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RUNWAY INCURSION PREVENTION USING AN ADVANCED SURFACE MOVEMENT GUIDANCE AND CONTROL SYSTEM (A-SMGCS)

Steven D. Young and Denise R. Jones, National Aeronautics and Space Administration, Langley Research Center, Hampton, Virginia

Abstract

An A-SMGCS architecture and operational concept is presented that has been designed to prevent runway incursions while also improving operational capability. Results of a full-mission simulation using 18 airline pilots and six air traffic controllers are presented along with a description of flight testing to be performed at the Dallas-Fort Worth International Airport (DFW). During the simulation, pilot test subjects executed multiple approaches followed by taxi to the gate in visibilities down to 150' using a Synthetic Vision (SV) display system. This system consists of a Head-Up Display (HUD) providing tactical guidance and a head-down moving map with position, traffic, and Air Traffic Control (ATC) instructions depicted to improve situational awareness in the flight deck. Runway incursion warnings were also generated in the flight deck based on surface traffic positions. Simulation scenarios modeled peak traffic conditions and included typical runway incursion events during both landing and takeoff roll. Results are presented as a function of visibility.

Introduction

Traditionally, pilots have relied on visual aids such as airfield markings, signs, and lighting, in conjunction with a paper chart to navigate on the airport surface. Radio communication between ATC and pilots is used to obtain the route to follow while on the surface and any hold-short points. Generally, a “ground” controller will provide this information to pilots using explicit instructions and a strict protocol (i.e. phraseology) so that there is no misunderstanding over the radio channel. The pilot must then memorize this route (or write it down), re-state it to the controller for confirmation, and then follow the signs and markings to the destination - avoiding other surface traffic and obstructions. Meanwhile, the ground controller must keep track of the routes given to all aircraft, as well as all aircraft locations, so that no one is directed into a potential collision.

Traffic surveillance on the airport surface is performed by the flight crews based primarily on the “see and be seen” principle to maintain safe separation. Similarly, ATC performs the surveillance task from the tower based primarily on visual cues. Occasionally, both pilots and controllers will use radio communications to confirm positions of relevant traffic. While the Traffic Alerting and Collision Avoidance System (TCAS) provides traffic advisories to flight crews in flight, it is not used on the airport surface. The Airport Surface Detection Equipment (ASDE-3) radar is used in the U. S. to provide secondary surveillance data to ATC; however, ASDE-3 does not identify aircraft and is scheduled to be deployed only at about 60 U. S. airports.

The traditional procedures have worked well in most cases as the airport surfaces have not been congested and visibility is usually good. However, as traffic volume has increased, the surface has become more congested. This higher volume has led to (1) a need to perform more operations in low visibility and at night, and (2) increasingly complex, large airport layouts. Unfortunately, the traditional operational procedures were not designed to accommodate high volume and the result is an increased risk of hazardous situations.

Runway Incursions

By definition, a runway incursion occurs any time an airplane, vehicle, person or object on the ground creates a collision hazard with an airplane that is taking off or landing at an airport under the supervision of ATC. Runway incursion accidents have claimed 719 lives and destroyed 20 aircraft since 1972, and despite the best efforts of the FAA, the National Transportation Safety Board (NTSB), and others, runway incursions continue to occur more frequently. In 1999, there were 321 runway incursions reported across the U. S., this is 71% greater than the number in 1993. Over this same period, the incursion rate rose 56%. Clearly, runway incursions remain a serious aviation safety hazard, and as such have been listed as #1 on the NTSB's ten most wanted aviation safety improvements list [1]. Recently, the NTSB has made specific recommendations for reducing runway incursions. From [2], the NTSB recommends that the FAA *"require, at all airports with scheduled passenger service, a ground movement safety system that will prevent runway incursions; the system should provide a direct warning capability to flight crews. In addition, demonstrate through computer simulations or other means that the system will, in fact, prevent incursions."*

A-SMGCS

The International Civil Aviation Organization (ICAO) has defined operational requirements for Advanced Surface Movement Guidance and Control Systems (A-SMGCS) [3] that specify what is required to support safe, orderly, and expeditious movement of aircraft and vehicles at airports under all visibility conditions, traffic densities, and airport layouts. These requirements have been proposed by ICAO to ensure standardization and safety with respect to global interoperability. In [3], ICAO has proposed specific recommendations including:

- Improved means of providing situational awareness information to pilots, controllers and vehicle operators
- Improved guidance and procedures to allow safe operations regardless of visibility, traffic density, and airport layout
- Conflict prediction and/or detection, analysis, and resolution
- All users should be provided with the same level of service while operating on the airport surface

SafeFlight 21

The FAA's SafeFlight21 Program has targeted nine free-flight operational enhancements to improve the safety and efficiency of the National Airspace System (NAS). Two of these are related to airport surface movements: improved surface navigation for the pilot, and enhanced surface surveillance for the controller [4].

LVLASO and RIRP

NASA has been working collaboratively with the FAA since 1993 under the auspices of NASA's Low Visibility Landing and Surface Operations (LVLASO) research project and the FAA's Runway Incursion Reduction Program (RIRP). Recently, this collaboration has continued under NASA's new focused Aviation Safety Program (AvSP), developing enabling technologies for SV systems.

The objective of this collaboration has been to investigate *technology* as a means to improve the safety and efficiency of aircraft movements on the surface. The investigated technologies would provide guidance to pilots that is independent of visibility and would potentially eliminate ownship[1] runway incursion incidents; while allowing the flight crew to monitor for incursions by others as well. In addition, ATC would be provided with an enhanced surveillance capability that included not only traffic positions, but also identity and a level of automatic hazard detection. In August of 1997, the LVLASO technologies were evaluated jointly with the FAA RIRP technologies at the Hartsfield-Atlanta International Airport (ATL) [5].

Operational Concept

The key to preventing runway incursions is maintaining an adequate level of situational awareness (SA). In particular, two components of SA must be maintained: traffic awareness (by both pilots and ATC), and ownship position awareness (by pilots). The first primarily enables *detection* of incursions, while the second *prevents* incursions by the crew of the ownship. Each of these will be discussed separately.

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[1] The term "ownship" refers to the perspective of the flight crew of the aircraft that is equipped with the proposed guidance system moving about on the surface.

Traffic Awareness

As mentioned previously, in today's environment, flight crews and ATC maintain surface traffic awareness by way of visual scans and radio communications. As visibility deteriorates, at night, or under high workload conditions, maintaining adequate awareness of traffic on the surface can become difficult.

Real-time airport surface surveillance data is available (via ASDE-3 radar) at several U. S. airports. At these airports, surface radar data is provided to ATC to supplement visual acquisition. An additional ATC system has been proposed to automatically detect hazardous situations on the airport surface using the radar data as input. This detection system is called the Airport Movement Area Safety System (AMASS).

With the development of ADS-B[2] and TIS-B[3] data link services, surveillance data can be made available to non-ATC users (e.g. pilots) and even at non-towered airports. Users of this surveillance data, along with an accurate, complete, airport mapping database (AMDB), can be provided with a supplemental means of observing traffic positions on the airport surface in any visibility condition on a graphical display (much like ATC use of ASDE-3). This overlay of traffic data onto a graphical depiction of the airport allows the user/pilot to determine relative location, velocity, identity, and intent of all aircraft/vehicles on the movement area. This application has been demonstrated in an operational environment [5] and is described in [6].

In addition, this operational concept enables runway incursions to be detected onboard in real-time. Once detected, advisories can be issued to either ATC (via data link) or directly to the flight crew. This detection and warning can be functionally similar to the approach taken by AMASS, the Runway Status Light System (RWSL), TCAS, or other traffic warning systems. Keep in mind that detection can still be accomplished by the human (pilots or ATC) by close monitoring of the external environment or the previously mentioned traffic display. In this manner, this A-SMGCS concept provides higher integrity with respect to incursion detection.

[2] Automatic Dependent Surveillance - Broadcast
[3] Traffic Information Service - Broadcast

Ownship Position Awareness

From the pilot's perspective, preventing runway incursions is not only dependent on maintaining adequate traffic awareness. In fact, it is just as important (if not more important) to maintain adequate position awareness. On the airport surface, this includes horizontal position, heading, and velocity - all relative to the ATC-approved route and any hold-short locations.

To prevent inadvertent ownship runway incursion, taxi routes and hold-short locations can be depicted on a graphical display of the airport layout. Further, once ATC has cleared the aircraft to continue taxi beyond a hold-short point, the display can be updated accordingly. This operational concept has been flight tested and shown to be effective [5]. To support this application, taxi routes and hold-short locations can be transmitted to the aircraft, stored onboard, or entered by the crew.

With the development of GPS augmentation systems [7] and improved accuracy for stand-alone GPS, technology is available to enable aircraft to obtain accurate ownship position information while operating on the airport surface [8]. Using GPS, accurate airport mapping data, and a display, the flight crew can determine, in real-time, both lateral and longitudinal track deviations (independent of visual aids). An additional feature of this operational concept is conformance monitoring. Deviations off route or over hold-short points can be detected and forwarded to the pilots or ATC (via data link) so that corrective action can be taken.

In most visibility conditions, surface navigation display functions, like the ones described above, would be intended to supplement visual cues. Visual aids such as airfield signs, painted markings, and lights would continue to be used as the primary method of guidance/navigation. The crew would use this supplemental information *as needed* to reduce uncertainties associated with visual aids (e.g. indeterminate or difficult to see sign direction arrows).

In extremely low visibility conditions or at airports not equipped with sufficient visual aids, surface navigation displays may be the primary, or sole, means of guidance/navigation. Currently, for either of these cases, airport operations cease; as there is no means of safe surface navigation.

Summary of Operational Concept

The operational concept presented makes use of display, data link, and GPS avionics to enable equipped aircraft to operate at airports independent of visibility while ensuring safety. This is accomplished by providing pilots with a real-time display of traffic information that enables *detection* of othership incursions, and supplemental guidance cues to *prevent* ownship incursion due to inadvertent blunder. Figure 1 shows a generic architecture that enables this concept.

An ATC display is also a critical component of this operational concept. In general, this display would be intended to improve traffic awareness for ATC in a manner analogous to that presented above for pilots and would include real-time traffic position and identity, a supplemental data link for instructions, and possibly alerts of runway incursions and route deviations by aircraft. This latter automation function may best be simply based on effective use by ATC of the traffic display and the external visual scene from the tower.

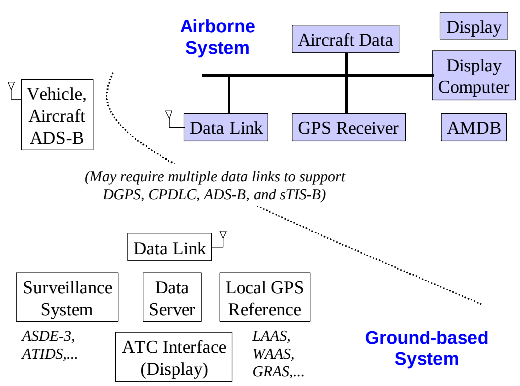

Figure 1. Conceptual Generic A-SMGCS Architecture

Flight Simulation

The validity of the operational concept presented above has been verified to a degree by previous flight simulation studies and two flight test activities [5][9][10][11]. However, two important capabilities had yet to be tested. These are the objectives of the flight simulation study presented.

- Test the hypothesis that clear-weather flow rates can be safely maintained in reduced visibilities using the proposed A-SMGCS architecture and operational concept
- Determine the appropriateness of automatic onboard runway incursion detection and alerting

Environment

The A-SMGCS architecture shown in Figure 1 was implemented using a fixed-based simulator cab called the Research Flight Deck (RFD) and a remote ATC position. The RFD is an all-glass flight deck that implements standard displays as well as a Head-up Display (HUD). B-757 vehicle dynamics were used for all simulations.

The airport environment that was modeled was the north side of ATL operating at near-peak capacity. In this case, near peak capacity consisted of an inter-arrival spacing of 3 nautical miles (nmi), between touchdowns and an inter-departure rate of 90 seconds between liftoffs. Traffic departed on the inner runway and arrived on the outer as is commonly done at ATL. Both north side airport configurations were implemented: runways 26L/26R and runways 8L/8R. Wind conditions were not modeled.

Flight Deck Displays

To implement the SV display component of the architecture in the RFD, the HUD and Navigation Display (ND) capabilities were extended to include not only their standard capabilities, but also those proposed by this paper. Figure 2 depicts the RFD configured for this experiment.

The HUD was used for tactical guidance during final approach, landing, roll-out, turn-off, and taxi. Symbology presented during landing was similar to the approach taken by commercial HUD vendors. During landing roll-out, deceleration guidance to a pilot-chosen exit was provided along with centerline and runway edge symbology [10]. During taxi, centerline and taxiway edge symbols were provided along the ATC-approved route [9]. All of the above were provided to improve ownship position awareness.

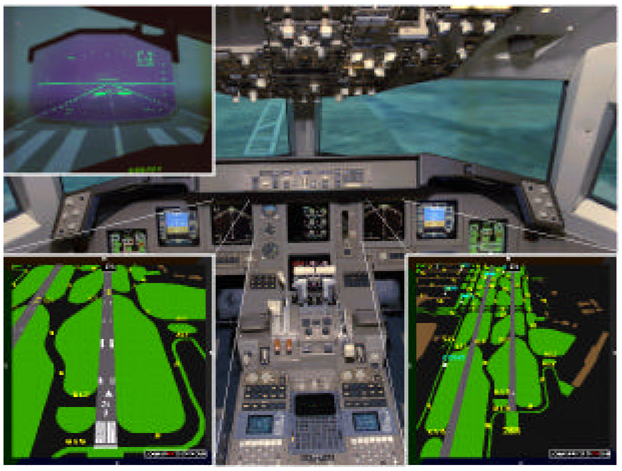

Figure 2. RFD Display Configuration

An Electronic Moving Map (EMM) mode was added to the standard suite of ND modes. If the pilot selected EMM mode, the ND would show the airport layout along with the current position of the ownship, current positions of other traffic, and ATC instructions [5]. Several zoom/scale levels were available to pilots when using this ND mode.

Figure 3. EMM Display during Departure (left) and Arrival (right) Runway Incursions

ATC instructions were depicted both graphically and textually. Graphic depictions of ATC instructions included the approved route and any hold-short locations. This ND mode was provided to support all weather navigation while reducing the likelihood of runway incursion by supplementing awareness of position, traffic, and routing constraints.

Runway incursion and route deviation alerts were also generated during the simulations. Incursion alerts took the form of an audible enunciation of the phrase "Runway Traffic, Runway Traffic" in the flight deck. The textual form of this alert was presented on both the HUD and the EMM mode of the ND. On the EMM, the traffic symbol representing the incurring aircraft/vehicle changed color (red) and flashed (figure 3). The system monitored the runway for incursions by other aircraft during ownship takeoff roll and during final approach. The system also detected deviations from the assigned taxi route and sent them to ATC. Corrective action could then be taken before a blunder lead to an incursion.

ATC Display

The Controller Communication and Situational Awareness Terminal (C-CAST) was provided to subject controllers during the simulations. C-CAST provided three basic capabilities in support of the A-SMGCS operational concept [12].

- Real-time display of surface traffic positions and identity;
- Real-time display of flight status information (digital flight strips) for all aircraft; including: flight number, aircraft type, push-back time or arrival time, and route deviation alerts;
- Controller-Pilot Data Link Communication (CPDLC). ATC can transmit messages via voice recognition or touchpad. Messages sent to pilots or received from pilots are displayed on the appropriate flight strip.

Test Matrix and Scenarios

The test matrix consisted of four control variables: the crew, the display configuration, the airport configuration, and the visibility conditions. As these variables changed from run to run, the operational task remained the same for either an arrival or departure scenario.

For arrival scenarios, the RFD was initialized 5 nmi out on the ILS glideslope and localizer for the outer runway. Traffic would be in the scene landing at 3 nmi (~80 sec) intervals in front of and behind the RFD position, as well as departing on the inner runway at the 90 second rate. At start, the crew would engage the autoland system. If the HUD was made available for a particular run, the crew would select the desired runway exit and receive guidance to that exit during roll-out. After exiting the runway, the crew would call ATC for taxi instructions; once received, the crew would taxi to the designated ramp area using the guidance and situational awareness displays as needed along the way. During the scenario, the ATC test subject was responsible for issuing routing instructions to all aircraft. ATC also issued hold-shorts as necessary. The RFD received CPDLC messages in addition to the standard voice radio instructions.

For departure scenarios, the RFD was initialized at ramp locations (after pushback). At start, the crew would call for taxi-out instructions. On receipt from the ATC test subject, the crew would taxi out to the designated runway, along with all other departing aircraft, and takeoff adhering to any additional ATC instructions (e.g. hold-shorts) along the way. Departure scenarios ended after breaking through 2000' altitude.

Two specific runway incursion scenarios were implemented as slight modifications to the above scenarios. Infrequently, during final approach, an aircraft would taxi onto the active runway in front of the RFD (figure 3). If the crew detected the incursion, either visually or based on an alert, they were instructed to perform an immediate go-around. The second incursion scenario occurred during a departure. On take-off roll, an aircraft would taxi onto the active runway in front of the RFD (figure 3). In this case, if the incursion was detected, the crew was instructed to abort the takeoff.

In summary, each three-person team (captain, first-officer, and controller) performed 24 such scenarios using a particular airport configuration. 24 additional scenarios were completed after switching the airport configuration and the captain/first-officer positions. In total, 432 scenarios were completed. Average scenario duration was about nine minutes.

Test Subjects and Procedures

For each trial, three test subjects participated; captain, first-officer, and ATC. The ATC subject was asked to perform the duties of both tower and ground controller and to issue instructions over the voice channel to all aircraft (including the RFD) in a manner consistent with normal duties. The two-person crew in the RFD was also instructed to perform normal duties (e.g. checklists) and to use the experimental displays only *as needed*. Because efficiency (time and velocity) was being measured, the crew was asked to expedite operations while mimicking a revenue flight - considering passenger comfort and safety at all times.

18 active commercial airline pilots and six active air traffic controllers participated. The average flight experience for the airline pilots was 10,600 hours. Test controllers had experience in tower facilities such as the Los Angeles, LaGuardia, and Norfolk International airports.

Results

To reiterate, the primary objective of this experiment was to test the hypothesis that safety and clear-weather flow rates can be maintained using this A-SMGCS architecture regardless of visibility condition. While it is practically impossible to prove this hypothesis in a simulator environment, a few key indicators have been quantified re-inforcing the operational concept.

Tables 1 and 2 show velocity data recorded during the study for six[4] of the pilots. Note that pilots, in general, maintained velocity regardless of the visibility conditions (down to 150'). Note also, that in many cases, pilots actually taxied faster in lower visibilities. This is due primarily to the fact that, as visibility deteriorates, pilots relied more on the guidance and less on external visual cues. Table 2 also lists runway occupancy time (ROT) data. The key finding here is that ROT remains consistent across the visibilities. In general, ROT would increase to a particular exit as the visibility reduced

[4] For brevity, data from all subjects and all runs is not shown.

(particularly at 150’), or at unfamiliar airports, without the supplemental guidance.

Table 1. Average Taxi Speeds (knots) vs. Visibility for 8R Departures

Pilot	Clear	1200’	700’	150’
1	15.3	17.4	17.7	19.9
2	16.0	17.5	18.7	18.5
3	17.0	16.0	13.2	14.6
4	13.3	15.6	15.2	15.5
5	12.1	16.0	13.9	16.0
6	17.4	16.7	18.9	15.0

Table 2. Average Taxi Speeds (knots) and ROT (sec) vs. Visibility for 8L Arrivals

Pilot	Clear	1200’	700’	150’
1	29.7 (43)	27.6 (43)	32.8 (39)	27.2 (44)
2	22.0 (30)	19.8 (29)	27.5 (29)	25.5 (30)
3	20.0 (44)	19.4 (33)	20.3 (37)	23.1 (31)
4	20.1 (32)	20.4 (32)	20.6 (30)	21.5 (32)
5	15.5 (31)	21.8 (31)	17.1 (32)	19.0 (33)
6	22.8 (31)	20.4 (32)	24.7 (31)	22.1 (34)

A secondary objective was related to the appropriateness of automatic onboard runway incursion detection and alerting. As was described, there were two types of incursions tested. Figure 4 compares the minimum altitudes prior to go-around for the arrival incursion scenarios. These incursions occurred in 1200’ visibility with ownship altitude at only 150’. Descent rate was about 10’/sec.

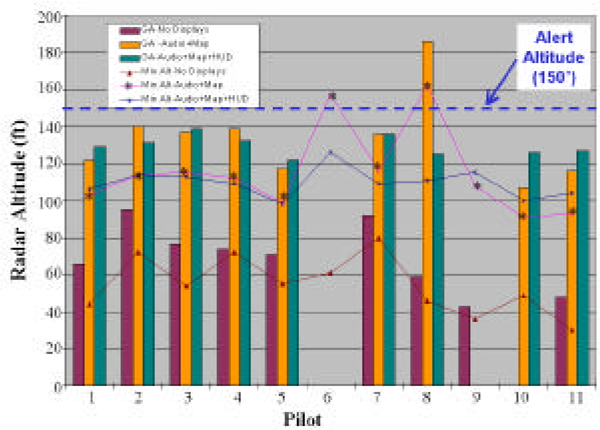

Figure 4. Runway Incursion Detection Altitudes by Pilots on Approach to 8L

Notice that the automatic detection and alerting system resulted in approximately six additional seconds (60 feet of altitude) for the pilot to avoid the conflict. Reaction time to the alert is about two seconds. Figure 4 also shows that without the automatic detection, a collision probably would have resulted. Pilots 1, 8, 9, and 11 were below 45’ when they started climbing. This is less than the height of some aircraft tail sections.

Finally, Figure 4 shows that detection can also be accomplished by strict monitoring of the cockpit traffic display. In this manner, pilots 6 and 8 detected the incursion before the automatic alert was triggered and performed the go-around.

Questionnaire data was also solicited from the subjects and can be summarized as follows. Both pilots and controllers were unanimous in supporting the operational concept in general. To maintain safety and efficiency, pilots felt the EMM would be sufficient to CAT II minima (1200’), but the HUD may be needed for CAT IIIA-B minima (700-150’). Pilots suggested that escape guidance for incursions during final approach was desirable. The audible incursion alerts were noted as an appropriate means of informing the crew. All pilots said they felt “safer” having this technology onboard.

Flight Testing

An operational flight test has been scheduled for DFW using NASA’s B-757 test aircraft. This testing is in cooperation with the FAA’s RIRP. The DFW implementation will build on the system demonstrated at ATL in 1997 [5]. In fact, the ATL system can be considered the “baseline” system. Basically, the research team seeks to implement the ATL system at DFW with the enhancements listed below. As the tests are currently scheduled to occur during DASC, results will be published separately.

- Runway incursion advisories in the flight deck
- RIRP surveillance data server integration
- Onboard ADS-B and surface TIS-B integration
- Local Area Augmentation System (LAAS) prototype integration
- CPDLC via VHF Data Link (VDL) Mode 2
- EMM retrofit onto Size B Navigation Display
- AMDB using a generic exchange format and consistent with RTCA draft requirements [6]

Summary

An operational concept and system architecture has been proposed for Advanced Surface Movement Guidance and Control Systems (A-SMGCS) that focuses on runway incursion prevention and operational efficiency. The operational concept lends itself to incremental implementation as particular technologies mature. To meet its full potential, the system requires aircraft be equipped with a positioning sensor (e.g. GPS), an airport mapping database, a data link capability, and a display. Controllers would require an all-weather surveillance capability (e.g. radar or ADS-B), a data link capability (CPDLC), and a display. It is important to note that even without a CPDLC capability, ownship position awareness and traffic awareness would be significantly improved, reducing the likelihood of runway incursion.

Results of the simulation study reinforce the hypothesis that clear-weather flow rates can be safely maintained down to very low visibilities. In particular, the simulation results have suggested that ROT and average taxi speeds can be maintained, if not improved, in low visibility conditions. Finally, the data suggests that further investigation into the automatic onboard detection of runway incursions is justified. While pilot detection of runway incursions based solely on strict use of a traffic display may be sufficient to catch the majority of incursion situations, this requires close monitoring of the displayed runway on short final approach or departure roll. This additional workload and the probability of human error must be traded against a non-zero probability of missed detection and false alarm associated with automatic detection schemes.

Acknowledgments

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