

AIRPORT SURFACE MOVEMENT TECHNOLOGIES - ATLANTA DEMONSTRATION OVERVIEW

Denise R. Jones, NASA Langley Research Center, Hampton, Virginia

Steven D. Young, NASA Langley Research Center, Hampton, Virginia

Abstract

A flight demonstration was conducted in August 1997 at the Hartsfield Atlanta (ATL) International Airport as part of low visibility landing and surface operations (LVLASO) research activities. This research was aimed at investigating technology to improve the safety and efficiency of aircraft movements on the surface during the operational phases of roll-out, turnoff, and taxi in any weather condition down to a runway visual range of 300 feet.

The system tested at ATL was composed of airborne and ground-based components that were integrated to provide both the flight crew and controllers with supplemental information to enable safe, expedient surface operations. Experimental displays were installed on a Boeing 757-200 research aircraft in both head-up and head-down formats. On the ground, an integrated system maintained surveillance of the airport surface and a controller interface provided routing and control instructions.

While at ATL, the research aircraft performed a series of flight and taxi operations to show the validity of the operational concept at a major airport facility, to validate simulation findings, and to assess each of the individual technologies' performance in an airport environment. The concept was demonstrated to over 100 visitors from the Federal Aviation Administration (FAA) and the aviation community. This paper gives an overview of the LVLASO system and ATL test activities.

Introduction

NASA's Terminal Area Productivity (TAP) program is aimed at developing requirements for terminal area operations and technologies that will safely enable the same, or

higher, capacity at the major airports in Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC). TAP research activities have been decomposed into four sub-elements: air traffic management, reduced separation operations, aircraft-ATC integration, and low visibility landing and surface operations. A flight test was conducted in 1997 as part of ongoing research under the LVLASO sub-element of TAP, in conjunction with the FAA and several industry partners.

In general, the LVLASO research is aimed at investigating technology to improve the safety and efficiency of aircraft movements on the surface during the operational phases of roll-out, turnoff, inbound taxi, and outbound taxi. This investigation becomes critical with the growing demands for air travel, the increasing number of reported surface incidents (287 in 1996) and fatal accidents (5 since 1990), and the economic, environmental, and geographic infeasibility of constructing new airports and/or runways. The goal of this research, which began in 1993, is to investigate technology to make better use of existing runways and ideally, enable safe VMC capacities (i.e. flow rates) on the surface in weather conditions down to a visibility of 300'.

Specifically, the objectives of the ATL flight test were to demonstrate a prototype system that has the potential to meet the LVLASO goal; validate selected simulation findings and the operational concept at a major airport facility; and assess the performance and suitability of the prototype as compared to (a) the operational requirements of an Advanced Surface Movement Guidance and Control System (A-SMGCS) [1], as well as (b) the requirements of NASA's conceptual system.

This testing was based on several pieces of prior and related work including "lessons-

learned” in flight simulation studies at NASA’s Langley [2] and Ames [3][4][5] Research Centers; a flight test performed at the FAA Technical Center in 1995 [6]; and two draft requirements documents [1] [7].

System Description

The surface operations system tested at ATL consisted of both ground and flight components that were integrated via three digital datalinks as well as the normal voice channels. The flight system provided the crew with enhanced guidance and situational awareness information through the use of a head-up display (HUD) and a head-down liquid-crystal display (LCD). These displays were integrated with onboard sensors and datalinks that provided the necessary input data as well as providing aircraft state data to the ground components. The displays were designed to function based on the phase of flight. The Roll-Out Turn-Off (ROTO) display symbologies and functions were used during high-speed roll-out and runway exit. The Taxiway Navigation and Situational Awareness (T-NASA) [3] display symbologies and functions were engaged during taxi. Regardless of the phase of flight, the information presented on the displays was intended to supplement missing visual cues in low visibility situations or at night, and to reinforce any available visual cues that may have an uncertainty associated with them (e.g. traffic positions, path to follow, etc.).

Similarly, ground components of the system provided the controller with supplemental information about traffic (e.g. position, identity, and intent), as well as a means for communicating with the flight crew over a digital link, in parallel with the normal voice channel. As with the flight crew, the information provided was meant to supplement missing visual cues and to reinforce uncertainties associated with the visual cues that were available.

Flight System

Figure 1 depicts the architecture for the experimental flight system employed at ATL. As mentioned previously, the testing was conducted using a Boeing 757-200 (B-757) research aircraft. Modifications to the flight

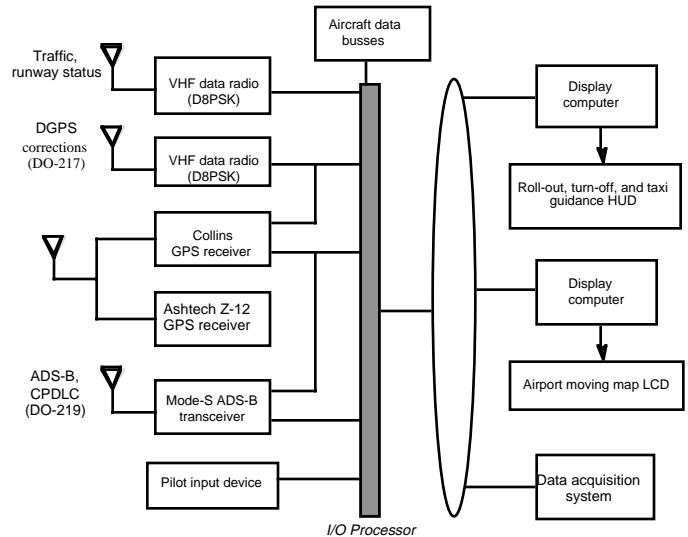


Figure 1. Flight System.

deck included installation of three hardware devices (figure 2).

A *Head-Up Display* device was mounted in front of the left seat position and was used to display ROTO and taxi guidance symbology. This specific HUD was manufactured by Flight Dynamics, Inc. and was capable of projecting a holographic image based on a raster-type graphics input. The field of view was 30 degrees horizontal by 24 degrees vertical.

A *Liquid-Crystal Display* device was mounted under the glare shield (left of center) and was used to render the raster moving map symbologies. This LCD was manufactured by



Figure 2. Flight Deck Layout

Rockwell International. It was sunlight readable and provided a 1024x768 pixel resolution, an 8"x6" viewing area, and a 65 degree horizontal viewing angle which allowed for viewing by both crew members.

A *Pilot Input Device (PID)* was mounted on the center aisle stand and allowed the pilots to control the experimental displays.

Aft of the flight deck, pallet workstations contained the necessary on-board systems required for data acquisition/recording, power, flight management, audio/video recording/telemetry, datalink, and display generation. Hardware aft of the flight deck included:

Dedicated computers were used to generate the experimental displays. A *Silicon Graphics Indigo2 Extreme* computer generated the map LCD display while a *Silicon Graphics Personal Iris (PI)* computer generated the HUD images. These computers supported a SCRAMNET (described below) interface that allowed them to communicate with each other and also the I/O subsystem. The software system design is described in [8].

Two identical *VHF data radios* were provided by Rockwell International. One radio was responsible for receiving DGPS corrections. The other radio was responsible for receiving traffic and runway status information provided by the ground surveillance system. The radios employed the Differentially encoded 8-Phase Key Shifting (D8PSK) modulation waveform and adhered to the RTCA standard protocol DO-217 [9].

An *Extended Mode-S transponder unit* was provided by Rockwell International. This unit contained a Mode-S radio, a GPS receiver, and an air datalink processor. The unit provided GPS position reports to the ground surveillance system. These reports adhered to Automatic Dependent Surveillance Broadcast (ADS-B) specifications [10]. This unit also supported the bi-directional Controller-Pilot Datalink (CPDLC) which adhered to the RTCA standard protocol DO-219 [11].

An *I/O processor* was responsible for reformatting data received by the experimental datalinks and providing it to the display computers. This processor also relayed data to

be downlinked to the test controller at the ground site via the Mode-S transceiver. Finally, the processor integrated DGPS and Inertial Reference Unit (IRU) position data ensuring a continuous position update on the experimental displays. This also allowed for intermittent outages of the DGPS system and convergence to an accurate position when DGPS data was valid. A description of the algorithms employed for DGPS/IRU integration is given in [12].

The *Data Acquisition System (DAS)* stored digital data that was time stamped using the GPS time reference.

A *SCRAMNET I/O network* is a ring network that allows nodes to communicate via virtual shared memory blocks. For this testing, the four nodes on the SCRAMNET were the DAS, I/O processor, Indigo2, and PI.

A *video recording system* logged the following images: tail perspective, nose perspective, flight deck activity, scan-converted HUD display, scan-converted map display, and a view from near the pilot's eyepoint.

An *audio management system* allowed researchers to communicate from any seat position with (1) each other, (2) the flight deck, and (3) the ground. All audio received in the flight deck (by both the pilot and co-pilot) as well as voice transmissions to ground locations were recorded on the video recorders.

A *telemetry system* was capable of sending two of the six available video images to the ground simultaneously for viewing by visitors and ground participants during the testing.

An independent *GPS survey system* was employed using an Ashtech Z-12 receiver. This system recorded GPS data and, along with data stored at the ground site, allowed for post-processing that resulted in nominal 5cm accurate position data. This data was used to evaluate the accuracy of the experimental real-time position determining system.

Ground-Based System

The ground subsystem is illustrated in figure 3. It provided surveillance of the airport surface and enabled the transfer of required

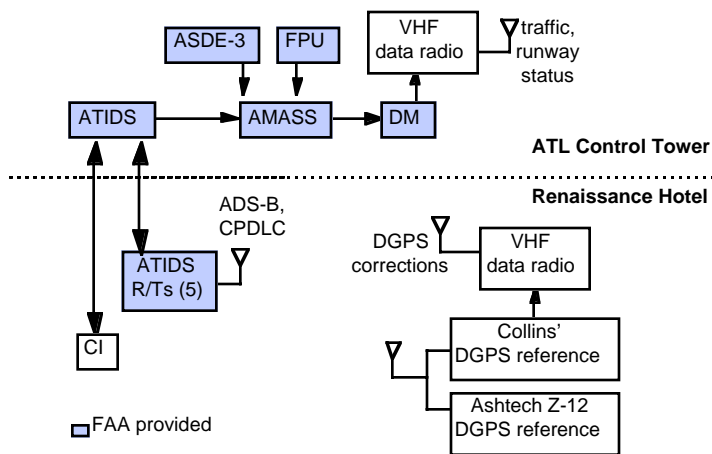


Figure 3. Ground System.

information among the functions implemented on the ground and the B-757 research aircraft.

The surveillance system consisted of four primary elements (ASDE-3, AMASS, FPU, and ATIDS). The first three are already part of the NAS and are used to provide controllers with supplemental traffic information in real-time such that safe separations can be maintained for surface movements. The fourth, ATIDS, is an FAA research and development project that is primarily aimed at providing identity information to controllers. The four elements were integrated in an attempt to provide full coverage of the airport surface, to provide identity information to both pilots and controllers, and to collect data so that multipath mitigation algorithms can be developed. Requirements for a surveillance function are listed in [1].

The *Airport Surface Detection Equipment (ASDE-3)* [13] captured position data (range and azimuth) at a 1 Hz rate for all aircraft or vehicles operating on the airport surface movement area. ASDE-3 does not require any equipment on aircraft or vehicles and is capable of detecting targets with a cross section as small as three meters. It operates in the Ku-band (15.7 - 16.2 GHz) and has a range specified to be 24,000 feet in all directions on the surface and up to 200' above the surface. ASDE-3 and its associated display is scheduled for deployment at 36 airports. At the time of the testing, the ASDE-3 display was available and operational in the ATL tower cab although it was not fully commissioned.

Although ASDE-3 is a high performance radar system, it does have certain limitations. ASDE-3 has a 500' "cone-of-silence" area encircling the antenna in which targets are not visible. Further, there can be other coverage gaps with particular ASDE-3 installations as it is a line-of-sight radar. Also, ASDE-3 is susceptible to multi-path reports. This can result in a false target being reported and possibly displayed. Finally, ASDE-3 does not report target identity information. It is because of these issues the other systems described below were integrated with ASDE-3 for this testing to maximize coverage, minimize multi-paths, and provide identification which is required in [1].

The *Airport Surface Target Identification System (ATIDS)* captured position and identity data for aircraft and ground vehicles with operating ADS-B and Mode-S transponders by performing a multilateration function [14] through the use of five fixed receiver/transmitters (R/Ts). In addition, ATIDS captured the ADS-B transmissions emanating from the research aircraft and also acquired data from the FPU (described below). The ATIDS update rate was specified to be 1 Hz. The coverage area for the ATL ATIDS was specified to be only on the north side of the airport out to 500' beyond the approach end of the runways and up to 500' above the surface.

The *Airport Movement Area Safety System (AMASS)*, as configured at ATL, provided the following: (a) tracking of ASDE-3 targets; (b) data fusion of ATIDS target data with ASDE-3 track data, and (c) safety logic to detect occupied runways and alert controllers and the test pilots. AMASS is an enhancement to the ASDE-3 radar that provides automatic alerts and warnings (visual and aural) to the controller [15][16]. AMASS is being designed to overlay information on the ASDE-3 display; however, for this testing, an independent AMASS display was used. AMASS was designed to track up to 200 targets.

For this testing, AMASS was also responsible for passing target information and runway status to a *Datalink Manager (DM)*. The DM converted this data into the protocol required by the D8PSK transmitter for transmission to the B-757. The DM was designed to be able to support multiple transmitter types simultaneously such that

aircraft/vehicles with different receivers could acquire the traffic broadcast (if a reciprocal transmitter were connected to the DM). This enables alternate datalinks to be utilized.

A *Flight Plan Unit (FPU)* provided a transparent interface to the ARTS-III A system database. This allowed ATIDS to extract the Mode-A code, the aircraft call sign, and the aircraft type from the database, in real-time, and associate this information with specific Mode-S transmissions received. All retrieved information was forwarded to AMASS for use by the fusion function. This resulting fused surveillance data was provided to both the test ground controller and the B-757's flight crew enabling them to have the same "picture" of the airport surface traffic at any point in time. This is a requirement specified in [1].

An independent *GPS ground station* was implemented to provide differential corrections. It consisted of two GPS receivers and a VHF data radio. These components were identical to those used onboard the research aircraft. One of the GPS receivers was an Ashtech Z-12 that was responsible for storing data for post-processing to obtain high accuracy "truth" position data. The other was the Rockwell-Collins GPS receiver that operated in conjunction with the D8PSK radio transmitter to fully implement the RTCA DO-217 specification [9].

Display Symbolologies

Moving Map LCD

The map LCD (figure 4) onboard the B-757 provided both crew members with:

- depiction of the airport layout
- depiction of current position and heading of the B-757
- depiction of current position of other traffic on the movement area
- display of ATC instructions including the taxi route
- display of runway status (indicated occupied runways)

This map display format was part of the T-NASA system that has undergone human factors testing in several simulation studies [3][4][5]. In addition to the input data received from the datalinks and the DGPS/IRU system

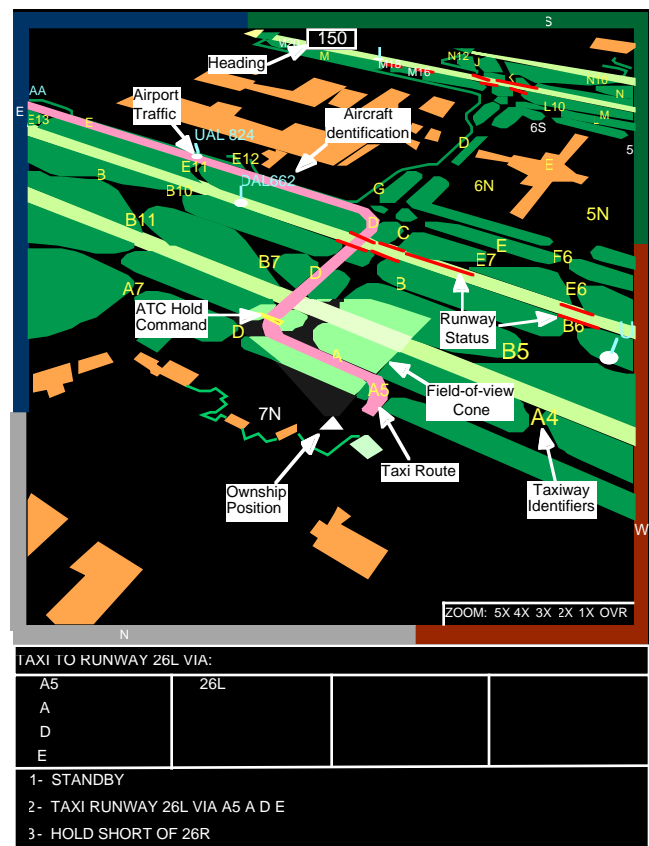


Figure 4. Moving Map LCD Symbolologies.

onboard, an accurate airport database was also required. This database was provided by Jeppesen-Sanderson and included all runway/taxiway edges and centerlines as well as hold-short lines. These were all required to be accurate to one foot (0.3m).

The flight crew interacted with the electronic map through the PID. The crew was able to select from six zoom levels, one of which was an overview of the entire airport. The airport overview zoom level was north up while all other zoom levels were track up. The crew also had the choice to display symbols for other traffic and, if displayed, show traffic identification labels, if desired. The capability also existed to scroll through the list of ATC instructions displayed in the lower portion of the map LCD.

In addition to rendering the display, the moving map computer generated downlink messages that were relayed to the test controller at the ground site. For example, if the B-757

deviated from the route issued by ATC, a message was sent to the test controller alerting him of this deviation. Similarly, if the B-757 got back on its approved path, a “taxi route resolved” message was sent to the test controller.

Roll-Out, Turn-Off, and Taxi Guidance HUD

On the HUD, from final approach until the B-757 had safely exited the runway, the roll-out and turn-off (ROTO) symbologies were enabled. Specifically, while in the landing phase, the ROTO system displayed symbology similar to that found on commercial HUD systems designed to provide landing guidance. Once the aircraft landed and the nose strut was compressed, the symbology transitioned from the in-flight symbology to the roll-out and turn-off guidance symbology (figure 5). While rolling out, the symbologies were presented to reinforce available visual cues that may be obscured due to visibility or darkness (i.e. runway edges and runway remaining markers) and to provide a deceleration profile to follow that would minimize runway occupancy time to the chosen exit. The goal was to maintain VMC roll-out turn-off times in IMC conditions or at night. After turning off of the runway, the pilot decelerated the aircraft to taxi speed, or to a stop, depending on controller instructions received.

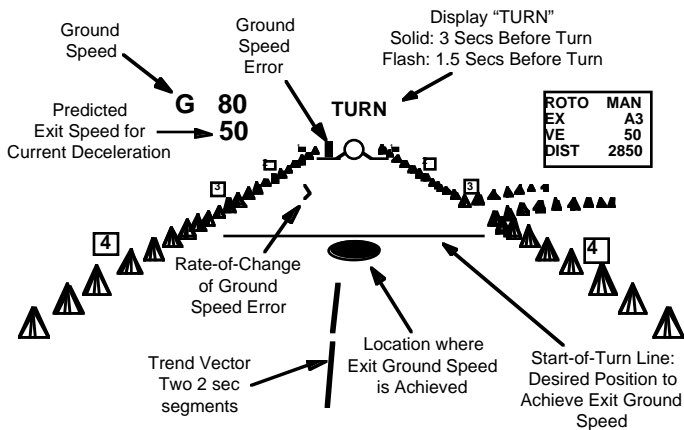


Figure 5. ROTO HUD Symbologies.

Once the taxi instructions were given by ATL control and were also delivered verbally by the test controller, the HUD symbology transitioned from the ROTO mode to the taxi mode (which was also part of the T-NASA system). The taxi symbols, which pertained to

the approved taxi route, are shown in figure 6 and included:

- taxiway centerline markings
- path boundary cones
- indications of location and angle of turns
- ground speed
- previous, current, and next taxiway identifiers

All HUD symbols were displayed relative to the pilot’s eye reference point such that they overlaid the outside scene.

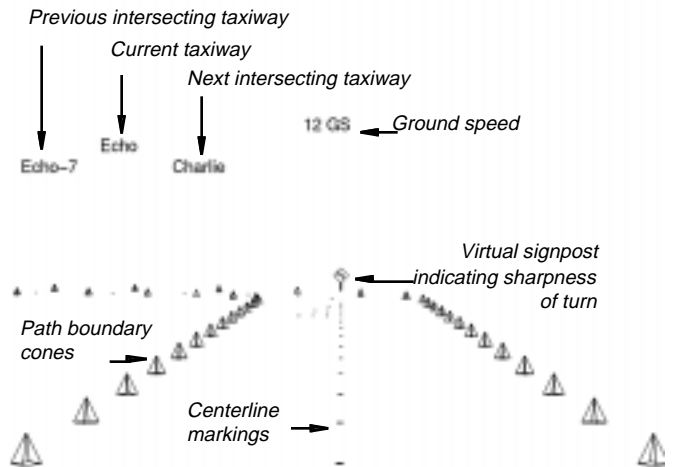


Figure 6. Taxi HUD Symbologies.

Controller Interface

A *Controller Interface (CI)* (figure 7) allowed a test controller located at a ground test site to mimic ATC verbal instructions in parallel,

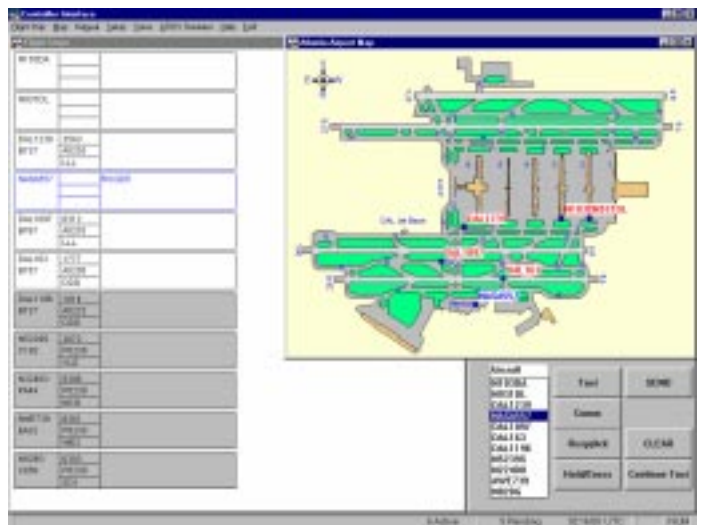


Figure 7. Controller Interface Display.

and then transmit these instructions digitally for display in the flight deck of the B-757. Two-way communications with the research aircraft were implemented using Mode-S Specific Services [17]. These adhered to the RTCA standard DO-219 [11]. The CI provided:

- electronic flight strips updated in real-time
- continuous display of surface traffic positions and identification on an airport map
- controller instruction capture and datalink to the B-757 via voice recognition or touchscreen
- alerts of route deviation by the B-757
- runway exit taken by the B-757

The CI was developed by St. Cloud State University [18].

Flight Test Operations

The deployment to ATL occurred during August 1997. Flight test runs were conducted using NASA test pilots and commercial B-757 captains as subjects. Demonstrations were conducted for over 100 visitors from the aviation community. These demonstrations included a briefing, an opportunity to view a flight test from the ground site, and a tour of the B-757.

All flight test runs were enacted with the following guideline: the operation shall follow, as close as possible, a routine flight operation from “gate-to-gate”. The only difference, operationally, would be the additional tools provided to both the test pilots and the test controller that would show the potential for improving the safety and efficiency of the surface operation.

The crew of the B-757 was instructed to maintain radio contact as needed with the ATL ATC during the testing. Because the CI was at the prototype stage, a test controller was used. This controller was located at the ground site (not in the tower cab) and monitored ATL ATC communications. Any instructions designated for the B-757 were sent electronically to the aircraft, in parallel, using the CI.

The crew was also instructed to utilize the HUD and map LCD while maneuvering the B-757 on an as-needed basis. The HUD was to be used by the captain for supplemental

guidance cues and enhanced situational awareness during landing, roll-out, turnoff, and taxi. The map LCD was to be used primarily by the first officer for situational awareness which could then be relayed to the captain if necessary. The captain could refer to the map LCD occasionally if desired. During test runs, the flight crew could manipulate the map LCD using the PID as desired. Specific details on how to use the LVLASO display system were provided as part of each pilots’ training procedure prior to the flight experiment.

All flight test runs began in the ramp area located at the Fixed Base Operator (FBO) just north of runway 8L/26R. At initiation of a run, the B-757 was in position to begin taxi and the responsible flight deck crew member called for taxi instructions from ATL ATC. These instructions were sent to the aircraft by the test controller in parallel with the verbal ATC commands. The captain then taxied to the designated departure runway. After taking the runway, the B-757 would either (1) takeoff/circle/land or (2) taxi down the runway depending on the test run. Once clear of the runway, the B-757 verbally received a taxi instruction from ATC. Again, this instruction was sent to the B-757 by the test controller in parallel via datalink. After the crew verbally acknowledged receipt of the instruction, the captain taxied back to the FBO ramp area following the designated path. While taxiing, the captain was instructed to taxi at a normal taxi rate or higher if he felt safety was not being compromised.

Runs that required a landing tested both the ROTO and T-NASA systems. If a takeoff was not required, only the taxi guidance system onboard (T-NASA) was evaluated.

Tests runs were conducted predominantly at night as this more closely represents a “low visibility” condition. A total of 53 test runs were successfully completed which resulted in 1378 minutes (almost 23 hours) of audio, video, and digital data. The average run time was 26 minutes.

Conclusion

This testing has successfully demonstrated and validated the potential for

using technology and a holistic systems approach for improving the safety and efficiency of airport surface operations. By providing supplemental guidance and situational awareness information to both pilots and controllers, safety margins can increase since there is more confidence in the understanding of the current state of the airport surface. In poor visibility, at night, or at unfamiliar airports, this supplemental information becomes critical, particularly if VMC flow rates are expected to be maintained safely.

This paper was meant to be an overview of the testing that occurred at ATL in August 1997 as part of the TAP LVLASO program. Results and findings were not addressed here but are documented in [19]. Several other papers presented at the 17th Digital Avionics Systems Conference discuss the details and analysis of the various subsystems employed at ATL.

References

1. "Draft Manual of Advanced Surface Movement Guidance and Control Systems (A-SMGCS)", 16th Meeting of the International Civil Aviation Organization's All Weather Operations Panel, Montreal, Canada, June 1997.
2. Batson, V., Harris, R., and Hunt, P., "Navigating the Airport Surface: Electronic vs. Paper Maps", Proceedings of the 13th Digital Avionics System Conference, October, 1994.
3. Foyle, D., "Taxiway Navigation and Situation Awareness (T-NASA) System", Ninth International Symposium on Aviation Psychology, Ohio State University, April, 1997.
4. McCann, R., Andre, A., Begault, D., Foyle, D., and Wenzel, E., "Enhancing Taxi Performance Under Low Visibility: Are Moving Maps Enough?", Proceedings of the 41st Annual Meeting of the Human Factors and Ergonomic Society, pp. 37-41, 1997.
5. Foyle, D., Andre, A., McCann, R., Wenzel, E., Begault, D., and Battiste, V., "Taxiway Navigation and Situation Awareness (T-NASA) System: Problem, Design Philosophy and Description of an Integrated Display Suite for Low Visibility Airport Surface Operations", SAE Transactions: Journal of Aerospace, v105, pp. 1411-1418, 1996.
6. Jones, D., Young, S., Wills, R., Smith, K., Shipman, F., Bryant, W., and Eckhardt, D., "Flight Demonstration of Integrated Airport Surface Technologies for Increased Capacity and Safety", NASA TM-1998-206930, February, 1998.
7. Cassell, R. and Smith, A., "Development of Required Navigation Performance Requirements for Airport Surface Movement Guidance and Control", Proceedings of the 14th Digital Avionics Systems Conference, November, 1995.
8. Beskenis, S., Green, D., Hyer, P., and Johnson, E., "Integrated Display System for Low Visibility Landing and Surface Operations", NASA/CR-1998-208446, July, 1998.
9. "Minimum Aviation System Performance Standards, DGNSS Instrument Approach System: Special Category I (SCAT-I)", Document No. RTCA/DO-217, RTCA, August 27, 1993.
10. "Minimum Aviation Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B)", Draft Version 6.0, RTCA Special Committee 186, August 28, 1997.
11. "Minimum Operational Performance Standards for ATC Two-Way Datalink Communications", Document No. RTCA/DO-219, RTCA, August 27, 1993.
12. Plyler, V., Slominski, C., and Wolverton, D., "The LVLASO I/O Concentrator Software Description, Version 3.5", NASA/CR-1998-206907, January, 1998.
13. Go, G., and Ianniello, J., "Third Generation Airport Surface Detection Equipment Design", Proceedings of NAECON '94, May, 1994.
14. Friedland, B.; and Hutton, M., "New Algorithms for Converting LORAN Time Differences to Position", Navigation: Journal of the Institute of Navigation, Vol. 20, No. 2, Summer, 1973.
15. Watnick, M., and Ianniello, J., "Airport Movement Area Safety System", Proceedings of the 11th Digital Avionics Systems Conference, October, 1992.
16. Ianniello, J., and Kruczek, R., "Airport Surface Collision Warning System Implementation", Proceedings of the 12th Digital Avionics Systems Conference, October, 1993.
17. "Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode-S) Airborne Equipment", Document No. RTCA/DO-181A, January 14, 1992.
18. Mattson, P., and Rankin, J., "Research and Design of an ATCT Ground Controller CPDLC Workstation", Proceedings of the 42nd Annual Air Traffic Control Association Conference, September, 1997.
19. Young, S., and Jones, D., "Flight Demonstration of Integrated Airport Surface Movement Technologies", NASA TM-1998-206283, January, 1998.