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Automatic Dependent Surveillance-Broadcast/Cockpit Display of Traffic Information: Innovations in Aircraft Navigation on the Airport Surface

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16. Abstract:
In 2000, the FAA's Office of Runway Safety made a concerted effort to reduce runway incursions. The Safe Flight 21 Program awarded contracts for CDTI avionics development and an operational demonstration that included a surface moving-map capability. An operational evaluation was conducted in October 2000 to assess pilot use of varying types of CDTI devices and how surface-map information could aid pilot situation awareness when taxiing. Complex taxi routes were designed to examine how well pilots navigated their aircraft using an electronic surface-map display (north-up, track-up) or a paper surface map. This study was designed to determine how the use of these displays might aid situational awareness and influence operational communications. Pilots navigated their aircraft during 3 day and 2 night operations, resulting in 31 structured and 37 unstructured taxi routes. As subject-matter experts listened to 15 hours of audiotapes and read verbatim transcripts, they identified operational concerns and noted problems. Communications involved in progressive taxi routes and routes instructing pilots to follow another aircraft were excluded from analysis. A Type-of-Route x Type-of-Map ANOVA revealed that more problems occurred for structured, compared with unstructured taxi routes, and more messages were exchanged. A statistically significant interaction indicated that most problems occurred for the north-up map during structured taxi routes, and the number of problems encountered was comparable for the other maps when pilots navigated along unstructured taxi routes. When designing electronic surface-map displays, providing a north-up map orientation appears to create more problems than either track-up or paper surface maps — especially when taxi routes are complex (or unfamiliar).

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Automatic Dependent Surveillance - Broadcast / Cockpit Display of Traffic Information: Innovations in Aircraft Navigation on the Airport Surface

"What a fog! Plane been buzzin' around overhead for the last half hour. Must be like trying to find your way through the inside of a cow. I never did see such a country. Even the birds are walkin'."

— *A Guy Named Joe,* complaining about the weather at the airfield in Scotland (1943). Dalton Trumbo, U.S. screenwriter.

Recreational and professional pilots form a diverse population of aviators who vary in piloting skills, experience with airport operations, and familiarity with the surface geography of their departure and destination airports. At one time or another, they – like all of us – make mistakes. Sometimes, adverse weather or poor visibility add complexity and contribute to human error. The more serious mistakes can result in runway incursions, surface incidents, near-collision ground incidents, and fatal runway collisions.

In its special-investigation report entitled *Runway Incursions at Controlled Airports in the United States* (May 6, 1986), the National Transportation Safety Board (NTSB) noted a significant increase in collision ground incidents.[1] That report included several new safety recommendations to reduce the frequency of runway incursions. Some of these recommendations remained open when, on January 18, 1990, a fatal runway collision involving a Boeing 727 and a Beechcraft King Air Al00 occurred at Atlanta, Georgia. As a result, the NTSB placed airport runway incursions on its "1990 Most Wanted Transportation Safety Improvements List," where it still remains.

The FAA is working diligently to address NTSB Safety Recommendation A-00-66 (NTSB, 2000): "… require, at all airports with scheduled passenger service, a ground movement safety system that will prevent runway incursions; the system should provide a direct warning capability to flight crews. In addition, the FAA should demonstrate through computer simulations or other means that the system will, in fact, prevent incursions."[2] A critical component of Safety Recommendation A-00-66 is that runway incursion prevention technologies should "provide a direct warning capability to flight crews."

In 2000 and again in 2002, the FAA's Office of Runway Safety made a concerted effort to reduce runway incursions. Several technologies are being developed that will provide a direct alerting capability to flight crews include ground markers, addressable signs, and surface moving maps. Under the Safe Flight 21 Program, contracts were awarded for avionics development and demonstration that included a surface moving-map capability. This capability was demonstrated (along with several others) in October 2000 during an operational evaluation of the automatic dependent surveillance broadcast (ADS-B) and cockpit display of traffic information (CDTI) at the Standiford International Airport (SDF) in Louisville, Kentucky.

The FAA's intent in undertaking technology operational evaluation activities is to refine, standardize, and certify a set of tools that airports can acquire to address their specific runway safety issues. In line with the FAA's intent, the stated purposes of the Louisville, Kentucky, operational evaluation were to develop and evaluate specific ADS-B air-air and air-ground applications, evaluate controller use of ADS-B, and demonstrate ADS-B technology. It also provided an opportunity to collect field data that could be used to guide the development of the ADS-B airport surface movement applications. These applications would improve surface surveillance and navigation for the pilot through enhancements to airport surface situational awareness.

There were several goals associated with the airport surface situational awareness application that were being addressed. One goal was to enhance safety and mitigate occasions for runway incursion by providing pilots with tools that graphically display the proximate location of other surface aircraft and vehicles moving about the airport. Another goal was to enhance pilots' positional awareness of their aircraft on the airport surface by providing them with tools that displayed real-time information to supplement out-the window speed, direction, and position information. The FAA envisions that CDTI applications may improve the efficiency and safety of surface operations at busy, (or unfamiliar) controlled airports.

The objectives of the operational evaluation for the airport surface situational awareness application were to assess how effective CDTI was in increasing pilot awareness of other like-equipped ADS-B aircraft and vehicles on the airport surface and to evaluate different levels of CDTI map capabilities as aids to surface situational awareness. To evaluate how ADS-B and surface-map information could be used to aid pilot situational awareness while on the airport surface, very specific and complex taxi routes were created. Each taxi route was designed to examine how well flight crews navigated their aircraft along the assigned taxi route using either an electronic surface-map display, such as the example displayed in Figure 1, or a paper surface map.

During the five-day event, objective (air traffic control voice tapes and radar data) and subjective data (surveys, questionnaires, jump-seat observer reports, small-group interviews) were collected from controller and pilot participants. This report provides a general description of the communication findings for airport-surface situational awareness. Due to time constraints, these findings were not available for inclusion into the final comprehensive report prepared by the Operational Evaluation Coordination Group (FAA, 2001), the flight deck observer data report prepared by Joseph, Domino, Battiste, Bone, and Olmos (2003), or the preliminary "quick-look" report prepared by Livack, McDaniel, and Battiste (2001).

METHOD

Participants

Twenty-five paid pilot volunteers flew 16 different aircraft. Two controllers and a coordinator (also volunteers) provided local- and ground-control services. They were on a temporary detail during training and on a regular schedule during the evaluation.

Materials

Experimentally Constructed Structured Taxi Routes and Taxi-Route Cards. The experimentally constructed taxi routes (structured taxi routes) described the routes necessary for pilots to navigate a defined course segment to or from the assigned runway. These defined, complex taxi routes were created exclusively for the operational evaluation. Pilots received individual uniquely labeled cards with these "canned" taxi routes presented in text format. Each card had a named taxi route associated with it (e.g., CUPS1, FBO1, ANG1) that provided very specific, and often complex, taxi instructions for portions of the outbound and inbound taxi routes. Each structured route was presented on a single sheet of paper, as in the example presented in Figure 2 (left panel). Ground controllers received these structured routes as a graphical image with the name of the taxi route clearly labeled across the card, as shown in the right panel of Figure 2.

Traditional Unstructured Taxi Routes. A majority of the airport surface operations were performed using established taxi patterns and procedures to and from the assigned runway and designated parking areas. For these unstructured, typical taxi routes, the ground controller verbally provided pilots with the instructions and frequency information necessary for the pilots to taxi their aircraft to or from the assigned runways. Pilots did not know in advance the taxi routes they would be

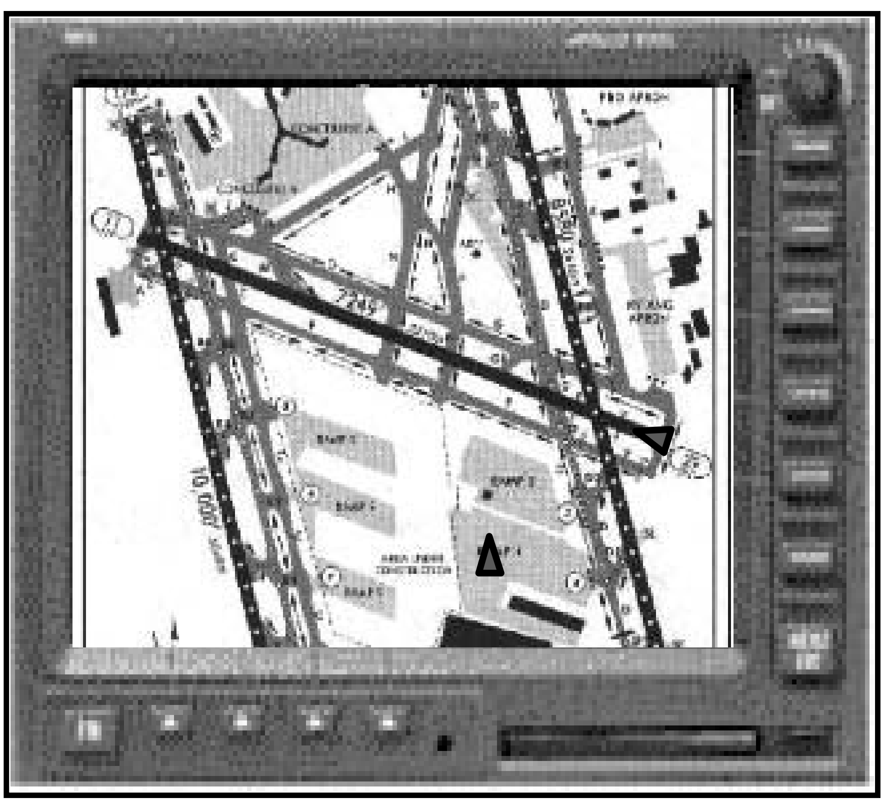

Figure 1. Example of a Moving Map Display With an Airport Surface Map Overlay.

FBO 2 Structured Taxi Route:

On Ground frequency off RWY 17R: ACID taxi to parking via the FBO2 routing. Hold short of RWY 17L at Delta. Contact ATC to continue clearance.

ROUTE:

- Exit RWY on Bravo 3
- TL on Bravo
- TR on Golf
- TL on Joulette
- 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

Legend: TL = Turn Left
TR = Turn Right

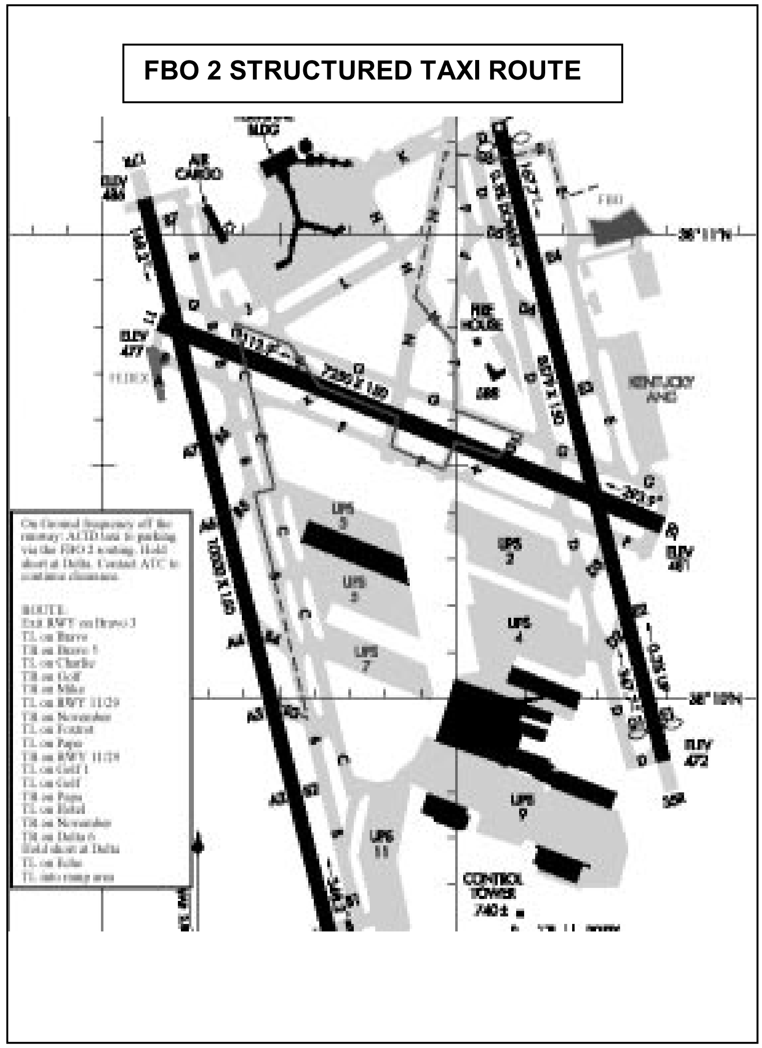

Figure 2. An Example of a Structured Inbound Taxi Route to Fixed Base Operations (FBO).

given. Also, there were no unstructured taxi-route cards that could serve as memory aids as they navigated these unstructured taxi routes.

Digitized Audiotapes. The Terminal Radar Approach Control (TRACON) facility provided five digital audiotapes (DATs), one for each test period. Each DAT contained separate voice records of all the transmissions made on the radio frequency assigned to the Ground East, Local West, or Final Radar West position on the left channel. The right channel contained the Universal Time Coordinated (UTC) time code expressed in date, hour (hr), minute (min), and whole second (s). The NiceLogger™ Digital Voice Recorder System (DVRS) decoded and displayed time and correlated it with the voice stream in real time. The data consisted of 15 hrs of digitized voice communications, of which 6 hr were from the Ground East position.

Procedure

During the operational evaluation, the tower was divided into two sections, with the West portion of the airspace dedicated to the evaluation. In addition, a portion of the airfield was set apart from normal operations, and tower controllers limited access to the West runway to participating aircraft. The experimental flight periods were scheduled during normally low airport activity.

The operational evaluation involved five flight periods that included a varying number of aircraft that participated in morning (Flight Period 1 = 11 aircraft, Flight Period 2 = 13 aircraft, Flight Period 4 = 6 aircraft) or night (Flight Period 3 = 4 aircraft, Flight Period 5= 14 aircraft) operations. Flight periods lasted between 2 hr 19 min and 2 hr 59 min.

A majority of the airport surface operations were performed using **customary taxi procedures**[3] using the unstructured taxi routes — following initial call-up,) ground controllers issued a taxi clearance such as the one found in *FAA Order 7710.65M Air Traffic Control* (2000): "American Four Ninety Two, Runway Three Six Left, taxi via taxiway Charlie, hold short of Runway Two Seven Right." However, for some portions of the taxi route, the participating ground controllers instructed the pilots who participated in the evaluation of the airport surface situational application to proceed outbound or inbound according to the script-defined taxi routes —using the structured taxi route cards (e.g., CUPS1, FBO1, ANG1). The distance, the numbers of turns, and the complexity of the inbound and outbound taxi routes were controlled. Examples of the communications for structured and unstructured routes are presented in Figure 3.

Prior to each flight period, participating ground controllers attended an activity briefing. They were instructed to clear participating aircraft via customary taxi routes (i.e., unstructured taxi routes) or defined structured taxi routes and monitor the aircraft's movement along its assigned taxi route to ensure compliance with the scripted scenario and FAA procedures.

Speaker ID	Message
	Structured Taxi Route
	FBO 7 Structured Taxi Route
N123	LOUISVILLE GROUND NOVEMBER ONE TWO THREE READY FOR TAXI
ATC	NOVEMBER ONE TWO THREE ROGER TAXI VIA FBO SEVEN HOLD SHORT OF RUNWAY ONE SEVEN LEFT AT ECHO
N123	FBO SEVEN HOLD SHORT OF ONE SEVEN LEFT AT ECHO NOVEMBER ONE TWO THREE
ATC	NOVEMBER ONE TWO THREE CROSS RUNWAY ONE SEVEN LEFT TAXI TO RUNWAY ONE SEVEN RIGHT VIA FBO SEVEN
N123	CROSS ONE SEVEN LEFT AND TAXI TO RUNWAY ONE SEVEN RIGHT FBO SEVEN NOVEMBER ONE TWO THREE
	Unstructured Taxi Route
N321	LOUISVILLE GROUND NOVEMBER THREE TWO ONE READY FOR TAXI
ATC	NOVEMBER THREE TWO ONE LOUISVILLE GROUND RUNWAY ONE SEVEN RIGHT TAXI VIA ECHO FOUR HOLD SHORT OF ONE SEVEN LEFT AT ECHO FOUR
N321	HOLD SHORT OF ONE SEVEN LEFT AT ECHO FOUR NOVEMBER THREE TWO ONE
ATC	NOVEMBER THREE TWO ONE CROSS RUNWAY ONE SEVEN LEFT TURN LEFT ON DELTA
N321	CROSS ONE SEVEN LEFT TURN LEFT ON DELTA NOVEMBER THREE TWO ONE
ATC	NOVEMBER THREE TWO ONE TURN RIGHT AT TAXIWAY GOLF RIGHT ON BRAVO FOR RUNWAY ONE SEVEN RIGHT
N321	RIGHT ON GOLF RIGHT ON BRAVO TO ONE SEVEN RIGHT NOVEMBER THREE TWO ONE

Figure 3. Examples of Pilots and Controller Communications by Type of Taxi Route.

Pilots participated in proficiency training exercises prior to the evaluation and attended pre-flight briefings before each event. During these briefings they received a set of taxi-route cards to use when ATC issued structured taxi-route clearances. They were instructed to interpret the textual route information presented on their taxi-route cards to determine the route to taxi. For example, following initial radio contact with November One Twenty-Three, the ground controller provided the pilot with the taxi clearance, "November one twenty-three Louisville Ground taxi via FBO TWO hold short of runway one seven left at delta six." Using the assigned taxi-route card for FBO2, the pilot navigated inbound to the fixed base operation spot 2.

Pilots taxied their aircraft along their assigned routes using Paper-Charts (35 segments), Track-up (11 segments) or North-up (22 segments) surface map overlays to find their way to the runway, ramp, or transient parking area. Each **outbound** taxi segment lasted between 530.0 s and 1763.0 s (M=1289.0 s, SE=89.11 s) during 9 structured routes and from 292.0 s to 1652.0 s (M=717.4 s, SE=59.8 s) during 20 unstructured routes. Each **inbound** taxi segment lasted between 520.0 s and 1321.0 s (M=734.82 s, SE=57.0 s) for 22 structured routes and from 134.0 s to 470.0 s (M=280.1 s, SE=64.8 s) for 17 unstructured routes.

Experimental Design

This study used a two-factor, between-groups design. The between-groups factors were Taxi Route (Structured, Unstructured) and Type of Surface Map (Paper-Chart, North-up, and Track-up). Each structured and unstructured taxi route segment was assigned to a different, pre-selected flight-crew as part of their outbound or inbound taxi segment.

The type of ADS-B equipment installed in each aircraft determined its assignment to a Type of Map group. Nine aircraft comprised the Paper-Chart Group. They could display ADS-B equipped aircraft on their CDTI, but no map overlay was available of the airport surface. Five of the aircraft had scanned Jeppesen airport surface map overlays on their CDTI, always depicted in a north-up orientation. They were classified as the North-up Group. The remaining two aircraft were classified as the track-up group, since their aircraft had a CDTI with a vector-based moving map of the airport surface map available for display. The messages recorded during the structured and unstructured routes allowed for a comparison with taxi performance by the Paper-Chart, North-up, and Track-up Groups.

Dependent Measures

Operational efficiency for each structured and unstructured taxi segment was of primary interest. It consisted of two components: communication workload and operational communications. Measures of communication workload included number and duration of communication. Measures of operational communication included problems and operational concerns.

To measure changes in communication workload and operational communication for each taxi segment, the messages transmitted between the ground controller and pilot of each aircraft were grouped into transactional communication sets (TCSs) that began with the pilots' first message to the ground controller and the last message that either switched the pilot to local control (outbound) or terminated at the ramp or transient parking area (inbound). TCSs are made up of several communication sets that each consists of all the messages that are transmitted between a controller and pilot and share a common goal or purpose (Prinzo 1996).

To illustrate, consider the partially encoded transcript presented in Figure 4. There are two transactional communication sets, one for each of two different taxi operations. Taxi #1, which is an outbound taxi, consists of two communication sets: a taxi route clearance (messages 1, 2, and 4) and transfer of communications (messages 12 through 14). Taxi #2 is comprised of three communication sets: position report (message 3), taxi route clearance (messages 5 through 11), traffic advisory (messages 10 and 11). Message 10 is complex, in that the first part of the message is a traffic-advisory while the latter part is a taxi instruction.

Objective Measures of Communication Workload. Four measures of communication workload were examined for each transactional communication set. They included (1) number of messages transmitted, (2) time on frequency per message (TOF), (3) frequency occupancy time (FOT), and (4) time under ground control (TGC). They were computed for each transactional communication set that began with the pilot's initial call-up and ended with the last recorded transmission.

As shown in Figure 4, six messages involved N123AB (TCS #1). The TOF for the first message was 4 s. Frequency occupancy time for TCS #1 was computed as the sum of the TOF. In the example, FOT was 17 s (FOT = Σ TOF = 4+2+1+5+3+2). As shown by the solid-line arrow, the time N123AB spent under ground control (time ground control, TGC) was computed as the time lapsed from the onset of the pilot's initial call-up in message 1 (at 4219 s) to the closing of the transaction in message 14 (at 4489 s). In the example, TGC was 270 s (4489 s - 4219 s). Computation of the TGC for N321CD is shown by the use of the dashed-line arrow, and it was 72 s. A taxi segment typically began with a pilot checking in and ended in the transfer of communication to local control (outbound route), as was the case with TCS #1, or with the last recorded transmission as the pilot navigated back

Message #	TCS #	Com Set #	SID	Message	Time (in seconds) Onset	Offset	TOF	TGC
1	1	1	N123AB	LOUISVILLE GROUND CONTROL THIS IS NOVEMBER ONE TWO THREE ALFA BRAVO READY TO TAXI	4219	4223	4	270
2	1	1	ATC	NOVEMBER ONE TWO THREE ALFA BRAVO TAXI TO RUNWAY ONE SEVEN LEFT	4224	4226	2	
3	2	2	N321CD	GROUND CITATION THREE TWO ONE CHARLIE DELTA IS WITH YOU AT FOXTROT CLEAR OF ONE SEVEN LEFT	4228	4232	4	72
4	1	1	N123AB	THREE ALFA BRAVO TAXI TO ONE SEVEN LEFT	4233	4234	1	
5	2	2	ATC	CITATION ONE CHARLIE DELTA TURN LEFT AT THE END LEFT ON GOLF HOLD SHORT OF TAXIWAY ECHO	4236	4240	4	
6	2	2	N321CD	LEFT AT THE END LEFT ON GOLF HOLD SHORT OF ECHO ONE CHARLIE DELTA	4241	4244	3	
7	2	2	N321CD	YOU WANT ME TO CROSS THERE AT ELEVEN TWO NINE	4248	4250	2	
8	2	2	ATC	ONE CHARLIE DELTA CROSS ELEVEN TWO NINE HOLD SHORT OF ECHO ON GOLF	4251	4254	3	
9	2	2	N321CD	CHARLIE DELTA SHORT OF ECHO ON GOLF	4255	4256	1	
10	2	2,3	ATC	CITATION ONE CHARLIE DELTA TRAFFIC TWO TRUCKS ON ECHO THEY'LL BE TURNING RIGHT ON GOLF PASS BEHIND THEM THEN TAXI TO THE RAMP	4291	4296	5	
11	2	2,3	N321CD	OKAY BEHIND THE TRUCKS AND TO THE RAMP ON ECHO BEHIND THEM	4297	4300	3	
12	1	4	N123AB	LOUISVILLE GROUND NOVEMBER ONE TWO THREE ALFA BRAVO AT RUNWAY ONE SEVEN LEFT HOLD SHORT READY FOR DEPARTURE	4473	4478	5	
13	1	4	ATC	THREE ALFA BRAVO CONTACT TOWER AT ONE TWO FOUR POINT TWO	4481	4484	3	
14	1	4	N123AB	ALFA BRAVO SWITCHING TO TOWER ONE TWO FOUR POINT TWO	4487	4489	2	

Figure 4. Example of a Transcript Encoded into Transactional Communication Sets.

to either the ramp or transient parking area (inbound), which was the case with TCS #2.

Measures of Operational Communications. Communications that have the potential to adversely affect operational efficiency were identified and classified as problems and operational concerns. Problems included **message reception** (say again, did you copy), **misunderstanding** (readback error, stolen transmission, intentional repetition of a previous message for emphasis), **erroneous information** (incorrect call sign, can't find route segment provided in taxi instructions), and **message production** (self-correction of the call sign or another piece of information during transmission). Operational concerns involved spatial and positional awareness. **Spatial awareness** includes a general understanding of the geography of the airport surface, whereas **positional awareness** relates more to the temporal and relational factors associated with maneuvering about the airport. Examples of spatial awareness (aircraft is not on its assigned route, correction made to a previous taxi instruction, incorrect taxi clearance issued, instructions given to rejoin route, confusion, lost, missed turn) and positional awareness (maneuver around aircraft, possible conflict, request clearance to cross an active runway) are presented in Figure 5.

In summary, message count, contents, and duration were the objectively derived measures of communication workload and operational communication extracted from the time-stamped voice tapes. They were used to compute descriptive statistics expressed as means (M) and standard errors (SE) that summarized CDTI electronic (north-up, track-up) versus paper-chart surface-map use on operational efficiency between ATC and the participating flight crews. Operational communication in the form of problems and operational concerns provided some insights and implications for future air traffic operations, workload, and communications procedures.

Qualifications, Training, and Data Encoding Procedures

This section begins with a description of the qualifications of the subject-matter experts (SMEs) and continues with the procedures used by the lead SME to train the other SMEs. The section ends with an explanation of the data-encoding process.

Qualifications of the Subject-Matter Experts. The lead air traffic SME was an instrument-rated pilot and former controller who had worked as an FAA Academy instructor for 8 years and had worked for 12 years in FAA supervision and management. Two additional air traffic SMEs had been instructors (Terminal Option) at the FAA Academy in Oklahoma City. The pilot subject-matter expert was a recently retired airline pilot with 31 years of experience. Prior to serving as an SME, he was an instructor on the B-727 and DC-8 aircraft; check airman on the DC-9 aircraft; and pilot of the CV-880, DC-8, B-727, DC-9, L-1011, B-757 and B-767 aircraft.

Training Subject-Matter Experts. The lead SME provided the other SMEs with 16 hours of training on the data-encoding process to achieve consistency and conformity in identifying communication transactions and evaluating the accuracy of content. Since OpEval-2 imposed minor operational constraints, SMEs received instruction on how to evaluate communications in light of those modifications. Furthermore, the lead SME encouraged the other SMEs to direct their attention to the detection and codification of any benefits that may have occurred from the pilots having access to a CDTI. In addition to identifying positive outcomes, they also were asked to comment on any situation involving a potential or real loss of separation or situational awareness, misunderstanding, or problem (missed readback of the identifiers, routes, altitudes, etc.). Finally, the SMEs received instruction on how to select and enter their codes onto the OpEval-2 Aviation Topics Speech Acts Taxonomy-Coding Form (see Prinzo, Britton, & Hendrix, 1995, for details).

Data Encoding. Once taught, each SME received a complete set of audiocassettes, transcripts, and the code and instruction manual. The audiotapes and transcripts aided the SMEs in the identification of communication sets for each inbound and outbound taxi segment. Each SME worked independently to identify and code the efficiency and accuracy of communications. However, they met on a weekly basis to discuss their encoding and to resolve any differences. Once the SMEs reached consensus, the data entry clerks received the final copy, and it was entered into the database for final analysis.

RESULTS

Operational communications from ADS-B/CDTI were evaluated from verbatim transcripts and digitized voice recordings provided by the TRACON facility. Although requests were made during the planning of the event that baseline circuits be included during the evaluation, none were conducted. Consequently, comparisons between the routine and communication protocol developed for pilot use during the evaluation could not be performed since the baseline data necessary for comparison were not included as part of the operational evaluation. The analysis of voice tapes did allow for preliminary comparisons between flight crews who had access to traditional paper-charts and electronic airport surface maps, in either a north-up or track-up orientation, as aids to their surface situational awareness.

Types of Problems	Example
Message Reception	
Did you copy	SIX TWO FOUR MIKE TANGO GROUND YOU COPY
Say again	SAY AGAIN
Misunderstanding	
Readback error	NO THAT'LL BE A RIGHT TURN ON DELTA …
Intentional repetition	I SAY AGAIN TAXI VIA THE CUPS THREE B ROUTE
Stolen transmission	NEGATIVE THAT WAS NOT FOR NOVEMBER ONE TWO THREE THAT WAS FOR RESCUE ONE TWO THREE …
Erroneous Information	
Incorrect call sign	OKAY THAT WAS UPS TWO TWELVE
Can't find route segment provided in taxi instructions	YOU TOLD US TO HOLD SHORT KILO AND NOVEMBER WE DON'T SEE A KILO ON OUR LISTING…
Message Production	
Self-correction of call sign during transmission	BONANZA NINE TWO CORRECTION PIPER NINE TWO ZERO JUST CONTINUE WEST …
Self-correction during transmission	MAKE A LEFT TURN ON RUNWAY CORRECTION MAKE A LEFT TURN ON TAXIWAY DELTA …
Types of Operational Concerns	**Example**
Spatial Awareness	
Aircraft is not on its assigned route	WE'RE ON PAPA AND WE WANT TO BE ON HOTEL …
Correct a previous taxi instruction	AMEND THAT - HOLD SHORT OF TAXIWAY NOVEMBER ON HOTEL
Incorrect taxi clearance issued	*FBO SIX* HOLD SHORT OF THE RIGHT AND I BELIEVE FBO SIX'S INSTRUCTION IS TO TAKE US TO ONE SEVEN RIGHT CAN YOU VERIFY YOU WANT US TO TAKE *FBO SIX BRAVO*
Instructions given to rejoin route	TURN LEFT ON PAPA REJOIN YOUR ROUTE AT …
Confusion	NO CROSS BRAVO TURN LEFT ON CHARLIE …
Lost	GROUND … AS YOU CAN SEE WE'RE LOST
Missed turn	WE MISSED A TURN THERE WE'RE TAXI LEFT NOW …
Position Awareness	
Maneuver around aircraft/vehicle	ARE YOU GOING TO BE ABLE TO GET BY THAT VAN
Possible conflict	CROSS RUNWAY ONE SEVEN LEFT WITH NO DELAY TRAFFIC TWO MILES OUT
Request clearance to cross an active runway	GROUND CONFIRM WE'RE STILL CLEARED TO CROSS THREE FIVE RIGHT

Figure 5. Examples of Problems and Operational Concerns.

The analyses were restricted to inbound and outbound taxi routes that either began or ended at the ramp or transient parking areas. All inbound taxi routes began with the pilot being clear of the runway and ended at the ramp or transient parking area. All outbound taxi routes began from the ramp or transient parking areas and ended to the runway of take-off. Furthermore, taxi routes that included "progressive taxi," "follow traffic" instructions, or instructed pilots to taxi their aircraft back to the same runway they just exited for another departure were excluded. Since progressive ground movement instructions include step-by-step routing directions, these taxi routes were excluded because pilot variance in navigating on the airport surface would be restricted since ground control would be providing detailed instructions to guarantee safe and expeditious flow to the destination point. There were 727 messages (pilots=401, controllers=326) transmitted between participating pilots and controllers during the 31 structured and 37 unstructured taxi routes that involved 39 inbound and 29 outbound taxi segments.

Communication Workload

Multivariate Analysis of Variance (MANOVA) was performed on the taxi-segment means for each objective measure of communication workload presented in Table 1 (standard errors (SE) are enclosed in parentheses). Univariate Analysis of Variance (ANOVA) was used to assess the statistically significant findings. The Tukey Honestly Significant Difference (HSD) statistic was performed on statistically significant main effects and interactions. An alpha level of .05 was set for all statistical tests.

A two-way Type-of-Route by Type-of-Map MANOVA revealed a statistically significant main effect for Type of Route [F (4,59)=9.76] and Type-of-Route by Type-of-Map interaction, [F(8,118)=6.85]. Subsequent Univariate ANOVAs revealed that not only were more messages transmitted during structured (M=12.70 SE=.99) compared with unstructured (M=8.82 SE=.87) taxi routes [F(1,62)=8.72], but more time was spent under the authority of the ground controller (Structured M=953.25 SE=55.73, Unstructured M=508.03 SE=49.22) [F(1,62)=35.86]. Although the time on frequency to transmit individual messages did not vary with the type of route navigated [F(1,62)=2.09], pilots and controllers jointly increased their overall frequency occupancy time by 9 s during the structured (M=41.24 SE=3.22) compared with unstructured (M=32.34 SE=2.84) taxi routes, [F(1,62)=4.29].

The Type-of-Route by Type-of-Map interaction revealed that the type of route navigated, in combination with the type of map available on the flight deck, affected communication workload for the number of messages transmitted [F(2,62)=5.70], frequency occupancy time [F(2,62)=4.48], and time spent under the authority of ground control [F(2,62)=25.02]. In particular, Tukey post hoc comparisons clearly indicated that controllers and pilots in the north-up surface map group exchanged twice as many messages during the structured routes, as compared with unstructured routes.

Statistically significant differences between the north-up surface map group for structured as compared with unstructured taxi routes (using Tukey post hoc comparisons) also revealed that participants in this group spent nearly twice as long communicating during the structured, as opposed to unstructured taxi routes, and were under the authority of ground control for an additional 18 mins (1084.52 s). Tukey results also showed that participants in the north-up surface map group who

Table 1. Objective Measures of Communication Workload

	Measures of Communication Workload, in seconds (Standard Error)			
Source	**TOF**	**N Messages**	**FOT**	**TGC**
Structured Taxi Route				
Paper-chart	3.24 (.25)	11.00 (1.13)	35.89 (3.69)	716.67 (63.88)
North-up	3.51 (.37)	16.50 (1.70)	52.63 (5.54)	1383.88 (95.81)
Track-up	3.59 (.47)	10.60 (2.14)	35.20 (7.00)	759.20 (121.19)
Unstructured Taxi Route				
Paper-chart	3.64 (.25)	11.24 (1.16)	36.82 (3.80)	688.24 (65.73)
North-up	3.67 (.28)	7.71 (1.28)	27.86 (4.18)	299.36 (72.43)
Track-up	4.28 (.43)	7.50 (1.96)	32.33 (6.39)	536.50 (110.63)

Table 2. Frequency of Problems Presented by Type of Route by Type of Map

	Type of Map						
	Paper-chart		Track up		North up		
Types of Problems (n=38)	**S**	**U**	**S**	**U**	**S**	**U**	**Total %**
Message Reception	5.3%	10.6%	5.3%	2.6%	7.9%	7.9%	39.4%
Misunderstandings	5.3%	5.3%			2.6%	2.6%	15.8%
Erroneous Information	2.6%	2.6%					5.3%
Message Production	5.3%	10.6%	2.6%	2.6%	13.1%		34.2%
Intentional Repetition	2.6%	2.6%					5.3%
Total Percentage	21.1%	31.6%	7.9%	5.3%	27.3%	10.5%	100.0%

Note: S = Structured Taxi Route and U = Unstructured Taxi Route

Table 3. Frequency of Operational Concerns Presented Type of Route by Type of Map

	Type of Map						
	Paper-chart		Track up		North up		
Types of Operational Concerns (n=33)	**S**	**U**	**S**	**U**	**S**	**U**	**Total %**
Spatial Awareness							
Aircraft is not on its assigned route	3.0%		6.1%		3.0%		12.1%
Correction to taxi instructions			3.0%		3.0%		6.1%
Incorrect taxi clearance issued					6.1%		6.1%
Instructions given to rejoin route	3.0%				6.1%		9.1%
Lost	6.1%						6.1%
Missed turn	3.0%		3.0%		6.1%		12.1%
Position Awareness							
Maneuver around aircraft		3.0%					3.0%
Possible conflict	3.0%	3.0%		3.0%		3.0%	12.1%
Request cleared to cross a runway	15.2%	9.1%	3.0%		3.0%	3.0%	33.3%
Total Percentage	33.3%	15.1%	15.0%	3.0%	27.3%	6.0%	100.0%

Note: S = Structured Taxi Route and U = Unstructured Taxi Route traveled via structured taxi routes also exchanged more messages than those in the track-up surface map group that navigated the unstructured taxi routes. They also spent more time on frequency than the track-up surface map group during structured taxis and spent more time under the authority of ground control than any of the other participating groups, regardless of their assigned type of taxi route. The north-up surface map group that navigated unstructured taxi routes spent the least amount of time under the authority of ground control.

Operational Communications

Previous research has demonstrated that when attentional resources are taxed, people may fail to detect that another person is talking, they may misspeak or mishear, or experience other problems identified from communication (Navarro, 1989). To gain some insights as to how the combination of the type of route navigated and type of map available on the flight deck affected communication workload, an examination of the operational communications was initiated.

Types of Problems. The types of problems, along with their frequency of occurrence, are presented in Table 2. Approximately 40% of the problems involved aspects of **message reception** that took the form of a request either from a pilot to have a transmission repeated (say again) or a controller request for confirmation that a message was received (did you copy). Another 16% of the problems involved **misunderstandings**. They involved pilots incorrectly repeating back information transmitted in a previous message (readback error) or pilots acting upon an instruction that was meant for someone else (stolen transmission). **Erroneous information** involved 5.2% of the problems, taking the form of an incorrectly spoken aircraft call sign and pilot failure to find a taxi intersection. A fourth group, **mid-stream corrections**, consisted of mid-utterance repairs that involved either the aircraft's call sign or taxi information, and they included 34.2% of the identified problems. The final type of problem involved the **purposeful repetition** or restatement of an earlier transmission, and it occurred 5.3% of the time. In each recurrence, the controllers instructed the pilots to navigate their aircraft along the assigned taxi routes or runways.

Types of Operational Concerns. The types of operational concerns, along with their frequency of occurrence, are presented in Table 3. The operational concerns noted in the data involved either **spatial awareness** (aircraft is not on its assigned route, correction to taxi instructions, incorrect taxi clearance issued, instructions given to rejoin route, lost, missed turn) or **positional awareness** (maneuver around aircraft, possible conflict, request cleared to cross a runway). Approximately 75% of the operational concerns were related to spatial awareness, while the remaining 25% centered on position awareness.

Prevalence of Problems and Operational Concerns. Before examining the data for problems and operational concerns, a chi-square (χ^2) test revealed no statistically significant difference in the number of structured, compared with unstructured taxi routes completed, when pilots had available either the paper-chart, track-up or north-up surface maps [$\chi^2(2)=1.24$]. Of the 68 taxi routes, 37 contained one or more problems. Subsequent chi-square tests revealed a significant difference in the number of problematic routes among pilots in the north-up surface map group [$\chi^2(1)=12.57$]— 100% of their structured (8/8) and 21% of their unstructured (3/14) taxi routes were problematic. The number of problematic routes was equivalent when pilots navigated their assigned structured or unstructured taxi routes with paper-charts (Structured=11/18 Unstructured=10/17) or track-up (Structured=3/5 Unstructured=2/6) surface-map displays.

A two-way Type-of-Route by Type-of-Map ANOVA was performed on the total number of problems and operational concerns associated with each assigned taxi-route clearance. As shown in Figure 6, more problems and operational concerns were present during the structured, as compared with the unstructured taxi routes [$F(1,62)=9.82$]. The Type-of-Route by Type-of-Map interaction also was statistically significant [$F(2,62)=3.90$]. Subsequently, the Tukey HSD statistic revealed significantly more overall problems; operational concerns resulted only for the north-up surface-map group during structured taxi routes, compared with the north-up and track-up surface map groups during unstructured taxi routes. Five of the 9 identified problems occurred during eight taxi operations and involved mid-stream corrections, three centered on problems in message reception, and one involved an incorrect readback of a taxi clearance. Eight of the 9 identified operational concerns involved spatial awareness (missed turn = 2, aircraft not on its assigned route =1, ATC issued instructions to rejoin a route = 2, incorrect taxi clearance issued = 2, and correction to taxi instructions = 1), and one concerned position operation (e.g., a pilot request to cross an active runway).

DISCUSSION

The analysis of voice communications that compared flight crews who had access to traditional paper-charts and electronic airport surface maps, in either a north-up or track-up orientation, as aids to their surface situational awareness revealed that the combination of the type of

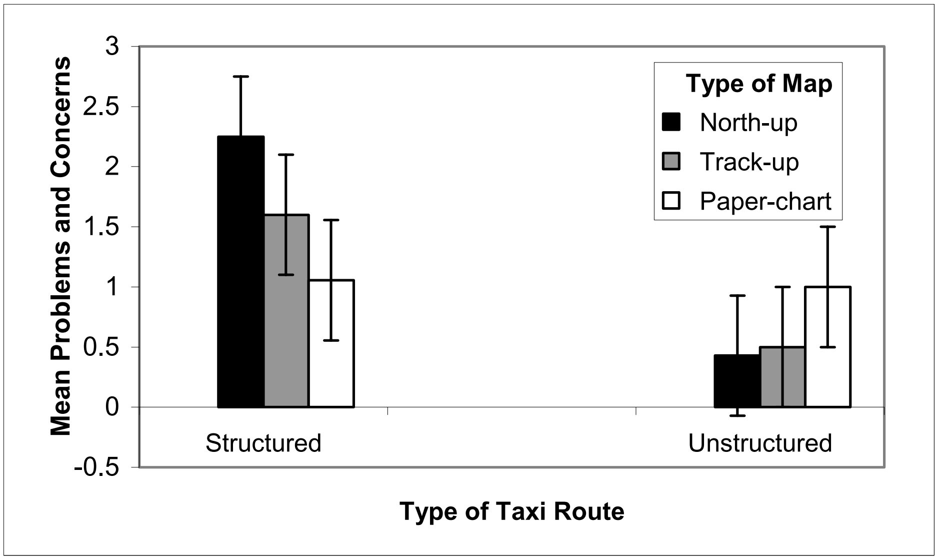

Figure 6. Combined Mean Total of Problems and Operational Concerns Presented by Type of Route and Type of Map.

assigned taxi route and surface map capability onboard the aircraft affected communication workload. Notably, participants in the north-up surface map group a) exchanged more messages than the track-up surface map group when they navigated the unstructured taxi routes, b) spent more time on frequency than the track-up surface map group during the structured taxi condition, and c) spent more time under the authority of ground control than the other groups regardless of their assigned taxi route (structured or unstructured).

Of the 68 taxi routes completed, 54% contained one or more operational concerns or problems — with more overall problems noted by the SMEs for participants in the north-up surface map group during the structured taxi routes, when compared with the north-up and track-up surface map groups during unstructured taxi routes. Notably, all of the structured and 21% of the unstructured taxi routes that involved the use of a north-up display were problematic. The number of problematic routes was equivalent when pilots navigated their assigned structured or unstructured taxi routes using paper-charts or a track-up surface-map display.

To illustrate the types of communication and navigational problems experienced by participants in the north-up map group, a transactional communication set is presented in Figure 7. It is comprised of eight transactions. The first four transactions were non-eventful and involved establishing contact (messages #1-2), issuing a taxi route clearance (messages #2-3), an instruction to hold short of an active runway (messages #2-3), and a clearance to cross that runway (messages #8-9). The first problem appeared in Transaction 5 when the ground controller observed that N123AB missed a turn (message #10), which was acknowledged by the pilot (message 11). About 20 s later, Transaction 6 began with the ground controller providing instructions to the pilot on how to rejoin FBO7B to runway 35L (message #11). Transaction 7 began with the ground controller instructing the pilot to hold short of taxiway Mike (message #14), at which point the pilot requested confirmation that N123AB was the intended recipient of that message (message #15). Such a request suggested that the pilot might not have been actively monitoring the radio frequency. Transaction 8 was comprised of messages #20-23, involving an expedited taxi operation and a confirmation of message receipt from the pilot by the ground controller. The entire transactional communication set took 1289 s to complete (21.48 m) and contained three operational concerns (missed turn, crossing an active runway, and an expedited taxi) and two problems (say again, did you copy) that required the repetition of previously transmitted messages and additional radio frequency time.

The results of the Wickens, Liang, Prevett, and Olmos (1996) simulations study, which investigated pilot use of either a rotating or fixed map display for conducting an approach to a landing, reported that access to a north-up display was not advantageous for pilots who were flying southerly headings — any changes to their flight path would require them to perform complex mental rotations. Their interpretation correlates well to the findings reported here in that approximately 75% of the identified operational concerns were related to spatial awareness. That is, for pilots in the north-up map group, more problems were experienced that related to missing a turn or attempting to rejoin their taxi route. For participants in the paper-chart group, problems took the form of getting lost; for the track-up map group, it was not being on their assigned route.

TCS #	Message #	Reply Time (s)	SID	Message
1	1	—	N123AB	ALFA BRAVO'S READY TO TAXI
1,2,3	2	2	ATC	ONE TWO THREE ALFA BRAVO LOUISVILLE GROUND ROGER RUNWAY THREE FIVE LEFT TAXI VIA FBO SEVEN BRAVO HOLD SHORT OF RUNWAY THREE FIVE RIGHT
2,3	3	2	N123AB	OKAY TAXI TO THREE FIVE LEFT VIA FBO BRAVO FBO SEVEN BRAVO AND HOLD SHORT OF THREE FIVE RIGHT
3	4	169	ATC	NOVEMBER THREE ALFA BRAVO HOLD SHORT OF RUNWAY THREE FIVE RIGHT
3	5	1	N123AB	BRAVO
3	6	7	N123AB	ALFA BRAVO HOLDING SHORT
3	7	0	ATC	ROGER
4	8	450	ATC	NOVEMBER THREE ALFA BRAVO CROSS RUNWAY THREE FIVE RIGHT AT DELTA SIX
4	9	2	N123AB	BRAVO CROSS THREE FIVE RIGHT AT DELTA SIX THANK YOU
5	10	68	ATC	NOVEMBER THREE ALFA BRAVO LOOKS LIKE YOU MISSED YOUR TURN THERE TURN RIGHT THERE AT YOUR NEXT TAXIWAY THEN A RIGHT ONTO PAPA
5	11	1	N123AB	OKAY UNDERSTAND SORRY
6	12	20	ATC	THREE ALFA BRAVO TURN RIGHT THERE INTO PAPA THEN A LEFT TURN NOVEMBER START TO REJOIN YOUR ROUTE THERE
6	13	1	N123AB	OKAY NOW WE GOT IT
7	14	202	ATC	NOVEMBER THREE ALFA BRAVO HOLD SHORT OF MIKE
7	15	4	N123AB	WAS THAT FOR THREE ALFA BRAVO
7	16	144	ATC	AFFIRMATIVE HOLD SHORT OF ALFA OPPOSITE DIRECTION TRAFFIC
7	17	2	N123AB	BRAVO
7	18	0	ATC	THREE ALFA BRAVO CONTINUE
7	19	2	N123AB	ALFA BRAVO THANK YOU
8	20	25	ATC	NOVEMBER THREE ALFA BRAVO EXPEDITE YOUR TAXIING ON BRAVO TO THREE FIVE LEFT THAT TRAFFIC TO FOLLOW YOU
8	21	2	ATC	NOVEMBER THREE ALFA BRAVO DID YOU COPY
8	22	113	N123AB	THREE ALFA BRAVO WE'RE EXPEDITING
8	23	10	ATC	THANK YOU

It would seem that having a north-up map display for navigating the airport surface provided no additional benefit over that of a paper chart. The findings suggest that the pilots in the paper-chart and north-up map groups also may have been busier performing complex mental operations (i.e., making left to right transformations) while navigating their aircraft along their assigned taxi route. As the data show, pilots in each of these two map groups requested a higher number of repetitions of previously spoken messages and were more likely to read back messages incorrectly. Consequently, fewer attentional resources would have been available to actively listen for their aircraft's call sign on the radio.

This is similar to driving on an unfamiliar metropolitan interstate highway requiring extra vigilance to make a timely and correct turn when approaching a fast-moving, cloverleaf intersection. If a passenger should attempt to engage the driver in casual conversation, the driver might miss the turn or not hear the passenger. The driver and pilot alike can request a "say again" or ask for assistance – both requiring additional communications.

Although some pilots (like drivers) turn their maps to be congruent with the direction they are going, the observer data reported by Joseph et al. (2002) did not mention whether jump-seat observers noted that pilots in the paper-chart group had rotated their maps or not. If the pilots manually rotated their paper maps to simulate a track-up surface-moving map, their performance should have been more aligned with that of the pilots in the track-up group instead of the north-up group.

When evaluating emerging avionics devices that aid pilots to quickly detect, avoid, monitor, and follow other aircraft, consideration as to the electronic format of these displays must be deliberated in light of the piloting task the operator is expected to perform (see Aretz, 1991, for a summary of previous research; Carel, McGarth, Hersherber, & Herman, 1974, for early research on design criteria). The format in which a map is presented can, and does, affect some aspects of pilot performance — north-up displays are better for some tasks (planning), and track-up displays are better at others (turning). In fact, data presented by Clarke, McCauley, Sharkey, Dingus, and Lee (1996) suggest that, when both north-up and track-up displays are available, pilots typically select a north-up map display when planning a route and a track-up display when flying. Some developers are making both north-up and track-up modes available on some of their CDTI devices, and this provides the pilot with the option to select one mode for some piloting tasks and the other mode for others. Of course, some pilots still may choose to use paper charts as their primary source of airport information.

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ENDNOTES

[1]Subsequently, in 1987, the FAA Administrator approved the definition of the term “runway incursion” as “any occurrence at an airport involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in loss of separation with an aircraft taking off, intending to take off, landing, or intending to land.” This definition was clarified in 1996 to refer only to airports with operating control towers (Order 7050.1 2002). Consequently, runway incursions should not include “events involving aircraft, vehicles, pedestrians, or objects on the runway without permission when there is no collision hazard or loss of separation, nor should they include incidents involving animals. Although these and other similar unauthorized or unapproved movements occur on the airport surface, they are surface incidents, not runway incursions.”

[2] Source: Letter of recommendation dated July 6, 2000, to the FAA addressing runway incursions.

[3] FAA Order 7110M Air Traffic Control, 3-7-2. TAXI AND GROUND MOVEMENT OPERATIONS was current at the time of the evaluation. “Issue, as required or requested, the route for the aircraft/vehicle to follow on the movement area in concise and easy to understand terms. When a taxi clearance to a runway is issued to an aircraft, confirm the aircraft has the correct runway assignment. “

[4] All Office of Aerospace Medicine technical reports are available in full-text from the Civil Aerospace Medical Institute’s publication Web site: http://www/cami.jccb.gov/aam-400A/Abstracts/Tech_Rep.htm.