ISSUES IN THE PROCEDURAL IMPLEMENTATION OF LOW-VISIBILITY SURFACE OPERATIONS DISPLAYS

Becky L. Hooey, Martin F. J. Schwirzke, Michael E. McCauley
Monterey Technologies, Inc., Monterey, California

Dan Renfroe
United Airlines (Retired), Los Gatos, California

Kevin Purcell and Anthony D. Andre
San Jose State Foundation / NASA Ames Research Center, Moffett Field, California

ABSTRACT

NASA has recently developed a Taxiway Navigation and Situation Awareness (T-NASA) system designed to increase taxi safety and efficiency in low-visibility surface operations. A series of focus groups was conducted to solicit opinions, concerns, and issues regarding the future deployment of T-NASA. Pilots from six commercial airlines and air traffic controllers from tower and ground stations received a pre-interview training package and viewed a training video that described the display components and procedural assumptions. Afterwards, participants discussed how these displays may alter their current standard operating procedures (SOPs) and what procedural implications this technology may have on their daily operations. This research highlights the importance of considering the system-wide procedural implications when designing new flight deck displays.

INTRODUCTION

The International Civil Aviation Organization (ICAO, 1997) proposed the development of a modular system to support safe, orderly, and expeditious movement of aircraft and vehicles on the airport surface under all circumstances, including low-visibility conditions. The need for such a system, termed Advanced Surface Movement Guidance and Control Systems (A-SMGCS) has arisen due to an increase in the number of surface incidents, the increasing complexity of airports, the increasing number of operations, and the desire to maintain capacity in all-weather conditions.

The operational concept for A-SMGCS is to reduce voice communications workload, increase surface guidance aids and reliance on avionics in the cockpit to help guide the pilot to and from the runway, and improve ATC surveillance of aircraft and vehicles by electronic means. ICAO developed a set of technology-independent guidelines to provide guidance for the development and analysis of such systems. Specifically, ICAO stated that in order to support safe and efficient gate-to-gate operations, A-SMGCS must provide the following basic functional requirements:

- Surveillance: Capture identification and positional information on aircraft, vehicle, and objects.
- Routing Plan and assign routes to individual aircraft and vehicles to provide safe, expeditious and efficient movement.
- Guidance: Provide necessary advisory information in a continuous unambiguous manner, such that pilots can follow their assigned route while maintaining an appropriate speed.
- Control: Measures to prevent collisions, runway incursions, and to ensure safe expeditious and efficient movement on the airport surface.

Concurrent with ICAO's development, and under the auspices of NASA's Terminal Area Productivity (TAP) program, NASA Ames Research Center has developed a Taxiway Navigation and Situation Awareness (T-NASA) cockpit display suite which includes an electronic moving map (EMM), scene-linked head-up display (HUD), and directional auditory traffic alerts. These T-NASA cockpit displays were coupled with a communication, navigation, and surveillance (CNS) system developed by a host of NASA, FAA, industry and university partners, Together they address the ICAO requirements of providing surveillance, routing, guidance, and control.

T-NASA SYSTEM

The proposed T-NASA system (see Figure 1 below), as tested at Atlanta Hartsfield International Airport (Young, 1998; Andre, Hooey, Foyle, & McCann, 1998; Foyle, Andre, McCann, Wenzel, Begault, & Battiste, 1996), consists of the following:

- A ground-based surveillance system that provides surveillance data to air traffic control (ATC) and to any equipped aircraft/vehicle via datalink.
- Flight deck displays that utilize differential global positioning systems (DGPS) and an onboard airport database to provide supplemental guidance, surveillance, routing, and control information to the flight deck.

Hooey, B.L., Schwirzke, M. F. J., McCauley, M. E., Renfroe, D., Purcell, K., and Andre, A. D., (1999). Issues in the Procedural Implementation of Low-Visibility Surface Operations Displays. In R.S. Jensen (Ed.), Proceedings of the Tenth International Symposium on Aviation Psychology, Columbus: Ohio State University.

· Controller-pilot datalink communications that allows ATC to issue routing and control instructions via an independent link.

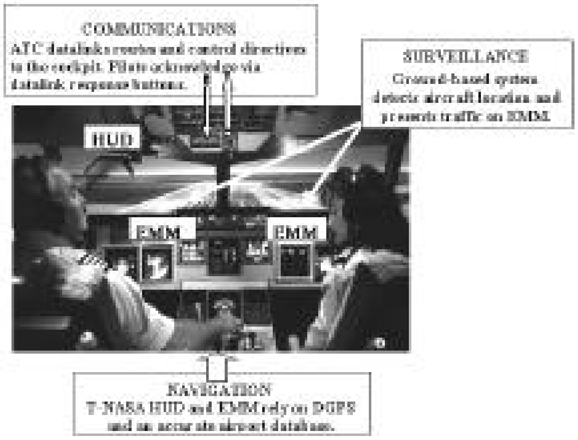

Figure 1. Schematic of T-NASA displays and CNS.

T-NASA Displays

The T-NASA suite of displays, including the taxi HUD, EMM, and directional auditory alerts serve as the interface between the controller, the CNS, and the pilots.

T-NASA HUD. Shown in Figure 2 below, the T-NASA HUD is available on the captain's side only, and presents scene-linked route guidance that directly overlays elements (taxiways, hold bars, etc.) that exist on the airport surface. Routing and guidance information are provided via the taxiway edge and centerline which display only the cleared taxiway route thereby providing both an overview of the route ahead and turn by turn guidance. Turn signs which indicate the location and sharpness of turns augment the guidance information. Control information, such as hold bars, is also portrayed in the HUD. The reader is directed to McCann et al (1998) for a more complete description of the T-NASA HUD.


Figure 2. T-NASA HUD symbology

T-NASA EMM. The EMM (shown in Figure 3 below) provides both pilots with routing, guidance, surveillance, and control information in a heads-down moving map format. The EMM clearly presents both routing and guidance information via the magenta strip which highlights the cleared taxi route. The EMM presents surveillance information by displaying, in real-time, the location of all aircraft and other vehicles on the airport surface. Control directives, such as a yellow flashing hold bar, are also presented. Please see Andre, Hooey, Foyle, and McCann (1998), for a complete description of the EMM.

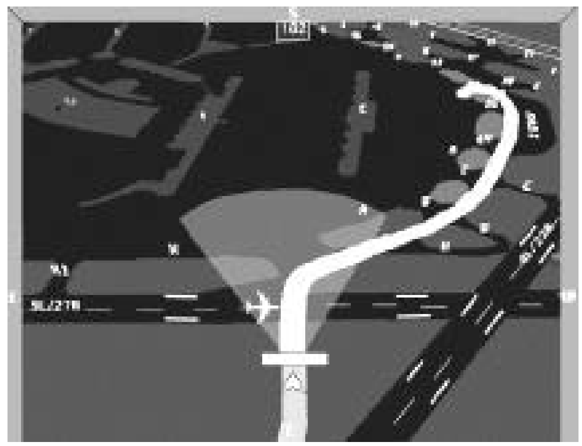
Figure 3. T-NASA EMM

Audio Alerts. Directional audio alerts provide surveillance information by warning pilots of impending collisions with another aircraft, vehicle, or object. Though not implemented at the time this research was conducted, future uses of audio may include control information such as hold short and proceed-to-cross commands.

The T-NASA crew interface has been subject to considerable research, including part-task simulations, full-mission simulations, and flight tests. A flight test at Atlanta's Hartsfield International Airport successfully demonstrated that T-NASA has the potential for meeting the proposed A-SMGCS requirements (Young, 1998; Andre, Hooey, Foyle, & McCann, 1998). However, less is known about the impact of this technology on the operating procedures of pilots. Like any new technology, it is anticipated that incorporating T-NASA into the cockpit will change the nature of ground navigation and decision making for pilots. This research was intended to identify issues that need resolution to enhance the probability that the safety and capacity benefits of the T-NASA technologies might be achieved.

METHOD

Scenario-based focus group discussions were conducted in order to foster the generation and sharing of ideas between small groups of pilots and controllers.

Participants

Nine focus groups were conducted with a total of 24 participants, with two to four participants in each group. In total, 16 pilots (7 captains and 9 first officers) from six airlines participated. Four pilots reported previous experience with HUD-equipped aircraft. Also, eight air traffic controllers, experienced with Tower and Ground Control operations, participated in the sessions. The controllers reported a mean of approximately 17 years of ATC experience (ranging from 12 to 22 years).

Procedure

Participant Training. Each focus group began with a training period which included an instructional video, and a briefing presented by the focus group moderator. Pilots were briefed on the T-NASA display suite as well as the communication, navigation, and surveillance features. Participants were asked to consider two operational implementations: a hybrid implementation where the display suite provides information to the pilots to augment current day voice controlled operations and a datalink implementation, where datalink completely replaces voice for all ATC-pilot communications. For the purposes of this paper, only the full datalink implementation will be discussed.

Focus Group Sessions. The moderator, a recently retired airline captain, began each session by defining a scenario to provide a context for the discussion. Participants were asked to consider an approach into an unfamiliar and complex airport in low visibility conditions. They were told to consider their tasks, roles, and typical communications during landing, roll out, turn off and taxiing to the gate. Throughout the discussion, a list of probe questions was used by the moderator to foster discussion regarding changes to current operating procedures.

Questionnaire. A summary of all comments was compiled and distributed to participants in the form of a mail-back questionnaire. Participants were asked to rate their level of agreement with each quote on a five point scale (from strongly disagree to strongly agree) as well as the degree of criticality of each statement on a three point scale (not critical, somewhat critical and very critical). Survey response rate was 88% for air traffic controllers (7 of 8 responded) and 56% for pilots (9 of 16 responded).

FOCUS GROUP SUMMARIES

The comments of the focus groups were synthesized and categorized according to the ICAO basic requirements: Surveillance, Routing, Guidance, and Control. The focus groups also revealed other system-wide procedural implementation issues, which will be discussed here as well. The focus group comments will be summarized below, beginning with a brief description of current day procedures, followed by a discussion of how these procedures might change with the introduction of T-NASA, and what implications this might have for pilots and controllers. Where applicable, survey data is provided to indicate the level of agreement among focus group members.

Surveillance

Current Day Operations. Pilots rely on three sources to avoid traffic conflicts. First and foremost, they rely on ATC to clear them on a conflict-free route, or modify their route if necessary to avoid conflicts. These routes are generated by ATC based on activity that can be seen from the tower (and radar) and a mental picture of the airport traffic and airport layout. However in low visibility, aircraft may be difficult to see from the tower, and are not always where ATC thinks they are. Second, pilots rely on their own vision to detect aircraft on the airport surface, which can also be degraded in low-visibility conditions. Third, pilots rely on voice communication between other aircraft and ATC. This ‘party line’ effect (Midkiff & Hansman, 1992) can be used by pilots to know which runways are active, where other aircraft are, who is moving and who is not, as well as who is lost on the airport surface.

Proposed Operations. With the proposed T–NASA system, pilots will communicate with ATC only by datalink. While this may reduce radio congestion, and increase efficiency, it comes at a cost of eliminating the only existing source of surveillance information which is not degraded in low-visibility, the party-line information. Instead, however, T-NASA provides real-time traffic information via the EMM, and arguably in a better, more reliable, and consistent fashion.

Procedural Implications. The use of EMM for surveillance information may produce a greater reliance on head-down visual information rather than the current out-the-window or auditory information. Procedurally, this may shift the responsibility of traffic awareness away from the taxiing captain and to the first officer. Focus group participants suggested that the captain should remain eyes out while navigating with the HUD, and the first officer should monitor the

EMM and communicate any potential threats to the captain. Focus group pilots argued for a formalized procedure that would have first officers monitor the EMM and make traffic call-outs to the captain. While 78% of the pilots agree this is a critical issue, only 44% of the pilots were in favor of adding this to the formal SOPs, preferring instead to determine these procedures on a crew-by-crew basis.

Another issue raised by focus group participants, is that while T-NASA may efficiently provide surveillance information, what happens if an aircraft or object is not depicted on the EMM? At a system wide-level, this means that all vehicles on the airport surface, including GA aircraft, emergency vehicles, baggage carts, and other service vehicles must be either detected by airport radar or equipped with the necessary technology to be depicted on the EMM. This will require cooperation from several sources including the FAA, airlines, airport operations and services.

Routing

Current Day Operations. Currently, pilots are required to stop after exiting the runway and contact ATC via radio for a taxi clearance. ATC provides a taxi route, which pilots either remember or write down, and acknowledge (usually by reading back to ATC). This process, is inefficient and prone to high workload. Ground control frequencies at major airports become congested and pilots often complain that the controllers speak too rapidly to be understood (Kelley & Adam, 1997). Often pilots cannot read back the clearance or clarify instructions because of the frequency congestion. Despite these communication problems, currently, this is the only mean by which the captain can develop a mental overview of the route, and possibly even catch an error in the route, while remaining eyes out.

Proposed Operations. T-NASA changes this task from the auditory domain to the visual domain. Now, to review the cleared route, a pilot must look down at the datalink text or the pending route shown graphically on the EMM. While pilots from the focus group acknowledge this difference in procedures, it was not perceived to be problematic. Pilots expect that the graphical overview, and the scene-linked turn-by-turn direction provided to the captain in the HUD, will more than mitigate any losses the captain may suffer by eliminating the current voice-based process.

Procedural Implications. One implication of this procedural change, however, concerns the error-checking process. Besides the fact that error checking of the taxi route must be done visually, and head down, with the addition of any automation, there are more sources for error or discrepancy in the route between the controllers intentions, the datalink message, the EMM, and the HUD. Pilots recommended that procedures that define the roles and communications for each pilot be implemented to ensure good error-checking techniques. For example, 100% of the pilots surveyed agreed with this statement made by one focus group member: Upon receiving a route, the first officer should verify that the route is correct, zoom to the biggest scale on the EMM to make sure the route goes to the right gate, and tell the captain: Route looks good. Further, 78% of pilots agreed that the first-officer should crosscheck their EMM display with the datalink clearance to ensure it is correct and complete.

Guidance

Current Day Operations. In today’s environment, pilots navigate on the airport surface by referring to painted markings (e.g., centerlines), signage, and in-pavement lights (Kelley & Adam, 1997). Airport Jeppesen charts are used for a more global reference. At an unfamiliar airport, in low visibility, it is not uncommon for the first officer to be continually checking his paper Jeppesen chart in order to provide turn-by-turn directions to the captain, i.e., “Turn left on Alpha.” This verbal process helps the captain by providing an extra pair of eyes to look for the next taxiway (either on the chart or out the window), and provide a redundant confirmation that the next planned action is correct. The first officer has additional confidence that the captain knows where he/she is going and intends to take the next turn.

Proposed Operations. With T-NASA, the HUD provides turn-by-turn guidance information to the captain. Due to installation and certification costs, all airlines to date have chosen to install only one HUD, on the left side. This means that the first officer, who is not equipped with a HUD, does not see what the captain is seeing. Both the captain and the first officer receive guidance information via the EMM which indicates the next taxiway and distance to the turn.

Procedural Implications. Focus group results suggest that one implication of the T-NASA HUD could be reduced communication between pilots. As one experienced captain stated, “The number one problem is lack of communication between captains and first officers during taxi.” Pilots agreed that first officers would be less likely to call out turns and communicate with the captain knowing that the captain had symbology in the HUD. This impression of the focus group participants was confirmed in a previous high-fidelity simulation (Parke, Kanki, McCann, & Hooey, 1999). To combat this tendency, focus group participants suggested that new standardized phraseology between pilots be implemented that would ensure communication and crosschecking between pilots. For example, pilots stated that the captain should communicate to the first officer: "I've got the stop sign in my HUD." In addition to keeping the first officer in the loop, this continual communication between captain and first officer will also serve to confirm that the information in the HUD is correct. Each communication would act as an error-checking mechanism between the pilots, the HUD and the EMM. While only 44% of the pilots surveyed felt that the airline should impose such phraseology as airline SOPs, 78% of pilots rated this a critical issue. Similarly, 67% of pilots surveyed agreed that "The first officer should continually cross-check their EMM display with the captain's HUD using a defined verbal protocol." Eighty-eight per cent of the pilots felt this issue was of critical importance.

Control

Current Day Operations. Taxi operations are closely controlled by ATC. While pilots may be responsible for "see and avoid" maneuvers, the controller frequently must issue movement constraints, such as hold-short and proceed to cross instructions, to reduce the likelihood of conflict. In general, pilots receive a timely voice command to direct them to hold for traffic utilizing intersecting taxiways or runways, and when to cross once the route is clear. Pilots are required to acknowledge and indicate their intent to comply with the directive.

Proposed Operations. With datalink, movement constraints and other control communications would be transmitted from ATC to the cockpit via datalink text message rather than voice. Pilots would receive an aural chime indicating the presence of an ATC message, review the message, and respond by pressing either an Accept or Reject Datalink button.

Procedural Implications. Both pilots and controllers voiced concerns about safety, if the positive voice control is replaced with datalink. Of the pilots surveyed, 78% stated that they would "be nervous just following the [displayed route guidance] with no voice control," and 100% of the pilots confirmed that this was an issue of critical importance. Similarly, 43% of controllers agreed they'd be nervous just sending clearances via datalink without receiving a verbal acknowledgement from the pilots. All controllers believed this was a critical issue that required further examination.

Focus group members suggested that controllers and pilots might share the responsibility of control operations. They suggested that for the full datalink implementation, it would be necessary to implement cockpit procedures to verify all control directives. One pilot suggested that "before crossing a runway, the first officer should be required to zoom his taxi map to the biggest scale [widest angle] to ensure that the runway is clear, and communicate this to the captain." Of the pilots surveyed, 78% agreed that this procedure should be adopted, and 89% agreed that it was of critical importance.

Focus group participants, specifically the controllers, raised concerns about the timing of the datalinked control message. Of the controllers, 86% agreed that "Busy airports are so dynamic and crossing active runways is difficult, it wouldn't be feasible to update routes and issue holds via datalink". Controllers voiced specific concerns that the datalink text message may not be perceived as urgent as the controller's voice, and therefore may not demand a prompt reply. If the datalink message is sent in a timely fashion, i.e. as the aircraft is approaching the hold point, there is a possibility that the hold command may not be accepted and acknowledged by the pilots in time. On the other hand, if sent too soon, the aircraft may stop or slow down unnecessarily, even if the reason for the hold has been removed.

Mixed-Equipped Fleets

Lastly, it is important that we consider how the implementation of T-NASA may affect more global or 'system-wide' procedures. TAP technologies are likely to be slowly integrated and retrofitted into current fleets. Therefore at least initially, mixed-equipped fleets will exist, where some aircraft are TAP-equipped and some are not. This may create procedural difficulties for airlines, pilots, and controllers. Airlines will be faced with difficult issues regarding training and whether to allow pilots to fly both equipped and non-equipped aircraft. For pilots, mixed-equipped fleets may mean losing awareness of the location of some surrounding aircraft, i.e., those datalinked, or being unsure of the information availability of nearby aircraft. For controllers, mixed-equipped fleets may mean increased workload, either to determine which aircraft are equipped and which are not, or at least during a transition phase, to send ATC directives redundantly via both voice and datalink.

DISCUSSION

The focus group participants revealed a number of important issues and implications regarding the implementation of a low-visibility surface operation display suite into the cockpit. In summary, the key issues are presented below.

Surveillance

- Traffic will be presented visually on the EMM rather than via party-line voice communications.
- First Officers will be required to monitor head-down EMM for traffic and communicate to the captain.
- All aircraft and vehicles on the airport surface must be equipped or seeable. What are the consequences if an aircraft is 'lost' by the surveillance?

Routing

- Taxi routing information will be visual rather than verbal.
- Pilots must develop error-checking mechanisms to counter more sources of error.

Guidance

- Standard phraseology should be developed to ensure continual communication between pilots.
- Communications should serve as an error-checking mechanism between the pilots, HUD, and EMM.

Control

- Is data link an appropriate means for transmitting control information?
- Procedures should be adopted by pilots to verify all datalink control directives with the EMM before complying.
- Procedures may be required to ensure pilots receive and respond to control messages in a timely manner.

In general, the introduction of cockpit technology to aid pilots in surveillance, routing, and guidance were received very favorably by both pilots and controllers. While it is expected that these displays will alter the nature of the pilots' tasks during surface operations, no serious flaws in the system concept were uncovered. The use of datalink to transmit control information, however, produced more serious concerns, and appears to be a concept that would require further research. A full-mission simulation is currently under development at NASA Ames Research Center to investigate this issue. The issues raised concerning mixed-equipped fleets provide a strong argument for considering all system-components (controllers, pilots, airlines, etc.) when designing and implementing such a system.

Conclusion

It is not surprising that the addition of new technology changes the way pilots taxi. It is important however, that display designers understand exactly how procedures change and the implications of these changes. Without considering these procedural implications, we risk compromising the overall safety of the air traffic system and interfering with productivity gains.

REFERENCES

Andre, A.D., Hooey, B. L., Foyle, D. C., and McCann, R.S. (1998). Field evaluation of T-NASA: Taxi navigation and situation awareness system. *IEEE/AIAA Digital Avionics Systems Conference.* Seattle, WA.

Foyle, D. C., Andre, A. D., McCann, R. S., Wenzel, E.M., Begault, D. R., and Battiste, V. (1996). Taxiway Navigation and Situation Awareness (T-NASA) system: Problem, design philosophy, and description of an integrated display suite for low-visibility airport surface operations. *In Proceedings of the SAE World Aviation Congress. (Paper Number 965551)* Los Angeles, CA.

International Civil Aviation Organization (1997). 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.

Kelley, D. R., & Adam, G. L. (1997). The human factors of runway incursions caused by "pilot error": A survey of U.S. airline pilots. In R. S. Jensen and L. A. Rakovan (Eds.), Proceedings of the Ninth International Symposium on Aviation Psychology, 911-917. Columbus, OH: The Ohio State University.

McCann, R.S., Hooey, B.L., Parke, B., Foyle, D.C., Andre, A.D. and Kanki, B. (1998). An evaluation of the T-NASA system in high fidelity simulation. In *Proceedings of the SAE World Aviation Congress. (Paper Number 985541).* Anaheim, CA.

Midkiff, A. H., and Hansman, R. J. (1992). Identification of important "party line" information elements and the implications for situational awareness in the datalink environment. *Proceedings of the SAE Aerotech 92 Conference (Paper Number 922023).* Warrendale, PA: SAE

Parke, B., Kanki, B. G., McCann, R. S., and Hooey, B. L. (1999). The effects of advanced navigation aids on crew roles and interactions in ground taxi. To appear in the *Proceedings of the 10th International Symposium on Aviation Psychology*. Columbus, OH.

Young, S. (1998). Comparison of A-SMGCS requirements with observed performance of an integrated airport CNS system. *IEEE/AIAA Digital Avionics Systems Conference.* Seattle, WA.

Acknowledgement:
This work was supported by NASA Ames Research Center under a contract issued to Monterey Technologies, Inc., (NAS2-14113, Delivery Order No. 35). Dr. David C. Foyle served as the technical monitor.