Airport Surface Moving Map Displays: OpEval-2 Evaluation Results and Future Plans **

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ABSTRACT

The Federal Aviation Administration (FAA), in cooperation with the Cargo Airline Association (CAA) and three of its member airlines (Airborne Express, Federal Express, and United Parcel Service), have embarked upon an aggressive yet phased approach to introduce new Free Flight-enabling technologies into the U.S. National Airspace System (NAS). General aviation is also actively involved, represented primarily by the Aircraft Owners and Pilots Association (AOPA). These new technologies being evaluated include advanced cockpit avionics and a complimentary ground infrastructure. In support of this initiative, a series of operational evaluations (OpEvals) have been conducted or are planned. The OpEvals have evaluated in-flight as well as airport surface movement applications. Results from the second OpEval, conducted at Louisville, Kentucky in October 2000, indicated that runway incursions might be significantly reduced with the introduction of a cockpit-based moving map system derived from emerging technologies. An additional OpEval is planned to evaluate the utility of an integrated cockpit and airport surface architecture that provides enhanced pilot and controller awareness of airport surface operations. It is believed that the *combination* of such an airborne and a ground-based system best addresses many of the safety issues surrounding airport surface operations. Such a combined system would provide both flight crews and controllers with a common awareness, or *shared* picture of airport surface operations.

Key words: FAA, Cargo Airline Association, runway incursions, aviation safety, cockpit moving map displays, ADS-B, airport map databases, avionics, surveillance, Safe Flight 21

1. INTRODUCTION

There is an increasing need to modernize the U.S. national airspace infrastructure to enhance safety, increase capacity and efficiency, and reduce delays. In this context, cockpit multifunction moving map displays, along with emerging data link technologies called ADS-B (Automatic Dependent Surveillance—Broadcast), TIS-B (Traffic Information Service—Broadcast), and FIS-B (Flight Information Services—Broadcast), are all seen as promising capabilities to help effect this modernization.

The airport surface movement domain, in particular, is ripe for technical innovation. Airport surface incidents, including runway incursions, are a serious safety concern. A runway incursion is defined as any occurrence at a towered airport involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in a loss of separation with an aircraft taking off, intending to take off, landing, or intending to land. Historical data indicate an increase in both the number and rate of runway incursions, even in those years when the number of airport operations decreased (see Table 1). In the eight years from 1993 to 2000, the *number* of runway incursions increased 130 percent. In the same eight-year period, the runway incursion *rate* increased 100 percent. The National Transportation Safety Board (NTSB) has listed runway incursions on its list of ten “most wanted” safety improvements each year since 1990, when the list was first initiated. Additionally, NTSB recommendation A-91-30 calls for the FAA to implement new lower cost equipment aimed at reducing runway incursions at a number of airports.

Almost all collision accidents on the airport surface have occurred because the aircraft or vehicles involved were unaware of each other. In this paper, we address how the introduction of cockpit-based moving maps, combined with certain data link technologies (e.g., ADS-B, TIS-B, FIS-B), can improve surface safety. We expect this emerging capability to result in a major reduction in runway incursion accidents and incidents.

*** This paper is for technical discussion only. It does not constitute FAA or NASA policy, nor is it endorsed by the U.S. Federal government, any of its agencies or others who may have participated in its preparation.*

1.1 What is ADS-B?

Functionally, ADS-B is a data link technology that automatically broadcasts selected aircraft information from suitably equipped aircraft. This information includes aircraft identification, position, velocity, altitude, and other essential information.(15) These broadcasts are then received by other suitably equipped aircraft, vehicles, and ground stations, providing services, functions, and capabilities based upon user or operator needs and requirements. From a runway incursion perspective, these broadcasts can be used to display aircraft and vehicles on an electronic, cockpit-based airport moving map display showing their location, direction of movement, and other attributes. This same information can also be provided to the controller. Although an ADS-B capability is an underlying assumption for the aircraft-based runway incursion system described in this paper, other ground-based surveillance sensors and appropriate data links may be needed to provide additional data to aircraft to supplement this ADS-B information. These additional sensors may include ground-based infrared (IR) systems, acoustical sensors, runway-in-pavement “loop” sensors, and primary and secondary surveillance radar. Analyses are required to determine what combinations of surveillance sources best mitigate risks at small, medium, and large airports.

Calendar Year	Number of Runway Incursions	Number of Airport Operations	Runway Incursion Rate (Per 100,000 Airport Operations)
1993	186	61,946,482	0.30
1994	200	62,452,572	0.32
1995	240	62,074,306	0.39
1996	275	61,817,425	0.44
1997	292	64,440,947	0.45
1998	325	66,218,975	0.49
1999	321	68,684,037	0.47
2000	429 (Preliminary)	70,500,000 (Estimated)	0.60 (Estimated)

Table 1: U. S. runway incursion data (17, 19)

1.2 Cockpit moving map display systems

Advances in navigational accuracy (e.g., GPS) and multifunction displays will enable new cockpit-based airborne and airport surface operational capabilities. When used on the airport surface, these new capabilities should mitigate runway incursion risks, reduce pilot deviations, and help reduce operational errors. New methods of surveillance of aircraft and vehicles on the airport surface (e.g., ADS-B and TIS-B) and vector-based, digitized, airport mapping databases will complement these new capabilities. New multifunction displays will incorporate a Cockpit Display of Traffic Information (CDTI) with an airport map database. Given mature human factors (HF) engineering, the hypothesis is that this new cockpit-based architecture should significantly decrease runway incursions. This capability may be implemented as either a panel-mounted or as a portable display system.

One likely feature of this cockpit display architecture is an alerting function that will inform the flight crew or the single pilot (of a small aircraft) of a potential loss of separation, and draw attention to a conflict. This feature should further enhance traffic situational awareness. Without an alerting feature in the cockpit, the flight crew or pilot could fail to identify potential conflicts. Additionally, this feature, if implemented appropriately, could reduce head-down time. Figure 1, below, depicts what this notional cockpit moving map display system might look like.

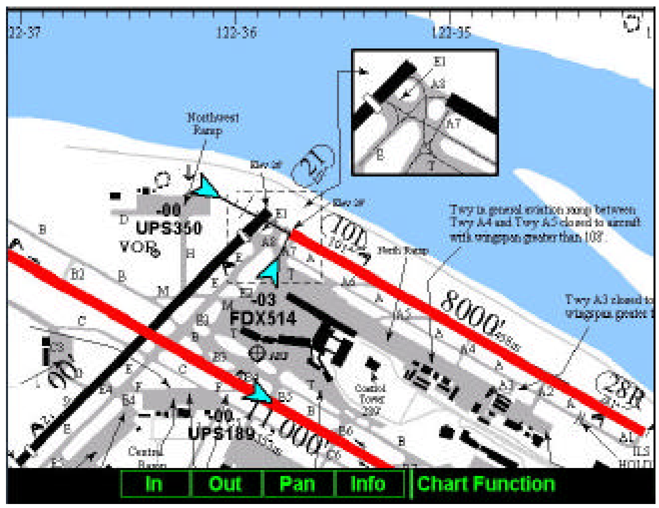
Cockpit moving map displays will augment the existing Airport Surface Detection Equipment (ASDE) and Airport Movement Area Safety Systems (AMASS) at those controlled airports that already have this equipment, and will add new capabilities for those airports that do not have this capability, including non-towered airports. At the smaller, domestic, towered and non-towered airports, and at many foreign airports, a cockpit-based moving map display system may be the only electronic line of defense against airport surface collisions. With a cockpit-based moving map, the benefits travel with the airplane from one airport to another. Also, in comparison with surface-based surveillance systems, cockpit-based displays are *proactive*, not reactive like AMASS, which is intended to generate an alert only *after* a runway incursion event has actually occurred. In this context, cockpit-based systems should also help reduce pilot deviations because they will be able to alert pilots of a potential error *before* the incursion actually occurs. In contrast to reactive alerting systems, cockpit-based systems should help prevent an incident from ever happening in the first place.

A moving map display that predicts the path of an airplane's landing gear while taxiing, and then displays this projected path to the pilot, could also help mitigate runway *excursion* incidents. A runway excursion occurs when an airplane runs off a runway or taxiway. While an extremely rare event, when it does occur, it happens most often during low visibility, at night, or when the airport surface is obscured, such as by snow. Runway excursion incidents can close airports for hours at a time, adversely affecting overall system capacity.

Other possible design features of a cockpit airport moving map system include "electronic" depictions of the location of hold-short bars and lights, graphical Notices to Airmen (NOTAM) overlays (e.g., closed runway or taxiway segments), and assigned route conformance monitoring with alerting.[8, 21] Imagine—the crew enters their assigned taxi clearance and instructions into their avionics unit (or, preferably, it is entered automatically), then, if the aircraft deviates from its assigned routing, the crew is alerted.

Example: Occupied Runways on Airport Map

- Illustration of two of three runways at Portland being occupied. Runways 10L and 10R are colored red.
- Note UPS350 on short final to Runway 10L, with FDX514 holding short, and UPS189 on Runway 10R.
- Runway 21 is clear of traffic. Runway is colored black.



Courtesy UPS Aviation Technologies; used with permission

Figure 1: Cockpit moving map display system with occupied runways highlighted

While conceptually incorporated in the above depiction, two additional capabilities will need to be introduced in the future to gain the greatest benefit from this emerging cockpit display technology. These include CPDLC (Controller-Pilot Data Link Communications) and graphical airport NOTAM overlays. Research on low-visibility airport surface navigation has shown that graphical taxi clearances and instructions significantly reduce pilot workload and potential confusion on the airport surface.[3, 4] Additionally, the introduction of graphical NOTAM overlays, implemented by FIS-B, will provide the pilot with current airport graphical depictions.[1] There is some evidence that pilots tend to accept a visual image provided on a cockpit

[1] An emerging supporting technology to advance the entire collection, processing, and dissemination of graphical airport NOTAMs was first evaluated by the FAA at Baltimore-Washington International (BWI) Airport, in 1997. This proof-of-concept system made use of an off-the shelf computer terminal and display combination, and an Internet server. The evaluation permitted BWI airport operations, automated weather reporting sites, and others, the ability to create, then insert graphical airport NOTAMs, and frequently updated weather reports, directly into a security-protected Internet server. Conceptually, this same server could then be used to provide these graphically formatted airport status NOTAMs directly to an FIS-B ground-server for subsequent broadcast to aircraft via FIS-B. This concept holds significant promise as a means to provide timely Special Use Airspace status reports to aircraft while in flight.

display as being accurate and current, even though it may not be because it lacks current NOTAM information.[8, 21, 22] NOTAM overlays would update the airport maps to reflect current airport status, including runway and taxiway closures and other safety hazards. This would ensure that pilots would not be lead astray by seeing a compelling depiction that may be out of date. Until this NOTAM overlay capability is introduced, operational procedures and training will be needed to mitigate potential confusion. Figure 2 depicts such an "end-state" notional cockpit moving map architecture.

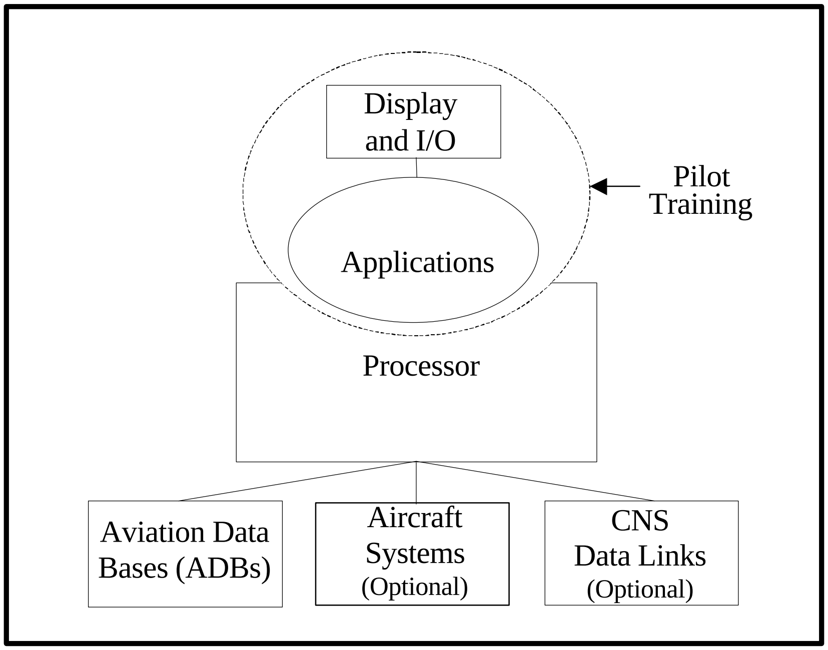


Figure 2: Notional cockpit moving map display system architecture

1.3 Distributed air and ground infrastructure

To make the overall airport surface surveillance *system* complete, a cockpit moving map display *sub-system* (designed using the above architecture or something similar) will need to be complemented by a synergetic airport surveillance infrastructure. Such a combined air and ground system will be needed at those airports with high activity, or at those airports that have a high incidence of runway incursions. Such an integrated system will enhance safety by providing distributed, cooperative, separation assurance. Providing the infrastructure to support both cockpit-based displays and a ground-based surveillance system should significantly help in reducing the runway incursion risk. In this environment, there would be at least three independent opportunities to detect conflicts—the pilot or operator on each aircraft or vehicle involved in a potential conflict and the ground-based controller. If necessary, each participant could act independently to preserve separation.

ADS-B technology also has the potential to extend surface surveillance to airports where ground-based surveillance is currently limited or non-existent. In the U.S., runway incursion prevention technology has achieved only limited implementation due to the high cost of surveillance equipment. By comparison, a surface surveillance system based only on ADS-B (that some have dubbed "ASDE-Lite") could be implemented at significantly reduced life-cycle costs. Consequently, given the lower costs involved, air traffic surveillance coverage could be expanded to airports that presently do not have any surface surveillance equipment, including even non-towered airports. (Surveillance of the airport surface at non-towered airports could become the responsibility of the nearest full-time air traffic facility.)

Probably the most serious impediment to ADS-B's current acceptance and potential use is the issue of mixed-equipage among users. Until everyone is equipped with ADS-B (and that may or may not happen in the near-term), there will continue to be a need for the pilot and controller to be aware of other, non-ADS-B equipped aircraft through other means. One such means is the uplink of ground-based primary radar returns (e.g., from ASDE-3) and secondary surveillance radar returns (e.g., from multilateration sensors) via TIS-B; hence the need to include TIS-B as part of a total systems solution.

1.4 Safety and efficiency benefits

Cockpit airport moving map display systems support increased safety and efficiency on the airport surface through:

- Improving aircrew and pilot surface situational awareness
- Achieving common situational awareness among controllers, pilots, and vehicle operators
- Reducing taxi navigation errors
- Reducing ATC and pilot workload
- Reducing voice frequency congestion
- Reducing voice communication errors
- Providing current airport status
- Enhancing cockpit crew resource management
- Reducing taxi spacing with the same or increased safety levels
- Increasing taxi speeds in reduced visibility, thus increasing efficiency

2. OVERVIEW OF THE FAA'S SAFE FLIGHT 21 PROGRAM

The FAA's Safe Flight 21 program is a cooperative government and private sector effort that has been charged with evaluating enhanced capabilities supporting the evolution of Free Flight. It is based on evolving Communications, Navigation, and Surveillance (CNS) technologies. Safe Flight 21 will demonstrate the in-cockpit display of traffic, weather and aeronautical data, and terrain and obstacle information for pilots, and will provide the necessary infrastructure to make available improved information to controllers. It will also evaluate the safety, service, and procedural improvements these technologies make possible. Safe Flight 21 is a two-part program that includes the operational evaluations (OpEvals) in the Ohio River Valley, as well as the Alaska Capstone project.

The RTCA-published Minimum Aviation System Performance Standards (MASPS) for ADS-B documents approximately 75 potential ADS-B and related operational applications (see RTCA DO-242).[15] Applications that apply to runway incursion protection are, in large part, a subset of these 75 initial applications. The RTCA Free Flight Select Committee, in conjunction with the Safe Flight 21 program office, has accepted over 20 of these applications and has categorized them into nine operational enhancement areas.[14] Two of these operational enhancements (that include four applications) are directly relevant to surface movement and runway incursion prevention.[20] They are:

- Operational Enhancement 6: Improved Surface Surveillance and Navigation for the Pilot:
    - Application 6.1.2: Final approach and runway occupancy awareness (using ADS-B & TIS-B)
    - Application 6.2: Airport surface situational awareness

- Operational Enhancement 7: Enhanced Surface Surveillance for the Controller:
    - Application 7.1: Enhanced existing surface surveillance using ADS-B
    - Application 7.2: Surveillance coverage at airports without existing surveillance coverage

2.1 The Ohio River Valley Operational Evaluations (OpEvals)

In 1998, three U.S. cargo airlines (Airborne Express, FedEx, and UPS), through their trade association, the Cargo Airline Association (CAA), entered into a cooperative venture with the FAA. The intent was to accelerate the development and introduction of ADS-B and related technologies into the NAS. The CAA's goal is to attain fleet-wide ADS-B equipage with CDTI capability, and their prioritized list of objectives include:

- Airborne Conflict Detection & Resolution
- Improved Terminal Area Operations
- Runway Incursion Risk Mitigation
- Surface Navigation
- TIS-B

The FAA and the airline community selected the Ohio River Valley as a place to conduct a series of OpEvals of this new technology.

Why the Ohio River Valley? The Ohio River Valley contains the airline hubs for all three participating cargo airlines. It's also the "heartland" of the nation's overnight package delivery infrastructure. Both conventional cargo shipping and the emerging "e-commence" delivery infrastructure demands reliable and dependable overnight delivery of goods and services globally, not just locally or nationally. ADS-B is seen as a means to make that possible. Again, the intent is to develop and eventually implement ADS-B and related technologies to enhance aviation safety and, at the same time, allow U.S. firms to more effectively compete in a global marketplace.

Overall, the OpEval objectives are to mature the needed technologies to accomplish the above objectives and make them "certification-ready" for use by the airlines and general aviation. The approach of each OpEval is to "build a little, test a little," as opposed to the "big bang, build, fix, then deploy" approach, which has historically not worked very well. The Ohio River Valley work is intended to allow public and private sector interests to work together to reduce the risks of future cockpit CNS implementations and NAS modernization decisions. OpEvals are being orchestrated as part of the larger, overall, FAA Safe Flight 21 program initiative.

2.1.1 OpEval-1

OpEval-1 occurred in July 1999 in Wilmington, Ohio, hosted by Airborne Express. One purpose of OpEval-1 was to explore the performance envelope surrounding ADS-B data link technology and to collect engineering data to evaluate the three competing RF data links: 1090 MHz, the Universal Access Transceiver (UAT), and VHF Data Link Mode 4 (VDL-M4). OpEval-1 also explored the performance envelope surrounding enhanced situational awareness for "see-and-avoid," enhanced visual approaches, and ground surface movement applications. While OpEval-1 took a limited look at ground operations, and initial indications supported the potential of ADS-B for surface movement, the evaluation was limited by the lack of good airport map databases and the fact that GPS Selective Availability (SA) was still turned on. As the focus of this paper is surface moving maps, we'll not spend time further discussing the results of OpEval-1.

2.1.2 OpEval-2

OpEval-2 was conducted in October 2000 in Louisville, Kentucky, hosted by UPS. Seventeen[2] aircraft participated, with various manufacturers providing different equipment implementations. A major focus of OpEval-2 included ADS-B approach spacing, departure spacing, and airport surface movement applications. Controllers in the Terminal Radar Approach Control facility (TRACON) at Louisville also made use of ADS-B enabled displays in evaluating the airborne applications. Another major focus of OpEval-2 was to evaluate cockpit moving map displays (with GPS-derived own-ship position and ADS-B provided traffic) and to determine the benefits to flight crews and pilots. For surface movement applications, an objective of OpEval-2 was to develop and evaluate avionics and procedural modifications needed to support the operational approval of Application 6.2, Airport Surface Situational Awareness.

3. OPEVAL-2 METHODOLOGY FOR SURFACE MOVEMENT EVALUATIONS

Data for surface movement applications during OpEval-2 were collected from flight crews and pilots in the aircraft and from controllers in the FAA tower at Louisville. Data was also collected from FAA controllers in the TRACON during the airborne application scenarios. All CDTIs could display the relative position of all other ADS-B traffic transmitting on their ADS-B data link frequency. Some CDTIs had surface maps while some did not. While comparative data link analysis was not made a part of the OpEval-2 test objectives, two different data links were in fact used during the OpEval (1090 MHz and the UAT on 966 MHz). Some avionics had the ability to receive both frequencies, but most only received one of the two. Those single-frequency receivers could not "see" or display ADS-B targets on their CDTI that were transmitting on the other frequency, either in the air or on the surface.

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[2] The majority of the flight events (for data collection purposes) involved 16 aircraft participants. These included four UPS B-727s, one FDX B-727, one FAA B-727, two FAA Convairs, a Honeywell King Air, a Rockwell Collins Sabreliner, a UPS Aviation Technologies King Air, an L3 Communications Citation, an AOPA Bonanza, a CNS Aviation Piper Lance, a DCA Cessna 210, and a Piper Aztec from the DOT Volpe National Transportation Center. In addition, one OpEval-2 participant (BF Goodrich) was involved in only the public event exercise conducted at the completion of the OpEval.

There were three levels of CDTI map capabilities installed in the various aircraft. These were:

- Aircraft with CDTIs but no surface map capability. Nine participants had CDTIs but no surface map capability. These included all the CAA and FAA aircraft as well as one aircraft from one of the avionics manufacturers.

- Aircraft with CDTIs and Jeppesen airport diagram underlays. Five participants had CDTIs with a scanned moving map of the Jeppesen airport diagram. These maps were always depicted as “North-up.” Participants with this capability were primarily general aviation (GA) aircraft.

- Aircraft with CDTIs and “vector-based” airport diagrams. Two participants had a CDTI with a vector-based moving map display of the airport surface map. These maps were developed to be consistent with the draft RTCA SC-193 / EUROCAE WG-44 airport mapping document. (Vector-based airport maps will likely be used in future airport surface map implementations.)

Two objectives of the surface application data collection effort were to assess CDTI effectiveness in increasing awareness of targets on the airport surface and to evaluate different levels of CDTI map capabilities as aids to surface situational awareness—including a comparison to those OpEval aircraft without surface moving maps.

In designing the OpEval-2 data collection process, attention was focused on the need to collect data to address an extensive list of technical and human factors “issues” from those FAA offices that are responsible for aircraft certification and for operational approval of this technology. A similar list of air traffic-related issues was developed to assist the air traffic community in their evaluations, and in defining their initial ADS-B requirements documents. The premise was that for each issue, there would be invoked an appropriate OpEval “resolution.” Consequently, an implicit objective of OpEval-2 (as well as future OpEvals) was to perform the work needed to resolve outstanding technical issues, thereby helping pave the way for timely certification and operational approval, should there become a need. This “issues” and “resolutions” methodology is described in RTCA DO-249 and in the OpEval-2 Test and Evaluation Master Plan (TEMP).[11, 16]

4. OPEVAL-2 DATA COLLECTION

The data collection process was structured as follows: There were six three-hour flight periods with multiple flight scenarios during each period. Evaluations were conducted during both day and night conditions. Surface movement taxi scenarios were conducted both at the beginning (outbound) and at the end (inbound) of each flight period. Aircraft movement positional data was collected and recorded by ADS-B surface equipment. Some of the avionics also recorded aircraft movement positional data as well. Human Factors (HF) data collection observers were in each aircraft and in the FAA tower during all taxi scenarios.

The majority of surface operations were conducted using standard taxi procedures, but “non-standard” taxi routes. There were portions of outbound and inbound taxi sequences where flight crews were assigned complex and very specific routing instructions via a pre-defined route card. These route cards were designed to assess how ADS-B and surface map information could be used to improve situational awareness on the airport surface. Flight crews were provided with these written textual descriptions of the various routes (Figure 3). ATC then assigned a specific route to an aircraft upon initial radio contact. Also, during specific OpEval-2 flight events (i.e., during the low approach segments), surface targets were positioned on or near the runway environment to evaluate the utility of the CDTI for pilot awareness of runway occupancy. When targets were positioned on the runway, ATC issued only a low approach clearance to inboard OpEval-2 aircraft, with an altitude restriction of 500 feet above ground level (AGL). In all other cases, low approaches were conducted to within 200 feet of the airport surface.

The human factors data collection observers utilized specially designed observer forms to record:

- Flight crew or pilot performance during surface orientation and navigation along assigned taxi routes
- Flight crew or pilot performance on traffic awareness tasks
- Flight crew or pilot assessment of runway environment awareness prior to departure and during approach and landing

For the airport surface applications, flight crews and pilots were instructed to:

- Navigate to and from parking or runways via tower-assigned coded taxi routes
- Establish the taxi sequence (find the lead aircraft, then establish the designated interval to follow)
- Evaluate local traffic situations (identify which parallel taxiways were in use, establish their sequence in line for take-off, line up behind static vs. moving traffic, etc.)
- Locate targets relative to specified ground reference points (such as a high speed taxiway, a runway end point, and an assigned ramp position)
- Evaluate local traffic situations (identify which parallel taxiways were in use, establish their sequence in line for take-off, line up behind static vs. moving traffic, etc.)
- From the Final Approach Fix (FAF) inbound, through rollout, use the CDTI to continuously assess runway occupancy
- Prior to entry onto the active runway, use the CDTI to assess runway occupancy

Taxi Route FBO2

Contact "Ground frequency" once off Runway 17R: ACID (aircraft ID). Taxi to parking via the FBO2 routing, below. Hold short of RWY 17L at Delta. Contact ATC to continue clearance.

ROUTE:

- Exit RWY on (taxiway) Bravo 3
- TL (turn left) on Bravo
- TR (turn right) on Golf
- TL on Juliet
- TR on Mike
- TL on RWY 11/29
- TR on November
- TL on Foxtrot
- TL on Papa
- TR on RWY 11/29
- TL on Golf 1
- TL on Golf
- TR on November
- TR on Delta
- TL on Delta 6
- Hold short at Delta
- TL on Echo
- TL to ramp area

Navigation/Traffic Awareness Task:
- Report intersection of taxiway Golf 1 and Golf
- Identify closest proximate traffic to own-ship.

Figure 3: Example of coded taxi route card

5. OPEVAL-2 RESULTS

As of the time of this writing, only the OpEval-2 "Quicklook Report" (QLR) has been prepared and published by the OpEval Coordinating Group (OCG).[10] This report is in briefing form and includes preliminary results based on an initial analysis of the data. An OpEval-2 Final Report (OFR) is being developed and will include more detailed data analysis and results. As a result, both the results and conclusions documented here may vary somewhat when the OFR is published in the summer of 2001. With this caveat in mind, here is a preliminary summary of results, to date.

Regarding general airport surface situational awareness, in routine taxi to and from the active runway, flight crews with a surface map (but with limited experience using the equipment) made fewer taxi errors than those without—two errors for those with electronic moving maps versus five for those without. Both groups made two errors during the first taxi-out event, and even though some of those without maps were familiar with the airport, they made additional errors during three of the later taxi periods. Also, those with a surface map capability were able to more easily recover from their errors, whereas flight crews without a surface map had difficulty even though their path and the assigned route crossed multiple times.

For the traffic awareness task using the taxi route card (see Figure 3), responses were collected from 12 participating aircraft. Of these, 11 of the flight crews successfully utilized the CDTI to locate the nearest proximate traffic. Of these 11 aircraft, seven were equipped with a CDTI with a surface moving map depiction, while the other four were equipped with only a CDTI (without a surface map). On one occasion, one flight crew involved in the evaluation, operating an aircraft equipped with a CDTI without an airport surface map depiction, incorrectly identified the nearest proximate traffic. Error rate analyses are not yet completed.

With respect to runway occupancy awareness, eight flight crews flying aircraft equipped with a surface map identified that an aircraft or vehicle was on the runway during their low approach. Flight crews with no surface map did not identify any aircraft or vehicles on the runway during these same events. Also, flight crews with a surface map used the CDTI to evaluate the approach and departure corridors for arriving and departing traffic.

In general, flight crews and pilots equipped with a CDTI (but not necessarily an airport surface moving map) successfully completed most surface geographical orientation, navigation, and traffic awareness tasks. However, crews equipped with a CDTI with an airport surface moving map showed improved:

- Geographical awareness: Crews equipped with a CDTI with a surface map could readily locate taxiways on the airport surface, while crews with CDTI only had difficulty.
- Navigational awareness: Crews equipped with a CDTI with a surface map made fewer errors while navigating on the surface and were able to quickly recover from error.
- Traffic awareness: Crews equipped with a CDTI with a surface map performed better on the surface traffic awareness task than crews with CDTI only.

Overall, pilots who operated aircraft equipped with a CDTI with a surface moving map reported increased surface situational awareness. While most of the subject pilots had little experience with the CDTI prior to OpEval, several statements made by the crews suggested that they became more familiar and comfortable with the CDTI in general during the course of the OpEval. Several pilots expressed a preference for a “track-up” surface moving map depiction. Such a depiction allows the display to be aligned with the actual outside view as seen by the pilot. It also allows taxiway labels and other text to remain properly oriented (right side up).

Some control/display hardware and interface issues identified by crews that were related to surface movement included a concern about increased head-down time, increased workload for the pilot-not-flying to convey traffic information to the pilot flying, and a quicker method of decluttering the display, if desired. An interesting comment made by one pilot during a debriefing session was that while the CDTI did, in fact, increase his head-down time, it vastly improved the *quality* of his head-up time.

6. FUTURE OPEVAL PLANS

There is one additional OpEval in the planning process, to be conducted in Memphis, Tennessee, hosted by FedEx. OpEval-3 is to be completed by late Spring 2002. Detailed planning is underway.

The focus of OpEval-3 will be airport surface management, specifically to evaluate means to provide controllers, pilots, and airline management with more effective, collaborative decision-making tools. A surface surveillance system will be used, and has in fact already been installed. It will provide the FAA tower controller at Memphis with a color display in the tower cab that will have an airport surface map overlaid with aircraft position and identification data (i.e., data tags). This system includes the capability to track all aircraft operating on the airport surface, both those equipped with ADS-B and those without, and most surface vehicles. This new ground-based surveillance system uses a variety of surveillance sensors and incorporates a sensor fusion platform to provide a single target to the tower controller and pilot (via TIS-B), regardless of the sensor being used to locate and identify that target. Sensors used include (1090 MHz- and UAT-enabled) ADS-B, multilateration technology using conventional aircraft transponders (to multilaterate on non-ADS-B equipped target aircraft), and the existing ASDE-3.

In Summer 2001, an "integration phase" will begin for the Surface Management System (SMS) demonstration that will include using the ADS-B based multilateration system described above, along with a real-time traffic data collection and analysis tool that makes use of a Dynamic Runway Occupancy Measurement System (DROMS). DROMS is a database measurement system designed to enhance airline gate and movement area efficiencies. There will also be a real-time "feed" of airport surface movement data to the FAA tower and to the FedEx airline operations center (AOC) for use with their displays and with their ramp management system. This integration phase will begin a baseline data collection activity for the newly installed surface surveillance system and a familiarization with the new equipment by the Memphis controllers. It is considered more a preliminary step to OpEval-3, and not an OpEval in itself.

OpEval-3 will focus on: (1) a demonstration of what should be by then a fully mature, integrated airport surface surveillance system; (2) use of TIS-B and FIS-B broadcast services in the Memphis terminal airspace; and (3) an aggressive evaluation of enhanced cockpit-based, ADS-B enabled, terminal airspace applications. This combined air/ground integrated system would also demonstrate a potential solution to the mixed-equipage problem by having the surface surveillance system transmit the position of non-ADS-B equipped aircraft and vehicular traffic operating on the airport surface to other ADS-B equipped aircraft via TIS-B. This will permit any non-ADS-B traffic detected by the surface surveillance system to be displayed on an ADS-B equipped aircraft's CDTI and airport surface moving map combination, not only those that are ADS-B equipped. FIS-B product depictions are also planned. It is also expected that some aircraft will be equipped with portable as well as panel-mounted electronic moving map displays. Portable cockpit display systems are seen as an emerging technology that might be used to address the retrofit issue at an affordable cost to the operator.

7. EMERGING FROM THE OPEVALS: A SURFACE TECHNOLOGY ROADMAP

There is a pressing need to help solve the runway incursion problem as well as to enhance airport capacity and reduce delays. Consequently, the following OpEval-related architecture is emerging as a distinct possibility for the NAS, with phased cockpit moving map display implementations possible beginning in the very near-term.

7.1 Ground architecture

Figure 4, below, depicts what this future air and ground combined architecture might look like. Such a ground architecture would make use of the various enabling technologies described in this paper. The FAA is currently under contract to deploy some of this functionality at 25 major airports starting in 2004 as part of the initial ASDE-X procurement. The introduction of ADS-B, TIS-B, and FIS-B functionality with ASDE-X is also possible, but not planned nor funded at this time. Additionally, an "ASDE-Lite" system with ADS-B UAT functionality only, modeled after the Alaska Capstone ADS-B implementation at Bethel, is also a possibility.

7.2 Cockpit architecture

There is considerable activity now underway within the private sector to certify the enabling cockpit technologies described in this paper, thereby making the above integrated air and ground system a distinct possibility. Technical standards are nearing completion, including technical standards for an airport mapping database. This mapping database standard will be a joint RTCA SC-193 and EUROCAE WG-44 document. Other technical standards and design guidelines are also nearing completion in other RTCA, SAE, and AEEC committees. Both portable (i.e., "Electronic Flight Bags") and panel-mounted display systems are being pursued, and there are currently technical discussions underway advocating a phased approach to cockpit equipage. For example, in Figure 5, below, a four-phase effort is described. In Phase 1, aircraft would be equipped with only a moving map display with own-ship position. Phase 2 would add ADS-B and TIS-B functionality to depict other aircraft and vehicles operating on the airport surface. Phase 3 would add an alerting function. Phase 4 would add taxi clearances and instructions in graphical format. A "fifth" phase, the introduction of graphical NOTAM overlays, can be introduced during any of these phases, and would be implemented by use of FIS-B. Some avionics manufacturers are proceeding with plans for certifying equipment, by late 2001, that combine the capabilities identified in Phases 1 and 2.

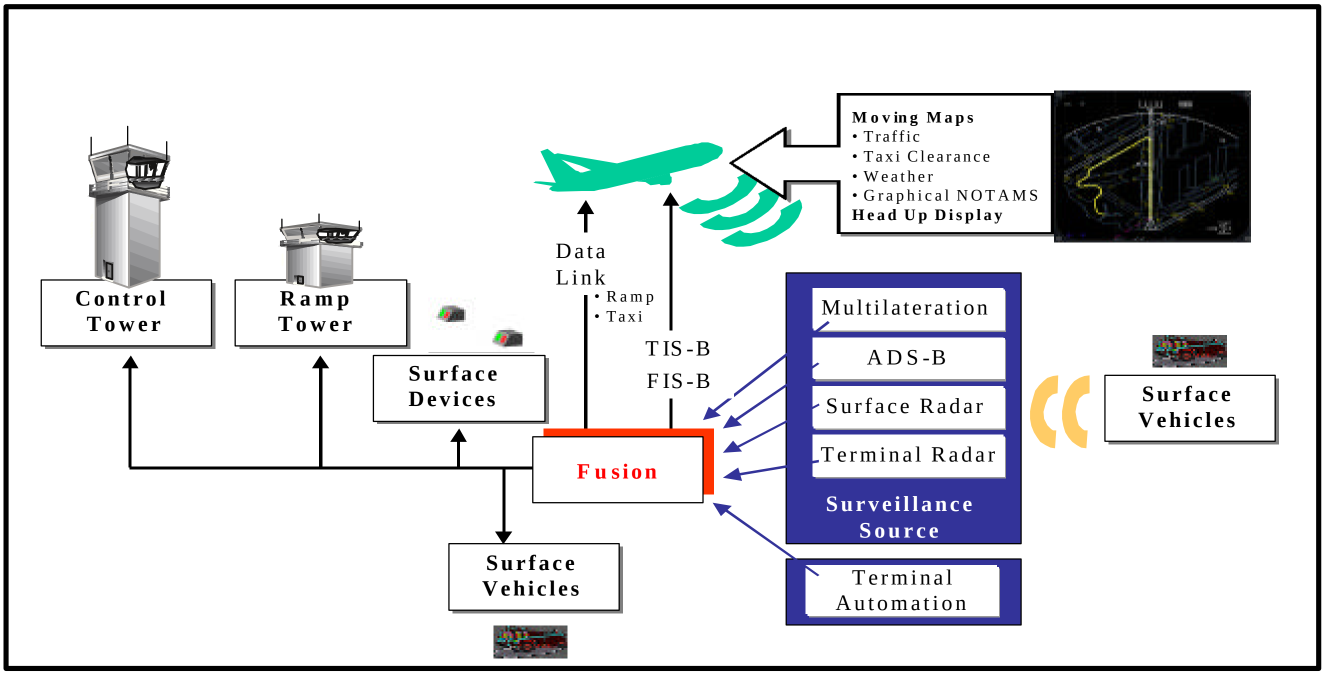

Figure 4: Integrated architecture for a "large / medium" airport

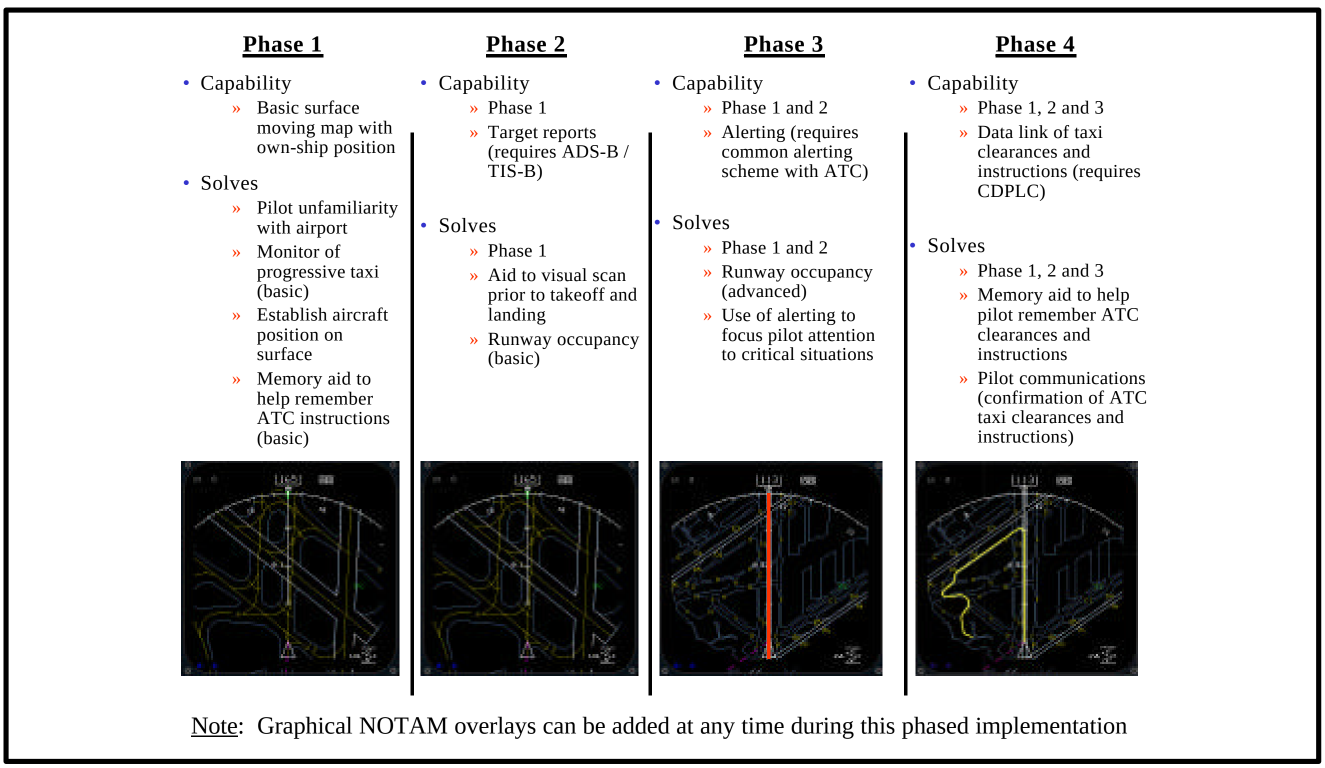

Figure 5: Cockpit surface moving map technology roadmap

8. CONCLUSIONS

For Airport Surface Situational Awareness (Safe Flight 21 Application 6.2), there was strong agreement from OpEval-2 pilots and controllers that ADS-B and CDTI information, when combined with an airport surface moving map, can provide significant safety and efficiency benefits. With an airport surface moving map, flight crews and pilots reported improved traffic and situational awareness. Orientation was straightforward, errors were fewer, and recovery (corrections) was made easier.

While the authors believe ADS-B technology possesses tremendous potential, it is an emerging capability that is still somewhat immature. Additional technical issues, as well as new benefits, were identified during OpEval-2. Airport-surface movement-related issues that need timely resolution include: consensus on standardized aircraft and vehicle CDTI symbology and colors; mature flight deck procedures; and ways to reduce CDTI and map display clutter when operating on the airport surface. Crew coordination and crew workload issues also need to be investigated further. In using this equipment, a need was identified to evaluate the relationship between formal training received, a pilot's competency gained through operational use of the equipment, and its relationship in reducing pilot error.

The authors believe that ADS-B aircraft ID and positional information overlaid on airport surface moving maps, especially when coupled with the depiction of current airport status information available through TIS-B, FIS-B, and CPDLC, provide perhaps the single most significant promise for increasing airport surface safety and efficiency. All these capabilities are near term and are candidates for evaluation in future Safe Flight 21 OpEvals. These combined technologies, when implemented in concert with effective cockpit crew resource management and accelerated ADS-B equipage, hold great promise for solving the bulk of the runway incursion safety problems, including reducing pilot deviations and controller operational errors. These conclusions are significant.

ACKNOWLEDGMENTS

This paper would not have been possible without the extraordinary dedication and commitment of the many individuals that supported the OpEval-2 evaluation effort. Just like OpEval-1, OpEval-2 was a unique undertaking—competing airlines, the FAA, NASA, contractors, avionics manufacturers, labor organizations, airport authorities, and others—all joining to work together to enhance aviation safety and to help modernize our airspace system. Our thanks to all for their help, and for making this paper possible.

REFERENCES

1. "ADS-B Avionics Management Plan, Draft Version 3.1," December 25, 1997, U.S. Department of Transportation, Federal Aviation Administration, AND-710, Washington, DC.
2. "Airport Movement Safety Runway Incursion Action Plan," April 1995, U.S. Department of Transportation, Federal Aviation Administration, Washington, DC.
3. Battiste, V., Downs, M. and McCann, R. S. (1996). "Advanced Taxi Map Display Design for Low-Visibility Operations," *Proceedings of the 40th Annual Meeting of the Human Factors and Ergonomics Society*, 997-1001. Santa Monica, CA.
4. Battiste, V., Downs, M., Sullivan, B. T., and Soukup, P. A. (1996). "Utilization of a Ground Taxi Map to Support Low Visibility Surface Operations," *Proceedings of the AIAA Flight Simulation Technologies Conference*, San Diego, CA.
5. "Flight Crew Mission Guide, Phase I – Operational Evaluation," OpEval Coordination Group, June 21, 1999, Safe Flight 21 Program Office, U.S. Department of Transportation, Federal Aviation Administration, Washington, DC.
6. Kelley, D. R., and G. J. Jacobs, "Reports by Airport Traffic Control Tower Controllers on Airport Surface Operations: The Causes and Prevention of Runway Incursions," September 1998, WTR980000033, MITRE Corporation, McLean, VA.
7. Kelley, D. R., and S. W. Schreckengast, "Safety Roundtable on Runway Incursion Prevention," October 1997, WN97W0000108, MITRE Corporation, McLean, VA.
8. McCann, R. S., et al, "An Evaluation of the Taxiway Navigation and Situation Awareness (T-NASA) System in High-Fidelity Simulation," Society of Automotive Engineers, Technical paper # 985541, 1998.
9. "1998 Airport Surface Operations Safety Action Plan to Reduce Runway Incursions and Improve Operations," July 1998, U.S. Department of Transportation, Federal Aviation Administration, Washington, DC.

10. “OpEval-2 Quicklook Report,” (Slide Set), March 5, 2001, Safe Flight 21, U.S. Department of Transportation, Federal Aviation Administration, Washington, DC.
11. OpEval-2 Test and Evaluation Master Plan (TEMP), October 2000, Safe Flight 21, U.S. Department of Transportation, Federal Aviation Administration, Washington, DC.
12. “Reports by Airline Pilots on Airport Surface Operations, Part 1. Identified Problems and Proposed Solutions for Surface Navigation and Communications,” May 1994, WN94W0000060, MITRE Corporation, McLean, VA.
13. “Reports by Airline Pilots on Airport Surface Operations, Part 2: Identified Problems and Proposed Solutions for Surface Operational Procedures and Factors Affecting Pilot Performance,” March 1996, WTR0000060.V2, MITRE Corporation, McLean, VA.
14. RTCA, “Joint Government/Industry Roadmap for Free Flight Operational Enhancements,” August 1998, RTCA, Washington, DC.
15. RTCA, DO-242, “Minimum Aviation System Performance Standards for Automatic Dependent Surveillance—Broadcast (ADS-B),” RTCA, Washington, DC.
16. RTCA, DO-249, “Development and Implementation Planning Guide for Automatic Dependent Surveillance—Broadcast (ADS-B),” RTCA, Washington, DC.
17. RTCA, DO-263, “Application of Airborne Conflict Management: Detection, Prevention, & Resolution,” RTCA, Washington, DC.
18. “Runway Incursion Joint Safety Analysis Team (JSAT), Results and Analysis,” June 2, 2000, U.S. Department of Transportation, Federal Aviation Administration, Commercial Aviation Safety Team (CAST) and General Aviation Joint Steering Committee (GAJSC), Washington, DC.
19. “Runway Safety Program,” U.S. Department of Transportaion, Federal Aviation Administration. http://www.faa.gov/runwaysafety/
20. “Safe Flight 21 Master Plan, Version 2.0,” April 2000, Safe Flight 21, U.S. Department of Transportation, Federal Aviation Administration, Washington, DC.
21. Williams, D. et al, “Concept of Operations for Commercial and Business Aircraft Synthetic Vision Systems, Version 1.0,” January 2001, National Aeronautics and Space Administration, Langley Research Center, Hampton, VA.
22. Yuchnovicz, D.E, et al, “Flight Information Services Data Link (FISDL) Experiment Final Report,” August 31, 2000, RTI/7286.010, Research Triangle Institute. Work performed for National Aeronautics and Space Administration (NASA) under contract NCA1-130, NASA, Langley Research Center, Hampton, VA.