, 0.0	110, 74.8	0, 0.0

Missed and nuisance alerts – The number of runs in which the aircraft entered the defined missed boundary increased as the position accuracy decreased, as shown in Table 69. The rate in which the aircraft entered the nuisance boundary was relatively low for all position accuracy levels. For both aircraft, there was a significant difference ($p < 0.001$) in the number runs in which the aircraft entered the missed boundary between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies. There was no significant difference in the number of runs in which the aircraft entered the nuisance boundary between accuracy levels for Aircraft A ($p = 0.136$) and Aircraft B ($p = 1.0$).

As previously discussed, the high rate of entering the missed boundary was due to the missed boundary definition. There was no buffer between when the aircraft was inside or outside the missed boundary; therefore, a very small difference between the true and detected position caused a missed boundary to be counted. The aircraft entered the nuisance boundary only for a small percentage of the test runs. Since the test run did not terminate when a collision occurred and the aircraft continued along their paths, all instances of entering the nuisance boundary were after a collision when the aircraft were exiting the taxiway.

The number of test runs that contained missed and nuisance alerts was low for this scenario, as shown in Table 70. Missed alerts for both aircraft were highest when transmitting data with NACp 8 accuracy. For Aircraft A, there was a significant difference in the number of runs in which missed CAs ($p < 0.001$) and missed WAs ($p = 0.004$) occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which missed CAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. There was no significant difference ($p = 0.088$) in the number of runs in which missed WAs occurred between accuracy levels. For both aircraft, there was no significant difference ($p = 0.333$) in the number of runs in which nuisance WAs occurred between accuracy levels. No nuisance CAs occurred.

The rate of missed alerts was similar for both aircraft since the aircraft conducted identical operations, traveling along a taxiway. The only nuisance alerts occurred on one test run after a collision when the aircraft were exiting the taxiway.

Table 69. ATCAM Missed and Nuisance Boundary Statistics for Taxi Following Scenario.

NACp	Entered Missed Boundary				Entered Nuisance Boundary			
	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Taxi behind)								
8	196, 100.0	23.9, 18.9	67.6, 54.0	57.6	4, 2.0	1.0, 0.0	3.9, 2.8	1.0
9	112, 66.7	7.9, 8.4	13.8, 18.4	9.2	5, 3.0	1.2, 0.4	1.9, 0.7	0.5
10	2, 1.8	1.0, 0.0	1.1, 0.9	0.3	2, 1.8	1.0, 0.0	0.8, 0.0	0.2
11	2, 2.4	1.0, 0.0	0.3, 0.0	0.1	0, 0.0	0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Aircraft B (Taxi ahead)								
8	196, 100.0	23.1, 18.1	66.4, 57.4	54.9	3, 1.5	2.3, 2.3	4.9, 1.4	1.3
9	115, 68.5	7.4, 6.0	13.3, 15.7	9.0	2, 1.2	1.0, 0.0	2.9, 0.2	0.7
10	2, 1.8	1.0, 0.0	1.1, 1.2	0.3	2, 1.8	1.0, 0.0	1.9, 0.5	0.5
11	1, 1.2	1.0, 0.0	0.5, 0.0	0.1	1, 1.2	1.0, 0.0	0.8, 0.0	0.2
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0

Table 70. ATCAM Missed and Nuisance Alert Statistics for All Evasive Actions by NACp for Taxi Following Scenario.

NACp	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Taxi behind)					
8	196	16, 8.2	5, 2.6	0, 0.0	1, 0.5
9	168	2, 1.2	0, 0.0	0, 0.0	0, 0.0
10	112	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	84	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	28	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Taxi ahead)					
8	196	14, 7.1	4, 2.0	0, 0.0	1, 0.5
9	168	2, 1.2	2, 1.2	0, 0.0	0, 0.0
10	112	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	84	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	28	0, 0.0	0, 0.0	0, 0.0	0, 0.0

Analyzing the data based on equipage level (Table 71) shows missed alerts occurred on 3.4% or less of the test runs, depending on the equipage level. Only one nuisance WA occurred for each aircraft when Neither aircraft was equipped. For Aircraft A, there was no significant difference in the number of runs in which missed CAs ($p = 0.811$) and nuisance WAs ($p = 0.250$) occurred between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which missed CAs ($p = 0.138$) and nuisance WAs ($p = 0.250$) occurred between equipage levels. There was a significant difference in the number of runs in which missed WAs occurred between Both aircraft equipped vs. Neither aircraft, Aircraft A, and Aircraft B equipped for Aircraft A ($p = 0.015$) and Aircraft B ($p = 0.004$).

Table 71. ATCAM Missed and Nuisance Alert Statistics for All NACp by Evasive Action for Taxi Following Scenario.

CD&R Equipage	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Taxi behind)					
Neither	147	5, 3.4	1, 0.7	0, 0.0	1, 0.7
Aircraft A	147	4, 2.7	0, 0.0	0, 0.0	0, 0.0
Aircraft B	147	5, 3.4	0, 0.0	0, 0.0	0, 0.0
Both	147	4, 2.7	4, 2.7	0, 0.0	0, 0.0
Aircraft B (Taxi ahead)					
Neither	147	5, 3.4	1, 0.7	0, 0.0	1, 0.7
Aircraft A	147	5, 3.4	0, 0.0	0, 0.0	0, 0.0
Aircraft B	147	5, 3.4	0, 0.0	0, 0.0	0, 0.0
Both	147	1, 0.7	5, 3.4	0, 0.0	0, 0.0

Unnecessary maneuvering - The percentage of test runs in which the aircraft maneuvered unnecessarily when transmitting data with the various accuracy levels is shown in Table 72. As the accuracy decreased, the frequency of occurrences of unnecessary maneuvers increased. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which unnecessary maneuvers occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 72. Unnecessary Maneuvers for All Evasive Actions by NACp Using ATCAM During Taxi Following Scenario.

NACp	Total # Runs	Aircraft A (Taxi behind) (# Runs, % Runs)	Aircraft B (Taxi ahead) (# Runs, % Runs)
8	98	50, 51.0	43, 43.9
9	84	21, 25.0	18, 21.4
10	56	4, 7.1	6, 10.7
11	42	0, 0.0	1, 2.4
Truth	14	0, 0.0	0, 0.0

The number and percentage of test runs in which the aircraft maneuvered unnecessarily based on the CD&R equipage level is shown in Table 73. There was no significant difference in the number of runs in which unnecessary maneuvers occurred between equipage levels for Aircraft A ($p = 1.0$) and Aircraft B ($p = 0.333$).

Table 73. Unnecessary Maneuvers for All NACp by Evasive Action Using ATCAM During Taxi Following Scenario.

CD&R Equipage	Total # Runs	Aircraft A (Taxi behind) (# Runs, % Runs)	Aircraft B (Taxi ahead) (# Runs, % Runs)
Neither	147	N/A	N/A
Aircraft A	147	37, 25.2	N/A
Aircraft B	147	N/A	30, 20.4
Both	147	38, 25.9	38, 25.9

Collision avoidance – For this scenario, CD&R equipage was effective for collision avoidance, as shown in Table 74. When neither aircraft was equipped with CD&R, all of the runs resulted in near collision and collision. There were no near collisions or collisions when transmitting data with NACp 9, 10, 11, and truth accuracy levels when Aircraft B (taxiing ahead) or Both aircraft were equipped. There were some near collisions and collisions when transmitting data with NACp 9 accuracy when only Aircraft A (taxi

following) was equipped. When neither aircraft was equipped with CD&R, there were no significant differences in the number of runs in which near collisions and collisions occurred between accuracy levels since they occurred on the same percentage of runs (100%) for each accuracy level. When Aircraft A was equipped, there was a significant difference in the number of runs in which near collisions ($p < 0.001$) and collisions ($p = 0.002$) occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. When Aircraft B was equipped, there was a significant difference ($p < 0.001$) in the number of runs in which near collisions and collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. When Both aircraft were equipped, there was a significant difference ($p < 0.001$) in the number of runs in which near collisions and collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 74. Number/Percentage Of Near Collisions (NC) and Collisions (C) Using ATCAM for Equipage Combinations for Taxi Following Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	49	49, 100	49, 100	10, 20.4	7, 14.3	11, 22.4	8, 16.3	8, 16.3	7, 14.3
9	42	42, 100	42, 100	2, 4.8	1, 2.4	0, 0.0	0, 0.0	0, 0.0	0, 0.0
10	28	28, 100	28, 100	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	21	21, 100	21, 100	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	7	7, 100	7, 100	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0

On all collision runs in which a WA was issued, maneuvering was initiated but not with enough time to avoid the collision. A WA was generated on the eight collision runs when Aircraft A was equipped with CD&R; however, on four runs the alert occurred after the collision and on the other four runs the alert occurred four seconds or less before the collision. For the eight collisions that occurred when Aircraft B was equipped, on four runs the WA occurred after the collision and on the other four runs the alert occurred five seconds or less before the collision. When Both aircraft were equipped, WAs were not issued on either aircraft for three collision runs and no maneuvering was conducted. On two runs the WA occurred after the collision and on two runs the WA occurred four seconds or less before the collision.

5.1.10 Taxi Scenario – Taxi Intersection

For each of the 20 cases in this scenario, an initiation delay and initial location for Aircraft B were evaluated at 76 levels, for a total of 6,384 test runs.

Algorithm performance – CAs were generated for 55% to 76% of the test runs and WAs were generated for 50% to 66% of the runs (Table 75). For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which CAs and WAs were generated between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies. For Aircraft B, there was no significant difference ($p = 0.758$) in the number of runs in which CAs were generated but there was a significant difference ($p < 0.001$) in the number of runs in which WAs were generated between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies.

When analyzing alerts that occurred when transmitting truth position data, for Aircraft A, CAs were issued when the aircraft was approximately 217 ft to 719 ft from Aircraft B and WAs were issued when approximately 198 ft to 399 ft from Aircraft B. For Aircraft B, CAs were issued when approximately 229 ft to 719 ft from Aircraft A and WAs were issued when approximately 217 ft to 399 ft from Aircraft A.

As the position accuracy was reduced, alert toggling occurred more frequently, especially when transmitting data with NACp 8 and 9 accuracies (Table 75). For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which multiple CAs and multiple WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The toggling included gaps between alerts when transmitting less accurate position data. In addition to position accuracy, the toggling was also a result of aircraft maneuvering. Multiple alerts occurred after Aircraft A or Aircraft B conducted accelerated braking and when the aircraft stopped on the taxiway.

Table 75. ATCAM Alert Statistics for All Evasive Actions by NACp for Taxi Intersection Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A					
8	2,128	1,629, 76.5	776, 36.5	1,421, 66.8	448, 21.1
9	1,824	1,286, 70.5	298, 16.3	1,116, 61.2	72, 4.0
10	1,216	707, 58.1	39, 3.2	653, 53.7	1, 0.1
11	912	514, 56.4	1, 0.1	469, 51.4	0, 0.0
Truth	304	169, 55.6	0, 0.0	152, 50.0	0, 0.0
Aircraft B					
8	2,128	1,220, 57.3	309, 14.5	1,358, 63.8	329, 15.5
9	1,824	1,030, 56.5	32, 1.8	1,053, 57.7	38, 2.1
10	1,216	672, 55.3	0, 0.0	650, 53.5	0, 0.0
11	912	513, 56.2	0, 0.0	468, 51.3	0, 0.0
Truth	304	178, 58.5	0, 0.0	152, 50.0	0, 0.0

When analyzing by equipage level (Table 76), CAs were issued on approximately 67% of the runs for Aircraft A and approximately 56% of the runs for Aircraft B for all equipage levels. For both aircraft, WAs were issued on approximately 59% of the runs for all equipage levels. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p= 0.927$) and WAs ($p = 0.807$) were generated between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which CAs ($p = 0.221$) and WAs ($p = 0.760$) were generated between equipage levels.

The rate of alert toggling was high for CAs (approximately 17% for Aircraft A and 3% to 7% for Aircraft B) and WAs (3% to 9%) for all equipage levels (Table 76). For Aircraft A, there was no significant difference in the number of runs in which multiple CAs ($p= 0.575$) and multiple WAs ($p= 0.226$) were generated between equipage levels. For Aircraft B, there was a significant difference ($p<0.001$) in the number of runs in which multiple CAs and multiple WAs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Table 76. ATCAM Alert Statistics for All NACp by Evasive Action for Taxi Intersection Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A					
Neither	1,596	1,087, 68.1	273, 17.1	956, 59.9	123, 7.7
Aircraft A	1,596	1,071, 67.1	272, 17.0	967, 60.6	124, 7.8
Aircraft B	1,596	1,075, 67.4	297, 18.6	946, 59.3	150, 9.4
Both	1,596	1,072, 67.2	272, 17.0	942, 59.0	124, 7.8
Aircraft B					
Neither	1,596	893, 56.0	73, 4.6	922, 57.8	68, 4.3
Aircraft A	1,596	929, 58.2	107, 6.7	937, 58.7	138, 8.7
Aircraft B	1,596	875, 54.8	51, 3.2	912, 57.1	52, 3.3
Both	1,596	916, 57.4	110, 6.9	910, 57.0	109, 6.8

Alert statistics were also compiled by CD&R equipage level when truth position data was transmitted (Table 77). In general, alerts were issued at a slightly lower rate than when transmitting data with various accuracy levels (Table 76). Multiple alerts did not occur when transmitting truth data. For both aircraft, there was no significant difference ($p = 0.077$) in the number of runs in which CAs were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which WAs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Table 77. ATCAM Alert Statistics When Transmitting Truth Position Data for Taxi Intersection Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A					
Neither	1,596	924, 57.9	0, 0.0	798, 50.0	0, 0.0
Aircraft A	1,596	867, 54.3	0, 0.0	691, 43.3	0, 0.0
Aircraft B	1,596	899, 56.3	0, 0.0	741, 46.4	0, 0.0
Both	1,596	859, 53.8	0, 0.0	687, 43.0	0, 0.0
Aircraft B					
Neither	1,596	924, 57.9	0, 0.0	798, 50.0	0, 0.0
Aircraft A	1,596	867, 54.3	0, 0.0	691, 43.3	0, 0.0
Aircraft B	1,596	899, 56.3	0, 0.0	741, 46.4	0, 0.0
Both	1,596	859, 53.8	0, 0.0	687, 43.0	0, 0.0

Missed and nuisance alerts – For a large percentage of test runs for all accuracy levels except truth, the aircraft entered the defined missed boundary, as shown in Table 78. The aircraft entered the missed boundary during all test runs when transmitting data with NACp 8 accuracy. The aircraft entered the nuisance boundary only when transmitting data with NACp 8 and 9 accuracies. The number of times (count) and amount of time (duration and percentage of run length) that the aircraft were within the missed and nuisance boundary was greater when transmitting less accurate data (Table 78). This was particularly true when transmitting data with NACp 8 accuracy. There was a significant difference ($p < 0.001$) in the number of runs in which both aircraft entered the missed boundary between NACp 8 and 9 accuracy vs. NACp 10, 11, and truth accuracies. There was a significant difference ($p < 0.001$) in the number of runs in which both aircraft entered the nuisance boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The aircraft entered the missed boundary when crossing the intersecting taxiway and when traveling along the taxiway. The high rate of entering the missed boundary was due to the missed boundary definition. There was no buffer between when the aircraft was inside or outside the missed boundary; therefore, a very small difference between the true and detected position caused a missed boundary to be counted. The aircraft entered the nuisance boundary only when transmitting data with NACp 8 and 9 accuracies. Since the aircraft's true taxi path was along the taxiway centerline, it was only possible to enter the nuisance boundary when crossing the intersecting taxiway.

Table 78. ATCAM Missed and Nuisance Boundary Statistics for Taxi Intersection Scenario.

	Entered Missed Boundary				Entered Nuisance Boundary			
NACp	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A								
8	2127, 100.0	8.1, 3.8	20.8, 11.4	61.2	702, 33.0	1.8, 1.6	3.4, 5.2	9.7
9	1334, 73.1	2.2, 2.0	3.5, 4.7	10.3	62, 3.4	1.1, 0.4	1.0, 1.8	2.8
10	663, 54.5	1.1, 0.3	0.5, 0.3	7.1	0, 0.0	0, 0.0	0, 0.0	0.0
11	327, 35.9	1.0, 0.1	0.3, 0.1	0.9	0, 0.0	0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Aircraft B								
8	2128, 100.0	8.0, 3.8	20.2, 11.3	59.2	669, 31.4	1.9, 1.5	3.8, 5.2	11.1
9	1106, 60.6	2.2, 1.9	2.9, 4.0	9.1	52, 2.8	1.2, 0.6	0.9, 0.9	2.7
10	415, 34.1	1.0, 0.2	0.5, 0.3	1.6	0, 0.0	0, 0.0	0, 0.0	0.0
11	190, 20.8	1.0, 0.1	0.3, 0.1	0.8	0, 0.0	0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0

The number of test runs that contained missed alerts increased as the position accuracy decreased, as shown in Table 79. Missed alerts for both aircraft were highest when transmitting data with NACp 8 accuracy (approximately 8% of the runs for Aircraft A; 13% for Aircraft B). For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which missed CAs and missed WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. It was only possible for a nuisance alert to be generated when taxiing across a taxiway; however, no nuisance alerts occurred for this scenario.

When analyzing missed CAs that occurred when transmitting truth position data, for Aircraft A, three of the alerts should have occurred when Aircraft A was 579 ft down the taxiway and Aircraft B was crossing 604 ft down the taxiway. Four of the alerts should have occurred when Aircraft A was 712 ft down the taxiway and Aircraft B was crossing 803 ft down the taxiway.

Table 79. ATCAM Missed and Nuisance Alert Statistics for All Evasive Actions by NACp for Taxi Intersection Scenario.

NACp	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A					
8	2,128	163, 7.7	152, 7.1	0, 0.0	0, 0.0
9	1,824	62, 3.4	38, 2.1	0, 0.0	0, 0.0
10	1,216	42, 3.5	9, 0.7	0, 0.0	0, 0.0
11	912	23, 2.5	0, 0.0	0, 0.0	0, 0.0
Truth	304	7, 2.3	0, 0.0	0, 0.0	0, 0.0
Aircraft B					
8	2,128	276, 13.0	174, 8.2	0, 0.0	0, 0.0
9	1,824	130, 7.1	42, 2.3	0, 0.0	0, 0.0
10	1,216	55, 4.5	7, 0.6	0, 0.0	0, 0.0
11	912	22, 2.4	0, 0.0	0, 0.0	0, 0.0
Truth	304	0, 0.0	0, 0.0	0, 0.0	0, 0.0

Analyzing the data based on equipage level (Table 80) shows that, missed CAs occurred on approximately 5% of the test runs for Aircraft A and 6% to 9% of the runs for Aircraft B. Missed WAs occurred on approximately 3% of the runs for both aircraft. For Aircraft A, there was no significant difference in the number of runs in which missed CAs ($p = 0.611$) and missed WAs ($p = 0.778$) occurred between equipage levels. For Aircraft B, there was a significant difference ($p = 0.023$) in the number of runs in which missed CAs occurred between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped. There was no significant difference ($p = 0.797$) in the number of runs in which missed WAs occurred between equipage levels.

Table 80. ATCAM Missed and Nuisance Alert Statistics for All NACp by Evasive Action for Taxi Intersection Scenario.

CD&R Equipage	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A					
Neither	1,596	70, 4.4	47, 2.9	0, 0.0	0, 0.0
Aircraft A	1,596	72, 4.5	48, 3.0	0, 0.0	0, 0.0
Aircraft B	1,596	84, 5.3	48, 3.0	0, 0.0	0, 0.0
Both	1,596	71, 4.4	56, 3.5	0, 0.0	0, 0.0
Aircraft B					
Neither	1,596	131, 8.2	54, 3.4	0, 0.0	0, 0.0
Aircraft A	1,596	107, 6.7	51, 3.2	0, 0.0	0, 0.0
Aircraft B	1,596	142, 8.9	61, 3.8	0, 0.0	0, 0.0
Both	1,596	103, 6.5	57, 3.6	0, 0.0	0, 0.0

Unnecessary maneuvering - The percentage of test runs in which the aircraft maneuvered unnecessarily when transmitting data of various accuracy levels is shown in Table 81. As the data accuracy decreased, the frequency of occurrences of unnecessary maneuvering increased. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which unnecessary maneuvers occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 81. Unnecessary Maneuvers for All Evasive Actions by NACp Using ATCAM During Taxi Intersection Scenario.

NACp	Total # Runs	Aircraft A (# Runs, % Runs)	Aircraft B (# Runs, % Runs)
8	1,064	248, 23.3	174, 16.4
9	912	94, 10.3	53, 5.8
10	608	3, 0.5	7, 1.2
11	456	0, 0.0	0, 0.0
Truth	152	0, 0.0	0, 0.0

The number and percentage of test runs in which the aircraft maneuvered unnecessarily based on the CD&R equipage level is shown in Table 82. There were no significant differences in the number of runs in which unnecessary maneuvers occurred between equipage levels for Aircraft A ($p= 0.362$) and Aircraft B ($p= 0.067$).

Table 82. Unnecessary Maneuvers for All NACp by Evasive Action Using ATCAM During Taxi Intersection Scenario.

CD&R Equipage	Total # Runs	Aircraft A (# Runs, % Runs)	Aircraft B (# Runs, % Runs)
Neither	1,596	N/A	N/A
Aircraft A	1,596	181, 11.3	N/A
Aircraft B	1,596	N/A	103, 6.5
Both	1,596	164, 10.3	131, 8.2

Collision avoidance – For this scenario, CD&R equipage was effective for collision avoidance, as shown in Table 83. Equipage for either aircraft dropped the near collision and collision rates in half, and with Both aircraft equipped, the near collision rate was reduced by an order of magnitude and the collision rate was reduced to 1% when transmitting data with NACp 10 accuracy. The effectiveness of collision avoidance increased when both aircraft were equipped with CD&R; however, collisions still occurred except when transmitting very accurate data. Since both aircraft conducted identical operations, it was expected that collision avoidance would be similar for both aircraft. However, collision avoidance was slightly more effective when Aircraft B was equipped than when Aircraft A was equipped, except when transmitting data with NACp 8 accuracy. Position accuracy did not have much effect on collision avoidance, except when Both aircraft were equipped. When neither aircraft were equipped with CD&R, there was no significant difference ($p = 1.0$) in the number of runs in which near collisions and collisions occurred between accuracy levels. When only Aircraft A was equipped, there was no significant difference in the number of runs in which near collisions ($p = 0.996$) and collisions ($p = 0.979$) occurred between accuracy levels. When only Aircraft B was equipped, there was a significant difference in the number of runs in which near collisions ($p = 0.002$) occurred between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies and in the number of runs in which collisions ($p < 0.001$) occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. When Both aircraft were equipped, there was a significant difference ($p < 0.001$) in the number of runs in which near collisions and collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Investigation was performed on the test runs that resulted in collision for the truth data condition. It was determined that for these test runs, WAs were generated; however, by the time the pilot reaction delay (2 seconds) was over, the aircraft was projected to stop closer than 100 ft from the intersecting taxiway centerline. As a result, the aircraft continued taxi and a collision occurred.

Table 83. Number/Percentage of Near Collisions (NC) and Collisions (C) Using ATCAM for Equipage Combinations for Taxi Intersection Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	532	266, 50.0	231, 43.4	156, 29.3	107, 20.1	168, 31.6	126, 23.7	123, 23.1	90, 16.9
9	456	228, 50.0	198, 43.4	130, 28.5	89, 19.5	120, 26.3	77, 16.9	49, 10.8	20, 4.4
10	304	152, 50.0	132, 43.4	90, 29.6	57, 18.8	66, 21.7	42, 13.8	16, 5.3	3, 1.0
11	228	114, 50.0	99, 43.4	67, 29.4	42, 18.4	46, 20.2	32, 14.0	5, 2.2	0, 0.0
Truth	76	38, 50.0	33, 43.4	23, 30.3	14, 18.4	15, 19.7	10, 13.2	2, 2.6	0, 0.0

5.1.11 Taxi Scenario – Taxi Head-On

For each of the 20 cases in this scenario, an initiation delay on either Aircraft A or B was evaluated at 13 levels, for a total of 1,092 test runs.

Algorithm performance – CAs were generated for 84% to 100% of the test runs for Aircraft A and for 84% to 96% of the test runs for Aircraft B (Table 84). WAs were generated for 85% to 95% of the runs for both aircraft. A lower alert rate occurred when transmitting data with NACp 8 accuracy. For both aircraft, there was a significant difference in the number of runs in which CAs ($p < 0.001$) and WAs (Aircraft A: $p = 0.016$; Aircraft B: $p < 0.001$) were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

On 44 of the 52 test runs that used truth position accuracy, CAs occurred when the aircraft were a mean distance of 1027 ft apart (10.8 ft standard deviation) and WAs occurred when a mean distance of 635 ft apart (21.7 ft standard deviation). For the four test runs in which Aircraft A was located 3,100 ft from Taxiway T1 when Aircraft B began to taxi, the alert timing for the aircraft were different. For Aircraft A, a CA was issued when the aircraft were a mean distance of 679 ft apart (0.7 ft standard deviation) and a WA was issued when 424 ft apart (0.0 ft standard deviation). For Aircraft B, a CA was issued when the aircraft were a mean distance of 667 ft apart (22.2 ft standard deviation) and a WA was issued when a mean distance of 388 ft apart (0.4 ft standard deviation). For the four test runs in which Aircraft A was located 1,500 ft from Taxiway T1 when Aircraft B began to taxi, only a CA was issued onboard Aircraft A when 391 ft (0.0 ft standard deviation) from Aircraft B. No alerts were issued on Aircraft B for these four runs.

Table 84. ATCAM Alert Statistics for All Evasive Actions by NACp for Taxi Head-On Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A					
8	364	305, 83.8	74, 20.3	317, 87.1	113, 31.0
9	312	296, 94.9	10, 3.2	294, 94.2	51, 16.4
10	208	195, 93.8	3, 1.4	193, 92.8	29, 13.9
11	156	147, 94.2	2, 1.3	144, 92.3	24, 15.4
Truth	52	52, 100.0	1, 1.9	48, 92.3	12, 23.1
Aircraft B					
8	364	304, 83.5	84, 23.1	309, 84.9	118, 32.4
9	312	297, 95.2	26, 8.3	295, 94.5	48, 15.4
10	208	199, 95.7	5, 2.4	192, 92.3	23, 11.1
11	156	145, 93.0	2, 1.3	144, 92.3	20, 12.8
Truth	52	48, 92.3	0, 0.0	48, 92.3	12, 23.1

As the position accuracy was reduced, CA toggling occurred more frequently, especially when transmitting data with NACp 8 accuracy (Table 84). WA toggling occurred most frequently when transmitting data with NACp 8 accuracy and least frequently when transmitting data with NACp 10 accuracy. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which CAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies and WAs were generated between NACp 8 and truth accuracies vs. NACp 9, 10, and 11 accuracies.

When analyzing the multiple alerts that occurred when transmitting truth position data, the multiple CA occurred on a test run where Both aircraft were equipped with CD&R and both aircraft had braked and began exiting the runway. For each test run in which multiple WAs occurred, either Aircraft A or Aircraft B was equipped with CD&R and a multiple WA occurred for each aircraft after the equipped aircraft conducted accelerated braking and stopped. On the majority of the test runs that contained multiple WAs in which NACp 9 to 11 position accuracy was used, each run only contained a multiple WA for either Aircraft A or Aircraft B but not both, which resulted in less multiple WAs per aircraft than when transmitting truth position data.

Analyzing the data based on equipage level (Table 85) shows alerts were issued on approximately 91% of the runs for both aircraft for all equipage levels. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 0.975$) and WAs ($p = 0.844$) were generated between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which CAs ($p= 0.884$) and WAs ($p = 0.952$) were generated between equipage levels.

The rate of CA toggling was highest when Both aircraft were equipped with CD&R (Table 85). The rate of WA toggling was high for all equipage levels but was lowest when Neither aircraft were equipped. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which multiple CAs were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped and when multiple WAs were generated between Aircraft A equipped vs. Neither aircraft, Aircraft B, and Both aircraft equipped. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which multiple CAs were generated between Both aircraft equipped vs. Neither aircraft, Aircraft A, and Aircraft B equipped and when multiple WAs were generated between Aircraft B equipped vs. Neither aircraft, Aircraft A, and Both aircraft equipped.

Table 85. ATCAM Alert Statistics for All NACp by Evasive Action for Taxi Head-On Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A					
Neither	273	247, 90.5	11, 4.0	252, 92.3	15, 5.5
Aircraft A	273	249, 91.2	13, 4.8	246, 90.1	124, 45.4
Aircraft B	273	249, 91.2	26, 9.5	249, 91.2	46, 16.9
Both	273	250, 91.6	40, 14.7	249, 91.2	44, 16.1
Aircraft B					
Neither	273	251, 91.9	14, 5.1	247, 90.5	14, 5.1
Aircraft A	273	247, 90.5	24, 8.8	245, 89.7	45, 16.5
Aircraft B	273	249, 91.2	16, 5.9	247, 90.5	110, 40.3
Both	273	246, 90.1	63, 23.1	249, 91.2	52, 19.1

Alert statistics were also compiled by CD&R equipage level when truth position data was transmitted (Table 86). The alert generation rate was slightly higher than when transmitting data with various accuracy levels (Table 85). The multiple CA rate was much lower when transmitting accurate data. The multiple WA rate was lower when transmitting accurate data but was still very high. For both aircraft, there was no significant difference in the number of runs in which CAs ($p= 0.998$), WAs (Aircraft A: $p= 0.666$; Aircraft B: $p= 0.562$), and multiple CAs (Aircraft A: $p = 0.5$; Aircraft B: $p = 0.25$) were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs were generated between Neither aircraft and Both aircraft equipped vs. Aircraft A and Aircraft B equipped.

Table 86. ATCAM Alert Statistics When Transmitting Truth Position Data for Taxi Head-On Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A					
Neither	273	253, 92.7	0, 0.0	256, 93.8	0, 0.0
Aircraft A	273	252, 92.3	0, 0.0	253, 92.7	113, 41.4
Aircraft B	273	252, 92.3	1, 0.4	255, 93.4	72, 26.4
Both	273	252, 92.3	1, 0.4	249, 91.2	4, 1.5
Aircraft B					
Neither	273	252, 92.3	0, 0.0	256, 93.8	0, 0.0
Aircraft A	273	252, 92.3	0, 0.0	253, 92.7	106, 38.8
Aircraft B	273	251, 91.9	1, 0.4	255, 93.4	88, 32.2
Both	273	252, 92.3	0, 0.0	248, 90.8	3, 1.1

Missed and nuisance alerts – The highest rate of entering the missed boundary occurred when transmitting data with NACp 8 and 9 position accuracies, as shown in Table 87. The number of times (count) and amount of time (duration and percentage of run length) that the aircraft were within the missed boundary was greater when transmitting less accurate data (Table 87). This was particularly true when transmitting data with NACp 8 accuracy. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs that the aircraft entered the missed boundary between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies.

Table 87. ATCAM Missed and Nuisance Boundary Statistics for Taxi Head-On Scenario.

	Entered Missed Boundary				Entered Nuisance Boundary			
NACp	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A								
8	337, 92.6	35.6, 22.0	97.1, 61.2	34.6	1, 0.3	3.0, 0.0	13.5, 0.0	4.7
9	234, 75.0	9.6, 7.3	14.9, 15.9	5.3	1, 0.3	2.0, 0.0	1.3, 0.0	0.4
10	0, 0.0	0, 0.0	0, 0.0	0.0	1, 0.5	1.0, 0.0	0.5, 0.0	0.2
11	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Aircraft B								
8	364, 100.0	60.0, 13.2	167.3, 43.9	57.0	22, 6.0	2.1, 1.1	5.7, 4.2	1.7
9	308, 98.7	12.2, 7.6	18.2, 15.2	6.2	24, 7.7	2.5, 2.2	5.4, 5.0	1.5
10	17, 8.2	2.2, 1.6	2.7, 2.6	0.8	19, 9.1	2.0, 1.0	4.2, 3.9	1.2
11	15, 9.6	2.4, 1.6	1.4, 1.6	0.4	10, 6.4	2.6, 1.4	1.4, 1.0	0.4
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0

The aircraft entered the nuisance boundary for a very small percentage runs for Aircraft A. For Aircraft B, the aircraft entered the nuisance boundary on 9% or less of the runs. There was no significant difference in the number of runs that the aircraft entered the nuisance boundary between equipage levels for Aircraft A ($p = 1.0$) and Aircraft B ($p = 0.180$).

As with previous scenarios, the high rate of entering the missed boundary was due to the missed boundary definition. There was no buffer between when the aircraft was inside or outside the missed boundary; therefore, a very small difference between the true and detected position caused a missed boundary to be counted. Since the aircraft's true taxi path was along the taxiway centerline, it was only possible to enter the nuisance boundary when exiting the taxiway. For this scenario, it was possible for either aircraft to exit the taxiway after taking action to avoid a collision if equipped with CD&R. Aircraft

B would also exit the taxiway after crossing Taxiway M and Runway 10 as part of its standard taxi operation.

Missed CAs only occurred when transmitting data with NACp 8 and 9 position accuracies, while missed WAs occurred for all position accuracies except truth, as shown in Table 88. The rate of missed alerts was similar for both aircraft since the aircraft conducted identical operations, traveling along a taxiway. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which missed CAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. There was no significant difference in the number of runs in which missed WAs occurred between accuracy levels for Aircraft A ($p = 0.084$) and Aircraft B ($p = 0.049$).

There were no nuisance alerts for Aircraft A and only minimal nuisance alerting for Aircraft B (with NACp 8 accuracy only) that occurred when exiting the taxiway. There was no significant difference in the number of runs in which nuisance CAs ($p = 0.037$) and nuisance WAs ($p = 0.111$) occurred between accuracy levels.

Table 88. ATCAM Missed and Nuisance Alert Statistics for All Evasive Actions by NACp for Taxi Head-On Scenario.

NACp	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A					
8	364	44, 12.1	43, 11.8	0, 0.0	0, 0.0
9	312	1, 0.3	30, 9.6	0, 0.0	0, 0.0
10	208	0, 0.0	20, 9.6	0, 0.0	0, 0.0
11	156	0, 0.0	12, 7.7	0, 0.0	0, 0.0
Truth	52	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B					
8	364	46, 12.6	51, 14.0	3, 0.8	2, 0.6
9	312	1, 0.3	35, 11.2	0, 0.0	0, 0.0
10	208	0, 0.0	29, 13.9	0, 0.0	0, 0.0
11	156	0, 0.0	17, 10.9	0, 0.0	0, 0.0
Truth	52	0, 0.0	0, 0.0	0, 0.0	0, 0.0

Table 89. ATCAM Missed and Nuisance Alert Statistics for All NACp by Evasive Action for Taxi Head-On Scenario.

CD&R Equipage	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A					
Neither	273	13, 4.8	8, 2.9	0, 0.0	0, 0.0
Aircraft A	273	12, 4.4	18, 6.6	0, 0.0	0, 0.0
Aircraft B	273	11, 4.0	67, 24.5	0, 0.0	0, 0.0
Both	273	9, 3.3	12, 4.4	0, 0.0	0, 0.0
Aircraft B					
Neither	273	8, 2.9	13, 4.8	0, 0.0	0, 0.0
Aircraft A	273	15, 5.5	95, 34.8	0, 0.0	0, 0.0
Aircraft B	273	10, 3.7	13, 4.8	1, 0.4	1, 0.4
Both	273	14, 5.1	11, 4.0	2, 0.7	1, 0.4

Analyzing the data based on equipage level (Table 89) shows that, the missed CA rate was similar across equipage levels. The missed WA rate was much higher onboard Aircraft A when only Aircraft B was equipped with CD&R and onboard Aircraft B when only Aircraft A was equipped. There was no significant difference in the number of runs in which missed CAs occurred between equipage levels for

Aircraft A ($p = 0.847$) and Aircraft B ($p = 0.405$). For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which missed WAs occurred between Aircraft B equipped vs. Neither aircraft, Aircraft A, and Both aircraft equipped. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which missed WAs occurred between Aircraft A equipped vs. Neither aircraft, Aircraft B, and Both aircraft equipped.

The nuisance alerts for Aircraft B occurred when only Aircraft B or when Both aircraft were equipped. There was no significant difference in the number of runs in which nuisance CAs ($p = 0.156$) and nuisance WAs ($p = 0.50$) occurred between equipage levels.

Unnecessary maneuvering - The percentage of test runs in which the aircraft maneuvered unnecessarily when transmitting data with the various data accuracy levels is shown in Table 90. Unnecessary maneuvers only occurred when transmitting data with NACp 8 and 9 accuracies. With NACp 8, approximately 6% to 9% of the maneuvers were unnecessary. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which unnecessary maneuvers occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 90. Unnecessary Maneuvers for All Evasive Actions by NACp Using ATCAM During Taxi Head-On Scenario.

NACp	Total # Runs	Aircraft A (# Runs, % Runs)	Aircraft B (# Runs, % Runs)
8	182	10, 5.5	16, 8.8
9	156	1, 0.6	1, 0.6
10	104	0, 0.0	0, 0.0
11	78	0, 0.0	0, 0.0
Truth	26	0, 0.0	0, 0.0

The number and percentage of test runs in which the aircraft maneuvered unnecessarily based on the CD&R equipage level is shown in Table 91. There was no significant difference in the number of runs in which unnecessary maneuvers occurred between equipage levels for Aircraft A ($p = 0.068$) and Aircraft B ($p = 0.139$).

Table 91. Unnecessary Maneuvers for All NACp by Evasive Action Using ATCAM During Taxi Head-On Scenario.

CD&R Equipage	Total # Runs	Aircraft A (# Runs, % Runs)	Aircraft B (# Runs, % Runs)
Neither	273	N/A	N/A
Aircraft A	273	2, 0.7	N/A
Aircraft B	273	N/A	5, 1.8
Both	273	9, 3.3	12, 4.4

Collision avoidance – For this scenario, CD&R equipage was not extremely effective for collision avoidance, as shown in Table 92. The rate of near collisions and collisions was approximately 93% over all position accuracy levels when Neither aircraft or only one aircraft (either A or B) was equipped with CD&R capability. Therefore, there was no significant difference in the number of runs in which near collisions or collisions occurred between accuracy levels:

- Neither aircraft equipped: near collisions ($p = 0.831$) and collisions ($p = 1.0$),
- Aircraft A equipped: near collisions ($p = 1.0$) and collisions ($p = 0.937$), and
- Aircraft B equipped: near collisions ($p = 0.625$) and collisions ($p = 0.937$).

When Both aircraft were equipped, the rate of near collisions ranged from 23% to 47% and the rate of collisions ranged from 0% to 34%, depending on the position accuracy level. There was a significant

difference in the number of runs in which near collisions ($p = 0.012$) and collisions ($p < 0.001$) occurred between NACp 8 accuracy vs. NACp 9, 10, 11, and truth accuracies.

The rate of near collisions and collisions was similar when Neither aircraft or one aircraft was equipped with CD&R capability because a collision is inevitable if neither or only one aircraft stops when in a head-on situation. When Both aircraft were equipped with CD&R capability and transmitting data with NACp 9, 10, and 11 position accuracies, on 83% (10 of 12) of the runs the WA occurred when Aircraft A was turning onto Taxiway T and the collision occurred just after the aircraft turned onto the taxiway. On the other 17% (2 of 12) of the runs, the collisions occurred when Aircraft B had stopped on the taxiway and Aircraft A was exiting the taxiway.

Table 92. Number/Percentage Of Near Collisions (NC) and Collisions (C) Using ATCAM for Equipage Combinations for Taxi Head-On Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	91	85, 93.4	84, 92.3	84, 92.3	83, 91.2	84, 92.3	83, 91.2	43, 47.3	31, 34.1
9	78	74, 94.9	72, 92.3	72, 92.3	72, 92.3	74, 94.9	72, 92.3	21, 26.9	7, 9.0
10	52	49, 94.2	48, 92.3	48, 92.3	48, 92.3	48, 92.3	48, 92.3	14, 26.9	3, 5.8
11	39	36, 92.3	36, 92.3	36, 92.3	36, 92.3	36, 92.3	36, 92.3	9, 23.1	2, 5.1
Truth	13	12, 92.3	12, 92.3	12, 92.3	12, 92.3	12, 92.3	12, 92.3	3, 23.1	0, 0.0

5.1.12 Air-To-Air Scenario – Arrival with Crossing Airborne Traffic

For each of the 20 cases in this scenario, 1,372 combinations of the initiation delay and initial location for Aircraft B (crossing airborne aircraft) were evaluated, for a total of 115,248 test runs.

Algorithm performance – CAs were generated on 22% to 28% of test runs (Table 93). WAs were generated on approximately 20% of the test runs for both aircraft, almost independent of the NACp levels. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which CAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft A, there was no significant difference ($p = 0.926$) in the number of runs in which WAs generated. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 93. ATCAM Alert Statistics for All Evasive Actions by NACp for Arrival with Crossing Airborne Traffic Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
8	38,416	10,890, 28.4	1,668, 4.3	7,606, 19.8	339, 0.9
9	32,928	8,073, 24.5	569, 1.7	6,292, 19.1	173, 0.5
10	21,952	5,310, 24.2	250, 1.1	4,198, 19.1	113, 0.5
11	16,464	3,980, 24.2	187, 1.1	3,150, 19.1	84, 0.5
Truth	5,488	1,327, 24.2	63, 1.1	1,048, 19.1	28, 0.5
Aircraft B (Crossing airborne)					
8	38,416	9,837, 25.6	1,413, 3.7	7,151, 18.6	285, 0.7
9	32,928	7,378, 22.4	504, 1.5	6,410, 19.5	179, 0.5
10	21,952	4,811, 21.9	259, 1.2	4,297, 19.6	108, 0.5
11	16,464	3,603, 21.9	189, 1.1	3,223, 19.6	82, 0.5
Truth	5,488	1,197, 21.8	65, 1.2	1,073, 19.6	28, 0.5

When analyzing alerts that occurred when transmitting truth position data, for approach Aircraft A, CAs were issued onboard when approximately 3.9 NM to 230 ft prior to the runway threshold and 1,270 ft to 50 ft AGL; approximately 988 ft to 8,886 ft slant range distance from the crossing airborne traffic

(Aircraft B) depending on the test run conditions. WAs were issued onboard when approximately 3.8 NM to 230 ft prior to the runway threshold and 1,270 ft to 50 ft AGL; approximately 260 ft to 5,940 ft slant range distance from the crossing airborne traffic depending on the test run conditions. As defined previously, Aircraft B flew perpendicular across Aircraft A's path at seven different altitudes (100, 250, 400, 550, 700, 850, and 1,000 ft AFE). When Aircraft B was at 1,000 ft AFE, CAs were issued when the aircraft was approximately 4,745 ft from the extended runway centerline until approximately 772 ft past the extended centerline. For all other altitude levels, CAs were issued when the aircraft was approximately 4,060 ft from the extended centerline until approximately 730 ft past the extended centerline. For all altitude levels, WAs were issued when the aircraft was approximately 2,675 ft from the extended centerline until 334 ft to 1,146 ft past the extended centerline, depending on the test run conditions.

The rate of alert toggling was low for this scenario (Table 93), but was slightly higher when transmitting data with NACp 8 accuracy. Position accuracy had minimal effect on the occurrence of multiple WAs. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which multiple CAs and multiple WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The alert toggling included gaps between alerts for the lower position accuracy levels (NACp 8 and 9). For both aircraft, multiple alerts were generated when truth position data was transmitted. In most cases, these multiple alerts were generated after Aircraft B had crossed the extended runway centerline. On test runs in which Aircraft B were to take action, these multiple alerts were issued after the aircraft had begun a climb maneuver and was at a higher altitude than the approach aircraft, which was still descending. In these situations, alerts are not necessary since the potential collision threat has passed.

Analyzing by CD&R equipage level (Table 94), CAs were issued on approximately 26% of the runs for Aircraft A and on approximately 23% of the runs for Aircraft B for all equipage levels. WAs were generated on approximately 19% of the runs for all equipage levels for both aircraft. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 0.925$) and WAs ($p = 0.986$) were generated between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which CAs ($p = 0.956$) and WAs ($p = 0.996$) were generated between equipage levels.

The rate of CA toggling was similar across all equipage levels (Table 94). The rate of WA toggling was slightly higher when Neither aircraft and Aircraft A were equipped with CD&R. There was no significant difference in the number of runs in which multiple CAs were generated between equipage levels for Aircraft A ($p = 0.503$) and Aircraft B ($p = 0.321$). There was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped.

Table 94. ATCAM Alert Statistics for All NACp by Evasive Action for Arrival with Crossing Airborne Traffic Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	28,812	7,355, 25.5	680, 2.4	5,569, 19.3	234, 0.8
Aircraft A	28,812	7,418, 25.8	664, 2.3	5,592, 19.4	215, 0.8
Aircraft B	28,812	7,416, 25.7	717, 2.5	5,576, 19.4	145, 0.5
Both	28,812	7,391, 25.6	676, 2.4	5,557, 19.3	143, 0.5
Aircraft B (Crossing airborne)					
Neither	28,812	6,681, 23.2	613, 2.1	5,525, 19.2	207, 0.7
Aircraft A	28,812	6,721, 23.3	593, 2.1	5,545, 19.2	195, 0.7
Aircraft B	28,812	6,731, 23.4	642, 2.2	5,544, 19.2	137, 0.5
Both	28,812	6,693, 23.2	582, 2.0	5,540, 19.2	143, 0.5

The rates of alerts and multiple alerts across equipage levels when truth position data was transmitted (Table 95) was similar to the rates across equipage levels when transmitting data with various position accuracy levels (Table 94). CAs were issued on approximately 24% of the runs for Aircraft A and on

approximately 22% of the runs for Aircraft B for all equipage levels. WAs were generated on approximately 19% of the runs for both aircraft for all equipage levels. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 0.998$), WAs ($p = 0.950$), and multiple CAs ($p = 0.983$) were generated between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which CAs ($p = 0.999$), WAs ($p = 0.955$), and multiple CAs ($p = 0.923$) were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped.

Table 95. ATCAM Alert Statistics When Transmitting Truth Position Data for Arrival with Crossing Airborne Traffic Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	28,812	6,971, 24.2	333, 1.2	5,502, 19.1	189, 0.7
Aircraft A	28,812	6,964, 24.2	331, 1.1	5,518, 19.1	170, 0.6
Aircraft B	28,812	6,983, 24.2	333, 1.2	5,479, 19.0	98, 0.3
Both	28,812	6,981, 24.2	324, 1.1	5,467, 19.0	101, 0.4
Aircraft B (Crossing airborne)					
Neither	28,812	6,285, 21.8	337, 1.2	5,628, 19.5	189, 0.7
Aircraft A	28,812	6,294, 21.9	324, 1.1	5,643, 19.6	172, 0.6
Aircraft B	28,812	6,299, 21.9	337, 1.2	5,605, 19.4	99, 0.3
Both	28,812	6,301, 21.9	325, 1.1	5,594, 19.4	101, 0.4

Missed and nuisance alerts – The number of runs in which the aircraft entered the defined missed and nuisance boundaries increased as the position accuracy decreased, as shown in Table 96. The number of times (count) and amount of time (duration and percentage of run length) that the aircraft were within the boundaries was greater when transmitting less accurate data. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. Aircraft A did not enter the nuisance boundary since the aircraft tracked the extended centerline on approach. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary and entered the nuisance boundary between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies.

Table 96. ATCAM Missed and Nuisance Boundary Statistics for Arrival with Crossing Airborne Traffic Scenario.

NACp	Entered Missed Boundary				Entered Nuisance Boundary			
	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Arrival)								
8	2,635, 6.9	2.1, 1.4	3.0, 2.9	5.9	0, 0.0	0, 0.0	0, 0.0	0.0
9	9, 0.0	1.3, 0.5	0.7, 0.6	1.8	0, 0.0	0, 0.0	0, 0.0	0.0
10	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
11	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Aircraft B (Crossing airborne)								
8	9,727, 25.3	1.2, 0.4	1.2, 0.8	2.5	9,759, 25.4	1.2, 0.4	1.2, 0.8	2.6
9	7,110, 21.6	1.1, 0.3	0.5, 0.2	1.0	7,171, 21.8	1.1, 0.3	0.5, 0.2	1.0
10	2,927, 13.3	1.0, 0.2	0.3, 0.1	0.5	2,932, 13.4	1.0, 0.2	0.2, 0.1	0.5
11	784, 4.8	1.0, 0.1	0.2, 0.0	0.5	719, 4.4	1.0, 0.1	0.2, 0.0	0.5
Truth	0, 0.0	0, 0.0	0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0

For the approach Aircraft A, the majority of occurrences of entering the missed boundary was after the aircraft had crossed the runway threshold for landing. The aircraft only entered the missed boundary while on approach before crossing the runway threshold during 0.4% of the test runs when transmitting data with NACp 8 accuracy.

The crossing airborne Aircraft B entered the missed and nuisance boundaries for accuracy levels of NACp 8 to 11 due to the criteria for entering the boundaries. The aircraft was counted as entering the missed boundary when the true position of the aircraft was determined to be within the bounds of the approach corridor (Figure 19), but the detected position was outside of the approach corridor. Similarly, the aircraft was counted as entering the nuisance boundary when the true aircraft position was outside of the approach corridor, but the detected position was within the approach corridor. As such, there was no buffer between when the aircraft was inside or outside the boundaries so a measurable difference between the true and detected position could cause a missed or nuisance boundary to be counted.

The percentage of test runs that contained missed and nuisance alerts was low, as shown in Table 97. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which missed CAs occurred between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies and missed WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which nuisance CAs and nuisance WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. No nuisance alerts occurred for Aircraft A.

Both aircraft did, however, experience missed CAs when transmitting truth position data. For Aircraft A, the CAs should have occurred when the crossing airborne traffic was at a higher altitude (two at 400 ft AGL, one at 850 ft AGL) than the arrival aircraft (two at 160 ft AGL, one at 50 ft AGL). For Aircraft B, the CA should have occurred near the beginning of the test run when Aircraft A was at 445 AGL on approach and the crossing aircraft was at 700 AGL.

Table 97. ATCAM Missed and Nuisance Alert Statistics for All Evasive Actions by NACp for Arrival with Crossing Airborne Traffic Scenario.

NACp	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival)					
8	38,416	541, 1.4	498, 1.3	0, 0.0	0, 0.0
9	32,928	276, 0.8	118, 0.4	0, 0.0	0, 0.0
10	21,952	97, 0.4	9, 0.0	0, 0.0	0, 0.0
11	16,464	26, 0.2	0, 0.0	0, 0.0	0, 0.0
Truth	5,488	3, 0.1	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Crossing airborne)					
8	38,416	501, 1.3	678, 1.8	16, 0.0	151, 0.4
9	32,928	278, 0.8	140, 0.4	0, 0.0	44, 0.1
10	21,952	113, 0.5	14, 0.1	0, 0.0	2, 0.0
11	16,464	25, 0.2	2, 0.0	0, 0.0	0, 0.0
Truth	5,488	1, 0.0	0, 0.0	0, 0.0	0, 0.0

Analyzing the data based on equipage level (Table 98) shows that, missed and nuisance alerts occurred for less than 1% of the runs for all CD&R equipage levels for both aircraft and also at similar rates per aircraft. For Aircraft A, there was no significant difference in the number of runs in which missed CAs ($p = 0.641$) and missed WAs ($p = 0.808$) occurred between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which missed CAs ($p = 0.511$) and missed WAs ($p = 0.619$) occurred between equipage levels. For Aircraft B, there was no significant difference in the number of runs in which nuisance CAs ($p = 0.567$) and nuisance WAs ($p = 0.346$) occurred between equipage levels.

Table 98. ATCAM Missed and Nuisance Alert Statistics for All NACp by Evasive Action for Arrival with Crossing Airborne Traffic Scenario.

CD&R Equipage	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	28,812	250, 0.9	166, 0.6	0, 0.0	0, 0.0
Aircraft A	28,812	236, 0.8	151, 0.5	0, 0.0	0, 0.0
Aircraft B	28,812	222, 0.8	157, 0.5	0, 0.0	0, 0.0
Both	28,812	235, 0.8	151, 0.5	0, 0.0	0, 0.0
Aircraft B (Crossing airborne)					
Neither	28,812	240, 0.8	222, 0.8	3, 0.0	58, 0.2
Aircraft A	28,812	229, 0.8	207, 0.7	4, 0.0	49, 0.2
Aircraft B	28,812	211, 0.7	210, 0.7	5, 0.0	50, 0.2
Both	28,812	238, 0.8	195, 0.7	4, 0.0	40, 0.1

Unnecessary maneuvering - The percentage of test runs in which the aircraft maneuvered unnecessarily when transmitting data with the various data accuracy levels is shown in Table 99. The frequency of unnecessary maneuvering was low for this scenario and data accuracy had little effect, although the occurrence of unnecessary maneuvers was slightly higher when transmitting data with NACp 8 accuracy. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which unnecessary maneuvers occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 99. Unnecessary Maneuvers for All Evasive Actions by NACp Using ATCAM During Arrival With Crossing Airborne Traffic Scenario.

NACp	Total # Runs	Aircraft A (Arrival) (# Runs, % Runs)	Aircraft B (Crossing airborne) (# Runs, % Runs)
8	19,208	296, 1.5	287, 1.5
9	16,464	75, 0.5	101, 0.6
10	10,976	8, 0.1	20, 0.2
11	8,232	2, 0.0	4, 0.0
Truth	2,744	0, 0.0	0, 0.0

The number and percentage of test runs in which the aircraft maneuvered unnecessarily based on the CD&R equipage level is shown in Table 100. There was no significant difference in the number of runs in which unnecessary maneuvers occurred between equipage levels for Aircraft A ($p = 0.918$) and Aircraft B ($p = 0.805$).

Table 100. Unnecessary Maneuvers for All NACp by Evasive Action Using ATCAM During Arrival With Crossing Airborne Traffic Scenario.

CD&R Equipage	Total # Runs	Aircraft A (Arrival) (# Runs, % Runs)	Aircraft B (Crossing airborne) (# Runs, % Runs)
Neither	28,812	N/A	N/A
Aircraft A	28,812	189, 0.7	N/A
Aircraft B	28,812	N/A	203, 0.7
Both	28,812	192, 0.7	209, 0.7

Collision avoidance – Overall, the rate of collisions was low for this scenario. The most collisions were avoided when Both aircraft were equipped with CD&R, as shown in Table 101. Collision avoidance was more effective when the crossing aircraft (Aircraft B) was equipped versus the approach aircraft

(Aircraft A). The most collisions occurred when neither aircraft were equipped. For all CD&R equipage levels, there was no significant difference in the number of runs in which near collisions and collisions occurred between the position accuracy levels:

- Neither aircraft equipped: near collisions (p = 1.0) and collisions (p = 1.0),
- Aircraft A equipped: near collisions (p = 1.0) and collisions (p = 0.995),
- Aircraft B equipped: near collisions (p = 0.999) and collisions (p = 0.996), and
- Both aircraft equipped: near collisions (p = 0.999) and collisions (p = 0.969).

Table 101. Number/Percentage of Near Collisions (NC) and Collisions (C) Using ATCAM for Equipage Combinations for Arrival with Crossing Airborne Traffic Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	9,604	588, 6.1	126, 1.3	589, 6.1	97, 1.0	410, 4.3	32, 0.3	435, 4.5	17, 0.2
9	8,232	504, 6.1	108, 1.3	504, 6.1	78, 1.0	350, 4.2	30, 0.4	375, 4.6	18, 0.2
10	5,488	336, 6.1	72, 1.3	336, 6.1	53, 1.0	238, 4.3	20, 0.4	246, 4.5	12, 0.2
11	4,116	252, 6.1	54, 1.3	252, 6.1	40, 1.0	177, 4.3	15, 0.4	185, 4.5	9, 0.2
Truth	1,372	84, 6.1	18, 1.3	84, 6.1	13, 1.0	59, 4.3	5, 0.4	61, 4.5	3, 0.2

A more detailed investigation was conducted for the collisions that occurred when transmitting truth position data. The initial location of Aircraft A and Aircraft B for each run that resulted in a collision are indicated in Figures 28, 29, 30, and 31. For example, in Figure 28, a collision resulted when Aircraft A was on approach and 4.0 NM prior to the runway threshold when Aircraft B began to fly toward the extended runway centerline from a position 8,945 ft back from the runway centerline, in line with the runway threshold, and at 100 ft AGL. When Both aircraft were equipped with CD&R, three collisions occurred (Figure 31) near the runway threshold when Aircraft B was flying at 100 ft AGL. WAs were issued but too late for either aircraft to maneuver. Collisions occurred for these three run conditions for all equipage combinations when transmitting truth position data. Collisions occurred on 13 runs when only Aircraft A was equipped with CD&R. On three of the runs the collision occurred near the runway threshold as described above. On 10 of the runs, Aircraft A initiated a missed approach but the collision occurred at the aircraft's lowest altitude, before the aircraft began ascending. Collisions occurred on five runs when only Aircraft B was equipped. As with the other two equipage conditions, the collision occurred near the runway threshold on three of the runs. On the other two runs, WAs were issued approximately 20 seconds prior to the collision; however, the aircraft did not attempt to maneuver.

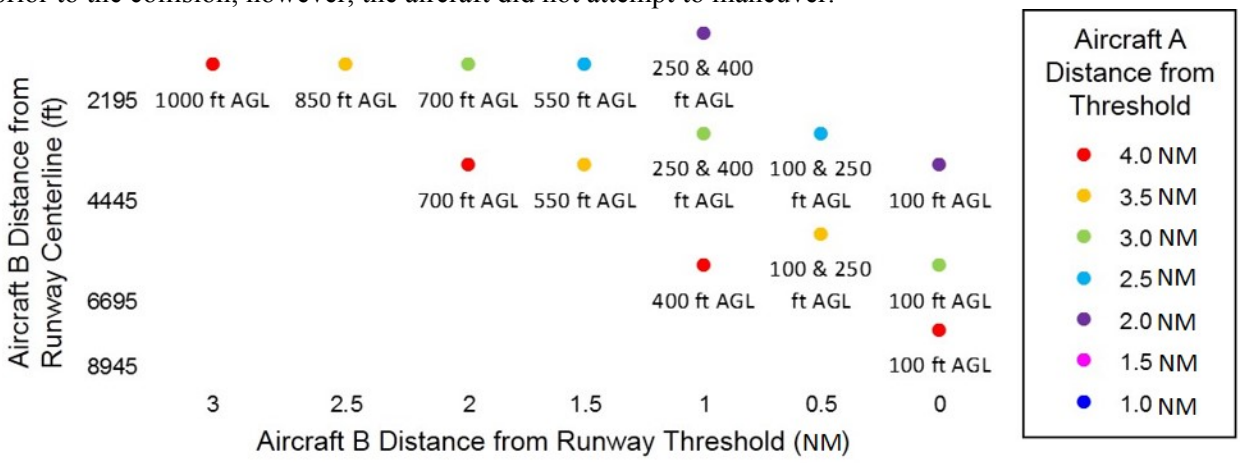

Figure 28. Aircraft Starting Locations for Collision Runs When Transmitting Truth Position Data When Neither Aircraft Maneuvers For Arrival with Crossing Airborne Traffic Scenario.

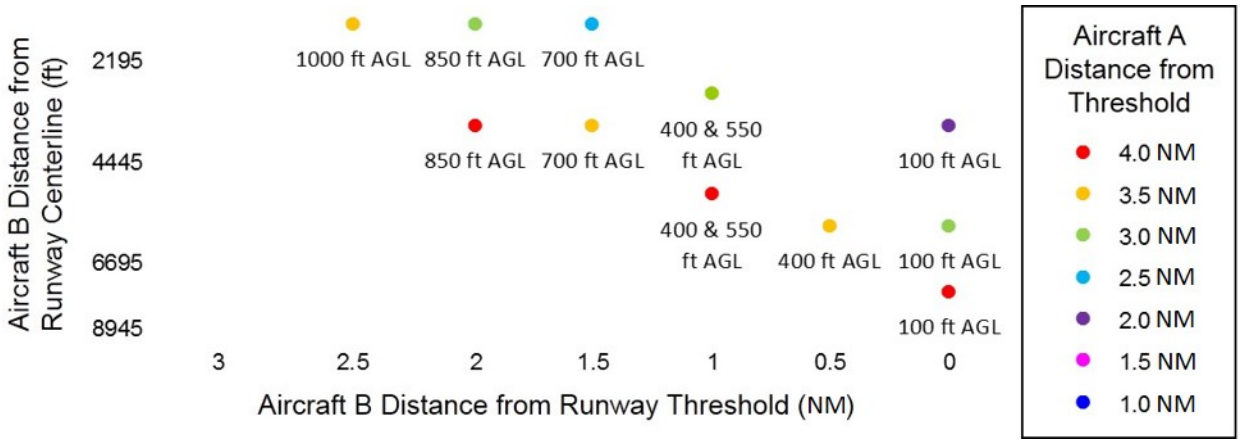

Figure 29. Aircraft Starting Locations for Collision Runs When Transmitting Truth Position Data When Only Aircraft A Maneuvers For Arrival with Crossing Airborne Traffic Scenario.

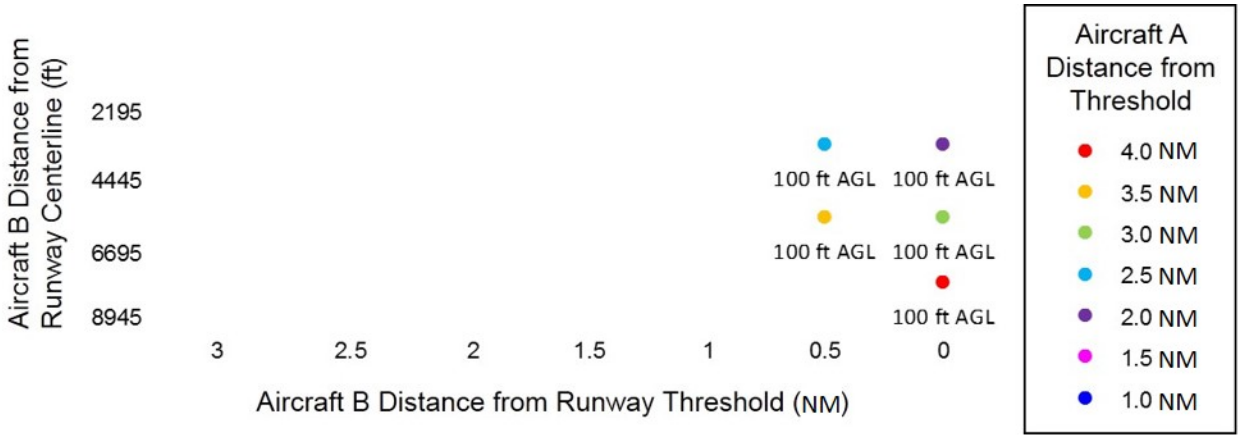

Figure 30. Aircraft Starting Locations for Collision Runs When Transmitting Truth Position Data When Only Aircraft B Maneuvers For Arrival with Crossing Airborne Traffic Scenario.

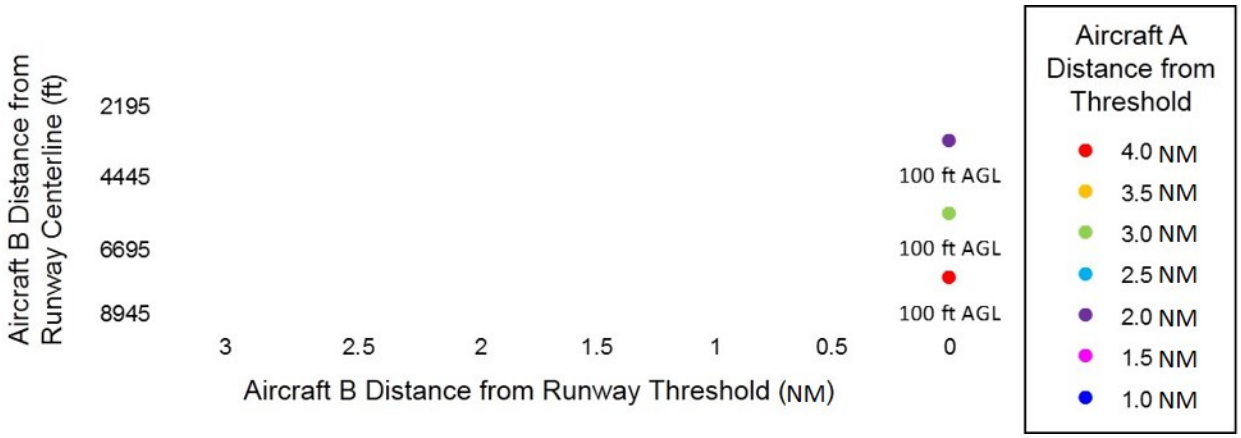

Figure 31. Aircraft Starting Locations For Collision Runs When Transmitting Truth Position Data When Both Aircraft Maneuver For Arrival With Crossing Airborne Traffic Scenario.

5.1.13 Air-To-Air Scenario – Departure Climb-Out with Crossing Airborne Traffic

For each of the 20 cases in this scenario, 1,029 combinations of the initiation delay and initial location for Aircraft B (crossing airborne aircraft) were evaluated, for a total of 86,436 test runs.

Algorithm performance – CAs were generated on approximately 49% of the test runs for Aircraft A (departure) and approximately 30% of the test runs for Aircraft B (airborne crossing), almost independent of the position levels (Table 102). WAs were generated on approximately 55% of the test runs for Aircraft A and 51% of the test runs for Aircraft B, almost independent of the position accuracy levels. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 0.188$) and WAs ($p = 0.044$) were generated between accuracy levels. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which CAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. There was no significant difference ($p = 0.959$) in the number of runs in which WAs were generated between accuracy levels.

When analyzing alerts that occurred when transmitting truth position data, for departure Aircraft A, CAs were issued onboard when approximately 5,650 ft to 1.7 NM down the runway from the threshold and 14 ft to 836 ft AGL; from approximately 609 ft to 6,309 ft slant range distance from the crossing airborne traffic (Aircraft B) depending on the test run conditions. WAs were issued onboard when approximately 4,793 ft down the runway from the threshold and 166 kt, just about to liftoff, until approximately 1.6 NM down the runway from the threshold and 660 ft AGL; from approximately 248 ft to 6,007 ft slant range distance from the crossing airborne traffic depending on the test run conditions. As defined previously, Aircraft B crossed orthogonally to the flight path of Aircraft A at seven different altitudes (100, 250, 400, 550, 700, 850, and 1,000 ft AFE). For all altitude levels, CAs were issued when the aircraft was from approximately 2,850 ft from the runway centerline until approximately 1,430 ft past the centerline, depending on the test run conditions. WAs were issued when the aircraft was from approximately 2,300 ft from the centerline until 1,160 ft past the centerline, depending on the test run conditions.

Table 102. ATCAM Alert Statistics for All Evasive Actions by NACp for Departure Climb-Out with Crossing Airborne Traffic Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Departure)					
8	28,812	14,369, 49.9	1,115, 3.9	16,156, 56.1	52, 0.2
9	24,696	12,097, 49.0	1,027, 4.2	13,560, 54.9	5, 0.0
10	16,464	8,085, 49.1	741, 4.5	9,050, 55.0	0, 0.0
11	12,348	6,045, 49.0	564, 4.6	6,791, 55.0	0, 0.0
Truth	4,116	2,005, 48.7	184, 4.5	2,266, 55.0	0, 0.0
Aircraft B (Crossing airborne)					
8	28,812	9,088, 31.5	731, 2.5	14,804, 51.4	254, 0.9
9	24,696	7,511, 30.4	621, 2.5	12,755, 51.6	110, 0.4
10	16,464	4,940, 30.0	450, 2.7	8,514, 51.7	1, 0.0
11	12,348	3,683, 29.8	336, 2.7	6,376, 51.6	0, 0.0
Truth	4,116	1,231, 29.9	113, 2.8	2,125, 51.6	0, 0.0

The rate of alert toggling was low for this scenario (Table 102). CA toggling occurred on less than 5% of the test runs for Aircraft A and on less than 3% of the test runs for Aircraft B, almost independent of the position accuracy levels. There was minimal WA toggling for both aircraft, mostly when transmitting data with NACp 8 accuracy. For Aircraft A, there was a significant difference in the number of runs in which multiple CAs ($p = 0.002$) were generated between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies and multiple WAs ($p < 0.001$) were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was no significant difference ($p = 0.499$) in the number of runs in which multiple CAs were generated between accuracy levels. There was a significant difference ($p < 0.001$) in

the number of runs in which multiple WAs were generated between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies.

For both aircraft, multiple CAs were generated when truth position data was transmitted. For Aircraft A, a CA was issued just after liftoff and a second CA was issued when the aircraft was approximately 200 ft to 845 ft AGL, 5 to 16 seconds after the first alert. For Aircraft B, on 85 of the test runs, a CA was issued when the aircraft was 2,567.9 ft mean distance (228.1 ft SD) from the runway centerline and a second CA was issued when 1,820.6 ft mean distance (22.0 ft SD) from the runway centerline. On 28 of the runs, a CA was issued when the aircraft was 544.4 ft mean distance (33.3 ft SD) past the runway centerline and a second CA was issued when 1,401.1 ft mean distance (21.0 ft SD) past the runway centerline. For these runs, an alert was not necessary since the potential collision threat had passed.

Analyzing the data based on equipage level (Table 103) shows that, CAs were issued on approximately 49% of the runs for Aircraft A and on approximately 30% of the runs for Aircraft B for all equipage levels. WAs were generated on approximately 55% of the runs for Aircraft A and 51% of the runs for Aircraft B for all equipage levels. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 0.993$) and WAs ($p = 0.988$) were generated between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which CAs ($p = 0.998$) and WAs ($p = 0.969$) were generated between equipage levels.

The rate of alert toggling was similar across all equipage levels for each aircraft (Table 103). For Aircraft A, there was no significant difference in the number of runs in which multiple CAs ($p = 0.941$) and multiple WAs ($p = 0.461$) were generated between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which multiple CAs ($p = 0.452$) and multiple WAs ($p = 0.460$) were generated between equipage levels.

Table 103. ATCAM Alert Statistics for All NACp by Evasive Action for Departure Climb-Out with Crossing Airborne Traffic Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Departure)					
Neither	21,609	10,637, 49.2	916, 4.2	11,969, 55.4	13, 0.1
Aircraft A	21,609	10,654, 49.3	898, 4.2	11,944, 55.3	18, 0.1
Aircraft B	21,609	10,666, 49.4	918, 4.2	11,941, 55.3	16, 0.1
Both	21,609	10,644, 49.3	899, 4.2	11,969, 55.4	10, 0.0
Aircraft B (Crossing airborne)					
Neither	21,609	6,603, 30.6	595, 2.8	11,165, 51.7	92, 0.4
Aircraft A	21,609	6,622, 30.6	555, 2.6	11,116, 51.4	100, 0.5
Aircraft B	21,609	6,614, 30.6	555, 2.6	11,139, 51.5	79, 0.4
Both	21,609	6,614, 30.6	546, 2.5	11,154, 51.6	94, 0.4

The rates of alerts and multiple alerts across equipage levels when truth position data was transmitted (Table 104) was similar to the rates across equipage levels when transmitting data with various position accuracy levels (Table 103). CAs were issued on approximately 48% of the runs for Aircraft A and on approximately 29% of the runs for Aircraft B for all equipage levels. WAs were generated on approximately 55% of the runs for Aircraft A and 51% of the runs for Aircraft B for all equipage levels. The rate of multiple CAs was similar to the rates when transmitting data with various position accuracy levels; however, there were no multiple WAs for either aircraft when transmitting truth position data. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 0.988$), WAs ($p = 1.0$), and multiple CAs ($p = 0.999$) were generated between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which CAs ($p = 1.0$), WAs ($p = 0.991$), and multiple CAs ($p = 0.998$) were generated between equipage levels.

Table 104. ATCAM Alert Statistics When Transmitting Truth Position Data for Departure Climb-Out with Crossing Airborne Traffic Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Departure)					
Neither	21,609	10,486, 48.5	979, 4.5	11,885, 55.0	0, 0.0
Aircraft A	21,609	10,503, 48.6	985, 4.6	11,879, 55.0	0, 0.0
Aircraft B	21,609	10,522, 48.7	982, 4.5	11,888, 55.0	0, 0.0
Both	21,609	10,494, 48.6	984, 4.5	11,883, 55.0	0, 0.0
Aircraft B (Crossing airborne)					
Neither	21,609	6,348, 29.4	582, 2.7	11,196, 51.8	0, 0.0
Aircraft A	21,609	6,349, 29.4	582, 2.7	11,176, 51.7	0, 0.0
Aircraft B	21,609	6,348, 29.4	588, 2.7	11,199, 51.8	0, 0.0
Both	21,609	6,350, 29.4	584, 2.7	11,171, 51.7	0, 0.0

Missed and nuisance alerts – The number of runs in which the aircraft entered the defined missed boundary and nuisance boundary (Aircraft B only) increased as the position accuracy decreased, as shown in Table 105. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary between NACp 8 vs. NACp 9, 10, 11 and truth accuracies. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary and nuisance boundary between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies.

Table 105. ATCAM Missed and Nuisance Boundary Statistics for Departure Climb-Out with Crossing Airborne Traffic Scenario.

NACp	Entered Missed Boundary				Entered Nuisance Boundary			
	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Departure)								
8	23,322, 81.0	4.2, 2.9	10.3, 9.7	28.8	0, 0.0	0.0, 0.0	0, 0.0	0.0
9	55, 0.2	2.0, 1.4	2.7, 3.9	7.1	0, 0.0	0.0, 0.0	0, 0.0	0.0
10	0, 0.0	0.0, 0.0	0, 0.0	0.0	0, 0.0	0.0, 0.0	0, 0.0	0.0
11	0, 0.0	0.0, 0.0	0, 0.0	0.0	0, 0.0	0.0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0, 0.0	0.0	0, 0.0	0.0, 0.0	0, 0.0	0.0
Aircraft B (Crossing airborne)								
8	15,177, 52.7	1.1, 0.3	1.2, 0.8	2.9	15,098, 52.4	1.1, 0.3	1.2, 0.8	2.9
9	10,966, 44.4	1.0, 0.2	0.5, 0.2	1.1	10,811, 43.8	1.0, 0.2	0.5, 0.2	1.1
10	4,178, 25.4	1.0, 0.1	0.3, 0.1	0.6	4,170, 25.3	1.0, 0.1	0.3, 0.1	0.7
11	995, 8.1	1.0, 0.0	0.3, 0.0	0.6	1,085, 8.8	1.0, 0.1	0.3, 0.0	0.6
Truth	0, 0.0	0.0, 0.0	0, 0.0	0.0	0, 0.0	0.0, 0.0	0, 0.0	0.0

The departing aircraft entered the missed boundary along its entire departure path. Since the aircraft tracked the runway centerline on departure and after liftoff, it was not possible for it to enter the nuisance boundary.

The crossing airborne Aircraft B entered the missed and nuisance boundaries for accuracy levels of NACp 8 to 11. This was due to the criteria for entering the boundaries. The aircraft was counted as entering the missed boundary when the true position of the aircraft was determined to be within the bounds of the approach corridor (Figure 19), but the detected position was outside of the approach corridor. Similarly, the aircraft was counted as entering the nuisance boundary when the true aircraft position was outside of the approach corridor, but the detected position was within the approach corridor. As such, there was no

buffer between when the aircraft was inside or outside the boundaries so a measurable difference between the true and detected position could cause a missed or nuisance boundary to be counted.

The rate of missed and nuisance alerts was relatively low, as shown in Table 106, but was highest when transmitting data with NACp 8 accuracy. There were no nuisance alerts for Aircraft A since the departing aircraft tracked the runway centerline. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which missed CAs and missed WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which nuisance CAs and nuisance WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 106. ATCAM Missed and Nuisance Alert Statistics for All Evasive Actions by NACp for Departure Climb-Out with Crossing Airborne Traffic Scenario.

NACp	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Departure)					
8	28,812	1,394, 4.8	552, 1.9	0, 0.0	0, 0.0
9	24,696	364, 1.5	76, 0.3	0, 0.0	0, 0.0
10	16,464	50, 0.3	4, 0.0	0, 0.0	0, 0.0
11	12,348	4, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	4,116	3, 0.1	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Crossing airborne)					
8	28,812	974, 3.4	718, 2.5	45, 0.2	498, 1.7
9	24,696	248, 1.0	134, 0.5	10, 0.0	211, 0.8
10	16,464	56, 0.3	28, 0.2	0, 0.0	61, 0.4
11	12,348	22, 0.2	19, 0.2	0, 0.0	20, 0.2
Truth	4,116	1, 0.0	7, 0.2	0, 0.0	0, 0.0

Both aircraft did, however, experience missed CAs when transmitting truth position data. For Aircraft A, the CAs should have occurred when the crossing airborne traffic was at a higher altitude (two at 850 ft AGL, one at 1,000 ft AGL) than the departing aircraft (361 ft, 576 ft, and 355 ft AGL respectively). For Aircraft B, the CA should have occurred when Aircraft A was at 108 AGL on departure and the crossing aircraft was at 850 AGL. All of these alerts would be necessary since the crossing traffic was further down the runway than the departing aircraft.

Table 107. ATCAM Missed and Nuisance Alert Statistics for All NACp by Evasive Action for Departure Climb-Out with Crossing Airborne Traffic Scenario.

CD&R Equipage	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Departure)					
Neither	21,609	450, 2.1	154, 0.7	0, 0.0	0, 0.0
Aircraft A	21,609	453, 2.1	166, 0.8	0, 0.0	0, 0.0
Aircraft B	21,609	441, 2.0	160, 0.7	0, 0.0	0, 0.0
Both	21,609	471, 2.2	152, 0.7	0, 0.0	0, 0.0
Aircraft B (Crossing airborne)					
Neither	21,609	313, 1.4	227, 1.1	21, 0.1	185, 0.9
Aircraft A	21,609	325, 1.5	239, 1.1	8 0.0	193, 0.9
Aircraft B	21,609	333, 1.5	228, 1.1	10, 0.0	189, 0.9
Both	21,609	330, 1.5	212, 1.0	16, 0.1	223, 1.0

Analyzing the data based on equipage level (Table 107) shows that, the rate of missed and nuisance alerts was similar for all CD&R equipage levels per aircraft. For Aircraft A, there was no significant

difference in the number of runs in which missed CAs (p = 0.785) and missed WAs (p = 0.858) occurred between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which missed CAs (p = 0.867) and missed WAs (p = 0.649) occurred between equipage levels. For Aircraft B, there was no significant difference in the number of runs in which nuisance CAs (p = 0.054) and nuisance WAs (p = 0.204) occurred between equipage levels.

Unnecessary maneuvering - The percentage of test runs in which the aircraft maneuvered unnecessarily when transmitting data with the various data accuracy levels is shown in Table 108. The frequency of unnecessary maneuvering was low for this scenario and data accuracy had little effect, although the occurrence of unnecessary maneuvers was slightly higher when transmitting data with NACp 8 accuracy. For both aircraft, there was a significant difference (p < 0.001) in the number of runs in which unnecessary maneuvers occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 108. Unnecessary Maneuvers for All Evasive Actions by NACp Using ATCAM During Departure Climb-Out With Crossing Airborne Traffic Scenario.

NACp	Total # Runs	Aircraft A (Departure) (# Runs, % Runs)	Aircraft B (Crossing Airborne) (# Runs, % Runs)
8	14,406	60, 0.4	207, 1.4
9	12,348	0, 0.0	23, 0.2
10	8,232	0, 0.0	1, 0.0
11	6,174	0, 0.0	1, 0.0
Truth	2,058	0, 0.0	0, 0.0

The number and percentage of test runs in which the aircraft maneuvered unnecessarily based on the CD&R equipage level is shown in Table 109. The rate of unnecessary maneuvers was the same for each equipage level for each aircraft There was no significant difference in the number of runs in which unnecessary maneuvers occurred between equipage levels for Aircraft A (p = 0.897) and Aircraft B (p = 0.948).

Table 109. Unnecessary Maneuvers for All NACp by Evasive Action Using ATCAM During Departure Climb-Out With Crossing Airborne Traffic Scenario.

CD&R Equipage	Total # Runs	Aircraft A (Departure) (# Runs, % Runs)	Aircraft B (Crossing airborne) (# Runs, % Runs)
Neither	21,609	N/A	N/A
Aircraft A	21,609	31, 0.1	N/A
Aircraft B	21,609	N/A	117, 0.5
Both	21,609	29, 0.1	115, 0.5

Collision avoidance – The rate of near collisions and the rate of collisions was similar across all CD&R system equipage and position accuracy levels, with slightly less collisions occurring when the departing aircraft (Aircraft A) was equipped, as shown in Table 110. For all CD&R equipage levels, there was no significant difference in the number of runs in which near collisions and collisions occurred between the position accuracy levels:

- Neither aircraft equipped: near collisions (p = 1.0) and collisions (p = 1.0),
- Aircraft A equipped: near collisions (p = 1.0) and collisions (p = 0.981),
- Aircraft B equipped: near collisions (p = 1.0) and collisions (p = 0.983), and
- Both aircraft equipped: near collisions (p = 0.995) and collisions (p = 0.882).

Table 110. Number/Percentage of Near Collisions (NC) and Collisions (C) Using ATCAM for Equipage Combinations for Departure Climb-Out with Crossing Airborne Traffic Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	7,203	1,400, 19.4	107, 1.5	1,351, 18.8	54, 0.8	1,394, 19.4	110, 1.5	1,237, 17.2	91, 1.3
9	6,174	1,206, 19.5	91, 1.5	1,165, 18.9	41, 0.7	1,194, 19.3	102, 1.6	1,050, 17.0	88, 1.4
10	4,116	802, 19.5	60, 1.5	775, 18.8	28, 0.7	795, 19.3	67, 1.6	697, 16.9	60, 1.5
11	3,087	601, 19.5	45, 1.5	580, 18.8	21, 0.7	594, 19.2	50, 1.6	522, 16.9	45, 1.5
Truth	1,029	201, 19.5	15, 1.5	192, 18.7	7, 0.7	200, 19.4	17, 1.6	173, 16.8	15, 1.5

A more detailed investigation was conducted for the collisions that occurred when transmitting truth position data. The initial location of Aircraft A and Aircraft B for each run that resulted in a collision are indicated in Figures 32, 33, 34, and 35. For example, in Figure 32, a collision occurred when Aircraft A was at the runway threshold initiating departure when Aircraft B began to fly toward the runway from a position of 4,800 ft back from the runway centerline, 11,000 ft from the runway threshold, and 1,000 ft AGL. There was seven collisions when only Aircraft A was equipped with CD&R. These collisions occurred between when Aircraft A had just lifted off (approximately 5,000 ft from the runway threshold) until it was approximately 450 ft AGL (9,000 ft from the runway threshold). For all runs in which Aircraft A was equipped with CD&R, the WA occurred when the aircraft was above the takeoff decision speed (131 kts); therefore, the departure was not aborted. When Aircraft B was equipped with CD&R, both aircraft were climbing for all collisions that occurred when Aircraft B was 10,000 ft or 11,000 ft from the runway threshold.

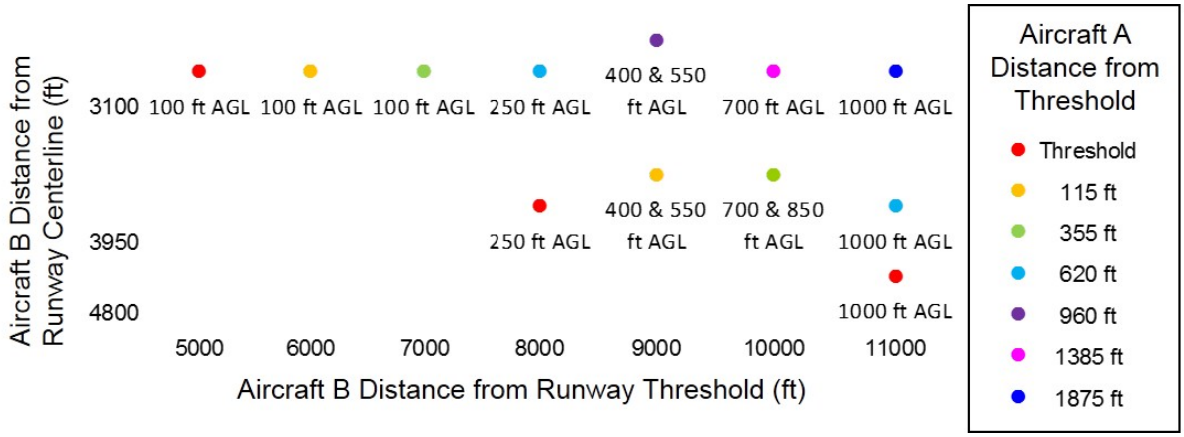

Figure 32. Aircraft Starting Locations for Collision Runs When Transmitting Truth Position Data When Neither Aircraft Maneuvers for Departure Climb-Out with Crossing Airborne Traffic Scenario.

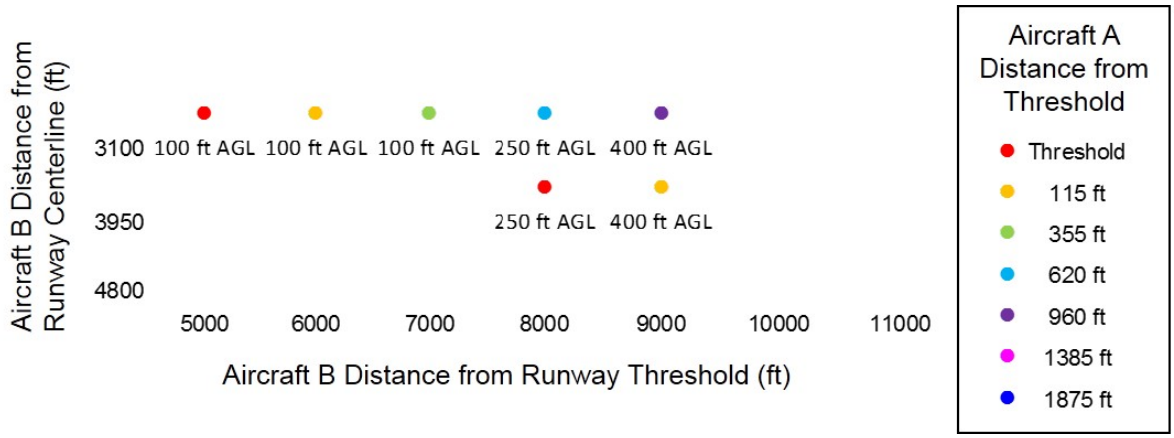

Figure 33. Aircraft Starting Locations for Collision Runs When Transmitting Truth Position Data When Only Aircraft A Maneuvers for Departure Climb-Out with Crossing Airborne Traffic Scenario.

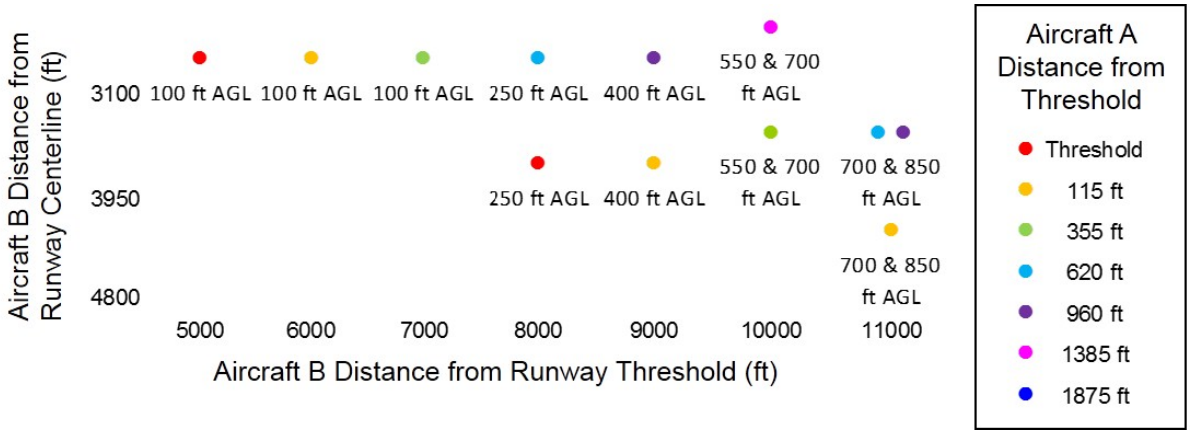

Figure 34. Aircraft Starting Locations for Collision Runs When Transmitting Truth Position Data When Only Aircraft B Maneuvers for Departure Climb-Out with Crossing Airborne Traffic Scenario.

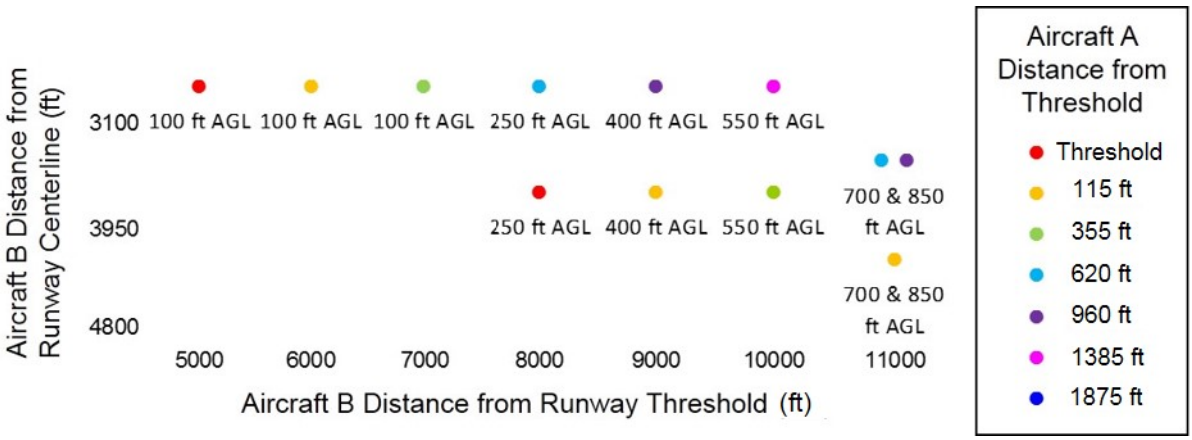

Figure 35. Aircraft Starting Locations for Collision Runs When Transmitting Truth Position Data When Both Aircraft Maneuver for Departure Climb-Out with Crossing Airborne Traffic Scenario.

5.2 SURF IA Algorithm Results

5.2.1 Position Data Analysis

An analysis was conducted to determine the difference between the true aircraft position and the detected aircraft position for each position accuracy category for all test runs conducted during the SURF IA algorithm evaluation (Table 111) in order to validate the surveillance simulation against the NACp 95% horizontal accuracy bounds specifications (Table 1). The prediction interval is an estimate of an interval in which future observations will fall, with a certain probability, given what has already been observed. The 95% prediction interval means there is a 95% probability that a future observation will be contained within the prediction interval. These values fall within the defined NACp 95% horizontal accuracy bounds.

Table 111. Position Data Analysis During SURF IA Evaluation.

NACp	Mean (ft)	Standard Deviation (ft)	95% Upper Prediction Interval (ft)
8	145.0	78.1	298.2
9	46.9	25.5	96.8
10	15.8	8.5	32.5
11	4.7	2.6	9.9

5.2.2 Runway Scenario – Arrival with Taxi Crossing

For each of the 20 cases in this scenario, 2,367 combinations of the initiation delay and initial position for Aircraft B (taxiing aircraft) were evaluated, for a total of 198,828 test runs.

The SURF IA algorithm issues indications in addition to alerts. Indications identify operational conditions that are generally normal, yet relevant for runway safety and could be a precursor to a non-normal situation (see Section 3.1.4). A traffic indication (TI) highlights a potential runway traffic collision/hazard that could emerge in the near future. TIs are intended to increase the flight crews' awareness of the relevant runway traffic. A runway status indication (RSI) identifies whether the runway that the ownship is approaching or using is in-use by other traffic and is not suitable for entering, takeoff, or landing.

Algorithm performance – For Aircraft A, TIs were generated on approximately 21% to 57% of the test runs and RSIs were issued on approximately 30% of runs (Table 112). For Aircraft B, TIs were generated on approximately 62% to 81% of runs and RSIs were issued on approximately 79% of runs. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which TIs and RSIs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was a significant difference in the number of runs in which TIs ($p < 0.001$) were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies and RSIs ($p = 0.004$) were generated between NACp 9 and 10 accuracies vs. NACp 8, 11, and truth accuracies.

For both aircraft, CAs were generated on approximately 24% of the runs and WAs were issued on approximately 37% of the runs, almost independent of the NACp levels (Table 113). For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which CAs and WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The location range of the approach Aircraft A and the taxi crossing Aircraft B when an indication or alert was issued when transmitting truth position data is presented in Table 114. Indications were issued when the approach aircraft was 2.8 NM to 1.2 NM prior to the runway threshold and alerts were issued when the aircraft was 1.2 NM to 184 ft prior to the runway threshold. For this study, the runway was 150 ft wide and the runway hold line was 225 ft from the runway centerline. Onboard the taxiing aircraft, indications were issued approximately 500 ft before reaching the runway centerline (275 ft before the runway hold line) and alerts were issued approximately 149 ft before reaching the centerline (76 ft after crossing the hold line). The data presented is in reference to the aircraft CG. The nose of the aircraft used in this simulation was 72.8 ft from the aircraft CG; therefore, the nose of the aircraft crossed the hold line

approximately 73 ft earlier than indicated. This means that an alert did not occur until the nose of the aircraft had reached the runway edge.

Table 112. SURF IA Indication Statistics for All Evasive Actions by NACp for Arrival with Taxi Crossing Scenario.

NACp	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival)					
8	66,276	37,748, 57.0	11,682, 17.6	21,515, 32.5	3,840, 5.8
9	56,808	15,882, 28.0	736, 1.3	17,780, 31.3	645, 1.1
10	37,872	8,011, 21.1	0, 0.0	11,931, 31.5	0, 0.0
11	28,404	6,002, 21.1	0, 0.0	8,987, 31.6	0, 0.0
Truth	9,468	1,998, 21.1	0, 0.0	3,004, 31.7	0, 0.0
Aircraft B (Taxi)					
8	66,276	53,689, 81.0	27,266, 41.1	52,089, 78.6	24,301, 36.7
9	56,808	38,550, 67.9	7,429, 13.1	45,149, 79.5	6,232, 11.0
10	37,872	23,960, 63.3	2,590, 6.8	29,939, 79.0	1,377, 3.6
11	28,404	17,688, 62.3	1,757, 6.2	22,383, 78.8	762, 2.7
Truth	9,468	5,844, 61.7	546, 5.8	7,460, 78.8	200, 2.1

Table 113. SURF IA Alert Statistics for All Evasive Actions by NACp for Arrival with Taxi Crossing Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
8	66,276	17,216, 26.0	1,677, 2.5	22,141, 33.4	6,471, 9.8
9	56,808	13,618, 24.0	4, 0.0	21,261, 37.4	995, 1.8
10	37,872	9,118, 24.1	0, 0.0	14,211, 37.5	0, 0.0
11	28,404	6,817, 24.0	0, 0.0	10,594, 37.3	0, 0.0
Truth	9,468	2,268, 23.9	0, 0.0	3,529, 37.3	0, 0.0
Aircraft B (Taxi)					
8	66,276	17,244, 26.0	3,353, 5.1	22,241, 33.6	7,662, 11.6
9	56,808	13,640, 24.0	47, 0.1	21,380, 37.6	1,167, 2.0
10	37,872	9,169, 24.2	0, 0.0	14,356, 37.9	0, 0.0
11	28,404	6,865, 24.2	0, 0.0	10,748, 37.8	0, 0.0
Truth	9,468	2,278, 24.1	0, 0.0	3,578, 37.8	0, 0.0

Table 114. Aircraft Location When IAs Issued When Transmitting Truth Position Accuracy Using SURF IA for Arrival with Taxi Crossing Scenario.

Indication or Alert Type	Aircraft A (Arrival)				Aircraft B (Taxi)	
	Maximum Distance prior to Threshold (ft)	AGL (ft)	Minimum Distance prior to Threshold (ft)	AGL (ft)	Distance Before Centerline (ft)	Distance Past Centerline (ft)
TI	17,069 (2.8 NM)	928	11,573 (1.9 NM)	642	500	176
RSI	11,287 (1.9 NM)	626	7,477 (1.2 NM)	427	499	136
CA	7,477 (1.2 NM)	427	3,352 (0.5 NM)	212	149	153
WA	3,139 (0.5 NM)	200	184	46	146	129

Toggling occurred when multiple instances of IAs were generated during a test run. Toggling is undesirable because it is a distraction to the flight crew and could cause mistrust in the technology. Toggling occurred frequently when transmitting data with NACp 8 accuracy (Tables 112 and 113). For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which multiple TIs,

multiple RSIs, multiple CAs, and multiple WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The toggling included gaps between IAs for less accurate position accuracy. The toggling was also a result of collision avoidance maneuvering; accelerated braking and conducting a go-around maneuver. For Aircraft B, toggling occurred for indications when transmitting truth position data. In some instances this occurred by design. Some situations warrant a multiple TI; as the situation progresses, an RSI or alert is generated, then, if the situation changes, the indication may be degraded back to a less severe TI. It was determined that some of the multiple indications occurred as Aircraft B taxied across an intersecting runway prior to crossing Runway 10. A TI was issued as the aircraft was taxiing toward Runway 10; however, before reaching Runway 10, the aircraft crossed an intersecting runway. Since indications are not required in that situation, the indication was no longer issued. After crossing the intersecting runway, however, the TI was issued again as the aircraft approached Runway 10. The SURF IA algorithm does not have any mechanisms in place to address toggling between aircraft states.

Table 115. SURF IA Indication Statistics for All NACp by Evasive Action for Arrival with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	49,707	17,431, 35.1	3,083, 6.2	15,510, 31.2	1,032, 2.1
Aircraft A	49,707	17,458, 35.1	3,082, 6.2	16,046, 32.3	1,165, 2.3
Aircraft B	49,707	17,429, 35.1	3,196, 6.4	15,631, 31.4	1,133, 2.3
Both	49,707	17,323, 34.9	3,057, 6.2	16,030, 32.2	1,155, 2.3
Aircraft B (Taxi)					
Neither	49,707	34,768, 70.0	9,773, 19.7	39,251, 79.0	8,204, 16.5
Aircraft A	49,707	35,058, 70.5	9,913, 19.9	39,234, 78.9	8,185, 16.5
Aircraft B	49,707	34,842, 70.1	9,979, 20.1	39,265, 79.0	8,256, 16.6
Both	49,707	35,063, 70.5	9,923, 20.0	39,270, 79.0	8,227, 16.6

Table 116. SURF IA Alert Statistics for All NACp by Evasive Action for Arrival with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	49,707	12,283, 24.7	395, 0.8	17,979, 36.2	2,021, 4.1
Aircraft A	49,707	12,208, 24.6	447, 0.9	17,890, 36.0	1,836, 3.7
Aircraft B	49,707	12,312, 24.8	443, 0.9	17,912, 36.0	1,911, 3.8
Both	49,707	12,234, 24.6	396, 0.8	17,955, 36.1	1,698, 3.4
Aircraft B (Taxi)					
Neither	49,707	12,334, 24.8	846, 1.7	18,115, 36.4	2,333, 4.7
Aircraft A	49,707	12,265, 24.7	878, 1.8	18,045, 36.3	2,196, 4.4
Aircraft B	49,707	12,328, 24.8	868, 1.8	18,053, 36.3	2,272, 4.6
Both	49,707	12,269, 24.7	808, 1.6	18,090, 36.4	2,028, 4.1

When analyzing by CD&R equipage level (Tables 115 and 116), the rate of IA generation and multiple IAs was similar between equipage levels per aircraft. For Aircraft A, there was no significant difference in the number of runs in which TIs ($p = 0.815$), multiple TIs ($p = 0.263$), CAs ($p = 0.869$), multiple CAs ($p = 0.117$), and WAs ($p = 0.935$) were generated between CD&R equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which RSIs and multiple WAs were generated between

Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped. There was also a significant difference ($p = 0.017$) in the number of runs in which multiple RSIs were generated between Neither aircraft equipped vs. Aircraft A, Aircraft B, and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which TIs ($p = 0.088$), multiple TIs ($p = 0.406$), RSIs ($p = 0.992$), multiple RSIs ($p = 0.938$), CAs ($p = 0.931$), multiple CAs ($p = 0.326$), and WAs ($p = 0.964$) were generated between CD&R equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

In order to demonstrate the effect of accurate position data on the occurrence of IA and multiple IA generation, IA statistics were also compiled by CD&R equipage level when truth position accuracy was transmitted (Tables 117 and 118). Fewer TIs were issued than when less accurate position data was transmitted (Table 115). The RSI, CA, and WA generation rates were similar when transmitting truth position data (Tables 117 and 118) and when transmitting data with various (less accurate) position data (Tables 115 and 116). For Aircraft A, there was no significant difference in the number of runs in which TIs ($p = 0.999$) and CAs ($p = 1.0$) were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which RSIs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped and in the number of runs in which WAs were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which RSIs ($p = 0.997$) and CAs ($p = 1.0$) were generated between equipage levels. There was a significant difference in the number of runs in which TIs ($p = 0.005$) were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped and in the number of runs in which WAs ($p <0.001$) were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped.

Multiple IAs were greatly reduced when transmitting accurate position data (Tables 117 and 118). There were virtually no multiple IAs for Aircraft A. For Aircraft B, the rate of TIs was reduced from approximately 20% to 6% and the rate of RSIs was reduced from approximately 16% to 2%. There were virtually no multiple alerts for Aircraft B. For Aircraft A, there was no significant difference ($p = 0.50$) in the number of runs in which multiple WAs were generated between equipage levels. For Aircraft B, there was no significant difference in the number of runs in which multiple RSIs ($p = 0.990$) and multiple WAs ($p = 0.50$) were generated; however, there was a significant difference ($p = 0.001$) in the number of runs in which multiple TIs were generated between Neither aircraft equipped vs. Aircraft A, Aircraft B, and Both aircraft equipped.

Table 117. SURF IA Indication Statistics When Transmitting Truth Position Data for Arrival with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	49,707	10,519, 21.2	0, 0.0	15,429, 31.0	0, 0.0
Aircraft A	49,707	10,514, 21.1	0, 0.0	16,022, 32.2	0, 0.0
Aircraft B	49,707	10,498, 21.1	0, 0.0	15,265, 30.7	0, 0.0
Both	49,707	10,506, 21.1	0, 0.0	15,786, 31.8	0, 0.0
Aircraft B (Taxi)					
Neither	49,707	30,682, 61.7	2,854, 5.7	39,143, 78.8	1,050, 2.1
Aircraft A	49,707	31,071, 62.5	3,031, 6.1	39,144, 78.8	1,052, 2.1
Aircraft B	49,707	30,901, 62.2	3,124, 6.3	39,124, 78.7	1,039, 2.1
Both	49,707	31,195, 62.8	3,104, 6.2	39,124, 78.7	1,052, 2.1

Table 118. SURF IA Alert Statistics When Transmitting Truth Position Data for Arrival with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	49,707	11,900, 23.9	0, 0.0	18,522, 37.3	0, 0.0
Aircraft A	49,707	11,901, 23.9	0, 0.0	18,411, 37.0	1, 0.0
Aircraft B	49,707	11,901, 23.9	0, 0.0	17,970, 36.1	0, 0.0
Both	49,707	11,898, 23.9	0, 0.0	17,963, 36.1	1, 0.0
Aircraft B (Taxi)					
Neither	49,707	11,900, 23.9	0, 0.0	18,521, 37.3	0, 0.0
Aircraft A	49,707	11,901, 23.9	0, 0.0	18,411, 37.0	1, 0.0
Aircraft B	49,707	11,901, 23.9	0, 0.0	17,970, 36.1	0, 0.0
Both	49,707	11,898, 23.9	0, 0.0	17,963, 36.1	1, 0.0

Missed and nuisance alerts – The number of runs in which the aircraft entered the defined missed and nuisance boundaries increased as the position accuracy decreased, as shown in Table 119. Aircraft can cross into the missed and nuisance boundary multiple times throughout a test run, for varying lengths of time. The number of times (count) and amount of time (duration and percentage of run length) that the aircraft were within the boundaries was generally greater when transmitting less accurate data (Table 119). For Aircraft A there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary and nuisance boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies and in the number of runs in which the aircraft entered the nuisance boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 119. SURF IA Missed and Nuisance Boundary Statistics for Arrival with Taxi Crossing Scenario.

	Entered Missed Boundary				Entered Nuisance Boundary			
NACp	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Arrival)								
8	54,246, 81.8	6.9, 5.8	11.8, 11.9	8.0	791, 1.2	1.0, 0.2	0.6, 0.2	0.3
9	738, 1.3	1.5, 2.1	1.5, 1.5	0.8	395, 0.7	1.0, 0.2	0.6, 0.2	0.2
10	220, 0.6	1.0, 0.0	0.5, 0.3	0.2	231, 0.6	1.0, 0.0	0.4, 0.2	0.2
11	116, 0.4	1.0, 0.0	0.2, 0.1	0.1	104, 0.4	1.0, 0.0	0.2, 0.1	0.1
Truth	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
Aircraft B (Taxi)								
8	54,590, 82.4	2.1, 1.2	4.1, 2.8	3.6	19,692, 29.7	3.7, 4.1	6.7, 10.6	5.3
9	42,294, 74.5	1.3, 0.5	1.5, 1.0	1.3	58, 0.1	1.6, 1.4	1.3, 2.0	1.2
10	25,003, 66.0	1.1, 0.3	0.6, 0.3	0.5	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
11	12,221, 43.0	1.1, 0.2	0.3, 0.1	0.2	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0

For the approach Aircraft A, the majority of occurrences of entering the missed boundary was after the aircraft had crossed the runway threshold for landing. The aircraft only entered the missed boundary while on approach before crossing the runway threshold during 2.8% of the test runs when transmitting data with NACp 8 accuracy. Since Aircraft A tracked the extended centerline on approach and centerline after landing, the nuisance boundary was entered as the aircraft was exiting the runway.

The taxiing Aircraft B entered the missed boundary at least once for a high percentage of the test runs for accuracy levels of NACp 8 to 11. This was due to the criteria for entering the missed boundary. The aircraft was counted as entering the missed boundary when the true position of any part of the aircraft was determined to be between the runway shoulder edges, but the detected nose position when entering or tail position when exiting was outside of the runway shoulder edges. There was no buffer between when the aircraft was inside or outside the missed boundary so measurable difference between the true and detected position could cause a missed boundary to be counted.

The number of test runs that contained missed and nuisance IAs was relatively low, overall, as shown in Tables 120 and 121. IAs for both aircraft were highest when transmitting data with NACp 8 accuracy. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which missed TIs, missed RSIs, missed CAs, and missed WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which nuisance TIs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which nuisance TIs, nuisance RSIs, nuisance CAs, and nuisance WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 120. SURF IA Missed IA Statistics for All Evasive Actions by NACp for Arrival with Taxi Crossing Scenario.

NACp	Total # Runs	Missed TI (#, Runs, % Runs)	Missed RSI (# Runs, % Runs)	Missed CA (#, Runs, % Runs)	Missed WA (# Runs, % Runs)
Aircraft A (Arrival)					
8	66,276	1,373, 2.1	3,347, 5.1	2,423, 3.7	5,339, 8.1
9	56,808	260, 0.5	683, 1.2	758, 1.3	570, 1.0
10	37,872	76, 0.2	172, 0.5	153, 0.4	58, 0.2
11	28,404	17, 0.1	54, 0.2	39, 0.1	14, 0.0
Truth	9,468	4, 0.0	0, 0.0	2, 0.0	0, 0.0
Aircraft B (Taxi)					
8	66,276	1,688, 2.5	3,056, 4.6	2,410, 3.6	5,274, 8.0
9	56,808	699, 1.2	819, 1.4	748, 1.3	548, 1.0
10	37,872	215, 0.6	197, 0.5	125, 0.3	49, 0.1
11	28,404	68, 0.2	14, 0.0	31, 0.1	17, 0.1
Truth	9,468	12, 0.1	0, 0.0	1, 0.0	1, 0.0

Table 121. SURF IA Nuisance IA Statistics for All Evasive Actions by NACp for Arrival with Taxi Crossing Scenario.

NACp	Total # Runs	Nuisance TI (# Runs, % Runs)	Nuisance RSI (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival)					
8	66,276	27, 0.0	0, 0.0	0, 0.0	0, 0.0
9	56,808	8, 0.0	0, 0.0	0, 0.0	0, 0.0
10	37,872	2, 0.0	0, 0.0	0, 0.0	0, 0.0
11	28,404	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	9,468	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Taxi)					
8	66,276	3,668, 5.5	3,489, 5.3	2,925, 4.4	2,723, 4.1
9	56,808	0, 0.0	1, 0.0	0, 0.0	0, 0.0
10	37,872	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	28,404	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	9,468	0, 0.0	0, 0.0	0, 0.0	0, 0.0

Both aircraft experienced missed IAs when transmitting truth position data. These unexpected events occurred because even though the aircraft were broadcasting truth position data, the ADS-B transmission model was still being used. The transmission model resulted in a slight delay between one aircraft's position at the time of transmitting the ADS-B message and the position at the time of reception of the ADS-B message by the other aircraft. This delay was present in all scenarios, but this position difference was negligible compared to the NACp position uncertainty error. In these scenarios, the aircraft did not detect a conflict with the other aircraft based on the broadcast position, but if instantaneous position information were used, a conflict would have been detected. The small error introduced by the movement of the aircraft between transmission and reception of the ADS-B message resulted in just enough difference in relation to the other aircraft's position to result in the missed IAs. For Aircraft A, the missed TIs should have occurred when the aircraft was approximately 1.9 NM prior to the runway threshold and the missed CAs should have occurred when approximately 3,360 ft prior to the runway threshold. For Aircraft B, the missed TIs should have occurred when approximately 445 ft from the runway centerline, the missed CA should have occurred when 126 ft from the runway centerline, and the missed WAs should have occurred when 121 ft from the runway centerline.

An IA was considered a nuisance if it was generated at the same time the aircraft was determined to be within the nuisance boundary. Therefore, nuisance indications for Aircraft A only occurred as the aircraft was exiting the runway.

When analyzing by CD&R equipage level (Tables 122 and 123), missed and nuisance IAs occurred for less than 3% of the runs for all CD&R equipage levels for both aircraft. There were no nuisance RSIs, CAs, and WAs for Aircraft A. For Aircraft A, there was no significant difference in the number of runs in which missed TIs ($p = 0.976$), missed RSIs ($p = 0.170$), missed CAs ($p = 0.724$) and missed WAs ($p = 0.480$) occurred between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which missed TIs ($p = 0.593$), missed RSIs ($p = 0.475$), missed CAs ($p = 0.924$) and missed WAs ($p = 0.446$) occurred between equipage levels. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which nuisance TIs occurred between Aircraft B equipped vs. Neither aircraft, Aircraft A, and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which nuisance TIs ($p = 0.076$), nuisance CAs ($p = 0.652$), and nuisance WAs ($p = 0.274$) occurred between equipage levels. There was a significant difference ($p = 0.015$) in the number of runs in which nuisance RSIs occurred between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped.

Table 122. SURF IA Missed IA Statistics for All NACp by Evasive Action for Arrival with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	Missed TI (#, Runs, % Runs)	Missed RSI (# Runs, % Runs)	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	49,707	428, 0.9	1,103, 2.2	853, 1.7	1,473, 3.0
Aircraft A	49,707	440, 0.9	1,090, 2.2	831, 1.7	1,538, 3.1
Aircraft B	49,707	433, 0.9	1,010, 2.0	825, 1.7	1,508, 3.0
Both	49,707	429, 0.9	1,053, 2.1	866, 1.7	1,462, 2.9
Aircraft B (Taxi)					
Neither	49,707	673, 1.4	1,025, 2.1	840, 1.7	1,434, 2.9
Aircraft A	49,707	645, 1.3	1,059, 2.1	820, 1.6	1,484, 3.0
Aircraft B	49,707	669, 1.3	990, 2.0	818, 1.6	1,516, 3.0
Both	49,707	695, 1.4	1,012, 2.0	837, 1.7	1,455, 2.9

Table 123. SURF IA Nuisance IA Statistics for All NACp by Evasive Action for Arrival with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	Nuisance TI (# Runs, % Runs)	Nuisance RSI (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	49,707	3, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft A	49,707	4, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B	49,707	22, 0.0	0, 0.0	0, 0.0	0, 0.0
Both	49,707	8, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Taxi)					
Neither	49,707	877, 1.8	849, 1.7	749, 1.5	721, 1.4
Aircraft A	49,707	880, 1.8	810, 1.6	704, 1.4	652, 1.3
Aircraft B	49,707	967, 2.0	935, 1.9	742, 1.5	682, 1.4
Both	49,707	944, 1.9	896, 1.8	730, 1.5	668, 1.3

Unnecessary maneuvering – As defined in Section 4.5.3, maneuvering was considered unnecessary if made based on a WA issued when the aircraft were broadcasting NACp accuracy, but for the same test conditions, a WA was not issued when broadcasting truth position data. Only the test runs in which maneuvering was possible were evaluated for unnecessary maneuvers. For Aircraft A, unnecessary maneuvering was only evaluated when Aircraft A or Both aircraft were equipped with CD&R. For Aircraft B, unnecessary maneuvering was evaluated when Aircraft B or Both aircraft were equipped. This measure quantifies untimely nuisance alerts using an algorithm-dependent methodology.

The percentage of test runs in which the aircraft maneuvered unnecessarily when transmitting data with the various accuracy levels is shown in Table 124. Unnecessary maneuvers only occurred when transmitting data with NACp 8 and 9 accuracies. With a NACp value of 8, approximately 4% or 4 in 100 of the maneuvers were unnecessary for Aircraft A and 2.5 in 100 were unnecessary for Aircraft B. With a NACp value of 9, approximately 5 in 1,000 maneuvers were unnecessary for Aircraft A and 1 in 1,000 were unnecessary for Aircraft B. There was a significant difference ($p < 0.001$) in the number of runs in which unnecessary maneuvers occurred for both aircraft between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The number and percentage of test runs in which the aircraft maneuvered unnecessarily based on the CD&R equipage level is shown in Table 125. The number of unnecessary maneuvers was similar between equipage levels per aircraft. There was no significant difference in the number of runs in which unnecessary maneuvers occurred between equipage levels for Aircraft A ($p = 0.042$) and Aircraft B ($p = 0.467$).

Table 124. Unnecessary Maneuvers for All Evasive Actions by NACp Using SURF IA During Arrival with Taxi Crossing Scenario.

NACp	Total # Runs	Aircraft A (Arrival) (# Runs, % Runs)	Aircraft B (Taxi) (# Runs, % Runs)
8	33,138	1,307, 3.9	820, 2.5
9	28,404	141, 0.5	20, 0.1
10	18,936	0, 0.0	0, 0.0
11	14,202	0, 0.0	0, 0.0
Truth	4,734	0, 0.0	0, 0.0

Table 125. Unnecessary Maneuvers for All NACp by Evasive Action Using SURF IA During Arrival with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	Aircraft A (Arrival) (# Runs, % Runs)	Aircraft B (Taxi) (# Runs, % Runs)
Neither	49,707	N/A	N/A
Aircraft A	49,707	685, 1.4	N/A
Aircraft B	49,707	N/A	431, 0.9
Both	49,707	763, 1.5	409, 0.8

Collision avoidance – By the design of the scenarios, approximately 19% of the runs resulted in a near collision and approximately 9% resulted in a collision in the absence of CD&R, as shown in Table 126. The addition of CD&R did not have much effect on collision avoidance with approximately 18% of the runs resulting in near collision and approximately 8% in collisions when Both were equipped. There was no significant difference in the number of runs in which near collisions occurred when neither aircraft was equipped ($p = 1.0$), when Aircraft A was equipped ($p = 0.961$), when Aircraft B was equipped ($p = 0.970$), and when Both aircraft were equipped ($p = 0.598$) between accuracy levels. There was no significant difference in the number of runs in which collisions occurred when neither aircraft was equipped ($p = 1.0$), when Aircraft A was equipped ($p = 0.887$), and when Both aircraft were equipped ($p = 0.063$); however, there was a significant difference ($p = 0.003$) when Aircraft B was equipped between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 126. Number/Percentage of Near Collisions (NC) and Collisions (C) Using SURF IA for Equipage Combinations for Arrival with Taxi Crossing Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	16,569	3,197, 19.3	1,543, 9.3	3,106, 18.8	1,467, 8.8	3,136, 18.9	1,304, 7.9	2,959, 17.9	1,320, 8.0
9	14,202	2,737, 19.3	1,318, 9.3	2,705, 19.1	1,301, 9.2	2,657, 18.7	1,273, 9.0	2,632, 18.5	1,242, 8.8
10	9,468	1,826, 19.3	880, 9.3	1,803, 19.0	868, 9.2	1,763, 18.6	845, 8.9	1,741, 18.4	833, 8.8
11	7,101	1,372, 19.3	659, 9.3	1,350, 19.0	642, 9.0	1,325, 18.7	634, 8.9	1,309, 18.4	622, 8.8
Truth	2,367	458, 19.4	220, 9.3	451, 19.1	215, 9.1	440, 18.6	212, 9.0	435, 18.4	205, 8.7

For the taxiing aircraft (Aircraft B), a WA was not timely. The WA generally did not occur until the aircraft was on or almost on the runway (i.e., the mean, true position of Aircraft B when it received the WA was 107.6 ft, SD 59.9 ft, from the runway centerline). Since the aircraft was already past the runway shoulder, no action was taken and the aircraft continued across the runway (as per the design of the test maneuvers).

Some collisions were also unavoidable since the approach aircraft (Aircraft A) was issued a WA during a critical operational phase. Most often, the WA occurred during high speed rollout without enough separation from the traffic to stop in time to avoid a collision. Other times the WA occurred when the aircraft was too close to the ground to go around and the collision occurred as the aircraft continued along its predetermined path. Some collisions also occurred during low speed taxi on the runway (< 40 kts) or as the aircraft was exiting the runway – conditions for which the SURF IA CD&R algorithm does not issue WAs; therefore, no avoidance action was taken.

Although collision avoidance was not affected by the horizontal position accuracy level, there were slightly less collisions when transmitting data with NACp 8 accuracy, in general. In some instances, the WA was generated when the sensed taxi aircraft was on the runway, but the true location of the aircraft was far enough back from the runway that it could come to a complete stop before actually reaching the runway shoulder.

5.2.3 Runway Scenario – Departure with Taxi Crossing

For each of the 20 cases in this scenario, 1,077 combinations of the initiation delay and initial position for Aircraft B were evaluated, for a total of 90,468 test runs.

Algorithm performance – For Aircraft A, TIs were generated on 0% to 50% of the test runs and RSIs were issued on approximately 3% or less of runs (Table 127). For Aircraft B, TIs were generated on 60% to 87% of runs and RSIs were issued on approximately 77% of runs. For both aircraft, WAs were issued on approximately 30% of the runs, almost independent of the position accuracy levels (Table 128). CAs were not generated by either aircraft for this scenario. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which TIs, RSIs, and WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 127. SURF IA Indication Statistics for All Evasive Actions by NACp for Departure with Taxi Crossing Scenario.

NACp	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Departure)					
8	30,156	15,012, 49.8	4,352, 14.4	990, 3.3	305, 1.0
9	25,848	1,908, 7.4	252, 1.0	282, 1.1	13, 0.0
10	17,232	0, 0.0	0, 0.0	112, 0.6	0, 0.0
11	12,924	0, 0.0	0, 0.0	91, 0.7	0, 0.0
Truth	4,308	0, 0.0	0, 0.0	30, 0.7	0, 0.0
Aircraft B (Taxi)					
8	30,156	26,251, 87.0	21,307, 70.7	19,894, 66.0	10,524, 34.9
9	25,848	17,521, 67.8	3,682, 14.2	20,108, 77.8	2,380, 9.2
10	17,232	10,547, 61.2	143, 0.8	13,404, 77.8	107, 0.6
11	12,924	7,773, 60.1	97, 0.8	10,038, 77.7	9, 0.1
Truth	4,308	2,580, 59.9	30, 0.7	3,348, 77.7	0, 0.0

Table 128. SURF IA Alert Statistics for ALL Evasive Actions by NACp for Departure with Taxi Crossing Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Departure)					
8	30,156	0, 0.0	0, 0.0	7,510, 24.9	1,895, 6.3
9	25,848	0, 0.0	0, 0.0	8,043, 31.1	292, 1.1
10	17,232	0, 0.0	0, 0.0	5,467, 31.7	0, 0.0
11	12,924	0, 0.0	0, 0.0	4,106, 31.8	0, 0.0
Truth	4,308	0, 0.0	0, 0.0	1,366, 31.7	0, 0.0
Aircraft B (Taxi)					
8	30,156	0, 0.0	0, 0.0	7,324, 24.3	2,257, 7.5
9	25,848	0, 0.0	0, 0.0	7,796, 30.2	260, 1.0
10	17,232	0, 0.0	0, 0.0	5,309, 30.8	0, 0.0
11	12,924	0, 0.0	0, 0.0	3,988, 30.9	0, 0.0
Truth	4,308	0, 0.0	0, 0.0	1,324, 30.7	0, 0.0

The location range of the departing Aircraft A and the taxi crossing Aircraft B when an indication or alert was issued when transmitting truth position data is presented in Table 129. Onboard the departing aircraft, TIs and CAs were not issued. RSIs were issued on only 30 runs when the aircraft was 850 ft to 1,191 ft from the runway threshold during departure roll. WAs were issued on departure when the aircraft was 434 ft from the threshold and 50 kts until the aircraft had lifted off and was 6,015 ft from the threshold and 175 kts (33 ft AGL). Recall that for this study, the runway was 150 ft wide and the runway hold line

was 225 ft from the runway centerline. Onboard the taxiing aircraft, initial indications were issued approximately 500 ft before reaching the runway centerline (275 ft before the runway hold line) until 162 ft before the runway centerline (63 ft after crossing the runway hold line). WAs were issued approximately 147 ft (78 ft after crossing the runway hold line) to 34 ft (41 ft onto the runway) before reaching the runway centerline. Since the data presented is in reference to the aircraft CG and the nose of the aircraft was 72.8 ft from the aircraft CG, a WA did not occur until the nose of the aircraft had just crossed the runway edge.

Table 129. Aircraft Location When IAs Issued When Transmitting Truth Position Accuracy Using SURF IA for Departure with Taxi Crossing Scenario.

Indication or Alert Type	Aircraft A (Departure)				Aircraft B (Taxi)	
	Minimum Distance from Threshold (ft)	GS (kts)	Maximum Distance from Threshold (ft)	GS (kts)	Maximum Distance Before Centerline (ft)	Minimum Distance before Centerline (ft)
TI	N/A	N/A	N/A	N/A	500	295
RSI	850	34	1,191	35	498	162
WA	434	50	6,015	175	147	34

As the position accuracy was reduced, IA toggling occurred more frequently, particularly when transmitting data with NACp 8 and 9 accuracies (Tables 127 and 128). For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which multiple TIs, multiple RSIs, and multiple WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The toggling included gaps between IAs for less accurate position data (NACp 8 and 9). The toggling was also a result of collision avoidance maneuvering, accelerated braking and rejected takeoffs. For Aircraft B, TI toggling occurred when truth position data was transmitted. This toggling occurred by design. A TI was initially issued for Aircraft B and as the situation progressed, an RSI and WA were issued. Then, after Aircraft A rejected the departure, a TI was issued again.

When analyzing by CD&R equipage level (Tables 130 and 131), the rate of IA generation and multiple IAs was similar between equipage levels per aircraft. For Aircraft A, there was no significant difference in the number of runs in which TIs ($p = 0.516$), multiple TIs ($p = 0.204$), and WAs ($p = 0.818$) were generated between equipage levels. There was a significant difference in the number of runs in which RSIs ($p < 0.001$), multiple RSIs ($p < 0.001$), and multiple WAs ($p = 0.014$) were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which TIs ($p = 0.728$), RSIs ($p = 0.784$), multiple RSIs ($p = 0.046$), WAs ($p = 0.950$), and multiple WAs ($p = 0.028$) were generated between equipage levels. There was a significant difference ($p = 0.011$) in the number of runs in which multiple TIs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Table 130. SURF IA Indication Statistics for All NACp by Evasive Action for Departure with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Departure)					
Neither	22,617	4,286, 18.9	1,107, 4.9	106, 0.5	3, 0.0
Aircraft A	22,617	4,205, 18.6	1,128, 5.0	625, 2.8	143, 0.6
Aircraft B	22,617	4,257, 18.8	1,172, 5.2	106, 0.5	2, 0.0
Both	22,617	4,172, 18.4	1,197, 5.3	668, 3.0	170, 0.8
Aircraft B (Taxi)					
Neither	22,617	16,201, 71.6	6,197, 27.4	16,657, 73.7	3,196, 14.1
Aircraft A	22,617	16,167, 71.5	6,415, 28.4	16,741, 74.0	3,173, 14.0
Aircraft B	22,617	16,199, 71.6	6,208, 27.4	16,721, 73.9	3,358, 14.8
Both	22,617	16,105, 71.2	6,439, 28.5	16,673, 73.7	3,293, 14.6

Table 131. SURF IA Alert Statistics for All NACp by Evasive Action for Departure with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Departure)					
Neither	22,617	0, 0.0	0, 0.0	6,627, 29.3	583, 2.6
Aircraft A	22,617	0, 0.0	0, 0.0	6,624, 29.3	491, 2.2
Aircraft B	22,617	0, 0.0	0, 0.0	6,574, 29.1	579, 2.6
Both	22,617	0, 0.0	0, 0.0	6,667, 29.5	534, 2.4
Aircraft B (Taxi)					
Neither	22,617	0, 0.0	0, 0.0	6,427, 28.4	632, 2.8
Aircraft A	22,617	0, 0.0	0, 0.0	6,435, 28.4	593, 2.6
Aircraft B	22,617	0, 0.0	0, 0.0	6,412, 28.4	689, 3.0
Both	22,617	0, 0.0	0, 0.0	6,467, 28.6	603, 2.7

IA statistics were also compiled by CD&R equipage level when truth position accuracy was transmitted (Tables 132 and 133). TIs were not issued for Aircraft A when transmitting data with truth position accuracy. The rate of TI generation was reduced by approximately 10% for Aircraft B and multiple TIs were practically eliminated. The rate of RSI generation transmitting data with truth position accuracy was similar to the rate when transmitting data with NACp accuracy (Tables 130 and 131) for both aircraft; however, there were no multiple RSIs for Aircraft B. The rate of WA generation was similar when transmitting data with truth position accuracy; however, multiple WAs were virtually eliminated. For Aircraft A, there was no significant difference ($p = 0.50$) in the number of runs in which multiple WAs were generated between equipage levels. There was a significant difference in the number of runs in which RSIs ($p < 0.001$) were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped and in the number of runs in which WAs ($p = 0.007$) were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which TIs ($p = 0.897$), RSIs ($p = 1.0$) and multiple WAs ($p = 0.50$) were generated between equipage levels. There was a significant difference in the number of runs in which multiple TIs ($p < 0.001$) were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped and in the number of runs in which WAs ($p = 0.007$) were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped.

Table 132. SURF IA Indication Statistics When Transmitting Truth Position Data for Departure with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Departure)					
Neither	22,617	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft A	22,617	0, 0.0	0, 0.0	735, 3.2	0, 0.0
Aircraft B	22,617	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Both	22,617	0, 0.0	0, 0.0	482, 2.1	0, 0.0
Aircraft B (Taxi)					
Neither	22,617	13,545, 59.9	0, 0.0	17,724, 78.4	0, 0.0
Aircraft A	22,617	13,594, 60.1	718, 3.2	17,724, 78.4	0, 0.0
Aircraft B	22,617	13,545, 59.9	0, 0.0	17,724, 78.4	0, 0.0
Both	22,617	13,608, 60.2	731, 3.2	17,723, 78.4	0, 0.0

Table 133. SURF IA Alert Statistics When Transmitting Truth Position Data for Departure with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Departure)					
Neither	22,617	0, 0.0	0, 0.0	7,182, 31.8	0, 0.0
Aircraft A	22,617	0, 0.0	0, 0.0	7,098, 31.4	1, 0.0
Aircraft B	22,617	0, 0.0	0, 0.0	6,929, 30.6	0, 0.0
Both	22,617	0, 0.0	0, 0.0	6,887, 30.4	1, 0.0
Aircraft B (Taxi)					
Neither	22,617	0, 0.0	0, 0.0	7,182, 31.8	0, 0.0
Aircraft A	22,617	0, 0.0	0, 0.0	7,098, 31.4	1, 0.0
Aircraft B	22,617	0, 0.0	0, 0.0	6,929, 30.6	0, 0.0
Both	22,617	0, 0.0	0, 0.0	6,887, 30.4	1, 0.0

The SURF IA SPR [RTCA, 2010] specifies that IAs must be inhibited above 80 kts. As currently implemented, the SURF IA algorithm calculates alerts throughout the departure when the aircraft's ground speed is greater than 80 kts (the mean ground speed when a WA was generated on Aircraft A was 121.7 kts, SD 36.6 kts for truth accuracy). These data were included in Tables 127 and 128 even though these alerts would not be displayed in the cockpit as per the SPR. For the test runs in which the departing aircraft was to take action (Aircraft A only and Both equipped), WAs were generated when the aircraft was less than 80 kts in only 5% to 7% of the test runs; without this restriction, WAs were generated on 23% to 32% of the test runs (Table 134). More research is necessary to determine the collision avoidance benefits of providing alerts to the flight crew after reaching 80 kts versus the risk of pilots making inappropriate responses at high speed.

Table 134. SURF IA WA Alert Data for Departure Aircraft.

NACp	Total # Runs	WA (# Runs, % Runs)	WA when < 80 kts (# Runs, % Runs)
8	15,078	3,528, 23.4	1,048, 7.0
9	12,924	4,201, 32.5	760, 5.9
10	8,616	2,734, 31.7	452, 5.3
11	6,462	2,053, 31.8	340, 5.3
Truth	2,154	683, 31.7	113, 5.3

Missed and nuisance alerts – The number of runs in which the aircraft entered the defined missed and nuisance boundaries increased as the position accuracy decreased, as shown in Table 135. The number of times (count) and amount of time (duration and percentage of run length) that the aircraft were within the boundaries was greater when transmitting less accurate data. This was particularly true when transmitting data with NACp 8 accuracy. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies and in the number of runs in which the aircraft entered the nuisance boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The departing aircraft (Aircraft A) entered the missed boundary along its entire departure path. Since Aircraft A tracked the runway centerline on departure, it was not possible for the aircraft to enter the nuisance boundary.

The taxiing aircraft (Aircraft B) entered the missed boundary at least once for a high percentage of the test runs for accuracy levels of NACp 8 to 11. This was due to the criteria for entering the missed boundary.

The aircraft was counted as entering the missed boundary when the true position of any part of the aircraft was determined to be between the runway shoulder edges, but the detected nose position when entering or tail position when exiting was outside of the runway shoulder edges. As such, there was no buffer between when the aircraft was inside or outside the missed boundary so a measurable difference between the true and detected position could cause a missed boundary to be counted.

Table 135. SURF IA Missed and Nuisance Boundary Statistics for Departure with Taxi Crossing Scenario.

NACp	Entered Missed Boundary				Entered Nuisance Boundary			
	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Departure)								
8	24,647, 81.7	4.4, 3.2	9.0, 8.4	23.7	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
9	48, 0.2	2.1, 1.5	2.1, 2.5	5.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
10	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
11	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
Aircraft B (Taxi)								
8	18,282, 60.6	1.6, 0.9	3.7, 2.6	9.7	5,941, 19.7	2.4, 2.7	4.2, 7.8	9.2
9	11,368, 44.0	1.1, 0.3	1.3, 0.9	3.8	7, 0.0	1.1, 0.4	0.4, 0.2	1.1
10	6,360, 36.9	1.0, 0.2	0.5, 0.3	1.5	0, 0.0	0.0, 0.0	0, 0.0	0.0
11	2,760, 21.4	1.0, 0.1	0.3, 0.1	0.8	0, 0.0	0.0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0, 0.0	0.0

The number of test runs that contained missed and nuisance IAs were relatively low, overall, as shown in Tables 136 and 137. Missed IAs for both aircraft were highest when transmitting data with NACp 8 accuracy. Nuisance IAs only occurred when transmitting data with NACp 8 accuracy for Aircraft B. Nuisance IAs were not issued on Aircraft A because the aircraft tracked the runway centerline during departure and liftoff. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which missed RSIs and missed WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which missed TIs occurred between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies. There was also a significant difference ($p < 0.001$) in the number of runs in which missed RSIs, missed WAs, nuisance TIs, nuisance RSIs, and nuisance WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 136. SURF IA Missed IA Statistics for All Evasive Actions by NACp for Departure with Taxi Crossing Scenario.

NACp	Total # Runs	Missed TI (#, Runs, % Runs)	Missed RSI (# Runs, % Runs)	Missed CA (#, Runs, % Runs)	Missed WA (# Runs, % Runs)
Aircraft A (Departure)					
8	30,156	0, 0.0	244, 0.8	0, 0.0	3,428, 11.4
9	25,848	0, 0.0	16, 0.1	0, 0.0	539, 2.1
10	17,232	0, 0.0	0, 0.0	0, 0.0	90, 0.5
11	12,924	0, 0.0	0, 0.0	0, 0.0	22, 0.2
Truth	4,308	0, 0.0	0, 0.0	0, 0.0	2, 0.0
Aircraft B (Taxi)					
8	30,156	120, 0.4	4,979, 16.5	0, 0.0	3,542, 11.7
9	25,848	130, 0.5	663, 2.6	0, 0.0	693, 2.7
10	17,232	52, 0.3	208, 1.2	0, 0.0	215, 1.2
11	12,924	15, 0.1	112, 0.9	0, 0.0	129, 1.0
Truth	4,308	0, 0.0	28, 0.6	0, 0.0	44, 1.0

Table 137. SURF IA Nuisance IA Statistics for All Evasive Actions by NACp for Departure with Taxi Crossing Scenario.

NACp	Total # Runs	Nuisance TI (# Runs, % Runs)	Nuisance RSI (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Departure)					
8	30,156	0, 0.0	0, 0.0	0, 0.0	0, 0.0
9	25,848	0, 0.0	0, 0.0	0, 0.0	0, 0.0
10	17,232	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	12,924	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	4,308	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Taxi)					
8	30,156	1,207, 4.0	766, 2.5	0, 0.0	1,285, 4.3
9	25,848	0, 0.0	0, 0.0	0, 0.0	0, 0.0
10	17,232	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	12,924	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	4,308	0, 0.0	0, 0.0	0, 0.0	0, 0.0

Both aircraft experienced missed IAs when transmitting truth position data. This was due to the transmission delay of the ADS-B model as described in Section 5.2.2. For Aircraft A, the two missed WAs should have occurred when the aircraft had lifted off and was approximately 6,000 ft down the runway and 32 ft AGL. For Aircraft B, the missed RSIs should have occurred when the aircraft was approximately 488 ft from the runway centerline and the missed WAs should have occurred when the aircraft was approximately 134 ft from the runway centerline.

When analyzing the missed (Table 138) and nuisance (Table 139) data by CD&R equipage level, the rate of IAs are similar across equipage levels per IA type and aircraft, except for Aircraft A, RSIs were only issued when Aircraft A and Both aircraft were equipped. For Aircraft A, there was no significant difference ($p = 0.828$) in the number of runs in which missed WAs occurred between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which missed RSIs occurred between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which missed RSIs ($p = 0.381$), missed WAs ($p = 0.699$), nuisance TIs ($p = 0.370$), nuisance RSIs ($p = 0.027$), and nuisance WAs ($p = 0.969$) occurred between equipage levels. There was a significant difference ($p = 0.011$) in the number of runs in which missed TIs occurred between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Table 138. SURF IA Missed IA Statistics for All NACp by Evasive Action for Departure with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	Missed TI (#, Runs, % Runs)	Missed RSI (# Runs, % Runs)	Missed CA (#, Runs, % Runs)	Missed WA (# Runs, % Runs)
Aircraft A (Departure)					
Neither	22,617	0, 0.0	0, 0.0	0, 0.0	1,029, 4.5
Aircraft A	22,617	0, 0.0	168, 0.7	0, 0.0	1,012, 4.5
Aircraft B	22,617	0, 0.0	0, 0.0	0, 0.0	1,039, 4.6
Both	22,617	0, 0.0	92, 0.4	0, 0.0	1,001, 4.4
Aircraft B (Taxi)					
Neither	22,617	58, 0.3	1,550, 6.9	0, 0.0	1,174, 5.2
Aircraft A	22,617	96, 0.4	1,479, 6.5	0, 0.0	1,137, 5.0
Aircraft B	22,617	73, 0.3	1,463, 6.5	0, 0.0	1,177, 5.2
Both	22,617	90, 0.4	1,498, 6.6	0, 0.0	1,135, 5.0

Table 139. SURF Nuisance IA Statistics for All NACp by Evasive Action for Departure with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	Nuisance TI (# Runs, % Runs)	Nuisance RSI (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Departure)					
Neither	22,617	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft A	22,617	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B	22,617	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Both	22,617	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Taxi)					
Neither	22,617	290, 1.3	172, 0.8	0, 0.0	324, 1.4
Aircraft A	22,617	296, 1.3	171, 0.8	0, 0.0	327, 1.4
Aircraft B	22,617	293, 1.3	203, 0.9	0, 0.0	318, 1.4
Both	22,617	328, 1.4	220, 1.0	0, 0.0	316, 1.4

Unnecessary maneuvering - The percentage of test runs in which the aircraft maneuvered unnecessarily when transmitting data with the various accuracy levels is shown in Table 140. Unnecessary maneuvers only occurred for Aircraft B when transmitting data with NACp 8 and 9 accuracies. With NACp 8, approximately 4% or 4 in 100 of the maneuvers were unnecessary. With NACp 9, approximately 3 in 1,000 of the maneuvers were unnecessary. There was a significant difference ($p < 0.001$) in the number of runs in which unnecessary maneuvers occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 140. Unnecessary Maneuvers for All Evasive Actions by NACp Using SURF IA During Departure with Taxi Crossing Scenario.

NACp	Total # Runs	Aircraft A (Departure) (# Runs, % Runs)	Aircraft B (Taxi) (# Runs, % Runs)
8	15,078	0, 0.0	580, 3.8
9	12,924	0, 0.0	44, 0.3
10	8,616	0, 0.0	0, 0.0
11	6,462	0, 0.0	0, 0.0
Truth	2,154	0, 0.0	0, 0.0

The number of unnecessary maneuvers was similar between equipage levels (Table 141). There was no significant difference ($p = 0.717$) in the number of runs in which unnecessary maneuvers occurred between equipage levels.

Table 141. Unnecessary Maneuvers for All NACp by Evasive Action Using SURF IA During Departure with Taxi Crossing Scenario.

CD&R Equipage	Total # Runs	Aircraft A (Departure) (# Runs, % Runs)	Aircraft B (Taxi) (# Runs, % Runs)
Neither	22,617	N/A	N/A
Aircraft A	22,617	0, 0.0	N/A
Aircraft B	22,617	N/A	307, 1.4
Both	22,617	0, 0.0	317, 1.4

Collision avoidance – Approximately 31% of the runs resulted in a near collision and approximately 14% resulted in a collision in the absence of CD&R, as shown in Table 142. The addition of CD&R only slightly improved collision avoidance with approximately 28% of the runs resulting in a near collision and approximately 12% in a collision when Both were equipped. For all CD&R equipage levels, there was no

significant difference in the number of runs in which near collisions and collisions occurred between the position accuracy levels:

- Neither aircraft equipped: near collisions ($p = 1.0$) and collisions ($p = 1.0$),
- Aircraft A equipped: near collisions ($p = 0.999$) and collisions ($p = 1.0$),
- Aircraft B equipped: near collisions ($p = 0.925$) and collisions ($p = 0.175$), and
- Both aircraft equipped: near collisions ($p = 0.994$) and collisions ($p = 0.479$).

Table 142. Number/Percentage of Near Collisions (NC) and Collisions (C) Using SURF IA for Equipage Combinations for Departure with Taxi Crossing Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	7,539	2,348, 31.1	1,087, 14.4	2,097, 27.8	950, 12.6	2,281, 30.3	968, 12.8	2,063, 27.4	882, 11.7
9	6,462	2,013, 31.1	931, 14.4	1,785, 27.6	821, 12.7	1,998, 30.9	903, 14.0	1,788, 27.7	810, 12.5
10	4,308	1,341, 31.1	623, 14.5	1,195, 27.7	545, 12.7	1,328, 30.8	608, 14.1	1,193, 27.7	544, 12.6
11	3,231	1,006, 31.1	467, 14.4	897, 27.8	406, 12.6	996, 30.8	456, 14.1	889, 27.5	405, 12.5
Truth	1,077	335, 31.1	155, 14.4	298, 27.7	135, 12.5	332, 30.8	152, 14.1	298, 27.7	135, 12.5

For the taxiing Aircraft B, a WA generally did not occur until the aircraft was on the runway (i.e., mean position of Aircraft B was 123.6 ft, SD 24.4 ft, from the runway centerline when transmitting data with truth accuracy). Since the aircraft was already past the runway shoulder, no action was taken and the aircraft continued across the runway.

For the departing Aircraft A when transmitting truth position data, 16.6% of the WAs occurred during takeoff roll when between 50 and 80 kts, 41.9% occurred when between 80 and 131 kts, and 41.5% occurred when greater than 131kts. The aircraft was unable to abort the departure after reaching takeoff decision speed (131 kts); therefore, for 41.5% of the departures in which WAs were issued, the aircraft continued along its predefined departure path and collisions were unavoidable. As described above, alerts were not inhibited above 80 kts as specified in the SURF IA SPR.

Position accuracy had little effect on collision avoidance; however, there were fewer collisions when Aircraft B was equipped when transmitting data with NACp 8 accuracy. As in the previous scenario, this was because, in some instances, Aircraft B was able to conduct emergency braking and stop before reaching the runway shoulder. Even though the WA was generated when the aircraft was already on the runway (according to the data), the actual location of the aircraft was far enough back from the runway that it could come to a complete stop before actually reaching the runway shoulder.

5.2.4 Runway Scenario – Arrival with Departure from Same Runway

For each of the 20 cases in this scenario, an initiation delay on Aircraft B (departure aircraft) was evaluated at 9 levels, for a total of 756 test runs.

Algorithm performance – For both aircraft, TIs were generated on approximately 100% of the test runs (Table 143). RSIs were issued on approximately 89% to 95% of the test runs for Aircraft A and on 5% to 94% of the test runs for Aircraft B, with higher percentages occurring when transmitting data with NACp 8 and 9 accuracy levels. CAs were generated on 78% to 81% of the test runs for Aircraft A and on 50% to 83% of the test runs for Aircraft B (Table 144). WAs were issued on 55% to 59% of the runs for Aircraft A and on 33% to 55% of the test runs for Aircraft B. For Aircraft A, there was no significant difference in the number of runs in which TIs ($p = 0.333$), RSIs ($p = 0.175$), CAs ($p = 0.881$), and WAs ($p = 0.930$) were generated between position accuracy levels. For Aircraft B, there was no significant difference ($p = 0.037$) in the number of runs in which TIs were generated between position accuracy levels. There was a significant difference ($p < 0.001$) in the number of runs in which RSIs and CAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies and in the number of runs in which WAs were generated between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies.

Table 143. SURF IA Indication Statistics Evasive Actions by NACp for Arrival with Departure from Same Runway Scenario.

NACp	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival)					
8	252	251, 99.6	131, 52.0	239, 94.8	49, 19.4
9	216	216, 100.0	21, 9.7	195, 90.3	3, 1.4
10	144	144, 100.0	12, 8.3	128, 88.9	0, 0.0
11	108	108, 100.0	9, 8.3	96, 88.9	0, 0.0
Truth	36	36, 100.0	4, 11.1	32, 88.9	0, 0.0
Aircraft B (Departure)					
8	252	249, 98.8	224, 88.9	236, 93.7	146, 57.9
9	216	216, 100.0	101, 46.8	72, 33.3	27, 12.5
10	144	144, 100.0	33, 22.9	7, 4.9	0, 0.0
11	108	108, 100.0	25, 23.1	5, 4.6	0, 0.0
Truth	36	36, 100.0	8, 22.2	2, 5.6	0, 0.0

Table 144. SURF IA Alert Statistics for All Evasive Actions by NACp Arrival with Departure from Same Runway Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
8	252	205, 81.3	54, 21.4	149, 59.1	69, 27.4
9	216	174, 80.6	8, 3.7	127, 58.8	7, 3.2
10	144	112, 77.8	0, 0.0	80, 55.6	0, 0.0
11	108	84, 77.8	0, 0.0	60, 55.6	0, 0.0
Truth	36	28, 77.8	0, 0.0	20, 55.6	0, 0.0
Aircraft B (Departure)					
8	252	209, 82.9	104, 41.3	139, 55.2	79, 31.4
9	216	133, 61.6	11, 5.1	96, 44.4	16, 7.4
10	144	73, 50.7	0, 0.0	48, 33.3	4, 2.8
11	108	55, 50.9	0, 0.0	36, 33.3	2, 1.8
Truth	36	18, 50.0	0, 0.0	12, 33.3	1, 2.8

When analyzing IAs that occurred when transmitting truth position data, TIs were issued on approach when approximately 2.8 NM prior to the runway threshold and 928 ft AGL, RSIs when 1.9 NM prior to the threshold and 626 ft AGL, CAs when 1.2 NM prior to the threshold and 420 ft AGL, and WAs when 0.5 NM prior to the threshold and 200 ft AGL. For the departing aircraft, the majority of the IAs occurred when the aircraft was in position and holding.

Toggling occurred frequently for TIs and also when transmitting data with NACp 8 position accuracy (Tables 143 and 144). For both Aircraft , there was a significant difference ($p < 0.001$) in the number of runs in which multiple TIs, multiple RSIs, multiple CAs, and multiple WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The toggling included gaps between IAs for less accurate position data (NACp 8 and 9). The toggling was also a result of aircraft maneuvering. Sometimes multiple alerts occurred after Aircraft A conducted a go-around maneuver and after Aircraft B began its takeoff roll. For both aircraft, TI toggling occurred when truth position data was transmitted. It was determined that for Aircraft A these multiple TIs were generated after the collision had already occurred. For Aircraft B, the multiple TIs occurred after Aircraft B had begun its takeoff roll. When transmitting accurate position data, one multiple WA occurred onboard Aircraft B after the aircraft had begun its takeoff roll and a collision occurred.

Analyzing by CD&R equipage level (Tables 145 and 146), for both aircraft, IAs were issued on a similar number of runs per IA and aircraft almost independent of the CD&R equipage level. For Aircraft A, there was no significant difference in the number of runs in which TIs (p = 0.25), RSIs (p = 0.27), CAs (p = 0.974) and WAs (p= 0.844) were generated between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which TIs (p = 0.249), RSIs (p = 0.425), CAs (p = 0.997) and WAs (p = 0.965) were generated between equipage levels.

Regarding IA toggling, for Aircraft A, there was no significant difference in the number of runs in which multiple TIs (p = 0.032), multiple RSIs (p = 0.954), multiple CAs (p= 0.822) and multiple WAs (p= 0.239) were generated between the levels of equipage. For Aircraft B, there was also no significant difference in the number of runs in which multiple TIs (p = 0.512), multiple RSIs (p= 0.10), multiple CAs (p= 0.895) and multiple WAs were generated (p= 0.151) between the levels of equipage.

Table 145. SURF IA Indication Statistics for All NACp by Evasive Action for Arrival with Departure from Same Runway Scenario.

CD&R Equipage	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	189	189, 100.0	55, 29.1	171, 90.5	14, 7.4
Aircraft A	189	189, 100.0	31, 16.4	167, 88.4	14, 7.4
Aircraft B	189	188, 99.5	47, 24.9	177, 93.7	12, 6.3
Both	189	189, 100.0	44, 23.3	175, 92.6	12, 6.3
Aircraft B (Departure)					
Neither	189	188, 99.5	103, 54.5	78, 41.3	36, 19.1
Aircraft A	189	189, 100.0	102, 54.0	90, 47.6	55, 29.1
Aircraft B	189	187, 98.9	90, 47.6	79, 41.8	43, 22.8
Both	189	189, 100.0	96, 50.8	75, 39.7	39, 20.6

Table 146. SURF IA Alert Statistics for All NACp by Evasive Action for Arrival with Departure from Same Runway Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	189	149, 78.8	18, 9.5	106, 56.1	25, 13.2
Aircraft A	189	152, 80.4	15, 7.9	111, 58.7	19, 10.1
Aircraft B	189	152, 80.4	13, 6.9	106, 56.1	19, 10.1
Both	189	150, 79.4	16, 8.5	113, 59.8	13, 6.9
Aircraft B (Departure)					
Neither	189	121, 64.0	31, 16.4	81, 42.9	33, 17.5
Aircraft A	189	123, 65.1	26, 13.8	84, 44.4	27, 14.3
Aircraft B	189	122, 64.5	30, 15.9	85, 45.0	24, 12.7
Both	189	122, 64.5	28, 14.8	81, 42.9	18, 9.5

IA statistics were also compiled by CD&R equipage level when truth position data was transmitted (Tables 147 and 148). The frequency of IA generation for Aircraft A was similar to that which occurred across all position accuracy levels (Tables 145 and 146). For Aircraft B, the frequency of RSI and alert generation was lower. The frequency of multiple TIs and multiple WAs were lower when transmitting data with truth position accuracy and there were no multiple RSIs or multiple CAs. For Aircraft A, there was no significant difference in the number of runs in which TIs (100% of runs for each equipage level), RSIs (p = 1.0), CAs (p = 0.999), WAs (p= 0.993), and multiple RSIs (p = 0.250) were generated between the

equipage levels. There was a significant difference in the number of runs in which multiple TIs ($p < 0.001$) were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and both aircraft equipped and in the number of runs in which multiple WAs ($p = 0.010$) were generated between Neither aircraft equipped vs. Aircraft A, Aircraft B, and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which TIs (100% of runs for each equipage level), CAs ($p = 0.998$), WAs ($p = 0.901$), and multiple TIs ($p = 0.126$) were generated between equipage levels. There was a significant difference in the number of runs in which RSIs ($p < 0.001$) were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped and multiple WAs ($p < 0.001$) were generated between Neither aircraft and Both aircraft equipped vs. Aircraft A and Aircraft B equipped.

Table 147. SURF IA Indication Statistics When Transmitting Truth Position Data for Arrival with Departure from Same Runway Scenario.

CD&R Equipage	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	189	189, 100.0	35, 18.5	168, 88.9	0, 0.0
Aircraft A	189	189, 100.0	5, 2.6	168, 88.9	1, 0.5
Aircraft B	189	189, 100.0	47, 24.9	168, 88.9	0, 0.0
Both	189	189, 100.0	21, 11.1	168, 88.9	0, 0.0
Aircraft B (Departure)					
Neither	189	189, 100.0	49, 25.9	13, 6.9	0, 0.0
Aircraft A	189	189, 100.0	47, 24.9	20, 10.6	0, 0.0
Aircraft B	189	189, 100.0	35, 18.5	0, 0.0	0, 0.0
Both	189	189, 100.0	34, 18.0	3, 1.6	0, 0.0

Table 148. SURF IA Alert Statistics When Transmitting Truth Position Data for Arrival with Departure from Same Runway Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	189	147, 77.8	0, 0.0	105, 55.6	6, 3.2
Aircraft A	189	146, 77.2	0, 0.0	105, 55.6	0, 0.0
Aircraft B	189	147, 77.8	0, 0.0	107, 56.6	3, 1.6
Both	189	147, 77.8	0, 0.0	107, 56.6	0, 0.0
Aircraft B (Departure)					
Neither	189	91, 48.1	0, 0.0	63, 33.3	20, 10.6
Aircraft A	189	89, 47.1	0, 0.0	63, 33.3	5, 2.6
Aircraft B	189	90, 47.6	0, 0.0	69, 36.5	5, 2.6
Both	189	90, 47.6	0, 0.0	66, 34.9	16, 8.5

Missed and nuisance alerts – The aircraft entered the missed and nuisance boundary mainly when transmitting data with NACp 8 position accuracy, as shown in Table 149. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was no significant difference ($p = 0.333$) in the number of runs in which the aircraft entered the nuisance boundary between position accuracy levels.

For the approach Aircraft A, the majority of occurrences of entering the missed boundary was after the aircraft had crossed the runway threshold for landing. The aircraft only entered the missed boundary while on approach before crossing the runway threshold during 2.0% of the test runs when transmitting data with

NACp 8 accuracy. Since Aircraft A tracked the extended centerline on approach and centerline after landing, the nuisance boundary was not entered.

The departing Aircraft B entered the missed boundary at least once for 97% of the test runs when transmitting data with NACp 8 accuracy. This was due to the criteria for entering the missed boundary. The aircraft was counted as entering the missed boundary when the aircraft's true position was within one runway width of the runway centerline, but the detected position was greater than one runway width from the centerline. As such, there was no buffer between when the aircraft was inside or outside the missed boundary so a measurable difference between the true and detected position could cause a missed boundary to be counted.

Table 149. SURF IA Missed and Nuisance Boundary Statistics for Arrival with Departure from Same Runway Scenario.

NACp	Entered Missed Boundary				Entered Nuisance Boundary			
	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Arrival)								
8	98, 38.9	3.4, 2.7	4.8, 4.4	4.6	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
9	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
10	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
11	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
Aircraft B (Departure)								
8	246, 97.6	9.5, 5.8	17.9, 13.0	20.8	1, 0.4	2.0, 0.0	0.4, 0.0	0.3
9	1, 0.5	3.0, 0.0	0.6, 0.0	0.6	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
10	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
11	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0

There was a low rate of missed IAs, as shown in Table 150, with a higher occurrence when transmitting data with NACp 8 position accuracy. There were no nuisance IAs for either aircraft. For Aircraft A, there was no significant difference ($p = 0.210$) in the number of runs in which missed TIs occurred between position accuracy levels. There was a significant difference ($p < 0.001$) in the number of runs in which missed RSIs, missed CAs, and missed WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was no significant difference ($p = 0.118$) in the number of runs in which missed CAs occurred between position accuracy levels. There was a significant difference ($p= 0.015$) in the number of runs in which missed TIs occurred between NACp 8 and 10 accuracies vs. NACp 9, 11, and truth accuracies. There was also a significant difference in the number of runs in which missed RSIs ($p = 0.019$) and missed WAs ($p < 0.001$) occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

For Aircraft A when transmitting data with NACp 8 accuracy, three of the missed TIs should have occurred approximately 2.8 NM prior to the threshold and 928 ft AGL. All other missed TIs should have occurred when approximately 30 ft prior to the threshold and 25 ft AGL. All of the missed RSIs should have occurred when approximately 1.9 NM prior to the threshold and 626 ft AGL. The missed CAs should have occurred when approximately 1.2 NM prior to the threshold and 418 AGL. The missed WAs should have occurred when approximately 0.5 NM prior to the threshold and 200 ft AGL. For Aircraft B, the missed TIs should have occurred at a variety of locations along the departure; in position prior to beginning departure roll until after lifting off and 827 ft AGL. The RSIs should have occurred when the aircraft had just begun its departure roll and at a 3 kt ground speed. When transmitting data with NACp 8 accuracy, the missed CAs should have occurred while the aircraft was in position and holding; all other missed CAs should have occurred after initiating the departure roll and at a 36 kt ground speed. Five of the missed WAs should have occurred after the aircraft initiated the departure roll and was from 35 to 153 kts. All other missed WAs should have occurred when the aircraft was in position prior to initiating the departure roll.

Table 150. SURF IA Missed IA Statistics for All Evasive Actions by NACp for Arrival with Departure from Same Runway Scenario.

NACp	Total # Runs	Missed TI (#, Runs, % Runs)	Missed RSI (# Runs, % Runs)	Missed CA (#, Runs, % Runs)	Missed WA (# Runs, % Runs)
Aircraft A (Arrival)					
8	252	22, 8.7	11, 4.4	9, 3.6	29, 11.5
9	216	12, 5.6	0, 0.0	0, 0.0	4, 1.9
10	144	8, 5.6	0, 0.0	0, 0.0	1, 0.7
11	108	5, 4.6	0, 0.0	0, 0.0	0, 0.0
Truth	36	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Departure)					
8	252	15, 6.0	8, 3.2	5, 2.0	30, 11.9
9	216	2, 0.9	1, 0.5	1, 0.5	6, 2.8
10	144	6, 4.2	1, 0.7	4, 2.8	0, 0.0
11	108	3, 2.8	1, 0.9	1, 0.9	1, 0.9
Truth	36	0, 0.0	0, 0.0	0, 0.0	0, 0.0

Analyzing by CD&R equipage level (Table 151), the rate of indications was higher for some equipage levels than others. For both aircraft, the rate of missed alerts was relatively evenly distributed across all CD&R equipage levels. For Aircraft A, there was a significant difference in the number of runs in which missed TIs ($p < 0.001$) occurred between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped and the number of runs in which missed RSIs ($p = 0.015$) occurred between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped. There was no significant difference in the number of runs in which missed CAs ($p = 0.505$) and missed WAs ($p = 0.946$) occurred between equipage levels. For Aircraft B, there was no significant difference in the number of runs in which missed TIs ($p = 0.077$), missed CAs ($p = 0.481$), and missed WAs ($p = 0.994$) occurred between equipage levels. There was a significant difference ($p = 0.002$) in the number of runs in which missed RSIs occurred between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped.

Table 151. SURF IA Missed IA Statistics for All NACp by Evasive Action for Arrival with Departure from Same Runway Scenario.

CD&R Equipage	Total # Runs	Missed TI (# Runs, % Runs)	Missed RSI (# Runs, % Runs)	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	189	13, 6.9	4, 2.1	2, 1.1	9, 4.8
Aircraft A	189	4, 2.1	6, 3.2	3, 1.6	9, 4.8
Aircraft B	189	27, 14.3	0, 0.0	1, 0.5	9, 4.8
Both	189	3, 1.6	1, 0.5	3, 1.6	7, 3.7
Aircraft B (Departure)					
Neither	189	12, 6.3	7, 3.7	2, 1.1	9, 4.8
Aircraft A	189	4, 2.1	4, 2.1	3, 1.6	9, 4.8
Aircraft B	189	6, 3.2	0, 0.0	2, 1.1	9, 4.8
Both	189	4, 2.1	0, 0.0	4, 2.1	10, 5.3

Unnecessary maneuvering - The number and percentage of test runs in which the aircraft maneuvered unnecessarily when transmitting data with the various accuracy levels is shown in Table 152. Unnecessary maneuvering only occurred when transmitting data with NACp 8 and 9 accuracies. For Aircraft A, there was no significant difference ($p = 0.026$) in the number of runs in which unnecessary maneuvers occurred between accuracy levels. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which unnecessary maneuvers occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 152. Unnecessary Maneuvers for All Evasive Actions by NACp Using SURF IA During Arrival with Departure from Same Runway Scenario.

NACp	Total # Runs	Aircraft A (Arrival) (# Runs, % Runs)	Aircraft B (Departure) (# Runs, % Runs)
8	126	5, 4.0	8, 6.3
9	108	3, 2.8	1, 0.9
10	72	0, 0.0	0, 0.0
11	54	0, 0.0	0, 0.0
Truth	18	0, 0.0	0, 0.0

The number and percentage of test runs in which the aircraft maneuvered unnecessarily based on the CD&R equipage level is shown in Table 153. There was no significant difference in the number of runs in which unnecessary maneuvers occurred between equipage levels for Aircraft A ($p = 0.284$) and Aircraft B ($p = 0.503$).

Table 153. Unnecessary Maneuvers for All NACp by Evasive Action Using SURF IA During Arrival with Departure from Same Runway Scenario.

CD&R Equipage	Total # Runs	Aircraft A (Arrival) (# Runs, % Runs)	Aircraft B (Departure) (# Runs, % Runs)
Neither	189	N/A	N/A
Aircraft A	189	6, 3.2	N/A
Aircraft B	189	N/A	6, 3.2
Both	189	2, 1.1	3, 1.6

Collision avoidance – The rate of near collisions was similar across all CD&R equipage levels and position accuracy levels, as shown in Table 154. The rate of collisions was similar when Neither aircraft or only the departing Aircraft B were equipped with CD&R. The rates were also similar (much less) when both aircraft or only the arriving Aircraft A were equipped, with no collisions occurring for NACp 9, 10, 11, and truth accuracies. For this scenario, collision avoidance was much more effective when the arrival aircraft was equipped with CD&R. When neither aircraft was equipped with CD&R, there was no significant difference ($p = 1.0$) in the number of runs in which near collisions or collisions occurred between position accuracy levels. When only Aircraft A was equipped, there was no significant difference ($p = 1.0$) in the number of runs in which near collisions occurred; however, there was a significant difference ($p < 0.001$) in the number of runs in which collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. When only Aircraft B was equipped, there was no significant difference in the number of runs in which near collisions ($p = 0.914$) or collisions ($p = 0.914$) occurred between position accuracy levels. When Both aircraft were equipped, there was no significant difference ($p = 0.981$) in the number of runs in which near collisions occurred; however, there was a significant difference ($p < 0.001$) in the number of runs in which collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 154. Number/Percentage of Near Collisions (NC) and Collisions (C) Using SURF IA for Equipage Combinations for Arrival with Departure from Same Runway Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	63	21, 33.3	21, 33.3	21, 33.3	12, 19.1	26, 41.3	26, 41.3	24, 38.1	8, 12.7
9	54	18, 33.3	18, 33.3	18, 33.3	0, 0.0	19, 35.2	19, 35.2	18, 33.3	0, 0.0
10	36	12, 33.3	12, 33.3	12, 33.3	0, 0.0	12, 33.3	12, 33.3	12, 33.3	0, 0.0
11	27	9, 33.3	9, 33.3	9, 33.3	0, 0.0	9, 33.3	9, 33.3	9, 33.3	0, 0.0
Truth	9	3, 33.3	3, 33.3	3, 33.3	0, 0.0	3, 33.3	3, 33.3	3, 33.3	0, 0.0

For the 152 runs in which a collision occurred, the approach aircraft was either 1.0 NM (4.6% of collision runs) or 0.5 NM (30.3%) prior to the runway threshold, at the threshold (33.6%), or at the glide-path aim-point (1,000 ft past threshold) (31.6%) when the other aircraft began its departure roll. Many of the collisions occurred when the approach aircraft was landing before the departure aircraft started its takeoff roll. Other times the departure aircraft had begun its roll but the approach aircraft landed and overtook the departing aircraft. When the departing aircraft was equipped with CD&R, the collision was sometimes caused by the aircraft aborting the departure, as was the case for two collisions when Both aircraft were equipped. In practice, a pilot would most likely continue the departure under these conditions.

For the twelve collisions when only Aircraft A was equipped, the aircraft received a WA on four of these runs but too late to take action before the collision. On two runs, WAs were not received; therefore, the aircraft did not take action. On these two runs a WA was issued for the truth accuracy condition; however, which indicates that the collisions occurred due to reduced data accuracy. On six runs, the aircraft initiated a go-around maneuver but collided with the departing aircraft just as it was beginning to ascend. For the 69 collisions that occurred when only Aircraft B was equipped, the aircraft received a WA but was in position and holding on 55 (79.7%) of these runs and did not take any action. On 14 (20.3%) of the runs, the departing aircraft aborted its departure but since the arrival aircraft continued its landing, collisions occurred. For the eight collisions that occurred when Both aircraft were equipped, on one run, neither aircraft received a WA and did not take action; however, there were WAs issued for the truth accuracy condition. On three runs, neither aircraft took action even though WAs were issued. The departing aircraft was in position and holding so it did not take action. The approach aircraft received the alerts too late to take action before the collision. On two runs, the approach aircraft initiated a go-around but the departing aircraft was in position and holding and did not maneuver. On two runs, both aircraft took action, on one run as the approach aircraft was climbing out and on the other run after the approach aircraft had landed.

5.2.5 Runway Scenario – Departures from Intersecting Runways

For each of the 20 cases in this scenario, an initiation delay on either Aircraft A or B was evaluated at 16 levels, for a total of 1,344 test runs.

Algorithm performance – For both aircraft, TIs were generated on approximately 54% to 81% of the test runs (Table 155). RSIs were issued during NACp 8 and 9 test runs only, for both aircraft. CAs were not generated for either departing aircraft (Table 156). WAs were issued on approximately 38% to 69% of the runs for both aircraft, depending on the position accuracy level. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which TIs, RSIs, and WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 155. SURF IA Indication Statistics for All Evasive Actions by NACp for Departures from Intersecting Runways Scenario.

NACp	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Departure Runway 14L)					
8	448	239, 53.4	77, 17.2	37, 8.3	1, 0.2
9	384	310, 80.7	131, 34.1	6, 1.6	0, 0.0
10	256	208, 81.2	96, 37.5	0, 0.0	0, 0.0
11	192	156, 81.2	72, 37.5	0, 0.0	0, 0.0
Truth	64	52, 81.2	24, 37.5	0, 0.0	0, 0.0
Aircraft B (Departure Runway 22R)					
8	448	248, 55.4	85, 19.0	49, 10.9	2, 0.4
9	384	306, 79.7	130, 33.9	10, 2.6	0, 0.0
10	256	208, 81.2	96, 37.5	0, 0.0	0, 0.0
11	192	156, 81.2	72, 37.5	0, 0.0	0, 0.0
Truth	64	52, 81.2	24, 37.5	0, 0.0	0, 0.0

Table 156. SURF IA Alert Statistics for All Evasive Actions by NACp for Departures from Intersecting Runways Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Departure Runway 14L)					
8	448	0, 0.0	0, 0.0	169, 37.7	19, 4.2
9	384	0, 0.0	0, 0.0	256, 66.7	7, 1.8
10	256	0, 0.0	0, 0.0	176, 68.8	0, 0.0
11	192	0, 0.0	0, 0.0	132, 68.8	0, 0.0
Truth	64	0, 0.0	0, 0.0	44, 68.8	0, 0.0
Aircraft B (Departure Runway 22R)					
8	448	0, 0.0	0, 0.0	171, 38.2	27, 6.0
9	384	0, 0.0	0, 0.0	255, 66.4	10, 2.6
10	256	0, 0.0	0, 0.0	176, 68.8	0, 0.0
11	192	0, 0.0	0, 0.0	132, 68.8	0, 0.0
Truth	64	0, 0.0	0, 0.0	44, 68.8	0, 0.0

The minimum and maximum distance from the runway threshold and ground speed when a TI and WA were issued when transmitting truth position data is presented in Table 157. For Aircraft A, TIs were issued from when the aircraft began its departure roll until approximately 3,900 ft from the runway threshold. WAs were generated when the aircraft was 292 ft to 5,064 ft from the runway threshold, when just lifting off. For Aircraft B, TIs were issued from when the aircraft began its departure roll until approximately 1,865 ft from the runway threshold. WAs were generated when the aircraft was 309 ft to 2,695 ft from the runway threshold.

Table 157. Aircraft Location When IAs Issued When Transmitting Truth Position Accuracy Using SURF IA for Departures from Intersecting Runways Scenario.

Indication or Alert Type	Aircraft A				Aircraft B			
	Minimum Distance from Threshold (ft)	GS (kts)	Maximum Distance from Threshold (ft)	GS (kts)	Minimum Distance from Threshold (ft)	GS (kts)	Maximum Distance from Threshold (ft)	GS (kts)
TI	2	2	3,905	150	-2	3	1,865	104
WA	292	41	5,064	169	309	42	2,695	125

For TIs, toggling occurred less frequently when transmitting data with NACp 8 accuracy (approximately 17% of the test runs) than when transmitting data with the other NACp accuracy levels (Tables 155 and 156). Minimal toggling occurred for RSIs when transmitting data with NACp 8 accuracy only. There was also a low toggling rate for WAs (NACp 8 and 9 accuracies only). There was no significant difference in the number of runs in which multiple RSIs occurred between position accuracy levels for Aircraft A ($p = 0.333$) and Aircraft B ($p = 0.111$). There was a significant difference ($p < 0.001$) in the number of runs in which multiple TIs and multiple WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The toggling included gaps between IAs for less accurate position accuracy (NACp 8 and 9). The toggling was also a result of aircraft maneuvering. Sometimes multiple IAs occurred after either or both aircraft aborted the takeoff. For both aircraft, multiple TIs were generated when transmitting truth position data. These multiple TIs occurred after either or both aircraft aborted the takeoff.

When analyzing by CD&R equipage level (Tables 158 and 159), IAs occurred consistently across equipage levels. For Aircraft A, there was no significant difference in the number of runs in which TIs ($p = 0.883$), RSIs ($p = 0.293$), and WAs ($p = 0.93$) occurred between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which TIs ($p = 0.81$), RSIs ($p = 0.134$), and WAs ($p = 0.935$) occurred between equipage levels.

Table 158. SURF IA Indication Statistics for All NACp by Evasive Action for Departures from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Departure 14L)					
Neither	336	236, 70.2	10, 3.0	13, 3.9	0, 0.0
Aircraft A	336	243, 72.3	113, 33.6	14, 4.2	0, 0.0
Aircraft B	336	245, 72.9	132, 39.3	6, 1.8	0, 0.0
Both	336	241, 71.7	145, 43.1	10, 3.0	1, 0.3
Aircraft B (Departure 22R)					
Neither	336	236, 70.2	11, 3.3	18, 5.4	0, 0.0
Aircraft A	336	243, 72.3	113, 33.6	12, 3.6	0, 0.0
Aircraft B	336	244, 72.6	136, 40.5	20, 6.0	1, 0.3
Both	336	247, 73.5	147, 43.8	9, 2.7	1, 0.3

Table 159. SURF IA Alert Statistics for All NACp by Evasive Action for Departures from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Departure 14L)					
Neither	336	0, 0.0	0, 0.0	196, 58.3	17, 5.1
Aircraft A	336	0, 0.0	0, 0.0	198, 58.9	3, 0.9
Aircraft B	336	0, 0.0	0, 0.0	193, 57.4	5, 1.5
Both	336	0, 0.0	0, 0.0	190, 56.5	1, 0.3
Aircraft B (Departure 22R)					
Neither	336	0, 0.0	0, 0.0	199, 59.2	21, 6.2
Aircraft A	336	0, 0.0	0, 0.0	191, 56.9	11, 3.3
Aircraft B	336	0, 0.0	0, 0.0	195, 58.0	3, 0.9
Both	336	0, 0.0	0, 0.0	193, 57.4	2, 0.6

The rate of TI toggling was high except when Neither aircraft were equipped with CD&R (Table 158). The rate of RSI toggling was very low. WA toggling was highest when Neither aircraft were equipped (Table 159). There was no significant difference in the number of runs in which multiple RSIs occurred between position accuracy levels for Aircraft A ($p = 0.250$) and Aircraft B ($p = 0.50$). There was a significant difference ($p < 0.001$) in the number of runs in which multiple TIs occurred between Neither aircraft equipped vs. Aircraft A, Aircraft B, and Both aircraft equipped. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs occurred between Neither aircraft equipped vs. Aircraft A, Aircraft B, and Both aircraft equipped. For Aircraft B, there was also a significant difference ($p < 0.001$) in the number of runs in which multiple WAs occurred between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped.

Alert statistics were also compiled by CD&R equipage level when truth position data was transmitted (Tables 160 and 161). The rate of IA generation was consistent across all equipage levels as was the case when transmitting data with various position accuracies (Tables 158 and 159); however, there were no multiple WAs when transmitting data with truth position accuracy. For both aircraft, there was no significant difference ($p = 1.0$) in the number of runs in which TIs and WAs occurred between the levels of equipage. However, there was a significant difference ($p < 0.001$) in the number of runs in which multiple TIs occurred between Neither aircraft equipped vs. Aircraft A, Aircraft B, and Both aircraft equipped.

Table 160. SURF IA Indication Statistics When Transmitting Truth Position Data for Departures from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Departure 14L)					
Neither	336	274, 81.5	0, 0.0	0, 0.0	0, 0.0
Aircraft A	336	274, 81.5	111, 33.0	0, 0.0	0, 0.0
Aircraft B	336	274, 81.5	125, 37.2	0, 0.0	0, 0.0
Both	336	274, 81.5	142, 42.3	0, 0.0	0, 0.0
Aircraft B (Departure 22R)					
Neither	336	274, 81.5	0, 0.0	0, 0.0	0, 0.0
Aircraft A	336	274, 81.5	111, 33.0	0, 0.0	0, 0.0
Aircraft B	336	274, 81.5	125, 37.2	0, 0.0	0, 0.0
Both	336	274, 81.5	142, 42.3	0, 0.0	0, 0.0

Table 161. SURF IA Alert Statistics When Transmitting Truth Position Data for Departures from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Departure 14L)					
Neither	336	0, 0.0	0, 0.0	231, 68.8	0, 0.0
Aircraft A	336	0, 0.0	0, 0.0	231, 68.8	0, 0.0
Aircraft B	336	0, 0.0	0, 0.0	231, 68.8	0, 0.0
Both	336	0, 0.0	0, 0.0	231, 68.8	0, 0.0
Aircraft B (Departure 22R)					
Neither	336	0, 0.0	0, 0.0	231, 68.8	0, 0.0
Aircraft A	336	0, 0.0	0, 0.0	231, 68.8	0, 0.0
Aircraft B	336	0, 0.0	0, 0.0	231, 68.8	0, 0.0
Both	336	0, 0.0	0, 0.0	231, 68.8	0, 0.0

Missed and nuisance alerts – The missed and nuisance boundaries were only entered when transmitting data with NACp 8 position accuracy, as shown in Table 162. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was no significant difference ($p = 0.333$) in the number of runs in which the aircraft entered the nuisance boundary between position accuracies.

The aircraft entered the missed boundary for a high percentage of the test runs when transmitting data with NACp 8 accuracy due to the criteria for entering the missed boundary. The aircraft was counted as entering the missed boundary when the aircraft's true position was within one runway width of the runway centerline, but the detected position was greater than one runway width from the centerline. There was no buffer between when the aircraft was inside or outside the missed boundary so a measurable difference between the true and detected position could cause a missed boundary to be counted.

For both aircraft, only missed TIs and missed WAs occurred when transmitting data with NACp 8 and 9 accuracies (Table 163). For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which missed TIs and missed WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. Nuisance IAs did not occur for either aircraft.

Further investigation was made into the missed IAs that occurred when transmitting data with NACp 9 accuracy. For both aircraft, the missed TIs occurred after both aircraft initiated the takeoff roll (Aircraft A: 3 runs; Aircraft B: 6 runs), after Aircraft A rejected the takeoff (Aircraft A: 1 run; Aircraft B: 2 runs), and

after Aircraft B rejected the takeoff (both aircraft: 2 runs). All of the missed WAs occurred after both aircraft initiated the takeoff roll and before any action was taken.

Table 162. SURF IA Missed and Nuisance Boundary Statistics for Departures from Intersecting Runways Scenario.

NACp	Entered Missed Boundary				Entered Nuisance Boundary			
	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Departure Runway 14L)								
8	362, 80.8	3.9, 2.8	8.1, 7.7	24.3	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
9	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
10	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
11	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
Aircraft B (Departure Runway 22R)								
8	313, 69.9	3.6, 2.5	7.8, 7.6	22.8	1, 0.2	1.0, 0.0	0.2, 0.0	0.3
9	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
10	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
11	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0

Table 163. SURF IA Missed IA Statistics for All Evasive Actions by NACp for Departures from Intersecting Runways Scenario.

NACp	Total # Runs	Missed TI (#, Runs, % Runs)	Missed RSI (# Runs, % Runs)	Missed CA (#, Runs, % Runs)	Missed WA (# Runs, % Runs)
Aircraft A (Departure Runway 14L)					
8	448	145, 32.4	0, 0.0	0, 0.0	139, 31.0
9	384	6, 1.6	0, 0.0	0, 0.0	8, 2.1
10	256	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	192	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	64	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Departure Runway 22R)					
8	448	128, 28.6	0, 0.0	0, 0.0	137, 30.6
9	384	10, 2.6	0, 0.0	0, 0.0	9, 2.3
10	256	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	192	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	64	0, 0.0	0, 0.0	0, 0.0	0, 0.0

Analyzing by CD&R equipage level (Table 164), the missed IAs occurred consistently across equipage levels. For Aircraft A, there was no significant difference in the number of runs in which missed TIs ($p = 0.864$) and missed WAs ($p = 0.772$) occurred between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which missed TIs ($p = 0.754$) and missed WAs ($p = 0.783$) occurred between equipage levels.

Unnecessary maneuvering – No unnecessary maneuvers occurred for this scenario.

Table 164. SURF IA Missed IA Statistics for All NACp by Evasive Action for Departures from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	Missed TI (# Runs, % Runs)	Missed RSI (# Runs, % Runs)	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)
Aircraft A (Departure 14L)					
Neither	336	41, 12.2	0, 0.0	0, 0.0	35, 10.4
Aircraft A	336	38, 11.3	0, 0.0	0, 0.0	33, 9.8
Aircraft B	336	34, 10.1	0, 0.0	0, 0.0	38, 11.3
Both	336	38, 11.3	0, 0.0	0, 0.0	41, 12.2
Aircraft B (Departure 22R)					
Neither	336	38, 11.3	0, 0.0	0, 0.0	32, 9.5
Aircraft A	336	37, 11.0	0, 0.0	0, 0.0	40, 11.9
Aircraft B	336	32, 9.5	0, 0.0	0, 0.0	36, 10.7
Both	336	31, 9.2	0, 0.0	0, 0.0	38, 11.3

Collision avoidance – Most near collisions and collisions occurred in the absence of CD&R, approximately 6% of the runs, as shown in Table 165. The addition of CD&R eliminated near collisions and collisions when transmitting data with NACp 10, 11, and truth position accuracy levels and reduced the occurrence when transmitting data with NACp 8 and 9 accuracy levels. When neither aircraft was equipped with CD&R, there was no significant difference ($p = 1.0$) in the number of runs in which near collisions and collisions occurred between position accuracy levels. When only Aircraft A was equipped, there was a significant difference ($p = 0.017$) in the number of runs in which near collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. There was no significant difference ($p = 0.044$) in the number of runs in which collisions occurred between accuracy levels. When only Aircraft B was equipped, there was a significant difference in the number of runs in which near collisions ($p = 0.004$) and collisions ($p = 0.012$) occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. When Both aircraft were equipped, there was no significant difference ($p = 0.086$) in the number of runs in which near collisions and collisions occurred between position accuracy levels.

Table 165. Number/Percentage of Near Collisions (NC) and Collisions (C) Using SURF IA for Equipage Combinations for Departures from Intersecting Runways Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	112	7, 6.2	7, 6.2	5, 4.5	4, 3.6	5, 4.5	4, 3.6	4, 3.6	4, 3.6
9	96	6, 6.2	6, 6.2	1, 1.0	1, 1.0	0, 0.0	0, 0.0	2, 2.1	2, 2.1
10	64	4, 6.2	4, 6.2	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	48	3, 6.2	3, 6.2	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	16	1, 6.2	1, 6.2	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0

For the 36 runs in which a collision occurred, except for one, Aircraft A (departing Runway 14L) was at approximately 50 kts (approximately 420 ft from the runway threshold) when Aircraft B began its departure from Runway 22R. For the other run, Aircraft A was at approximately 70 kts (approximately 820 ft from the runway threshold) when Aircraft B began its departure. Most of the collisions occurred when Aircraft A had just lifted off and Aircraft B was on departure roll at approximately 125 kts.

For the five collisions that occurred when Aircraft A was equipped, on three runs no WA was generated and the aircraft did not take action. On one run, a WA was issued but too late to take action before the collision. On one run, the aircraft received a WA and took action but did not have time to avoid the collision. For the four collisions that occurred when Aircraft B was equipped, no action was taken on three runs because no WAs were issued. On the other run, a WA was issued too late for the aircraft to maneuver. For the six collisions that occurred when Both aircraft were equipped, Aircraft A did not receive a WA on

five of the runs and did not maneuver; on one run an alert was issued but too late for maneuvering. Aircraft B did not receive alerts on any of these runs and did not maneuver. For all of the runs in which WAs were not generated when transmitting data with NACp 8 and 9 accuracy, alerts would have been issued generally 16 to 17 seconds before the collision if truth data were available.

5.2.6 Runway Scenario – Arrival and Departure from Intersecting Runways

For each of the 20 cases in this scenario, an initiation delay on Aircraft B was evaluated at 13 levels, for a total of 1,092 test runs.

Algorithm performance – For both aircraft, TIs were generated on approximately 76% to 85% of the test runs, with less TIs generated when transmitting data with NACp 8 accuracy (Table 166). RSIs were issued on approximately 11% and 3% of the test runs for approach Aircraft A and on 24% and 5% of the test runs for departure Aircraft B, when transmitting data with NACp 8 and 9 accuracy levels, respectively. CAs were generated on 18% to 23% of the test runs for Aircraft A for all position accuracy levels and on 7% and 1% of the test runs for Aircraft B when transmitting data with NACp 8 and 9 accuracy levels, respectively (Table 167). WAs were issued on 40% to 50% of the runs for both aircraft. For Aircraft A, there was a significant difference in the number of runs in which TIs ($p = 0.007$) and RSIs ($p < 0.001$) were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. There was no significant difference in the number of runs in which CAs ($p = 0.474$) and WAs ($p = 0.080$) were generated between accuracy levels. For Aircraft B, there was a significant difference in the number of runs in which TIs ($p = 0.010$), RSIs ($p < 0.001$), and CAs ($p < 0.001$) were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. There was no significant difference ($p = 0.204$) in the number of runs in which WAs were generated between accuracy levels.

When analyzing IAs that occurred when transmitting truth position data, for the approach aircraft, TIs were issued beginning approximately 2.9 NM prior to the runway threshold. RSIs were not issued. CAs were issued when approximately 1.3 NM to 0.7 NM prior to the threshold. WAs were issued when approximately 0.5 NM to 0.2 NM prior to the threshold and after landing approximately 2,065 ft to 4,600 ft from the threshold when 129 kts to 55 kts. For the departing aircraft, TIs were issued when initiating the takeoff roll until 1,025 ft from the threshold and 77 kts. WAs were issued when 297 ft to 745 ft from the threshold when 42 kts to 66 kts. RSIs and CAs were not issued onboard the departing aircraft when transmitting accurate position data.

Table 166. SURF IA Indication Statistics for All Evasive Actions by NACp for Arrival and Departure from Intersecting Runways Scenario.

NACp	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival)					
8	364	276, 75.8	113, 31.0	40, 11.0	1, 0.3
9	312	267, 85.6	100, 32.0	10, 3.2	1, 0.3
10	208	176, 84.6	60, 28.9	0, 0.0	0, 0.0
11	156	132, 84.6	45, 28.9	0, 0.0	0, 0.0
Truth	52	44, 84.6	15, 28.9	0, 0.0	0, 0.0
Aircraft B (Departure)					
8	364	275, 75.5	125, 34.3	89, 24.4	4, 1.1
9	312	264, 84.6	103, 33.0	15, 4.8	0, 0.0
10	208	176, 84.6	60, 28.9	0, 0.0	0, 0.0
11	156	132, 84.6	45, 28.9	0, 0.0	0, 0.0
Truth	52	44, 84.6	15, 28.9	0, 0.0	0, 0.0

Table 167. SURF IA Alert Statistics for All Evasive Actions by NACp for Arrival and Departure from Intersecting Runways Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
8	364	66, 18.1	10, 2.8	147, 40.4	35, 9.6
9	312	72, 23.1	3, 1.0	156, 50.0	11, 3.5
10	208	48, 23.1	0, 0.0	104, 50.0	0, 0.0
11	156	36, 23.1	0, 0.0	76, 48.7	0, 0.0
Truth	52	12, 23.1	0, 0.0	24, 46.1	0, 0.0
Aircraft B (Departure)					
8	364	25, 6.9	0, 0.0	153, 42.0	30, 8.2
9	312	3, 1.0	0, 0.0	157, 50.3	11, 3.5
10	208	0, 0.0	0, 0.0	104, 50.0	0, 0.0
11	156	0, 0.0	0, 0.0	76, 48.7	0, 0.0
Truth	52	0, 0.0	0, 0.0	24, 46.1	0, 0.0

For TIs, toggling occurred on approximately 29% to 34% of the test runs. For RSIs, CAs, and WAs, toggling only occurred when transmitting data with NACp 8 and 9 accuracy levels (Tables 166 and 167). For Aircraft A, there was no significant difference in the number of runs in which multiple TIs ($p = 0.918$) and multiple RSIs ($p = 0.528$) were generated between accuracy levels. There was a significant difference in the number of runs in which multiple CAs ($p = 0.002$) and multiple WAs ($p < 0.001$) were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was no significant difference ($p = 0.564$) in the number of runs in which multiple TIs were generated between accuracy levels. There was a significant difference in the number of runs in which multiple RSIs ($p = 0.012$) and multiple WAs ($p < 0.001$) were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The toggling included gaps between IAs for less accurate position accuracy (NACp 8 and 9). The toggling was also a result of aircraft maneuvering. Sometimes multiple IAs occurred after Aircraft A conducted a go-around maneuver or conducted accelerated braking and when Aircraft B aborted the takeoff or stopped. For both aircraft, multiple TIs were generated when transmitting truth position data. These multiple TIs occurred after Aircraft A conducted accelerated braking (3 runs), Aircraft A conducted a go-around and Aircraft B aborted the takeoff (1 run), Aircraft A conducted accelerated braking and Aircraft B aborted the takeoff (3 runs), or Aircraft B aborted the takeoff (8 runs).

When analyzing by CD&R equipage level (Tables 168 and 169), the rate of IA generation was similar between equipage levels per aircraft. For Aircraft A, there was no significant difference in the number of runs in which TIs ($p = 0.67$), RSIs ($p = 0.079$), CAs ($p = 0.978$), and WAs ($p = 0.588$) were generated between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which TIs ($p = 0.983$), RSIs ($p = 0.054$), CAs ($p = 0.562$), and WAs ($p = 0.563$) were generated between equipage levels.

For both aircraft, the TI toggling rate was highest when Both aircraft were equipped with CD&R and lowest when Neither aircraft were equipped. The RSI and CA toggling rate was low and similar across all equipage levels per aircraft. WA toggling occurred more frequently when Neither aircraft and Aircraft A were equipped. For Aircraft A, there was no significant difference in the number of runs in which multiple RSIs ($p = 0.50$) and multiple CAs ($p = 0.264$) were generated but there was a significant difference ($p < 0.001$) in the number of runs in which multiple TIs and multiple WAs were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped. For Aircraft B, there was no significant difference ($p = 0.124$) in the number of runs in which multiple RSIs were generated but there was a significant difference ($p < 0.001$) in the number of runs in which multiple TIs and multiple WAs were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped.

Table 168. SURF IA Indication Statistics for All NACp by Evasive Action for Arrival and Departure from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	273	217, 79.5	26, 9.5	18, 6.6	1, 0.4
Aircraft A	273	227, 83.2	72, 26.4	15, 5.5	1, 0.4
Aircraft B	273	225, 82.4	112, 41.0	11, 4.0	0, 0.0
Both	273	226, 82.8	123, 45.0	6, 2.2	0, 0.0
Aircraft B (Departure)					
Neither	273	222, 81.3	24, 8.8	23, 8.4	0, 0.0
Aircraft A	273	224, 82.0	76, 27.8	19, 7.0	0, 0.0
Aircraft B	273	224, 82.0	117, 42.9	37, 13.6	2, 0.7
Both	273	221, 81.0	131, 48.0	25, 9.2	2, 0.7

Table 169. SURF IA Alert Statistics for All NACp by Evasive Action for Arrival and Departure from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	273	60, 22.0	2, 0.7	136, 49.8	26, 9.5
Aircraft A	273	59, 21.6	2, 0.7	127, 46.5	12, 4.4
Aircraft B	273	56, 20.5	5, 1.8	122, 44.7	5, 1.8
Both	273	59, 21.6	4, 1.5	122, 44.7	3, 1.1
Aircraft B (Departure)					
Neither	273	7, 2.6	0, 0.0	138, 50.5	21, 7.7
Aircraft A	273	5, 1.8	0, 0.0	126, 46.1	14, 5.1
Aircraft B	273	10, 3.7	0, 0.0	122, 44.7	5, 1.8
Both	273	6, 2.2	0, 0.0	128, 46.9	1, 0.4

IA statistics were also compiled by CD&R equipage level when truth position data was transmitted (Tables 170 and 171). The TI rate for both aircraft was slightly higher than the rate when transmitting data with various position accuracy levels (Tables 168 and 169); however, the rate of multiple TIs was reduced. RSIs were not issued when transmitting accurate data. The CA rate for Aircraft A was similar to that which occurred when transmitting data with various position accuracy levels. CAs were not generated for Aircraft B when transmitting accurate data. The WA rate for both aircraft was similar to the rate when transmitting data with various position accuracy levels. There were no multiple CAs or WAs when transmitting accurate data. For Aircraft A, there was no significant difference in the number of runs in which TIs ($p = 0.966$), CAs ($p = 1.0$), and WAs ($p = 1.0$) were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which multiple TIs were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which TIs ($p = 0.966$) and WAs ($p = 1.0$) were generated but there was a significant difference ($p < 0.001$) in the number of runs in which multiple TIs were generated between Neither aircraft and aircraft A equipped vs. Aircraft B and Both aircraft equipped.

Table 170. SURF IA Indication Statistics When Transmitting Truth Position Data for Arrival and Departure from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	273	235, 86.1	0, 0.0	0, 0.0	0, 0.0
Aircraft A	273	237, 86.8	54, 19.8	0, 0.0	0, 0.0
Aircraft B	273	236, 86.5	99, 36.3	0, 0.0	0, 0.0
Both	273	233, 85.3	111, 40.7	0, 0.0	0, 0.0
Aircraft B (Departure)					
Neither	273	235, 86.1	0, 0.0	0, 0.0	0, 0.0
Aircraft A	273	237, 86.8	54, 19.8	0, 0.0	0, 0.0
Aircraft B	273	236, 86.5	99, 36.3	0, 0.0	0, 0.0
Both	273	233, 85.3	111, 40.7	0, 0.0	0, 0.0

Table 171. SURF IA Alert Statistics When Transmitting Truth Position Data for Arrival and Departure from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	273	63, 23.1	0, 0.0	126, 46.1	0, 0.0
Aircraft A	273	63, 23.1	0, 0.0	126, 46.1	0, 0.0
Aircraft B	273	63, 23.1	0, 0.0	126, 46.1	0, 0.0
Both	273	63, 23.1	0, 0.0	126, 46.1	0, 0.0
Aircraft B (Departure)					
Neither	273	0, 0.0	0, 0.0	126, 46.1	0, 0.0
Aircraft A	273	0, 0.0	0, 0.0	126, 46.1	0, 0.0
Aircraft B	273	0, 0.0	0, 0.0	126, 46.1	0, 0.0
Both	273	0, 0.0	0, 0.0	126, 46.1	0, 0.0

Missed and nuisance alerts – The number of runs in which the aircraft entered the defined missed and nuisance boundaries increased as the position accuracy decreased, as shown in Table 172. The number of times (count) and amount of time (duration and percentage of run length) that the aircraft were within the boundaries was generally greater when transmitting less accurate data. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. Since Aircraft A tracked the extended centerline on approach and centerline after landing, the nuisance boundary was not entered. For Aircraft B, there was a significant difference ($p = 0.006$) in the number of runs in which the aircraft entered the nuisance boundary between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies.

For the approach Aircraft A, the majority of occurrences of entering the missed boundary was after the aircraft had crossed the runway threshold for landing. The aircraft only entered the missed boundary while on approach before crossing the runway threshold during 1.1% of the test runs when transmitting data with NACp 8 accuracy.

The departing Aircraft B entered the missed boundary for a high percentage of the test runs when transmitting data with NACp 8 accuracy. This was due to the criteria for entering the missed boundary. The aircraft was counted as entering the missed boundary when the aircraft's true position was within one runway width of the runway centerline, but the detected position was greater than one runway width from the centerline. There was no buffer between when the aircraft was inside or outside the missed boundary so a measurable difference between the true and detected position could cause a missed boundary to be

counted. The departing aircraft entered the nuisance boundary after lifting off and over 600 ft AGL. The aircraft started drifting from the runway centerline. Since there was no buffer between when the aircraft was inside or outside the nuisance boundary, as was the case for the missed boundary definition, a measurable difference between the true and detected position near the boundary (one runway width from the centerline) could cause a nuisance boundary to be counted.

Table 172. SURF IA Missed and Nuisance Boundary Statistics for Arrival and Departure from Intersecting Runways Scenario.

	Entered Missed Boundary				Entered Nuisance Boundary			
NACp	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Arrival)								
8	214, 58.8	5.0, 3.3	9.1, 7.9	7.5	0, 0.0	0, 0.0	0, 0.0	0.0
9	1, 0.3	2.0, 0.0	1.6, 0.0	1.2	0, 0.0	0, 0.0	0, 0.0	0.0
10	0, 0.0	0, 0.0	0.0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
11	0, 0.0	0, 0.0	0.0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0, 0.0	0.0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Aircraft B (Departure)								
8	311, 85.4	5.3, 3.4	10.2, 8.9	12.3	35, 9.6	1.3, 0.9	2.7, 2.2	5.3
9	38, 12.2	1.1, 0.4	2.0, 1.4	3.6	26, 8.3	1.2, 0.4	1.1, 0.7	2.1
10	28, 13.5	1.0, 0.2	0.7, 0.4	1.3	11, 5.3	1.0, 0.0	0.7, 0.4	1.3
11	15, 9.6	1.0, 0.0	0.4, 0.2	0.7	4, 2.6	1.0, 0.0	0.4, 0.2	0.8
Truth	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0

The number of test runs that contained missed IAs was low except when transmitting data with NACp 8 accuracy, as shown in Table 173. For both aircraft, missed TIs occurred when transmitting data with NACp 8 and 9 accuracy only. Missed RSIs did not occur for either aircraft. Missed CAs only occurred for Aircraft A when transmitting data with NACp 8 accuracy. Missed WAs occurred mostly when transmitting data with NACp 8 accuracy. Nuisance alerts were not generated for either aircraft. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which missed TIs, missed CAs, and missed WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which missed TIs and missed WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 173. SURF IA Missed IA Statistics for All Evasive Actions by NACp for Arrival and Departure from Intersecting Runways Scenario.

NACp	Total # Runs	Missed TI (#, Runs, % Runs)	Missed RSI (# Runs, % Runs)	Missed CA (#, Runs, % Runs)	Missed WA (# Runs, % Runs)
Aircraft A (Arrival)					
8	364	77, 21.2	0, 0.0	18, 4.9	34, 9.3
9	312	4, 1.3	0, 0.0	0, 0.0	1, 0.3
10	208	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	156	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	52	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Departure)					
8	364	65, 17.9	0, 0.0	0, 0.0	30, 8.2
9	312	4, 1.3	0, 0.0	0, 0.0	0, 0.0
10	208	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	156	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	52	0, 0.0	0, 0.0	0, 0.0	0, 0.0

Missed TIs should have occurred after Aircraft B initiated its takeoff roll (92% of missed TIs), after Aircraft B rejected its takeoff (4.7% of missed TIs), and after Aircraft A conducted accelerated braking after landing (3.3% of missed TIs). All of the missed CAs and missed WAs should have occurred after Aircraft B initiated its takeoff roll.

Analyzing by CD&R equipage level (Table 174), the missed TIs and missed CAs occurred fairly evenly across equipage levels. For Aircraft A, missed WAs occurred slightly more often when Aircraft B and Both aircraft were equipped with CD&R. For Aircraft B, slightly more missed WAs occurred when Aircraft A and Aircraft B were equipped. For Aircraft A, there was no significant difference in the number of runs in which missed TIs ($p = 0.948$) and missed CAs ($p = 0.175$) occurred but there was a significant difference ($p = 0.018$) in the number of runs in which missed WAs occurred between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which missed TIs ($p = 0.704$) and missed WAs ($p = 0.044$) occurred between equipage levels.

Table 174. SURF IA Missed IA Statistics for All NACp by Evasive Action for Arrival and Departure from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	Missed TI (#, Runs, % Runs)	Missed RSI (# Runs, % Runs)	Missed CA (#, Runs, % Runs)	Missed WA (# Runs, % Runs)
Aircraft A (Arrival)					
Neither	273	21, 7.7	0, 0.0	3, 1.1	2, 0.7
Aircraft A	273	21, 7.7	0, 0.0	4, 1.5	7, 2.6
Aircraft B	273	21, 7.7	0, 0.0	7, 2.6	13, 4.8
Both	273	18, 6.6	0, 0.0	4, 1.5	13, 4.8
Aircraft B (Departure)					
Neither	273	14, 5.1	0, 0.0	0, 0.0	2, 0.7
Aircraft A	273	20, 7.3	0, 0.0	0, 0.0	10, 3.7
Aircraft B	273	19, 7.0	0, 0.0	0, 0.0	12, 4.4
Both	273	16, 5.9	0, 0.0	0, 0.0	6, 2.2

Unnecessary maneuvering - The percentage of test runs in which the aircraft maneuvered unnecessarily when transmitting data with various accuracy levels is shown in Table 175. Unnecessary maneuvers did not occur for Aircraft A. The frequency of occurrences of unnecessary maneuvers for Aircraft B was steady across accuracy levels, approximately 3% of test runs, with no unnecessary maneuvers when transmitting accurate data. There was no significant difference ($p = 1.0$) in the number of runs in which unnecessary maneuvers occurred between accuracy levels.

Table 175. Unnecessary Maneuvers for ALL Evasive Actions by NACp Using SURF IA During Arrival and Departure from Intersecting Runways Scenario.

NACp	Total # Runs	Aircraft A (Arrival) (# Runs, % Runs)	Aircraft B (Departure) (# Runs, % Runs)
8	182	0, 0.0	6, 3.3
9	156	0, 0.0	5, 3.2
10	104	0, 0.0	3, 2.9
11	78	0, 0.0	2, 2.6
Truth	26	0, 0.0	0, 0.0

The number and percentage of test runs in which the aircraft maneuvered unnecessarily based on the CD&R equipage level is shown in Table 176. There was no significant difference ($p = 1.0$) in the number of runs in which unnecessary maneuvers occurred between equipage levels.

Table 176. Unnecessary Maneuvers for All NACp by Evasive Action Using SURF IA During Arrival and Departure from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	Aircraft A (Arrival) (# Runs, % Runs)	Aircraft B (Departure) (# Runs, % Runs)
Neither	273	N/A	N/A
Aircraft A	273	0, 0.0	N/A
Aircraft B	273	N/A	8, 2.9
Both	273	0, 0.0	8, 2.9

Collision avoidance – The most near collisions and collisions occurred in the absence of CD&R, approximately 8% of the runs, as shown in Table 177. The addition of CD&R eliminated near collisions and collisions when transmitting data with NACp 9, 10, 11, and truth position accuracy levels and reduced the occurrence when transmitting data with NACp 8 accuracy. Collision avoidance was most effective when only arrival Aircraft A was equipped with CD&R. When neither aircraft was equipped with CD&R, there was no significant difference ($p = 1.0$) in the number of runs in which near collisions and collisions occurred between accuracy levels. When only Aircraft A was equipped, there was no significant difference in the number of runs in which near collisions ($p = 0.036$) and collisions ($p = 0.11$) occurred between accuracy levels. When only Aircraft B was equipped, there was a significant difference ($p = 0.004$) in the number of runs in which near collisions and collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. When Both aircraft were equipped, there was a significant difference ($p = 0.012$) in the number of runs in which near collisions and collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 177. Number/Percentage of Near Collisions (NC) and Collisions (C) Using SURF IA for Equipage Combinations for Arrival and Departure from Intersecting Runways Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	91	7, 7.7	7, 7.7	3, 3.3	2, 2.2	5, 5.5	5, 5.5	4, 4.4	4, 4.4
9	78	6, 7.7	6, 7.7	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0
10	52	4, 7.7	4, 7.7	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	39	3, 7.7	3, 7.7	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	13	1, 7.7	1, 7.7	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0

All of the collisions but one occurred on runs in which the arrival Aircraft A landed and was approximately 0.25 NM from the runway threshold when the departing Aircraft B began its takeoff roll. The other collision occurred on a run in which the arrival aircraft was approximately 630 ft from the runway threshold after landing when the departing aircraft began to roll. For the two collisions when Aircraft A was equipped, the aircraft did not take action because the WAs were issued too late for maneuvering to occur before the collision. For the five collisions when Aircraft B was equipped, on one run no WA was issued and the aircraft did not take action. On two runs, the WA actually occurred just after the collision. On the last two runs, WAs were issued and action was taken but too late to avoid the collision. For the four collisions when Both aircraft were equipped, only the departing aircraft maneuvered on one run but too late to avoid the collision. The aircraft did not maneuver for these runs because WAs were not issued or issued too late. For four of these runs that resulted in collision, a WA was not issued on an aircraft transmitting NACp 8 data but was issued for the same situation with truth accuracy; therefore, collisions may have been avoided on these runs if the data was more accurate.

5.2.7 Runway Scenario – Head-On Arrivals

For each of the 20 cases in this scenario, an initiation delay on Aircraft B was evaluated at 14 levels, for a total of 1,176 test runs.

Algorithm performance – For Aircraft A, TIs were generated on 11% to 69% of the test runs (Table 178). For Aircraft B, TIs were generated on 80% to 91% of the test runs. RSIs were issued on approximately 93% to 99% of the test runs for Aircraft A and on 85% to 90% of the test runs for Aircraft B. CAs were generated on 43% to 86% of the test runs for Aircraft A and on 82% to 87% of the test runs for Aircraft B (Table 179). WAs were issued on 81% to 86% of the test runs for both aircraft. For Aircraft A, there was no significant difference ($p = 0.551$) in the number of runs in which WAs were generated but there was a significant difference ($p < 0.001$) in the number of runs in which TIs, RSIs, and CAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was no significant difference in the number of runs in which RSIs ($p = 0.499$), CAs ($p = 0.493$), and WAs ($p = 0.365$) were generated but there was a significant difference ($p < 0.001$) in the number of runs in which TIs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 178. SURF IA Indication Statistics for All Evasive Actions by NACp for Head-On Arrivals Scenario.

NACp	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
8	392	270, 68.9	169, 43.1	390, 99.5	289, 73.7
9	336	52, 15.5	3, 0.9	317, 94.3	139, 41.4
10	224	24, 10.7	0, 0.0	208, 92.9	40, 17.9
11	168	18, 10.7	0, 0.0	156, 92.9	30, 17.9
Truth	56	6, 10.7	0, 0.0	52, 92.9	10, 17.9
Aircraft B (Arrival Runway 28)					
8	392	357, 91.1	259, 66.1	351, 89.5	95, 24.2
9	336	274, 81.5	55, 16.4	288, 85.7	25, 7.4
10	224	179, 79.9	11, 4.9	191, 85.3	16, 7.1
11	168	133, 79.2	11, 6.5	147, 87.5	12, 7.1
Truth	56	45, 80.4	2, 3.6	49, 87.5	4, 7.1

Table 179. SURF IA Alert Statistics for All Evasive Actions by NACp for Head-On Arrivals Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
8	392	338, 86.2	252, 64.3	318, 81.1	238, 60.7
9	336	188, 56.0	36, 10.7	283, 84.2	107, 31.9
10	224	96, 42.9	0, 0.0	191, 85.3	48, 21.4
11	168	72, 42.9	0, 0.0	144, 85.7	36, 21.4
Truth	56	24, 42.9	0, 0.0	48, 85.7	12, 21.4
Aircraft B (Arrival Runway 28)					
8	392	339, 86.5	175, 44.6	316, 80.6	215, 54.9
9	336	277, 82.4	60, 17.9	286, 85.1	90, 26.8
10	224	184, 82.1	40, 17.9	191, 85.3	48, 21.4
11	168	138, 82.1	30, 17.9	144, 85.7	36, 21.4
Truth	56	46, 82.1	10, 17.9	48, 85.7	12, 21.4

When analyzing IAs that occurred when transmitting truth position data, TIs were issued onboard Aircraft A when the aircraft had landed and was taxiing on the runway (1 run, 4,874 ft from the runway

threshold at 49 kt), had already exited the runway (4 runs, 10,033 ft from the threshold), or after the aircraft had conducted a go-around (9,171 ft from the threshold and 432 ft AGL). RSIs were issued on approach when 2.8 NM to 1.3 NM prior to the threshold and 928 ft to 454 ft AGL and again after landing when 5,246 ft from the threshold at 39 kts until the aircraft had exited the runway (10,033 ft from the threshold). CAs were issued when approximately 1.2 NM to 0.8 NM prior to the threshold and 420 ft to 295 ft AGL and again after landing when exiting the runway (9,835 ft from the threshold). WAs were issued when 0.5 NM to 0.3 NM prior to the threshold and 200 ft to 140 ft AGL and again after landing when 7,646 ft from the threshold and at 30 kt until having exited the runway (9,920 ft from the threshold). Four WAs were also issued after the aircraft had conducted a go-around maneuver. For Aircraft B, both TIs and RSIs were issued on approach beginning approximately 2.8 NM prior to the threshold and 932 ft AGL. CAs were also issued beginning 2.8 NM to 1.2 NM prior to the threshold and 925 ft to 1 416 ft AGL. WAs were issued when 2.8 NM to 0.5 NM prior to the threshold and 930 ft to 190 ft AGL.

The highest rate of IA toggling was when transmitting data with NACp 8 position accuracy (Tables 178 and 179). In general, the rate of toggling was consistent across NACp 10, 11, and truth accuracy levels. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which multiple TIs, multiple RSIs, multiple CAs, and multiple WAs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The toggling included gaps between alerts for the lower position accuracy levels. The toggling was also a result of aircraft maneuvering, such as one or both aircraft conducting a go-around maneuver or Aircraft A conducting accelerated braking or exiting the runway. IA toggling occurred for both aircraft when transmitting truth position data. For Aircraft A, these multiple IAs occurred when the aircraft had landed and exited the runway, or after either or both aircraft had conducted a go-around maneuver. For Aircraft B when transmitting accurate position data, the multiple IAs occurred after either or both aircraft had conducted a go-around maneuver. The two multiple TIs occurred after a collision occurred.

When analyzing by CD&R equipage level (Tables 180 and 181), the indication rate varied somewhat by equipage level. The alert rate was more consistent across equipage levels. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 0.995$) and WAs ($p = 0.826$) were generated between equipage levels. There was a significant difference ($p = 0.003$) in the number of runs in which TIs were generated between Aircraft B equipped vs. Neither aircraft, Aircraft A, and Both aircraft equipped. There was a significant difference ($p < 0.001$) in the number of runs in which RSIs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which CAs ($p = 0.228$) and WAs ($p = 0.857$) were generated between equipage levels. There was a significant difference in the number of runs in which TIs ($p < 0.001$) and RSIs ($p = 0.008$) were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

The IA toggling rate also varied by equipage level (Tables 180 and 181). For Aircraft A, there was no significant difference ($p = 0.312$) in the number of runs in which multiple CAs were generated between equipage levels. There was a significant difference in the number of runs in which multiple TIs ($p = 0.003$), multiple RSIs ($p = 0.004$), and multiple WAs ($p < 0.001$) were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which multiple RSIs ($p = 0.189$) and multiple CAs ($p = 0.129$) were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which multiple TIs were generated between Neither aircraft, Aircraft A, and Aircraft B equipped vs Both aircraft equipped and in the number of runs in which multiple WAs were generated between Neither aircraft and Aircraft B equipped vs Aircraft A and Both aircraft equipped.

Table 180. SURF IA Indication Statistics for All NACp by Evasive Action for Head-On Arrivals Scenario.

CD&R Equipage	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
Neither	294	89, 30.3	44, 15.0	294, 100.0	145, 49.3
Aircraft A	294	88, 29.9	33, 11.2	268, 91.2	120, 40.8
Aircraft B	294	117, 39.8	61, 20.8	294, 100.0	138, 46.9
Both	294	76, 25.9	34, 11.6	267, 90.8	105, 35.7
Aircraft B (Arrival Runway 28)					
Neither	294	251, 85.4	103, 35.0	269, 91.5	36, 12.2
Aircraft A	294	239, 81.3	90, 30.6	243, 82.7	46, 15.7
Aircraft B	294	277, 94.2	91, 30.9	262, 89.1	41, 13.9
Both	294	221, 75.2	54, 18.4	252, 85.7	29, 9.9

Table 181. SURF IA Alert Statistics for All NACp by Evasive Action for Head-On Arrivals Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
Neither	294	178, 60.5	69, 23.5	251, 85.4	136, 46.3
Aircraft A	294	180, 61.2	72, 24.5	243, 82.7	91, 30.9
Aircraft B	294	179, 60.9	83, 28.2	245, 83.3	129, 43.9
Both	294	181, 61.6	64, 21.8	245, 83.3	85, 28.9
Aircraft B (Arrival Runway 28)					
Neither	294	252, 85.7	80, 27.2	251, 85.4	130, 44.2
Aircraft A	294	238, 81.0	72, 24.5	245, 83.3	66, 22.4
Aircraft B	294	253, 86.0	93, 31.6	245, 83.3	131, 44.6
Both	294	241, 82.0	70, 23.8	244, 83.0	74, 25.2

IA statistics were also compiled by CD&R equipage level when truth position data was transmitted (Tables 182 and 183). For Aircraft A, the TI and CA rate was lower when transmitting accurate data, but the RSI and WA rate was similar to the rate of generation when transmitting data with various accuracy levels (Tables 180 and 181). For Aircraft B, the IA rate was similar to the rate of generation when transmitting data with various accuracy levels. The rate of multiple IAs was lower when transmitting truth position accuracy and multiple CAs were eliminated for Aircraft A. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 1.0$), WAs ($p = 0.999$), and multiple TIs ($p = 0.341$) were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which TIs were generated between Neither aircraft and Both aircraft equipped vs. Aircraft A and Aircraft B equipped. There was also a significance difference in the number of runs in which RSIs ($p < 0.001$), multiple RSIs ($p = 0.017$), and multiple WAs ($p < 0.001$) were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which WAs ($p = 1.0$) and multiple RSIs ($p = 0.972$) were generated between equipage levels. There was a significant difference in the number of runs in which TIs ($p < 0.001$) were generated between Aircraft B equipped vs. Neither aircraft, Aircraft A, and Both aircraft equipped. There was a significant difference in the number of runs in which multiple TIs ($p < 0.001$) were generated between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped. There was also a significant difference in the number of runs in which RSIs ($p < 0.001$), CAs ($p = 0.020$), multiple CAs (p

= 0.024), and multiple WAs ($p < 0.001$) were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Table 182. SURF IA Indication Statistics When Transmitting Truth Position Data for Head-On Arrivals Scenario.

CD&R Equipage	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
Neither	294	25, 8.5	4, 1.4	294, 100.0	63, 21.4
Aircraft A	294	51, 17.4	2, 0.7	255, 86.7	46, 15.7
Aircraft B	294	46, 15.7	3, 1.0	294, 100.0	68, 23.1
Both	294	25, 8.5	1, 0.3	255, 86.7	43, 14.6
Aircraft B (Arrival Runway 28)					
Neither	294	231, 78.6	24, 8.5	273, 92.9	21, 7.1
Aircraft A	294	231, 78.6	34, 11.6	234, 79.6	22, 7.5
Aircraft B	294	276, 93.9	13, 4.4	273, 92.9	24, 8.2
Both	294	213, 72.5	7, 2.4	235, 79.9	22, 7.5

Table 183. SURF IA Alert Statistics When Transmitting Truth Position Data for Head-On Arrivals Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
Neither	294	126, 42.9	0, 0.0	252, 85.7	84, 28.6
Aircraft A	294	126, 42.9	0, 0.0	251, 85.4	39, 13.3
Aircraft B	294	126, 42.9	0, 0.0	252, 85.7	97, 33.0
Both	294	126, 42.9	0, 0.0	252, 85.7	49, 16.7
Aircraft B (Arrival Runway 28)					
Neither	294	252, 85.7	63, 21.4	252, 85.7	84, 28.6
Aircraft A	294	231, 78.6	45, 15.3	252, 85.7	27, 9.2
Aircraft B	294	252, 85.7	63, 21.4	252, 85.7	103, 35.0
Both	294	232, 78.9	41, 13.9	252, 85.7	45, 15.3

Missed and nuisance alerts – The number of runs in which the aircraft entered the defined missed and nuisance boundaries increased as the position accuracy decreased, as shown in Table 184. The number of times (count) and amount of time (duration and percentage of run length) that the aircraft were within the boundaries was greater when transmitting less accurate data. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies and in the number of runs in which the aircraft entered the nuisance boundary between NACp 8 and 9 accuracy vs. NACp 10, 11, and truth accuracies. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed and nuisance boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

The majority of occurrences of entering the missed boundary was after the aircraft had crossed the runway threshold for landing. The aircraft only entered the missed boundary while on approach before crossing the runway threshold during 0.8% of the test runs for Aircraft A and 2.0% of the test runs for Aircraft B when transmitting data with NACp 8 accuracy. Since the aircraft tracked the extended centerline on approach and centerline after landing, the nuisance boundary was entered as the aircraft exited the runway.

Table 184. SURF IA Missed and Nuisance Boundary Statistics for Head-On Arrivals Scenario.

NACp	Entered Missed Boundary				Entered Nuisance Boundary			
	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Arrival Runway 10)								
8	382, 97.5	9.1, 5.7	16.6, 12.6	15.5	72, 18.4	5.0, 5.9	14.3, 21.2	10.4
9	35, 10.4	1.4, 0.7	1.4, 1.2	1.4	41, 12.2	1.3, 0.7	1.8, 1.4	1.8
10	24, 10.7	1.0, 0.0	0.5, 0.4	0.5	19, 8.5	1.0, 0.0	0.6, 0.4	0.6
11	7, 4.2	1.0, 0.0	0.3, 0.1	0.3	7, 4.2	1.0, 0.0	0.2, 0.1	0.2
Truth	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
Aircraft B (Arrival Runway 28)								
8	274, 69.9	4.0, 3.3	7.4, 7.0	6.3	10, 2.5	2.2, 2.8	6.8, 10.2	3.2
9	2, 0.6	1.0, 0.0	0.2, 0.0	0.2	0, 0.0	0, 0.0	0, 0.0	0.0
10	0, 0.0	0, 0.0	0.0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
11	0, 0.0	0, 0.0	0.0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0, 0.0	0.0, 0.0	0.0	0, 0.0	0, 0.0	0, 0.0	0.0

The number of test runs that contained missed and nuisance IAs were relatively low, as shown in Tables 185 and 186. Missed and nuisance IAs for both aircraft were highest when transmitting data with NACp 8 accuracy. For Aircraft A, there was no significant difference in the number of runs in which missed TIs ($p = 0.292$) and missed CAs ($p = 0.111$) occurred between accuracy levels. There was a significant difference in the number of runs in which missed RSIs ($p < 0.001$), missed WAs ($p < 0.001$), nuisance TIs ($p < 0.001$), nuisance RSIs ($p = 0.006$), nuisance CAs ($p < 0.001$), and nuisance WAs ($p < 0.001$) occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft B, there was no significant difference in the number of runs in which missed TIs ($p = 0.149$), nuisance TIs ($p = 0.333$), and nuisance RSIs ($p = 0.333$) occurred between accuracy levels. There was a significant difference ($p < 0.001$) in the number of runs in which missed RSIs, missed CAs, and missed WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

Table 185. SURF IA Missed IA Statistics for All Evasive Actions by NACp for Head-On Arrivals Scenario.

NACp	Total # Runs	Missed TI (#, Runs, % Runs)	Missed RSI (# Runs, % Runs)	Missed CA (#, Runs, % Runs)	Missed WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
8	392	2, 0.5	7, 1.8	2, 0.5	46, 11.7
9	336	1, 0.3	0, 0.0	0, 0.0	7, 2.1
10	224	0, 0.0	0, 0.0	0, 0.0	1, 0.4
11	168	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	56	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Arrival Runway 28)					
8	392	15, 3.8	25, 6.4	8, 2.0	34, 8.7
9	336	8, 2.4	10, 3.0	0, 0.0	2, 0.6
10	224	2, 0.9	5, 2.2	0, 0.0	1, 0.4
11	168	2, 1.2	0, 0.0	0, 0.0	0, 0.0
Truth	56	1, 1.8	0, 0.0	0, 0.0	0, 0.0

For Aircraft A, the missed TIs should have occurred after Aircraft A or Aircraft B conducted a go-around maneuver, depending on CD&R equipage. The missed RSIs should have occurred after Aircraft A landed and was less than 39 kts. The missed CAs should have occurred after Aircraft A had landed and was exiting the runway. Two of the missed WAs should have occurred after Aircraft A conducted a go-around maneuver; the rest of the missed WAs should have occurred after Aircraft A landed and was less

than 39 kts. For Aircraft B, six of the missed TIs should have occurred while the aircraft was on approach, prior to crossing the runway threshold; nine should have occurred just prior to touchdown, at 16 ft AGL; 11 should have occurred soon after the aircraft landed and was greater than 86 kts; and two should have occurred after the aircraft conducted a go-around maneuver. Three of the missed RSIs should have occurred after Aircraft B landed and was approximately 36 kts. All of the other missed RSIs should have occurred when the aircraft was on approach at approximately 633 ft AGL. All of the missed CAs should have occurred when the aircraft was on approach and 419 ft AGL. One of the missed WAs should have occurred when Aircraft B was on approach and 505 ft AGL; two should have occurred after Aircraft B conducted a go-around maneuver; and other missed WAs should have occurred when the aircraft was on approach and 194 ft AGL.

An IA was considered a nuisance if it was generated at the same time the aircraft was determined to be within the nuisance boundary. Nuisance IAs for both aircraft occurred after the aircraft landed and exited the runway.

Table 186. SURF IA Nuisance IA Statistics for All Evasive Actions by NACp for Head-On Arrivals Scenario.

NACp	Total # Runs	Nuisance TI (# Runs, % Runs)	Nuisance RSI (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
8	532	19, 4.8	21, 5.4	13, 3.3	23, 5.9
9	456	0, 0.0	10, 3.0	0, 0.0	0, 0.0
10	304	0, 0.0	5, 2.2	0, 0.0	0, 0.0
11	228	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	76	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Arrival Runway 28)					
8	532	1, 0.3	1, 0.3	0, 0.0	0, 0.0
9	456	0, 0.0	0, 0.0	0, 0.0	0, 0.0
10	304	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	228	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	76	0, 0.0	0, 0.0	0, 0.0	0, 0.0

When analyzed by equipage level (Tables 187 and 188), in general, the missed and nuisance IAs were similarly distributed between equipage levels. For Aircraft A, there was a significant difference ($p = 0.020$) in the number of runs in which nuisance RSIs occurred between Neither aircraft and Aircraft A equipped vs. Aircraft B and Both aircraft equipped. There was no significant difference in the number of runs in which missed TIs ($p = 0.578$), missed RSIs ($p = 0.203$), missed CAs ($p = 0.50$), missed WAs ($p = 0.168$), nuisance TIs ($p = 0.644$), nuisance CAs ($p = 0.265$), and nuisance WAs occurred ($p = 0.754$) between equipage levels. For Aircraft B, there was no significant difference in the number of runs in which missed TIs ($p = 0.092$), missed RSIs ($p = 0.442$), missed CAs ($p = 0.113$), missed WAs ($p = 0.228$), and nuisance TIs ($p = 0.25$), nuisance RSIs ($p = 0.25$) occurred between equipage levels.

Unnecessary maneuvering - The percentage of test runs in which the aircraft maneuvered unnecessarily when transmitting data with the various accuracy levels is shown in Table 189. Unnecessary maneuvers only occurred during NACp 8 and 9 accuracy test runs. There was a significant difference in the number of runs in which unnecessary maneuvers occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies for Aircraft A ($p < 0.001$) and Aircraft B ($p = 0.012$).

The number and percentage of test runs in which the aircraft maneuvered unnecessarily based on the CD&R equipage level is shown in Table 190. There was no significant difference ($p = 1.0$) in the number of runs in which unnecessary maneuvers occurred between equipage levels for Aircraft A and Aircraft B.

Table 187. SURF IA Missed IA Statistics for All NACp by Evasive Action for Head-On Arrivals Scenario.

CD&R Equipage	Total # Runs	Missed TI (#, Runs, % Runs)	Missed RSI (# Runs, % Runs)	Missed CA (#, Runs, % Runs)	Missed WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
Neither	294	0, 0.0	0, 0.0	1, 0.3	7, 2.4
Aircraft A	294	1, 0.3	2, 0.7	0, 0.0	14, 4.8
Aircraft B	294	1, 0.3	3, 1.0	0, 0.0	18, 6.1
Both	294	1, 0.3	2, 0.7	1, 0.3	15, 5.1
Aircraft B (Arrival Runway 28)					
Neither	294	12, 4.1	7, 2.4	4, 1.4	4, 1.4
Aircraft A	294	8, 2.7	8, 2.7	1, 0.3	10, 3.4
Aircraft B	294	4, 1.4	13, 4.4	1, 0.3	11, 3.7
Both	294	4, 1.4	12, 4.1	2, 0.7	12, 4.1

Table 188. SURF IA Nuisance IA Statistics for All NACp by Evasive Action for Head-On Arrivals Scenario.

CD&R Equipage	Total # Runs	Nuisance TI (# Runs, % Runs)	Nuisance RSI (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
Neither	294	4, 1.4	15, 5.1	4, 1.4	7, 2.4
Aircraft A	294	6, 2.0	12, 4.1	2, 0.7	7, 2.4
Aircraft B	294	4, 1.4	4, 1.4	2, 0.7	4, 1.4
Both	294	5, 1.7	5, 1.7	5, 1.7	5, 1.7
Aircraft B (Arrival Runway 28)					
Neither	294	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft A	294	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B	294	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Both	294	1, 0.3	1, 0.3	0, 0.0	0, 0.0

Table 189. Unnecessary Maneuvers for All Evasive Actions by NACp Using SURF IA During Head-On Arrivals Scenario.

NACp	Total # Runs	Aircraft A (Arrival Runway 10) (# Runs, % Runs)	Aircraft B (Arrival Runway 28) (# Runs, % Runs)
8	196	25, 12.8	4, 2.0
9	168	4, 2.4	0, 0.0
10	112	0, 0.0	0, 0.0
11	84	0, 0.0	0, 0.0
Truth	28	0, 0.0	0, 0.0

Table 190. Unnecessary Maneuvers for All NACp by Evasive Action Using SURF IA During Head-On Arrivals Scenario.

CD&R Equipage	Total # Runs	Aircraft A (Arrival Runway 10) (# Runs, % Runs)	Aircraft B (Arrival Runway 28) (# Runs, % Runs)
Neither	294	N/A	N/A
Aircraft A	294	15, 5.1	N/A
Aircraft B	294	N/A	2, 0.7
Both	294	14, 4.8	2, 0.7

Collision avoidance –All of the runs resulted in a near collision and approximately 79% resulted in a collision in the absence of CD&R, as shown in Table 191. CD&R was most effective when Aircraft B was equipped, resulting in no collisions when transmitting data with NACp 9, 10, 11 and truth accuracies. When neither aircraft were equipped with CD&R, there was no significant difference in the number of near collisions (100% of runs for each equipage level) and collisions ($p = 1.0$) between accuracy levels. When only Aircraft A was equipped, there was no significant difference in the number of runs in which near collisions ($p = 0.954$) and collisions ($p = 0.842$) occurred between accuracy levels. When only Aircraft B was equipped, there was no significant difference ($p = 0.250$) in the number of runs in which near collisions occurred but there was a significant difference ($p < 0.001$) in the number of runs in which collisions occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. When Both aircraft were equipped, there was no significant difference in the number of runs in which near collisions ($p = 0.424$) and collisions ($p = 0.916$) occurred between accuracy levels.

Table 191. Number/Percentage of Near Collisions (NC) and Collisions (C) Using SURF IA for Equipage Combinations for Head-On Arrivals Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	98	98, 100	77, 78.6	81, 82.7	42, 42.9	63, 64.3	27, 27.6	84, 85.7	26, 26.5
9	84	84, 100	66, 78.6	66, 78.6	30, 35.7	42, 50.0	0, 0.0	78, 92.9	18, 21.4
10	56	56, 100	44, 78.6	44, 78.6	20, 35.7	28, 50.0	0, 0.0	52, 92.9	12, 21.4
11	42	42, 100	33, 78.6	33, 78.6	15, 35.7	21, 50.0	0, 0.0	39, 92.9	9, 21.4
Truth	14	14, 100	11, 78.6	11, 78.6	5, 35.7	7, 50.0	0, 0.0	13, 92.9	3, 21.4

For the condition when truth position data was used and neither aircraft maneuvered (11 collisions), the scenario was designed such that a collision occurred when Aircraft A (arrival to Runway 10) was located from 3.5 NM prior to the threshold, at 0.5 NM intervals, crossing the runway threshold, and 1,400 ft, 3,700 ft, and 5,500 ft past the threshold when Aircraft B began its approach to Runway 28, 3.5 NM prior to the runway threshold. For nine of these collisions, both aircraft had landed and were decelerating or taxiing down the runway when the collision occurred. For one collision, Aircraft A was taxiing down the runway and Aircraft B was just about to touchdown. For one collision, Aircraft A was exiting the runway as Aircraft B was about to touchdown.

When only Aircraft A was equipped and transmitting data with NACp 9, 10, 11, and truth position accuracies, collisions occurred when Aircraft A was located 0.5 NM prior to the threshold, crossing the threshold, and 1,400 ft, 3,700 ft, and 5,500 ft down the runway after landing when Aircraft B began its approach. No maneuvering (accelerated braking to exit the runway) was made for the collisions that occurred when Aircraft A was 5,500 ft down the runway when Aircraft B began its approach. At the collision, Aircraft A was exiting the runway and Aircraft B was about to touch down (25 ft AGL). For these runs, the WA was not issued until the collision point, except for two runs when transmitting NACp 9 accuracy which had multiple WAs. For the 42 collisions that occurred when transmitting data with NACp 8 position accuracy, Aircraft A was located at the five locations above when Aircraft B began its approach along with 3.5 NM, 3.0 NM, 2.5 NM, 2.0 NM, and 1.5 NM prior to the runway threshold. Twenty-nine collisions occurred when both aircraft were taxiing on the runway and 13 occurred when Aircraft A was exiting the runway. Maneuvering (accelerated braking) occurred on 18 of the 42 collision runs but not with enough time to avoid the collision. For the 24 collisions in which maneuvering did not occur, WAs were not issued on nine runs, multiple alerts occurred on nine runs, and single WAs were generated on six runs. The aircraft was to maneuver after the first WA but this was not always the case, resulting in a maneuver that was initiated later than intended.

For the 27 collisions that occurred when Aircraft B was equipped, 20 occurred when both aircraft were taxiing on the runway; five occurred when Aircraft A was exiting the runway; and two occurred when Aircraft B was climbing out. WAs were not issued on Aircraft B on three of these runs. Maneuvering

occurred on nine of the 27 collision runs but not in enough time to avoid the collision; on six runs accelerated braking was conducted and on three runs a go-around was conducted.

When Both aircraft were equipped, when transmitting data with NACp 9, 10, 11, and truth position accuracies, both aircraft received WAs on the other aircraft, both aircraft maneuvered (conducted a go-around), and the collision occurred when the aircraft were climbing out. For the 26 collisions that occurred when transmitting data with NACp 8 accuracy, 11 collisions (42%) also occurred when both aircraft were climbing out (both aircraft conducted a go-around maneuver). These collisions occurred on runs in which Aircraft A was located 3.5 NM, 3.0 NM or 2.5 NM prior to the runway threshold when Aircraft B began its approach. These collisions may not have occurred if the CD&R system coordinated alerting between aircraft so that only one aircraft received a WA. For the remaining 15 collisions in which NACp 8 accuracy was used, nine collisions occurred when both aircraft were taxiing on the runway; one occurred when Aircraft A was taxiing on the runway and Aircraft B had conducted a go-around; and five occurred when Aircraft A was exiting the runway. Maneuvering occurred on six of these 15 runs; on one run both aircraft conducted accelerated braking, on three runs only Aircraft A conducted accelerated braking, and on two runs only Aircraft B conducted a go-around.

5.2.8 Runway Scenario – Arrivals to Intersecting Runways

For each of the 20 cases in this scenario, an initiation delay on Aircraft B was evaluated at 13 levels, for a total of 1,092 test runs.

Algorithm performance – For both aircraft, TIs were generated on approximately 85% of the test runs (Table 192). RSIs were only issued when transmitting data with NACp 8 and 9 accuracy levels. CAs were generated on approximately 39% of the test runs for Aircraft A and 42% of the test runs for Aircraft B (Table 193). The rate of WAs was slightly lower when transmitting data with NACp 8 accuracy. For both aircraft there was a significant difference ($p < 0.001$) in the number of runs in which TIs and RSIs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 0.983$) and WAs ($p = 0.331$) occurred between accuracy levels. For Aircraft B, there was also no significant difference in the number of runs in which CAs ($p = 0.646$) and WAs ($p = 0.29$) were generated between accuracy levels.

Table 192. SURF IA Indication Statistics for All Evasive Actions by NACp for Arrivals to Intersecting Runways Scenario.

NACp	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
8	364	324, 89.0	182, 50.0	91, 25.0	8, 2.2
9	312	265, 84.9	76, 24.4	14, 4.5	2, 0.6
10	208	176, 84.6	34, 16.4	0, 0.0	0, 0.0
11	156	132, 84.6	24, 15.4	0, 0.0	0, 0.0
Truth	52	44, 84.6	8, 15.4	0, 0.0	0, 0.0
Aircraft B (Arrival Runway 22R)					
8	364	305, 83.8	154, 42.3	40, 11.0	2, 0.6
9	312	264, 84.6	50, 16.0	9, 2.9	0, 0.0
10	208	176, 84.6	16, 7.7	0, 0.0	0, 0.0
11	156	132, 84.6	12, 7.7	0, 0.0	0, 0.0
Truth	52	44, 84.6	4, 7.7	0, 0.0	0, 0.0

When analyzing IAs that occurred when transmitting truth position data, TIs were issued onboard Aircraft A when on approach and approximately 2.9 NM to 1.4 NM prior to the runway threshold and 965 ft to 489 ft AGL and when 35 ft prior to the threshold and 35 ft AGL until 5,101 ft past the threshold and 43 kts. CAs were issued onboard Aircraft A when approximately 1.3 NM prior to the runway threshold and 440 ft AGL (16 runs) and when approximately 0.9 NM prior to the threshold and 330 ft AGL (4 runs).

WAs were issued when Aircraft A was on approach from approximately 0.5 NM prior to the runway threshold and 200 ft AGL (20 runs) and when 0.4 NM prior to the threshold and 177 ft AGL (4 runs). For Aircraft B, TIs were issued when on approach and approximately 2.9 NM to 2.0 NM prior to the runway threshold and 965 ft to 662 ft AGL. CAs occurred when the aircraft was between approximately 2.9 NM prior to the runway threshold and 960 ft AGL and 1.2 NM prior to the threshold and 430 ft AGL. WAs occurred when the aircraft was between approximately 2.9 NM to 0.5 NM prior to the runway threshold and 955 ft to 200 ft AGL. RSIs were not issued onboard either aircraft.

Table 193. SURF IA Alert Statistics For All Evasive Actions by NACp for Arrivals to Intersecting Runways Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
8	364	149, 40.9	24, 6.6	162, 44.5	60, 16.5
9	312	121, 38.8	1, 0.3	144, 46.1	37, 11.9
10	208	80, 38.5	0, 0.0	96, 46.1	20, 9.6
11	156	60, 38.5	0, 0.0	72, 46.1	15, 9.6
Truth	52	20, 38.5	0, 0.0	24, 46.1	5, 9.6
Aircraft B (Arrival Runway 22R)					
8	364	153, 42.0	70, 19.2	161, 44.2	67, 18.4
9	312	132, 42.3	49, 15.7	144, 46.1	35, 11.2
10	208	88, 42.3	32, 15.4	96, 46.1	20, 9.6
11	156	66, 42.3	24, 15.4	72, 46.1	15, 9.6
Truth	52	22, 42.3	8, 15.4	24, 46.1	5, 9.6

The highest rate of IA toggling was when transmitting NACp 8 position data (Tables 192 and 193). In general, the rate of toggling was consistent across NACp 10, 11, and truth accuracy levels per multiple alert type and aircraft. The overall rate of toggling for RSIs was very low. For Aircraft A, there was a significant difference in the number of runs in which multiple TIs ($p < 0.001$), multiple RSIs ($p = 0.005$), and multiple CAs ($p < 0.001$) were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. There was no significant difference ($p = 0.257$) in the number of runs in which multiple WAs were generated between accuracy levels. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which multiple TIs were generated between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. There was no significant difference in the number of runs in which multiple RSIs ($p = 0.127$), multiple CAs ($p = 0.959$), and multiple WAs ($p = 0.042$) were generated between accuracy levels.

Table 192. SURF IA Indication Statistics for All Evasive Actions by NACp for Arrivals to Intersecting Runways Scenario.

NACp	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
8	364	324, 89.0	182, 50.0	91, 25.0	8, 2.2
9	312	265, 84.9	76, 24.4	14, 4.5	2, 0.6
10	208	176, 84.6	34, 16.4	0, 0.0	0, 0.0
11	156	132, 84.6	24, 15.4	0, 0.0	0, 0.0
Truth	52	44, 84.6	8, 15.4	0, 0.0	0, 0.0
Aircraft B (Arrival Runway 22R)					
8	364	305, 83.8	154, 42.3	40, 11.0	2, 0.6
9	312	264, 84.6	50, 16.0	9, 2.9	0, 0.0
10	208	176, 84.6	16, 7.7	0, 0.0	0, 0.0
11	156	132, 84.6	12, 7.7	0, 0.0	0, 0.0
Truth	52	44, 84.6	4, 7.7	0, 0.0	0, 0.0

Table 193. SURF IA Alert Statistics for All Evasive Actions by NACp for Arrivals to Intersecting Runways Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
8	364	149, 40.9	24, 6.6	162, 44.5	60, 16.5
9	312	121, 38.8	1, 0.3	144, 46.1	37, 11.9
10	208	80, 38.5	0, 0.0	96, 46.1	20, 9.6
11	156	60, 38.5	0, 0.0	72, 46.1	15, 9.6
Truth	52	20, 38.5	0, 0.0	24, 46.1	5, 9.6
Aircraft B (Arrival Runway 22R)					
8	364	153, 42.0	70, 19.2	161, 44.2	67, 18.4
9	312	132, 42.3	49, 15.7	144, 46.1	35, 11.2
10	208	88, 42.3	32, 15.4	96, 46.1	20, 9.6
11	156	66, 42.3	24, 15.4	72, 46.1	15, 9.6
Truth	52	22, 42.3	8, 15.4	24, 46.1	5, 9.6

The toggling included gaps between IAs at the lower position accuracy levels. The toggling was also a result of aircraft maneuvering. Multiple IAs occurred after Aircraft A or Aircraft B or both conducted a go-around maneuver and also when Aircraft A had crossed the runway threshold. Sometimes a multiple IA occurred onboard the aircraft after it was in the intersection of the runways or had passed the intersecting runway, which is not necessary since the aircraft is moving away from the intersection.

When analyzing by CD&R equipage level (Tables 194 and 195), IA generation was similar across all equipage levels for both aircraft. For Aircraft A, there was no significant difference in the number of runs in which TIs ($p = 0.386$), RSIs ($p = 0.71$), CAs ($p = 0.987$), and WAs ($p = 0.998$) were generated between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which TIs ($p = 0.77$), RSIs ($p = 0.902$), CAs ($p = 0.242$), and WAs ($p = 0.998$) were generated between equipage levels.

Table 194. SURF IA Indication Statistics for All NACp by Evasive Action for Arrivals to Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
Neither	273	236, 86.5	93, 34.1	22, 8.1	4, 1.5
Aircraft A	273	232, 85.0	69, 25.3	26, 9.5	1, 0.4
Aircraft B	273	243, 89.0	93, 34.1	30, 11.0	3, 1.1
Both	273	230, 84.2	69, 25.3	27, 9.9	2, 0.7
Aircraft B (Arrival Runway 22R)					
Neither	273	230, 84.2	70, 25.6	14, 5.1	2, 0.7
Aircraft A	273	230, 84.2	46, 16.9	11, 4.0	0, 0.0
Aircraft B	273	235, 86.1	68, 24.9	13, 4.8	0, 0.0
Both	273	226, 82.8	52, 19.1	11, 4.0	0, 0.0

For both aircraft, the TI toggling rate was higher when Neither aircraft and Aircraft B was equipped. The RSI toggling rate was similar between equipage levels. The CA toggling rate was similar between equipage levels for Aircraft A but was higher when Neither aircraft and Aircraft B was equipped for Aircraft B. The WA toggling rate was higher when Neither aircraft and Aircraft B was equipped for both aircraft. For Aircraft A, there was no significant difference in the number of runs in which multiple RSIs ($p = 0.341$) and multiple CAs ($p = 0.989$) were generated between equipage levels. There was a significant difference in the number of runs in which multiple TIs ($p = 0.018$) and multiple WAs ($p < 0.001$) were generated

between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which multiple TIs ($p = 0.028$) and multiple RSIs ($p = 0.062$) were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which multiple CAs and multiple WAs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Table 195. SURF IA Alert Statistics for All NACp by Evasive Action for Arrivals to Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
Neither	273	109, 39.9	6, 2.2	124, 45.4	57, 20.9
Aircraft A	273	106, 38.8	7, 2.6	126, 46.1	11, 4.0
Aircraft B	273	109, 39.9	6, 2.2	124, 45.4	62, 22.7
Both	273	106, 38.8	6, 2.2	124, 45.4	7, 2.6
Aircraft B (Arrival Runway 22R)					
Neither	273	122, 44.7	64, 23.4	125, 45.8	52, 19.1
Aircraft A	273	106, 38.8	27, 9.9	125, 45.8	13, 4.8
Aircraft B	273	125, 45.8	63, 23.1	124, 45.4	64, 23.4
Both	273	108, 39.6	29, 10.6	123, 45.0	13, 4.8

IA statistics were also compiled by CD&R equipage level when truth position accuracy was transmitted (Tables 196 and 197). The TI, CA, and WA generation rate was similar to the rate of generation when transmitting data with various position accuracy levels (Tables 194 and 195). RSIs were not issued when transmitting accurate data. The multiple TI and multiple WA rate was reduced. Multiple CAs for Aircraft A did not occur with accurate data, but, for Aircraft B, the rate was similar to the rate that occurred when transmitting data with various position accuracy levels. For Aircraft A, there was no significant difference in the number of runs in which TIs ($p = 1.0$), multiple TIs ($p = 0.980$), CAs ($p = 1.0$), and WAs ($p = 1.0$) were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which TIs ($p = 1.0$), multiple TIs ($p = 0.961$), CAs ($p = 0.143$), and WAs ($p = 1.0$) were generated between equipage levels. There was a significant difference ($p < 0.001$) in the number of runs in which multiple CAs and multiple WAs were generated between Neither aircraft and Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Table 196. SURF IA Alert Statistics When Transmitting Truth Position Data for Arrivals to Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	TI (# Runs, % Runs)	Multiple TI (# Runs, % Runs)	RSI (# Runs, % Runs)	Multiple RSI (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
Neither	273	231, 84.6	42, 15.4	0, 0.0	0, 0.0
Aircraft A	273	231, 84.6	45, 16.5	0, 0.0	0, 0.0
Aircraft B	273	231, 84.6	42, 15.4	0, 0.0	0, 0.0
Both	273	231, 84.6	42, 15.4	0, 0.0	0, 0.0
Aircraft B (Arrival Runway 22R)					
Neither	273	231, 84.6	21, 7.7	0, 0.0	0, 0.0
Aircraft A	273	231, 84.6	24, 8.8	0, 0.0	0, 0.0
Aircraft B	273	231, 84.6	21, 7.7	0, 0.0	0, 0.0
Both	273	231, 84.6	22, 8.1	0, 0.0	0, 0.0

Table 197. SURF IA Alert Statistics When Transmitting Truth Position Data for Arrivals to Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
Neither	273	105, 38.5	0, 0.0	126, 46.1	42, 15.4
Aircraft A	273	105, 38.5	0, 0.0	126, 46.1	0, 0.0
Aircraft B	273	105, 38.5	0, 0.0	126, 46.1	61, 22.3
Both	273	105, 38.5	0, 0.0	126, 46.1	3, 1.1
Aircraft B (Arrival Runway 22R)					
Neither	273	126, 46.1	63, 23.1	126, 46.1	42, 15.4
Aircraft A	273	106, 38.8	22, 8.1	126, 46.1	0, 0.0
Aircraft B	273	126, 46.1	63, 23.1	126, 46.1	61, 22.3
Both	273	108, 39.6	27, 9.9	126, 46.1	3, 1.1

Missed and nuisance alerts – The number of runs in which the aircraft entered the defined missed and nuisance boundaries increased as the position accuracy decreased, as shown in Table 198. The number of times (count) and amount of time (duration and percentage of run length) that the aircraft were within the boundaries was greater when transmitting less accurate data. Aircraft B did not enter the nuisance boundary because the aircraft always tracked the runway centerline and did not exit the runway. For both aircraft, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. There was also a significant difference ($p < 0.001$) in the number of runs in which Aircraft A entered the nuisance boundary between NACp 8 and 9 accuracies vs. NACp 10, 11, and truth accuracies.

The majority of occurrences of entering the missed boundary was after the aircraft had crossed the runway threshold for landing. When transmitting data with NACp 8 accuracy, the aircraft only entered the missed boundary while on approach before crossing the runway threshold during 1.1% of the test runs for Aircraft A and 0.0% of the test runs for Aircraft B. Since the aircraft tracked the extended centerline on approach and centerline after landing, the nuisance boundary was entered as the aircraft exited the runway.

Table 198. SURF IA Missed and Nuisance Boundary Statistics for Arrivals to Intersecting Runways Scenario.

	Entered Missed Boundary				Entered Nuisance Boundary			
NACp	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Arrival Runway 14L)								
8	351, 96.4	7.5, 4.6	13.6, 10.1	12.5	154, 42.3	4.3, 3.3	7.1, 6.5	6.2
9	78, 25.0	1.4, 1.0	1.4, 1.2	1.2	97, 31.1	1.2, 0.4	1.7, 1.3	1.6
10	47, 22.6	1.0, 0.0	0.5, 0.3	0.5	42, 20.2	1.0, 0.0	0.5, 0.3	0.5
11	27, 17.3	1.0, 0.0	0.3, 0.1	0.2	17, 10.9	1.0, 0.0	0.2, 0.0	0.2
Truth	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
Aircraft B (Arrival Runway 22R)								
8	268, 73.6	3.8, 2.6	6.8, 6.2	6.1	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
9	4, 1.3	2.0, 0.8	0.4, 0.1	0.4	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
10	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
11	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0.0, 0.0	0.0	0, 0.0	0.0, 0.0	0.0, 0.0	0.0

The number of test runs that contained missed and nuisance IAs was low, as shown in Tables 199 and 200. Missed IAs for both aircraft mainly occurred when transmitting data with NACp 8 accuracy. For both

aircraft, there were no instances of missed RSI's. Nuisance indications only occurred when transmitting data with NACp 8 accuracy for Aircraft A. There were no nuisance alerts for either aircraft. For Aircraft A, there was a significant difference in the number of runs in which missed TIs ($p < 0.001$), missed WAs ($p < 0.001$), nuisance TIs ($p < 0.001$), and nuisance RSIs ($p = 0.004$) occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies. There was no significant difference ($p = 0.111$) in the number of runs in which missed CAs occurred between accuracy levels. For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which missed TIs, missed CAs, and missed WAs occurred between NACp 8 vs. NACp 9, 10, 11, and truth accuracies.

For Aircraft A, 24 of the missed TIs should have occurred when the aircraft was on approach while 14 should have occurred after the aircraft landed. The missed CAs should have occurred while the aircraft was on approach. Seven of the missed WAs should have occurred when the aircraft was on approach while 11 should have occurred after the aircraft landed. For Aircraft B, 20 missed TIs should have occurred when the aircraft wan on approach and two should have occurred after the aircraft landed. All of the missed CAs and missed WAs should have occurred when the aircraft was on approach.

An indication was considered a nuisance if it was generated at the same time the aircraft was determined to be within the nuisance boundary. Therefore, the nuisance indications for Aircraft A occurred as the aircraft was exiting the runway.

Table 199. SURF IA Missed IA Statistics for All Evasive Actions by NACp for Arrivals to Intersecting Runways Scenario.

NACp	Total # Runs	Missed TI (#, Runs, % Runs)	Missed RSI (# Runs, % Runs)	Missed CA (#, Runs, % Runs)	Missed WA (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
8	364	36, 9.9	0, 0.0	2, 0.5	17, 4.7
9	312	2, 0.6	0, 0.0	0, 0.0	1, 0.3
10	208	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	156	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	52	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Arrival Runway 22R)					
8	364	21, 5.8	0, 0.0	16, 4.4	17, 4.7
9	312	1, 0.3	0, 0.0	0, 0.0	0, 0.0
10	208	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	156	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	52	0, 0.0	0, 0.0	0, 0.0	0, 0.0

Table 200. SURF IA Nuisance IA Statistics for All Evasive Actions by NACp for Arrivals to Intersecting Runways Scenario.

NACp	Total # Runs	Nuisance TI (# Runs, % Runs)	Nuisance RSI (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
8	364	10, 2.8	5, 1.4	0, 0.0	0, 0.0
9	312	0, 0.0	0, 0.0	0, 0.0	0, 0.0
10	208	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	156	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	52	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Arrival Runway 22R)					
8	364	0, 0.0	0, 0.0	0, 0.0	0, 0.0
9	312	0, 0.0	0, 0.0	0, 0.0	0, 0.0
10	208	0, 0.0	0, 0.0	0, 0.0	0, 0.0
11	156	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	52	0, 0.0	0, 0.0	0, 0.0	0, 0.0

When analyzing based on CD&R equipage level (Tables 201 and 202), the rate of missed TIs was higher when Aircraft A and Both aircraft were equipped. The missed CAs for Aircraft A occurred when Both aircraft were equipped and, for Aircraft B, the rate of missed CAs was higher when Neither aircraft or Aircraft B was equipped. The rate of missed WAs was highest when Aircraft B was equipped. Nuisance indications occurred when Aircraft A, Aircraft B, and Both aircraft were equipped. For Aircraft A, there was no significant difference in the number of runs in which missed TIs ($p = 0.069$), missed CAs ($p = 0.062$), and nuisance RSIs ($p = 0.374$) occurred between equipage levels. There was a significant difference in the number of runs in which missed WAs ($p = 0.005$) and nuisance TIs ($p = 0.019$) occurred between Aircraft B equipped vs. Neither aircraft, Aircraft A equipped, and Both aircraft equipped. For Aircraft B, there was no significant difference in the number of runs in which missed TIs ($p = 0.076$), missed CAs ($p = 0.208$), and missed WAs ($p = 0.046$) occurred between equipage levels.

Table 201. SURF IA Missed IA Statistics for All NACp by Evasive Action for Arrivals to Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	Missed TI (#, Runs, % Runs)	Missed RSI (# Runs, % Runs)	Missed CA (#, Runs, % Runs)	Missed WA (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
Neither	273	5, 1.8	0, 0.0	0, 0.0	4, 1.5
Aircraft A	273	14, 5.1	0, 0.0	0, 0.0	0, 0.0
Aircraft B	273	6, 2.2	0, 0.0	0, 0.0	10, 3.7
Both	273	13, 4.8	0, 0.0	2, 0.7	4, 1.5
Aircraft B (Arrival Runway 22R)					
Neither	273	3, 1.1	0, 0.0	6, 2.2	4, 1.5
Aircraft A	273	9, 3.3	0, 0.0	3, 1.1	1, 0.4
Aircraft B	273	2, 0.7	0, 0.0	5, 1.8	8, 2.9
Both	273	8, 2.9	0, 0.0	2, 0.7	4, 1.5

Table 202. SURF IA Nuisance IA Statistics for All NACp by Evasive Action for Arrivals to Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	Nuisance TI (# Runs, % Runs)	Nuisance RSI (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival Runway 14L)					
Neither	273	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft A	273	2, 0.7	1, 0.4	0, 0.0	0, 0.0
Aircraft B	273	6, 2.2	2, 0.7	0, 0.0	0, 0.0
Both	273	2, 0.7	2, 0.7	0, 0.0	0, 0.0
Aircraft B (Arrival Runway 22R)					
Neither	273	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft A	273	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B	273	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Both	273	0, 0.0	0, 0.0	0, 0.0	0, 0.0

Unnecessary maneuvering – No unnecessary maneuvers occurred for this scenario.

Collision avoidance – As shown in Table 203, near collisions only occurred when Both aircraft were equipped with CD&R (no significant difference ($p= 0.674$) between accuracy levels). These near collisions occurred after both aircraft had conducted a go-around maneuver. Collisions did not occur during this scenario.

Table 203. Number/Percentage of Near Collisions (NC) and Collisions (C) Using SURF IA for Equipage Combinations for Arrivals to Intersecting Runways Scenario.

NACp	# Runs per Equipage	CD&R Equipage							
		Neither		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C	NC	C
8	91	0, 0.00	0, 0.00	0, 0.00	0, 0.00	0, 0.00	0, 0.00	5, 5.5	0, 0.00
9	78	0, 0.00	0, 0.00	0, 0.00	0, 0.00	0, 0.00	0, 0.00	6, 7.7	0, 0.00
10	52	0, 0.00	0, 0.00	0, 0.00	0, 0.00	0, 0.00	0, 0.00	4, 7.7	0, 0.00
11	39	0, 0.00	0, 0.00	0, 0.00	0, 0.00	0, 0.00	0, 0.00	3, 7.7	0, 0.00
Truth	13	0, 0.00	0, 0.00	0, 0.00	0, 0.00	0, 0.00	0, 0.00	1, 7.7	0, 0.00

5.3 Directive Alerting Results

Directive alerting specifies the action to take to resolve a conflict situation in lieu of providing a generic WA. The directive given depends on the conflict situation. Examples of directive alerts are as follows: "go-around" when on approach, "abort" when departing, "stop" when taxiing or rolling-out, and "climb" when air-to-air conflict on approach. The directive alerts can be displayed in the cockpit visually and audibly, similar to the method used for WAs.

Directive alerting was evaluated for three scenarios (two runway and one taxiway), two levels of surveillance accuracy (NACp 10 and truth), and three levels of CD&R system equipage (only Aircraft A equipped, only Aircraft B equipped, and Both aircraft equipped), for a total of 18 cases (Appendix A). These three scenarios were selected because the directive alert generated by ATCAM could have a different outcome from the standard maneuvering conducted for the other test cases. Truth surveillance accuracy was evaluated to obtain results of directive alerting with accurate data. NACp 10 surveillance accuracy was selected for evaluation based on the SURF IA requirements for large airports [RTCA, 2010]. There was no need to evaluate the condition where neither aircraft take action since directive alerting requires action.

5.3.1 Directive Alerting - Arrival and departure from intersecting runways

For each of the 6 cases in this scenario, an initiation delay on Aircraft B was evaluated at 13 levels, for a total of 195 test runs.

Algorithm performance – For the arrival Aircraft A, CAs were generated on 2.6% of runs and WAs were generated on approximately 16% of the runs, independent of position accuracy level (Table 204). For the departing Aircraft B, CAs were not issued. WAs were generated on 69% of the runs, independent of accuracy level. There was no significant difference ($p = 1.0$) in the number of runs in which CAs and WAs were generated between accuracy levels.

When analyzing alerts that occurred when transmitting truth position data, only one CA was issued onboard the approach aircraft when 1,323 ft prior to the runway threshold and 106 ft AGL. WAs were issued when the aircraft was between 184 ft prior to the runway threshold and 47 ft AGL until 4,093 ft past the runway threshold after landing and 71 kts. For the departing aircraft, WAs were issued when 4 ft to 141 ft from the runway threshold and 7 kts to 29 kts.

Alert toggling did not occur for either aircraft for these test conditions.

When analyzing by CD&R equipage level (Table 205), for Aircraft A, all of the CAs and the majority of the WAs were issued when only Aircraft A was equipped with CD&R. The rate of WA generation was evenly distributed across equipage levels for Aircraft B. For Aircraft A, there was a significant difference in the number of runs in which CAs ($p = 0.004$) and WAs ($p < 0.001$) were generated between Aircraft A equipped vs. Aircraft B and Both aircraft equipped. For Aircraft B, there was no significant difference ($p = 1.0$) in the number of runs in which WAs were generated between equipage levels.

Table 204. ATCAM Alert Statistics for Directive Alerting for All Evasive Actions by NACp for Arrival and Departure from Intersecting Runways Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
10	156	4, 2.6	0, 0.0	26, 16.7	0, 0.0
Truth	39	1, 2.6	0, 0.0	6, 15.4	0, 0.0
Aircraft B (Departure)					
10	156	0, 0.0	0, 0.0	108, 69.2	0, 0.0
Truth	39	0, 0.0	0, 0.0	27, 69.2	0, 0.0

Table 205. ATCAM Alert Statistics for Directive Alerting for All NACp by Evasive Action for Arrival and Departure from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Aircraft A	65	5, 7.7	0, 0.0	30, 46.1	0, 0.0
Aircraft B	65	0, 0.0	0, 0.0	2, 3.1	0, 0.0
Both	65	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Departure)					
Aircraft A	65	0, 0.0	0, 0.0	45, 69.2	0, 0.0
Aircraft B	65	0, 0.0	0, 0.0	45, 69.2	0, 0.0
Both	65	0, 0.0	0, 0.0	45, 69.2	0, 0.0

Alert statistics were also compiled by CD&R equipage level when truth position data was transmitted (Table 206). The CA rate for Aircraft A was the same as that which occurred when transmitting data with various position accuracy levels (Table 205). The frequency of WA generation was higher for Aircraft A than that which occurred when transmitting data with various position accuracy levels; however, the WA rate was the same for Aircraft B. For Aircraft A, there was a significant difference ($p = 0.004$) in the number of runs in which CAs were generated between Aircraft A equipped vs. Aircraft B and Both aircraft equipped. There was no significant difference in the number of runs in which WAs were generated between equipage levels for Aircraft A ($p = 0.108$) and Aircraft B ($p = 1.0$).

Table 206. ATCAM Alert Statistics for Directive Alerting When Transmitting Truth Position Data for Arrival and Departure from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival)					
Aircraft A	65	5, 7.7	0, 0.0	30, 46.1	0, 0.0
Aircraft B	65	0, 0.0	0, 0.0	20, 30.8	0, 0.0
Both	65	0, 0.0	0, 0.0	20, 30.8	0, 0.0
Aircraft B (Departure)					
Aircraft A	65	0, 0.0	0, 0.0	45, 69.2	0, 0.0
Aircraft B	65	0, 0.0	0, 0.0	45, 69.2	0, 0.0
Both	65	0, 0.0	0, 0.0	45, 69.2	0, 0.0

Missed and nuisance alerts – The arrival Aircraft A did not enter the missed or nuisance boundary during any of the runs (Table 207). The departure Aircraft B only entered the missed and nuisance boundary when transmitting data with NACp 10 accuracy. For Aircraft B, there was no significant difference in the

number of runs in which the aircraft entered the missed boundary (p = 0.209) and nuisance boundary (p = 0.125) between accuracy levels.

The departing Aircraft B entered the missed boundary when transmitting data with NACp 10 accuracy due to the criteria for entering the missed boundary. The aircraft was counted as entering the missed boundary when the aircraft's true position was within one runway width of the runway centerline, but the detected position was greater than one runway width from the centerline. As such, there was no buffer between when the aircraft was inside or outside the missed boundary so a measurable difference between the true and detected position could cause a missed boundary to be counted. The departing aircraft entered the nuisance boundary after lifting off and over 620 ft AGL. The aircraft started drifting from the runway centerline. Since there was no buffer between when the aircraft was inside or outside the nuisance boundary, as was the case for the missed boundary definition, a measurable difference between the true and detected position near the boundary (one runway width from the centerline) could cause a nuisance boundary to be counted.

Table 207. ATCAM Missed and Nuisance Boundary Statistics for Directive Alerting for Arrival and Departure from Intersecting Runways Scenario.

	Entered Missed Boundary				Entered Nuisance Boundary			
NACp	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Arrival)								
10	0, 0.0	0.0, 0.0	0, 0.0	0.0	0, 0.0	0.0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0, 0.0	0.0	0, 0.0	0.0, 0.0	0, 0.0	0.0
Aircraft B (Departure)								
10	9, 5.8	1.1, 0.3	0.7, 0.4	1.3	11, 7.0	1.0, 0.0	0.5, 0.2	1.1
Truth	0, 0.0	0.0, 0.0	0, 0.0	0.0	0, 0.0	0.0, 0.0	0, 0.0	0.0

Missed CAs did not occur for either aircraft (Table 208). Missed WAs only occurred for Aircraft A (approximately 20% of the runs). Nuisance alerts did not occur for either aircraft during this scenario. For Aircraft A, there was no significant difference (p = 1.0) in the number of runs in which missed WAs occurred between accuracy levels. When analyzing missed WAs that occurred when transmitting truth position data, for Aircraft A, an alert should have been issued onboard the aircraft as the other aircraft aborted its departure.

Table 208. ATCAM Missed and Nuisance Alert Statistics for Directive Alerting for All Evasive Actions by NACp for Arrival And Departure from Intersecting Runway Scenario.

NACp	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival)					
10	156	0, 0.0	30, 19.2	0, 0.0	0, 0.0
Truth	39	0, 0.0	8, 20.5	0, 0.0	0, 0.0
Aircraft B (Departure)					
10	156	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	39	0, 0.0	0, 0.0	0, 0.0	0, 0.0

When analyzing by CD&R equipage level (Table 209), the missed WAs occurred when Aircraft B and Both aircraft were equipped. For Aircraft A, there was a significant difference (p < 0.001) in the number of runs in which missed WAs occurred between Aircraft A equipped vs. Aircraft B and Both aircraft equipped.

Table 209. ATCAM Missed and Nuisance Alert Statistics for Directive Alerting for All NACp by Evasive Action for Arrival and Departure from Intersecting Runways Scenario.

CD&R Equipage	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival)					
Aircraft A	65	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B	65	0, 0.0	18, 27.7	0, 0.0	0, 0.0
Both	65	0, 0.0	20, 30.8	0, 0.0	0, 0.0
Aircraft B (Departure)					
Aircraft A	65	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B	65	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Both	65	0, 0.0	0, 0.0	0, 0.0	0, 0.0

Unnecessary maneuvering – No unnecessary maneuvers occurred for this scenario.

Collision avoidance – Near collisions only occurred when transmitting data with NACp 10 accuracy and Aircraft A was equipped with CD&R (Table 210). There were no collisions. When Aircraft A was equipped, there was no significant difference ($p = 1.0$) in the number of runs in which near collisions occurred between accuracy levels.

The two near collisions occurred after the arrival Aircraft A landed, conducted accelerated braking after receiving a WA and stopped on the runway. The departing aircraft continued its departure since it was not equipped with CD&R on these test runs.

Table 210. Number/Percentage of Near Collisions (NC) and Collisions (C) Using ATCAM for Equipage Combinations for Directive Alerting For Arrival and Departure from Intersecting Runways Scenario.

NACp	# Runs per Equipage	CD&R Equipage					
		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C
10	52	2, 3.8	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	13	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0	0, 0.0

5.3.2 Directive Alerting – Head-on arrivals

For each of the 6 cases in this scenario, an initiation delay on Aircraft B was evaluated at 14 levels, for a total of 210 test runs.

Algorithm performance – For Aircraft A, CAs were generated on 21% of the runs, independent of position accuracy level (Table 211). For Aircraft B, CAs were generated on 51% of the runs when transmitting data with NACp 10 accuracy and 47% of the runs when transmitting data with truth accuracy. WAs were generated on 86% of the runs for either aircraft, independent of the position accuracy levels. There was no significant difference in the number of runs in which CAs were generated between accuracy levels for Aircraft A ($p = 1.0$) and Aircraft B ($p = 0.857$). There was also no significant difference in the number of runs in which WAs ($p = 1.0$) were generated between accuracy levels for both aircraft.

When analyzing alerts that occurred when transmitting truth position data, CAs were issued onboard Aircraft A when approximately 2,680 ft prior to the runway threshold and 177 ft AGL, 1,325 ft prior to the threshold and 106 ft AGL, or 9,848 ft past the threshold after landing and 5 kts. WAs were issued when approximately 870 ft prior to the runway threshold and 82 ft AGL until approximately 8,565 ft past the threshold after landing and 30 kts. For Aircraft B, four of the CAs occurred after the aircraft had conducted a go-around maneuver. The remainder of the CAs occurred when the aircraft was between 7,768 ft to 2,673 ft prior to the runway threshold and 443 ft AGL to 177 ft AGL. WAs occurred when the aircraft was between 2.3 NM to 861 ft prior to the runway threshold and 764 ft AGL to 82 ft AGL.

Table 211. ATCAM Alert Statistics for Directive Alerting for All Evasive Actions by NACp for Head-on Arrivals Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
10	168	36, 21.4	1, 0.6	144, 85.7	8, 4.8
Truth	42	9, 21.4	0, 0.0	36, 85.7	2, 4.8
Aircraft B (Arrival Runway 28)					
10	168	85, 50.6	0, 0.0	144, 85.7	29, 17.3
Truth	42	20, 47.6	0, 0.0	36, 85.7	7, 16.7

CA toggling only occurred on one run for Aircraft A (Table 211). WA toggling occurred on 5% of the runs for Aircraft A, independent of position accuracy level, with toggling occurring on approximately 17% of the runs for Aircraft B for each accuracy level. There was no significant difference ($p = 1.0$) in the number of runs in which multiple CAs and multiple WAs were generated between accuracy levels.

Multiple alerts occurred after both aircraft conducted a go-around maneuver, when both aircraft conducted accelerated braking, and when Aircraft A exited the runway. WA toggling occurred for both aircraft when transmitting truth position data. For Aircraft A, these two multiple alerts occurred when Aircraft B conducted a go-around maneuver and when Aircraft B had conducted a go-around maneuver and Aircraft A conducted accelerated braking. For Aircraft B when transmitting accurate position data, all of the multiple alerts occurred after Aircraft A had exited the runway; on two of these runs, Aircraft B also conducted a go-around maneuver.

When analyzing by CD&R equipage level (Table 212), for both aircraft, alert generation was similar across all equipage levels. There was no significant difference ($p = 1.0$) in the number of runs in which CAs and WAs were generated between equipage levels.

The multiple CA occurred onboard Aircraft A when Both aircraft were equipped with CD&R. The WA toggling rate was 7% for Aircraft A when only Aircraft B and Both aircraft were equipped. For Aircraft B, the WA toggling rate was higher when only Aircraft A and Both aircraft were equipped. For Aircraft A, there was no significant difference ($p = 0.333$) in the number of runs in which multiple CAs and multiple WAs were generated between equipage levels. For Aircraft B, there was a significant difference ($p = 0.003$) in the number of runs in which multiple WAs were generated between Aircraft A equipped vs. Aircraft B and Both aircraft equipped.

Table 212. ATCAM Alert Statistics for Directive Alerting for All NACp by Evasive Action for Head-on Arrivals Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
Aircraft A	70	15, 21.4	0, 0.0	60, 85.7	0, 0.0
Aircraft B	70	15, 21.4	0, 0.0	60, 85.7	5, 7.1
Both	70	15, 21.4	1, 1.4	60, 85.7	5, 7.1
Aircraft B (Arrival Runway 28)					
Aircraft A	70	35, 50.0	0, 0.0	60, 85.7	20, 28.6
Aircraft B	70	35, 50.0	0, 0.0	60, 85.7	5, 7.1
Both	70	35, 50.0	0, 0.0	60, 85.7	11, 15.7

Alert statistics were also compiled by CD&R equipage level when truth position data was transmitted (Table 213). All alert rates were the same as when transmitting data with various accuracy levels (Table 212), except the rate of CAs was slightly lower for Aircraft B when only Aircraft B was equipped with CD&R. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 1.0$) and WAs ($p = 1.0$) were generated between equipage levels. For Aircraft B, there was also no significant

difference in the number of runs in which CAs ($p = 0.620$) and WAs ($p = 1.0$) were generated between equipage levels.

Multiple alerts were eliminated for Aircraft A when transmitting accurate position data. The multiple alert rate for Aircraft B was similar to the rate when transmitting data with various accuracy levels (Table 212). For Aircraft B, there was a significant difference ($p < 0.001$) in the number of runs in which multiple WAs were generated between Aircraft B equipped vs. Aircraft A and Both aircraft equipped.

Table 213. ATCAM Alert Statistics for Directive Alerting When Transmitting Truth Position Data for Head-on Arrivals Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
Aircraft A	70	15, 21.4	0, 0.0	60, 85.7	0, 0.0
Aircraft B	70	15, 21.4	0, 0.0	60, 85.7	0, 0.0
Both	70	15, 21.4	0, 0.0	60, 85.7	0, 0.0
Aircraft B (Arrival Runway 28)					
Aircraft A	70	35, 50.0	0, 0.0	60, 85.7	20, 28.6
Aircraft B	70	30, 42.9	0, 0.0	60, 85.7	0, 0.0
Both	70	35, 50.0	0, 0.0	60, 85.7	13, 18.6

Missed and nuisance alerts – The missed boundary was only entered when transmitting data with NACp 10 accuracy (Table 214). The nuisance boundary was entered when transmitting data with NACp 10 accuracy for Aircraft A only. For Aircraft A, there was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary and nuisance boundary between NACp 10 vs. truth accuracy. For Aircraft B, there was no significant difference ($p = 1.0$) in the number of runs in which the aircraft entered the missed boundary between accuracy levels.

All occurrences of entering the missed boundary was after the aircraft had crossed the runway threshold for landing. Since the aircraft tracked the extended centerline on approach and centerline after landing, the nuisance boundary was entered as the aircraft exited the runway.

Table 214. ATCAM Missed and Nuisance Boundary Statistics for Directive Alerting for Head-on Arrivals Scenario.

	Entered Missed Boundary				Entered Nuisance Boundary			
NACp	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A (Arrival Runway 10)								
10	51, 30.4	1.0, 0.0	0.4, 0.3	0.5	40, 23.8	1.0, 0.0	0.4, 0.2	0.4
Truth	0, 0.0	0.0, 0.0	0, 0.0	0.0	0, 0.0	0.0, 0.0	0, 0.0	0.0
Aircraft B (Arrival Runway 28)								
10	3, 1.8	1.0, 0.0	0.3, 0.1	0.2	0, 0.0	0.0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0, 0.0	0.0	0, 0.0	0.0, 0.0	0, 0.0	0.0

Missed alerts only occurred onboard Aircraft B on 1% of the test runs when transmitting data with NACp 10 accuracy (Table 215). Nuisance alerts did not occur for either aircraft. For Aircraft B, there was no significant difference ($p = 1.0$) in the number of runs in which missed WAs occurred between accuracy levels. Both of the missed WAs for Aircraft B should have occurred after the aircraft conducted a go-around maneuver and was 680 ft AGL.

When analyzing by CD&R equipage level (Table 216), the two missed WAs occurred onboard Aircraft B when Both aircraft were equipped with CD&R. For Aircraft B, there was no significant difference ($p = 0.11$) in the number of runs in which missed WAs occurred between equipage levels.

Table 215. ATCAM Missed and Nuisance Alert Statistics for Directive Alerting for All Evasive Actions by NACp for Head–on Arrivals Scenario.

NACp	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
10	168	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Truth	42	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Arrival Runway 28)					
10	168	0, 0.0	2, 1.2	0, 0.0	0, 0.0
Truth	42	0, 0.0	0, 0.0	0, 0.0	0, 0.0

Table 216. ATCAM Missed and Nuisance Alert Statistics for Directive Alerting for All NACp by Evasive Action for Head-on Arrivals Scenario.

CD&R Equipage	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A (Arrival Runway 10)					
Aircraft A	70	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B	70	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Both	70	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B (Arrival Runway 28)					
Aircraft A	70	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Aircraft B	70	0, 0.0	0, 0.0	0, 0.0	0, 0.0
Both	70	0, 0.0	2, 2.9	0, 0.0	0, 0.0

Unnecessary maneuvering – No unnecessary maneuvers occurred for this scenario.

Collision avoidance – Collision avoidance was most effective when Both aircraft were equipped with CD&R and least effective when only Aircraft B was equipped (Table 217). When Aircraft A and Aircraft B were equipped with CD&R, there was no significant difference ($p = 1.0$) in the number of runs in which near collisions and collisions occurred between accuracy levels. When Both aircraft were equipped, there was no significant difference ($p = 1.0$) in the number of runs in which near collisions occurred between accuracy levels.

Table 217. Number/Percentage of Near Collisions (NC) and Collisions (C) Using ATCAM for Equipage Combinations for Directive Alerting for Head-on Arrivals Scenario.

NACp	# Runs per Equipage	CD&R Equipage					
		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C
10	56	16, 28.6	4, 7.1	16, 28.6	8, 14.3	8, 14.3	0, 0.0
Truth	14	4, 28.6	1, 7.1	4, 28.6	2, 14.3	2, 14.3	0, 0.0

For equipped aircraft, WAs were issued on 10 runs when the aircraft was 82 ft AGL and on five runs when the aircraft was 179 ft AGL, with all aircraft landing and conducting accelerated braking. When Aircraft A was equipped with CD&R, the collision occurred just before Aircraft A exited the runway. When Aircraft B was equipped, the collision occurred on five runs just before Aircraft B exited the runway, on four runs after Aircraft B conducted accelerated braking and was taxiing down the runway at 30 kts, and on one run after Aircraft B had stopped on the runway.

5.3.3 Directive Alerting – Taxi intersection

For each of the 6 cases in this scenario, an initiation delay and initial location for Aircraft B were evaluated at 76 levels, for a total of 1,140 test runs.

Algorithm performance – CAs were generated for 56% to 59% of the test runs and WAs were generated for 50% to 54% of the runs depending on the position accuracy level (Table 218). For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 0.462$) and WAs ($p = 0.335$) were generated between accuracy levels. For Aircraft B, there was also no significant difference in the number of runs in which CAs ($p = 0.799$) and WAs ($p = 0.306$) were generated between accuracy levels.

When analyzing alerts that occurred when transmitting truth position data, for Aircraft A, CAs were issued when the aircraft was approximately 217 ft to 718 ft from Aircraft B and WAs were issued when approximately 198 ft to 399 ft from Aircraft B. For Aircraft B, CAs were issued when approximately 236 ft to 718 ft from Aircraft A and WAs were issued when approximately 217 ft to 399 ft from Aircraft A.

Alert toggling only occurred when transmitting data with NACp 10 accuracy (Table 218). For Aircraft A, there was a significant difference ($p = 0.008$) in the number of runs in which multiple CAs were generated between NACp 10 accuracy and truth accuracy. There was no significant difference ($p = 1.0$) in the number of runs in which multiple WAs were generated between accuracy levels. For Aircraft B, there was no significant difference ($p = 1.0$) in the number of runs in which multiple CAs were generated between accuracy levels.

For Aircraft A, CA toggling was due to position accuracy (13 runs) and maneuvering (11 runs). Multiple CAs occurred after Aircraft B began to taxi. The WA toggling was due to position accuracy. For Aircraft B, the CA toggling occurred after both aircraft stopped on the taxiway.

Table 218. ATCAM Alert Statistics for Directive Alerting for All Evasive Actions by NACp for Taxi Intersection Scenario.

NACp	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A					
10	912	535, 58.7	24, 2.6	491, 53.8	1, 0.1
Truth	228	127, 55.7	0, 0.0	114, 50.0	0, 0.0
Aircraft B					
10	912	517, 56.7	2, 0.2	493, 54.1	0, 0.0
Truth	228	132, 57.9	0, 0.0	114, 50.0	0, 0.0

When analyzing by equipage level (Table 219), CAs were issued on approximately 56% to 59% of the runs for both aircraft. WAs were issued on approximately 53% of the runs for all equipage levels for both aircraft. For Aircraft A, there was no significant difference in the number of runs in which CAs ($p = 0.838$) and WAs ($p = 0.996$) were generated between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which CAs ($p = 0.804$) and WAs ($p = 0.986$) were generated between equipage levels.

Table 219. ATCAM Alert Statistics for Directive Alerting for All NACp by Evasive Action for Taxi Intersection Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A					
Aircraft A	380	225, 59.2	9, 2.4	201, 52.9	0, 0.0
Aircraft B	380	217, 57.1	8, 2.1	202, 53.2	1, 0.3
Both	380	220, 57.9	7, 1.8	202, 53.2	0, 0.0
Aircraft B					
Aircraft A	380	221, 58.2	0, 0.0	201, 52.9	0, 0.0
Aircraft B	380	212, 55.8	0, 0.0	203, 53.4	0, 0.0
Both	380	216, 56.8	2, 0.5	203, 53.4	0, 0.0

The rate of alert toggling was low for all equipage levels (Table 219). For Aircraft A, there was no significant difference in the number of runs in which multiple CAs ($p = 0.88$) and multiple WAs ($p = 0.333$) were generated between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which multiple CAs ($p = 0.111$) and multiple WAs ($p = 0.333$) were generated between equipage levels.

Alert statistics were also compiled by CD&R equipage level when truth position data was transmitted (Table 220). In general, alerts were issued at a similar rate as when transmitting data with various accuracy levels (Table 219). Multiple alerts did not occur when transmitting accurate data. For both aircraft, there was no significant difference in the number of runs in which CAs ($p = 0.996$) and WAs ($p = 0.986$) were generated between equipage levels.

Table 220. ATCAM Alert Statistics for Directive Alerting When Transmitting Truth Position Data for Taxi Intersection Scenario.

CD&R Equipage	Total # Runs	CA (# Runs, % Runs)	Multiple CA (# Runs, % Runs)	WA (# Runs, % Runs)	Multiple WA (# Runs, % Runs)
Aircraft A					
Aircraft A	380	220, 57.9	0, 0.0	188, 49.5	0, 0.0
Aircraft B	380	220, 57.9	0, 0.0	190, 50.0	0, 0.0
Both	380	219, 57.6	0, 0.0	190, 50.0	0, 0.0
Aircraft B					
Aircraft A	380	220, 57.9	0, 0.0	188, 49.5	0, 0.0
Aircraft B	380	220, 57.9	0, 0.0	190, 50.0	0, 0.0
Both	380	219, 57.6	0, 0.0	190, 50.0	0, 0.0

Missed and nuisance alerts – Both aircraft entered the defined missed boundary for a large percentage of test runs when transmitting data with NACp 10 accuracy (Table 221). Neither aircraft entered the nuisance boundary for this scenario. There was a significant difference ($p < 0.001$) in the number of runs in which the aircraft entered the missed boundary between NACp 10 accuracy vs. truth accuracy.

The aircraft entered the missed boundary only when crossing the intersecting taxiway. As previously discussed, the high rate of entering the missed boundary was due to the missed boundary definition. There was no buffer between when the aircraft was inside or outside the missed boundary; therefore, a very small difference between the true and detected position caused a missed boundary to be counted.

Table 221. ATCAM Missed and Nuisance Boundary Statistics for Directive Alerting for Taxi Intersection Scenario.

	Entered Missed Boundary				Entered Nuisance Boundary			
NACp	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length	# Runs, % Runs	Count (weighted mean, SD)	Duration (seconds) (mean, SD)	% of Run Length
Aircraft A								
10	513, 56.2	1.1, 0.3	0.6, 0.3	1.7	0, 0.0	0.0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0, 0.0	0.0	0, 0.0	0.0, 0.0	0, 0.0	0.0
Aircraft B								
10	353, 38.7	1.1, 0.3	0.6, 0.6	1.9	0, 0.0	0.0, 0.0	0, 0.0	0.0
Truth	0, 0.0	0.0, 0.0	0, 0.0	0.0	0, 0.0	0.0, 0.0	0, 0.0	0.0

The missed alert rate was low for this scenario (Table 222). It was only possible for a nuisance alert to be generated when taxiing across a taxiway; however, no nuisance alerts were issued for either aircraft for this scenario. For Aircraft A, there was no significant difference in the number of runs in which missed CAs ($p = 0.687$) and missed WAs ($p = 1.0$) occurred between accuracy levels. For Aircraft B, there was a significant difference ($p = 0.013$) in the number of runs in which missed CAs occurred between NACp 10

accuracy vs. truth accuracy. There was no significant difference (p = 1.0) in the number of runs in which missed WAs occurred between accuracy levels.

When analyzing missed CAs that occurred when transmitting truth position data, for Aircraft A, two of the alerts should have occurred when Aircraft A was 579 ft down the taxiway and Aircraft B was crossing 604 ft down the taxiway. Three of the alerts should have occurred when Aircraft A was 712 ft down the taxiway and Aircraft B was crossing 803 ft down the taxiway.

Table 222. ATCAM Missed and Nuisance Alert Statistics for Directive Alerting for All Evasive Actions by NACp for Taxi Intersection Scenario.

NACp	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A					
10	912	27, 3.0	3, 0.3	0, 0.0	0, 0.0
Truth	228	5, 2.2	0, 0.0	0, 0.0	0, 0.0
Aircraft B					
10	912	29, 3.2	2, 0.2	0, 0.0	0, 0.0
Truth	228	0, 0.0	0, 0.0	0, 0.0	0, 0.0

Analyzing the data based on equipage level (Table 223) shows that, missed CAs occurred on approximately 2% to 3% of the test runs for both aircraft depending on the equipage level. The missed WA rate was very low for all equipage levels for both aircraft. For Aircraft A, there was no significant difference in the number of runs in which missed CAs (p = 0.543) and missed WAs (p = 0.259) occurred between equipage levels. For Aircraft B, there was also no significant difference in the number of runs in which missed CAs (p = 0.371) and missed WAs (p = 0.111) occurred between equipage levels.

Table 223. ATCAM Missed and Nuisance Alert Statistics for Directive Alerting for All NACp by Evasive Action for Taxi Intersection Scenario.

CD&R Equipage	Total # Runs	Missed CA (# Runs, % Runs)	Missed WA (# Runs, % Runs)	Nuisance CA (# Runs, % Runs)	Nuisance WA (# Runs, % Runs)
Aircraft A					
Aircraft A	380	8, 2.1	2, 0.5	0, 0.0	0, 0.0
Aircraft B	380	13, 3.4	0, 0.0	0, 0.0	0, 0.0
Both	380	11, 2.9	1, 0.3	0, 0.0	0, 0.0
Aircraft B					
Aircraft A	380	7, 1.8	2, 0.5	0, 0.0	0, 0.0
Aircraft B	380	13, 3.4	0, 0.0	0, 0.0	0, 0.0
Both	380	9, 2.4	0, 0.0	0, 0.0	0, 0.0

Unnecessary maneuvering – Only one unnecessary maneuver occurred for Aircraft A when transmitting data with NACp 10 accuracy (Table 224). There was no significant difference (p = 1.0) in the number of runs in which unnecessary maneuvers occurred for Aircraft A between accuracy levels.

The unnecessary maneuver occurred onboard Aircraft A when only Aircraft A was equipped with CD&R (Table 225). There was no significant difference (p = 1.0) in the number of runs in which unnecessary maneuvers occurred for Aircraft A between equipage levels.

Table 224. Unnecessary Maneuvers Using ATCAM for Directive Alerting for All Evasive Actions by NACp for Taxi Intersection Scenario.

NACp	Total # Runs	Aircraft A (# Runs, % Runs)	Aircraft B (# Runs, % Runs)
10	608	1, 0.2	0, 0.0
Truth	152	0, 0.0	0, 0.0

Table 225. Unnecessary Maneuvers Using ATCAM for Directive Alerting for All NACp by Evasive Action for Taxi Intersection Scenario.

CD&R Equipage	Total # Runs	Aircraft A (# Runs, % Runs)	Aircraft B (# Runs, % Runs)
Aircraft A	380	1, 0.3	N/A
Aircraft B	380	N/A	0, 0.0
Both	380	0, 0.0	0, 0.0

Collision avoidance – Collision avoidance was most effective when Both aircraft were equipped with CD&R, although approximately 5% of the test runs still resulted in collision (Table 226). Since both aircraft conducted identical operations, it was expected that collision avoidance would be similar for both aircraft. When Aircraft A was equipped, there was no significant difference in the number of runs in which near collisions ($p = 0.979$) and collisions ($p = 1.0$) occurred between equipage levels. When Aircraft B was equipped, there was no significant difference in the number of runs in which near collisions ($p = 0.462$) and collisions ($p = 0.713$) occurred between equipage levels. When Both aircraft were equipped, there was no significant difference in the number of runs in which near collisions ($p = 0.779$) and collisions ($p = 1.0$) occurred between equipage levels.

Investigation was performed on the test runs that resulted in collision for the truth data condition. It was determined that for these test runs, WAs were generated (4 to 8 seconds before collision); however, by the time the pilot reaction delay (2 seconds) was over, the aircraft was projected to stop closer than 100 ft from the intersecting taxiway centerline. As a result, the aircraft continued taxi and a collision occurred.

Table 226. Number/Percentage of Near Collisions (NC) and Collisions (C) Using ATCAM for Equipage Combinations for Directive Alerting for Taxi Intersection Scenario.

NACp	# Runs per Equipage	CD&R Equipage					
		Aircraft A		Aircraft B		Both	
		NC	C	NC	C	NC	C
10	304	107, 35.2	60, 19.7	104, 34.2	56, 18.4	67, 22.0	18, 5.9
Truth	76	26, 34.2	15, 19.7	22, 28.9	12, 15.8	15, 19.7	4, 5.3

6 Discussion

The SURF IA SPR has proposed horizontal position accuracy requirements [RTCA, 2010] for the SURF IA function. Through analysis, the SPR identified that to meet safety requirements, horizontal position accuracy when on the airport surface must be NACp 10 or higher for large airports (the Operational Evolution Partnership 35 airports). This study was conducted at KORD, which fits into this airport category. Experimental results are summarized and discussed in this section, in relation to this NACp 10 position accuracy requirement.

6.1 ATCAM and SURF IA Algorithms

6.1.1 Algorithm Performance

Alert generation varied during this study due to the accuracy of the data transmitted by the aircraft and the initial starting location and movement timing of the aircraft. When conducting a standard approach operation while transmitting truth data, the ATCAM algorithm generally issued a CA when the aircraft was approximately 1.3 NM prior to the runway threshold and a WA when approximately 1 NM prior to the threshold. The SURF IA algorithm issued TIs when approximately 2.8 NM prior to the threshold, RSIs when approximately 1.9 NM prior to the threshold, CAs when approximately 1.2 NM prior to the threshold, and WAs when approximately 0.5 NM prior to the threshold.

During departure, the algorithms are designed to rarely issue CAs since this is a critical phase of flight and there is little time to evaluate the potential conflict situation. However, when transmitting truth data, the ATCAM algorithm issued CAs during the departure with crossing taxi traffic scenario after a WA was issued and the aircraft aborted the departure. When conditions were met, ATCAM issued WAs early in the departure; when the aircraft's ground speed was 15 kts or less. Taking action based on these timely alerts saves wear on the aircraft and aborts the departure early enough that the aircraft can attempt the departure again without having to reposition. The SURF IA algorithm issued TIs when in position and holding or just after takeoff roll was initiated, RSIs when 35 kts or less, and WAs when greater than 40 kts. SURF IA did not issue CAs. Although the SURF IA SPR [RTCA, 2010] specifies that IAs must be inhibited above 80 kts, both the ATCAM and SURF IA algorithm currently generate alerts throughout the departure; any alerts issued when the aircraft is greater than 80 kts would not be displayed to the flight crew.

When an aircraft was taxiing across a runway and accurate position data was being transmitted, ATCAM issued a CA when approximately 345 ft to 245 ft before the runway hold line and a WA when approximately 245 ft before the hold line. SURF IA issued a TI and RSI approximately 275 ft before the runway hold line but did not issue an alert until the aircraft nose was at the runway edge (approximately 76 ft over the hold line).

The ATCAM algorithm also generates alerts for potential conflicts on taxiways. When aircraft were taxiing in the same direction, alerts were issued earlier the faster the aircraft were closing. During taxi intersection conflict scenarios, CAs were issued when the aircraft were 719 ft to 217 ft apart and WAs were issued when 399 ft to 198 ft apart. In head-on taxi situations, CAs were issued when the aircraft were approximately 1027 ft apart and WAs when approximately 635 ft apart.

IA toggling occurred when multiple instances of IAs were generated during a test run. IA toggling is undesirable (i.e., it is a distraction to the flight crew and could cause mistrust in the technology). The alert toggling rates (percent of test runs) when using the ATCAM algorithm are presented in Table 227. For all scenario types, the multiple alert rates were highest when transmitting NACp 8 accuracy. The rate of multiple CAs when transmitting NACp 10 and higher accuracies was 2% of the runs or less for the runway scenarios, 22.3% or less for the taxi scenarios, and 1.1% to 4.6% for the low altitude scenarios. The rate of multiple WAs when transmitting NACp 10 and higher accuracies was 19.2% or less for the runway scenarios, 23.1% or less for the taxi scenarios, and 0.5% or less for the low altitude scenarios. The higher rate of multiple WAs occurred during the arrival and departure from same runway scenario, head-on arrivals scenario, taxi following scenario, and taxi head-on scenario. For all other runway scenarios, the rate of multiple WAs when transmitting NACp 10 and higher accuracies was 2.2% or less of the runs and for the

other taxi scenario, the rate was 0.1% of the runs or less. In many instances, the toggling included gaps between alerts when transmitting less accurate data (NACp 8 and 9 accuracies). Not all toggling was due to inaccurate position data; multiple alerts also occurred as a result of aircraft maneuvering; i.e., after an aircraft rejected the takeoff, conducted accelerated braking, conducted a go-around maneuver, initiated the takeoff, stopped on the runway or taxiway, or exited the runway. On intersecting runway scenarios, a multiple alert would sometimes occur after the aircraft has past the intersection, which was not necessary since the threat had passed. The ATCAM algorithm utilizes techniques to minimize alert toggling [Otero et al, 2013].

Table 227. Alert Toggling Rates (% of Test Runs) When Using the ATCAM Algorithm.

	Multiple CA					Multiple WA				
NACp	8	9	10	11	Truth	8	9	10	11	Truth
Aircraft A										
Arrival / taxi crossing	3.9	1.1	0.0	0.0	0.0	15.7	3.5	1.1	0.5	0.0
Departure / taxi crossing	0.4	0.0	0.0	0.0	0.0	11.8	3.2	1.4	0.6	0.1
Arrival / departure same rwy	11.9	1.8	0.0	0.0	0.0	28.2	5.6	5.6	5.6	5.6
Departures intersecting rwys	0.0	0.0	0.0	0.0	0.0	9.6	6.2	0.0	0.0	0.0
Arrival / departure intersecting	0.6	0.3	0.0	0.0	0.0	8.0	6.1	1.9	1.9	1.9
Head-on arrivals	52.5	2.4	0.9	0.0	0.0	63.5	8.6	3.6	3.0	3.6
Arrivals intersecting rwys	10.7	0.6	0.0	0.0	0.0	27.5	5.8	0.5	0.0	0.0
Taxi following	42.4	34.5	19.6	2.4	0.0	33.7	22.0	6.3	0.0	0.0
Taxi intersection	36.5	16.3	3.2	0.1	0.0	21.1	4.0	0.1	0.0	0.0
Taxi head-on	20.3	3.2	1.4	1.3	1.9	31.0	16.4	13.9	15.4	23.1
Arrival / crossing airborne	4.3	1.7	1.1	1.1	1.1	0.9	0.5	0.5	0.5	0.5
Departure / crossing airborne	3.9	4.2	4.5	4.6	4.5	0.2	0.0	0.0	0.0	0.0
Aircraft B										
Arrival / taxi crossing	19.4	3.0	1.8	1.9	2.0	17.6	5.6	2.2	1.7	1.4
Departure / taxi crossing	0.9	0.1	0.1	0.1	0.1	15.2	4.4	1.1	0.4	0.1
Arrival / departure same rwy	48.0	5.6	0.0	0.0	0.0	42.9	6.0	5.6	5.6	5.6
Departures intersecting rwys	0.0	0.0	0.0	0.0	0.0	8.3	4.7	0.0	0.0	0.0
Arrival / departure intersecting	0.0	0.0	0.0	0.0	0.0	17.9	8.0	0.0	0.0	0.0
Head-on arrivals	9.7	1.5	0.9	0.0	0.0	62.8	34.8	19.2	14.3	14.3
Arrivals intersecting rwys	4.7	1.0	0.0	0.0	0.0	21.4	5.1	0.0	0.0	0.0
Taxi following	45.4	33.9	22.3	1.2	0.0	37.8	22.0	5.4	1.2	0.0
Taxi intersection	14.5	1.8	0.0	0.0	0.0	15.5	2.1	0.0	0.0	0.0
Taxi head-on	23.1	8.3	2.4	1.3	0.0	32.4	15.4	11.1	12.8	23.1
Arrival / crossing airborne	3.7	1.5	1.2	1.1	1.2	0.7	0.5	0.5	0.5	0.5
Departure / crossing airborne	2.5	2.5	2.7	2.7	2.8	0.9	0.4	0.0	0.0	0.0

The alert toggling rates when using the SURF IA algorithm are presented in Table 228. Overall, the rate of multiple TIs was high, even when transmitting more accurate position data. In contrast, the rate of multiple RSIs was low when transmitting NACp 10 and higher accuracies, except for the head-on arrivals scenario. There were no multiple CAs when transmitting NACp 10 and higher accuracies, except during the head-on arrivals scenario and arrivals to intersecting runways scenario. The rate of multiple WAs was highest when transmitting NACp 8 accuracy. There were also no multiple WAs when transmitting NACp 10 and higher accuracies, except during the arrival and departure from the same runway scenario, the head-on arrivals scenario, and the arrivals to intersecting runways scenario. The highest rate of multiple CAs and WAs occurred during the head-on arrivals scenario and arrivals to intersecting runways scenario. In many instances, the toggling included gaps between IAs when transmitting less accurate data (NACp 8 and 9 accuracies). Not all toggling was due to inaccurate position data; multiple alerts also occurred as a result of aircraft maneuvering; i.e., after an aircraft aborted the takeoff, conducted accelerated braking, conducted a go-around maneuver, initiated the takeoff, stopped on the runway, or exited the runway. On intersecting

runway scenarios, a multiple alert would sometimes occur onboard an aircraft after it was in the intersection of the runways or had passed the intersection, which was not necessary since the aircraft is moving away from the intersection. In some instances indication toggling occurred by design. Some situations warrant a multiple TI; as the situation progresses, an RSI or alert is generated, then, if the situation changes, the indication may be degraded back to a less severe TI. The SURF IA algorithm does not have any mechanisms in place to address toggling between aircraft states.

Table 228. IA Toggling Rates (% of Test Runs) When Using the SURF IA Algorithm.

	Multiple TI					Multiple RSI				
NACp	8	9	10	11	Truth	8	9	10	11	Truth
Aircraft A										
Arrival / taxi crossing	17.6	1.3	0.0	0.0	0.0	5.8	1.1	0.0	0.0	0.0
Departure / taxi crossing	14.4	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
Arrival / departure same rwy	52.0	9.7	8.3	8.3	11.1	19.4	1.4	0.0	0.0	0.0
Departures intersecting rwys	17.2	34.1	37.5	37.5	37.5	0.2	0.0	0.0	0.0	0.0
Arrival / departure intersecting	31.0	32.0	28.9	28.9	28.9	0.3	0.3	0.0	0.0	0.0
Head-on arrivals	43.1	0.9	0.0	0.0	0.0	73.7	41.4	17.9	17.9	17.9
Arrivals intersecting rwys	50.0	24.4	16.4	15.4	15.4	2.2	0.6	0.0	0.0	0.0
Aircraft B										
Arrival / taxi crossing	41.1	13.1	6.8	6.2	5.8	36.7	11.0	3.6	2.7	2.1
Departure / taxi crossing	70.7	14.2	0.8	0.8	0.7	34.9	9.2	0.6	0.1	0.0
Arrival / departure same rwy	88.9	46.8	22.9	23.1	22.2	57.9	12.5	0.0	0.0	0.0
Departures intersecting rwys	19.0	33.9	37.5	37.5	37.5	0.4	0.0	0.0	0.0	0.0
Arrival / departure intersecting	34.3	33.0	28.9	28.9	28.9	1.1	0.0	0.0	0.0	0.0
Head-on arrivals	66.1	16.4	4.9	6.5	3.6	24.2	7.4	7.1	7.1	7.1
Arrivals intersecting rwys	42.3	16.0	7.7	7.7	7.7	0.6	0.0	0.0	0.0	0.0

	Multiple CA					Multiple WA				
NACp	8	9	10	11	Truth	8	9	10	11	Truth
Aircraft A										
Arrival / taxi crossing	2.5	0.0	0.0	0.0	0.0	9.8	1.8	0.0	0.0	0.0
Departure / taxi crossing	0.0	0.0	0.0	0.0	0.0	6.3	1.1	0.0	0.0	0.0
Arrival / departure same rwy	21.4	3.7	0.0	0.0	0.0	27.4	3.2	0.0	0.0	0.0
Departures intersecting rwys	0.0	0.0	0.0	0.0	0.0	4.2	1.8	0.0	0.0	0.0
Arrival / departure intersecting	2.8	1.0	0.0	0.0	0.0	9.6	3.5	0.0	0.0	0.0
Head-on arrivals	64.3	10.7	0.0	0.0	0.0	60.7	31.9	21.4	21.4	21.4
Arrivals intersecting rwys	6.6	0.3	0.0	0.0	0.0	16.5	11.9	9.6	9.6	9.6
Aircraft B										
Arrival / taxi crossing	5.1	0.1	0.0	0.0	0.0	11.6	2.0	0.0	0.0	0.0
Departure / taxi crossing	0.0	0.0	0.0	0.0	0.0	7.5	1.0	0.0	0.0	0.0
Arrival / departure same rwy	41.3	5.1	0.0	0.0	0.0	31.4	7.4	2.8	1.8	2.8
Departures intersecting rwys	0.0	0.0	0.0	0.0	0.0	6.0	2.6	0.0	0.0	0.0
Arrival / departure intersecting	0.0	0.0	0.0	0.0	0.0	8.2	3.5	0.0	0.0	0.0
Head-on arrivals	44.6	17.9	17.9	17.9	17.9	54.9	26.8	21.4	21.4	21.4
Arrivals intersecting rwys	19.2	15.7	15.4	15.4	15.4	18.4	11.2	9.6	9.6	9.6

6.1.2 Nuisance and Missed Alerts

As discussed in Section 4.5.2, a nuisance IA is defined as any indication or alert generated by a properly functioning CD&R system that is inappropriate or unnecessary for the particular situation [RTCA, 2010]. Nuisance IAs could distract the flight crew unnecessarily, reduce confidence in the system, and negatively affect safety and operational effectiveness. Repeated nuisance IAs could decrease the use of CD&R and reduce expeditious flight crew response to true IAs.

As determined by the SURF IA SPR [RTCA, 2010], acceptable rates for displaying nuisance IA from a safety perspective are as follows: nuisance indications, 4×10^{-2} per operation or less and nuisance alerts, 1×10^{-3} per operation or less. An operation is defined as all of the states that comprise one takeoff and one landing procedure, i.e., taxiing, holding short of runway, entering/exiting/crossing a runway, in position and holding, takeoff roll, approach, and landing. For this study, each runway conflict scenario only contained one takeoff or landing procedure per aircraft, but not both; therefore, the nuisance rates stated above are being divided in half (nuisance indication: 2×10^{-2} or less, nuisance alerts, 5×10^{-4} or less) to determine acceptability of the rate of nuisance IAs issued during the testing. Only the runway conflict scenarios were evaluated for nuisance rate acceptability since the SURF IA SPR does not address taxi and low altitude air-to-air conflict situations at this time.

When using the ATCAM algorithm, the rate of nuisance CAs and WAs met the SURF IA nuisance acceptability rate for all runway conflict scenarios and position accuracy levels except as shown in Table 229.

Table 229. ATCAM Conditions That Did Not Meet Nuisance Acceptability Rate.

Scenario	Aircraft	NACp	Alert
Arrival / taxi crossing	Taxi crossing	8	CA, WA
Departure / taxi crossing	Taxi crossing	8	CA, WA
Arrival / departure same runway	Departure	8	CA, WA
Head-on arrivals	Arrival Runway 10	8	CA, WA
Head-on arrivals	Arrival Runway 10	9	WA

When using the SURF IA algorithm, the rate of nuisance IAs met the SURF IA nuisance acceptability rate for all runway conflict scenarios and positions accuracy levels except as shown in Table 230.

Table 230. SURF IA Conditions That Did Not Meet Nuisance Acceptability Rate.

Scenario	Aircraft	NACp	Alert
Arrival / taxi crossing	Taxi crossing	8	TI, RSI, CA, WA
Departure / taxi crossing	Taxi crossing	8	TI, RSI, WA
Head-on arrivals	Arrival Runway 10	8	TI, RSI, CA, WA
Head-on arrivals	Arrival Runway 10	9	RSI
Head-on arrivals	Arrival Runway 10	10	RSI
Arrivals to intersecting runways	Arrival Runway 14L	8	TI

For both algorithms, the nuisance acceptability rate was not met in many instances when transmitting NACp 8 accuracy. Each algorithm had one instance of not meeting the nuisance acceptability rate when transmitting NACp 9 accuracy (head-on arrival scenario). The SURF IA algorithm had one instance of not meeting the nuisance acceptability rate for an indication when transmitting NACp 10 accuracy. Based on this evaluation, NACp 10 and higher accuracy is sufficient for meeting acceptable nuisance alert rates and may be acceptable for meeting nuisance indication rates, NACp 9 accuracy may be acceptable for meeting the nuisance IA rate, and NACp 8 is not acceptable.

A missed IA is defined as a failure to provide an indication or alert when it is necessary provided ownship and traffic are adequately equipped [RTCA, 2010]. Missed IAs represent a reduction in CD&R benefits and result in operations that are similar to today's operations where IAs are not provided. The SURF IA SPR did not address missed IA from the safety perspective; therefore, acceptable rates for missed IAs were not provided.

In this study, an algorithm dependent definition was used to determine the rate of missed IAs. If an IA was generated when transmitting truth data but an IA was not generated at the same instance when transmitting NACp data, then a missed IA was counted.

The missed alert rates when using the ATCAM algorithm are presented in Table 231. For all scenario types except the arrival and departure from intersecting runways, the missed alert rates were highest when transmitting NACp 8 accuracy. When transmitting NACp 10 and higher accuracies, the rate of missed CAs was 0.6% of the runs or less for the runway scenarios, 4.5% or less for the taxi scenarios, and 0.5% or less for the low altitude scenarios. When transmitting NACp 10 and higher accuracies, the rate of missed WAs was low for the low altitude scenarios (0.2% of runs) but was much higher for the runway (14.9% to 15.4% of runs) and taxi (13.9% of runs or less) scenarios. The higher rate of missed WAs occurred during the departures from intersecting runway scenario, arrival and departure from intersecting runways scenario, and taxi head-on scenario. For all other runway scenarios, the rate of missed WAs when transmitting NACp 10 and higher accuracy was 1.5% or less of the runs and for the other taxi scenarios, the rate was 0.7% of the runs or less.

Table 231. Missed Alert Rates (% of Test Runs) When Using the ATCAM Algorithm.

	Missed CA					Missed WA				
NACp	8	9	10	11	Truth	8	9	10	11	Truth
Aircraft A										
Arrival / taxi crossing	2.3	0.8	0.4	0.2	0.0	7.3	2.4	0.4	0.2	0.0
Departure / taxi crossing	0.2	0.0	0.0	0.0	0.0	8.1	2.6	1.1	0.5	0.2
Arrival / departure same rwy	2.4	0.0	0.0	0.0	0.0	2.0	0.9	0.0	0.9	0.0
Departures intersecting rwys	0.0	0.0	0.0	0.0	0.0	40.4	15.4	12.9	12.5	12.5
Arrival / departure intersecting	3.0	0.0	0.0	0.0	0.0	14.3	13.1	14.9	15.4	15.4
Head-on arrivals	0.6	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0
Arrivals intersecting rwys	0.0	0.0	0.0	0.0	0.0	14.3	1.6	0.5	1.3	0.0
Taxi following	8.2	1.2	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0
Taxi intersection	7.7	3.4	3.5	2.5	2.3	7.1	2.1	0.7	0.0	0.0
Taxi head-on	12.1	0.3	0.0	0.0	0.0	11.8	9.6	9.6	7.7	0.0
Arrival / crossing airborne	1.4	0.8	0.4	0.2	0.1	1.3	0.4	0.0	0.0	0.0
Departure / crossing airborne	4.8	1.5	0.3	0.0	0.1	1.9	0.3	0.0	0.0	0.0
Aircraft B										
Arrival / taxi crossing	3.4	1.5	0.4	0.1	0.0	8.5	2.1	0.6	0.2	0.0
Departure / taxi crossing	0.5	0.3	0.2	0.1	0.0	10.8	1.9	0.7	0.4	0.3
Arrival / departure same rwy	4.0	0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.9	0.0
Departures intersecting rwys	0.0	0.0	0.0	0.0	0.0	33.0	9.9	6.6	6.2	6.2
Arrival / departure intersecting	0.0	0.0	0.0	0.0	0.0	14.8	0.0	0.0	0.0	0.0
Head-on arrivals	0.8	0.0	0.0	0.6	0.0	2.6	2.7	0.0	0.0	0.0
Arrivals intersecting rwys	6.3	0.6	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0
Taxi following	7.1	1.2	0.0	0.0	0.0	2.0	1.2	0.0	0.0	0.0
Taxi intersection	13.0	7.1	4.5	2.4	0.0	8.2	2.3	0.6	0.0	0.0
Taxi head-on	12.6	0.3	0.0	0.0	0.0	14.0	11.2	13.9	10.9	0.0
Arrival / crossing airborne	1.3	0.8	0.5	0.2	0.0	1.8	0.4	0.1	0.0	0.0
Departure / crossing airborne	3.4	1.0	0.3	0.2	0.0	2.5	0.5	0.2	0.2	0.2

The missed IA rates when using the SURF IA algorithm are presented in Table 232. The SURF IA algorithm was only evaluated for the runway scenarios. The missed IA rates were highest when transmitting NACp 8 accuracy. When transmitting NACp 10 and higher accuracies, the rate of missed TIs was 5.6% of the runs or less, missed RSIs was 0.6% to 2.2% of the runs, missed CAs was 2.8% of the runs or less, and missed WAs was 1.0% to 1.2% of the runs. The higher occurrence of missed TIs were for the arrival and departure from same runway scenario; otherwise, the rate was 1.8% or less.

For both algorithms, when transmitting truth position accuracy, missed alerts occurred because of the ADS-B transmission model. The transmission model resulted in a slight delay between the aircraft's position at the time of transmitting the ADS-B message and the position at the time of reception of the ADS-B message by the other aircraft. This delay was present in all scenarios, but this position difference

was negligible compared to the NACp position uncertainty error. As a result, one aircraft did not detect a conflict with the other aircraft based on the broadcast position, but if instantaneous position information were used, a conflict would have been detected. The small error introduced by the movement of the aircraft between transmission and reception of the ADS-B message resulted in just enough difference in relation to the other aircraft's position to result in the missed alerts.

Table 232. Missed IA Rates (% of Test Runs) When Using the SURF IA Algorithm.

	Missed TI					Missed RSI				
NACp	8	9	10	11	Truth	8	9	10	11	Truth
Aircraft A										
Arrival / taxi crossing	2.1	0.5	0.2	0.1	0.0	5.1	1.2	0.5	0.2	0.0
Departure / taxi crossing	0.0	0.0	0.0	0.0	0.0	0.8	0.1	0.0	0.0	0.0
Arrival / departure same rwy	8.7	5.6	5.6	4.6	0.0	4.4	0.0	0.0	0.0	0.0
Departures intersecting rwys	32.4	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Arrival / departure intersecting	21.2	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Head-on arrivals	0.5	0.3	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0
Arrivals intersecting rwys	9.9	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aircraft B										
Arrival / taxi crossing	2.5	1.2	0.6	0.2	0.1	4.6	1.4	0.5	0.0	0.0
Departure / taxi crossing	0.4	0.5	0.3	0.1	0.0	16.5	2.6	1.2	0.9	0.6
Arrival / departure same rwy	6.0	0.9	4.2	2.8	0.0	3.2	0.5	0.7	0.9	0.0
Departures intersecting rwys	28.6	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Arrival / departure intersecting	17.9	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Head-on arrivals	3.8	2.4	0.9	1.2	1.8	6.4	3.0	2.2	0.0	0.0
Arrivals intersecting rwys	5.8	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	Missed CA					Missed WA				
NACp	8	9	10	11	Truth	8	9	10	11	Truth
Aircraft A										
Arrival / taxi crossing	3.7	1.3	0.4	0.1	0.0	8.1	1.0	0.2	0.0	0.0
Departure / taxi crossing	0.0	0.0	0.0	0.0	0.0	11.4	2.1	0.5	0.2	0.0
Arrival / departure same rwy	3.6	0.0	0.0	0.0	0.0	11.5	1.9	0.7	0.0	0.0
Departures intersecting rwys	0.0	0.0	0.0	0.0	0.0	31.0	2.1	0.0	0.0	0.0
Arrival / departure intersecting	4.9	0.0	0.0	0.0	0.0	9.3	0.3	0.0	0.0	0.0
Head-on arrivals	0.5	0.0	0.0	0.0	0.0	11.7	2.1	0.4	0.0	0.0
Arrivals intersecting rwys	0.5	0.0	0.0	0.0	0.0	4.7	0.3	0.0	0.0	0.0
Aircraft B										
Arrival / taxi crossing	3.6	1.3	0.3	0.1	0.0	8.0	1.0	0.1	0.1	0.0
Departure / taxi crossing	0.0	0.0	0.0	0.0	0.0	11.7	2.7	1.2	1.0	1.0
Arrival / departure same rwy	2.0	0.5	2.8	0.9	0.0	11.9	2.8	0.0	0.9	0.0
Departures intersecting rwys	0.0	0.0	0.0	0.0	0.0	30.6	2.3	0.0	0.0	0.0
Arrival / departure intersecting	0.0	0.0	0.0	0.0	0.0	8.2	0.0	0.0	0.0	0.0
Head-on arrivals	2.0	0.0	0.0	0.0	0.0	8.7	0.6	0.4	0.0	0.0
Arrivals intersecting rwys	4.4	0.0	0.0	0.0	0.0	4.7	0.0	0.0	0.0	0.0

6.1.3 Unnecessary Maneuvering

Previous research has shown that pilots instinctively react upon receiving airport traffic WAs in the flight deck [Jones et al, 2010] without necessarily confirming with secondary or additional information first; therefore, it is critical that alerting only occurs when needed. Otherwise, the flight crew could make unnecessary maneuvers that can cause delays, equipment wear, and other costs to airlines.

Since this was not a human-in-the-loop study, an algorithm-dependent method was devised to determine whether a maneuver (go-around, accelerated braking, rejected take-off, climb, descend,

accelerate during taxi, and decelerate during taxi) was unnecessary. Maneuvering was considered unnecessary if made based on a WA issued when the aircraft were broadcasting NACp accuracy, but for the same test conditions, a WA was not issued when broadcasting truth position data. Only the test runs in which maneuvering was possible were evaluated for unnecessary maneuvers.

The unnecessary maneuvering rates when using the ATCAM algorithm were as shown in Table 233.

Table 233. Unnecessary Maneuvering Rates When Using the ATCAM Algorithm.

	Unnecessary Maneuvering Rate Aircraft A (% of runs)					Unnecessary Maneuvering Rate Aircraft B (% of runs)				
NACp	8	9	10	11	Truth	8	9	10	11	Truth
Arrival / taxi crossing	11.0	3.8	0.4	0.1	0.0	3.4	1.9	0.4	0.3	0.2
Departure / taxi crossing	0.0	0.0	0.0	0.0	0.0	5.4	2.6	0.4	0.0	0.0
Arrival / departure same rwy	1.6	0.9	0.0	0.0	0.0	9.5	4.6	1.4	0.0	0.0
Head-on arrivals	1.5	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
Taxi following	51.0	25.0	7.1	0.0	0.0	43.9	21.4	10.7	2.4	0.0
Taxi intersection	23.3	10.3	0.5	0.0	0.0	16.4	5.8	1.2	0.0	0.0
Taxi head-on	5.5	0.6	0.0	0.0	0.0	8.8	0.6	0.0	0.0	0.0
Arrival / crossing airborne	1.5	0.5	0.1	0.0	0.0	1.5	0.6	0.2	0.0	0.0
Departure / crossing airborne	0.4	0.0	0.0	0.0	0.0	1.4	0.2	0.0	0.0	0.0

The unnecessary maneuvering rates when using the SURF IA algorithm were as shown in Table 234.

Table 234. Unnecessary Maneuvering Rates When Using the SURF IA Algorithm.

	Unnecessary Maneuvering Rate Aircraft A (% of runs)					Unnecessary Maneuvering Rate Aircraft B (% of runs)				
NACp	8	9	10	11	Truth	8	9	10	11	Truth
Arrival / taxi crossing	3.9	0.5	0.0	0.0	0.0	2.5	0.1	0.0	0.0	0.0
Departure / taxi crossing	0.0	0.0	0.0	0.0	0.0	3.8	0.3	0.0	0.0	0.0
Arrival / departure same rwy	4.0	2.8	0.0	0.0	0.0	6.3	0.9	0.0	0.0	0.0
Arrival / departure intersecting	0.0	0.0	0.0	0.0	0.0	3.3	3.2	2.9	2.6	0.0
Head-on arrivals	12.8	2.4	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0

Unnecessary maneuvers were more prevalent when transmitting less accurate position data, particularly when transmitting NACp 8 and 9 accuracies. When using the ATCAM algorithm, there were no unnecessary maneuvers for the intersecting runway scenarios. When transmitting NACp 10 and higher accuracy, unnecessary maneuvers occurred on 0.4% of the runs or less for the arrival and taxi crossing aircraft, on 1.4% or less for the departing aircraft, and on 0.2% or less for the airborne crossing aircraft. The occurrence of unnecessary maneuvers was higher for the taxi aircraft (10.7% of the runs or less when transmitting NACp 10 and higher accuracy). When using the SURF IA algorithm, unnecessary maneuvers occurred for the departing aircraft during the arrival and departure from intersecting runways scenario; otherwise, there were no unnecessary maneuvers for the arrival, departure, and taxi crossing aircraft when transmitting NACp 10 accuracy or higher.

6.1.4 Collision Avoidance

Overall, collision avoidance was more effective when both aircraft were equipped with CD&R and maneuvered to avoid a collision after a WA was issued. As expected, collisions occurred most often when neither aircraft were equipped and did not take any action to avoid a collision. Sometimes, however, collision avoidance was more effective when one aircraft was equipped with CD&R over the other aircraft. For example, during the arrival with departure from same runway scenario, collision avoidance was more effective when the arrival was equipped with CD&R.

Positional accuracy did not have any effect on the collision rate when neither aircraft was equipped with CD&R. This was due to the fact that for some scenario conditions a collision was unavoidable because neither aircraft took evasive action.

The collision rates when using the ATCAM algorithm are presented in Table 235. When using NACp 10 and higher accuracy and both aircraft were equipped with CD&R, collisions occurred on 0% to 0.2% of the test runs for the runway conflict scenarios, 0% to 5.8% of the test runs for the taxi scenarios, and 0.2% to 1.5% of the test runs for the low altitude conflict scenarios. Collisions were sometimes unavoidable for the approach aircraft due to the phase of the operation when a WA was issued; i.e., high speed rollout or too low to conduct a go-around maneuver. As described above, alerts were not inhibited on departure when above 80 kts as specified in the SURF IA SPR. For the departing aircraft, WAs were sometimes issued after the aircraft reached the decision takeoff speed (131 kts) and the departure was not aborted. Sometimes WAs were issued but not with enough time for the aircraft to stop prior to a collision. Other times the collision was caused when the aircraft aborted the departure. For example, if the departing aircraft aborted the takeoff and stopped on the runway as another aircraft was landing on the same runway, a collision resulted. During the taxi trials that resulted in collision, either a WA was not issued, a WA was issued after the collision, or the alert was not provided in enough time for maneuvering to be effective.

Table 235. Collision Rates (% of Test Runs) When Using the ATCAM Algorithm.

	Neither Aircraft CD&R Equipped					Aircraft A CD&R Equipped				
NACp	8	9	10	11	Truth	8	9	10	11	Truth
Arrival / taxi crossing	9.3	9.3	9.3	9.3	9.3	6.4	7.0	7.1	7.1	7.2
Departure / taxi crossing	14.4	14.4	14.4	14.4	14.5	10.2	8.1	8.0	8.0	7.9
Arrival / departure same rwy	33.3	33.3	33.3	33.3	33.3	1.6	0.0	0.0	0.0	0.0
Departures intersecting rwys	6.2	6.2	6.2	6.2	6.2	3.6	1.0	0.0	0.0	0.0
Arrival / departure intersecting	7.7	7.6	7.5	7.5	7.7	6.6	0.0	0.0	0.0	0.0
Head-on arrivals	78.6	78.6	78.6	78.6	78.6	34.7	3.6	0.0	0.0	0.0
Arrivals intersecting rwys	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Taxi following	100.0	100.0	100.0	100.0	100.0	20.4	4.8	0.0	0.0	0.0
Taxi intersection	43.4	43.4	43.4	43.4	43.4	20.1	19.5	18.8	18.4	18.4
Taxi head-on	92.3	92.3	92.3	92.3	92.3	91.2	92.3	92.3	92.3	92.3
Arrival / crossing airborne	1.3	1.3	1.3	1.3	1.3	1.0	1.0	1.0	1.0	1.0
Departure / crossing airborne	1.5	1.5	1.5	1.5	1.5	0.8	0.7	0.7	0.7	0.7

	Aircraft B Aircraft CD&R Equipped					Both Aircraft CD&R Equipped				
NACp	8	9	10	11	Truth	8	9	10	11	Truth
Arrival / taxi crossing	3.1	0.8	0.6	0.3	0.3	2.6	0.5	0.2	0.1	0.0
Departure / taxi crossing	7.3	1.5	0.2	0.0	0.0	5.7	0.7	0.1	0.1	0.1
Arrival / departure same rwy	50.8	44.4	44.4	44.4	44.4	3.2	0.0	0.0	0.0	0.0
Departures intersecting rwys	4.5	0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.0
Arrival / departure intersecting	4.4	1.3	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0
Head-on arrivals	16.3	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0
Arrivals intersecting rwys	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Taxi following	16.3	0.0	0.0	0.0	0.0	14.3	0.0	0.0	0.0	0.0
Taxi intersection	23.7	16.9	13.8	14.0	13.2	16.9	4.4	1.0	0.0	0.0
Taxi head-on	91.2	92.3	92.3	92.3	92.3	34.1	9.0	5.8	5.1	0.0
Arrival / crossing airborne	0.3	0.4	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.2
Departure / crossing airborne	1.5	1.6	1.6	1.6	1.6	1.3	1.4	1.5	1.5	1.5

When using the SURF IA algorithm, the collision rates were as shown in Table 236. When using NACp 10 accuracy and higher and both aircraft were equipped with CD&R, collisions occurred on 0% to 21.5% of the test runs for the runway conflict scenarios. Again, collisions were sometimes unavoidable for the approach aircraft due to the phase of the operation when a WA was issued; i.e., high speed rollout or too

low to conduct a go-around maneuver. As when using the ATCAM algorithm, for the departing aircraft, WAs were sometimes issued after the aircraft reached the decision takeoff speed (131 kts) and the departure was not aborted; other times the collision was caused when the aircraft aborted the departure. When an aircraft was taxiing across a runway, a WA was not timely; the alert generally did not occur until the aircraft was on or almost on the runway resulting in no action since the aircraft was past the runway shoulder.

Table 236. Collision Rates (% of Test Runs) When Using the SURF IA Algorithm.

	Neither Aircraft CD&R Equipped					Aircraft A CD&R Equipped				
NACp	8	9	10	11	Truth	8	9	10	11	Truth
Arrival / taxi crossing	9.3	9.3	9.3	9.3	9.3	8.8	9.2	9.2	9.0	9.1
Departure / taxi crossing	14.4	14.4	14.5	14.4	14.4	12.6	12.7	12.7	12.6	12.5
Arrival / departure same rwy	33.3	33.3	33.3	33.3	33.3	19.1	0.0	0.0	0.0	0.0
Departures intersecting rwys	6.2	6.2	6.2	6.2	6.2	3.6	1.0	0.0	0.0	0.0
Arrival / departure intersecting	7.7	7.7	7.7	7.7	7.7	2.2	0.0	0.0	0.0	0.0
Head-on arrivals	78.6	78.6	78.6	78.6	78.6	42.9	35.7	35.7	35.7	35.7
Arrivals intersecting rwys	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	Aircraft B Aircraft CD&R Equipped					Both Aircraft CD&R Equipped				
NACp	8	9	10	11	Truth	8	9	10	11	Truth
Arrival / taxi crossing	7.9	9.0	8.9	8.9	9.0	8.0	8.8	8.8	8.8	8.7
Departure / taxi crossing	12.8	14.0	14.1	14.1	14.1	11.7	12.5	12.6	12.5	12.5
Arrival / departure same rwy	41.3	35.2	33.3	33.3	33.3	12.7	0.0	0.0	0.0	0.0
Departures intersecting rwys	3.6	0.0	0.0	0.0	0.0	3.6	2.1	0.0	0.0	0.0
Arrival / departure intersecting	5.5	0.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0
Head-on arrivals	27.6	0.0	0.0	0.0	0.0	26.5	21.4	21.4	21.4	21.4
Arrivals intersecting rwys	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

6.1.5 Unwanted Alert

Unwanted alerts were evaluated for the approach and departure with crossing taxi traffic scenarios when only using the ATCAM CD&R algorithm. An alert was considered to be unwanted (i.e., nuisance) if the true position of the taxi aircraft was behind the hold line but the detected position indicated that the aircraft was over the hold line, causing an alert. Based on the analysis, 99% of unwanted alerts could be avoided if the alert zone was placed 390 ft past the hold line if traffic were transmitting NACp 8 position data, 135 ft past the hold line with NACp 9 accuracy, and 55 ft past the hold line with NACp 10 accuracy. The maximum standard for separation between the hold line and runway centerline is 280 ft [FAA, 2009b] to accommodate the largest aircraft. Assuming the runway is 150 ft wide, the distance between the runway hold line and runway edge is 205 ft.; therefore, a 390 ft alerting zone buffer is not practical. A 135 ft buffer would place the alert zone 70 ft before the runway edge and a 55 ft buffer would place the alert zone 150 ft before the runway edge. Consideration must also be given to the reference point for the aircraft data. If the data is referenced from the aircraft CG and translation to the aircraft's nose position is not made, a larger alerting zone buffer may be required. For example, for the aircraft used in this study, the nose position was 72.8 ft from the CG. Using a 135 ft buffer would cause alerts to not be issued until the aircraft's nose was on the runway. To summarize, transmitting NACp 9 data accuracy may be sufficient for reducing unwanted alerts when taxiing across a runway provided the data is translated to the aircraft nose position. NACp 10 and higher data accuracy is sufficient even if the data is referenced from the aircraft CG. NACp 8 data accuracy is not sufficient.

6.2 Directive Alerting

An initial implementation of directive alerting was developed for the ATCAM algorithm. Directive alerting specifies the action to take to resolve a conflict situation in lieu of providing a generic WA. The directive given depends on the conflict situation. The directives that were possible for the scenarios evaluated and the directives that were actually issued during the testing are shown in Table 237. These directives were issued at the same time an ATCAM WA was issued.

Table 237. Directives Alerts.

Scenario	Directives Possible	Directives Issued
Arrival / departure intersecting runways	No resolution available Go-around Land and emergency stop Abort takeoff Expedite takeoff Emergency stop	No resolution available Land and emergency stop Abort takeoff Emergency stop
Head-on arrivals	No resolution available Go-around Land and emergency stop Abort takeoff Emergency stop Exit / clear runway	No resolution available Go-around Exit / clear runway
Intersecting taxi	No resolution available Emergency stop Reduce speed Increase speed Turn right Turn left	No resolution available Emergency stop Reduce speed

A comparison was conducted of the maneuvers made by the aircraft during the ATCAM evaluation, when maneuvers were made based on a standard set of actions according to the scenario type, and during the directive alerting evaluation, when maneuvers were made based on the directive issued (Table 240). For the arrival and departure from intersecting runways scenario, the actions taken were equivalent, with no collisions for the ATCAM evaluation and directive alerting evaluation. For the head-on arrivals scenario, the actions were equivalent for the aircraft approaching Runway 10 (Aircraft A). For the aircraft approaching Runway 28 (Aircraft B); however, fewer go-around maneuvers and more frequent accelerated braking occurred when directive alerting was in effect. More collisions also occurred with directive alerting. For the intersecting taxi scenario, during the ATCAM evaluation the action taken after a WA was issued was to conduct accelerated braking and stop. With directive alerting, the 'stop' directive was also issued, but for some scenarios a 'reduce speed' directive was issued that resulted in normal braking. As a result, more collisions occurred with directive alerting. Based on these results, directive alerting was not as effective and more research is necessary to determine the feasibility of providing directive alerts to the flight crew.

Table 240. ATCAM versus Directive Alerting Comparison.

Scenario	NACp	Aircraft	ATCAM		Directive Alerting	
			Collisions #runs	Actions* (# runs, type)	Collisions #runs	Actions (# runs, type)
Arrival / departure intersecting runways	Truth (13 runs)	A	0	5 accelerated braking	0	5 accelerated braking
		B		18 rejected takeoffs		18 rejected takeoffs
	10 (52 runs)	A	0	21 accelerated braking	0	20 accelerated braking
		B		72 rejected takeoffs		72 rejected takeoffs
Head-on arrivals	Truth (14 runs)	A	0	24 accelerated braking	3	24 accelerated braking
		B		2 accelerated braking 21 go-around		4 accelerated braking 19 go-around
	10 (56 runs)	A	0	96 accelerated braking	12	96 accelerated braking
		B		8 accelerated braking 84 go-around		16 accelerated braking 76 go-around
Intersecting taxi	Truth (76 runs)	A	24	40 accelerated braking	31	26 accelerated braking 16 normal braking
		B		52 accelerated braking		29 accelerated braking 29 normal braking
	10 (304 runs)	A	102	152 accelerated braking	134	115 accelerated braking 61 normal braking
		B		214 accelerated braking		109 accelerated braking 133 normal braking

*ATCAM actions only include scenarios when Aircraft A, Aircraft B, or both aircraft were equipped with CD&R.

7 Conclusions

Two CD&R algorithms for the airport TMA were evaluated in a fast-time batch simulation study. The purpose of the study was to evaluate the performance of the aircraft-based CD&R algorithms during various runway, taxiway, and low altitude scenarios, multiple levels of CD&R system equipage, and various levels of horizontal position accuracy.

Alert generation varied during this study due to the accuracy of the data transmitted by the aircraft and the initial starting location and movement timing of the aircraft. Although both algorithms effectively issued alerts for collision avoidance, differences were noted in implementation. The SURF IA algorithm issued indications, which provide an early awareness of potential traffic threats in many situations; the ATCAM algorithm does not currently issue indications. For the scenarios reported on herein, when transmitting truth data and the aircraft was conducting a standard approach, the SURF IA algorithm issued WAs when the aircraft was closer to the runway threshold (approximately 0.5 NM) than with the ATCAM algorithm (approximately 1 m). When conditions were met, the ATCAM algorithm issued WAs early in the departure (15 kts or less). Taking action based on these timely alerts saves wear on the aircraft and aborts the departure early enough that the aircraft can attempt the departure again without having to reposition. Although the SURF IA algorithm did not issue WAs on departure until the aircraft's ground speed was greater than 40 kts, indications were issued as early as when the aircraft was in position and holding, providing traffic awareness. When an aircraft was taxiing across a runway, the ATCAM algorithm issued alerts as early as 345 ft before the runway hold line, whereas, SURF IA issued indications approximately 275 ft before the runway hold line but did not issue alerts until the aircraft nose was at the

runway edge, which may be too late for the aircraft to stop, provided the pilot does not take action until an alert is issued.

Alert toggling occurs when multiple instances of indications or alerts are generated as a result of position accuracy or aircraft maneuvering. Alert toggling can be a distraction to the flight crew and could cause mistrust in the technology. In general, alert toggling occurred more frequently as the position accuracy was reduced, especially when transmitting NACp 8 and NACp 9 accurate data; however, for some test scenarios, the rate of toggling was high for all position accuracy levels. The toggling included gaps between alerts in many instances, i.e., the alert would turn "on" and "off" and then later would be issued again. Other times, an alert would be issued more than once during a test run as a result of maneuvering. In some instances, indication toggling occurred by design. For some situations, indications were issued initially, as the situation became more critical alerts were issued, and once the situation began to be resolved, an indication would be reissued.

It is critical that alerts only occur when needed; otherwise, the flight crew could make unnecessary maneuvers that can cause delays, equipment wear, and other costs to airlines. The rate of unnecessary maneuvers was affected by position accuracy, with more unnecessary maneuvers occurring as the position accuracy decreased (NACp 8 and 9). When using the ATCAM algorithm and the aircraft were transmitting NACp 10 and higher accuracy, the rate of unnecessary maneuvers was 1.4% or less, except during the taxi conflict scenarios, where the rate was higher (10.7% or less). There were no unnecessary maneuvers when using the SURF IA algorithm and the aircraft were transmitting NACp 10 and higher accuracy, except for the departing aircraft during an intersecting runway scenario.

Nuisance indications and alerts could distract the flight crew unnecessarily, reduce confidence in the system, and negatively affect safety and operational effectiveness. For runway conflict scenarios, acceptable rates for displaying nuisance indications and alerts from a safety perspective are specified in the SURF IA SPR. For both algorithms, the nuisance acceptability rate was not met in many instances when transmitting NACp 8 accuracy. Each algorithm had one instance of not meeting the nuisance acceptability rate when transmitting NACp 9 accuracy (head-on arrival scenario). The SURF IA algorithm had one instance of not meeting the nuisance acceptability rate for an indication when transmitting NACp 10 accuracy. Based on this evaluation, NACp 10 and higher accuracy is sufficient for meeting acceptable nuisance alert rates and may be acceptable for meeting nuisance indication rates, NACp 9 accuracy may be acceptable for meeting the nuisance IA rate, and NACp 8 is not acceptable.

Missed indications and alerts represent a reduction in CD&R benefits and result in operations such as they currently exist, where CD&R indications and alerts are not provided. Missed indications and alerts were not assessed in the SURF IA SPR from the safety perspective; therefore, acceptable rates for missed indications and alerts were not provided. Based on the algorithm dependent definition used in determining the rate of missed indications and alerts, overall, the missed indication and alert rates were highest when the aircraft were transmitting NACp 8 accuracy. When the aircraft were transmitting NACp 10 and higher accuracy, the overall rate of missed indications and alerts was low for both algorithms, except for the missed WA rate during select scenarios (intersecting runway and taxi head-on) when using the ATCAM algorithm.

Overall, collision avoidance was more effective when both aircraft were equipped with CD&R and maneuvered to avoid a collision after a WA was issued. As expected, collisions occurred most often when neither aircraft were equipped and did not take any action to avoid a collision. Sometimes, however, collision avoidance was more effective when one aircraft was equipped with CD&R over the other aircraft. For example, for the arrival with departure from same runway scenario, collision avoidance was more effective when the arrival was equipped with CD&R. Collisions were sometimes unavoidable due to the phase of the operation when a WA was issued; i.e., high speed rollout or too low to conduct a go-around maneuver. Other times the collision was caused by the maneuvering aircraft; e.g., the departing aircraft aborted takeoff and stopped on the runway as another aircraft was landing on the same runway. In some instances, the alert was not timely and the aircraft was in a position (e.g., on the runway) in which action could not be taken to avoid a collision.

In order to reduce the number of unwanted alerts when taxiing across a runway, a buffer is needed between the hold line and the alerting zone so alerts are not generated when an aircraft is behind the hold

line. Testing indicated that as the position accuracy decreases, a larger buffer is required. When transmitting NACp 8 data accuracy, such a large buffer would be required that it is not practical. Transmitting NACp 9 data accuracy may be sufficient provided the data is referenced from the aircraft nose position. NACp 10 and higher data accuracy is sufficient even if the data is referenced from the aircraft center-of-gravity.

The SURF IA SPR has proposed horizontal position accuracy requirements for the SURF IA function. Through analysis, the SPR identified that to meet safety requirements, horizontal position accuracy when on the airport surface must be NACp 10 or higher for large airports, such as that used for this study. The analysis conducted in this experiment (nuisance and missed IAs, alert toggling, unnecessary maneuvering, collision avoidance, and unwanted alerts) supports the NACp 10 requirement for performing the runway conflict CD&R function to reduce the likelihood and severity of runway incursions and collisions.

Finally, an initial implementation of directive alerting was evaluated for select scenarios, position accuracy levels, and CD&R equipage. Directive alerting specifies the action to take to resolve a conflict situation in lieu of providing a generic WA. Based on this evaluation, maneuvering based on directive alerts resulted in more collisions than when maneuvers were made based on a standard set of actions according to scenario type. More research is necessary to determine the feasibility of providing directive alerts to the flight crew.

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Appendix A: Test Matrix

Scenario	R1	Arrival / Taxi
	R2	Departure / Taxi
	R3	Arrival / Departure – same runway
	R4	Departure / Departure – intersecting runways
	R5	Arrival / Departure – intersecting runways
	R6	Arrival / Arrival – same runway
	R7	Arrival / Arrival – intersecting runways
	T1	Taxi following
	T2	Taxi / Taxi intersection
	T3	Taxi / Head-on
	L1	Arrival / Traffic crossing
	L2	Departure / Traffic crossing

Algorithm	A	ATCAM
	S	ATSA SURF IA

Evasive Action		Aircraft A	Aircraft B
	NN	No	No
	YN	Yes	No
	NY	No	Yes
	YY	Yes	Yes

Horizontal Position Accuracy	8	NACp8 (< 92.6m (305.6 ft))
	9	NACp9 (< 30 m (99 ft))
	10	NACp10 (< 10 m (33 ft))
	11	NACp11 (< 3 m (9.9 ft))
	T	truth

Directive Alert	Y	(evasive action based on directive alert)
	N	(evasive action not based on directive alert)

Repeat 1-40 for R1, R2, R3, R4, R5, R6, R7 = 280 cases
Repeat 1-20 for T1, T2, T3, L1, L2 = 100 cases (380 cases total)

Case No.	Scenario	Algorithm	Evasive Action	Horizontal Position	Directive Alert
ATCAM evaluation					
1	All	A	NN	T	N
2	All	A	NN	8	N
3	All	A	NN	9	N
4	All	A	NN	10	N
5	All	A	NN	11	N
6	All	A	YN	T	N
7	All	A	YN	8	N
8	All	A	YN	9	N
9	All	A	YN	10	N
10	All	A	YN	11	N
11	All	A	NY	T	N
12	All	A	NY	8	N
13	All	A	NY	9	N
14	All	A	NY	10	N
15	All	A	NY	11	N
16	All	A	YY	T	N
17	All	A	YY	8	N
18	All	A	YY	9	N
19	All	A	YY	10	N
20	All	A	YY	11	N
SURF IA evaluation					
21	R1 – R7	S	NN	T	N
22	R1 – R7	S	NN	8	N
23	R1 – R7	S	NN	9	N
24	R1 – R7	S	NN	10	N
25	R1 – R7	S	NN	11	N
26	R1 – R7	S	YN	T	N
27	R1 – R7	S	YN	8	N
28	R1 – R7	S	YN	9	N
29	R1 – R7	S	YN	10	N
30	R1 – R7	S	YN	11	N
31	R1 – R7	S	NY	T	N
32	R1 – R7	S	NY	8	N
33	R1 – R7	S	NY	9	N
34	R1 – R7	S	NY	10	N
35	R1 – R7	S	NY	11	N
36	R1 – R7	S	YY	T	N
37	R1 – R7	S	YY	8	N
38	R1 – R7	S	YY	9	N
39	R1 – R7	S	YY	10	N
40	R1 – R7	S	YY	11	N

Case No.	Scenario	Algorithm	Evasive Action	Horizontal Position	Directive Alert
Directive alert evaluation					
381	R5	A	YN	T	Y
382	R5	A	YN	10	Y
383	R5	A	NY	T	Y
384	R5	A	NY	10	Y
385	R5	A	YY	T	Y
386	R5	A	YY	10	Y
387	R6	A	YN	T	Y
388	R6	A	YN	10	Y
389	R6	A	NY	T	Y
390	R6	A	NY	10	Y
391	R6	A	YY	T	Y
392	R6	A	YY	10	Y
392	T2	A	YN	T	Y
394	T2	A	YN	10	Y
395	T2	A	NY	T	Y
396	T2	A	NY	10	Y
397	T2	A	YY	T	Y
398	T2	A	YY	10	Y

Appendix B: Standard Test Runs by Scenario

B.1 Runway Scenario – Arrival with Taxi Crossing

For this scenario, Aircraft A was initially 3.5 NM prior to the Runway 10 threshold. Aircraft B's initial position was placed at 14 different locations along the length of Runway 10 (0, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 6000, 7500, 9000, and 10,000 feet from the runway threshold) simulating various taxiway entry points and at 18 locations away from the runway (300, 320, 340, 360, 380, 400, 450, 500, 550, 600, 650, 700, 800, 900, 1000, 1200, 1400, and 1600 feet from the runway centerline). Aircraft B began to taxi when Aircraft A was at 14 different points in its approach and rollout (see Aircraft B Initiation Delay in Table B.1). For each initiation delay for Aircraft B, the number of test runs to be conducted was determined by the initial locations of Aircraft B that were relevant. For example, all locations where Aircraft B would cross the runway behind Aircraft A were considered not relevant. As shown in Table B.1, the number of test runs was the number of locations along the runway (maximum of 14 locations from 0 to 10,000 ft from the Runway 10 threshold) by the number of locations away from the runway (maximum of 18 locations).

Table B.1. Arrival with Taxi Crossing Standard Test Runs.

Aircraft B Initiation Delay (sec)	Number of Test Runs (locations along runway x locations away from runway)
0 (Aircraft A 3.5 NM to threshold)	All locations (14 x 18 = 252)
13 (Aircraft A 3.0 NM to threshold)	All locations (14 x 18 = 252)
26 (Aircraft A 2.5 NM to threshold)	All locations (14 x 18 = 252)
40 (Aircraft A 2.0 NM to threshold)	All locations (14 x 18 = 252)
53 (Aircraft A 1.5 NM to threshold)	0 to 10,000 ft (14 x 16) 1,000 to 10,000 ft (13 x 1) 1,500 to 10,000 ft (12 x 1) (14x16) + 13 + 12 = 249
66 (Aircraft A 1.0 NM to threshold)	0 to 10,000 ft (14 x 14) 1,000 to 10,000 ft (13 x 2) 2,000 to 10,000 ft (11 x 1) 3,000 to 10,000 ft (9 x 1) (14x14)+(13x2)+11+9 = 242
80 (Aircraft A 0.5 NM to threshold)	0 to 10000 (14 x 7) 1,000 to 10,000 ft (13 x 3) 1,500 to 10,000 ft (12 x 1) 2,000 to 10,000 ft (11 x 2) 2,500 to 10,000 ft (10 x 1) 3,000 to 10,000 ft (9 x 1) 3,500 to 10,000 ft (8 x 1) 4,000 to 10,000 ft (7 x 1) 4,500 to 10,000 ft (6 x 1) (14x7)+(13x3)+12+(11x2)+10+9+8+7+6 = 211
93 (Aircraft A crosses threshold)	0 to 10000 (14 x 4) 1,000 to 10,000 ft (13 x 2) 1,500 to 10,000 ft (12 x 1) 2,000 to 10,000 ft (11 x 1) 2,500 to 10,000 ft (10 x 2) 3,000 to 10,000 ft (9 x 2) 3,500 to 10,000 ft (8 x 2) 4,000 to 10,000 ft (7 x 1)

	4,500 to 10,000 ft (6 x 2) 5,000 to 10,000 ft (5 x 1) (14x4)+(13x2)+12+11+(10x2)+(9x2)+(8x2)+7+(6x2)+5 = 183
97 (glide-path aim-point, 1000 ft past threshold)	1,000 to 10,000 ft (13 x 1) 1,500 to 10,000 ft (12 x 1) 2,000 to 10,000 ft (11 x 2) 2,500 to 10,000 ft (10 x 2) 3,000 to 10,000 ft (9 x 1) 3,500 to 10,000 ft (8 x 2) 4,000 to 10,000 ft (7 x 3) 4,500 to 10,000 ft (6 x 5) 5,000 to 10,000 ft (5 x 1) 13+12+(11x2)+(10x2)+9+(8x2)+(7x3)+(6x5)+5 = 148
109 (Aircraft A 3400 ft past threshold)	3,500 to 10,000 ft (8 x 4) 4,000 to 10,000 ft (7 x 4) 4,500 to 10,000 ft (6 x 5) 5,000 to 10,000 ft (5 x 5) (8x4)+(7x4)+(6x5)+(5x5) = 115
129 (Aircraft A 5400 ft past threshold)	4,500 to 10,000 ft (6 x 3) 5,000 to 10,000 ft (5 x 11) 6,000 to 10,000 ft (4 x 4) (6x3)+(5x11)+(4x4) = 89
160 (Aircraft A 7000 ft past threshold)	6,000 to 10,000 ft (4 x 14) 7,500 to 10,000 ft (3 x 4) (4x14)+(3x4) = 68
198 (Aircraft A 9000 ft past threshold)	9,000 to 10,000 ft (2 x 18) 2x18 = 36
218 (Aircraft A 9800 ft past threshold)	10,000 ft (1 x 18) = 18

The standard number of test runs for this scenario is:
252+252+252+252+249+242+211+183+148+115+89+68+36+18 = 2367 runs

B.2 Runway Scenario – Departure with Taxi Crossing

For this scenario, Aircraft A was initially in position on Runway 10 for departure. Aircraft B's initial position was placed at 12 different locations along the length of Runway 10 (0, 60, 280, 660, 1100, 1800, 2500, 3400, 5200, 6800, 8000, and 9000 feet from the runway threshold) simulating various taxiway entry points and at 18 locations away from the runway (300, 320, 340, 360, 380, 400, 450, 500, 550, 600, 650, 700, 800, 900, 1000, 1200, 1400, and 1600 feet from the runway centerline). Aircraft B began to taxi when Aircraft A was at 12 different locations along its departure and climb out (see Aircraft B Initiation Delay in Table B.2). For each initiation delay for Aircraft B, the number of test runs to be conducted was determined by the initial locations of Aircraft B that were relevant. For example, all locations where Aircraft B would cross the runway behind Aircraft A were considered not relevant. As shown in Table B.2, the number of test runs was the number of locations along the runway (maximum of 12 locations from 0 to 9,000 ft from the Runway 10 threshold) by the number of locations away from the runway (maximum of 18 locations).

Table B.2. Departure with Taxi Crossing Standard Test Runs.

Aircraft B Initiation Delay (sec)	Number of Test Runs (locations along runway x locations away from runway)
0 (Aircraft A at threshold)	0 to 9,000 ft (12 x 7) 60 to 9,000 ft (11 x 3) 280 to 9,000 ft (10 x 2) 660 to 9,000 ft (9 x 2) 1,100 to 9,000 ft (8 x 1) 2,500 to 9,000 ft (6 x 1) 5,200 to 9,000 ft (4 x 1) 6,800 to 9,000 ft (3 x 1) (12x7)+(11x3)+(10x2)+(9x2)+8+6+4+3 = 176
6 (Aircraft A 180 ft from threshold)	0 to 9,000 ft (12 x 3) 60 to 9,000 ft (11 x 4) 280 to 9,000 ft (10 x 3) 660 to 9,000 ft (9 x 2) 1,100 to 9,000 ft (8 x 1) 1,800 to 9,000 ft (7 x 1) 2,500 to 9,000 ft (6 x 1) 3,400 to 9,000 ft (5 x 1) 6,800 to 9,000 ft (3 x 1) 9,000 to 9,000 ft (1 x 1) (12x3)+(11x4)+(10x3)+(9x2)+8+7+6+5+3+1 = 158
10 (Aircraft A 470 ft from threshold)	60 to 9,000 ft (11 x 6) 280 to 9,000 ft (10 x 2) 660 to 9,000 ft (9 x 3) 1,100 to 9,000 ft (8 x 1) 1,800 to 9,000 ft (7 x 1) 2,500 to 9,000 ft (6 x 1) 3,400 to 9,000 ft (5 x 1) 5,200 to 9,000 ft (4 x 1) 8,000 to 9,000 ft (2 x 1) (11x6)+(10x2)+(9x3)+8+7+6+5+4+2 = 145
14 (Aircraft A 890 ft from threshold)	60 to 9,000 ft (11 x 2) 280 to 9,000 ft (10 x 4) 660 to 9,000 ft (9 x 2) 1,100 to 9,000 ft (8 x 2) 1,800 to 9,000 ft (7 x 2) 2,500 to 9,000 ft (6 x 1) 3,400 to 9,000 ft (5 x 1)

	5,200 to 9,000 ft (4 x 1) 6,800 to 9,000 ft (3 x 1) (11x2)+(10x4)+(9x2)+(8x2)+(7x2)+6+5+4+3 = 128
18 (Aircraft A 1,430 ft from threshold)	280 to 9,000 ft (10 x 2) 660 to 9,000 ft (9 x 4) 1,100 to 9,000 ft (8 x 2) 1,800 to 9,000 ft (7 x 2) 2,500 to 9,000 ft (6 x 2) 3,400 to 9,000 ft (5 x 1) 5,200 to 9,000 ft (4 x 2) 8,000 to 9,000 ft (2 x 1) (10x2)+(9x4)+8+8+7+7+6+6+5+4+4+2 = 113
22 (Aircraft A 2,100 ft from threshold)	1,100 to 9,000 ft (8 x 5) 1,800 to 9,000 ft (7 x 3) 2,500 to 9,000 ft (6 x 2) 3,400 to 9,000 ft (5 x 2) 5,200 to 9,000 ft (4 x 2) 6,800 to 9,000 ft (3 x 1) (8x5)+(7x3)+(6+x2)+(5x2)+(4x2)+3 = 94
26 (Aircraft A 2,920 ft from threshold)	1,100 to 9,000 ft (8 x 1) 1,800 to 9,000 ft (7 x 4) 2,500 to 9,000 ft (6 x 3) 3,400 to 9,000 ft (5 x 3) 5,200 to 9,000 ft (4 x 2) 6,800 to 9,000 ft (3 x 1) 8,000 to 9,000 ft (2 x 1) 8+(7x4)+(6x3)+(5x3)+(4x2)+3+2 = 82
30 (Aircraft A 3,860 ft from threshold)	1,800 to 9,000 ft (7 x 1) 2,500 to 9,000 ft (6 x 4) 3,400 to 9,000 ft (5 x 4) 5,200 to 9,000 ft (4 x 3) 6,800 to 9,000 ft (3 x 1) 9,000 to 9,000 ft (1 x 1) 7+(6x4)+(5x4)+(4x3)+3+1 = 67
37 (Aircraft A 5,810 ft from threshold)	3,400 to 9,000 ft (5 x 5) 5,200 to 9,000 ft (4 x 4) 6,800 to 9,000 ft (3 x 2) 8,000 to 9,000 ft (2 x 1) (5x5)+(4x4)+(3x2)+1 = 49
43 (Aircraft A 7,600 ft from threshold)	5,200 to 9,000 ft (4 x 5) 6,800 to 9,000 ft (3 x 3) 8,000 to 9,000 ft (2 x 1) 9,000 to 9,000 ft (1 x 1) (4x5)+(3x3)+2+1 = 32
47 (Aircraft A 8,790 ft from threshold)	6,800 to 9,000 ft (3 x 6) 8,000 to 9,000 ft (2 x 1) 9,000 to 9,000 ft (1 x 1) (3x6)+2+1 = 21
50 (Aircraft A 10,000 ft from threshold)	6,800 to 9,000 ft (3 x 2) 8,000 to 9,000 ft (2 x 2) 9,000 to 9,000 ft (1 x 2) (3x2)+(2x2)+(1x2) = 12

The standard number of test runs for this scenario is:
176+158+145+128+113+94+82+67+49+32+21+12 = 1077 runs

B.3 Runway Scenario – Arrival with Departure from Same Runway

For this scenario, Aircraft A was initially 3.5 NM prior to the Runway 10 threshold. Aircraft B was initially in position on Runway 10 for departure. Aircraft B began its departure when Aircraft A was at 9 different points in its approach (Table B.3). Since the initial locations of Aircraft A and B did not vary, there were only 9 standard test runs for this scenario.

Table B.3. Arrival with Departure from Same Runway Standard Test Runs.

Aircraft B Initiation Delay (sec)
0 (Aircraft A 3.5 NM to threshold)
13 (Aircraft A 3.0 NM to threshold)
26 (Aircraft A 2.5 NM to threshold)
40 (Aircraft A 2.0 NM to threshold)
53 (Aircraft A 1.5 NM to threshold)
66 (Aircraft A 1.0 NM to threshold)
80 (Aircraft A 0.5 NM to threshold)
93 (Aircraft A cross threshold)
97 (Aircraft A at glide-path aim-point)

B.4 Runway Scenario – Departures from Intersecting Runways

For this scenario, Aircraft A was initially in position on Runway 14L for departure. Aircraft B was initially in position on Runway 22R for departure. Aircraft A began its departure when Aircraft B was at 7 different points in its departure (Table B.4). Conversely, Aircraft B began its departure when Aircraft A was at 10 different points in its departure (Table B.4). There were 16 unique standard test runs for this scenario.

Table B.4. Departures from Intersecting Runways Standard Test Runs.

Aircraft B Initiation Delay (sec)	Aircraft A Initiation Delay (sec)
0 (Aircraft A at threshold)	0 (Aircraft B at threshold)
6 (Aircraft A at 30 kts)	4 (Aircraft B at 20 kts)
10 (Aircraft A at 50 kts)	8 (Aircraft B at 40 kts)
14 (Aircraft A at 70 kts)	12 (Aircraft B at 60 kts)
18 (Aircraft A at 90 kts)	16 (Aircraft B at 80 kts)
22 (Aircraft A at 110 kts)	20 (Aircraft B at 100 kts)
26 (Aircraft A at 130 kts)	25 (Aircraft B at 120 kts, runway intersection)
30 (Aircraft A at 150 kts)	
34 (Aircraft A at 170 kts)	
37 (Aircraft A at intersection, just lifted off)	

B.5 Runway Scenario – Arrival And Departure from Intersecting Runways

For this scenario, Aircraft A was initially 3.5 NM prior to the Runway 10 threshold. Aircraft B was initially in position on Runway 22R for departure. Aircraft B began its departure roll when Aircraft A was at 13 different points in its approach and rollout (Table B.5). There were 13 unique standard test runs for this scenario.

Table B.5. Arrival and Departure from Intersecting Runways Standard Test Runs.

Aircraft B Initiation Delay (sec)
0 (Aircraft A 3.5 NM to threshold)
13 (Aircraft A 3.0 NM to threshold)
26 (Aircraft A 2.5 NM to threshold)
39 (Aircraft A 2.0 NM to threshold)
53 (Aircraft A 1.5 NM to threshold)
66 (Aircraft A 1.0 NM to threshold)
79 (Aircraft A 0.5 NM to threshold)
93 (Aircraft A crossing threshold)
96 (Aircraft A 635 ft from threshold)
100 (Aircraft A 0.25 NM from threshold)
110 (Aircraft A 0.5 NM from threshold)
126 (Aircraft A 0.8 NM from threshold)
140 (Aircraft A 1 NM from threshold)

B.6 Runway Scenario – Head-On Arrivals

For this scenario, Aircraft A was initially 3.5 NM prior to the Runway 10 threshold. Aircraft B was initially 3.5 NM prior to the Runway 28 threshold. Aircraft B began its approach when Aircraft A was at 14 different points in its approach and roll out (Table B.6). Aircraft A always began its approach at the beginning of the test run. As a result, there were 14 standard test runs for this scenario.

Table B.6. Head-On Arrivals Standard Test Runs.

Aircraft B Initiation Delay (sec)
0 (Aircraft A 3.5 NM to threshold)
13 (Aircraft A 3.0 NM to threshold)
26 (Aircraft A 2.5 NM to threshold)
40 (Aircraft A 2.0 NM to threshold)
53 (Aircraft A 1.5 NM to threshold)
66 (Aircraft A 1.0 NM to threshold)
80 (Aircraft A 0.5 NM to threshold)
93 (Aircraft A crossing threshold)
97 (Aircraft A 1,400 ft past threshold)
109 (Aircraft A 3,700 ft past threshold)
129 (Aircraft A 5,500 ft past threshold)
160 (Aircraft A 7,100 ft past threshold)
198 (Aircraft A 9,000 ft past threshold)
218 (Aircraft A 9,800 ft past threshold)

B.7 Runway Scenario – Arrivals to Intersecting Runways

For this scenario, Aircraft A was initially 3.5 NM prior to the Runway 14L threshold. Aircraft B was initially 3.5 NM prior to the Runway 22R threshold. Aircraft B began its approach when Aircraft A was at 13 different points in its approach and rollout (Table B.7). There were 13 unique standard test runs for this scenario.

Table B.7. Arrivals to Intersecting Runways Standard Test Runs.

Aircraft B Initiation Delay (sec)
0 (Aircraft A 3.5 NM to threshold)
13 (Aircraft A 3.0 NM to threshold)
26 (Aircraft A 2.5 NM to threshold)
39 (Aircraft A 2.0 NM to threshold)
53 (Aircraft A 1.5 NM to threshold)
66 (Aircraft A 1.0 NM to threshold)
79 (Aircraft A 0.5 NM to threshold)
93 (Aircraft A crossing threshold)
96 (Aircraft A 1,100 ft past threshold)
100 (Aircraft A 2,000 ft past threshold)
110 (Aircraft A 3,800 ft past threshold)
126 (Aircraft A 5,300 ft past threshold)
140 (Aircraft A 1 NM past threshold)

B.8 Taxi Scenario – Taxi Following

Aircraft A taxied at a constant speed on Taxiway M toward Runway 10 (Table B.8). Aircraft B was also taxiing on Taxiway M toward Runway 10, ahead of Aircraft A, but at 10 kts. There were 7 standard test runs for this scenario.

Table B.8. Taxi Following Standard Test Runs.

Aircraft A start speeds (kts)
12
14
16
18
20
22
24

B.9 Taxi Scenario – Taxi Intersection

Aircraft A began taxi on Taxiway M at M7, taxiing toward Runway 10, at 15 kts. Aircraft B taxied across Taxiway M, heading south, starting from a complete stop and accelerating to 15 kts at 3.3 ft/s^2. Aircraft B's initial position was placed at 4 different locations along Taxiway M (400, 600, 800, and 1000 feet ahead of Aircraft A) simulating various taxiway crossing points and at 5 locations away from the runway (260, 410, 560, 710, and 860 feet from Taxiway M centerline). Aircraft B began to taxi when Aircraft A was at 5 different locations along Taxiway M (Aircraft B Initiation Delay in Table B.9). For each initiation delay for Aircraft B, the number of test runs to be conducted was determined by the initial locations of Aircraft B that were relevant. For example, all locations where Aircraft B would cross the taxiway behind Aircraft A were considered not relevant. As shown in Table B.9, the number of test runs was the number of locations along the taxiway (maximum of 4 locations from 400 to 1,000 ft ahead of Aircraft A) by the number of locations away from the taxiway (maximum of 5 locations).

Table B.9. Taxi Intersection Standard Test Runs.

Aircraft B Initiation Delay (sec)	Number of Test Runs (locations along runway x locations away from runway)
0 (Aircraft A starting position)	400 to 1,000 (4 x 5 = 20)
6 (Aircraft A 150 ft from starting position)	400 to 1,000 (4 x 5 = 20)
12 (Aircraft A 300 ft from starting position)	400 to 1,000 (4 x 1) 600 to 1,000 (3 x 3) 800 to 1,000 (2 x 1) 4+(3x3)+2 = 15
18 (Aircraft A 450 ft from starting position)	600 to 1,000 (3 x 2) 800 to 1,000 (2 x 2) 1,000 to 1,000 (1 x 1) (3x2)+(2x2)+1 = 11
24 (Aircraft A 600 ft from starting position)	600 to 1,000 (3 x 1) 800 to 1,000 (2 x 3) 1,000 to 1,000 (1 x 1) 3+(2x3)+1 = 10

The standard number of test runs for this scenario is:
20+20+15+11+10 = 76 runs

B.10 Taxi Scenario – Taxi Head-On

Aircraft A, began taxi on Taxiway M at M2, traveling toward Runway 10 at 15 kts, taking a right turn onto Taxiway T. Aircraft B began taxi on Taxiway T at T1 traveling toward Taxiway M at 15 kts. Aircraft A began to taxi when Aircraft B was at 7 different locations along its taxi route (at T1, 1,600 ft, 3,200 ft, 4,800 ft, 6,400 ft, 8,000 ft, and 9,600 ft (crossing Taxiway M) from T1). Conversely, Aircraft B began to taxi when Aircraft A was at 7 different locations along its taxi route (at M2, 9,500 ft, 7,900 ft, 6,300 ft, 4,700 ft, 3,100 ft, and 1,500 ft from T1). There were 13 unique standard test runs for this scenario.

Table B.10. Taxi Head-On Standard Test Runs.

Aircraft B Initiation Delay (sec)	Aircraft A Initiation Delay (sec)
0 (Aircraft A at M2)	0 (Aircraft B at T1)
50 (Aircraft A 9,500 ft from T, finish turn onto T)	63 (Aircraft B 1,600 ft from T1)
113 (Aircraft A 7,900 ft from T)	126 (Aircraft B 3,200 ft from T1)
176 (Aircraft A 6,300 ft from T)	189 (Aircraft B 4,800 ft from T1)
239 (Aircraft A 4,700 ft from T)	252 (Aircraft B 6,400 ft from T1)
302 (Aircraft A 3,100 ft from T)	315 (Aircraft B 8,000 ft from T1)
365 (Aircraft A 1,500 ft from T)	378 (Aircraft B 9,600 ft from T1, crossing M)

B.11 Air-To-Air Scenario – Arrival with Crossing Traffic

Aircraft A was initially 4 NM prior to the Runway 10 threshold. Aircraft B's initial position was placed at 7 different locations along Aircraft A's approach path (3, 2.5, 2, 1.5, 1, 0.5 and 0 NM from the Runway 10 threshold), at 4 locations away from Aircraft A's approach path (2195, 4445, 6695, and 8945 feet from the extended runway centerline), and at 7 different altitudes (100, 250, 400, 550, 700, 850, and 1000 ft AFE). Aircraft B began to fly forward when Aircraft A was at 7 different points along its approach (Table B.11). There were 1,372 standard test runs for this scenario (7 x 4 x 7 x 7).

Table B.11. Arrival with Crossing Traffic Standard Test Runs.

Aircraft B Initiation Delay (sec)
0 (meet Aircraft A when 4 NM to threshold)
13 (meet Aircraft A when 3.5 NM to threshold)
27 (meet Aircraft A when 3 NM to threshold)
40 (meet Aircraft A when 2.5 NM to threshold)
53 (meet Aircraft A when 2 NM to threshold)
67 (meet Aircraft A when 1.5 NM to threshold)
80 (meet Aircraft A when 1.0 NM to threshold)

B.12 Air-To-Air Scenario – Departure Climb-Out with Crossing Traffic

Aircraft A was initially in position on Runway 10 for departure. Aircraft B's initial position was placed at 7 different locations along Aircraft A's departure path (5000, 6000, 7000, 8000, 9,000, 10,000, and 11,000 ft from the runway threshold), at 3 locations away from the runway (3100, 3950, and 4800 feet from the runway centerline), and at 7 different altitudes (100, 250, 400, 550, 700, 850, and 1000 ft AFE). Aircraft B began to fly forward when Aircraft A was at 7 different points in its departure (Table B.12). There were 1,029 standard test runs for this scenario (7 x 3 x 7 x 7).

Table B.12. Departure Climb-Out with Crossing Traffic Standard Test Runs.

Aircraft B Initiation Delay (sec)	
0	(Aircraft A at threshold)
3	(Aircraft A 115 ft from threshold)
7	(Aircraft A 355 ft from threshold)
10	(Aircraft A 620 ft from threshold)
13	(Aircraft A 960 ft from threshold)
16	(Aircraft A 1,385 ft from threshold)
19	(Aircraft A 1,875 ft from threshold)

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14. ABSTRACT

Two conflict detection and resolution (CD&R) algorithms for the terminal maneuvering area (TMA) were evaluated in a fast-time batch simulation study at the National Aeronautics and Space Administration (NASA) Langley Research Center. One CD&R algorithm, developed at NASA, was designed to enhance surface situation awareness and provide cockpit alerts of potential conflicts during runway, taxi, and low altitude air-to-air operations. The second algorithm, Enhanced Traffic Situation Awareness on the Airport Surface with Indications and Alerts (SURF IA), was designed to increase flight crew awareness of the runway environment and facilitate an appropriate and timely response to potential conflict situations. The purpose of the study was to evaluate the performance of the aircraft-based CD&R algorithms during various runway, taxiway, and low altitude scenarios, multiple levels of CD&R system equipage, and various levels of horizontal position accuracy. Algorithm performance was assessed through various metrics including the collision rate, nuisance and missed alert rate, and alert toggling rate.

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Airport surface; Algorithms; Awareness; Conflict detection; Enhanced traffic; Flight crew; Runway incursion; Terminal maneuvering area

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