

FLIGHT DEMONSTRATION OF INTEGRATED AIRPORT SURFACE AUTOMATION CONCEPTS

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ABSTRACT

A flight demonstration was conducted to address airport surface movement area capacity issues by providing pilots with enhanced situational awareness information. The demonstration showed an integration of several technologies to government and industry representatives. These technologies consisted of an electronic moving map display in the cockpit, a Differential Global Positioning System (DGPS) receiver, a high speed VHF data link, an ASDE-3 radar, and the Airport Movement Area Safety System (AMASS). Aircraft identification was presented to an air traffic controller on AMASS. The onboard electronic map included the display of taxi routes, hold instructions, and clearances, which were sent to the aircraft via data link by the controller. The map also displayed the positions of other traffic and warning information, which were sent to the aircraft automatically from the ASDE-3/AMASS system. This paper describes the flight demonstration in detail, along with preliminary results.

INTRODUCTION

The U.S. aviation industry is investing \$6 billion over 20 years to increase airport capacity; however, there is a gap between the industry's desired capacity and the ability of the National Airspace System to handle the increased air traffic. The Federal Aviation Administration (FAA) reported that currently 23 of the largest U.S. airports experience more than 20,000 hours of delays each year, and that by the year 2000, 40 major airports are likely to be experiencing delays of this magnitude [1]. Furthermore, these air traffic delays were estimated to cost \$3 billion for airline operations and \$6 billion for passenger delays in 1990. These costs are projected to increase 50 percent in 10 years based on current trends. Action must be taken to safely increase airport capacity of existing airport facilities while reducing controller and pilot workload. The FAA plans to address these concerns by providing air traffic control, the airlines, and airfield management with positive identification of surface targets on the movement area; providing pilots with airfield safety alerts; providing controllers with automated warnings of potential and actual runway incursions; providing a surface traffic planning capability; and providing an

automated method of sending instructions, such as taxi route clearances, to aircraft.¹

Similarly, the National Aeronautics and Space Administration's (NASA) Terminal Area Productivity (TAP) Program is focused on providing technology and operating procedures for safely achieving clear-weather capacity in instrument-weather conditions. In cooperation with the FAA, NASA's approach is to develop and demonstrate airborne and ground technology and procedures to safely reduce aircraft spacing in the terminal area, enhance air traffic management, reduce controller workload, improve low visibility landing and surface operations, and integrate aircraft and air traffic systems.

This paper describes a flight demonstration that was conducted by the NASA Langley Research Center (LaRC) which addressed many of the FAA and TAP program issues.

FLIGHT DEMONSTRATION

The flight demonstration was part of the NASA TAP Low Visibility Landing and Surface Operations (LVLASO) Program. The demonstration was conducted in conjunction with industry partners from Westinghouse Norden Systems and ARINC, Incorporated. The goals of the testing were (1) to demonstrate an integrated system that would provide the pilot with enhanced situational awareness information to safely increase the traffic capacity on the airport surface movement area and (2) to identify system integration issues. The demonstration was conducted at the Atlantic City International (ACY) airport in June 1995 with the cooperation of the FAA Technical Center.

Demonstration Technologies

The demonstration showed an integration of technologies developed by each of the partners as depicted in figure 1. The following sections describe these technologies in detail.

¹ Obtained from the ASTA System Design Overview, Federal Aviation Administration.

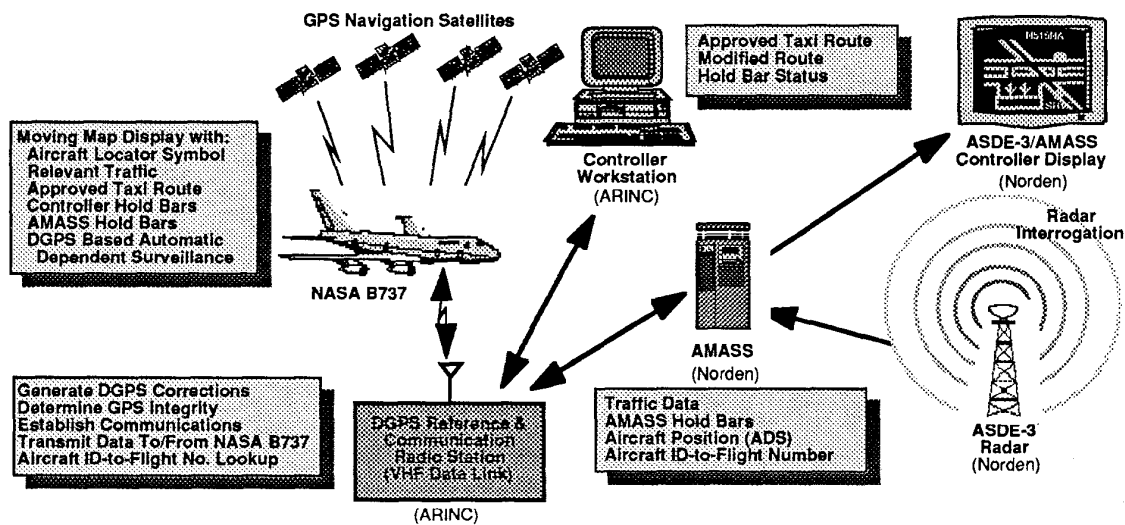


Figure 1. Flight demonstration schematic.

Transport Systems Research Vehicle -- The Transport Systems Research Vehicle (TSRV), a modified Boeing 737-130, is a NASA LaRC research aircraft [2]. The TSRV has two flight decks. The forward flight deck is a conventional Boeing 737 cockpit that provides operational support and safety backup. The "all-glass" research flight deck, located in the aircraft cabin, can be readily reconfigured to support research programs.

Ground Station -- The personal computer based ground station served as a message routing center among the various demonstration subsystems. The station included a Global Positioning System (GPS) receiver and communication radio for the data link of messages to/from the TSRV. The uplinked messages included GPS corrections, controller instructions, ASDE-3 traffic positions, and AMASS hold warnings. The downlinked messages included TSRV position reports and pilot acknowledgment of controller instructions.

Differential Global Positioning System -- DGPS was used to determine the location of the TSRV. A NASA provided GPS receiver was located onboard the aircraft. This receiver was updated with differential corrections generated by the ARINC provided GPS receiver located at the ground station.

An ARINC provided GPS receiver was also located onboard the TSRV. This GPS position data was differentially corrected as well and the resulting DGPS position was transmitted to the ground station in the form of high precision Automatic Dependent Surveillance (ADS) reports.

Data Link -- The high speed bi-directional VHF data link transmitted data at 31,500 bits per second between the TSRV and ground station. The radios used were software programmable and operated in the frequency band 118.000 through 136.975 MHz at a power output of about 20 watts. This was the world's first demonstration of the new high speed VHF Digital Link (VDL) waveform as defined in section 2 of [3].

ASDE-3 radar -- The ASDE-3 [4] is a high resolution airport ground mapping radar with maximum weather penetration capability. It scans, tracks, and identifies airport surface targets once every second. Highly integrated computer technology provides accurate runway surface maps, multiple windowing capabilities, and magnification of designated areas. Controllers use ASDE-3 to monitor airport activity.

AMASS -- AMASS [5] was designed under FAA sponsorship to enhance the surveillance and collision avoidance capabilities of the ASDE-3 radar. AMASS provides controllers with automatic conflict warnings and alerts to help prevent collisions and other runway and taxiway accidents. A research and development version of AMASS was used for the demonstration.

Controller Interface -- An interface was developed to enable the simulation ground controller to send taxi routes, hold short instructions, and clearances via data link to the TSRV for display on the electronic map. The interface was menu driven.

Electronic Moving Map -- An electronic moving map (figure 2) was developed and evaluated in simulator studies [6] at NASA LaRC. For the demonstration, the

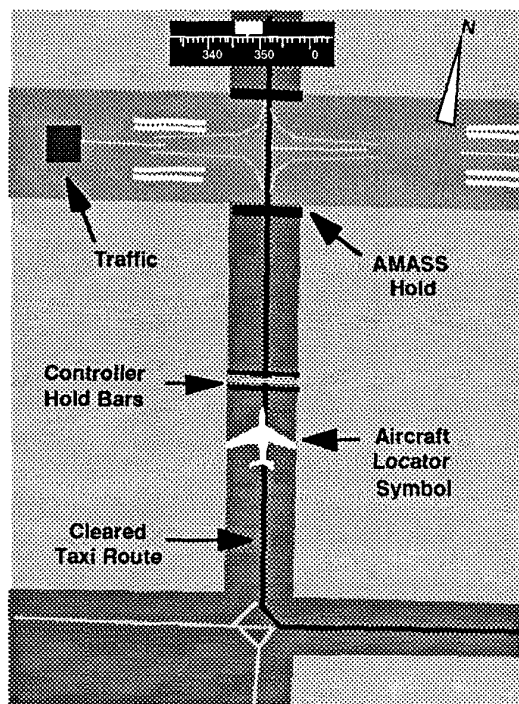


Figure 2. Electronic moving map display.

map was generated by a graphics workstation and displayed on a liquid crystal flat panel that had a 640 by 480 pixel resolution and display dimensions of 8.5 inches by 6.5 inches. The pilot interacted with the moving map through bezel switches located on each side of the display. The available functions included acknowledging the taxi route, acknowledging hold short commands, zoom in/out, show/hide other traffic, show/hide five second position prediction indicator, track/north up mode, display an insert containing the airport, and Air Traffic Control (ATC) message recall. Additionally, the map could be set at a level such that navigational aids within a 25 mile radius of the airport were visible.

Figure 2 shows the major components of the moving map. The aircraft locator was updated at 20 HZ from a blending of the position received from the TSRV's Inertial Reference System (IRS) and from the differentially corrected NASA provided GPS receiver onboard the aircraft.

Warning information that indicated occupied runways (AMASS hold bars) and positions of other traffic was transmitted to the TSRV via data link automatically from AMASS for display on the moving map. The positions of other traffic were obtained from the ASDE-3 radar via the data link.

The cleared taxi route, modified routes, and hold short clearances were sent to the TSRV by the simulation ground controller via data link. For this demonstration, the routes and modified routes were scripted for each run.

Demonstration Description

Scenario -- During a demonstration session, the TSRV followed a departure and arrival taxi route that included a real-time modification to the route. Government and industry representatives observed the taxi run from a building adjacent to the old ACY control tower. This building also housed all ground equipment and was the base of operation for the simulation ground controller.

At all times during the demonstration, the TSRV was under ACY air traffic control. The safety pilot in the forward flight deck was in contact with the control tower. The simulation controller monitored ACY control to determine what information to transmit to the aircraft through the menu driven interface. The simulation controller communicated with the research pilot in the research flight deck on the TSRV strictly by data link and with the researchers on the TSRV by voice. The research pilot was not monitoring the tower. To lessen the burden on the tower, ACY asked that the safety pilot request the desired route and holds before each run. The tower then repeated the command. At that point, the simulation controller sent the appropriate route and hold short information to the TSRV for acknowledgment by the research pilot. When a modification to the route was desired, the safety pilot requested the desired change while at a hold bar or when taxiing along the route, the tower then broadcast the command, and the simulation controller sent the route change to the TSRV. On departure, the route request was made at the gate (which was the FAA ramp in this case). Upon arrival, the request was made after exit from the runway.

The FAA Technical Center mounted three cameras on the ASDE-3 radar tower. These images were displayed at the ground site so the simulation controller could view the airport since the movement area was not visible from that location.

Additionally, the identification of the TSRV was shown on the controller's AMASS display next to the aircraft's symbol. AMASS used the ADS position report to fuse the identification with the appropriate ASDE-3 radar track.

For this flight demonstration, the electronic moving map was located in the research flight deck of the TSRV. The safety pilot in the forward flight deck was controlling the aircraft during taxi because the research flight deck did not have a steering tiller. At all times, the safety pilot was to taxi the aircraft on the centerlines. The research pilot verbally relayed routing and situation information obtained from the electronic map to the safety pilot. The

situation information included status of the TSRV on the taxi route (when turns were approaching, etc.), when holds were approaching, and the location of relevant traffic. The safety pilot was able to determine the effectiveness of the map through the situation awareness information relayed from the research pilot. The research pilot could also determine any anomalies in the electronic map by viewing how well the aircraft symbol followed the centerlines.

A video link was established between the TSRV and the ground site. This enabled the simulation controller and visitors to selectively view the electronic map image, tail camera image, or research flight deck in real-time.

RESULTS

Although these flight trials were primarily aimed at demonstrating the feasibility of integrating several advanced technologies, they also provided an opportunity to gather qualitative and quantitative real-time data. Preliminary analysis of this data has revealed characteristics about the performance of each technology individually and the system as a whole.

Data Collection

During each flight (taxi out, takeoff acceleration, landing deceleration, taxi in), data was recorded in three locations: (1) at the ASDE/AMASS site; (2) at the ground station; and (3) onboard the TSRV. All data was time-stamped to allow for synchronization and analysis after the flights.

Data recorded at the ASDE/AMASS site included all ASDE/AMASS data sent to the ground station (e.g. traffic positions and AMASS hold bars), as well as the data received from the ground station (e.g. ADS messages downlinked from the aircraft). This data was recorded every second.

Data recorded at the ground station included messages sent to and received from the aircraft (e.g. DGPS corrections, ADS messages, controller instructions, and ASDE/AMASS data). This data was also recorded every second.

Data was stored onboard the TSRV in three locations. GPS-related information (e.g. satellites tracked, GPS time, latitude/longitude, DGPS corrections, etc.) was stored in the GPS receiver every second. The flight management system recorded 80 aircraft state variables at 20 Hz (e.g. ground speed, yaw rate, nosewheel position, braking force, etc.) and also all the data received across the datalink. Five video tapes were made during each flight. These recorded video from a tail camera, a nose camera, the electronic map display, the rear flight deck cockpit, and the flight instruments. An audio tape was made of the conversations between the safety and research pilots; the safety pilots and the control tower; the research pilot and

the researchers; and the researchers and the simulation controller. Lastly, subjective comments were obtained from the pilots, controllers, and visitors on the effectiveness, content and operation of each subsystem.

Preliminary Analysis

The initial analysis has been focused on data availability, integrity, and accuracy. Availability is important in an operational environment because information must be received in a timely manner both onboard the aircraft and by the controller. Integrity ensures that the data received has not been corrupted as it moves along its path. Accuracy ensures that all target positions, including the TSRV, are correct with respect to their true position on the airport surface.

Accuracy

Table 1 lists the position accuracies obtained during testing on June 27 and June 28. The "true" position of the TSRV at all times was calculated using algorithms developed at Ohio University. These algorithms can process GPS data during post flight to determine position within five centimeters (two inches) [7] [8].

The raw ASDE-3 track data received onboard was slightly skewed from its location on the ASDE-3 display. This probably resulted from the conversion process from the ASDE's coordinate system (rho, theta) to the TSRV's coordinate system (latitude, longitude). A rotation of 0.01 radians was added (during post-processing) to the radar data received on the TSRV to minimize this skew. Had time permitted, this could have easily been done during testing at the ASDE site to eliminate this skew in real-time.

This preliminary analysis of position accuracy reveals that both sensors are adequate to allow pilots to observe relative locations of other traffic on the airport surface;

Run	DGPS		ASDE-3	
	Mean	Std Dev	Mean	Std Dev
6/27 #1	1.428'	0.872'	18.870'	12.450'
6/27 #2	0.981'	0.758'	19.271'	12.250'
6/27 #3	1.071'	0.710'	27.610'	18.919'
6/27 #4	2.124'	1.060'	24.630'	15.694'
6/27 #5	1.853'	0.680'	42.483'	33.221'
6/27 #6	2.468'	1.018'	30.134'	22.845'
6/27 #7	2.175'	0.860'	24.171'	16.207'
6/28 #1	2.320'	3.175'	45.177'	27.329'
6/28 #2	2.122'	1.175'	27.366'	13.451'
6/28 #3	2.400'	1.030'	20.680'	13.596'
6/28 #4	1.880'	1.070'	27.740'	15.912'
Overall	1.893'	0.517'	28.012'	8.655'

Table 1. Position sensor accuracies for 6/27 and 6/28.

however, for navigation or guidance, only the DGPS sensor had sufficient accuracy.

Availability

Ideally, in an operational environment, data should be available at all times both onboard the aircraft (e.g. traffic position data, DGPS corrections, and controller instructions) and on the ground (e.g. ADS messages and pilot acknowledgments). Below is a preliminary analysis of the uplinked data received onboard the TSRV during testing. Analysis of the downlinked data is ongoing and will not be presented herein.

Uplinked data consisted of the controller instructions, AMASS hold bars, DGPS corrections, and traffic positions. Instructions from the simulation ground controller were always received in a timely manner by the test pilot monitoring the cockpit map display. These instructions included the taxi route, hold short instructions, and clearances to proceed. Delays in issuing commands would sometimes occur due to unfamiliarity with the user interface at the controller workstation. However, once a command was issued, its appearance on the cockpit display was nearly immediate. Future work should address developing a more user-friendly controller interface.

To validate the uplink of AMASS hold bars, the TSRV performed a high-speed taxi while on the runway surface.

By performing a takeoff abort in this fashion, the AMASS hold bar function would be stimulated. In the 11 runs where this was attempted, the AMASS hold bars were illuminated on the cockpit display 10 times. In each of these occurrences, the bars appeared and disappeared appropriately with respect the TSRV's location on the runway. The one occurrence when the hold bars did not illuminate suggested that the TSRV did not achieve the necessary acceleration and velocity to be deemed a takeoff (or landing) by the AMASS software.

DGPS corrections received onboard the TSRV were usually received every second. However, sometimes the rate slipped to every 3-5 seconds, and occasionally every 10-20 seconds. The important thing to note here is that despite the occasional delay in receiving a correction, the DGPS solution was maintained to within one meter. (See Table 1) This is because corrections need not be updated very frequently while moving slowly on the ground (e.g. taxiing). It is apparent that an update rate of 3-15 seconds would be sufficient for DGPS corrections while taxiing on an airport surface. The exact update rate that would be sufficient to maintain accurate DGPS is dependent on the Selective Availability (SA) component of the GPS system. SA is currently controlled by the Department of Defense.

The availability of the ASDE-3 traffic data onboard the TSRV is represented in Figure 3. For these tests, traffic data was received every second 55% of the time. Similarly, traffic data was received within two seconds

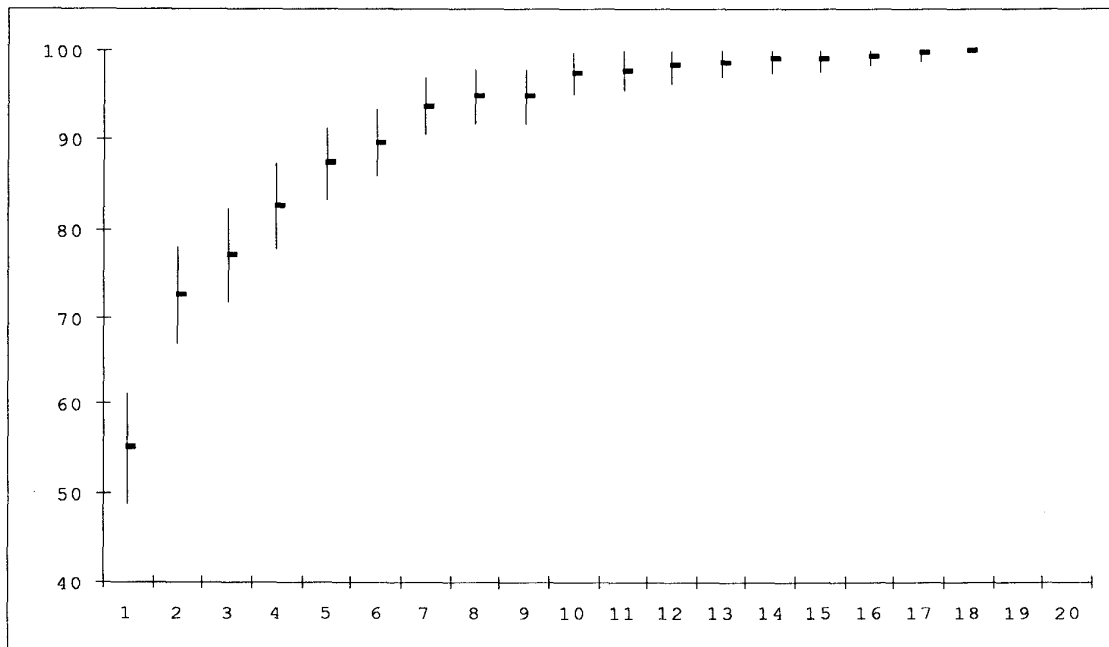


Figure 3. Availability of traffic data onboard the TSRV versus delay (seconds).

ID	ASDE-3			TSRV			%Received
	points	time (sec)	rate (sec/pt)	points	time (sec)	rate (sec/pt)	
TSRV	462	658	1.42	302	657	2.17	65.4
4260048	202	202	1.00	127	200	1.57	62.9
4260107	111	111	1.00	96	135	1.41	86.5
4260192	6	6	1.00	3	4	1.33	50.0
4260063	6	6	1.00	0	0	NA	0.0
Overall	767	983	1.25	528	996	1.89	71.6

Table 2. Target track data (6/28 Run 4).

75% of the time. Finally, if five second delays can be tolerated in receiving traffic data, it will be available 90% of the time. Future studies should address how much delay can be tolerated in receiving traffic data.

Integrity

Less than 1% of the messages received onboard the TSRV were observed to be corrupted (and these were due to format errors). However, one integrity issue observed was the intermittent disappearance of target tracks onboard the aircraft for short periods of time during specific runs.

Table 2 depicts target track data recorded at the radar site and onboard the TSRV respectively for a run performed on June 28. Note that vehicle 4260048 was tracked for 202 seconds by ASDE-3, however, the TSRV received only 127 position updates during this time. At this point it is not clear what caused this phenomena, however, it bears directly on the target availability issue described above. It is suspected that the cause is related to the method chosen to package data and/or the priorities assigned to the various message types prior to uplink.

Notice also in Table 2 (id 4260063 and 4260192) the "ghost" targets. These are general radar disturbances caused by multipath that must be considered in future testing. Future work should also address developing techniques to minimize the probability of tracking "ghost" targets both on the AMASS display and on the aircraft display.

CONCLUDING REMARKS

The flight trials successfully demonstrated an integration of current technologies that provided the pilot and controller with situation awareness information that promise to safely increasing traffic capacity on the airport surface. Preliminary analysis shows that both DGPS and ASDE-3 position data was adequate for pilot observation of relative locations of airport traffic; however, DGPS was required for navigation and guidance accuracy. Uplink data delays of traffic position were generally within 5 seconds. Further study is required to determine safe delay tolerances. Less than 1% of uplink messages were

observed to be corrupted. However, work is needed to eliminate time gaps in receiving airport traffic data onboard and the tracking of "ghost" targets. The results from this test will be used as drivers (or lessons learned) for subsequent flight testing that will occur over the next several years.

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