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Initial Concept for Terminal Area Conflict Detection, Alerting, and Resolution Capability On or Near the Airport Surface, Version 2.0

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October 2013

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Acronyms

ADS-B	Automatic Dependent Surveillance - Broadcast
AGL	Above Ground Level
AMASS	Airport Movement Area Safety System
ASDE-X	Airport Surface Detection Equipment – Model X
A-SMGCS	Advanced Surface Movement Guidance and Control Systems
ATC	Air Traffic Control
ATCAM	Airport Traffic Collision Avoidance Monitor
ATMA	Airport Terminal Maneuvering Area
CAAT	Collision Avoidance for Airport Traffic
CD&R	Conflict Detection & Resolution
CG	Center of Gravity
ConOps	Concept of Operations
CPA	Closest Point of Approach
CPDLC	Controller-Pilot Data Link Communications
EPR	Engine Pressure Ratio
EUROCAE	European Organization for Civil Aviation Equipment
FAA	Federal Aviation Administration
FAROS	Final Approach and Runway Occupancy Signal
GA	General Aviation
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
JPDO	Joint Planning and Development Office
LACM	Low Altitude Conflict Monitor
LAHSO	Land and Hold Short Operations
MSL	Mean Sea Level
NA	Not Applicable
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
NPRM	Notice of Proposed Rulemaking
NTSB	National Transportation Safety Board
ORD	Chicago-O'Hare International Airport
RA	Resolution Advisory
RAAS	Runway Awareness and Advisory System
RI	Runway Incursion
RIPS	Runway Incursion Prevention System
RSI	Runway Status Indication
RSM	Runway Safety Monitor
RTCA	Radio Technical Commission for Aeronautics
RWSL	Runway Status Lights
SPR	Safety, Performance, and Interoperability Requirements
SURF IA	Surface Indications and Alerts
TCAS	Traffic Alert and Collision Avoidance System
TCM	Taxi Conflict Monitor
TI	Traffic Indication
TIS-B	Traffic Information Service-Broadcast
4-D	4-Dimensional

Abstract

The Next Generation Air Transportation System (NextGen) concept for 2025 envisions the movement of large numbers of people and goods in a safe, efficient, and reliable manner. The NextGen will remove many of the constraints in the current air transportation system, support a wider range of operations, and deliver an overall system capacity up to 3 times that of current operating levels. In order to achieve the NextGen vision, research is necessary in the areas of surface traffic optimization, maximum runway capacity, reduced runway occupancy time, simultaneous single runway operations, and terminal area conflict prevention, among others.

The National Aeronautics and Space Administration (NASA) is conducting Collision Avoidance for Airport Traffic (CAAT) research to develop technologies, data, and guidelines to enable Conflict Detection and Resolution (CD&R) in the Airport Terminal Maneuvering Area (ATMA) under current and emerging NextGen operating concepts. The term ATMA was created to reflect the fact that the CD&R concept area of operation is focused near the airport within the terminal maneuvering area. In the following, an initial concept for an aircraft-based method for CD&R in the ATMA is presented. This method is based upon previous NASA work in CD&R for runway incursion prevention, the Runway Incursion Prevention System (RIPS).

1 Introduction

By 2025, U.S. air traffic is predicted to increase significantly, yet the current air traffic management system may not be able to accommodate this growth. In response to this challenge, a consortium of industry, academia, and government agencies have proposed a revolutionary new concept for U.S. aviation operations, termed the Next Generation Air Transportation System or "NextGen" [JPDO, 2004]. Emerging NextGen operational concepts represent a different approach to air traffic management and as a result, a dramatic shift in the tasks, roles, and responsibilities for the flight deck to ensure a safe, sustainable air transportation system.

To support the operational goals – the "vision" – of NextGen, the Joint Planning and Development Office (JPDO) has published a Concept of Operations (ConOps) [JPDO, 2010] and a research and development plan [JPDO, 2007] to develop the technologies that it considers vital to reach the NextGen goals. While this vision is not necessarily shared by all nor is it the only way to achieve NextGen, it does illustrate many of the challenges to achieving a NextGen operating environment. In this report, the term Airport Terminal Maneuvering Area (ATMA) was created to reflect the fact that the CD&R concept area of operation is focused near the airport within the terminal maneuvering area. In particular, key challenges associated with the NextGen ATMA include:

- Trajectory-based operations that use closely spaced arrivals and departures to enable airport safety and capacity, independent of the visibility and weather conditions.
- Arrival and departure procedures that shift away from rigid, clearance-based air traffic control processes to flexible, adaptive air traffic management principles utilizing reduced spacing buffers, more runways, and innovative merging and spacing 4-dimensional (4-D) trajectory operations.
- Automated surface management systems that utilize dynamic algorithms to calculate the most efficient movement of all surface traffic to increase efficiency [Cheng et al., 2003]. Pilots will be required to comply with 4-D taxi clearances, dictating that aircraft arrive at specific locations within specific time windows.
- Potential pilot responsibility for "separation" from other aircraft, during all phases of flight, regardless of visibility conditions.

Proactive safety layers are being designed to enable these emerging NextGen operational concepts. Automation to manage, assist, and even conduct these procedures and operations will be developed. Nonetheless, it is imperative to have a conflict detection system that is an integral part of and integrated with, the emerging NextGen technologies to provide an additional protective layer should these proactive measures unforeseeably fail. This critical need is recognized under the JPDO vision in its research and development plan [JPDO, 2007].

This paper presents a concept for an aircraft-based method for CD&R in the ATMA. A concept and technical description is given for CD&R algorithms that detect potential conflicts in the ATMA during runway, taxiway, and low altitude operations and generate indications and alerts and possibly resolution advisories for display to the pilot. Note that in this paper, a conflict is defined as a condition that can lead to a collision if no avoidance action is taken. This version updates previously published work [Green et al., 2009] with the revisions summarized in the document revision history.

2 Background

Relevant research and systems for CD&R in the ATMA are discussed.

2.1 Runway Incursions

The harmonized Federal Aviation Administration (FAA)/International Civil Aviation Organization (ICAO) definition for runway incursion [FAA, 2009a], adopted on October 1, 2007, is:

Any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and take-off of aircraft.

Runway incursions are a serious aviation safety hazard. The National Transportation Safety Board continues to have improving runway safety on its most wanted list of transportation safety improvements for aviation [NTSB, 2011]. The FAA is committed to reducing the severity, number, 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, 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 18.9 incursions per million operations in FY 2010. [FAA, 2011 and FAA, 2009a] The worst aviation accident – 583 fatalities – was caused by a runway incursion in 1977 when two fully loaded 747 airplanes collided on a runway at Tenerife airport. The accident occurred in low visibility (300 meters visual range) conditions. A departing aircraft crashed head-on into an aircraft taxiing in the opposite direction on the same runway. The present-day statistics and events are cause enough for alarm but, without proactive counter-measures, the increase in air traffic forecasted under NextGen could potentially result in catastrophic increases in runway incursion accidents.

Numerous efforts have been launched by the FAA, industry, and others to reduce the frequency of runway incursions and the risk of runway collisions to meet the recommendations put forth by the NTSB [NTSB, 2000]. These solutions include Airport Surface Detection Equipment Model X (ASDE-X), Airport Movement Area Safety System (AMASS); Final Approach Runway Occupancy Signal (FAROS); Runway Status Lights (RWSL); enhanced controller training; airport surface operations advisory circulars; improved airport markings and lighting; improved pilot education, training, and awareness; and revised pilot/controller communications phraseology. These efforts target improved awareness and enhanced surveillance, but do not include technology solutions for the flight deck.

Currently, no system is available (either ground or aircraft-based) that directly provides the flight deck with alerts of potential runway conflicts with other traffic. However, some flight deck-based ATMA situation awareness systems are available, including:

- Honeywell International Inc. has developed an aircraft-based Runway Awareness and Advisory System (RAAS) [Honeywell, 2006]. RAAS uses Global Positioning System (GPS) position data and a database to provide aural–only advisories that supplement flight crew awareness of own aircraft position during ground operations and on approach to landing. RAAS does not, however, provide alerts of runway incursion conflicts with other traffic.
- SafeRoute™, developed by Aviation Communication & Surveillance Systems, provides the pilot with an electronic map of the airport surface on an electronic flight bag, showing ownship and other aircraft positions. The system will also indicate when a runway is occupied by highlighting the runway on the display [Evans, 2007]. SafeRoute™ does not, however, detect and alert for conflicts between aircraft and vehicles.

NASA- and FAA-sponsored research has also been conducted by Honeywell Aerospace and Sensis Corp. to transmit ASDE-X runway incursion alerts (which are optimized for Air Traffic Control (ATC)) to the flight deck [Hughes, 2007]. Additional research is needed to determine the effectiveness of providing the ATC-optimized ASDE-X alerts to the flight crew and data link requirements.

Working cooperatively with NASA, Era Corporation has developed a conflict detection and alerting system, known as PathProx™, that detects potential runway conflicts and generates alerts for display to the flight crew [Cassell et al., 2003]. PathProx™ does not include the cockpit display device and is not commercially available at this time.

Under NASA's Aviation Safety Program, Synthetic Vision Systems Project, the Runway Incursion Prevention System (RIPS) was developed to address the growing problem of runway incursions as a significant contributor to the fatal aviation accident rate in commercial, business, and general aviation sectors [Jones et al., 2001, Jones, 2002, Jones, 2005, and Jones and Prinzel, 2006]. As part of this work, the Runway Safety Monitor (RSM) was conceived as a method of automated CD&R for approach, landing, and surface (runway) operations. This effort focused on flight deck technologies and alerting, in contrast to other agency and company initiatives.

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, 2010b] have been developed under SURF IA to increase flight crew situation awareness of the runway environment and facilitate an appropriate and timely response to potential conflict situations. As part of this effort, the FAA sponsored flight demonstrations, conducted by Aviation Communication and Surveillance System and Honeywell, to show the feasibility of implementing this technology. NASA also conducted research that was integrated into this effort.

2.2 Low Altitude Air-to-Air Conflicts

In today's operations, the most notable airborne method of flight deck-based CD&R is provided by the Traffic Alert and Collision Avoidance System (TCAS). TCAS predicts a penetration to an aircraft's airspace and provides associated alerts to the flight crew. TCAS has been developed and improved for over 25 years and has been very effective in reducing or eliminating airborne collisions. This system does have known limitations in the vicinity of airports and TCAS alerts are inhibited at low altitudes. Resolution Advisories are not issued below 1000 feet Above Ground Level (AGL) and audible Traffic Advisories are not issued below 500 feet AGL [FAA, 2000]. Research to date indicates that the use of TCAS may work for envisioned trajectory-based 4-D operations [Ivanescu et al., 2004], but the suitability of TCAS degrades in operations nearing the airport [Pritchett et al., 1995].

RTCA SC-147, Traffic Alert and Collision Avoidance System, is addressing how to make TCAS II more compatible within the National Airspace System and how to integrate ADS-B into the next Collision Avoidance System [RTCA, 2010a]. In the area of collision avoidance, RTCA SC-147 is specifically chartered to:

- make collision avoidance more compatible with routine operations in congested airspace, including busy terminal areas in the National Airspace System (NAS), now and out through the 2025 time frame;
- make appropriate use of ADS-B information in a future collision avoidance system (or next-CAS); and
- reduce the radio frequency congestion at 1090 MHz.

Since international harmonization of CAS equipment is essential, SC-147 will work collaboratively with EUROCAE Working Group 75 (WG75) and appropriate ICAO bodies. Many experts in ADS-B technology, a potentially important component of a future CAS, already support RTCA through Special Committee 186. Recommendations on the development of future collision avoidance systems are slated for delivery by September 2011 [RTCA, 2010].

2.3 Taxi Conflicts

The NextGen concept proposes the use of ground-based automation to schedule surface traffic and generate 4-D taxi clearances to enable precise departure times and limited simultaneous runway occupancy [JPDO, 2010]. This move toward 4-D surface operations pushes the CD&R need beyond the runway and must include surface operations. Research has been initiated to determine the information display requirements for presentation of automated 4-D taxi clearances to the pilot and the ability of the pilot to comply with the 4-D clearances [Williams et al., 2006, Foyle et al., 2009, Prinzel et al., 2009, Shelton et al., 2009, Cheng et al., 2009, and Foyle et al., 2011]. The safety impact of following 4-D taxi clearances has not been determined, however; it is a concern that the pilot may be so focused on following 4-D clearances to meet scheduled arrival times that unintentional taxi conflicts could result. If this is the case, taxi conflict detection capability becomes critical.

2.4 ATCAM Concept

For emerging NextGen operating concepts, CD&R capabilities are desirable as the last of several proactive safety-enabling separation assurance layers. To provide a basis for this development and to begin research under CAAT, an initial concept for CD&R in the ATMA is proposed in the following as an extension of the RIPS work. This concept – Airport Traffic Collision Avoidance Monitor (ATCAM) – is described in the following sections. Also, the data communications to support this application are described to assess the feasibility of the concept, given current and projected equipage and current and NextGen operating environments.

3 ATCAM Concept Description

The goal of ATCAM is to detect potential traffic conflicts in the ATMA and generate flight deck-based indications, alerts, and possibly resolution advisories to provide sufficient awareness so that collisions are avoided. ATCAM operates at low altitudes near the airport without conflicting with TCAS, as well as on the runway and during taxi operations for multiple classes and equipage of aircraft and surface vehicles.

ATCAM is comprised of three separate aircraft-based algorithms that rely on target state information that can be obtained from various sources:

1. The *Runway Safety Monitor* (RSM) is designed to detect runway incursion conflicts and generate alerts and indications that provide the flight crew with sufficient awareness to take action to avoid a collision. RSM was developed in support of RIPS research and is retained as a core element of ATMA CD&R. Enhancements are planned for RSM based on current and emerging NextGen operational concepts and research findings.

2. The *Low Altitude Conflict Monitor* (LACM) is designed to detect and alert for air-to-air conflicts at low altitudes near the airport. Indications are not currently generated for LACM.

3. The *Taxi Conflict Monitor* (TCM) is designed to detect and alert for ground taxi conflicts anywhere in the airport movement and ramp areas. Indications are not currently generated for TCM.

The three algorithms are separate and independent but are integrated and share data to increase the probability of detection for all possible conflicts during airport operations. RSM has been through extensive simulation and flight testing. LACM and TCM are less mature but have been evaluated in simulation studies. Results of those studies suggest further refinements to these algorithms.

Figure 1 is a high level flow chart depicting the process for ATCAM conflict detection including coordination and prioritization of indications and alerts in the event of multiple indications and alerts from the same or multiple algorithms. A description of this process follows.

When the ownship is on the surface or at low altitude and new traffic data becomes available (see Section 4.0, ATCAM Data Communications Requirements), the RSM algorithm runs first to monitor other airborne or ground traffic for possible runway incursions. After RSM completes, either the LACM algorithm or the TCM algorithm is called depending on the position of the ownship. If the ownship is on the ground, TCM monitors possible conflicts with other aircraft or vehicles anywhere on the airport surface. If the ownship is airborne, LACM monitors possible conflicts with other airborne aircraft.

It is possible for conflicts detected by TCM or LACM to overlap with RSM (i.e., a TCM/LACM conflict could also be a runway incursion) and conflicts can also occur that are not runway incursions. ATCAM resolves any differences between alerts issued by the algorithms and prioritizes the alert data for output. The alert data, or null data if no alerts, is then output for use by the flight deck aural and graphical displays (see Section 4.3, Output Data Requirements).

This process of reading the ownship and traffic data, calling the conflict detection algorithms, coordinating and prioritizing indications and alerts, then outputting the indication and alert data is repeated approximately once per second. All algorithms are enabled by default but can be individually disabled. Each algorithm is implemented using the concept and technical approach that is optimal for the type of conflict being monitored.

A high level description of the indication and alerting concept and algorithms is given in the following sections. The ATCAM concept will be updated as necessary to address new or different (based on test and evaluation) CAAT requirements and concepts for NextGen.

3.1 Alert Definitions

The SURF IA SPR has adopted the definition of alerts [FAA, 2009] as follows: Alerts refer to flight deck annunciations meant to attract the attention of, and identify to the flight crew a non-normal operational or airplane system condition. Cautions and warnings are examples of alerts. Caution alerts are generated for conditions that require immediate flight crew awareness and subsequent flight crew response. An auditory signal and the yellow/amber color are associated with cautions. Warning alerts are generated for conditions that require immediate flight crew awareness and immediate flight crew response. An auditory signal and the red color are associated with warnings.

The criteria and thresholds used for the ATCAM alerts are defined in Sections 5.4, 5.5, and 5.6.

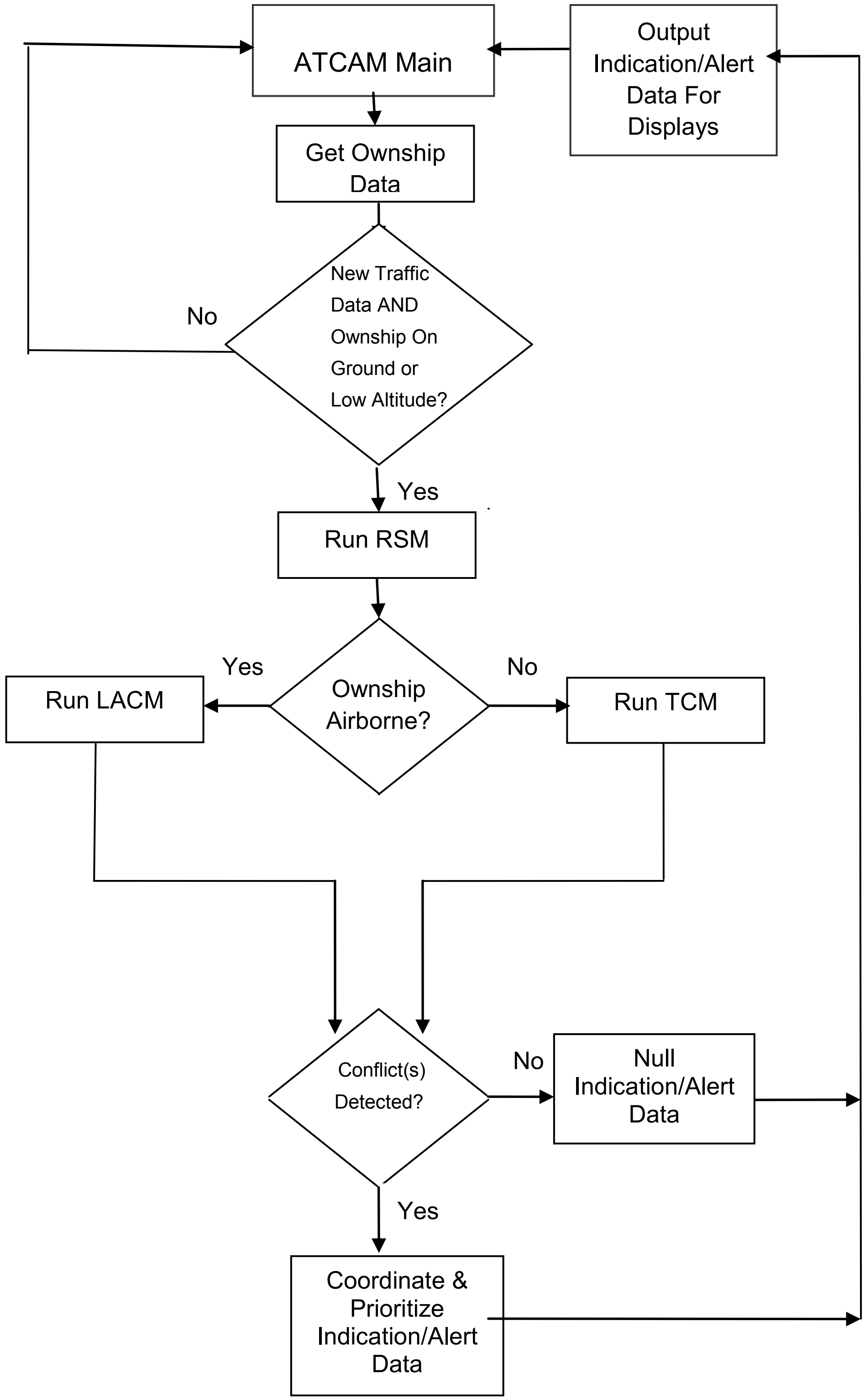


Figure 1. ATCAM High Level Flow Diagram

The alert terminology used by ATCAM is as follows:

3.1.1 Caution Alert

A caution alert provides immediate awareness of other traffic that may cause an unsafe or a hazardous situation. In the initial design, cautions are issued by LACM and TCM for low altitude and taxi operations and by RSM for runway incursions during approach or when holding in position on the runway. The feasibility and appropriateness of generating caution alerts for these types of operations will be determined based on test and evaluation. Avoidance maneuvers are not required and resolution instructions are not given when a caution is issued. In some cases, appropriate action may be advisable at the pilot's discretion to prevent the condition from progressing to a more serious situation. For example, when a caution is issued for taxi operations, avoidance action such as slowing down or stopping may be done to prevent the situation from progressing to the point a warning alert is warranted.

3.1.2 Warning Alert

A warning alert indicates there is a high probability of collision or near collision with other traffic and, therefore, avoidance maneuvering should be initiated. The specific maneuver taken (e.g., go-around, abort takeoff, stop taxi, etc.) is at the pilot's discretion. Warnings are issued by RSM, LACM and TCM using criteria and thresholds that are algorithm specific. The criteria and thresholds will be refined based on test and evaluation.

3.1.3 Resolution Advisories (RA)

RAs are intended to provide the pilot direction on the maneuver to take to safely avoid a collision. RAs are issued in the current version of ATCAM, in prototype form. Further research is required, and currently in progress, to determine the feasibility of providing RAs in conjunction with warning alerts to effectively resolve conflict situations without producing undesired consequences. For example, what avoidance maneuvers should be taken without creating secondary conflicts with other traffic? Section 6.0, Initial Requirements for ATCAM Resolution Advisories, describes current RA research.

3.2 Indication Definitions

In addition to alerts, the SURF IA SPR has also adopted the definition of indications [RTCA, 2010b], as follows: *Indications* identify to the flight crew a normal operational condition that could become a runway safety hazard. Indications do not actively attract attention from flight crews but provide enhanced situation relevant information to facilitate flight crew perception of safety hazards. Indications are not alerts.

Only the RSM algorithm currently implements indications (as defined in the SURF IA SPR [RTCA, 2010b]), for potential runway conflicts. Neither LACM nor TCM implement indications for low altitude or taxi scenarios.

3.2.1 Traffic Indication (TI)

Traffic indication (TI) highlights a potential runway traffic collision/hazard that may emerge in the near future. TIs are intended to increase the flight crews' awareness of relevant traffic that could affect runway safety. If appropriately cleared, the flight crew proceeds with the intended operation.

3.2.2 Runway Status Indication (RSI)

Runway Status Indication (RSI) identifies if the runway that own-ship is approaching or using is in-use or occupied by other traffic. Before proceeding, the crew should ensure they have the appropriate clearance and the indicated traffic is not a factor. Note: The absence of an RSI does not alleviate pilots from verifying the runway status prior to proceeding.

3.3 Runway Safety Monitor (RSM)

RSM monitors data for the ownship aircraft and other aircraft or vehicles and predicts potential incursions/collisions and notifies the flight crew to avoid a possible incursion/collision. Testing has included single runway, intersecting runways and intersecting flight path scenarios during both simulation and flight [Green, 2006, Jones, 2002 and 2005, Jones et al., 2001, and Jones and Prinzel, 2006]. In some scenarios, RSM detects a runway incursion early and issues an alert before the situation degenerates into a severe incursion. In other scenarios, RSM predicts the incursion before it occurs and alerts the pilot early to avoid the incursion. RSM also detects runway conflicts that are not part of the strict definition of runway incursion, such as when both aircraft are airborne in the process of landing in the approach phase and/or taking off in the climb out phase. RSM is generic for both general aviation (GA) and large commercial air carrier operations, and for any ownship aircraft type. The most recent version of RSM is described in detail in [Green, 2006].

A major concept of RSM is the use of runway incursion (RI) zones. A RI zone is a three-dimensional virtual zone that overlays a runway and the approach area. A detailed description of the RI zone placement is given in Section 5.4.2. A two-dimensional plan view of the RI zones at the Wallops Flight Facility is shown in Figure 2. RSM monitors for conflicts/incursions only when the ownship is inside a RI zone and traffic is inside or approaching the same zone as the ownship or in an intersecting zone.

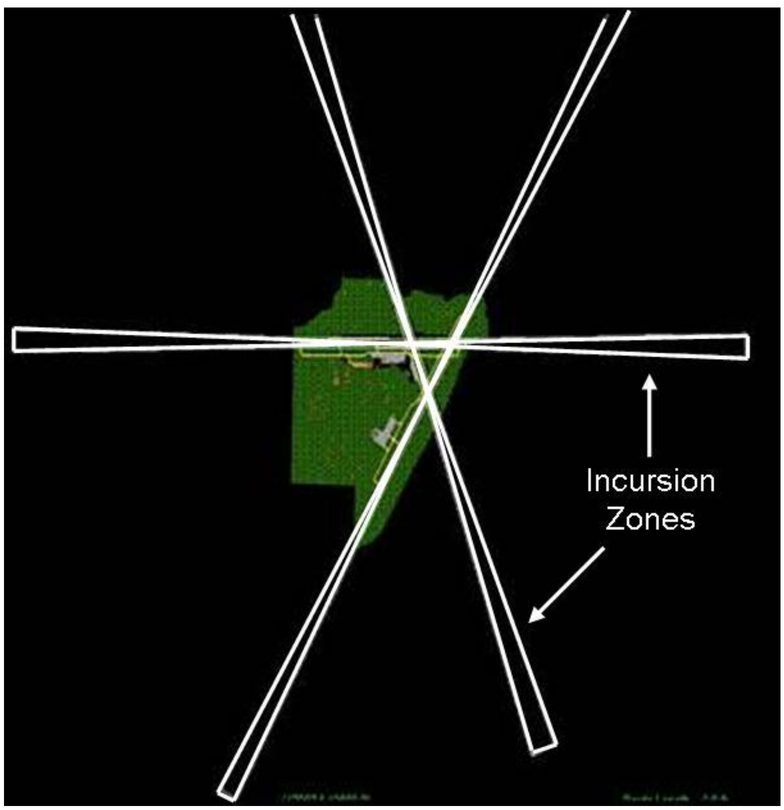


Figure 2. Runway Incursion Zones at Wallops Flight Facility

Another major RSM concept is the use of operational states for the ownship and traffic. Seven operational states or flight phases are defined: taxi, pre-takeoff, takeoff roll, climb-out, approach, rollout and fly-thru. These states are described in Appendix A. Combinations of these states between the ownship and traffic, positions inside the RI zones, and other criteria determine whether or not an indication or alert will be issued. More detail is provided in Section 5.4 and Appendices A, B, and C.

CD&R under the RIPS concept includes aural and visual displays in the flight deck. For instance, an airport map display depicting a warning alert for a runway incursion from a simulation at the Chicago (ORD) airport is shown in Figure 3.

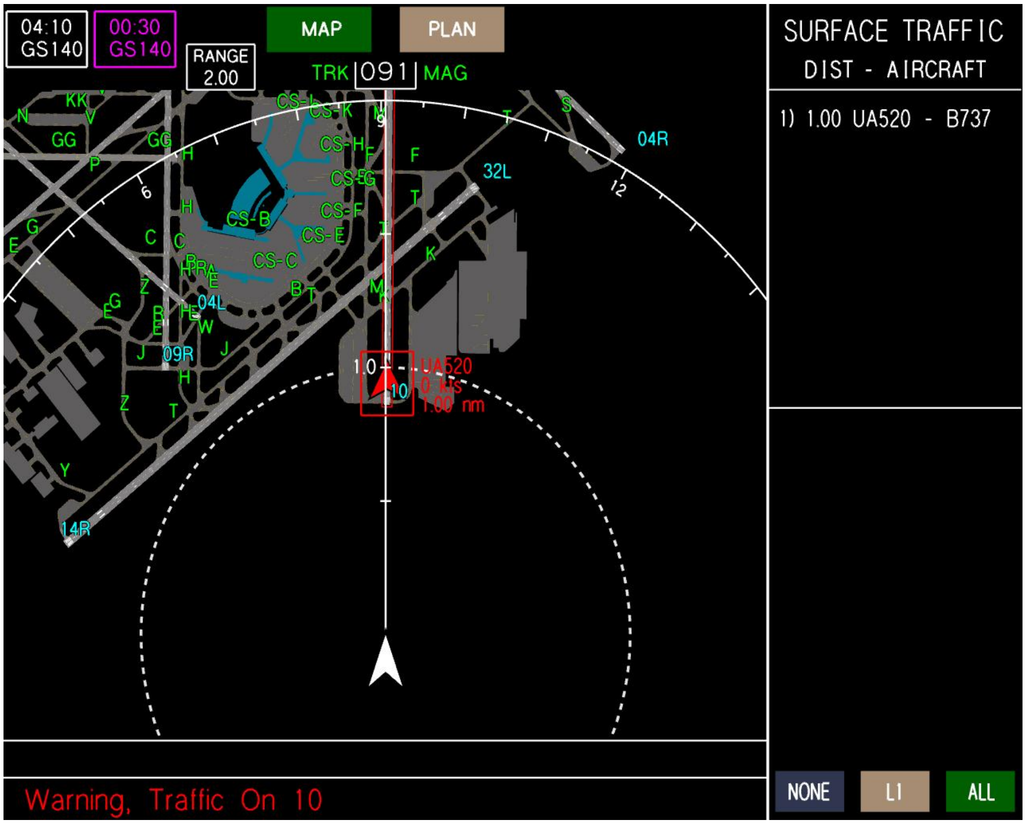
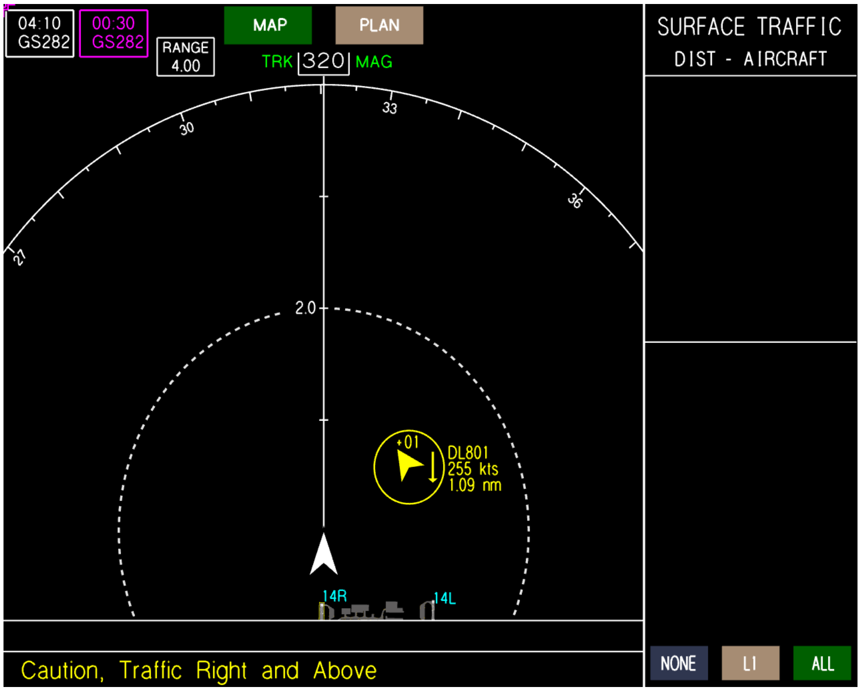


Figure 3. Airport Map Display showing Warning Alert for a Runway Incursion

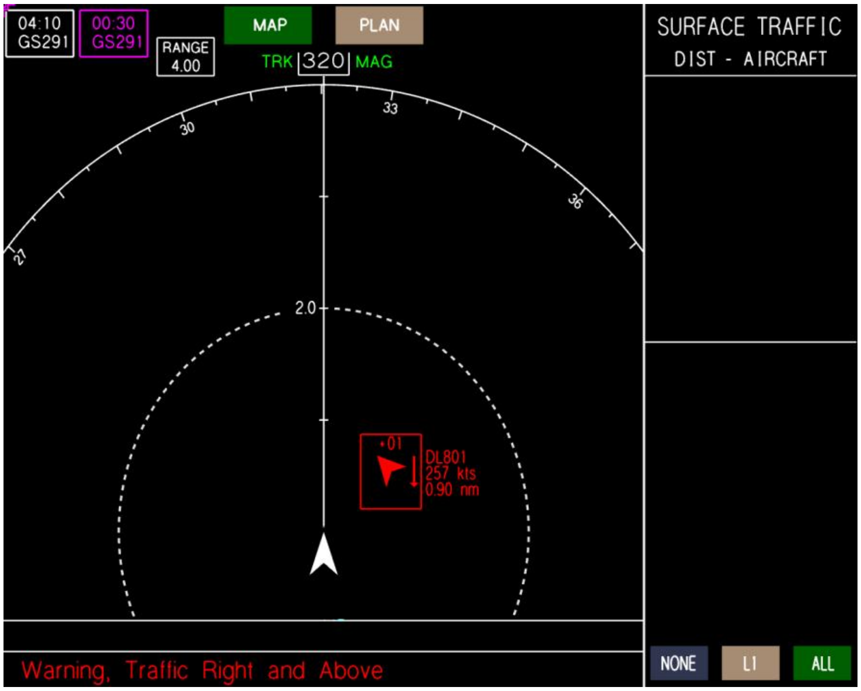
3.4 Low Altitude Conflict Monitor (LACM)

The intent of the LACM algorithm is to monitor conflicts that can occur at low altitudes near the airport including conflicts that may not be detected by RSM. As shown in Figure 1 above, LACM is run in addition to RSM. LACM provides conflict detection coverage at altitudes below 1000 feet. The implementation of LACM does not utilize aircraft operational state information and RI zones as does RSM. Instead, the algorithm's initial design is based on many of the same concepts that are used in the current operational version of TCAS II [FAA, 2000]. However, there are a number of significant differences between LACM and TCAS in the way traffic data is obtained, the methods of computation, the criteria and thresholds used for alerting, and the types of alerts that are issued (see Section 5.5). Some of the TCAS terminology is also used by LACM such as Closest Point of Approach (CPA), time to CPA (called range tau) and time to co-altitude (called vertical tau). The technical approach for LACM is to compute closing speed, range tau, vertical tau and other data between ownship and an approaching aircraft to determine if specific criteria and thresholds are met for issuing alerts. The alerts and methodologies used by LACM are designed to achieve the same high level of performance as TCAS and are described in Section 5.5.

Figure 4 gives examples of LACM caution and warning alerts at the ORD airport. In Figure 4a, the ownship has departed a runway. The traffic has departed a parallel runway and is turning on a path to cross in front of ownship. LACM detects this potential conflict and initially issues a caution (indicated by yellow icons). As the scenario progresses, the aircraft continue toward a potential collision point and LACM issues a warning (indicated by red icons), as shown in Figure 4b.



4a. LACM Caution Alert



4b. LACM Warning Alert

Figure 4. LACM Alerts.

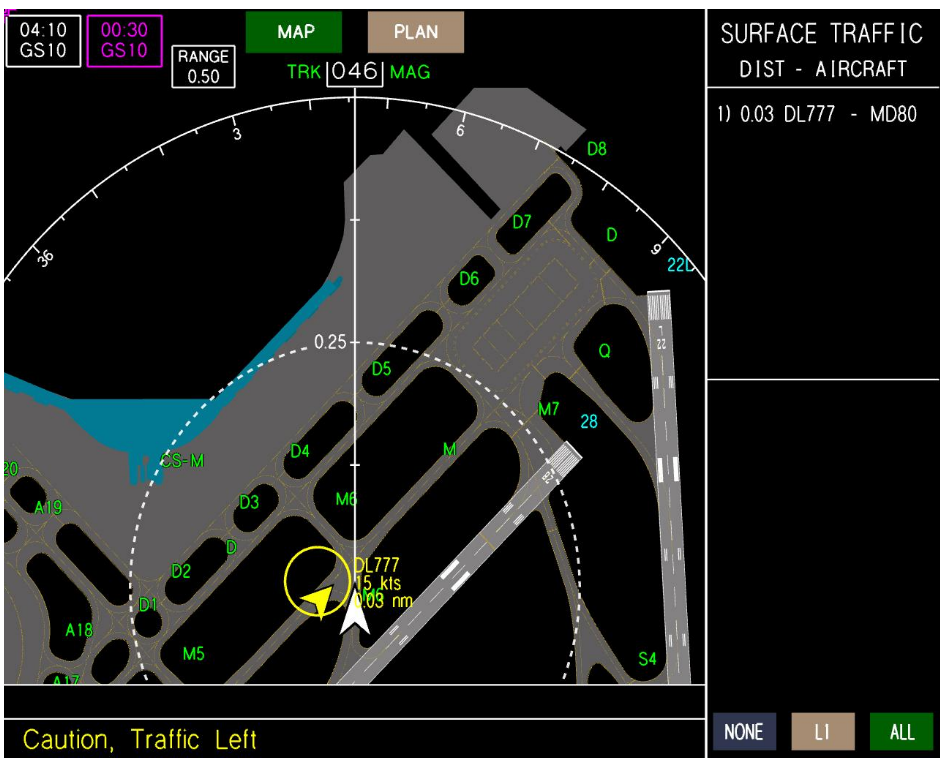
3.5 Taxi Conflict Monitor (TCM)

The TCM algorithm is designed to improve safety on the airport surface by monitoring for conditions that cause conflicts and collisions during taxi operations for multiple classes of aircraft as well as surface vehicles. The algorithm's design uses an approach similar to LACM by computing distances between aircraft, closing speeds, time to closest point of approach (range tau) and other parameters used for alert criteria. The obvious difference from LACM is that all aircraft, vehicles, etc., on the airport surface can be very close to each other while moving or not moving.

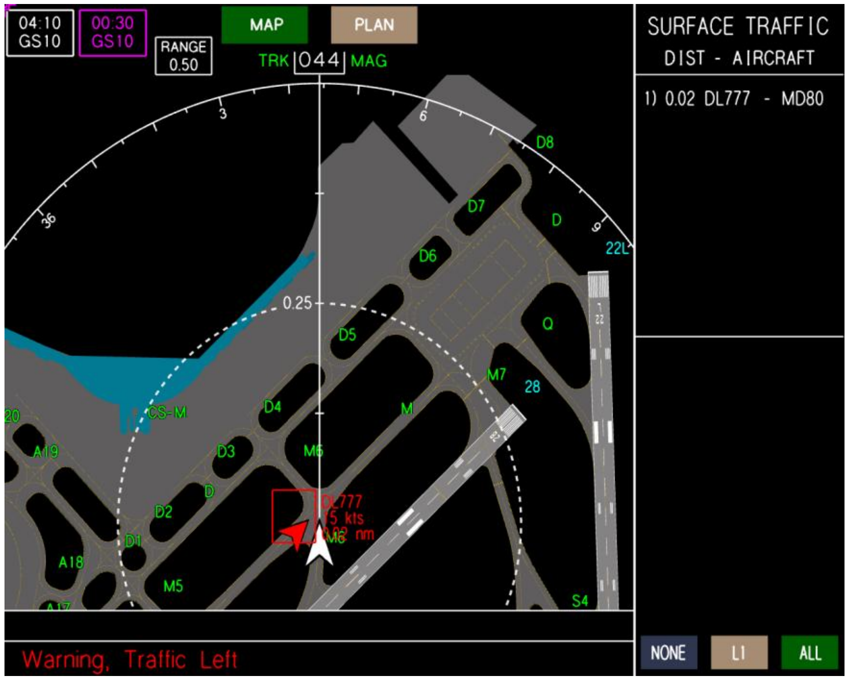
The close proximity of aircraft and vehicles to one another on the surface requires very strict accuracy tolerances. These tolerances, as well as all alert criteria and thresholds for TCM, are described in Section 5.6. Some of the parameters used by LACM (e.g., vertical speed, altitude, vertical tau, etc.) are not required by TCM. However, based on developmental testing, additional alert criteria are required by TCM because of the higher probability of nuisance alerts (see Section 5.2). All alert criteria and thresholds are described in Section 5.6. Because TCM is based on the LACM and the TCAS concept, the algorithm does not use a detailed database of airport taxiways, runways and ramps.

The feasibility of utilizing traffic's ATC clearances, specifically, assigned taxi route and hold short instructions, as a factor in taxi conflict detection and alerting is being investigated. Knowledge of the traffic's intent on the surface combined with the current state information could result in delayed alerting and reduced nuisance alerts. A detailed database of the airport including taxiways and ramp areas would be required in this instance. Future versions of TCM may utilize this information if determined to be a feasible approach.

Figure 5 gives examples of TCM caution and warning alerts. In Figure 5a, the taxiing traffic and ownship are approaching the same intersection as ownship exits the runway after landing. TCM detects this potential conflict, and initially issues a caution (indicated by yellow icons). In Figure 5b, as the aircraft continue to converge, TCM issues a warning (indicated by red icons).



5a. TCM Caution Alert



5b. TCM Warning Alert

Figure 5. TCM Alerts between commercial aircraft.

4 ATCAM Data Communications

The ICAO defined operational requirements for Advanced Surface Movement Guidance and Control Systems (A-SMGCS) are to achieve safe, orderly and expeditious movement of aircraft and vehicles at airports under all visibility conditions, traffic densities, and airport layouts. These standards were proposed by ICAO to ensure safety and standardization with respect to global interoperability [ICAO, 1997]. NASA and its industry partners developed a prototype A-SMGCS architecture and operational concept that was initially designed to improve operational capability. This operational concept and system design have been tested in both full-mission simulation and operational flight test experiments at major airport facilities. The data structure developed for the first implementation of an aircraft-based A-SMGCS, demonstrated at the Atlanta Hartsfield International Airport in 1997 [Jones and Young, 1998], coupled with the enhanced design to provide runway incursion detection and alerting demonstrated at Dallas-Fort Worth International Airport in 2000 [Jones et al., 2001] were used as the basis for the current data parameters for ATCAM.

ATCAM data communications is handled by a separate software program that accesses data from various sources available on the aircraft and provides the data to ATCAM. Flight and traffic data are obtained from available sources and converted and processed into the format required by ATCAM. This method of data communications has been utilized successfully in past RIPS research and has proven to be highly reliable and effective during flight tests and simulations. A significant advantage of this method is that ATCAM does not have to perform data communications functions. Appendix D lists the current data parameters used by ATCAM.

Appendix E contains a discussion on surveillance performance and intent data as it relates to ATMA CD&R.

4.1 Ownship Data

The ownship data used by the ATCAM software is obtained from the aircraft systems and consists of the data described in Appendix D, as available. Additional parameters may be required with future development of the ATCAM software.

4.2 Traffic Data

Data for airport traffic can be obtained from several different sources, such as:

- Traffic Information Service-Broadcast (TIS-B) comprised of traffic information from surface surveillance radar and multi-lateration [RTCA, 2007],
- Automatic Dependent Surveillance-Broadcast (ADS-B) [RTCA, 2002],
- TCAS [FAA, 2000], and
- GPS-based surface vehicle location tracking system such as Era Corporation's Squid [Era, 2008].

Appendix D contains a list of the traffic data parameters currently used by ATCAM.

For CAAT, the data communications software accesses traffic data from any available source. If any of the parameters are not available from the data source in use, they are marked accordingly, so that ATCAM does not attempt to use any spurious values. Unavailable parameters may be computed independently, or may be subject to data smoothing, described below. ADS-B Out deployment has been mandated and is expected to be the primary source for future NextGen requirements. However, current Mode-S/Mode-C TCAS data (range, bearing and relative altitude) will continue to be used as well as other new sources from on-board sensors and ground systems. Since ATCAM does not utilize range, bearing and relative altitude, TCAS data must be converted to lat/long and altitude mean sea level (MSL) by the communications program for use by ATCAM. Currently, ATCAM accesses data once per second, regardless of the rate at which the data was received.

When traffic parameters are not reported or not up to date, an estimate of the current value(s) must be computed by the algorithms based on the last known value(s). This process, known as data smoothing, involves computations that decrease in accuracy with increasing time between updates. Computation accuracy is further decreased if data rates for specific values are different and the exact times since the last update are uncertain (for example, the position update is one hertz but the ground speed is updated at two or three hertz and the exact update times are unknown).

4.3 Output Data

ATCAM output parameters provide information on the generated alert or indication and conflict traffic to enable display of the alert or indication to the flight crew or ATC. The specific output parameters for the alert or indication are based on the aural and graphical flight deck alerting display requirements. The current ATCAM output parameters, listed below, were defined for RSM alerts. Additional parameters are available in RSM and can be provided in future upgrades as required. Other output parameters derived from LACM and TCM alerting display requirements will also be added as required.

- Traffic ID (e.g., ICAO aircraft address)
- Alert code
- Distance to traffic (range)
- Distance to collision point
- Time (sec) to collision point
- Time (sec) to closest point of approach (range tau)
- Traffic bearing relative to ownship
- Traffic relative altitude

- RA maneuver, if provided (RSM or TCM)
  Or
  Horizontal, vertical and acceleration maneuver & navigation pairs (LACM)

The alert code is a single four digit hex number that compresses information including type of alert or indication (i.e., caution or warning, TI or RSI), the name of the traffic's runway and the traffic's departure/arrival status (for example, a warning for traffic departing runway 25). The efficient encoding and decoding routines used to generate the alert code are generic for any airport and compatible with the ATC two-way Controller-Pilot Data Link Communications (CPDLC) protocols defined in references [ICAO, 1999] and [RTCA, 1993]. A benefit of being compatible with CPDLC is the alert information can be data linked to ATC for display on a controller's workstation as well as be presented aurally, visually or both to the pilot.

When an alert is given, an RA directive may be provided to the pilot. For RSM, a runway maneuver may be directed, such as go around. For TCM, a taxi maneuver such as slow down may be directed. For LACM, however, a horizontal, vertical, acceleration or a combination of these maneuvers and corresponding navigation may be directed. Examples of this include climb 300 ft/min (vertical), bear left 30 degrees (horizontal) or reduce speed (acceleration). A more detailed discussion of RAs is located in Section 6, Initial Description of ATCAM Resolution Advisories.

5 Technical Description of ATCAM Algorithms

The previous section described data communications and parameters for the ATCAM algorithms. This section provides a technical description for each of the three algorithms. The first three subsections on integration of algorithms, performance, and aircraft reference positions are applicable to all three algorithms. Finally, algorithm-specific details are presented.

5.1 Integration of Algorithms

Because there is overlap in the coverage of component algorithms in ATCAM, the algorithms are integrated to share data and insure that consistent and accurate alerts are issued. The LACM algorithm is integrated with the RSM algorithm to detect any air-to-air conflicts that RSM does not alert for when the conflict does not meet incursion criteria. The TCM algorithm is also integrated with RSM because ground taxi conflicts can also be runway incursions if the conflict occurs on or near a runway. Integration between LACM and TCM is not necessary since there is no overlap between the algorithms' operational domains.

The integration of LACM and TCM with RSM is implemented by sharing and coordinating alert output data. Since LACM and TCM run after RSM (see Figure 1) and have access to RSM data, information is known about ownship and traffic operational states and RSM alert status. This information is used to coordinate the alert data that is output for aural and graphical display in the cockpit. For example, when air-to-air conflicts are also runway incursions, the ownship and traffic runway status information from RSM can be issued in addition to the low altitude alert data. Due to design differences, there are cases when alert criteria will be met by only one algorithm or one algorithm may detect a conflict earlier than the other. This redundancy in conflict monitoring significantly improves overall performance.

5.2 Algorithm Performance

The algorithms can be evaluated based on the timeliness of indications and alerts and missed, false, and nuisance indication and alert rates. The timeliness of an alert is determined by whether a caution is issued with sufficient time to provide adequate traffic situation awareness prior to a potential hazardous situation, or whether a warning is issued with sufficient time for the pilot to take action and safely avoid a collision. The definition of missed, false, and nuisance alerts are taken from RTCA 2010b. A missed alert is a condition where an alert is needed but not provided, including non-equipped vehicles and aircraft. For example, a runway incursion or near collision occurs and a warning is not issued, or aircraft come close enough to meet the caution minimum separation threshold but the caution is not issued. A false alert is an incorrect or spurious alert caused by a failure of the alerting system including the sensor. The false alert rate is composed of ownship avionics failures, undetected ownship avionics errors, map integrity, and undetected traffic avionics failures. A nuisance alert is generated by a system that is functioning as designed but which is inappropriate or unnecessary for the particular condition. The nuisance alert rate is composed of position integrity, ownship accuracy, traffic accuracy, and map accuracy. A false or nuisance alert could cause an avoidance maneuver that is not necessary and could possibly cause secondary conflicts or unnecessary delays.

The algorithms are being designed to completely eliminate collisions/near collisions in the airport area. To accomplish this goal, performance results should be near zero missed and untimely alerts. Analyses are required to determine acceptable missed, nuisance, and false alert rates and desired probability of detection. Some analyses have been conducted by RTCA SC-186 WG1 subcommittee for runway conflicts [RTCA, 2010b].

Performance objectives for RSM have been tested in previous flight tests and piloted simulations. The most recent RSM flight test at the Wallops Flight Facility resulted in a success rate of no missed or late alerts and only one nuisance alert for all incursion scenarios tested [Green, 2006]. Initial simulation evaluations of LACM and TCM have been conducted [Jones et al., 2009 and Jones et al., 2010]. Enhancements have been made to LACM and TCM based on these evaluations and are reflected in this document.

5.3 Aircraft Reference Positions

ATCAM uses the latitude and longitude reported for ownship and traffic as the navigation reference point for the aircraft (or vehicles). This reference point is the aircraft center of gravity. To determine distance between aircraft, ATCAM measures the distance between the exteriors of the aircraft, not the distance between reference points. To determine whether an aircraft is in a runway incursion zone, ATCAM considers whether any exterior point of the aircraft is in the zone, not just the reference point. ATCAM determines the aircraft exterior points by considering the aircraft type (B-757, DC-7, etc.) and using the dimensions for that aircraft type (body length, wing span, distance to nose, and distance to tail). If the aircraft type is unknown, ATCAM uses a default type of a large aircraft (B-747) to allow a conservative estimate.

5.4 RSM

5.4.1 Airport Databases

RSM does not require detailed terrain or airport databases that include taxiways, ramps, buildings, etc. However, RSM does require highly accurate information for all runways on the airport to include latitude and longitude of thresholds and displaced thresholds, runway length and width, length of run-up areas, runway true heading, ILS glide slope angle if applicable, runway touchdown aim points, and distance from threshold to land-and-hold-short positions on the runway. The existence of intersecting runways and intersecting arrival/departure flight paths is determined from the airport diagram. Required information is available from publically-available sources.

5.4.2 Runway Incursion Zone Placement

Accurate placement of RI zones is critical for correct performance of the algorithm and prevention of missed and nuisance alerts. The coordinates for the sides and ends of each zone are computed based on runway information in the airport configuration file and vary for each runway. The sides of the zones along the runways are set to be at or just inside the hold short positions if they are known. If runway hold short position data are not available, the sides of zones are placed 200 feet from the runway edges.

The sides of the zones are extended by a *look-ahead distance*, if an aircraft outside the zone is taxiing toward the zone. The look-ahead distance is based on the distance the aircraft requires to stop, given its current ground speed and assuming a standard deceleration rate that is not aircraft type specific. If the distance between the aircraft and the zone edge is less than the look-ahead distance, the aircraft is considered to be inside the zone. This approach allows RSM to issue alerts in time for the aircraft to stop before entering the zone.

The ends of zones will vary based on the intersection of the ILS glide slope path with the RI zone altitude. The example below (Figure 6) shows that with a typical zone altitude of 800 feet and a typical glide slope angle of 3 degrees, the end of the zone would be calculated to extend approximately 15,265 feet prior to the touchdown aim-point. (The touchdown aim-point is abeam the ILS glideslope antenna.) Assuming the touchdown aim-point is located 1,000 feet from the end of the runway, the zone would extend approximately 14,265 feet, or 2.34 nm, prior to the runway threshold.

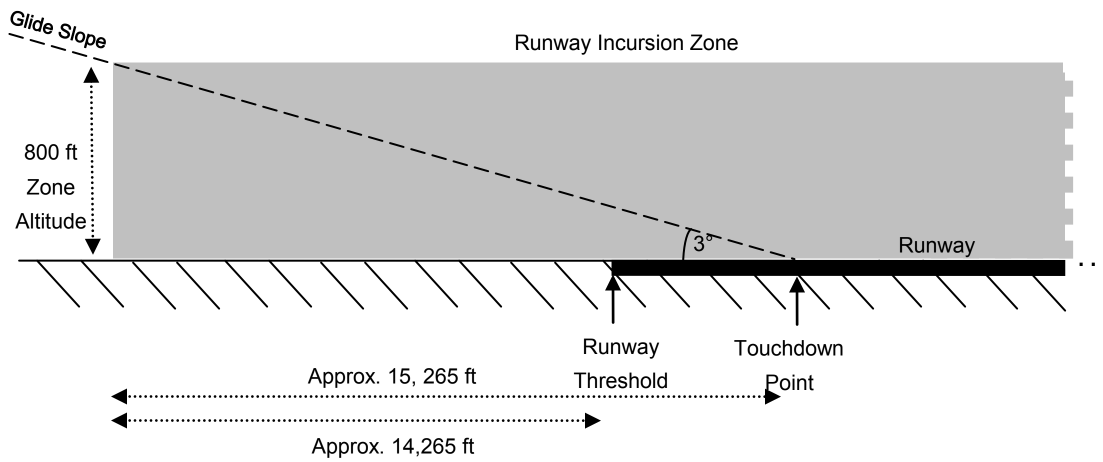


Figure 6. Example Using 3-Degree Glide Slope to Determine Incursion Zone Ends

The width of extended RI zones is greater at the approach ends than at the runway thresholds as shown in Figure 2. Greater detail is shown in Figure 7, in plan view, with the extended zone shaded gray. The angle at which the extended zone flares, or increases, is determined by the maximum ILS localizer deviation, up to a two-dot deviation. For each dot of ILS error, the zone perimeter is 175 feet from the centerline at the runway threshold, as modeled by [Parrish et al., 2006]. The angle of flare for the extended zone is determined by using a straight line that starts at the estimated location of the ILS antenna, 1,000 feet from the opposite runway threshold, intercepts the defined zone perimeter distance at the runway threshold, and terminates at the end of the extended zone. The example RI zone in Figure 7 uses a one-dot ILS deviation, and the zone ends at 14,265 feet past the threshold, as determined by the 3-degree ILS slope shown in Figure 6.

All values for RI zone placement can be modified in configuration files to be optimal for any airport. Site-specific adaptation of some values may be necessary due to conditions at individual airports. For example, if parallel runways are closely spaced, runway zones may need to be narrower. Airports in mountainous regions may require steeper glide slopes. Construction at airports may cause runway dimensions to change or may lead to creation of new runways or removal of existing runways.

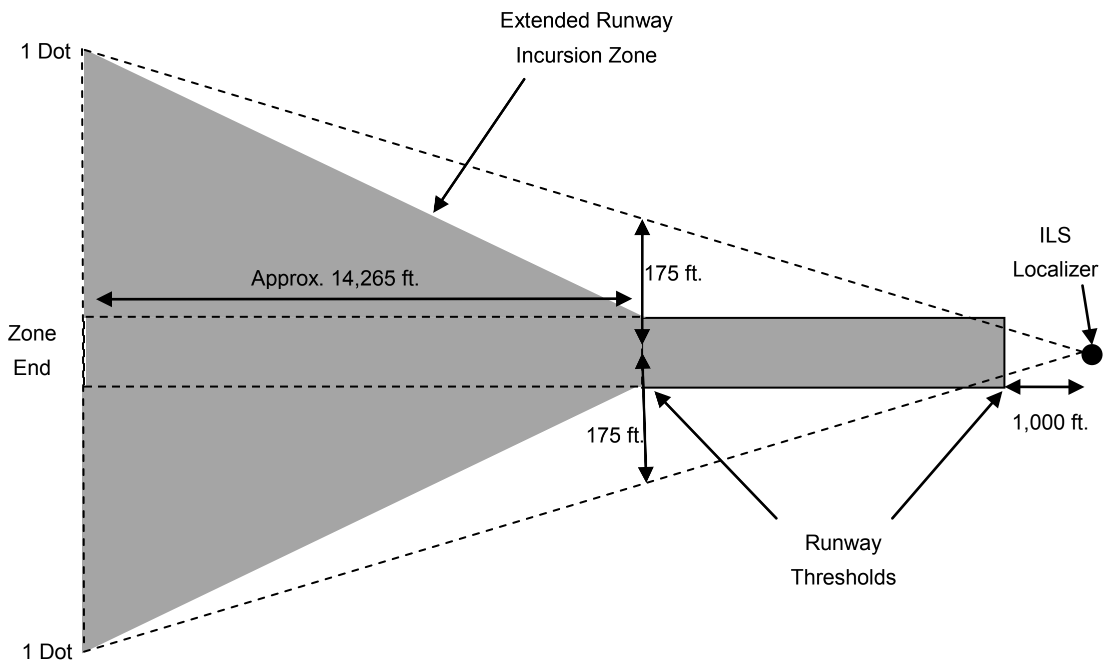


Figure 7. Example Extended Runway Zone with 1 Dot ILS Deviation

5.4.3 Incursion Scenarios and Alert Criteria

RSM is designed to detect all possible runway incursion scenarios including conflicts on single runways, intersecting runways and intersecting flight paths. This capability is accomplished using a generic approach that is based on the concept of ownship and traffic operational states as defined in Appendix A. Conflict scenarios are defined by the combination of operational states that determine whether or not alert criteria should be tested for conflicts. There are separate criteria for single runway and intersecting runway/flight path conflicts. Appendix B describes the alert criteria and default thresholds and provides a set of tables that define the scenario conditions for all possible combinations of ownship and traffic states. Appendix C provides a mapping between RSM operational states and SURF IA operational states, and RTCA 2010b describes the criteria, thresholds, and state combination tables for SURF IA indications.

5.4.4 Determining Operational States

Since incursion scenarios and indication and alert criteria are based on the operational states of ownship and traffic (Section 5.4.3 above), the correct performance of RSM depends on, among other things, how accurately these states are determined. The criteria and data for determining states include on or off the runway, heading/track in direction of runway, ground speed, acceleration, altitude and vertical speed.

Additional data may also be available for determining ownship states such as auto throttle, engine pressure ratio (EPR) mode, throttle position, thrust reversers, air-ground, nose wheel squat, etc. (see Appendix D and Table D1). Ownship states can be computed accurately because the additional data help to indicate "intent" to takeoff, "intent" to land, etc. However, these intent data are not available for traffic. Although RSM has good results in computing traffic states without the intent data, accuracy could potentially be improved if this data becomes available. See discussion on intent data in Appendix E.

5.4.5 Alert Output Data

The current alert output parameters for the RSM caution and warning, that provide the flight crew with optimal alert awareness, are based on the aural and graphical display requirements developed through simulation and flight testing. The current parameters are listed in Section 4.3. Additional parameters are available in RSM and can be provided in future upgrades as required.

5.5 LACM

5.5.1 Integration with TCAS

LACM is designed to detect and alert for air-to-air conflicts at low altitudes near the airport without conflicting with TCAS operation. As mentioned in Section 2.2, TCAS resolution advisories are inhibited below 1000 feet AGL ±100 feet and aural traffic advisories are inhibited below 500 feet AGL. LACM monitors for conflicts below 1000 feet AGL. Any overlap in coverage with TCAS will require integration and coordination so LACM does not interfere with existing TCAS operations. For example, LACM will not alert if TCAS is already alerting for the same traffic. Research regarding LACM and TCAS integration is necessary. The results of this research could possibly support RTCA SC-147 objectives (see Section 2.2).

5.5.2 Traffic Data and Computations

A major difference between LACM and TCAS design is the way traffic data is acquired and the resulting methods of computing distance to aircraft, bearing, and closing speed. TCAS uses Mode S and Mode C surveillance of nearby airborne traffic at exact time intervals to continually measure the distance (range), direction (bearing), and altitude (if available). This system provides accurate, timely, and consistent data to compute parameters. TCAS determines closing speed between ownship and traffic by interrogating nearby Mode C or Mode S transponder-equipped traffic and using the position data to compute changes in distance over time.

Currently, LACM does not use TCAS Mode-S/Mode-C data directly but primarily depends on data available from ADS-B. (See Section 4) Closing speed is critical in determining the timing of a potential conflict. During previous RSM research, closing speed had been calculated using ADS-B aircraft position data, and the timestamps associated with that data. However, flight testing found that using ADS-B position reports and associated timestamps to calculate closing speeds produced erratic results since neither of these data items were reported with sufficient accuracy. Future upgrades to ADS-B may improve accuracy and timeliness; however, an immediate solution is needed.

Another method of computing closing speed is to use ADS-B ground speeds that are consistent and not as dependent on time stamps as position data. By computing the components of ground speed in the direction of closure for both ownship and traffic, and comparing these components, the closing speeds and times to CPA are highly accurate and smooth (not erratic). This method of computation is currently used by LACM when ADS-B is the data source. Further testing is needed to determine how sensitive this method is to variations in flight data accuracy.

5.5.3 Monitoring and Alert Criteria

Since LACM is designed to operate at low altitudes, the monitoring and alert criteria and thresholds must be optimized to prevent nuisance alerts and allow sufficient lead time for avoidance action to prevent collisions. The current alert criteria are based on those used by TCAS but thresholds may differ based on testing and operational requirements (e.g., approach spacing, etc.). For example, criteria for time to CPA (range tau) and time to co-altitude (vertical tau), may have different thresholds for LACM, to customize the lead time for pilot response to alerts. Also, to prevent nuisance alerts, some additional LACM criteria are required such as projected separation at CPA, relative altitude at CPA, and position of CPA on the ground or airborne. Table 1 lists the initial traffic monitoring and alert criteria, and thresholds that have been determined based on developmental testing and evaluation. The threshold values for monitoring and alerts are contained in software configuration files and can be modified as required based on future testing. For a caution or warning to be issued, all criteria listed in the table must be satisfied.

For LACM criteria which specify a distance threshold, the distance is measured from the aircraft center of gravity (CG). Distance between ownship and traffic is measured from the ownship CG to the traffic CG.

Table 1. Initial LACM Alert Criteria and Thresholds

Monitoring Criteria		
Target proximity < 18000 ft from ownship position. Ownship and target altitudes 50 – 1000 ft AGL ±100 ft.		
Alert Criteria	**Caution**	**Warning**
Range tau (sec)	<35	<20
OR current distance to target (range) (ft)	<2000	<1200
Vertical tau (sec)	<35	<20
OR current relative altitude (ft)	<1000	<400
OR projected relative altitude at CPA (ft)	<1000	<400
Projected horizontal separation at CPA (ft)	<2000	<1200
Projected ownship and/or target altitudes at CPA (ft) (Own/target not near the ground at CPA)	>50	>50

5.5.4 Alert Data Output

The parameters that are output for the LACM caution and warning depend on the cockpit alerting display (aural and graphical) requirements for NextGen. The future alert display requirements are unknown at this time, but a list of parameters can be constructed based on previous RIPS alert output as well as display data currently utilized by TCAS. The following list of alert output parameters is based on developmental testing and evaluation but is subject to change based on future testing and requirements. Alert parameters previously used for RIPS are identified with asterisks.

- Traffic ID (e.g., ICAO aircraft address)*
- Alert code (includes type of alert caution/warning, traffic runway, traffic arrival/departure state)*
- Distance to traffic (range)*
- Time (sec) to collision or closest point of approach (range tau)*
- Bearing
- Traffic air or ground
- Relative altitude (if airborne)
- Traffic climb/descend (if airborne)
- Time (sec) to co-altitude (vertical tau) (if airborne)

5.6 TCM

In taxi scenarios, the traffic may be an aircraft or a surface vehicle. In this discussion, the term "vehicle" refers to both aircraft and surface vehicles.

5.6.1 Data Accuracy

A high degree of data accuracy is necessary because of the very close distance and time tolerances involved in surface conflict situations and the greater likelihood of nuisance alerting. The criteria and threshold tables in the next section indicate the accommodations TCM makes for variations in data accuracy.

Ground speed accuracy can be problematic since reported ground speed can be incorrect by more than one knot, and a stationary vehicle may report a non-zero ground speed. Therefore, TCM allows for a discrepancy of up to two knots for reported ground speed.

Specific data accuracy requirements are yet to be determined.

5.6.2 Monitoring and Alert Criteria

Since TCM is designed to operate only when the ownship is on the ground, the monitoring and alert criteria and associated thresholds must be optimized for much closer tolerances than for airborne operations. The thresholds must be set to allow sufficient lead times to prevent collisions but minimize or eliminate over-alerting.

For TCM criteria which specify a distance threshold, the distance is measured differently from RSM and LACM, due to the closer proximity between vehicles and the need for greater precision. Distance for TCM is measured from the vehicle exterior instead of from the aircraft CG. For example, if ownship is following traffic, the distance between vehicles is measured from the ownship nose to the traffic tail.

Table 2 lists the monitoring criteria, alert criteria and thresholds that have been determined based on developmental and simulation testing [Jones et al., 2009 and Jones et al., 2010]. These criteria are applied in a three-step process.

5.6.2.1 Step 1 – General Criteria

In Step 1, monitoring criteria determine what traffic is monitored for conflicts, and alert criteria determine if and which alerts to issue. The threshold values for monitoring and alerts are contained in software configuration files and can be modified as required based on future testing. For a caution or warning to be issued, all criteria for Step 1 (see Table 2) must be satisfied. The threshold modification factors listed in Table 3 are secondary criteria that modify the standard thresholds to prevent nuisance alerting and alert toggling (alerts on and off or switching between caution and warning).

In Table 2, special treatment is given to the minimum separation threshold for cautions. The standard value for this threshold is 50 feet, but a larger value may be used, depending on vehicle size. If either the ownship radius or the traffic radius is greater than 50 feet, the radius of the larger vehicle is used for minimum separation. For example, if ownship is a B757 with a body radius of 77.4 feet, and the target is a DC3 with a body radius of 32.5 feet, then 77.4 feet would be the threshold value. Vehicle size is not used to determine the minimum separation threshold for warnings, which has a standard value of 30 feet.

5.6.2.2 Step 2 – Following Criteria

If Step 1 does not issue an alert, then Step 2 is applied. Step 2 has a single criterion, which is only applied if one vehicle is following the other.

The goal of this step is to calculate a safe separation distance for the following vehicle, so that an alert may be issued if separation is not adequate. This distance threshold is calculated using the following vehicle's ground speed and body length.

The criterion in Table 2, "Ground speed per body length of separation", specifies the ground speed at which the distance threshold is equal to one body length of separation. This criterion is abbreviated `bodyLengthKnots`. The default values are 8 knots for a caution, and 11 knots for a warning.

If ground speed is greater than `bodyLengthKnots`, then the required separation is proportionally larger than one body length. If ground speed is less than `bodyLengthKnots`, then the required separation is proportionally less than one body length. The formula is below:

```
(groundSpeed / bodyLengthKnots) * bodyLength = separationThreshold
```

Table 2. Initial TCM Alert Criteria and Thresholds

Monitoring Criteria					
Target proximity < 1500 ft from ownship position. Either ownship or target speed must be > 5 kts. (No alert if both stopped or both < 5 kts)					
	Standard Thresholds*			Modified Thresholds	
Alert Criteria – Step 1	Caution	WA +	Threshold Modification Factors	CA+	WA +
Range tau (sec)	18	10	one stopped	12	7
			slower taxi	16	7
			same Direction	12	7
			Turning	12	7
			Following	10	7
			head-on	18	10
			turning head-on	no limit	10
Current distance to target (range) < min alert distance (ft)	700	400	one stopped AND slower taxi	150	150
			turning AND in path	150	150
			head-on	900	600
Projected separation at CPA < min separation (ft) OR Current distance to target (range) < min separation (ft)	Maximum: 50, or ownship radius, or target radius	30	one stopped AND slower taxi	15	15
			not one stopped AND slower taxi AND same Direction AND in path	10	10
			slower taxi AND range tau = 0	20	20
			one stopped OR slower taxi	40	30
			WA in progress	60	45
			CA in progress	60	30
Alert Criteria – Step 2			Threshold Modification Factors	CA	WA
Ground speed per body length of separation (kts) (use body length of vehicle that is following)			Following	8	11
Alert Criteria – Step 3				CA	WA
Current distance to target (range) = very close (ft)				<10	0

* Standard thresholds are used when no threshold modification factors apply.
\+ CA = caution WA = warning

Table 3. Initial TCM Threshold Modification Factors

Threshold Modification Factors	Description
One stopped	At least one vehicle is stopped or moving < 2 kts.
Slower taxi	Both vehicles are taxiing < 15.5 kts. (One can be stopped.)
Same direction	Both vehicles are moving in the same direction within ±50° of heading.
Turning	One or both vehicles is/are turning with turn rate > 4°/sec.
Following	One vehicle is following the other and neither is stopped.
In path	One of the vehicles is in the path of the other, and neither is stopped
Head-on	Both vehicles are in each other's paths within ±15°.
Turning head-on	Ownship is turning with turn rate > 4°/sec, and turn is projected to cause head-on conflict, with paths within ±15°. Condition has lasted for at least 5 seconds. Traffic may be stopped or moving.

For example, if ownship is a B757, body length 154.8 feet, taxiing behind a DC3 at 15 knots, then the separation threshold to trigger a caution is:

```
(15 / 8) * 154.8 = 290.25 feet
```

The separation threshold to trigger a warning is:

```
(15 / 11) * 154.8 = 211.09 feet
```

So a caution is triggered if ownship follows within 290.25 feet of the traffic, and a warning is triggered if ownship follows within 211.09 feet.

If ownship was in front and the traffic was following, the DC3 body length of 65.0 feet would be used, instead of 154.8 feet, and traffic ground speed would be used instead of 15 knots.

5.6.2.3 Step 3 – Close Traffic Criteria

If neither Step 1 nor Step 2 issues an alert, then Step 3 is applied. If the two vehicles are within 10 feet of each other, but do not otherwise prompt alerts, a caution is issued.

5.6.3 Alert Data Output

The parameters that are output for the TCM caution and warning depend on the cockpit alerting display (aural and graphical) requirements for NextGen. The future alert display requirements are unknown at this time, but a list of parameters can be constructed based on previous RIPS alert output. The following is a list of initial parameters that is subject to change based on future testing and requirements. Alert parameters previously used for RIPS are identified with asterisks.

- Traffic ID (e.g., ICAO aircraft address)*
- Alert code (type alert caution/warning, traffic runway and traffic arrival/departure state if applicable)*
- Distance to traffic (range)*
- Time (sec) to collision or closest point of approach (range tau)*
- Bearing

6 Initial Description of ATCAM Resolution Advisories

The need or efficacy of Resolution Advisories (RA) for an aircraft-based CD&R system for ATMA operations has not been firmly established by research. To conduct this research, RA implementations have been created as outlined in this section. Various means are being used to validate this concept, such as qualitative pilot evaluation, automated simulation, and piloted simulation. Limited testing of the efficacy of recommending avoidance maneuvers has been performed but conclusive results have not been achieved.

6.1 Resolution Advisories

When ATCAM determines that a conflict has occurred, either a warning, indicating that ownship must take avoidance action, or a less severe caution, or both, are issued. When ATCAM issues a warning, an RA may also be issued, indicating the maneuver that should be performed by ownship to deconflict a possible collision or incursion. Currently, ATCAM determines the resolution maneuver based on the conflict scenario. Navigational data, such as turning angle or climb rate, may accompany the RA, depending on the scenario.

If ATCAM issues multiple warnings, an RA is only issued based on the first alert. ATCAM currently does not consider the second conflict when determining the RA. Similarly, ATCAM currently does not perform any coordinated resolutions with the traffic like TCAS (i.e., it does not project whether the resolution maneuver will create a new conflict with other traffic or if the resolution maneuvers being performed by each vehicle might in fact conflict).

6.2 RSM RAs

This section outlines the approach taken for runway conflict RAs, in RSM.

6.2.1 RSM Avoidance Maneuvers

Table 4 lists the avoidance maneuvers that ATCAM currently defines for runway conflicts. RSM RAs only indicate a recommended maneuver, and do not provide navigational guidance.

Table 4. RSM Avoidance Maneuvers

Avoidance Maneuver	Description
No Resolution Available	No viable resolution found, leave resolution to pilot discretion
Go Around	Terminate approach and climb away
Touchdown Emergency Stop	Expedite landing, decelerate quickly
Reject Takeoff	Abort takeoff, stop
Emergency Stop	Stop immediately (severe slowdown may suffice)
Exit/Clear Runway	Proceed immediately to nearest runway exit

6.2.2 RSM Maneuver Selection

When RSM issues a warning, avoidance maneuvers are considered as shown in Table 5, for each ownship/traffic combination. These maneuvers are usually considered in the order shown.

RSM considers a maneuver by projecting whether or not it will prevent the possible collision. If so, that maneuver is used for the RA, and no other maneuvers will be considered. If not, other maneuvers in the list will be considered. If none of the candidate maneuvers is projected to prevent the collision, RSM issues a 'No Resolution Available' maneuver.

Table 5. RSM Scenario Resolutions

Ownship State	Traffic State *	Single Runway Avoidance Maneuvers	Intersecting Runway Avoidance Maneuvers
taxi	taxi	NA	NA
	takeoff roll	Emergency Stop Exit/Clear Runway	NA
	climb-out	Emergency Stop Exit/Clear Runway	NA
	approach	Emergency Stop Exit/Clear Runway	NA
	rollout	Emergency Stop Exit/Clear Runway	NA
	fly-thru	NA	NA
pre-takeoff	taxi	Reject Takeoff Exit/Clear Runway	NA
	takeoff roll	Reject Takeoff Exit/Clear Runway	Reject Takeoff
	climb-out	Reject Takeoff Exit/Clear Runway	Reject Takeoff
	approach	Reject Takeoff Exit/Clear Runway	Reject Takeoff
	rollout	Reject Takeoff Exit/Clear Runway	Reject Takeoff
	fly-thru	Reject Takeoff	NA
takeoff roll	taxi	Reject Takeoff Exit/Clear Runway	NA
	takeoff roll	Reject Takeoff Exit/Clear Runway	Reject Takeoff
	climb-out	Reject Takeoff Exit/Clear Runway	Reject Takeoff
	approach	Reject Takeoff Exit/Clear Runway	Reject Takeoff
	rollout	Reject Takeoff Exit/Clear Runway	Reject Takeoff
	fly-thru	Reject Takeoff	NA
approach	taxi	Go Around Touchdown Emergency Stop	NA
	takeoff roll	Go Around Touchdown Emergency Stop	Touchdown Emergency Stop
	climb-out	Go Around Touchdown Emergency Stop	Touchdown Emergency Stop
	approach	Go Around	Go Around Touchdown Emergency Stop
	rollout	Go Around Touchdown Emergency Stop	Go Around Touchdown Emergency Stop
	fly-thru	Touchdown Emergency Stop Go Around	NA
rollout	taxi	Emergency Stop Exit/Clear Runway	NA
	takeoff roll	Emergency Stop Exit/Clear Runway	Emergency Stop
	climb-out	Emergency Stop Exit/Clear Runway	Emergency Stop
	approach	Emergency Stop Exit/Clear Runway	Emergency Stop
	rollout	Emergency Stop Exit/Clear Runway	Emergency Stop
	fly-thru	Emergency Stop	NA

* Pre-takeoff state is not currently defined for traffic. 'NA' indicates no alert will be issued, so no resolution is necessary.

Different methods are used to forecast the results of the various maneuvers. ‘Go Around’ is forecast by simulating a climb at 480 ft per minute by ownship, and projecting ownship and traffic positions into the future, one second at a time, until time to conflict is 0 seconds. At any one-second interval projection, if the conflict is found to no longer exist, then ‘Go Around’ is considered to be a successful maneuver. On the other hand, if the conflict exists until ownship passes the projected point of conflict, then the ‘Go Around’ maneuver is considered to fail.

The maneuvers ‘Emergency Stop’, ‘Touchdown Emergency Stop’, and ‘Reject Takeoff’ are forecast by first calculating whether ownship can stop in time to prevent a collision, and then calculating whether a conflict will exist once ownship has stopped. If ownship can stop in time and no conflict will exist afterward, the maneuver is considered to be successful; otherwise, it is considered to fail. Stopping distance for ‘Touchdown Emergency Stop’ and ‘Reject Takeoff’ is calculated using a deceleration rate of -8 kts per second per second. For ‘Emergency Stop’, a deceleration rate of -5 kts per second per second is used.

The maneuver ‘Exit/Clear Runway’ is actually not forecast at all, but is issued as a default second choice in some scenarios. If the maneuver of first choice fails, then ‘Exit/Clear Runway’ will be used. This maneuver is discussed more below, under “Runway Exits”.

6.2.3 RSM Unresolved Scenarios

As shown in Table 6, all scenarios in which ownship is in climb out or fly through states are assigned ‘No Resolution Available’.

Table 6. RSM Unresolved Scenarios

Ownship State	Traffic State	Single Runway Avoidance Maneuvers	Intersecting Runway Avoidance Maneuvers
climb-out	taxi	No Resolution Available	NA
	takeoff roll	No Resolution Available	No Resolution Available
	climb-out	No Resolution Available	No Resolution Available
	approach	No Resolution Available	No Resolution Available
	rollout	No Resolution Available	No Resolution Available
	fly-thru	No Resolution Available	NA
fly-thru	taxi	NA	NA
	takeoff roll	No Resolution Available	NA
	climb-out	No Resolution Available	NA
	approach	No Resolution Available	NA
	rollout	No Resolution Available	NA
	fly-thru	NA	NA

6.2.4 Runway Exits

RSM currently does not maintain data on runway exit locations, so the ‘Exit/Clear Runway’ maneuver requires clarification. There is no way of discerning whether ownship can reach the nearest exit in time to escape a conflict situation. However, if ownship is on the runway and the other viable maneuvers, such as ‘Emergency Stop’ or ‘Reject Takeoff’ do not avoid the conflict, ownship must get out of the way somehow, if a true conflict (i.e., not a false alarm or nuisance alert) is confirmed.

The current interpretation of ‘Exit/Clear Runway’, then, is that the pilot must determine the most appropriate location to exit or clear the runway. If reaching a runway exit is not feasible, then the pilot should look for another way to get off of the runway, or to move to the side of the runway as far as practical. RSM performs no calculation to predict the success of ‘Exit/Clear Runway’.

A similar issue exists for TCM, when exiting seems a viable maneuver for a taxiing ownship. TCM’s approach to this issue is described later, in Section 6.4.4, Taxiway Exits.

6.3 LACM RAs

This section outlines the approach taken for low altitude conflict RAs, in LACM.

6.3.1 LACM Avoidance Maneuvers

As shown in Table 7, LACM avoidance maneuvers are composed of three separate dimensions: vertical, horizontal, and acceleration maneuvers. Navigational guidance can be provided for each dimension.

In theory, it is possible for an LACM RA to combine maneuvers from multiple dimensions. For example, a single maneuver may involve a vertical climb and a right turn, while accelerating. In practice, though, all of the currently-supported maneuvers only involve a single dimension.

Table 7. LACM Avoidance Maneuver Combinations

Avoidance Maneuver	Navigational Data	Description
V:*H*:*A*	*v*:*h*:*a*	Perform a combination of: • Vertical maneuver *V*, with navigational data *v*, • Horizontal maneuver *H*, with navigational data *h*, and • Acceleration maneuver *A*, with navigational data *a*.
No Resolution Available		No viable resolution found, leave resolution to pilot discretion

6.3.1.1 LACM Vertical Maneuvers

Table 8 lists the vertical avoidance maneuvers that ATCAM defines for low altitude conflicts. LACM RAs indicate a recommended vertical maneuver, coupled with navigational guidance which is the required vertical rate in feet per minute.

Table 8. LACM Vertical Avoidance Maneuvers

Avoidance Maneuver (*V*)	Navigational Data (*v* fpm)			Description
	Min	Max	Step	
No Change				Maintain current vertical trajectory
Climb	500	4400	100	Climb at a rate of *v* feet per minute.
Reduce Climb	1	1	0	Reduce rate of climb to *v* feet per minute. (Currently used only to implement 'Level Off'.)

If the vertical maneuver is 'No Change', the avoidance maneuver does not have a vertical dimension.

Navigational Data is listed as a range, because LACM attempts to find the least disruptive maneuver which will avert the conflict. LACM first attempts a maneuver using the minimum navigational value listed under 'Min'. If that maneuver does not avert the conflict, LACM adds the value under 'Step' to the navigational value, and tries again, and keeps incrementing the navigational value by 'Step' until it is determined that the conflict is averted. The successful value is then included in the RA. If the navigational value reaches the maximum value 'Max' without averting the conflict, then the maneuver fails.

The ‘Climb’ maneuver is implemented by first trying a climb at 500 feet per minute. If this climb does not avert the conflict, then LACM tries a climb at 600 feet per minute, then 700 feet per minute, and so on, until a navigational value is found, or until 4,400 feet per minute is tried. LACM chooses this maximum climb rate of 4,400 feet per minute because TCAS also uses that maximum value. However, smaller aircraft are not able to climb at such a high rate. ATCAM may be adapted in future version to make such navigational data configurable, according to aircraft type.

‘Reduce Climb’ is currently used only to implement a maneuver identical to ‘Level Off’. It was meant specifically to address a takeoff scenario in which traffic was too high to climb over, and turning was not effective. The maneuver directs the pilot to fly under the traffic. Further testing is needed to determine the viability of this maneuver.

A climb rate of 1 foot per minute is used for ‘Reduce Climb’, instead of 0 feet per minute. This value is used because the LACM code internally assumes that a climb rate of 0 indicates that no vertical maneuver is intended, and 1 foot per minute is nearly level.

6.3.1.2 LACM Horizontal Maneuvers

Table 9 lists the horizontal avoidance maneuvers that ATCAM defines for low altitude conflicts. LACM RAs indicate a recommended horizontal maneuver, coupled with navigational guidance which is the angle in degrees by which to turn.

Table 9. LACM Horizontal Avoidance Maneuvers

Avoidance Maneuver (*H*)	Navigational Data (*h* degrees)			Description
	Min	Max	Step	
No Change				Maintain current horizontal trajectory.
Bear Right	10	60	10	Bear to the right by *h* degrees.
Bear Left	-10	60	-10	Bear to the left by *h* degrees.

If the horizontal maneuver is ‘No Change’, the avoidance maneuver does not have a horizontal dimension.

Navigational Data is listed as a range, and LACM steps through horizontal navigational values in the same way it steps through vertical navigational values.

For example, the ‘Bear Right’ maneuver is implemented by first trying a right turn of 10 degrees. If this turn does not avert the conflict, then LACM tries a right turn of 20 degrees, then 30 degrees, and so on, until a navigational value is found, or until 60 degrees is tried. ‘Bear Left’ is implemented in the same fashion.

***6.3.1.3* LACM Acceleration Maneuvers**

Acceleration avoidance maneuvers are currently not implemented (Table 10). More analysis is needed to determine how maneuvers such as reduce and increase speed can realistically be recommended. Acceleration maneuvers would seem to be more dependent on the capabilities of the individual aircraft than vertical or horizontal maneuvers.

Table 10. LACM Acceleration Avoidance Maneuvers

Avoidance Maneuver (*A*)	Navigational Data (*a*)	Description
No Acceleration Maneuver		Maintain current velocity.

6.3.2 LACM Maneuver Selection

When LACM issues a warning, avoidance maneuvers are considered in the order below. If the first maneuver fails, the second is tried, and so on, until the end of the list.

- 'Vertical Climb', determining the climb rate as described above.
- 'Level Off'/'Reduce Climb' maneuver.*
- 'Bear Right', determining the turn angle as described above.
- 'Bear Left', determining the turn angle as described above.
- 'No Resolution Available'.

* If 'Level Off' is successful, LACM actually issues a 'Reduce Climb' RA, with a climb rate of 1 fpm.

LACM considers a maneuver by forecasting whether or not it will prevent the possible collision. Each maneuver is forecast by simulating vertical or horizontal movement by ownship, and projecting ownship and traffic positions into the future, one second at a time. If, at any one-second interval, the conflict is found to no longer exist, then the maneuver is considered to be successful. On the other hand, if the conflict exists until ownship passes the point of conflict, then the maneuver is considered to fail.

6.4 TCM RAs

This section outlines the approach taken for taxi conflict RAs, in TCM.

6.4.1 TCM Avoidance Maneuvers

Table 11 lists the avoidance maneuvers that ATCAM defines for taxi conflicts. TCM RAs only indicate a recommended maneuver, and do not provide navigational guidance.

Table 11. TCM Avoidance Maneuvers

Avoidance Maneuver	Description
No Resolution Available	No viable resolution found, leave resolution to pilot discretion
Emergency Stop	Stop immediately (severe slowdown may suffice)
Slow Down	Reduce taxi speed
Speed Up	Increase taxi speed

6.4.2 TCM Maneuver Selection

When TCM issues a warning, avoidance maneuvers are considered in the order below. If the first maneuver fails, the second is tried, and so on, until the end of the list.

- 'Slow Down'
- 'Emergency Stop'
- 'Speed Up'
- 'No Resolution Available'.

TCM considers a maneuver by forecasting whether or not it will prevent the possible collision. Each maneuver is forecast by simulating acceleration or deceleration by ownship, and projecting ownship and traffic positions into the future, one second at a time. If, at any one-second interval, the conflict is found to no longer exist, then the maneuver is considered to be successful. On the other hand, if the conflict exists until ownship passes the point of conflict, then the maneuver is considered to fail.

6.4.3 TCM Unresolved Scenarios

TCM currently assigns ‘No Resolution Available’ for head-on conflicts, in which ownship and traffic are moving in opposite directions toward each other. None of the currently-supported maneuvers allow ownship to move out of the way of traffic in this scenario.

6.4.4 Taxiway Exits

TCM currently does not maintain data on taxiway locations. If ownship is on a taxiway, TCM has no way of discerning whether ownship can reach the nearest taxiway intersection in time to escape a conflict situation. In a large gate area or a wide taxiway intersection, ownship has more flexibility, but TCM cannot exploit this flexibility without taxiway or gate knowledge.

A similar issue exists for RSM, when exiting the runway is the only viable maneuver. RSM does not maintain runway exit data, but still uses the ‘Exit/Clear Runway’. An ‘Exit Taxiway’ maneuver could be considered for TCM. Currently, though, ‘No Resolution Available’ is used in such scenarios. Taxi speeds are slower, so split-second reaction is less critical, and 'Exit' sometimes makes less sense while taxiing, for example in gate areas.

If, in the future, taxiway data and taxi routing information are added to ATCAM, then a 'Turn Right' and 'Turn Left' maneuver could be added which specifies which taxiway to turn onto. With such additional data, ATCAM would be able to confidently project whether ownship can reach the next intersection in time, whether the intersecting taxiway is already occupied by other traffic, or whether any traffic is approaching that taxiway.

6.5 Pilot Reaction Delays

To realistically forecast the potential success of a candidate avoidance maneuver, ATCAM includes an estimated pilot reaction delay. A pilot does not respond to an alert instantaneously. Some time is taken to notice and understand the alert and decide on a response, before undertaking avoidance action. If ATCAM were to assume immediate action, the pilot may not be able to perform the recommended maneuver in time to avoid the conflict as predicted.

ATCAM estimates pilot delay periods as listed in Table 12. The values were obtained from averaging pilot reaction data from previous flight and simulation studies. Pilot delays are not listed for RSM operational states climb-out and fly-thru, since RAs are currently not issued when ownship is in those states.

Table 12. Estimated Pilot Delays

Algorithm	Operational State	Pilot Delay (seconds)
RSM	approach	5
RSM	rollout	3
RSM	taxi	2
RSM	pre-takeoff	2
RSM	takeoff roll	2
LACM		3
TCM		2

If an alert is not already in progress when a warning alert is issued, ATCAM calculates that ownship will continue on its current trajectory during the pilot delay period, before ownship performs the maneuver. For example, if ownship is on approach, ATCAM calculates whether a Go Around will work by projecting that ownship will continue its approach for five seconds, and will then begin the Go Around climb.

If an RA is already in progress from a previous warning alert and a new warning alert is issued, ATCAM attempts to use the avoidance maneuver from the alert already in progress to resolve the latest conflict. In this case, ATCAM does not consider the pilot delay to decide whether the maneuver can still avoid the conflict, since the pilot delay has already been accounted for in the initial calculation.

7 Summary

NASA is conducting research to enable safe airport operations for both current and future NextGen operations. Aircraft-based conflict detection and alerting algorithms (known as the Airport Traffic Collision Avoidance Monitor (ATCAM)) are being developed to detect potential traffic conflicts in the terminal area and generate indications and alerts that can be displayed to the pilot.

ATCAM is comprised of three separate but integrated algorithms that operate at low altitudes near the airport, on the runway, and during taxi and ramp operations for multiple classes of aircraft as well as surface vehicles. The Runway Safety Monitor (RSM) detects runway incursion conflicts and generates indications and alerts that provide the flight crew with sufficient awareness to take action to avoid a collision. RSM has been under development and testing for many years and has proven to be effective in reducing all types of runway incursions and eliminating the most severe incursions. The Low Altitude Conflict Monitor (LACM) detects and alerts for air-to-air conflicts at low altitudes near the airport without conflicting with TCAS. The Taxi Conflict Monitor (TCM) detects and alerts for ground taxi conflicts anywhere in the airport movement and ramp areas. LACM and TCM are in development; however, initial testing has proved to be very promising for elimination of collisions in these operating areas. The technical approaches for each of these algorithms are presented in this report along with the data communications that are necessary for successful implementation and integration.

Work is currently in progress to test and refine the algorithms as part of NextGen research. This work is also being closely coordinated with other NASA research in emerging NextGen technologies including synthetic and enhanced vision systems and 4D surface operations. On-going surface safety research also includes determination of the feasibility and development of requirements for conflict resolution advisories.

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Appendix A – RSM Operational States

The ownship (O) and traffic (T) operational states used by RSM are defined as follows:

taxi state:	Aircraft/vehicles taxiing or stopped and stationary obstacles or equipment.
pre-takeoff state:	Ownship positioned for takeoff but before or at the beginning of takeoff roll. (This state is not available for traffic.)
takeoff roll state:	Ground takeoff roll in progress, not airborne.
climb-out state:	Airborne climb out after takeoff roll or after an aborted landing.
approach state:	Airborne on final approach.
rollout state:	Ground roll out after landing or after an aborted takeoff.
fly-thru state:	Flying through or crossing the RI zone but not landing or taking off. Includes turning from the runway heading during departure climb out or go-around

The operational states are determined using the criteria described in the tables below. Table A1 describes the criteria used to determine ownship operational states, supplemented by the ownship takeoff mode criteria described in Table A2. Table A3 describes the criteria used to determine traffic operational states. Table A4 details how the criteria from Tables A1 and A3 are used to define each operational state.

The threshold parameters listed in these tables are customizable via configuration files. The ownship parameters can be configured differently for each type of ownship aircraft, while the traffic parameters are applied generically to all traffic aircraft. The threshold values listed under "Default Thresholds" should be considered examples, and can be adjusted as necessary. The general aviation thresholds under "GA" are untested estimates, and are expected to be refined based on future simulation and flight testing.

Table A1. Ownship Operational State Criteria & Default Thresholds

Operational State Criteria – Ownship			
		Default Threshold	
Code	Description *	GA**	Non-GA
A	Altitude above ground level (ft) <= 0	NA	NA
B	All wheels on the ground (true/false)	NA	NA
C	Ground speed <= **taxi high speed (knots)**	20	40
D	Aircraft is on the runway	NA	NA
E	True heading differs from runway zone true heading <= **heading tolerance (degrees)**	10	10
F	In takeoff mode (true/false), from Table A2: F1 or (F2 and F7) or ((F3 or F4) and F5) or (C and F8) or ((not C) and F6)	NA	NA
G	Vertical speed > **minimum climb-out vertical speed (ft/min)**	60	60
H	Distance from ownship position to end of runway >= **approximate land rollout distance for type of landing (ft)** (able to stop before end of runway)	2000	6000

* Text in **bold** indicates parameters specified under "Default Threshold".
****** GA thresholds have not been verified through testing.

Table A2. Ownship Takeoff Mode Criteria & Default Thresholds

Takeoff Mode Criteria – Ownship			
		Default Threshold	
Code	Description *	GA**	Non-GA
F1	EPR mode set (true/false)	NA	NA
F2	Auto throttle engaged (true/false)	NA	NA
F3	Throttle position >= **takeoff throttle position (degrees)**(non-GA)	-	90
F4	Throttle position is at full forward GA	NA	-
F5	Track acceleration > 0.0G	NA	NA
F6	Track acceleration >= 0.1G	NA	NA
F7	Track acceleration > 0.1G	NA	NA
F8	Track acceleration >= **takeoff acceleration (G)**	0.2	0.2

Table A3. Traffic Operational State Criteria & Default Thresholds

Operational State Criteria – Traffic			
		Default Threshold	
Code	Description *	GA**	Non-GA
I	Altitude above ground level (ft) <= 0	NA	NA
J	Aircraft is on the runway	NA	NA
K	True heading differs from runway zone true heading <= **heading tolerance (degrees)**	10	10
L	Ground speed <= **taxi high speed (knots)**	20	40
M	Ground speed >= **taxi low speed (knots)**	4	4
N	Ground speed > **minimum start takeoff speed for traffic (knots)**	15	15
O	Acceleration >= **minimum start takeoff acceleration for traffic (knots/sec)**	3	3
P	Acceleration > **minimum takeoff acceleration for traffic (knots/sec)**	0.1	0.1
Q	Vertical speed > **minimum climb-out vertical speed for traffic (ft/min)**	60	60
R	Distance from traffic position to end of runway >= **maximum traffic rollout distance (ft)** (able to stop before end of runway)	2000	6000

Table A4. Operational State Definitions

Operational State	Ownship Criteria	Traffic Criteria
taxi/stationary (on or near runway)	A and B and C and ((not D) or (not E) or (not F))	I and L and M and J and K and ((not N) or (not O))
		I and L and M and ((not J) or (not K))
		I and L and (not M)
	A and B and (not C) and ((not D) or (not E))	I and (not L) and ((not J) or (not K))
pre-takeoff	A and B and C and D and E and F	NA
takeoff roll	A and B and (not C) and D and E and F	I and L and M and J and K and N and O
		I and (not L) and J and K and P
climb-out	((not A) or (not B)) and E and G	(not L) and K and Q
	((not A) or (not B)) and E and (not G) and (not H)	(not L) and K and (not Q) and (not R)
approach	((not A) or (not B)) and E and (not G) and H	(not L) and K and (not Q) and R
rollout	A and B and (not C) and D and E and (not F)	I and (not L) and J and K and (not P)
fly-thru RI zone	((not A) or (not B)) and (not E)	(not L) and (not K)

Appendix B – RSM Scenarios and Alert Criteria

This appendix describes in detail the scenarios, alert criteria, and thresholds used by RSM to issue caution alerts and warning alerts (see Sections 3.1.1 and 3.1.2). The alert criteria and default thresholds are listed separately for conflicts on single runways (Table B1) and conflicts on intersecting runways or intersecting flight paths (Table B2). An intersecting flight path occurs when runway incursion (RI) zones intersect before or beyond the runway boundary (see Section 3.3). The default thresholds for alert criteria are implemented as parameters that are contained in software configuration files. The default values for warning thresholds were determined through simulation and flight testing, but can be modified as required based on future research. The default values for caution thresholds have undergone simulation evaluation, but are subject to change based on future research and testing. Previous testing [Jones, 2002 and Jones and Prinzel, 2006] revealed that cautions were only effective/desirable when the ownship was in the approach state, or when the ownship was in position and hold and the traffic was approaching the same runway. Therefore, cautions are only implemented for two types of scenarios: (i) ownship state is approach, or (ii) ownship state is taxi or pre-takeoff, and traffic state is approach.

For RSM criteria which specify a distance threshold, the distance is measured from the aircraft center of gravity (CG). Distance between ownship and traffic is measured from the ownship CG to the traffic CG.

The tables B3 – B9 define the scenarios for each combination of ownship and traffic states for both single and intersecting runway/flight path conditions and list the alert criteria associated with each scenario from the appropriate criteria table (B1 or B2). RSM detects and issues alerts for runway conflicts only when both the ownship aircraft and traffic are inside RI zones and below the zone altitude. For single runway scenarios, traffic is defined as other aircraft, vehicles, obstacles or equipment inside the same RI zone as the ownship aircraft. For intersecting zone scenarios, traffic is defined as other aircraft departing, arriving, or taxiing inside the RI zone that intersects the ownship RI zone. Traffic position and other traffic data must be available via data link to the ownship aircraft (see Section 4.2).

Table B1. Alert Criteria & Default Thresholds for Single Runway Scenarios

Alert Criteria – Single Runway Scenarios (Assumes Ownship and Traffic are inside the same runway incursion zone)					
		Default Threshold			
		GA		Non-GA	
Code	Description *	CA**	WA+	CA**	WA+
A	Alert immediately at any distance	NA	NA	NA	NA
B	O/T < **minimum horizontal separation threshold (ft)**	6000	4500	8000	6000
C	O/T < **close horizontal separation (ft)** (**lower separation threshold** for some scenarios)	**	700	**	700
D	Distance from runway threshold of aircraft taxiing or stopped on runway is < approximate land rollout distance for type of landing aircraft (ft)	2000	2000	6000	6000
E	Aircraft rolling out not able to stop before aircraft taxiing or stopped on runway	**	NA	**	NA
Fa	Ownship distance to runway threshold or traffic position < **airborne approach alert distance (ft)** (airborne alert distance based on approximate ownship landing speed, e.g., B-757 4400 ft for warning, 8000 ft for caution)	Per own landing speed	Per own landing speed	Per own landing speed	Per own landing speed
Fc	Ownship distance to runway threshold or traffic position < **airborne climb-out alert distance (ft)** (airborne alert distance based on approximate ownship climbing speed, e.g., B-757 6000 ft for warning, 8000 ft for caution)	Per own landing speed	Per own landing speed	Per own landing speed	Per own landing speed
G	Stationary aircraft time to exit runway < **alert time threshold (sec)**	NA	30	NA	30
H	Ownship distance to traffic position < **2.0 times the minimum horizontal separation threshold (ft)** (increased horizontal separation required for some scenarios)	12000	9000	16000	12000
I	Arriving aircraft past the runway threshold	NA	NA	NA	NA
J	O/T current or projected closest altitude separation < **minimum air-to-air altitude separation (ft)**	1000	850	1000	850
K	O/T current or projected closest vertical separation < **minimum air-to-ground vertical separation** when one aircraft is on the ground **(ft)**	**	400	**	400

* Text in **bold** indicates parameters specified under "Default Threshold".

****** Caution alert (CA) thresholds will only be applied for single runway scenarios of taxi/approach, pre-takeoff/approach, or any ownship approach scenario.

\+ WA = warning alert

Table B2. Alert Criteria & Default Thresholds for Intersecting Runway/Flight Path Scenario

Alert Criteria – Intersecting Runway and Flight Path Scenarios (Assumes Ownship and Traffic are inside intersecting RI zones and not past the zone intersection)					
Code	Description *	Default Threshold			
		GA		Non-GA	
		CA**	WA+	CA**	WA+
L	Alert immediately at any distance	NA	NA	NA	NA
M	Current O/T difference in separation from intersection is < **min separation threshold (ft)**	6000	4500	8000	6000
N	Current O/T difference in separation from intersection is **< 0.5 times the min separation (ft)**	3000	2250	4000	3000
O	Projected O/T closest separation at the intersection is < **minimum separation threshold (ft)**	6000	4500	8000	6000
P	Projected O/T closest separation at the intersection is < **0.5 times the min separation (ft)**	3000	2250	4000	3000
Qa	Ownship distance to runway threshold < **airborne approach alert distance (ft)** (airborne alert distance based on approximate ownship landing speed, e.g., B-757 4400 ft for warning, 8000 ft for caution)	Per own landing speed	Per own landing speed	Per own landing speed	Per own landing speed
Ra	Ownship distance to intersection < **airborne approach alert distance (ft)** (airborne alert distance based on approximate ownship landing speed, e.g., B-757 4400 ft for warning, 8000 ft for caution)	Per own landing speed	Per own landing speed	Per own landing speed	Per own landing speed
Rc	Ownship distance to intersection < **airborne climb-out distance (ft)** (airborne alert distance based on approximate ownship climbing speed, e.g., B-757 6000 ft for warning, 8000 ft for caution)	Per own landing speed	Per own landing speed	Per own landing speed	Per own landing speed
S	Distance from touchdown to intersection for landing aircraft is < **approximate land rollout distance for type aircraft (ft)**	2000	2000	6000	6000
T	Aircraft rolling out is not able to stop before intersection	NA	NA	NA	NA
U	Aircraft rolling out is < **close distance to the intersection (ft)**	700	700	700	700
V	O/T current or projected closest air-to-air altitude separation is < **minimum airborne altitude separation threshold (ft)**	1000	850	1000	850
W	O/T current or projected closest air-to-ground vertical separation is < **minimum air-ground separation threshold (ft)**	400	400	400	400
X	O/T current or projected difference in separation from intersection is < **close distance to the intersection (ft)**	700	700	700	700
Y	O/T current or projected difference in separation from intersection is < **1.5 times the close distance to the intersection (ft)**	1050	1050	1050	1050

* Text in **bold** indicates parameters specified under "Default Threshold".

****** Caution alert (CA) thresholds will only be applied for intersecting runway scenarios in which the ownship state is approach.

\+ WA = warning alert

Table B3. Scenario Conditions and Alert Criteria - Ownship in Taxi State

Ownship (O) State – Taxi On or Near Runway (Inside RI zone)				
	Single Runway		Intersecting Runways and RI Zones	
Traffic (T) State	Scenario Conditions	Alert Criteria	Scenario Conditions	Alert Criteria
taxi/stationary	Disabled for RSM scenarios (Taxi conflicts are monitored by TCM)	—	Not defined for ownship taxi scenarios	—
pre-takeoff	NA (Traffic pre-takeoff state not avail in current version)	—	—	—
takeoff roll	O in path of T and closing	A	—	—
climb-out	O Taxi / T Closing O Stationary / T Closing	B and K K	—	—
approach	O/T Closing	(B or G) and D (warning) D (caution)*	—	—
rollout	O/T Closing	(E or C)	—	—
fly-thru RI zone	Not defined; alerts not issued	—	—	—

* Criteria B and G are not applied for cautions in this scenario.

Table B4. Scenario Conditions and Alert Criteria - Ownship in Pre-takeoff State

Ownship (O) State – Pre-takeoff				
	Single Runway		Intersecting Runways and RI Zones	
Traffic (T) State	Scenario Conditions	Alert Criteria	Scenario Conditions	Alert Criteria
taxi/stationary	T in path of O	A	Not defined for traffic taxi scenarios	—
pre-takeoff	NA (Traffic pre-takeoff state not avail in current version)	—	—	—
takeoff roll	T in path of O	A	Intersect before end of O runway	L
	T behind O and closing	A	Intersect beyond end of O runway	N or O
climb-out	O/T same heading & runway	B and K	All conditions	W and (N or O)
	O/T head-on, opposite runways	K		
approach	O/T same heading & runway and T behind O	B or G (warning) A (caution)*	Intersect before end of O runway	S
	O/T same heading & runway and T in path of O	B (warning)*	Intersect beyond end of O runway	—
	O/T head-on, opposite runways	B or G (warning) A (caution)*		
rollout	T in path of O	A	Intersect before end of O runway	T or ((not T) and U)
	T behind O and closing	B	Intersect beyond end of O runway	—
fly-thru RI zone	Closing or T in path of O	C and K	Not defined for traffic fly-thru scenarios	—

* Criteria B and G are not applied for cautions in this scenario.

Table B5. Scenario Conditions and Alert Criteria - Ownship in Takeoff roll State

Ownship (O) State – Takeoff roll				
Traffic (T) State	Single Runway		Intersecting Runways and RI Zones	
	Scenario Conditions	Alert Criteria	Scenario Conditions	Alert Criteria
taxi/stationary (on or near runway)	T in path of O and closing	A	Not defined for traffic taxi scenarios	—
pre-takeoff	NA (Traffic pre-takeoff state not avail in current version)	—	—	—
takeoff roll	O/T same heading & runway	B	O able to abort takeoff and intersect before end of O runway	L
			O able to abort takeoff and intersect beyond end of O runway	N or P
	O/T head-on, opposite runways	A	O not able to abort takeoff	X
climb-out	O/T same heading & runway	B	O able to abort takeoff	M or O
	O/T head-on, opposite runways	A	O not able to abort takeoff	X
approach	O/T same heading & runway and T behind O	B	O able to abort takeoff and intersect before end of O runway	S
	O/T same heading & runway and T in path of O	A	O not able to abort takeoff and intersect before end of O runway	S and Y
	O/T head-on, opposite runways	A	Intersect beyond end of O runway	—
rollout	O/T same heading & runway and T in path of O	A	O able to abort takeoff and intersect before end of O runway	T or ((not T) and U)
	O/T same heading & runway and T behind O and closing	B	O not able to abort takeoff and intersect before end of O runway	(T and Y) or ((not T) and U)
	O/T head-on, opposite runways	A	Intersect beyond end of O runway	—
fly-thru RI zone	Closing or T in path of O	C and K	Not defined for traffic fly-thru scenarios	—

Table B6. Scenario Conditions and Alert Criteria - Ownship in Climb-out State

Ownship (O) State – Climb-out				
	Single Runway		Intersecting Runways and RI Zones	
Traffic (T) State	Scenario Conditions	Alert Criteria	Scenario Conditions	Alert Criteria
taxi/stationary	O/T closing	K and Fc	Not defined for traffic taxi scenarios	—
pre-takeoff	NA (Traffic pre-takeoff state not avail in current version)	—	—	—
takeoff roll	O/T same heading & runway	B	All conditions	W and Rc and (N or P)
	O/T head-on, opposite runways	A		
climb-out	O/T same heading & runway	B	All conditions	Rc and (N or P)
	O/T head-on, opposite runways	(I or H)		
approach	O/T same heading & runway	B	All conditions	V and S and Rc and (N or P)
	O/T head-on, opposite runways	J and (I or H)		
rollout	O/T same heading & runway and T in path of O	K and B	All conditions	W and (N or P) and Rc and (T or U)
	O/T same heading & runway and T behind O and closing	K and B		
	O/T head-on, opposite runways	K and (I or B)		
fly-thru RI zone	O/T closing or T in path of O	B	Not defined for traffic fly-thru scenarios	—

Table B7. Scenario Conditions and Alert Criteria - Ownship in Approach State

Ownship (O) State – Approach				
	Single Runway		Intersecting Runways and RI Zones	
Traffic (T) State	Scenario Conditions	Alert Criteria	Scenario Conditions	Alert Criteria
taxi/stationary	Closing	D and Fa	Not defined for traffic taxi scenarios	—
pre-takeoff	NA (Traffic pre-takeoff state not avail in current version)	—	—	—
takeoff roll	O/T same heading & runway	B	All conditions	S and (N or P) and (Qa or Ra)
	O/T head-on, opposite runways	A		
climb-out	O/T same heading & runway	B	All conditions	S and V and P and (Qa or Ra)
	O/T head-on, opposite runways	J and (H or I)		
approach	O/T same heading & runway	B	All conditions	S and (N or P) and (Qa or Ra)
	O/T head-on, opposite runways	(H or I)		
rollout	O/T same heading & runway	B	All conditions	S and (T or U) and (Qa or Ra)
	O/T head-on, opposite runways	A		
fly-thru RI zone	O/T closing or T in path of O	B	Not defined for traffic fly-thru scenarios	—

Table B8. Scenario Conditions and Alert Criteria - Ownship in Rollout State

Ownship (O) State – Rollout				
	Single Runway		Intersecting Runways and RI Zones	
Traffic (T) State	Scenario Conditions	Alert Criteria	Scenario Conditions	Alert Criteria
taxi/stationary	O/T closing	E or C	Not defined for traffic taxi scenarios	—
pre-takeoff	NA (Traffic pre-takeoff state not avail in current version)	—	—	—
takeoff roll	O/T same heading & runway and T ahead of O	B	All conditions	(T or U)
	O/T same heading & runway and T behind O	A		
	O/T head-on and opposite runways	A		
climb-out	O/T same heading & runway and T behind O	K and B	All conditions	W and (M or O) and (T or U)
	O/T same heading & runway and T ahead of O	K and B		
	O/T head-on, opposite runways	K and (I or B)		
approach	O/T same heading & runway (T behind or ahead)	B	All conditions	S and (T or U)
	O/T head-on, opposite runways	A		
rollout	O/T same heading & runway	B	All conditions	(T or U)
	O/T head-on, opposite runways	A		
fly-thru RI zone	O/T closing or T in path of O	C and K	Not defined for traffic fly-thru scenarios	—

Table B9. Scenario Conditions and Alert Criteria - Ownship in Fly-thru RI Zone State

Ownship (O) State – Fly-thru RI Zone				
	Single Runway		Intersecting Runways and RI Zones	
Traffic (T) State	Scenario Conditions	Alert Criteria	Scenario Conditions	Alert Criteria
taxi/stationary	Incursion scenario not defined; alerts not issued	—	Not defined for ownship fly-thru scenarios	—
pre-takeoff	NA (Traffic pre-takeoff state not avail in current version)	—	—	—
takeoff roll	Closing or O in T path	C and K	—	—
climb-out	Closing or O in T path	B	—	—
approach	Closing or O in T path	B	—	—
rollout	Closing or O in T path	C and K	—	—
fly-thru RI zone	Incursion scenario not defined; alerts not issued	—	—	—

Appendix C – RSM Scenarios and SURF IA Indication Criteria

In parallel with CAAT, the RTCA SC-186 WG1 subcommittee for surface indication and alerting (SURF IA) has defined criteria to determine whether a potential conflict exists between an ownship and traffic aircraft [RTCA, 2010b]. SURF IA is only concerned with runway scenarios, and is not relevant to low altitude or taxi scenarios. Similar to CAAT, SURF IA identifies operational states for each aircraft. Resembling CAAT, for each possible combination of ownship state and traffic state, SURF IA defines a set of criteria to determine whether an alert should be issued. SURF IA also classifies alerts to be either Cautions or Warnings, as does ATCAM. SURF IA defines alerts for "non-normal operational situations where collision hazard exists or a collision appears imminent". ATCAM does not implement alerts as defined by SURF IA, but instead uses the RSM algorithm defined previously.

In addition to alerts, SURF IA also specifies indications, which are defined for "normal operational situations where collision hazard exists". In other words, indications are less serious than alerts. SURF IA classifies indications to be either Traffic Indications (TI) or Runway Status Indications (RSI).

RSM has been extended to implement SURF IA indications. RSM operational states are converted into SURF IA states, as defined in Table A-1 of reference RTCA 2010b. This conversion is described in Table C1 below. RSM will issue indications prior to alerts if the criteria in Table A-2 of reference RTCA 2010b are met. However, alerts have priority over indications and will be issued instead of indications if the alert criteria is met.

Table C1. ATCAM-to-SURF IA State Mapping

ATCAM States	Mapping Conditions	SURF IA States
hold short*	Stopped outside RI zone within 500 ft. of centerline, facing runway	I. Taxiing on taxiway toward hold line or stopped at hold line
	Taxiing outside RI zone beyond look-ahead distance, within 500 ft. of centerline, facing runway	
taxi/stationary	Outside RI zone, within look-ahead distance	I. Taxiing on taxiway toward hold line or stopped at hold line
	Inside RI zone, heading differs from runway heading by more than 10 degrees	II. Entering / Crossing / Exiting
	Inside RI zone, heading within 10 degrees of runway heading	VI. Stopped or taxiing along runway
pre-takeoff		VI. Stopped or taxiing along runway
takeoff roll		III. Takeoff
climb-out		0. Unknown
approach		IV. Approach
rollout		V. After Landing
fly-thru		0. Unknown

* *Hold short* is a new RSM state, created to support SURF IA state I. A new state is necessary because RSM currently does not consider stationary aircraft at the hold line to be traffic; but such aircraft are candidates for indications. This state is only relevant when determining indications, and does not affect alert calculations.

RSM can be expected to issue indications according to SURF IA specifications, except in the following cases:

- If RSM issues an alert for a case in which SURF IA does not issue an alert, then RSM will not issue any SURF IA indications, because the alert takes precedence.
- RSM will not classify an aircraft to be in approach state until it reaches the extended runway zone, and will not issue indications for that aircraft outside the extended zone. SURF IA defines the approach state to begin within three nautical miles, once the aircraft descends below one thousand feet. Consequently, SURF IA may issue approach indications earlier than RSM.

Appendix D – Flight Data Requirements

This appendix lists the flight data that is currently used by the ATCAM software. Table D1 lists the ownship data, while Table D2 lists the traffic data. Note that the throttle position or power lever angle is assumed to be available to indicate forward thrust (with thrust reverser data available as well) for a ‘commercial transport aircraft’ (i.e., “non-GA”), whereas for general aviation aircraft, the throttle position ranging between 0 (full closed) and 1 (full open) is used to imply forward thrust (i.e., “GA”).

Table D1. Ownship Data Parameters

DESCRIPTION	BINARY RANGE	UNITS	POSITIVE REFERENCE	MINIMUM UPDATE RATE
Update counter		NA	Always positive	10 HZ
Standard time in GMT	0 to 86,400	Sec	Seconds from midnight	10 HZ
Scaled GPS/INS blended latitude	+/-90	Deg	North from 0	10 HZ
Scaled GPS/INS blended long	+/-180	Deg	East from 0	10 HZ
GPS/INS blended altitude-feet MSL	+/-32,768	Feet	Above touchdown	10 HZ
Geoid separation corrected hybrid GPS altitude	+/-32,768	Feet	Above touchdown	10 HZ
Corrected barometric altitude - 4 sources	+/-32,768	Feet	Above sea level	10 HZ
Radar altitude	+/-32,768	Feet	Above touchdown	10 HZ
Ground speed	0 - 4096	Knots	Always positive	10 HZ
Vertical speed	+/-19,384	Ft/Min	Up	10 HZ
True heading	+/-180	Deg	CW from North	10 HZ
Yaw rate	+/-128	Deg/Sec	Nose right	10 HZ
Track angle (true)	+/-180	Deg	CW from North	10 HZ
Along track acceleration	+/-4	G's	Forward	10 HZ
Throttle position/power lever angle – left (non-GA)	+/-180	Deg	Forward thrust	10 HZ
Throttle position/power lever angle – right (non-GA)	+/-180	Deg	Forward thrust	10 HZ
Throttle position (GA)	Discrete	NA	1 = Full open	10 HZ
Reverser isolation valves	Discrete	NA	1=Reverse thrust	10 HZ
Air ground discrete	Discrete	NA	1=Main gear on ground	10 HZ
Nose wheel squat	Discrete	NA	1=Nose wheel on ground	10 HZ
Go around discrete	Discrete	NA	1=Go around engaged	10 HZ
Auto-throttle engaged	Discrete	NA	1=Engaged	10 HZ
Decision speed	0-512	Knots	Always positive	10 HZ
GPS hybrid position status	Discretes	NA	0=Good	10 HZ

Table D2. Traffic Data Parameters

DESCRIPTION	BINARY RANGE	UNITS	POSITIVE REFERENCE	UPDATE RATE
# Traffic/intruders	0-64	NA	Always positive	1-2 HZ
Traffic update counter		NA	Always positive	1-2 HZ
24 bit ICAO address or unique intruder id	0-32	NA	NA	1-2 HZ
Intruder flight or tail number	Character field	NA	NA	1-2 HZ
A/C category (A380, B757, etc.)	0-7	NA	NA	1-2 HZ
A/C type (if known)	Character field	NA	NA	1-2 HZ
Latitude	+/-90	Deg	North from 0	1-2 HZ
Longitude	+/-180	Deg	East from 0	1-2 HZ
Altitude MSL	+/-32,768	Feet	Above mean sea level	1-2 HZ
Radar altimeter	+/-32,768	Feet	Above touchdown	1-2 HZ
Ground speed	0-32,768	Knots	Always positive	1-2 HZ
True track (airborne) or heading (on ground)	+/-180	Deg	CW from North	1-2 HZ
Vertical speed	+/-19,384	Ft/Min	Up	1-2 HZ
Track acceleration	+/-4	G’s	Forward	1-2 HZ
Slant range		NM	Always positive	1-2 HZ
Bearing	+/-180	Deg	CW from ownship	1-2 HZ
Relative altitude	+/-32768	Feet	Above ownship	1-2 HZ
Traffic acquisition in msec GMT	0 to 86,400,000	Msec	Always positive	1-2 HZ

Appendix E – Surveillance Discussion

E.1 Surveillance Performance

Requirements for ground-based surveillance systems have been proposed. As mentioned above, ICAO proposed operational requirements for A-SMGCS, which includes surveillance performance requirements [ICAO, 1997]. A prototype A-SMGCS architecture was evaluated during a flight test at the Atlanta Hartsfield International Airport [Jones and Young, 1998] and observed performance was compared against the A-SMGCS requirements [Young, 1998].

More recently, the European Organization for Civil Aviation Equipment (EUROCAE) has proposed surveillance performance requirements for a Level 2 A-SMGCS that will be expected to monitor the airport surface and provide alerts to users when hazardous situations occur, such as runway incursions [EUROCAE, 2007]. These requirements are listed in Table E1.

The FAA is in the process of deploying ADS-B throughout the NAS. A final rule [FAA, 2010] has been enacted to specify ADS-B Out performance requirements necessary to support ATC service. Although the FAA is not mandating ADS-B In at this time, the final rule includes a discussion of potential ADS-B In applications and accuracy requirements. The Notice of Proposed Rulemaking (NPRM) [FAA, 2007] had proposed that a horizontal accuracy of 30 meters (98.4 feet) and a vertical accuracy of 45 meters (147.6 feet) would be sufficient to enable certain applications on the airport surface, such as traffic alerting, however, the final rule only requires a horizontal accuracy of 0.05 nm (92.6 meters or 303.8 feet) and has removed the vertical accuracy and integrity requirement. The RTCA SC-186 WG1 subcommittee for surface indication and alerting (SURF IA) has conducted analyses and requires a minimum of a Navigation Accuracy Category position (NACp) of 9 for the SURF IA application [RTCA, 2010b] (see Table E2), which corresponds to the position accuracy proposed in the NPRM. Unfortunately, the final rule requires position accuracy of traffic data corresponding to a NACp of 8, which may be insufficient for CD&R applications. More analysis is needed to determine whether these proposed accuracies are really sufficient for conflict detection.

Table E1. EUROCAE A-SMGCS Surveillance Performance Requirements

Performance Parameter	Level 2 System Requirement
Probability of target detection	≥ 99.9% on maneuvering area ≥ 98% on apron
Probability of false target detection	≤ 10^{-3} per report
Probability of identification	≥ 99.9% on maneuvering area ≥ 98% on apron
Probability of false identification	≤ 10^{-3} per report
Reported position accuracy	≤ 7.5 meters (95%) on maneuvering area ≤12 meters (95%) on apron
Reported velocity accuracy	Speed < 5 meters/second, Direction – consistent with use in alerting algorithms
Target report update rate	At least 1 per second
Position renewal time out period	< 4 seconds
Identification renewal time out period	< 20 seconds
Track continuity	≥ 99.8% on maneuvering area ≥ 98% on apron
Target report position resolution	≤1 meter
Target report velocity resolution	≤0.25 meter/second
Target report time resolution	≤ 0.1 second

Table E2. SURF IA Surveillance Performance Requirements

Performance Parameter	Requirement
Traffic horizontal position accuracy	Distance from runway Shoulder to hold line (m) NACp 20 – 25 11 30 – 60 10 65 – 100 9 95% containment radius
Ownship and traffic geometric altitude	45m, 95%
Ownship and traffic velocity	10 m per second
Vehicle horizontal position accuracy	10 m, 95% containment
Ownship and traffic integrity level	Indication – 1 x 10-4 per hour Caution - 1 x 10-4 per hour Warning - 1 x 10-5 per hour

E.2 Intent Data

ADS-B provides a minimal set of data for airport traffic. Historically, the RSM algorithm has had good results in computing traffic states, utilizing the currently available data from ADS-B, however, knowledge of traffic intent could potentially provide a more accurate assessment of traffic state and result in more precise conflict detection with reduced missed, and nuisance alerts. Some intent data currently specified for ADS-B involve intent to change trajectory at a particular position. However, the type of intent data that may improve the performance of the conflict detection function in the ATMA is related to operations on or near the airport surface.

Ownship states can be computed accurately because the data to indicate "intent" to takeoff, "intent" to land, etc., is available from the ship's flight computers. Some examples of these data sources might include:

- *Takeoff intent* - on the runway, lined up with runway heading and Engine Pressure Ratio (EPR) button or Auto-throttle button pushed, throttle position.

- *Intent to land* – Auto-land engaged, lined up with runway and descending, ILS tuned and aircraft following localizer and glideslope, landing configuration and airspeed.

However, these intent data are not available for traffic. With the increase in capacity envisioned by NextGen, traffic will be more densely spaced making the need for knowledge of traffic intent even more critical.

The following traffic intent data/information could potentially enable more effective, timely, and error free CD&R in the ATMA. More analysis is necessary to determine the potential benefits of utilizing this data/information.

- *Takeoff mode* – Determining when traffic is actually taking off can currently be determined by monitoring ground speed. Knowing that the pilot has taken the runway and has engaged the EPR mode or Auto throttle mode, for example, would indicate takeoff intent as well as knowing throttle position (advanced full forward) in lesser equipped aircraft.

- *Go Around mode* – Knowing when traffic is aborting a landing can currently be determined by noting that the aircraft is climbing and accelerating. A more timely means would be to transmit when the go around is initiated (go around button pressed or throttles advanced and aircraft configured for climbing).

- *Rejected Takeoff mode* – Knowing when an aircraft aborts takeoff can eventually be determined by observing the traffic's greatly reduced speed and either stopping on or exiting the runway. The ability to know if the power goes to idle (throttle position), brakes are pressed and/or thrust reversers are used could result in a more effective means of determining if a rejected takeoff occurred.

- *Land and Hold Short Operations (LAHSO)* – Knowing intent to follow LAHSO operations at airports like ORD might prevent nuisance runway incursion alerts in an intersecting runway situation. The logic would be similar to the rejected takeoff criteria above for determining intent to stop. Knowledge of intent to LAHSO could be obtained via pilot entry or, in the absence of such an entry, via broadcast of ATC instructions (see below).

- *Termination of taxi* – Knowing that the traffic that *could* become a conflict is aware and braking might allow the CD&R algorithms to delay alerting to prevent nuisance alerts in cases where the errant traffic's nose barely passed the hold short line or the errant traffic could stop before becoming dangerously close to another aircraft on the surface.

- *Air-ground* – Knowing whether traffic is in the air or on the ground is critical for ATMA CD&R. Airborne ADS-B messages are needed for runway and low altitude CD&R because the message contains altitude data. When an aircraft is determined to be on the ground, ADS-B transmissions will contain surface message content (with no altitude data) instead of airborne message content. If surface ADS-B messages are transmitted prematurely, runway and low altitude CD&R could be affected. Since surface position messages are transmitted less frequently than airborne position messages, valuable position data required when the aircraft is indeed airborne with a rapid closure rate is unavailable, possibly leading to an avoidable collision. It is not clear that the current method of switching between airborne and surface ADS-B messages will be sufficient for ATMA CD&R. Aircraft with air-ground detection would switch at the proper time. All others would switch based on the presence or absence of airspeed, ground speed, and radar altitude which will either cause an early or delayed switch between airborne position messages and surface position messages. Knowing precisely when traffic is on the ground based on weight on wheels or nose wheel squat could potentially resolve this ambiguity.

- *Air Traffic Control Instructions* – Knowledge of other traffic's clearances (e.g., "cleared for takeoff", cleared to land", "land and hold short") for operations in the ATMA could potentially increase safety and prevent conflicts and collisions through awareness of the intentions of other traffic. Awareness of traffic's intended taxi path and hold short clearances may also reduce conflicts at taxiway and runway intersections. Taxi awareness and conflict prevention/detection can be further refined in the NextGen environment with knowledge of traffic's 4-D taxi path and required times of arrival at intersections.

E.3 ADS-B Altitude Data

An area of concern for CD&R in the ATMA is the granularity of all ADS-B reported altitudes. The source for ADS-B altitude is currently either Global Navigation Satellite System (GNSS) or barometric altitude reported to the nearest 100 feet or 25 feet [RTCA, 2009]. These accuracies are sufficient for aircraft that are airborne and not near the surface (above 1000 feet AGL). However, since altitude changes rapidly during takeoff and departure, these accuracies may not be good enough for the current implementation of an algorithm such as ATMA CD&R. The current implementation uses three separate algorithms with very different capabilities operating to cover all flight realms and altitude is a key trigger for switching between the algorithms. This issue has not, at this time, been rigorously evaluated.

Sources of error for barometric altitude reporting include instrument calibration, rounding altitude to the nearest 25 ± 12.5 feet or 100 feet ± 50 feet, and incorrect barometric pressure setting. An incorrect setting of 0.5 inches Mercury could cause the altitude report to be 500 feet higher or lower than the actual barometric altitude. GNSS position data also has the greatest error in its vertical measurements, i.e., the height above the ellipsoid. As a result, aircraft could be mistaken for being on the ground while airborne or vice versa, which could cause CD&R algorithms, such as ATCAM, to incorrectly determine the traffic operational states. (See Section 5.4.4***)***. Further testing is needed to determine the effects of altitude variance on CD&R algorithms, and in what ways algorithms need to account for such variance.

ADS-B altitude accuracy could be improved if radio altitude were used in lieu of GNSS or barometric altitude when the aircraft is within 1000 feet of the airport surface. Many radar altitudes provide radio altitude accuracy to within 2 feet. (Unfortunately, radar altitude is not required on most aircraft.) Barometric and GNSS altitudes are encoded to the nearest 25 feet or 100 feet within the airborne position message format to conserve the number of bits utilized in data transmission while still providing suitable altitude accuracy at the higher altitudes. Since the range of values for the radio altitude are capped, usually to 2500 feet, the space allocated within the ADS-B airborne message format can represent the radio altitude to the nearest foot. Using radio altitude in lieu of GNSS or barometric altitude to represent a much more accurate value for altitude AGL, would enable ATMA CD&R algorithms to make more accurate aircraft state decisions.

Another area of concern is the transition between ADS-B airborne and surface messages (see previous section). Radio altitude is used as the criteria to switch between airborne and surface messages. Aircraft with a radio altitude of 50 feet or less are considered to be on the ground when ground speed is 100 knots or less [RTCA, 2009]. Since ADS-B surface position messages do not include altitude, the transition to surface messages at 50 feet AGL or greater due to the errors mentioned above would cause the loss of altitude reports before touchdown, which could cause nuisance CD&R alerts. Using alternate criteria, such as weight-on-wheels or nose wheel squat for those aircraft that provide that information, would ensure the switch to surface position message transmission would occur when the aircraft is on the ground.

Further research is needed to determine the effect of ADS-B altitude accuracy and surface message reporting on ATMA CD&R.

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14. ABSTRACT
The Next Generation Air Transportation System (NextGen) concept for 2025 envisions the movement of large numbers of people and goods in a safe, efficient, and reliable manner. The NextGen will remove many of the constraints in the current air transportation system, support a wider range of operations, and deliver an overall system capacity up to 3 times that of current operating levels. In order to achieve the NextGen vision, research is necessary in the areas of surface traffic optimization, maximum runway capacity, reduced runway occupancy time, simultaneous single runway operations, and terminal area conflict prevention, among others. The National Aeronautics and Space Administration (NASA) is conducting Collision Avoidance for Airport Traffic (CAAT) research to develop technologies, data, and guidelines to enable Conflict Detection and Resolution (CD&R) in the Airport Terminal Maneuvering Area (ATMA) under current and emerging NextGen operating concepts. The term ATMA was created to reflect the fact that the CD&R concept area of operation is focused near the airport within the terminal maneuvering area. In this report, an initial concept for an aircraft-based method for CD&R in the ATMA is presented. This method is based upon previous NASA work in CD&R for runway incursion prevention, the Runway Incursion Prevention System (RIPS).

15. SUBJECT TERMS
Air traffic; Air transportation; Collision avoidance; Runway incursions; Runways

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