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

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March 2009

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# Acronyms

| | |
|---|---|
| ACSS | Aviation Communication & Surveillance Systems |
| 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 |
| ATL | Atlanta Hartsfield International Airport |
| ATMA | Airport Terminal Maneuvering Area |
| CA | Conflict Advisory |
| CAAT | Collision Avoidance for Airport Traffic |
| CD&R | Conflict Detection & Resolution |
| ConOps | Concept of Operations |
| CPA | Closest Point of Approach |
| CPDLC | Controller-Pilot Data Link Communications |
| DFW | Dallas-Ft. Worth International Airport |
| 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 |
| 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 |
| RSM | Runway Safety Monitor |
| RTCA | Radio Technical Commission for Aeronautics |
| RWSL | Runway Status Lights |
| TA | Traffic Advisory |
| TCAS | Traffic Alert and Collision Avoidance System |
| TCM | Taxi Conflict Monitor |
| TIS-B | Traffic Information Service-Broadcast |
| WAL | Wallops Flight Facility |
| 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. 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). CAAT research is conducted jointly under NASA's Airspace Systems Program, Airportal Project and the Aviation Safety Program, Integrated Intelligent Flight Deck Project.*


# 1 Introduction

By 2025, U.S. air traffic is predicted to increase 3-fold, 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 June 2007] and a research and development plan [JPDO August 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 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 August 2007].

This paper presents an initial 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 alerts and possibly resolution advisories for display to the pilot. Note that in this paper, conflict is defined as a condition that can lead to a collision if no avoidance action is taken.

# 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 September 2007], 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 2007]. In the four year period between 2003 and 2006, 1,306 runway incursion events were reported, which is a rate of almost 1 runway incursion event per day [FAA September 2007]. 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]. Current FAA initiatives include a combination of technology, infrastructure, procedural, and training interventions [FAA September 2007]. 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, there is not a system available (either ground or aircraft-based) that directly provides pilots with alerts of potential runway conflicts with other traffic. However, some flight deck incursion awareness systems are available, including:

- Honeywell International Inc. has developed an aircraft-based Runway Awareness and Advisory System (RAAS) [Honeywell 2006]. RAAS uses 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 (ACSS), 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.

### 2.2 Low Altitude Air-to-Air Conflicts

In today's operations, the principal airborne method of CD&R for separation assurance 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 15 years and has been very effective in reducing or eliminating airborne collisions. This system has limitations in the vicinity of airports and TCAS alerts are inhibited at low altitudes. Resolution Advisories (RAs) are not issued below 1000 feet Above Ground Level (AGL) and audible Traffic Advisories (TAs) 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].

A new RTCA committee (SC-218, Future ADS-B/TCAS Relationships) is being established to assess the relationship between ADS-B and TCAS from 2020 to 2025 and is expected to further develop concepts for interoperation between ADS-B and TCAS [RTCA 2008].

### 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 June 2007]. This move toward 4-D surface operations pushes the CD&R need beyond the runway and must include all 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]. Research is yet to be conducted to determine the safety impacts of following 4-D taxi clearances. It is anticipated that the pilot may be so focused on following 4-D clearances to meet scheduled arrival times that unintentional taxi conflicts 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 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 alerts and possibly resolution advisories that can be displayed to the pilot 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 and ramp operations for multiple classes 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 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.
3. The *Taxi Conflict Monitor* (TCM) is designed to detect and alert for ground taxi conflicts anywhere in the airport movement and ramp areas.

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 testing, however, LACM and TCM are in the initial development stage and have not been fully tested. The ATCAM algorithms are being developed for NASA by Lockheed Martin.

Figure 1 is a high level flow chart depicting the process for ATCAM conflict detection including coordination and prioritization of alerts in the event of multiple 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 alerts, then outputting the 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 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.

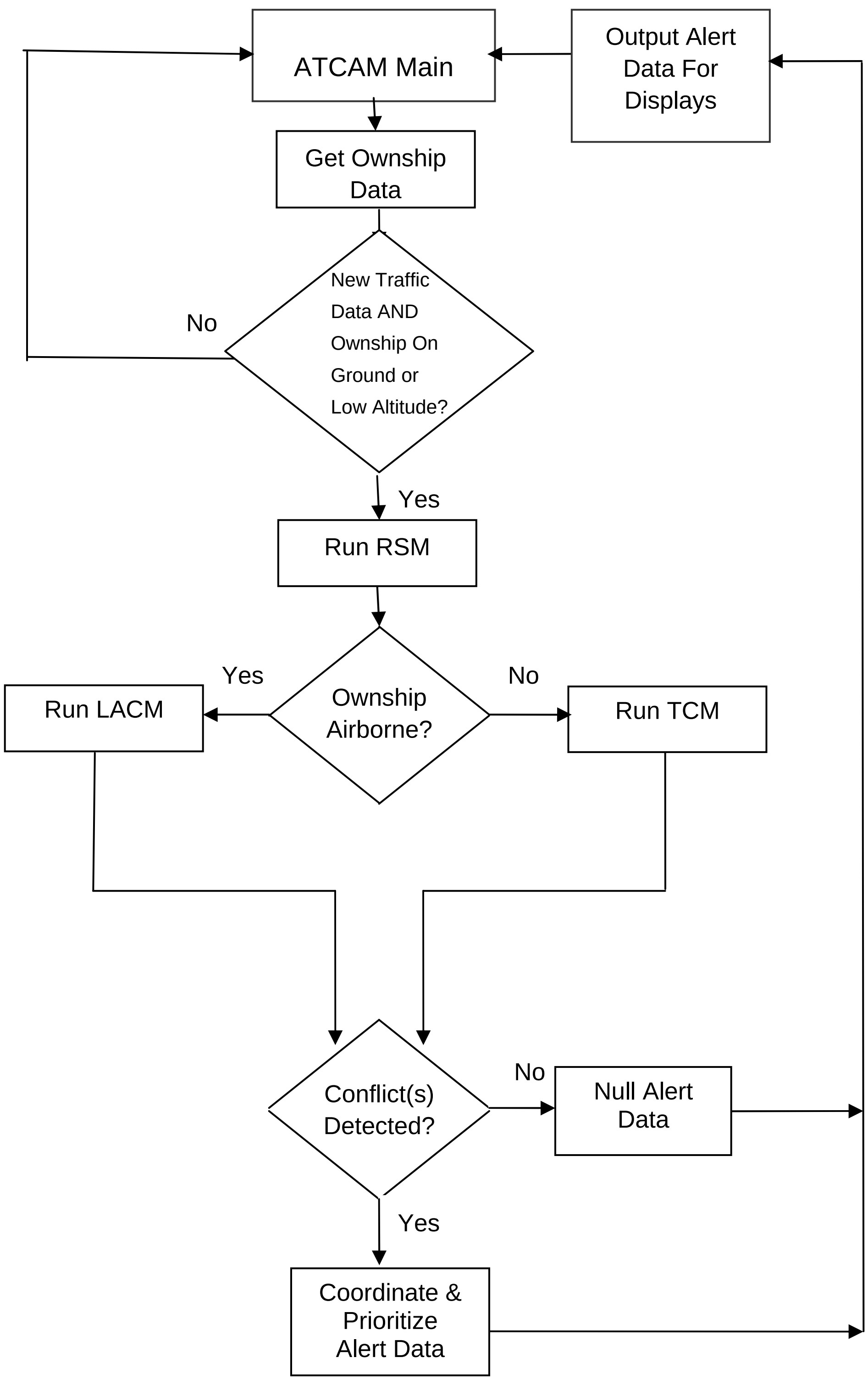



Figure 1. ATCAM High Level Flow Diagram

## 3.1 Alert Definitions

A government/industry subcommittee (RTCA Special Committee (SC) 186, Working Group (WG) 1) is in the process of developing an application description for aircraft-based surface alerting, focusing on runway safety. This subcommittee has adopted the definition of alerts as specified in [FAA 2007], 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. *Cautions* alert 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. *Warnings* alert for conditions that require immediate flight crew awareness and immediate flight crew response. An auditory signal and the red color are associated with Warnings.

All ATCAM algorithms use a common concept and naming convention for alerts that is based on the convention used by TCAS and RTCA SC-186 WG1 definitions. The criteria and thresholds used for the ATCAM alerts are defined in Sections 5.4, 5.5, and 5.6.

The alert terminology used by ATCAM is as follows:

### *3.1.1 Traffic Advisories (TA)*

A TA is a cautionary alert that provides immediate awareness of other traffic that may cause an unsafe or a hazardous situation. In the initial design, TAs 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 TAs for these types of operations will be determined based on test and evaluation. Evasive maneuvers are not required and resolution instructions are not given when a TA 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 TA is issued for taxi operations, evasive action such as slowing down or stopping may be done to prevent the situation from progressing to the point a conflict advisory is warranted.

### *3.1.2 Conflict Advisories (CA)*

A CA is a warning that there is a high probability of collision or near collision with other traffic and, therefore, evasive action should be initiated. The specific maneuver taken (e.g., go-around, abort takeoff, stop taxi, etc.) is at the pilot's discretion. CAs 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 not issued in the initial version of ATCAM. Further research is required, and currently in progress, to determine the feasibility of providing RAs in conjunction with CAs to effectively resolve conflict situations without producing undesired consequences. For example, what evasive 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 Runway Safety Monitor (RSM)

RSM monitors data for the ownship aircraft and other aircraft, obstacles, or vehicles and predicts potential incursions/collisions and alerts the pilot in anticipation to avoid the 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 software-derived three-dimensional virtual zone that overlays a runway and the approach area (see Section 5.4.2). The width of the zone extends a constant distance from both sides of the runway, and the length of the zone extends a constant distance from both thresholds of the runway. The zone altitude extends vertically a constant altitude above the runway surface. Figure 2 shows a two-dimensional plan view of the RI zones at the Wallops Flight Facility (WAL). RSM monitors for conflicts/incursions only when the ownship is inside a RI zone and below the zone altitude, and traffic is inside the same zone as the ownship or in an intersecting zone.

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 a conflict advisory will be issued. More detail is provided in Section 5.4 and Appendices A and B.

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

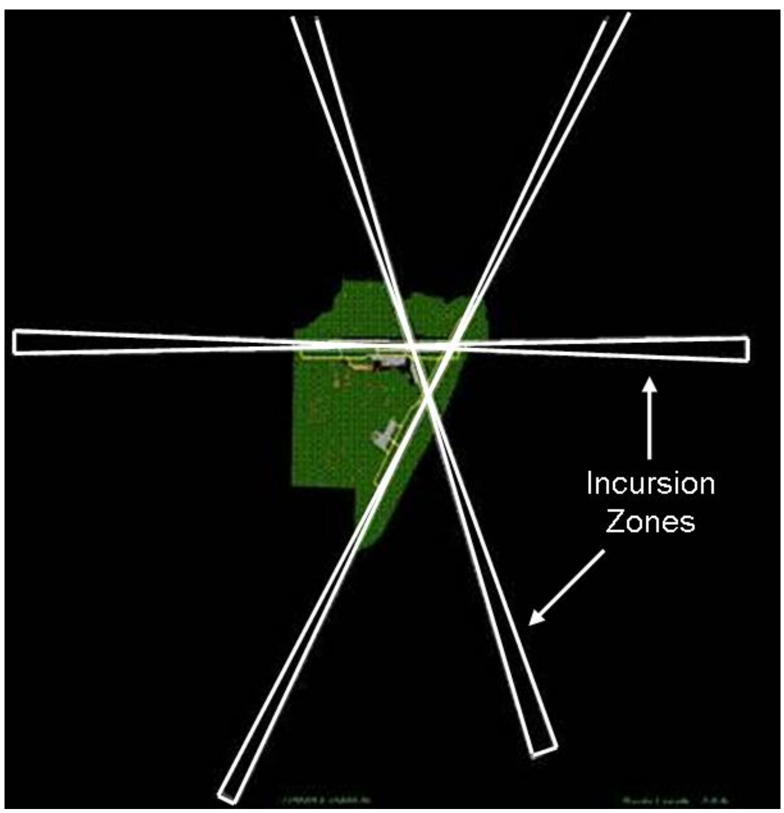



Figure 2. Runway Incursion Zones at Wallops Flight Facility

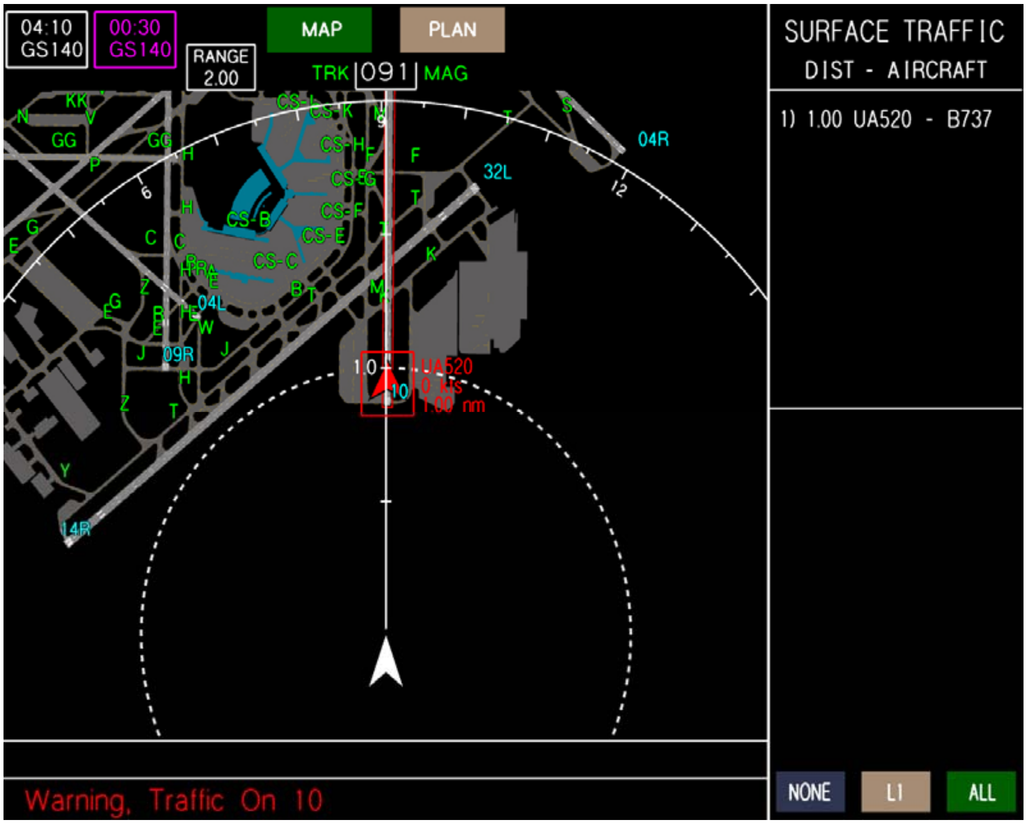
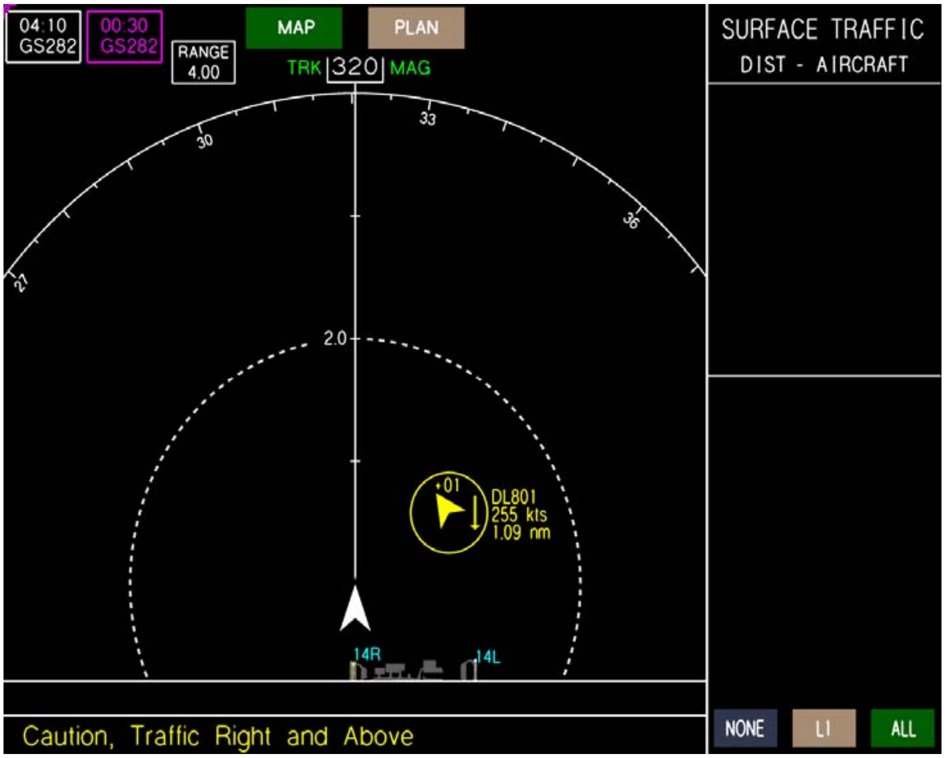



Figure 3. Airport Map Display showing Runway Incursion

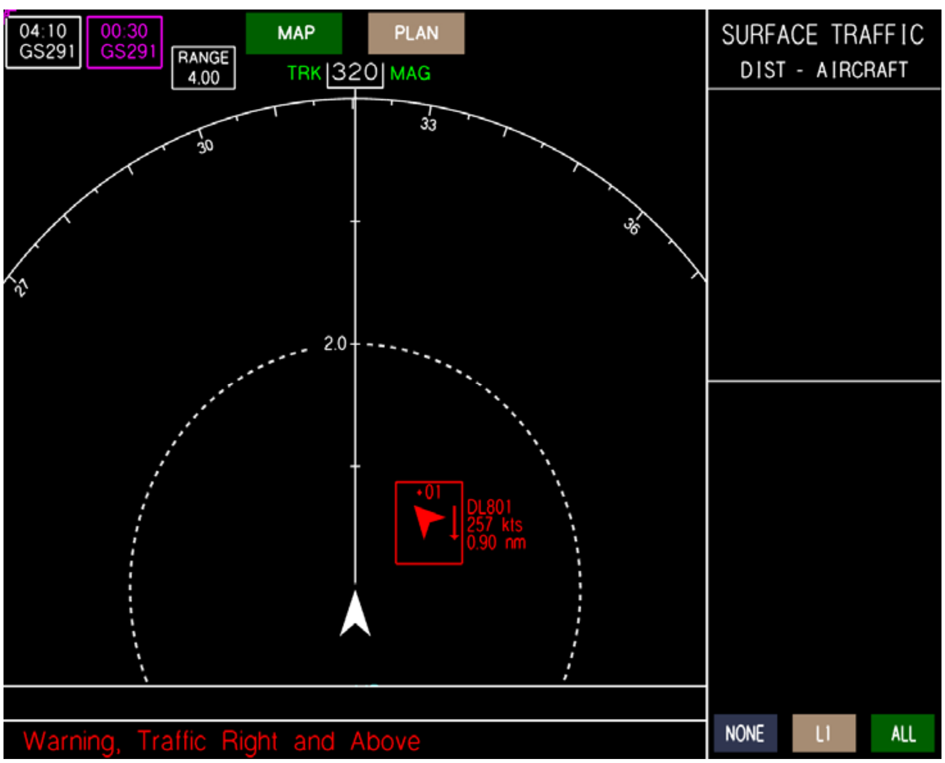
### 3.3 Low Altitude Conflict Monitor (LACM)

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 traffic and conflict advisories 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 TA (indicated by yellow icons). As the scenario progresses, the aircraft continue toward a potential collision point and LACM issues a CA (indicated by red icons), as shown in Figure 4b.




4a. LACM Traffic Advisory




4b. LACM Conflict Advisory

Figure 4. LACM Alerts.

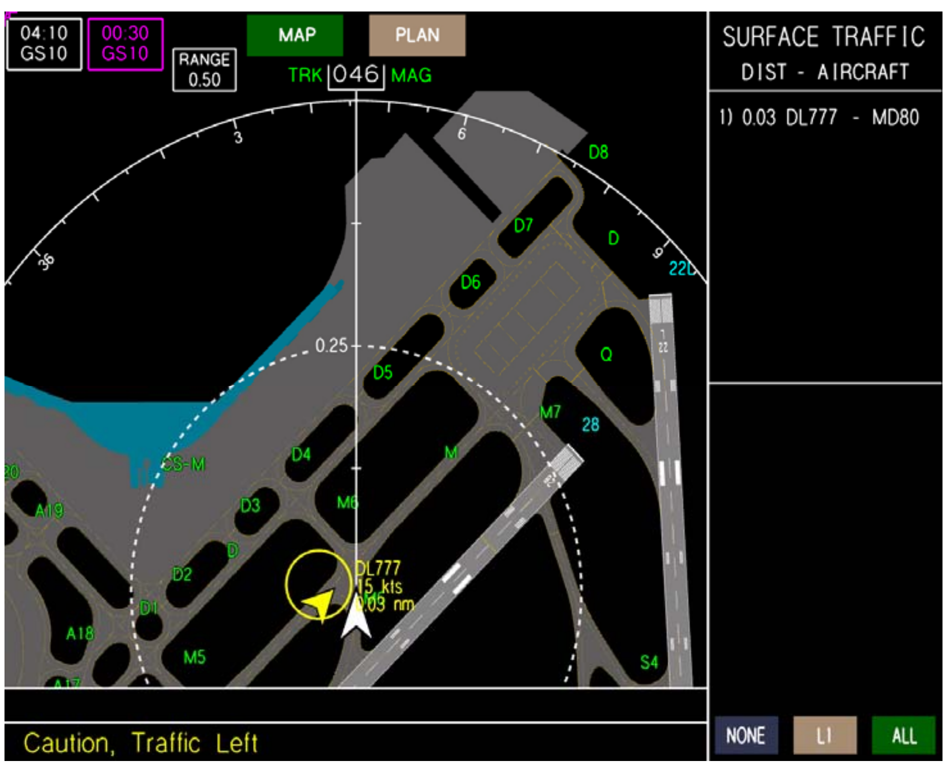
## 3.4 Taxi Conflict Monitor (TCM)

The TCM algorithm is designed to improve safety on the airport surface by monitoring for conditions that cause conflicts and collisions during taxi and ramp operations for multiple classes of aircraft as well as surface vehicles (trucks, baggage carts, etc.). The algorithm's initial 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.

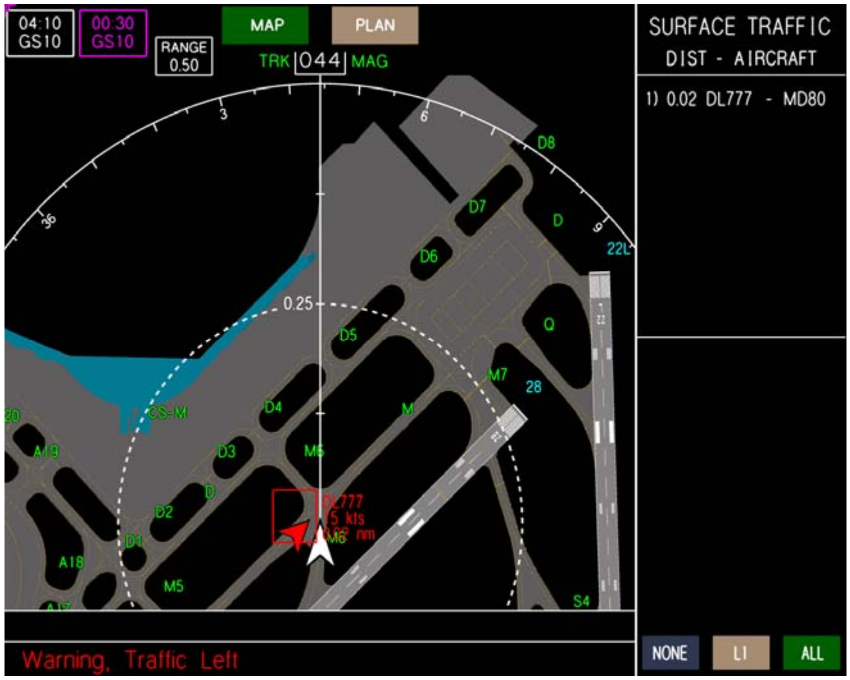
The close proximity of aircraft and vehicles to one another on the surface requires very strict accuracy tolerances. These tolerances, as well as all alert criteria and thresholds for TCM, are described in Section 5.6. Some of the parameters used by LACM (e.g., vertical speed, altitude, vertical tau, etc.) are not required by TCM. However, based on developmental testing, additional alert criteria are required by TCM because of the higher probability of false and nuisance alerts. 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 traffic and conflict advisories. 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 TA (indicated by yellow icons). In Figure 5b, as the aircraft continue to converge, TCM issues a CA (indicated by red icons).




5a. TCM Traffic Advisory




5b. TCM Conflict Advisory

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 (ATL) 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 (DFW) 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 C lists the current data parameters used by ATCAM.

ATCAM does not utilize data on current weather conditions or other phenomena such as wake vortices in the conflict detection calculations.

Appendix D 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 C, 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 multilateration [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 C 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 is being improved 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 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 and conflict traffic to enable display of the alert to the flight crew or ATC. The specific output parameters for the alert 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 or collision point (range)
- Time (sec) to collision point or closest point of approach (range tau)

The alert code is a single four digit hex number that compresses information for the alert including type of alert (i.e., caution or warning), 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

[RTCA1993]. 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.

# 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 will be evaluated based on timeliness of alerts, missed alerts, false alerts, and nuisance alerts for TAs and CAs. The timeliness of an alert is determined by whether a TA is issued with sufficient time to provide adequate traffic situation awareness prior to a potential hazardous situation, or whether a CA is issued with sufficient time for the pilot to take action and safely avoid a collision. A missed alert occurs when conditions meet the criteria for a CA or TA but the alert is not issued. For example, a runway incursion or near collision occurs and a CA was not issued, or aircraft come close enough to meet the TA minimum separation threshold but the TA is not issued. A false alert is an incorrect or spurious alert caused by a failure of the alerting system including the sensor [FAA 2007]. An example of a false alert is an alert issued on traffic that is not real (i.e., erroneous traffic data). A nuisance alert is generated by a system that is functioning as designed but which is inappropriate or unnecessary for the particular condition [FAA 2007]. A false or nuisance alert could cause an evasive 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 and false alert rates and desired probability of detection. These analyses will be a product of the RTCA SC-186 WG1 subcommittee.

Performance objectives for RSM have been met in previous flight tests and piloted simulations. The most recent RSM flight test results at Wallops Flight Facility verified a success rate of no missed or late alerts and only one false alert for all incursion scenarios tested [Green 2006].

## 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. All airport information is easily available from internet sources.

### *5.4.2 Runway Incursion Zone Placement*

Accurate placement of RI zones is critical for correct performance of the algorithm and prevention of false, 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 are set to be at or just inside the hold short positions if the exact positions are known. If hold short position data are not available, the sides of zones are placed 200 feet from the runway edges.

The ends of zones will vary based on the intersection of the ILS glide slope path (or standard path if no ILS) 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 past the touchdown point. (The touchdown point is next to the ILS antenna.) Assuming the touchdown point is typically located 1,000 feet from the end of the runway, the zone would extend approximately 14,256 feet, or 2.34 nm, past the runway threshold.

The width of RI zones is wider at the approach ends than at the runway threshold (see Figure 2) to allow for up to a two-dot ILS localizer deviation error on approaches.

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.

### *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.

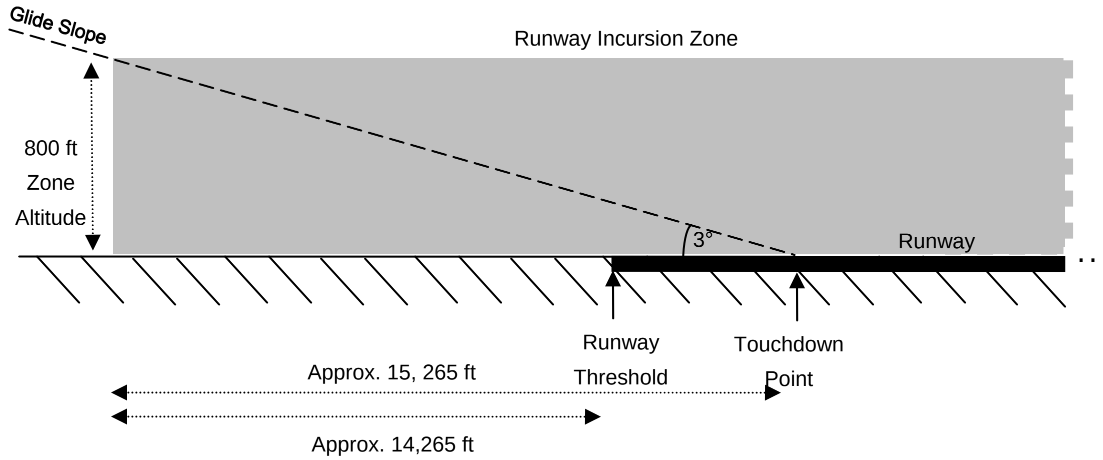



Figure 6. Example Using 3-Degree Glide Slope to Determine Incursion Zone Ends

#### *5.4.4 Determining Operational States*

Since incursion scenarios 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 are also available for ownship states such as auto throttle, EPR mode, throttle position, thrust reversers, air-ground, nose wheel squat, etc. (see Appendix C and Table C1). 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 D.

#### *5.4.5 Alert Output Data*

The current alert output parameters for the RSM TA and CA are based on the aural and graphical display requirements developed through simulation and flight testing that provide the flight crew with optimal alert awareness. 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. Future research regarding LACM and TCAS integration is planned. The results of this research could possibly support RTCA SC-218 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.

### *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 and false alerts and allow sufficient lead times for evasive 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 closest point of approach (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 false and 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 monitoring criteria, alert criteria, and thresholds that have been determined based on developmental testing and evaluation. 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 TA or CA to be issued, all criteria listed in the table must be satisfied.

Table 1. Initial LACM Alert Criteria and Thresholds

| Monitoring Criteria | | |
|---|---|---|
| Target proximity < 18000 ft from ownship position.<br>Ownship and target altitudes 50 – 1000 ft AGL ±100 ft. | | |
| **Alert Criteria** | **TA** | **CA** |
| 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 TA and CA 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 TA/CA, traffic runway, traffic arr/dep 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

### *5.6.1 Data Accuracy*

A high degree of data accuracy on the ground is necessary because of the very close distance and time tolerances involved in conflict situations and the greater likelihood of false and nuisance alerting. Therefore, TCM data accuracy requirements are stated more explicitly than those for RSM and LACM. The criteria and threshold tables in the next section indicate the accommodations TCM makes for variations in data accuracy.

Based on initial developmental testing, position reports for ownship and traffic are required to be within 3 meters, aircraft headings (yaw) to the nearest tenth of a degree, and time stamps to the nearest millisecond.

Ground speed accuracy requirements are less straightforward, since reported ground speed may be incorrect by more than one knot, and a stationary aircraft may report a non-zero ground speed. Initial testing shows that ground speed should be reported to the nearest tenth of a knot at a minimum. At the same time, TCM allows for a discrepancy of up to two knots for reported ground speed.

These data requirements will be validated based on future testing.

### *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. Table 2 lists the initial monitoring criteria, alert criteria and thresholds that have been determined based on developmental testing and evaluation.

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 TA or CA to be issued, all criteria listed in the table must be satisfied. The threshold modification factors, listed in the table are secondary criteria that modify the standard thresholds to prevent nuisance alerting and alert toggling (alerts on and off or switching between TA and CA). Threshold modification factors are described in Table 3.

Table 2. Initial TCM Alert Criteria and Thresholds

| Monitoring Criteria | | | | | |
|---|---|---|---|---|---|
| Target proximity < 1500 ft from ownship position.<br>Either ownship or target speed must be > 5 kts. (No alert if both stopped or both < 5 kts) | | | | | |
| Alert Criteria | TA | CA | Threshold Modification Factors | TA | CA |
| Range tau (sec) | 16 | 10 | one stopped | 12 | 7 |
| | | | slower taxi | 12 | 7 |
| | | | same Direction | 12 | 7 |
| | | | Turning | 12 | 7 |
| | | | Following | 10 | 7 |
| | | | head-on | 16 | 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 |
| Projected separation at CPA < min separation (ft)<br>OR<br>Current distance to target (range) < min separation (ft) | 50 | 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 |
| | | | CA in progress | 60 | 45 |
| | | | TA in progress | 60 | 30 |

Table 3. Initial TCM Threshold Modification Factors

| Threshold Modification Factors | Description |
|---|---|
| one stopped | At least one aircraft is stopped or moving < 2 kts. |
| slower taxi | Both aircraft are taxiing < 15 kts. (One can be stopped.) |
| same direction | Both aircraft are moving in the same direction within ±50° of heading. |
| turning | One or both aircraft is/are turning with turn rate > 3°/sec. |
| following | One aircraft is following the other and neither is stopped. |
| in path | One of the aircraft is in the path of the other, and neither is stopped |
| head-on | Both aircraft are in each other's paths within ±20°. |

### *5.6.3 Alert Data Output*

The parameters that are output for the TCM TA and CA 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 TA/CA, traffic runway and traffic arr/dep 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

## 6.1 Resolution Advisories (RA)

As mentioned previously, the ATCAM initial design does not include Resolution Advisories (RA). This section describes how ATCAM might provide such a feature.

A distinction must be made between an RA and an evasive maneuver. The term "evasive maneuver" is used to describe an action taken to avoid or mitigate a conflict. As described earlier, a TA may occasionally warrant an evasive maneuver, while a CA requires an evasive maneuver; in both cases, the evasive maneuver is currently left to the discretion of either the pilot or ATC, and ATCAM provides no direction. A RA, on the other hand, can be considered a CA that specifies an evasive maneuver.

The initial model for defining conflict resolutions is TCAS RAs. ATCAM, however, encounters a much wider variety of potential conflicts than TCAS. Selection of resolutions under ATCAM must be dependent upon the individual algorithm that detects the conflict (RSM, LACM, or TCM), as well as the operational state within the algorithm.

An area of high concern for any resolution is that diverting the ownship from its path does not in turn create a new conflict with different traffic. A related concern is the ability to detect and resolve conflicts with multiple traffic simultaneously, as TCAS does.

Eventually, ATCAM must be able to coordinate RAs between multiple aircraft/vehicles equipped with ATCAM, as well as handle unequipped traffic. However, the RA coordination capability will be reserved for future consideration, and will not be addressed in this document.

The RA concept outlined in the following sections is an initial proposal that, once prototyped, will be validated through various means such as qualitative pilot evaluation, automated simulation, and piloted simulation.

## 6.2 RA Logic

### *6.2.1 Processing RAs*

The flow chart in Figure 7 indicates the logic that each individual algorithm might use to process RAs. No integration or prioritization is made between RAs from separate algorithms.

When the ATCAM algorithms detect a conflict, it is determined whether the conflict meets CA criteria. If so, the conflict is categorized according to the algorithm's states (for example, arrival/departure/taxi for RSM). A CA is then issued immediately, before the RA, to allow immediate notification while the RA is being determined. ATCAM will issue an RA once an appropriate resolution is determined.

ATCAM will continue to monitor traffic after issuing the RA. Since the pilot cannot be expected to implement the resolution instantly, ATCAM will maintain a "grace period" for the RA, to accommodate the time required for the pilot to react. ATCAM will not recommend further action to address the conflict until the grace period has expired. The resolution chosen may assume particular behavior on the part of the traffic and ownship, to resolve the conflict. If unexpected behavior is observed after the grace period has expired, a new RA may need to be issued. A new RA may possibly reverse the original RA (for example, bear left instead of bear right). TCAS only allows one reversal per conflict. Further simulation and analysis will determine whether such a limit is appropriate for ATCAM.

As ATCAM continues to monitor traffic, the conflict should either mitigate or be resolved. As the conflict mitigates, ATCAM may issue a downgraded RA. Once the conflict resolves, the RA will be removed. If the conflict neither mitigates nor resolves after a suitable grace period, a new RA may need to be issued.

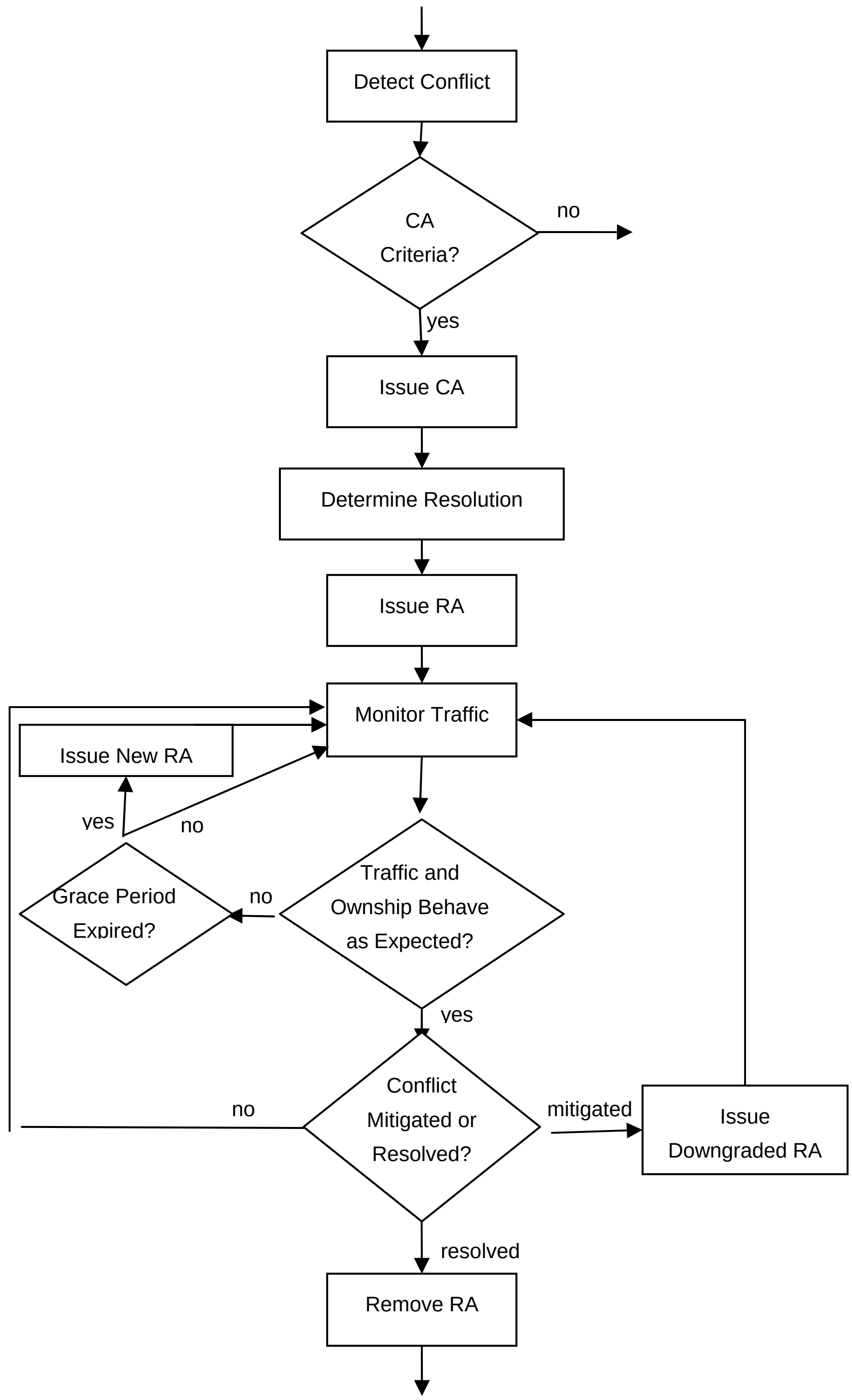



Figure 7. Resolution Advisory Logic for ATCAM Algorithm

### 6.2.2 *Determining Resolutions*

The flow chart in Figure 9 expands the logic for the "Determine Resolution" box in Figure 8.

Once a CA has been issued, ATCAM will examine the list of potential resolutions for the conflict, and attempt to select an acceptable maneuver from the list. Potential resolutions may be dependent on the algorithm's current state, or on the geometric relationship between the two aircraft/vehicles.

For each potential resolution, ATCAM will calculate whether implementing the resolution will cause a new conflict, perhaps with different traffic in the area. This calculation will require the following steps:

- Estimate the time necessary to perform the maneuver,
- Project ownship's position and heading at the end of the maneuver,
- Project the conflicting traffic's position and heading at the end of the maneuver,
- Project the positions and headings of all nearby targets at the end of the maneuver, and
- Determine if any conflicts will exist at the end of the maneuver.

It may also be necessary to calculate projected conflicts at interim steps during the maneuver, instead of waiting until the end of the maneuver. Further analysis and simulation will be required to determine the best forecasting logic.

If a resolution is found that does not cause a new conflict, an RA will be issued using that resolution. Further processing may be performed to determine whether multiple acceptable resolutions exist, and to determine which is most desirable among them.

If no viable resolution is found, a "No Resolution" RA will be issued, to notify the pilot that ATCAM failed to determine a resolution, and that the pilot's discretion should be used to determine a resolution for the CA. (An open issue is whether RAs are best maintained separately from CAs, or whether resolutions should just be added as a separate field to CA.)

Since the resolution is chosen by considering the ramifications on all nearby traffic, this method will address simultaneous conflicts involving multiple traffic.

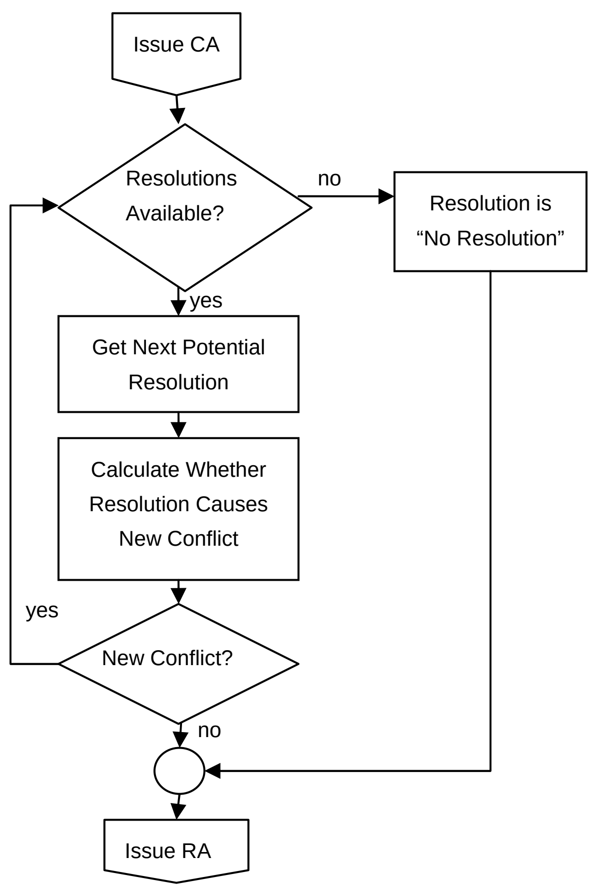



Figure 8. Resolution Determination Logic for ATCAM Algorithm

## 6.3 RSM RAs

### *6.3.1 Single Runway Resolutions*

Table 4 describes an initial set of potential evasive maneuvers that may be specified by an RSM RA, when both aircraft are in a single runway incursion zone.

When a CA is issued, ATCAM will attempt to select one of these evasive maneuvers to address the conflict. An RA specifying the evasive maneuver will then be issued, as described earlier. The maneuvers considered for each CA will be dependent on the set of conditions that led to the CA. These conditions will include at minimum the combination between ownship state and traffic state. Other conditions may be considered as well, such as separation distance, and whether the aircraft are moving toward each other. In addition to the CA conditions, additional conditions may need to be considered to determine an evasive maneuver, such as whether traffic is in front of the ownship or behind.

This document currently does not state which evasive maneuvers will be selected for specific CA conditions. Extensive simulation will be necessary to determine a suitable set of maneuvers for RSM. None of the proposed resolutions for RSM provide navigational specifics, such as how sharply to turn, climb, or adjust velocity. Different airports, and different carriers, often have strict, but very different, procedures for aborting approach and takeoff. Also, the evasive maneuvers might be very different for various types of aircraft. Further analysis and simulation will be required to determine the feasibility of including more detailed evasive maneuvers and, if feasible, the specifics of the maneuvers.

Table 4. Potential RSM Evasive Maneuvers

| Evasive Maneuver | Potential Ownship States | Description |
|---|---|---|
| Go Around | Approach, Flythru | Terminate approach and climb away |
| Go Around and Sidestep | Approach, Flythru | Terminate approach, sidestep runway, and climb away |
| Sidestep | Climbout, Flythru | Veer to the side, continue takeoff |
| Touchdown Emergency Stop | Approach | Expedite landing, stop quickly |
| Reject Takeoff | Takeoff roll | Abort takeoff, stop |
| Expedite Takeoff | Pre-takeoff, Takeoff roll, Climbout | Take off as quickly as possible |
| Emergency Stop | Taxi, Pre-takeoff, Rollout | Stop immediately (severe slowdown may suffice) |
| Exit/Clear Runway | Taxi, Pre-takeoff, Takeoff roll, Rollout | Proceed immediately to nearest runway exit |
| Slow | Approach, Fly-thru, Climbout | Reduce speed while airborne |
| Speed Up | Fly-thru | Increase speed while airborne |
| No Resolution | | Issue CA, leave resolution to pilot discretion |

### *6.3.2 Intersecting Runway Resolutions*

When the ownship and traffic are in separate but intersecting runway incursion zones, it is expected that evasive maneuvers will be chosen from the same table used for single runway resolutions, above. However, an intersecting runway conflict might not require the same evasive maneuver as a single runway conflict with similar circumstances, and a different maneuver from the table might be chosen. In general, the conditions which cause an intersecting runway CA to be issued are more complicated than for single runway CAs.

Simulation will be necessary to determine a suitable set of maneuvers for intersecting runway resolutions.

### *6.3.3 Advisory Data Output*

The output parameters for RSM RAs will be implemented as an enhancement to the parameters for RSM CAs, documented in Section 5.4.5. An additional type of advisory, Resolution, will be added to the existing Caution and Warning Advisories. A new code will be created to indicate the evasive maneuver associated with the RA. Both of these parameters will be included in the four-digit alert code, which will be encoded into a CPDLC-compatible format. Consequently, ATC can be informed of the resolution advice at the same time as the pilot.

## 6.4 LACM RAs

### *6.4.1 LACM Resolutions*

LACM is modeled after TCAS II, but for low altitude conflicts. TCAS II evasive maneuvers consist solely of vertical movements, with instructions about how steeply to ascend or descend. An enhanced version of TCAS has long been envisioned that includes resolutions with horizontal movements, but that version has not been released yet.

Because LACM operates at low altitudes, LACM is not able to direct aircraft to descend. This constraint does limit the options for vertical resolutions in LACM, although aircraft can still be directed to climb. Consequently, LACM will support horizontal evasive maneuvers and acceleration evasive maneuvers, in addition to vertical evasive maneuvers.

Tables 5a through 5d describe an initial set of potential evasive maneuvers that may be specified by an LACM RA. Tables 5a, 5b, and 5c provide specific maneuvers for each dimension, while Table 5d provides a template for combining maneuvers in the three different dimensions.

Table 5a. Potential LACM Vertical Evasive Maneuvers

| Evasive Maneuver (*V*) | Navigational Data (*v*) | Description |
|---|---|---|
| Climb | TBD | Climb at a rate of TBD feet per minute (fpm). |
| Do Not Descend | TBD | Do not descend at a rate greater than TBD fpm. If already descending past that rate, reduce descent rate to TBD or less. |
| Do Not Climb | TBD | Do not climb at a rate greater than TBD fpm. If already climbing past that rate, reduce climb rate to TBD or less. |
| Level Off | | Level off vertically to neither climb nor descend. (Same as Climb at 0 fpm, or Do Not Descend at 0 fpm, or Do Not Climb at 0 fpm.) |
| No Vertical Maneuver | | Maintain current vertical trajectory. |

Table 5b. Potential LACM Horizontal Evasive Maneuvers

| Evasive Maneuver (*H*) | Navigational Data (*h*) | Description |
|---|---|---|
| Bear Right | TBD | Bear to the right by TBD degrees. If already bearing right by more than TBD degrees, reduce turn angle to TBD degrees. |
| Bear Left | TBD | Bear to the left by TBD degrees. If already bearing left by more than TBD degrees, reduce turn angle to TBD degrees. |
| No Horizontal Maneuver | | Maintain current horizontal trajectory. |

Table 5c. Potential LACM Acceleration Evasive Maneuvers

| Evasive Maneuver (*A*) | Navigational Data (*a*) | Description |
|---|---|---|
| Slow | TBD | Reduce speed by TBD knots |
| Speed | TBD | Increase speed by TBD knots |
| No Acceleration Maneuver | | Maintain current velocity. |

Table 5d. Potential LACM Evasive Maneuver Combinations

| Evasive Maneuver | Navigational Data | Description |
|---|---|---|
| *V*:*H*:*A* | *v*:*h*:*a* | Perform a combination of:<br>• Vertical maneuver *V*, with navigational data *v*,<br>• Horizontal maneuver *H*, with navigational data *h*, and<br>• Acceleration maneuver *A*, with navigational data *a*. |
| No Resolution | | Issue CA, leave resolution to pilot discretion |

The "Navigational Data" field has different meanings for different dimensions. This field contains some quantification of the degree by which the ownship should alter its course. For vertical maneuvers, the Navigational Data is the required vertical rate (in feet per minute, or fpm), for horizontal maneuvers it is the angle (in degrees) by which to turn, and for acceleration maneuvers it is the amount (in knots) by which the velocity should be changed. Simulation will help determine the appropriate measures for these fields.

Like TCAS, and unlike RSM, the LACM conflict criteria utilize no real operational state information, but merely indicate that the two aircraft will pass too closely to each other. (LACM may in some instances have access to RSM state information, but such information may not be relevant to low altitude conflicts, even when available.) Without such operational state information, determining potential resolutions for the conflict requires further analysis.

TCAS only allows the option of vertical maneuvers, and chooses the least-disruptive maneuver that will provide the most vertical separation. LACM, however, must support maneuvers in multiple dimensions, as described previously. So comparing separations between resolutions becomes more complicated.

An alternate approach for choosing potential evasive maneuvers might be to compare the ownship's position at CPA with the traffic's position at CPA, and choose a maneuver that increases whatever separation is already expected to exist. For example, if the ownship will be above and to the right of the traffic at CPA, the most likely maneuver to choose might be a combination of Climb and Bear Right. A similar approach has been developed for conflict resolution as part of distributed air/ground traffic management research for the en-route environment [Ballin, et. al., 2002, Hoekstra, et. al., 2002].

Potential evasive maneuvers should potentially be prioritized according to the following criteria, in descending order:

- Avoid the conflict.
- Avoid creating new conflicts.
- Avoid crossing flight paths.
- Minimize disruption to ownship's current flight path.

### *6.4.2 Advisory Data Output*

The output parameters for LACM RAs will be implemented as an enhancement to the parameters for LACM CAs, documented in Section 5.5.4. An additional type of advisory, Resolution, will be added to the Caution and Warning alerts. A new code will be created to indicate the evasive maneuver associated with the RA. Navigation instructions, such as vertical rates, may be included in the evasive maneuver codes, or they may require additional fields. All of these parameters will be included in the four-digit alert code, which will be encoded into a CPDLC-compatible format. Consequently, ATC can be informed of the resolution advice at the same time as the pilot.

## 6.5 TCM RAs

### *6.5.1 TCM Resolutions*

Table 6 describes an initial list of potential evasive maneuvers that may be specified by a TCM RA.

Table 6. Potential TCM Evasive Maneuvers

| Taxi Evasive Maneuver | Description |
|---|---|
| Emergency Stop | Stop immediately (severe slowdown may suffice) |
| Slow down | Reduce taxi speed |
| Speed Up | Increase taxi speed |
| Turn Right | Turn sharply to right |
| Turn Left | Turn sharply to left |
| No Resolution | Issue CA, leave resolution to pilot discretion |

Similar to LACM, the TCM conflict criteria utilize little operational state information, but merely indicate that the two aircraft will pass too closely to each other. Determination of TCM resolutions may be similar to determination of LACM resolutions, and may be based on relative positions at CPA between ownship and traffic. A difference, however, is that TCM will not generate vertical RA maneuvers since the aircraft is on the airport surface during taxi operations.

Potential evasive maneuvers for TCM should be prioritized according to the same criteria as stated for LACM.

### *6.5.2 Advisory Data Output*

The output parameters for TCM RAs will be implemented as an enhancement to the parameters for TCM CAs, documented in Section 5.6.3. An additional type of advisory, Resolution, will be added to the Caution and Warning advisories. A new code will be created to indicate the evasive maneuver associated with the RA. Both of these parameters will be included in the four-digit alert code, which will be encoded into a CPDLC-compatible format. Consequently, ATC can be informed of the resolution advice at the same time as the pilot.

# 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 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 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 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 the early stage of development; however, developmental testing has proved to be very promising for elimination of collisions in these operating areas. The technical approach 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 airborne precision spacing. On-going surface safety research also includes determination of feasibility and development of requirements for the addition of conflict resolution advisories to warning alerts. Results of this research and changes to requirements will be provided in updates to this report.

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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:<br>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 >= **approx 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 rwy) | 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 D 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 Traffic Advisories (TA) and Conflict Advisories (CA) (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 3.2). The default thresholds for alert criteria are implemented as parameters that are contained in software configuration files. The default values for CA thresholds were determined through simulation and flight testing, but can be modified as required based on future research. The default values for TA thresholds are untested estimates, and are subject to change based on future simulation and flight testing. Previous testing [Jones 2002, Jones and Prinzel 2006] revealed that TAs 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, TAs 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.

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<br>(Assumes Ownship and Traffic are inside the same runway incursion zone) | | | | | |
|---|---|---|---|---|---|
| Code | Description * | Default Threshold | | | |
| | | GA | | Non-GA | |
| | | TA** | CA | TA** | CA |
| **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 rwy threshold of aircraft taxiing or stopped on rwy is < **approx 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 |
| **F** | Ownship distance to runway threshold or traffic position < **airborne alert distance (ft)**<br>(airborne alert dist based on approx ownship landing speed, e.g., B-757 6000 ft for CA, 8000 ft for TA) | Per own landing speed | Per own landing speed | Per own landing speed | Per own landing speed |
| **G** | Ownship time to runway threshold or traffic position < **alert time threshold (sec)** | 40 | 30 | 40 | 30 |
| **H** | Ownship distance to traffic position < **2.0 times the airborne alert distance (ft)**<br>(increased airborne alert dist required for some scenarios, e.g., B-757 12000 ft for CA, 16000 ft for TA) | Per own landing speed | Per own landing speed | Per own landing speed | Per own landing speed |
| **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".

****** TA thresholds will only be applied for single runway scenarios of taxi/approach, pre-takeoff/approach, or any ownship approach scenario.

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) | | | | | |
|---|---|---|---|---|---|
| | | Default Threshold | | | |
| | | GA | | Non-GA | |
| Code | Description * | TA** | CA | TA** | CA |
| **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 |
| **Q** | Ownship distance to runway threshold < **airborne alert distance (ft)** (airborne alert dist based on approx ownship landing speed, e.g., B-757 6000 ft for CA, 8000 ft for TA) | Per own landing speed | Per own landing speed | Per own landing speed | Per own landing speed |
| **R** | Ownship distance to intersection < **airborne alert distance (ft)** (airborne alert dist based on approx ownship landing speed, e.g., B-757 6000 ft for CA, 8000 ft for TA) | 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 < **approx 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 |

* Text in **bold** indicates parameters specified under "Default Threshold".
****** TA thresholds will only be applied for intersecting runway scenarios in which the ownship state is approach.

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/T Closing | B and K | — | — |
| Approach | O/T Closing | (B or G) and D (CA)<br>D (TA)* | — | — |
| Rollout | O/T Closing | (E or C) | — | — |
| Fly-thru RI Zone | Not defined; alerts not issued | — | — | — |

* Criteria B and G are not applied for TAs 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 rwy | L |
| | T behind O and closing | A | Intersect beyond end of O rwy | M or O |
| Climb-out | O/T same heading & rwy | B and K | Intersect before end of O rwy | L |
| | O/T head-on, opposite rwys | A | Intersect beyond end of O rwy | W and (M or O) |
| Approach | O/T same heading & rwy and T behind O | B or G (CA)<br>A (TA)* | Intersect before end of O rwy | S |
| | O/T same heading & rwy and T in path of O | B (CA)* | Intersect beyond end of O rwy | S and (M or O) |
| | O/T head-on, opposite rwys | B or G (CA)<br>A (TA)* | | |
| Rollout | T in path of O | A | Intersect before end of O rwy | (T or U) |
| | T behind O and closing | B | Intersect beyond end of O rwy | (T or U) and (M or O) |
| Fly-thru RI Zone | Closing | B and K | Not defined for traffic fly-thru scenarios | — |

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

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

| Ownship (O) State – Takeoff roll | | | | |
|---|---|---|---|---|
| | Single Runway | | Intersecting Runways and RI Zones | |
| Traffic (T) State | Scenario Conditions | Alert Criteria) | Scenario Conditions | Alert Criteria |
| Taxi/Stationary (on or near rwy) | 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 & rwy | B | O able to abort takeoff | L |
| | O/T head-on, opposite rwys | A | O not able to abort takeoff | N or P |
| Climb-out | O/T same heading & rwy | B | O able to abort takeoff | W |
| | O/T head-on, opposite rwys | A | O not able to abort takeoff | N or P |
| Approach | O/T same heading & rwy and T behind O | B | O able to abort takeoff and intersect before end of O rwy | S |
| | O/T same heading & rwy and T in path of O | A | O able to abort takeoff and intersect beyond end of O rwy | S and (M or O) |
| | O/T head-on, opposite rwys | A | O not able to abort takeoff | S and (N or P) |
| Rollout | O/T same heading & rwy and T in path of O | A | O able to abort takeoff and intersect before end of O rwy | (T or U) |
| | O/T same heading & rwy and T behind O and closing | B | O able to abort takeoff and intersect beyond end of O rwy | (T or U) and (M or O) |
| | O/T head-on, opposite rwys | A | O not able to abort takeoff | (T or U) and (N or P) |
| Fly-thru RI Zone | Closing | B 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 (F or G) | Not defined for traffic taxi scenarios | — |
| Pre-takeoff | NA (Traffic pre-takeoff state not avail in current version) | — | — | — |
| Takeoff roll | O/T same heading & rwy | B | All conditions | W and R and (M or O) |
| | O/T head-on, opposite rwys | A | | |
| Climb-out | O/T same heading & rwy | B | All conditions | R and (M or O) |
| | O/T head-on, opposite rwys | (I or H) | | |
| Approach | O/T same heading & rwy | B | All conditions | V and S and R and (N or P) |
| | O/T head-on, opposite rwys | J and (I or H) | | |
| Rollout | O/T same heading & rwy and T in path of O | K and G | All conditions | W and (N or P) and R and (T or U) |
| | O/T same heading & rwy and T behind O and closing | K and B | | |
| | O/T head-on, opposite rwys | K and (I or H) | | |
| Fly-thru RI Zone | O/T closing | B and J | 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 (F or G) | Not defined for traffic taxi scenarios | — |
| Pre-takeoff | NA (Traffic pre-takeoff state not avail in current version) | — | — | — |
| Takeoff roll | O/T same heading & rwy | B | All conditions | S and (N or P) and (Q or R) |
| | O/T head-on, opposite rwys | A | | |
| Climb-out | O/T same heading & rwy | J and B | All conditions | S and V and (N or P) and (Q or R) |
| | O/T head-on, opposite rwys | J and (H or I) | | |
| Approach | O/T same heading & rwy | B | All conditions | S and (N or P) and (Q or R) |
| | O/T head-on, opposite rwys | (H or I) | | |
| Rollout | O/T same heading & rwy | G | All conditions | S and (T or U) and (Q or R) |
| | O/T head-on, opposite rwys | A | | |
| Fly-thru RI Zone | O/T closing | B and J | 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 & rwy and T ahead of O | B | All conditions | (T or U) |
| | O/T same heading & rwy and T behind O | A | | |
| | O/T head-on and opposite rwys | A | | |
| Climb-out | O/T same heading & rwy and T behind O | K and B | All conditions | W and (M or O) and (T or U) |
| | O/T same heading & rwy and T ahead of O | K and B | | |
| | O/T head-on, opposite rwys | K and (I or H) | | |
| Approach | O/T same heading & rwy (T behind or ahead) | B | All conditions | S and (T or U) |
| | O/T head-on, opposite rwys | A | | |
| Rollout | O/T same heading & rwy | B | All conditions | (T or U) |
| | O/T head-on, opposite rwys | A | | |
| Fly-thru RI Zone | O/T closing | B 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 | B and K | — | — |
| Climb-out | Closing | B and J | — | — |
| Approach | Closing | B and J | — | — |
| Rollout | Closing | B and K | — | — |
| Fly-thru RI Zone | Incursion scenario not defined; alerts not issued | — | — | — |

# Appendix C – Flight Data Requirements

This appendix lists the flight data that is currently used by the ATCAM software. Table C1 lists the ownship data, while Table C2 lists the traffic data.

Table C1. 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 Alt. | +/-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 Grnd | 10 HZ |
| Nose Wheel Squat | Discrete | NA | 1=Nose Wheel on Grnd | 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 C2. 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 D – Surveillance Discussion

## D.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 ATL [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 D1.

The FAA is in the process of deploying ADS-B throughout the National Airspace System (NAS). A Notice of Proposed Rulemaking (NPRM) [FAA July 2007] has been developed to propose ADS-B Out performance requirements to support ATC service. Although the FAA is not mandating ADS-B In at this time, the NPRM includes a discussion of potential ADS-B In applications and accuracy requirements. The NPRM proposes that a horizontal accuracy of 30 meters (98.4 feet) and a vertical accuracy of 45 meters (147.6 feet) are sufficient to enable certain applications on the airport surface, such as traffic alerting. More analysis is needed to determine whether these proposed accuracies are really sufficient for conflict detection.

As part of the RTCA SC-186 WG1 subcommittee, Mitre Corporation is in the process of conducting analysis to determine the surveillance accuracy requirements for the traffic conflict detection application.

Table D1. EUROCAE A-SMGCS Surveillance Performance Requirements

| Performance Parameter | Level 2 System Requirement |
|---|---|
| Probability of target detection | ≥ 99.9% on maneuvering area<br>≥ 98% on apron |
| Probability of false target detection | $\leq 10^{-3}$ per report |
| Probability of identification | ≥ 99.9% on maneuvering area<br>≥ 98% on apron |
| Probability of false identification | $\leq 10^{-3}$ per report |
| Reported position accuracy | ≤ 7.5 meters (95%) on maneuvering area<br>≤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<br>≥ 98% on apron |
| Target report position resolution | ≤1 meter |
| Target report velocity resolution | ≤0.25 meter/second |
| Target report time resolution | ≤ 0.1 second |

## D.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 false, 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 Autothrottle button pushed, throttle position.

- *Intent to land* – Autoland 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 false 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* – When an aircraft is determined to be on the ground, ADS-B transmissions will contain surface message content instead of airborne message content. The ADS-B surface message lacks altitude data which is necessary for low altitude CD&R. 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.

## D.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 2003]. These accuracies are sufficient for aircraft that are airborne and not near the surface (above 1000 feet AGL), however, they may not be accurate enough for ATMA CD&R.

Sources of error for barometric altitude reporting include instrument calibration, rounding altitude to the nearest 25 or 100 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***).***

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. 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. This rounding of altitude values coupled with the errors inherent in GNSS height above the ellipsoid or barometric altitude may prove to be unacceptable for CD&R in the ATMA. 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 2006]. 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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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. 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). CAAT research is conducted jointly under NASA's Airspace Systems Program, Airportal Project and the Aviation Safety Program, Integrated Intelligent Flight Deck Project.

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