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A Summary of Flightdeck Observer Data From SafeFlight 21 OpEval-2

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16. Abstract

In 2000, the Cargo Airlines Association and the Federal Aviation Administration conducted Operational Evaluation 2 (OpEval-2) of Cockpit Display of Traffic Information (CDTI) and Automatic Dependent Surveillance - Broadcast (ADS-B) technologies at the Standiford International Airport in Louisville, KY. This evaluation was designed to demonstrate the benefits of CDTI/ADS-B, including safety, efficiency, and capacity. Toward this end, five flight periods were designed to test five different applications: Airport Surface Situation Awareness (ASSA), Departure Spacing, Initial and Final Approach Spacing, Final Approach Runway Occupancy Awareness (FAROA), and Visual Acquisition and Traffic Awareness. OpEval-2 included 16 aircraft of various types and their flight crews. Flightdeck observers accompanied these flight crews to record human factors data. This report summarizes the collection and analysis of flightdeck observer data. In addition, the report includes empirically based recommendations for addressing human factors issues related to certification of CDTI for the five applications that were tested in OpEval-2.

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A Summary of Flightdeck Observer Data From SafeFlight 21 OpEval-2

INTRODUCTION

The availability of new technologies for the flightdeck and air traffic control facilities is creating new capabilities for enhanced aircraft operations and, with them, the need to evaluate the effectiveness of these new technologies in operational settings. Two such systems, Cockpit Display of Traffic Information (CDTI) and Automatic Dependent Surveillance-Broadcast (ADS-B), were recently demonstrated in Operational Evaluation 2 (OpEval-2), which was conducted at Standiford International Airport in Louisville, KY. OpEval-2 was sponsored by the Cargo Airlines Association (CAA) and the SafeFlight21 Office of the Federal Aviation Administration (FAA), and included aircraft and flight crews from industry, government, and private organizations.

The purpose of OpEval-2 was to demonstrate the use of CDTI and ADS-B and their expected benefits, which include increased safety, enhanced capacity, and greater efficiency. Three objectives were planned for OpEval-2. The first objective was to develop and evaluate avionics and procedural modifications needed to support operational approval for the following applications: Initial and Final Approach Spacing, Departure Spacing, Final Approach and Runway Occupancy Awareness (FAROA), and Airport Surface Situation Awareness (ASSA). A fifth application, Visual Acquisition and Traffic Awareness, was tested in OpEval-1, but also was included in OpEval-2 to evaluate a specific procedure (see OpEval-1 Final Report, 1999, for OpEval-1 summary). The visual acquisition application included the use of call sign in the traffic call-out to take advantage of the information available on the traffic display. The second objective was to use these applications to evaluate ADS-B technology in a terminal area environment with air traffic controllers. The third objective was to highlight the safety and efficiency benefits of ADS-B by providing a limited demonstration to key industry participants, including labor, airline operations, general aviation, and the FAA.

An important part of OpEval-2 was the collection and analysis of flightdeck observer data to aid in quantifying and verifying the expected benefits of CDTI. This report summarizes the development of flightdeck observer data forms and flight crew questionnaires, the training of flightdeck observers, and the collection and analysis of flightdeck observer data for OpEval-2. In addition, a summary of human factors issues related to CDTI is presented for each OpEval-2 application based on the results of flightdeck observer data analysis. Before these summaries are presented, a brief overview of OpEval-2 procedures and applications is given.

OPEVAL-2 PROCEDURES

Several procedures were implemented to ensure the safety of flight operations at Standiford International Airport during OpEval-2, which consisted of six, three-hour flight periods that occurred between October 26th and October 30th of 2000. No observer data was collected during the sixth flight period, which comprised a limited demonstration to key industry participants. This flight period is not discussed further. The flight periods were timed to ensure that OpEval-2 occurred during low traffic volume at the airport. A separate team of eight controllers, including a coordinator for both the Air Traffic Control Tower (ATCT) and Terminal Radar Approach Control (TRACON), was trained to provide standard air traffic control services for all OpEval-2 aircraft.

The ATCT limited access to runway 17R/35L to only the 16 aircraft participating in OpEval-2. In addition, the ATCT isolated the airspace near the airport for OpEval-2 air traffic to minimize disruption to normal flight arrivals and departures that used runway 17L/35R. The controllers established two traffic patterns for OpEval-2. The first pattern was labeled Outer Covey, and it was restricted to the jet aircraft that were participating in OpEval-2. The second pattern was labeled Inner Covey, and it consisted of a wide variety of aircraft and equipage, including general aviation aircraft. Traffic from these two patterns was merged by the controllers at a point 20 miles from the 17R/35L runway threshold.

Table 1 displays the participating aircraft by flight period, application, and equipment type. Surface map capability is also indicated. The flight periods were developed such that the systematic variation of

Table 1. Opeval-2 aircraft classified by Flight Event, Application, and CDTI Type.

	Aircraft ID	Flight Period 1	Flight Period 2	Flight Period 3	Flight Period 4	Flight Period 5	ASSA	FAROA Air and Ground	Departure Spacing	Initial and Final Spacing	Visual Acquisition/ Traffic Awareness
Build 2/4	UPS 1 (Build 4) Boeing 727 UPS101		✓	✓	✓	✓	No Map	✓	✓	✓	✓
	UPS 2 (Build 4) Boeing 727 UPS202		✓	✓	✓	✓	No Map	✓	✓	✓	✓
	UPS 3 (Build 4) Boeing 727 UPS303		✓	✓	✓	✓	No Map	✓	✓	✓	✓
	UPS 4 (Build 4) Boeing 727 UPS404		✓	✓	✓	✓	No Map	✓	✓	✓	✓
	FedEx1 (Build 2) Boeing 727 FDX1			✓	✓		No Map	✓	✓	✓	✓
Basic Prototype	FAA1 Boeing 727 N40	✓	✓			✓	No Map	✓	✓	✓	✓
	FAA2 Convair 580 N49	✓	✓			✓	No Map	✓	✓	✓	✓
	FAA3 Convair 580 N39	✓	✓			✓	No Map	✓	✓	✓	✓
Advanced Prototype	Collins[1] Sabreliner N50CR	✓	✓		✓	✓	No Map	✓	✓	✓	✓
	L3 Cessna Citation V N189H	✓	✓		✓	✓	Moving Map	✓	✓	✓	✓
	Honeywell[2] Beech King Air A90 N52EL	✓	✓			✓	Moving Map	✓			✓
MX20/GX60	AOPA Beech Bonanza N7236W	✓	✓			✓	North Up Map	✓			✓
	DCA Cessna 210 N624MT	✓	✓			✓	North Up Map	✓			✓
	CNS Aviation Piper Lance N31920	✓	✓			✓	North Up Map	✓			✓
	Volpe Piper Aztec 327DR	✓	✓			✓	North Up Map	✓			✓
	UPS AT[3] Beech King Air C90 N89TM	✓	✓			✓	North Up Map	✓			✓

[1] The Collins Sabreliner had the advanced spacing algorithm, but not the Surface Moving Map.

[2] The Honeywell King Air had the Surface Moving Map, but not the advanced spacing algorithm.

[3] The UPS AT King Air was equipped with both CDTI Build2/4 and MX20 platforms. CDTI Build2/4 platform was used during Flight Event 1. Both platform types were used during Flight Event 2.

procedures within and across these periods produced an extensive set of data that was used to evaluate OpEval-2 applications. The following paragraphs briefly summarize each of the five flight periods in which flightdeck observers collected data.

Flight Period 1

Operations during Flight Period 1 were conducted on RWY 17R. The first 90 minutes of flight time included three full-stops, one after each of the long approach spacing profiles (i.e., closing to 5 miles or 120 seconds at the runway threshold). Table 1 displays the participating aircraft by flight period, application, and equipment type. Surface map capability is also indicated. Table 1 shows that the three FAA aircraft participated, as did the L3 and Collins business jets. The remaining 90 minutes of flight time consisted of low approaches and use of the OpEval-2 traffic call sign procedure, as well as runway occupancy awareness scenarios. These low approaches included four GA (Beech Bonanza, Cessna 210, Piper Lance, Piper Aztec), two Beech King Air (A90, C90), and two FAA Convair 580 aircraft.

Flight Period 2

Operations during Flight Period 2 were similar to those of Flight Period 1, and they also were conducted on RWY 17R. Flight crews conducted two full-stops, one after each of the long approach spacing profiles in the first 90 minutes of flight time, followed by low approaches for the remaining 90 minutes. Table 1 shows that the same aircraft participated in Flight Periods 1 and 2. In addition, four UPS aircraft performed three full-stops, one after each of the long approach spacing profiles in the first 90 minutes of Flight Period 2. Also, four UPS aircraft performed three long-approach spacing profiles to a full stop landing in the first 90 minutes of Flight Period 2.

Flight Period 3

Operations during Flight Period 3 consisted of four full-stop sequences to RWY 35L. Long- approach spacing profiles were flown and operations were limited to the Outer Covey pattern. Table 1 shows that only the UPS and Federal Express aircraft participated in Flight Period 3.

Flight Period 4

Operations during Flight Period 4 consisted of four full-stop sequences to RWY 35L. Short- approach spacing profiles (i.e., closing to 3 miles or 90 seconds at the runway threshold) were flown and operations again were limited to the Outer Covey pattern. Table 1 shows that the UPS and Federal Express aircraft participated in Flight Period 4, along with the L3 and Collins business jets.

Flight Period 5

Flight Period 5 operations were similar to those of Flight Period 2, and they were conducted on RWY 35L. Whereas in Flight Period 2, flight crews conducted long-approach spacing profiles; for Flight Period 5, they conducted two full-stop, short-approach spacing profiles in the first 90 minutes of flight time, followed by low approaches for the remaining 90 minutes. Table 1 shows that the same aircraft participated in Flight Periods 2 and 5.

OPEVAL-2 APPLICATIONS

The five flight periods provided a means for evaluating each of the OpEval-2 applications. The following paragraphs briefly describe tasks and operations that were developed and then embedded within the flight periods to allow for evaluation of each OpEval-2 application.

Airport Surface Situation Awareness (ASSA)

A set of circuitous taxi routes was designed to evaluate the ability of flight crews to accurately navigate with either an electronic surface map display or a paper surface map. The routes were created to assess the extent to which a CDTI system that displayed airport surface information as well as traffic could improve the situation awareness of flight crews during airport surface operations. This evaluation assessed the flight crews' ability to identify specific geographic locations on the airport surface and the relative location of other aircraft and surface vehicles. Routes were predefined, named, and provided to the controllers in graphical format and to the flight crews in written text format. Within each flight period, the taxi routes were assigned to pre-selected aircraft on either their outbound or inbound taxi legs. The Ground controllers cleared aircraft to taxi via the route name, and then they monitored aircraft movements to ensure compliance with the prescribed route. Flight crews interpreted the written text as a series of turn instructions to determine the route to taxi. Flight crews were asked to stop the aircraft at a predetermined point along the prescribed route to answer two questions posed by observers. The first question asked them to identify their current location and the second question asked them to identify the most proximal surface traffic. Additional information was recorded during normal taxi to and from the ramp area.

Departure Spacing

Aircraft participating in the Outside Covey participated in the Departure Spacing application, which was designed to evaluate the ability of the flight crew and controllers to manage a pre-determined spacing interval between departing aircraft. Long spacing (i.e., 6.0 nm) and short spacing (i.e., 4.5 nm) scenarios were defined for each flight period. Each time the Outer Covey pattern was flown, flight crews determined the departure spacing interval between all but the last aircraft, for which the local tower controller provided the initial departure spacing interval.

Two procedures were used during OpEval-2 to evaluate the Departure Spacing application and ensure compliance with standard ATC procedures. The first procedure, known as flight crew-managed departure spacing, required flight crews to use mission reference cards that outlined the procedures to follow and distances to maintain. As part of this procedure, controllers referred to scenario cards that defined the departure spacing interval. Local control provided a take-off clearance using standard phraseology when standard departure separation was achieved from a preceding departure (i.e., 6000 ft. and airborne). The flight crews then positioned the aircraft on the OpEval-2 runway, waited until the appropriate distance was achieved, and then began the take-off roll. ATC ensured the runway was protected while the flight crew was waiting for the preceding departure to achieve the appropriate distance.

In the second procedure, known as controller-managed departure spacing, flight crews were required to use the mission reference cards and controllers used the scenario cards that defined the to-be-achieved departure spacing interval. However, the controller first placed the aircraft on the runway with instructions to taxi into position and hold. The controller issued a take-off clearance using standard phraseology once the aircraft achieved the appropriate departure spacing distance.

Initial and Final Approach Spacing

The purpose of the Initial and Final Approach Spacing application was to evaluate the ability of the flight crew and controllers to manage a pre-determined approach spacing interval between arriving aircraft. The required spacing changed as the aircraft continued along the pattern and approached the airport. The final spacing between aircraft as the lead aircraft crossed the threshold was either 5 nm/120 sec or 3 nm/90 sec (depending on the flight period). The scenarios were designed to evaluate two levels of CDTI approach spacing capability - an initial capability (herein referred to as UPS AT Build 2/4) and a more advanced prototype avionics capability that included approach spacing algorithms (herein referred to as Advanced Prototype). The traffic flows from the Inner and Outer Covey patterns were merged and sequenced by ATC at 20 miles from the runway threshold. The initial approach spacing at the 20-mile point was intended to be 6.5 nm (long spacing) during some of the flight periods and 5.5 nm (short spacing) during other flight periods. The ability of ATC to meet these distances depended on several factors, including spacing at the end of the departure profile and separation from non-participating aircraft that were inbound to the non-OpEval-2 runway. Flight crews used CDTI during the 20-mile approach to reduce the spacing interval to a long (5 nm or 120 sec if initial spacing was 6.5 nm) or a short (3 nm or 90 sec if initial spacing was 5.5 nm) final approach spacing criteria. ATC monitored both participating and non-participating aircraft and responded appropriately to ensure that at least minimum standard separation was maintained.

Final Approach and Runway Occupancy Awareness (FAROA)

The FAROA application included use of the CDTI during OpEval-2 departure and arrival operations. Flight crews were required to use CDTI immediately prior to departures and arrivals to scan for targets that were positioned on or near the runway. This procedure was used to determine if CDTI use increased flight crew awareness of runway occupancy. Occasionally, an ADS-B equipped surface vehicle and/or OpEval-2 aircraft were required to hold on the taxiways to provide flight crews using CDTI with targets that were off the runway. Three flight periods included scenarios in which the FAA B727 and an ADS-B equipped surface vehicle were positioned on the OpEval-2 runway. When a vehicle was on the runway, flight crews were cleared to complete a low approach at 500 feet above ground level (AGL) and data were collected on whether the flight crews became aware of the conflict using CDTI and associated flight crew workload.

Visual Acquisition and Traffic Awareness

The Visual Acquisition and Traffic Awareness application involved the use of ATC traffic advisories during each of the five flight periods. The availability of aircraft call sign on CDTI made it possible to collect data on the use of aircraft call sign in traffic advisories. Although this is not standard ATC phraseology, FAA Order 7110.65 does allow additional information to be appended to traffic advisories. Therefore, the flight profiles were designed to evaluate the inclusion of aircraft call sign in traffic advisories and replies by flight crews. Normal traffic calls were used during the Departure and Approach Spacing applications for aircraft in the Outer Covey pattern. However, aircraft in the Inner Covey pattern were vectored by ATC to create as many traffic calls as possible during flight periods 1, 2 and 5. This procedure was used to assess the effect of including aircraft call sign in traffic advisories when air traffic was increased.

DESCRIPTION OF CDTI FUNCTION

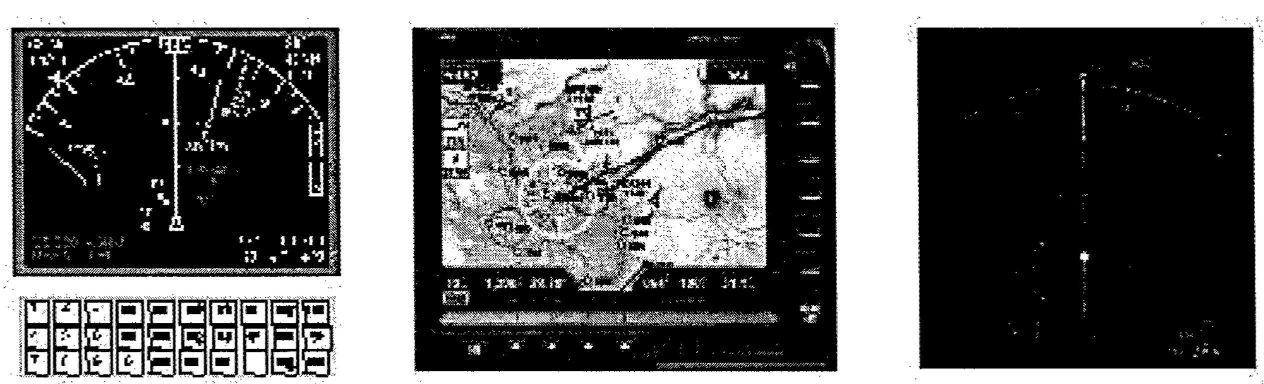
The CDTI displays the relative position of proximal traffic to own aircraft. Additional information also may be displayed, such as navigational aids and obstructions. The CDTI can obtain traffic information from several different sources, including ADS-B, Traffic Information Service (TIS), or an on-board Traffic Alert and Collision Avoidance System (TCAS). Traffic information is displayed via a dedicated avionics device (i.e., a CDTI), or the information can be displayed on a shared avionics device (i.e., multi-function display). The latter form of display attempts to integrate information from several sources into a single display.

Figure 1 shows the three different CDTI platforms that were evaluated during OpEval-2. These were the UPS AT Build 2/4, the UPS AT MX20, and Prototype Avionics. The UPS AT Build 2/4 platform included two unique UPS AT Link and Display Processor Unit (LDPU) versions that were identified as Build 2 and Build 4. The Build 2 platform consisted of a Mode S Transponder, TIS, and a ADC/Universal CDTI and Keyboard. The Build 4 platform consisted of both a Mode S and a UAT Transponder, and an Astronautics CDTI and Keyboard. The Build 4 platform was a newer (updated) version of the Build 2 platform. The UPS AT MX-20 platform included an Apollo GX50 GPS receiver, a UAT transceiver, and the Apollo MX-20 multi-function cockpit display. Finally, the Prototype Avionics platform consisted of an Advanced Prototype capability and a Basic Prototype capability. The former capability included either a surface map overlay and/or an algorithm for advanced approach spacing. The Basic Prototype included rudimentary CDTI capability and was not intended to be representative of potential CDTI implementation.

FLIGHTDECK OBSERVATION METHOD

Flight crew interaction with each of the CDTI platforms was evaluated during the ASSA, Departure Spacing, Visual Acquisition and Traffic Awareness, Initial and Final Approach Spacing, and FAROA OpEval-2 applications. As Table 1 illustrates, some aircraft were not equipped to perform certain OpEval-2 applications; hence, flightdeck observer data was not collected for these applications. Flightdeck observer data aided in the identification of human factors and performance issues associated with the use of each CDTI display platform for the OpEval-2 applications.

Two methods of flightdeck observer data collection were designed to capture flight crew interaction with CDTI platforms. The first method consisted of flightdeck observation using trained observers. This method allowed for direct observation of flight crew procedures and recording of events by a flightdeck observer. The second method entailed indirect observation and included the use of structured interviews and a questionnaire. The structured interview was completed by flight crews immediately after their



UPS-AT Build 2/4 UPS-AT MX20 Prototype Avionics

Figure 1. Illustration of the three different CDTI Platforms that were evaluated in OpEval-2.

participation in each flight period. The questionnaire was completed immediately after flight crews participated in their final OpEval-2 flight period.

Flightdeck Observers and Training

Nineteen flightdeck observers participated in OpEval-2; all had previous flightdeck experience, either as flight crews or as observers. Prior to OpEval-2, the observers participated in a training program that consisted of conference calls, email distribution of materials, attendance at pre-OpEval-2 simulations, and an eight-hour, on-site orientation session the day before OpEval-2 began. The on-site orientation session provided a review of CDTI platform operating procedures, and the final briefing on the flight schedule. Observers were trained in the following areas:

- Overview and use of the data-collection materials
- Normal flight crew operations procedures, including use of checklists, typical workload management procedures, and sterile cockpit requirements
- Structured interview techniques
- OpEval-2 aircraft and flight assignments
- Review of the structure and timing of the OpEval-2 flight periods to which they were assigned.

The majority of flightdeck observer data were collected by direct observation of flight crew procedures by an observer occupying the jump seat of the transport category aircraft, or one of the rear seats of the single-pilot, general aviation aircraft. The single pilot aircraft also carried a safety pilot occupying the right seat. All flight crews were instructed to perform their normal duties without regard to the presence of the observer, and to freely exercise their judgment to terminate data collection if in-flight circumstances required it. Flight crews also were asked to verbalize their thought processes so that the observers could gain a better understanding of how the crews used CDTI.

Observers were instructed not to interact directly with crewmembers, except as required to collect data for the ASSA and Initial and Final Approach Spacing applications. In the instances where flight crew-observer interaction was necessary, data collection occurred only during ground operations with the aircraft stopped and parking brakes set. Although observers were asked to make all other observations silently as the flight crew performed their normal cockpit duties, the observer was considered a member of the flight crew in all other respects and was expected to call attention to any safety situation requiring the attention of the flight crew.

Flightdeck Observer Forms

Flightdeck observers recorded their observations on the following forms, which were designed for directly observing OpEval-2 applications and procedures during flight. A brief description of each form is given in the following section and the actual forms used in OpEval-2 are included in Appendix B:

- Checklists Form
- Visual Acquisition and Traffic Awareness Form
- Procedures Forms
- Modified Cooper-Harper Workload Scale
- Observers also administered the following materials to flight crews at the end of OpEval-2 flight periods:
- Post-Flight Structured Interview
- Flight Crew Questionnaires

Checklists Form

This Checklists Form was used to determine the effects, if any, of CDTI platforms on flight crew use of checklists. Observers recorded whether checklists were completed, not completed, suspended, interrupted, missed by the crew, etc. A frequency analysis was used to analyze this data and identify the most frequent causes of checklist intrusions. Written comments from the forms were used to illustrate examples of specific types of intrusions.

Visual Acquisition and Traffic Awareness Form

This form was used to record how flight crews used CDTI to aid in visual acquisition of traffic in the Inner and Outer Covey patterns. The analysis of this data focused on the order in which information was accessed to support target acquisition during OpEval-2 flight periods. In particular, the analysis determined the extent to which the introduction of CDTI affected the procedure typically used to acquire targets visually. A frequency analysis was used to assess the effects of displays on the order in which information was accessed to support target acquisition. Observers' written comments were used to supplement the frequency analysis.

Procedures Forms

Two OpEval-2 Procedures Forms were used by observers: the CDTI Build 2/4 Procedures Form and the MX-20 Procedures Form. No forms were developed for the Prototype Avionics platform because its development was in an early stage. Observers used the Procedures Forms to assess crew use of recommended CDTI techniques as defined in flight crew maneuver cards. Analysis of data from the forms determined the frequency with which crews used procedures defined in the maneuver cards or deviated from these procedures and created their own procedures. Deviations from suggested procedures may indicate flight crew preferences or strategies for completing a procedure and these may be more efficient or "better" than the strategies defined in the maneuver cards. From a certification perspective, such preferences or strategies may represent acceptable and safe practices for use of CDTI for OpEval-2 applications. Written comments from this form were used to describe specific deviations in procedures that occurred frequently.

Modified Cooper-Harper Workload Scale

The Modified Cooper-Harper Workload Scale was used by observers to assess flight crew workload of the Pilot Flying (PF) and Pilot Not Flying (PNF) immediately after the crew used CDTI to perform the final approach spacing application. The flight crew used a scale that ranged from 1 to 10 to assign a workload rating. Each number corresponded with a qualitative description of the workload rating. For example, a rating of 1 corresponded with "Mental effort is minimal and desired CDTI performance is easily attainable" whereas a rating of 10 corresponded with "Acceptable CDTI performance cannot be accomplished reliably". The ratings provided by flightcrew members were analyzed for possible differences due to several final approach spacing factors (e.g., time of day, spacing interval).

Post-Flight Structured Interview

Following each OpEval-2 flight period, flightdeck observers debriefed the participating flight crews by conducting a structured interview. The interview consisted of nine (MX-20) or ten (Build 2/4 and Prototype Avionics) questions and was audiotaped. Interview questions focused on procedures associated with CDTI/MX-20 platform, training and preparation, interaction with ATC, and any tradeoffs that may have been associated with the use of CDTI for the OpEval-2 applications. Flight crew members were interviewed together to promote discussion and elicit additional information. After each interview, observers created a written summary of the audiotaped recording that was used in the data analysis. The flight crew responses to the questions in the structured interview form were categorized and aggregated with the flight crew responses to the open-ended questions from the respective flight crew questionnaires to identify operational and human factors issues associated with use of CDTI for OpEval-2 applications.

Flight Crew Questionnaires

CDTI Build 2/4 and Prototype Platforms

A 173-item questionnaire was the primary means for gathering information on flight crew demographics, previous CDTI experience and training, and acceptability of the following characteristics associated with OpEval-2 applications:

- CDTI functionality
- Use of color in display modes
- Display symbology
- Display features
- Display location and readability

Descriptive statistics are reported for the questionnaire data, and factor analyses were used to determine if particular CDTI features or functional components could be grouped according to some underlying factor. Responses to open-ended questions were analyzed to identify other issues that the flight crew judged to be pertinent. Open-ended responses from this questionnaire were aggregated with responses from the structured interviews to summarize operational and human factors issues associated with OpEval-2 applications.

MX-20 Platform

A 163-item questionnaire served as the primary means for gathering information on crew demographics, previous MX-20 experience and training, and acceptability of the following characteristics associated with OpEval-2 applications:

- CDTI functionality
- Use of color in display modes
- Display symbology
- Display features
- Display location and readability

The analysis of this questionnaire was similar to that used to analyze the Build 2/4 questionnaire.

Data Analysis

All data were screened for errors, outliers, and other anomalies that would bias statistical analyses. Descriptive statistics and frequency analyses were computed where appropriate, as were ANOVA and principal components analysis. The following section provides a summary of results that are based on analyses of data from each of the flightdeck observer forms. OpEval-2 applications and effects associated with CDTI platforms also are reported in this section.

RESULTS

Airport Surface Situation Awareness

A set of circuitous taxi routes was designed to evaluate the ability of flight crews to accurately navigate with either an electronic surface map or a paper surface map. The routes were created to assess the extent to which the CDTI platform could be used for the ASSA application to improve the situation awareness of flight crews during airport surface operations. This evaluation assessed flight crews' ability to identify specific geographic locations on the airport surface and the relative location of other aircraft and surface vehicles. Routes were predefined, named, and provided to the controllers in graphical and text format and to the flight crews in written text format.

Figure 2 shows that the flightdeck observers noted that 53% of flight crews used CDTI to identify Traffic to Follow (TTF) during taxi operations. Of this group, a larger percentage of flight crews used an electronic surface map (65% vs. 40% with a paper surface map). Additional analyses revealed that the flightdeck observers reported that flight crews used CDTI for enhancing surface traffic awareness 63% of the time. Of these positive responses, 82% of flight crews used an electronic surface map, and 40% had a paper surface map (Figure 4). Flightdeck observers also noted that 53% of flight crews used CDTI to assess the location of traffic on the airport surface. Of this group, 76% used an electronic surface map, and 27% used a paper surface map (Figure 4).

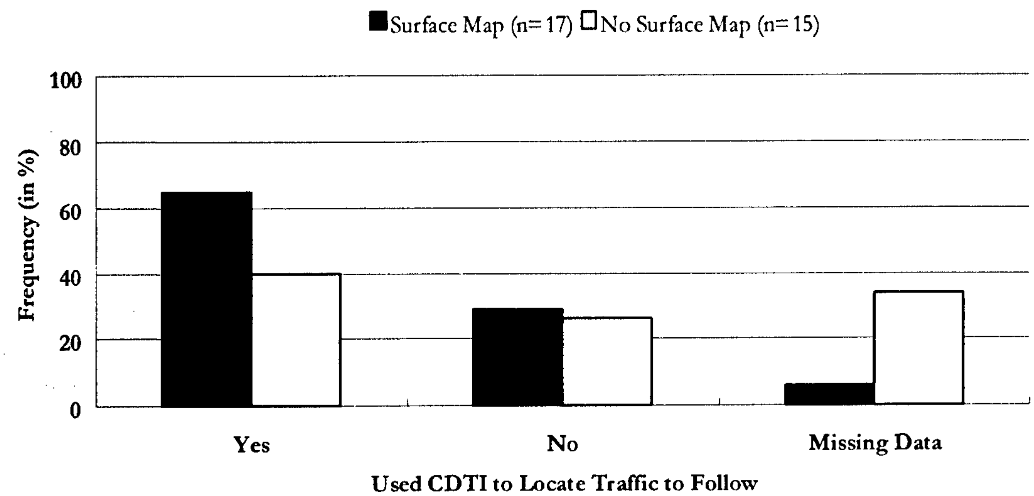


Figure 2. Use of CDTI to locate Traffic-to-Follow (TTF) in taxi sequence by flight crews with an electronic surface map and those with a paper surface map.

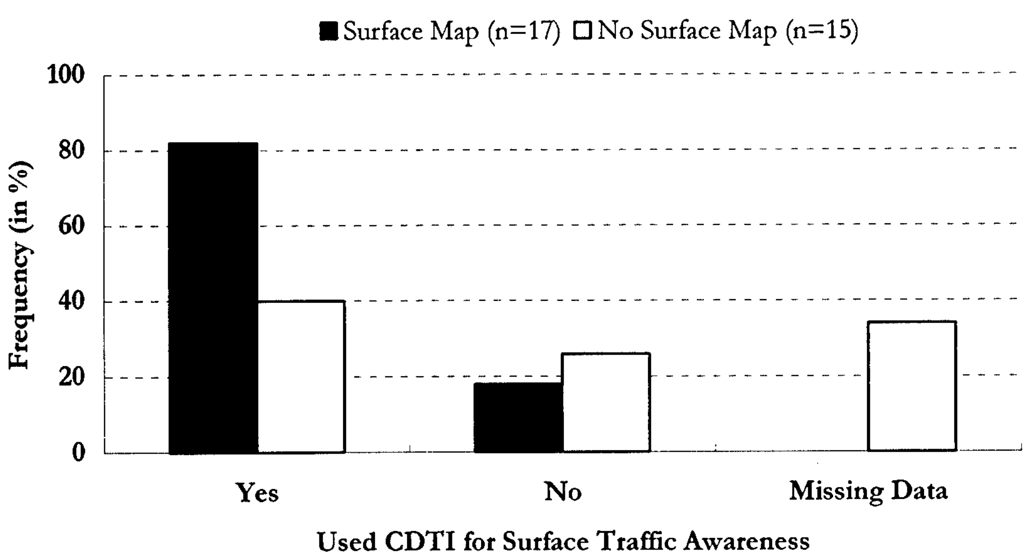


Figure 3. Use of CDTI for surface traffic awareness by flight crews with an electronic surface map and those with a paper surface map.

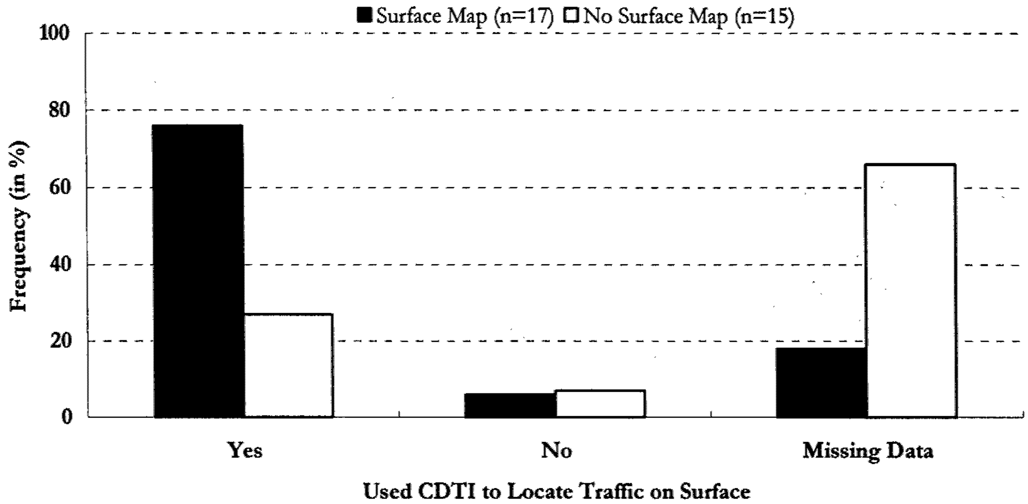


Figure 4. Use of CDTI to assess traffic location on the airport surface by flight crews with an electronic surface map and those with a paper surface map.

Flightdeck observers also recorded flight crew use of two CDTI platform features: the Target Selection function and the Ground Track Vector function. Overall, 31% of flight crews used the Target Selection function on CDTI to identify TTF during taxi operations. Approximately 12% of flight crews used the Ground Track Vector function on CDTI to evaluate the target speed during airport surface operations. These percentages were nearly equivalent for flight crews with an electronic surface map and those with a paper surface map.

Flightdeck observer data indicated that one-third of the flight crews utilized CDTI to identify taxiway locations on the airport surface. Of this group, 65% of flight crews with an electronic surface map used the CDTI to identify taxiway locations during surface navigation. None of the flight crews with a paper surface map used CDTI for this purpose.

Flightdeck observers also recorded whether flight crews correctly identified the most proximal surface traffic when they were asked this question. The data indicated that only 12 of the 32 flight crews responded to this question. Of the 12 flight crews, 7 had the electronic surface map, and all correctly identified the most proximal traffic. Four of the five flight crews with a paper surface map correctly identified the most proximal traffic.

FAROA

Flight crews were instructed to utilize the CDTI to assess runway occupancy prior to entering or crossing runways (FAROA ground). During airborne operations from the final approach fix through rollout, flight crews were instructed to utilize CDTI to continuously assess runway occupancy (FAROA air). Flightdeck observers recorded data for the FAROA application during these airborne and ground events. Additionally, during Flight Periods 1 and 2, a surface vehicle and an aircraft were positioned at two locations on the active runway to evaluate the effect of the CDTI on flight crew awareness of runway occupancy.

FAROA Air

Flightdeck observer data indicated that during FAROA Air operations 62% of flight crews used the CDTI to evaluate the runway environment for possible conflicts. Figure 5 shows that within this group, 71% of flight crews used an electronic surface map, and 56% used a paper surface map. During final on low approaches, flightdeck observers reported that flight crews using CDTI equipped with an electronic surface map were more effective at determining when the runway was occupied than flight crews with the paper surface map. Eight flight crews with an electronic surface map identified the traffic on the runway, whereas flight crews with a paper surface map failed to identify the traffic on the runway. These results suggest that the addition of an electronic surface map may aid in identifying traffic on a runway.

Flightdeck observers also recorded CDTI display modes that were used most frequently by flight crews during the FAROA Air application. Observer data indicated Arc mode was used 51% of the time by the flight crews who had a paper surface map. The Compass Rose and No Arc/No Rose modes both were used nearly 21% of the time. The Compass Rose mode was selected 39% of the time and the Arc mode 14% of the time by the flight crews who had an electronic surface map.

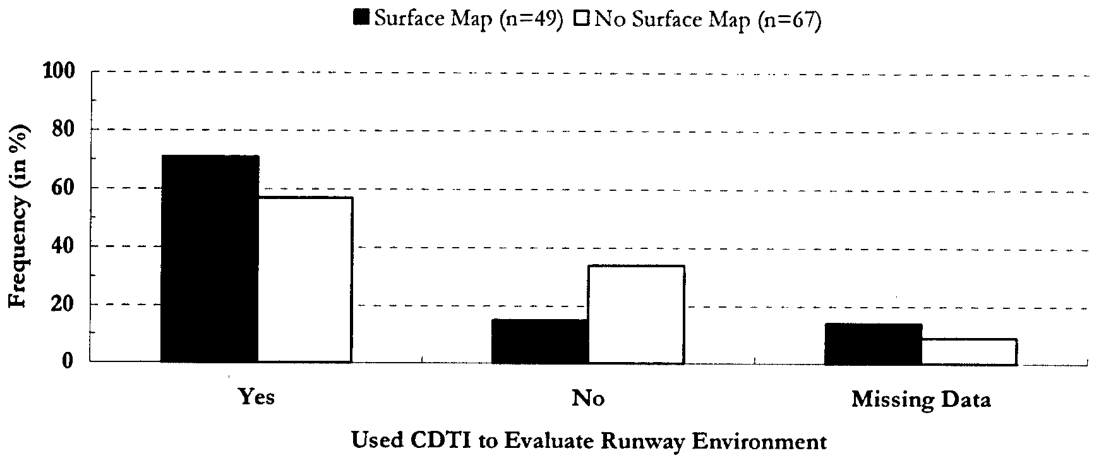


Figure 5. Use of the CDTI during FAROA Air operations to evaluate runway environment for possible conflicts by flight crews with an electronic surface map and those with a paper surface map.

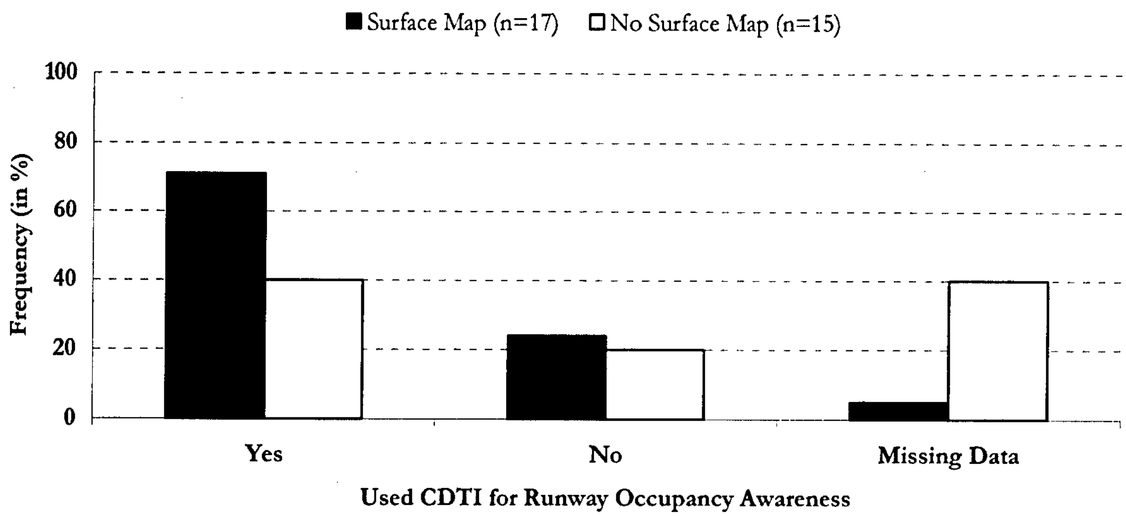


Figure 6. Use of the CDTI during FARAO Ground operations for runway occupancy awareness by flight crews with an electronic surface map and those with a paper surface map.

Flight crew use of two CDTI platform features, the Range function and the Ground Track Vector function, was recorded by flightdeck observers during the FAROA Air application. Approximately 53% of the flight crews used the Range function to adjust viewing range while on the final approach. Of this group, 69% of flight crews with an electronic surface map utilized the Range function, and 41% of flight crews with a paper surface map used the function. Observer data indicated that only 23% of flight crews used the Ground Track Vector function to evaluate the target speed of the leading aircraft or to identify an aircraft accelerating onto the runway. These flight crews were split evenly between those with an electronic surface map and those with a paper surface map.

FAROA Ground

Flightdeck observers reported that during FAROA Ground operations, 56% of flight crews used CDTI to assess runway occupancy. Figure 6 reveals that nearly 71% of flight crews with an electronic surface map and 40% of crews with a paper surface map used CDTI to support this task. A majority of flight crews used CDTI to check for traffic on the approach, and half of the crews used the CDTI to check the departure corridors for possible conflicts. Again, flight crews with an electronic surface map utilized CDTI with greater frequency (71% for approach and 59% for departure, respectively), than flight crews with a paper surface map (47% for approach and 40% departure, respectively).

Flightdeck observers noted that 65% of flight crews used the Range function. Flight crews with a surface map tended to use the Range function more often (71%) than those with no surface map (53%). Only 12% of the crews with a surface map and none of the crews without a surface map used the Ground Track Vector function to evaluate target speed.

Checklists

Flightdeck observers recorded flight crew behavior associated with checklists used during the flight. Data from the Checklist Observer Form were used to determine the effects of the four display types on flight crew use of checklists. Observers recorded whether checklists were Completed, Suspended, Interrupted, Not Completed, Missed by the Crew, or Missed by the Observer. In addition, observers were told to use Other as a category, if necessary. Preliminary analyses showed very low counts in the Suspended, Interrupted, Not Completed, Missed by the Crew, and Missed by the Observer categories. These categories were later pooled into two more general categories: Not Completed, which included the original Not Completed and Missed by Crew categories; and, Completed, which the included the original Completed, Suspended, and Interrupted categories.

A frequency analysis was used to determine checklist completion rates across the four different traffic display types. After recoding the data into the Completed and Not Completed categories, the data were statistically analyzed using a chi-square test. The results of the frequency analysis are shown in Figure 7, which shows checklist completion rates by display type. Overall, the checklist completion rate was equivalent across display types, and it was greater than 98% for all display types. Completion rates were not affected by time of day (i.e., day vs. night) in which the OpEval-2 flight periods occurred.

Although use of CDTI did not appear to affect checklist completion rates, written comments by some of the flight crews using each display type suggested that the timely completion of checklists came with a cost (viz., additional workload). For example, interpretation of the flight crew data suggested that two of the five checklist suspensions and five of the ten checklist interruptions were due to CDTI. Another factor that may have induced workload was the closed traffic pattern operations used in OpEval-2, which required repetitive checklist operations that are not typical in normal flight operations, thereby increasing workload. The checklist data do not reveal whether the increase in perceived workload was due to the novel displays, per se, the higher-than-normal checklist repetition resulting from the closed traffic patterns used in OpEval-2, or the interaction of these two factors. Some flight crews reported that their perceived workload was reduced as they became more familiar with the displays.

Visual Acquisition and Traffic Awareness Form

Observers used the Visual Acquisition and Traffic Awareness Form to record the order and manner in which the flight crews used three different information methods to enhance traffic awareness while in the Outer

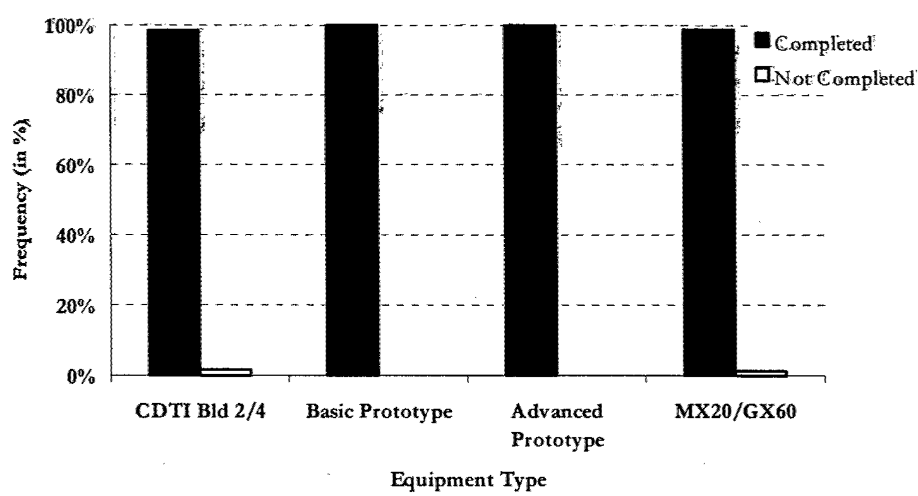


Figure 7. Checklist completion rate by platform type.

and Inner Covey traffic patterns. These three methods included use of the CDTI, ATC traffic advisories, and visual acquisition of traffic.

The analysis of the acquisition data focused on the order in which information was accessed to support target acquisition and traffic awareness during OpEval-2 flight periods. In particular, the analysis sought to determine the extent to which the introduction of the display platform affected the procedure typically used to acquire targets (i.e., ATC advisory/visual acquisition), during both the night and the day flight periods. A frequency analysis, which included a chi-square test, was used to determine if the three methods were used equally often. The frequency analysis was also used to define the order in which methods were used to support target acquisition and traffic awareness.

The chi-square test for the first method used (CDTI) was significant, $\chi^2(2)=17.49$, $p<.0001$. During day and night events, the observed usage rate for the CDTI method was significantly higher than expected, whereas the observed usage for the visual method was significantly lower than expected. As Figures 8 and 9 show, flight crews initially identified nearly two-thirds of the traffic targets using the traffic display. The chi-square test for the second (ATC Traffic Advisors), $\chi^2(2)=10.94$, $p<.004$, and third methods (Visual Acquisition), $\chi^2(2)=10.94$, $p<.004$, used also were significant. Interestingly, Figure 8 reveals that flight crews were somewhat more likely to use ATC traffic advisories than visual sighting as the second method during day operations. However, during night operations the flight crews were far more likely to use visual sighting than ATC traffic advisories as the second method. This effect is attributable to the better visibility that prevailed during OpEval-2 night flight periods. The traffic awareness benefits associated with the CDTI were more apparent during day flight periods when the visibility was poor (hazy VFR). Overall, about 75% of all traffic events involved use of the CDTI.

Modified Cooper-Harper Workload Scale

Flightdeck observers used the Modified Cooper-Harper Workload Scale to obtain a workload rating from the Pilot Flying (PF) immediately after the flight crew used the platform to perform the Final Approach Spacing application. After each full-stop landing, flight crews using CDTI Build 2/4, Advanced Prototype, and Basic Prototype platforms rated perceived workload using the scale items, which were read by the observer after the flight crew set the aircraft brakes. Because flight crew tasks were not identical and comparisons between platform types based on workload ratings alone would be misleading, the workload ratings were analyzed within platform types for possible differences due to time of day (i.e., day vs. night) and final approach spacing interval (closing to 5 nm vs. 3 nm). No significant differences were found for time of day or final approach spacing interval.

Pilot workload ratings for the Final Approach Spacing application varied by CDTI platform. Pilot workload ratings are shown in Table 2. The rating 2.9 corresponds to the Modified Cooper-Harper scale value "Mental effort is required to attain acceptable performance." The rating 8.2 corresponds to the

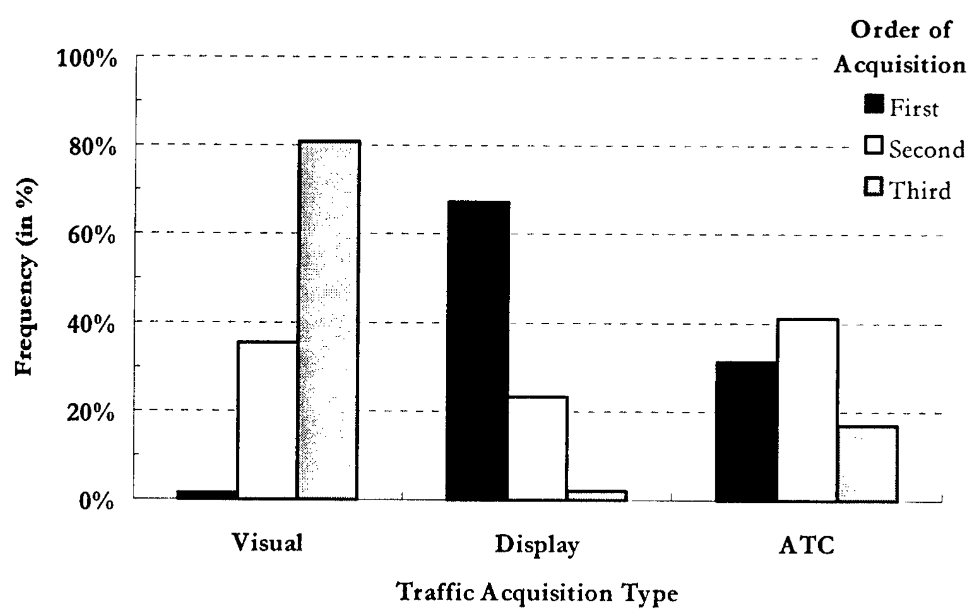


Figure 8. Three methods used for detecting traffic and the order in which flight crews used these methods during OpEval-2 **day** flight periods.

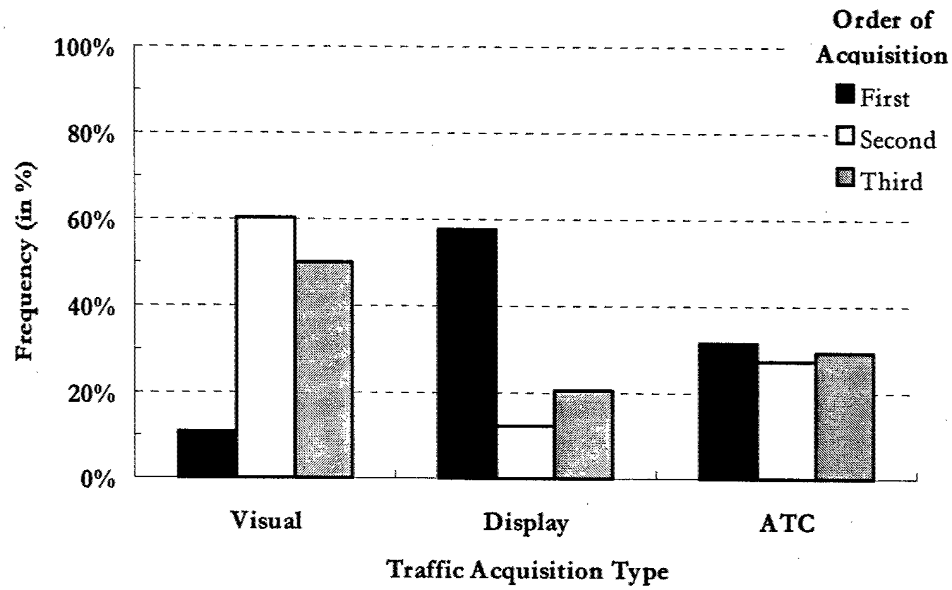


Figure 9. Three methods used for detecting traffic and the order in which flight crews used these methods during OpEval-2 **night** flight periods.

Table 2. Mean pilot workload ratings as a function of CDTI platform.

Platform Type	N	Mean Rating	Standard Deviation
CDTI Build 2/4	42	2.9	2.2
Basic Prototype	21	8.2	1.5
Advanced Prototype	15	4.8	0.9

Modified Cooper-Harper scale value "Maximum mental effort is required to avoid large or numerous errors." The rating 4.8 corresponds to the Modified Cooper-Harper scale value " High mental effort is required to attain acceptable performance."

Flight crew tasks for the Final Approach Spacing application varied as a function of platform type. Flight crews using CDTI Build 2/4 and the Basic Prototype platforms were to achieve a desired spacing at the threshold by observing the raw speed, closure and range data on CDTI and determining the necessary speed adjustments to achieve the desired spacing behind TTF. Flight crews using the Advanced Prototype were to adjust speed in response to a speed command, which was computed as a function of planned approach speeds, current speeds and distance to threshold. This speed command was displayed as a supplementary cursor on the EFIS airspeed display. For these flight crews, matching current speed with commanded speed should have resulted in the targets spacing in seconds behind TTF. Flight crews using MX-20 did not perform spacing tasks.

None of the displays had been certified for use in the Final Approach Spacing application and only the Advanced Prototype platform had design features that specifically supported the spacing-at-threshold task. Nevertheless, flight crews using CDTI Build 2/4 platform rated the workload lower than the flight crews using the other two platform types. Flight crews using the Basic Prototype rated the workload highest, and flight crews using the Advanced Prototype display rated workload as intermediate (i.e., lower than Basic Prototype platform, but higher than CDTI Build 2/4 platform).

Anecdotal evidence from the observers suggests that in some cases, the PF may have rated both the Initial Approach Spacing and Final Approach Spacing tasks and not just the latter task. Workload ratings should be interpreted with caution due to the differences between crew tasks, platform capability and small sample sizes for some ratings.

Procedures Form

CDTI Build 2/4 Platform

The CDTI Build 2/4 platform flight crew Mission Cards specified tasks to be accomplished using CDTI information. For the Departure Spacing application, the task was to determine the assigned separation interval (either 4.5 nm or 6.0 nm) between ownship and TTF on departure, and then release brakes for takeoff. A completion standard was not specified in the Mission Card for this task, and flightdeck observers used their own judgment to determine whether the task was completed.

The Initial Approach Spacing application task required flight crews to establish and maintain the target separation interval on the downwind leg as defined for that flight period. The target value was either 7 nm or 9 nm, with a completion standard of ± 1 nm. The Final Approach Spacing application task required flight crews to close to the target separation distance at the runway threshold. Target values were either 5 nm or 3 nm, with a completion standard of +1.0 nm to 0.5 nm. Task completion rates for flight crews using the CDTI Build 2/4 platform are presented in Table 3.

Completion rates were approximately the same for the three OpEval-2 applications. These data provide some insight into the ability of flight crews to follow a procedure for achieving an assigned spacing based on the use of CDTI. The results may be useful for discussing minimum acceptable reliability of performance in an actual operational setting when ATC may be relying on a flight crew's ability to achieve an assigned spacing.

The flight crew Mission Cards also provided flight crews using the CDTI Build 2/4 platform with suggested techniques for completing the applications. Techniques that related specifically to the use of CDTI information were evaluated by the flightdeck observers in accordance with Table 4. These techniques were included in the Procedures Form, which was used to record the data for each circuit flown by aircraft in the Outer Covey pattern. These data were

Table 3. CDTI Build 2/4 platform task completion by OpEval-2 application (in percent).

Task Completed	Departure Spacing	Initial Approach Spacing	Final Approach Spacing
Yes	83.3	86.7	88.5
No	10.0	8.9	11.5
Missing Data	6.7	4.4	0.0

Table 4. CDTI Build 2/4 platform tasks and recommended techniques for Departure Spacing, Initial Approach Spacing and Final Approach Spacing applications.

Recommended Techniques for OpEval-2 Applications	Departure Spacing	Initial Approach Spacing	Final Approach Spacing
	Determine departure separation interval	Establish and maintain desired initial separation distance	Establish and maintain desired final approach separation
Set range ring to separation distance (SET_RR)	✓	✓	✓
Adjust display range prior to takeoff (RUP_RDN)	✓		
Set the desired altitude range for traffic display for the application (USE_LVL)	✓	✓	
Use vector display to evaluate target speed (USE_VEC)		✓	✓
Select TGT (SEL) to identify target (SEL_TGT)		✓	✓
Set vector time to 2 min Long or 1.5 min Short (SET_VEC)	✓	✓	✓
Eval spacing by PNF only			✓

aggregated across circuits to compute overall percentage of use. Percentages for each technique are presented by OpEval-2 application.

Departure Spacing

Data on the use of each of the techniques during the Departure Spacing application are provided in Figure 10. The most notable deviation from the recommended techniques was in the use of the altitude range filter (USE_LVL). This display feature, which can be adjusted by the flight crew, determines the altitude range in which ADS-B targets would be displayed. The default value displays targets up to 2500 feet above and below ownship. In LK-mode, which was the recommended departure setting, the range above ownship changes to 9500 feet (the system default value), or a value set by the flight crew. The purpose of the recommendation is to ensure that the display continuously shows the target of interest during its climb-out on departure. Most flight crews did not change the setting prior to departure. The flight crew Mission Card for the preceding application (i.e., FAROA Ground) suggested that this mode be selected; thus, further adjustment was not necessary. In addition, flightdeck observers reported that the climb performance of departing aircraft during OpEval-2 was such that the aircraft did not climb above the altitude filter setting (and thus disappear from the display) regardless of its setting. Therefore, even when they did not set CDTI display features as suggested, flight crews were not prompted to adjust settings to the recommended configuration because the departing aircraft did not disappear from the display. Finally, observers noted that in most cases, settings made at the ramp before departure were often not changed for the duration of the flight.

In most aircraft, the Range Ring (SET_RR) was set to a value appropriate for tasks in the Departure Spacing application. Fewer flight crews were seen adjusting or heard verbally verifying that the display range was set prior to departure (RUP_RDN). For the short-spacing departure interval (closing to 4.5 nm), the best display resolution was at the five-mile scale; however, a longer scale also could be used, and some flight crews may have decided that an adjustment was unnecessary under the circumstances. In fact, there would have been no loss of accuracy from using the longer display range if flight crews had highlighted the target using the SEL function. Target Selection behavior for tasks in the Departure Spacing application was not assessed specifically, nor did observers record their own observations regarding Target Selection. However, informal discussions with observers indicate that many flight crews retained the Target Selection that they used for tasks in the ASSA and FAROA Ground applications, which preceded Departure Spacing and occurred during taxi operations. Once selected, the range to the target to the nearest tenth of a mile would be available in its displayed data tag regardless of display range setting or range ring value. In lieu of the range ring, this information could be used readily to support tasks in the Departure Spacing application. Direct alphanumeric readout of target range using the Select function would provide the most accurate data given the size and resolution of the display, and the size of the traffic symbology.

Similarly, although most flight crews adjusted vector display time to the recommended value (SET_VEC), some did not. The recommendation to set the vector time supported the Initial Approach Spacing task, and not the immediate tasks in the Departure Spacing application. Flight crews who

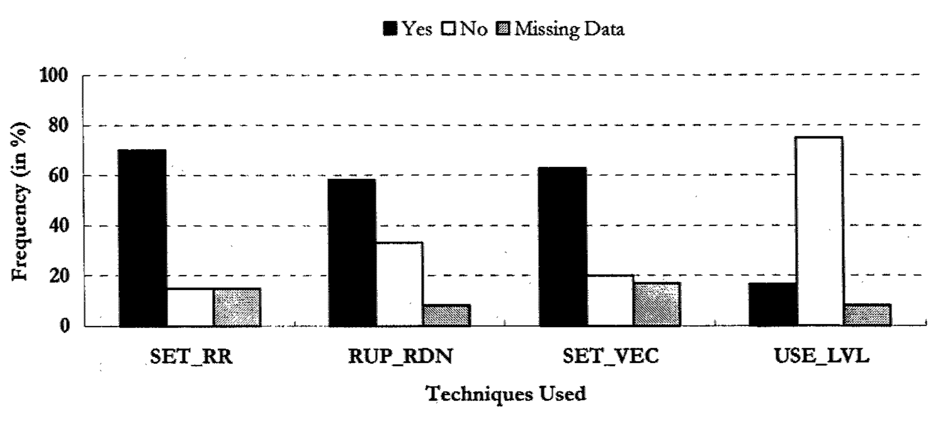


Figure 10. Flight crew techniques using CDTI Build2/4 platform for the Departure Spacing application.

elected not to set the display may have correctly determined that it did not provide useful information for the tasks in the Departure Spacing application. The vector display is time-based, providing an indication of ownship position at a selectable future time, and the tasks in the Departure Spacing application were distance-based. This particular technique also had the highest missed data rate; some observers notes recorded difficulty in determining the status of the display from their vantage point in the cockpit jumpseat.

Initial Approach Spacing

Data on the use of techniques during the Initial Approach Spacing application appear in Figure 11. The notable deviations from the recommended techniques during tasks associated with the Initial Approach Spacing application were in the use of the Altitude Filter (SET_TGT) and use of the Vector Time Display (USE_VEC) to evaluate target speed. The lack of observed compliance with these techniques is due in part to a difference between the techniques suggested on the Mission Card and the techniques listed on the Procedures Form. Adjustment of the altitude filter and use of the vector display to evaluate target speed are not among the techniques recommended on the Mission Card. Therefore, it is not surprising that observed compliance is low. Flightdeck observer comments indicated that the altitude filter setting made on the ramp was sometimes not changed for the duration of the flight. The relatively higher compliance with the SEL_TGT technique and several recorded observer comments indicated that TTF speed information was most commonly acquired from the alphanumeric readout of selected target speed. In addition, there were two recorded observations of active use of the closure rate display to capture the initial approach spacing interval.

The highest compliance rate for techniques in the Initial Approach Spacing application was setting the vector time (SET VEC) to recommended values. However, several observer comments indicated that high compliance rates were not due to active choices made by the flight crews. Instead, the rates were attributable to initial selections made by flight crews while they were on the ramp or during previous application tasks. No observer reported active use of the vector display for this application. As was the case for the Departure Spacing application, the Initial Approach Spacing application was fundamentally a distance-based, in-trail separation task. In contrast, the ownship vector is time-based, and thus would represent the correct spacing only at one particular true airspeed.

Final Approach Spacing

For the Final Approach Spacing Application, the Build 2/4 flight crew Mission Card specified two of the five techniques evaluated by flightdeck observers: use of Target Selection (SEL_TGT) and evaluation of spacing by the PNF only. The latter technique is not a CDTI function; rather, it is a crew resource management technique for using CDTI. As shown in Figure 12, Target Selection was used on most of the arrivals, whereas evaluation of spacing by PNF only was judged by observers to have occurred just over half the time. The Target Select function provides essential information for tasks associated with the Final Approach Spacing application, including the ground speed of the selected target and closure rate display. The high

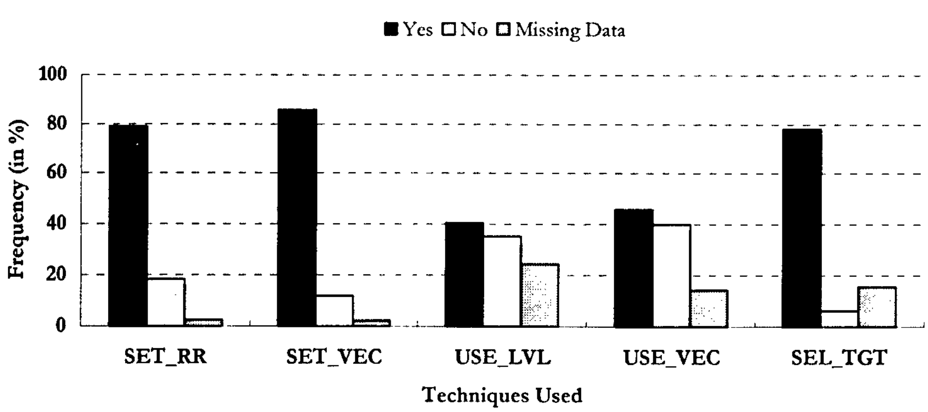


Figure 11. Flight crew techniques using CDTI Build2/4 platform for the Departure Spacing application.

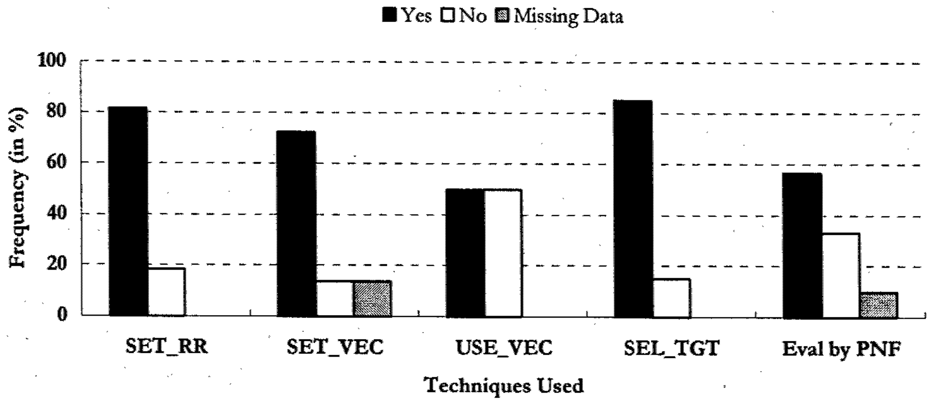


Figure 12. Flight crew techniques using CDTI Build2/4 platform for the Final Approach Spacing application.

percentage of use of this feature may reflect the importance of such information. Flight crews reported using this information as a primary source of information about the TTF during the Final Approach Spacing application, a finding confirmed by the flightdeck observers.

The lower rate associated with the evaluation of spacing by PNF is noteworthy, given that the intent of the technique was to enable the PF to concentrate on the aircraft control tasks associated with the final approach phase of flight. When using this technique, the PNF manipulates the traffic display and provides the PF with appropriate information. Flightdeck observer data indicated that about a third of PFs devoted some attention to the display during the final approach spacing task. One explanation for these results may be that the novelty of CDTI captured the attention of the entire flight crew. Prior experience with the implementation of the Traffic Alert and Collision Avoidance System (TCAS) suggests that this novelty phenomenon may be short-lived, diminishing with additional experience. More effective flightdeck procedures based on a thorough task analysis of the target procedures and emphasis during training also may enhance performance.

Post-Flight Structured Interview Form

Flightdeck observers debriefed flight crews using a structured interview. A content analysis of the resulting interview summaries was conducted to identify the operational and human factors issues that crewmembers found to be particularly relevant to the OpEval-2 applications. Content analyses were performed on 35 interview summaries that represented the responses of 38 unique crewmembers. Approximately 430 individual statements were evaluated and categorized. Crewmember responses for all CDTI platforms were represented. Flight crews using the CDTI Build 2/4 platform composed nearly 53% of the responses.

Interpretation of the interview data was complicated by factors related to the method used to collect it. For example, interviewers were free to choose their own method of transcription and subsequent reporting of the data. There was significant variation in the level of detail provided for analysis, from very short, written summaries to a verbatim transcript. In at least one case, the interview questions appeared to have been answered in writing, with no additional discussion by the interviewer and crewmembers. Given these factors, it is possible that additional issues may have been raised by the crew and not captured in the written summaries. Furthermore, the relative proportion of responses within the issue categories shown in Figure 13 may not be reliable because these proportions are based on a small number of crewmember responses. Based on these factors, the structured interview data are reported in aggregate, with the intent of providing a broad overview of the opinions and concerns about operational and human factors issues that were expressed by flight crews who participated in OpEval-2.

- The content analysis suggested five broad categories of issues:
- Applications - Direct comments on OpEval-2 applications.
- ATC Interaction - Reported effects of CDTI on the ATC procedures, communications, or comments related to flightdeck/ATC procedures integration.
- Crew Resource Management (CRM) - Flight crew interaction, use of checklists, flightdeck procedures

design, workload, tradeoffs, and other aspects of flightdeck operations.

- System - Comments related to the design and operation of the CDTI, or its operating context; includes, controls, displays, installation and other aspects of usability.
- Training - Platform-specific training concerns and OpEval-2 learning effects.

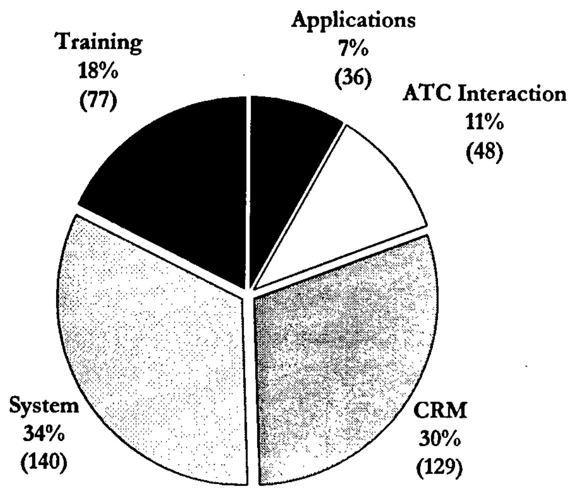


Figure 13. Percentage of interview statements by category for all CDTI platforms.

The two largest categories are System and Crew Resource Management (CRM), followed by Training, ATC Interaction, and Applications. Positive and negative reactions were recorded within each category, but the general trend was to focus on system deficiencies or issues that crews felt needed improvement. The responses within a category were separated by CDTI platform type to determine if the platform types were associated more frequently with particular comments.

System

Mixed Equipage

Flight crews expressed concerns about the utility of CDTI platforms in a mixed or partial equipage environment. Two ADS-B links were evaluated during OpEval-2, and each was "blind" to the other. That is, flight crews who used a CDTI platform with one of the ADS-B links could not see or be seen by flight crews using a CDTI platform with the other ADS-B link. Of course, unequipped aircraft also would not be seen on CDTI regardless of the ADS-B link used. A large majority of crewmembers commented on the enhanced situation awareness benefit that would be derived if all aircraft were displayed. As would be expected with CDTI use, some flight crews also noted that they would have to continue their visual search and "see-and-avoid," out-the-window surveillance procedure to detect and avoid unequipped aircraft in a mixed-equipage environment. One of the flight crews using the Advanced Prototype platform commented very favorably on its advanced TCAS/ADS-B system, which displayed both ADS-B and transponder-equipped aircraft, essentially providing an approximation of the full equipage that crews thought would be necessary to achieve full CDTI benefits. Future operational evaluations include plans to demonstrate a multilateration-based Traffic Information System - Broadcast (TIS-B) that would enable the display of all transponder-equipped aircraft during surface and near-surface observations.

Display Clutter, Display Resolution, Control of Display Range

The second most frequently mentioned issue in the System category was display clutter. In addition, there were several related comments on display resolution, which refers to the ability of the display to illustrate targets in sufficient detail so that flight crews can resolve them from other information. Display-range control, which is one means of removing unnecessary information from the display, also was mentioned by flight crews. Examples of the effects of clutter mentioned by the crews included the momentary merging of the TTF target with a grouping of surface targets as TTF approached the runway. Flight crews reported that this complicated tasks associated with the FAROA Air application for the airplane that was following, and made it more difficult to determine runway occupancy. The runway occupancy task also highlighted display resolution problems, especially when conducted without benefit of an electronic surface map. Flight crews had to infer from their own runway alignment and positions of other displayed aircraft whether or not TTF was on the runway. The comments regarding control of display range also were related to tasks associated with the FAROA Air application. These comments referenced both workload issues and display size and resolution. The available display scales and the size of the display required manual adjustment of range to allow monitoring of the runway environment. The most suitable scale (generally agreed to be 1 or 2 miles) had to be selected after passing the final approach fix and during the final descent for landing, which is normally when flight crews are devoting full attention to the landing task. Several crews noted additional workload associated with reconfiguring the CDTI.

Overall, flight crew comments about clutter indicated that they desired a more effective means to eliminate unnecessary information and configure the CDTI to provide the information necessary to support OpEval-2 applications.

Display Integration

The last issue in the System category mentioned frequently by flight crews was display integration. Flight crews from the CDTI Build 2/4, Advanced Prototype and Basic Prototype platforms all noted that traffic integration with the flightdeck navigation display would provide the most effective tactical picture for situation awareness. Additionally, flight crews using the Advanced Prototype platform desired integration of the approach spacing speed commands with the Primary Flight Display airspeed tape to reduce the mental and physical workload of translating a stand-alone speed command into a speed control response. Flight crews using the CDTI Build 2/4 platform became aware of the integration issue while performing tasks associated with the Final Approach Spacing application. They noted competition for attention between the Head-Up Display (HUD), which was providing primary flight control information, and the centrally located CDTI. This competition occurred despite a recommended technique that suggested the PNF only attend to the CDTI. Perhaps with practice flight crews may find it easier to disregard the display and rely on the PNF conveyance of display information. Without the benefit of practice, flight crews using the CDTI Build 2/4 platform suggested that providing spacing data on the HUD would be more effective than verbal transmission of the information from the PNF.

Crew Resource Management

The second-most frequent set of issues mentioned in the structured interview were related to Crew Resource Management (CRM). This category included comments on workload, procedures, allocation of PF and PNF duties, intra-cockpit communication, and situation awareness. Nearly 80% of CRM-related comments from flight crews using the CDTI Build 2/4 platform related to workload. These comments included mention by flight crews of workload being higher than that in normal line operations, distraction from other tasks, and crew management issues related to extracting information from the CDTI.

Workload and Task Interference

Flight crew comments about workload were usually in the context of the Final Approach Spacing application. Crews reported that the level of perceived workload depended somewhat on the distance that needed to be made up during the final segment. The technique of using the Pilot not flying (PNF) to provide information from the display to the PF appeared to be effective in performance terms, but it apparently increased workload, primarily for the PNF. Effects on the PNF included a heavier checklist management burden when it was necessary to suspend an ongoing checklist to provide spacing information, and interference with the monitoring of airspeed and altitude during the final approach segment inside the final approach fix. Several flight crews using the Build 2/4 CDTI platform indicated that they missed some of the ATC communications due to PNF workload.

Flight crews using the Advanced Prototype platform also expressed concern about a higher than expected workload when using the advanced spacing algorithm speed commands during the Final Approach Spacing application. However, these crews indicated that this task had little impact on crew interaction. These comments may be due to the integrated speed command, which placed a command bug directly on the speed tape, eliminating the requirement for verbal transfer of the speed command data by the PNF. The high reported workload for the Final Approach Spacing application was related to the frequency and magnitude of speed adjustments. Under certain conditions, flight crews judged the frequency of adjustment to be too great, and the magnitude too large.

A crewmember using the Basic Prototype platform noted that the scenarios within the OpEval-2 flight periods induced a higher-than-normal workload due to the closed traffic patterns and repetitive checklist requirements. This compressed the normal arrival workload into a much shorter time period, even without the additional CDTI-related spacing tasks. As noted by more than one flight crew, successful integration of CDTI procedures with ongoing flightdeck tasks will require good management skills supported by well-designed and explicit procedures.

Interestingly, the structured interview data revealed that flight crews using the MX-20 platform gave many CRM-related comments; but, these indicated few effects on workload and no tradeoffs between attending to the CDTI and other cockpit tasks. Several factors could explain the different crew reactions based on CDTI platform. Flight crews using the MX-20 platform were operating as single-pilot and safety pilot crews. However, the MX-20 pilots generally were most familiar with single pilot operations and were not given specific training in CRM, or how to use their safety pilot resource efficiently. Therefore, although CRM seemed to be a difficult task, it did not seem to interfere with other cockpit operations. In addition, pilots using the MX-20 platform also were not assigned the spacing tasks that generated a significant proportion of workload comments from the flight crews flying other CDTI platforms.

Finally, many flight crews using the MX-20 platform were flying personally owned aircraft and were very familiar with the operation of their traffic displays. In contrast, many flight crews using other CDTI platforms did not see the platform in operation until the beginning of OpEval-2. They had minimal training on the CDTI platform and no formal training on integrating CDTI procedures with OpEval-2 applications. The platform was being flown in "normal" flight operations, but the OpEval-2 flight periods were not equal to normal revenue operations experienced by line flight crews. Hence, these data provide a snapshot of the workload that existed during OpEval-2 conditions and further research and analysis is required to adequately characterize the workload associated with CDTI platforms when they are used during normal revenue operations.

Situation Awareness

Enhanced situation awareness was reported by flight crews using all CDTI platforms and was a consistently positive finding in the interview statements. Among the reported benefits were perceived improvements in tasks associated with the Final Approach Spacing application, improved awareness of local traffic situations, and the ability to determine the best merge into an existing traffic flow. For example, as one crewmember indicated, being able to view the location of the downwind to base turn makes it possible to efficiently schedule approach briefings and checklist completion without guessing how much time is available. For surface operations, flight crews reported that having traffic information was beneficial, but such information would be of greater value with the addition of an electronic surface map. Although flight crews were aware of a workload cost imposed by the addition of CDTI platforms, most indicated that this cost might be mitigated or eliminated with more experience, better procedures design, and training.

Training

Flight crews using the Build 2/4 platform provided most of the comments in the training category. Several comments indicated that the training for the OpEval-2 applications was inadequate and there were many suggestions for improvement. The most frequent comment was a desire for hands-on practice with the platform, preferably in the workload context of a full mission simulation or line-oriented, flight-training scenario. Short of this, a desktop simulation, dedicated CDTI training aids, or, as suggested by more than one pilot using the MX-20 platform, a CD-ROM demonstration of acceptable procedures should be provided. Additional training would be very beneficial to crew performance and it could significantly reduce workload. Evidence for this statement comes from the frequent observation by flight crews and observers that there was a noticeable learning curve from one flight period to the next. These improvements appeared to be due to flight crews' exposure to CDTI platforms and OpEval-2 applications. The exact form of an appropriate training program must be determined by operators and approved by the FAA.

ATC Interaction

Regardless of the CDTI platform, the majority of flight crew responses in this category pointed to a need for exact specification of procedures for flight crews and controllers governing the use of CDTI. Advanced Prototype flight crews also noted that it would be very important for controllers to be familiar with CDTI capabilities and limitations. Spacing techniques by flight crews using CDTI may result in observed aircraft behavior that differs substantially from controller spacing techniques. Flight crews also noted that some of the OpEval-2 restrictions on CDTI-based maneuvering limited their ability to effectively use CDTI to accomplish spacing objectives. In particular, the prohibition on lateral maneuvers, combined with short leg lengths, made it difficult to achieve spacing goals using speed control alone. Flight crews using the Advanced Prototype platform indicated that it would be very important to have procedures in place that specify when and where flight crews would assume responsibility for tasks associated with the Final Approach Spacing application. Their comments included a broad range of suggestions, including improved phraseology, explicit spacing assignments, and the possible creation of 'electronic flight rules' to govern the integration of final approach spacing tools with existing ATC procedures.

Several flight crews suggested that the general knowledge of the traffic situation due to CDTI reduced the level of ATC communication. Others reported more accurate visual search for called traffic as a benefit.

Applications

Comments on applications came from the flight crews using the CDTI Build 2/4 and Basic Prototype platforms. In general, they indicated that Departure Spacing was easily accomplished and that Initial Spacing using CDTI was accurate and provided for earlier detection of spacing error than would be possible with spacing provided by ATC. Flight crew comments also indicated that the absence of an electronic surface map made it difficult, especially with existing display resolutions, to determine directly from the display whether or not a runway was occupied. On the other hand, observer comments indicated that flight crews did become aware of possible incursion traffic by referencing CDTI, which resulted in increased visual search out the window to locate traffic.

Comments by flight crews using the CDTI Build 2/4 platform for tasks associated with the Final Approach Spacing application suggest that this task was difficult under OpEval-2 conditions. The restriction on lateral maneuvering reduced the ability of flight crews to use CDTI for establishing position to complete the spacing task. When forced to use speed alone, they expressed concern about the possible negative impact on a stabilized final approach. Finally, several comments related to the need for an electronic surface map to support the Airport Surface Situation Awareness application. Flight crews commented that although the display of other traffic is useful, without an electronic surface map there is little support for runway incursion prevention.

Post-Flight Flight Crew Questionnaires

Two post-flight questionnaires, one for the MX-20 platform and one for the three other CDTI platforms, were administered after flight crews completed participation in their final OpEval-2 flight period. The questionnaires included statements about OpEval-2 applications and CDTI platform usability. These statements were representative of the following topics:

- Training - previous experience with and operation of platform.
- OpEval-2 Applications - use of CDTI platform for ASSA, Departure Spacing, Traffic Awareness, Initial Approach Spacing, Final Approach Spacing, and FAROA.
- Platform Functions - ease of use of functions during operation (e.g., Map Range, Target Select, etc).
- Platform Color and Symbology - assessed meaningfulness of display colors and symbols during operation of the platform.
- Platform Features - assessed utility of platform functions, as well as flight crew perceptions of workload, heads-down time and effect on decision making.
- Location and Readability - assessed location and integration of the platform into the cockpit display suite, and assessed issues associated with legibility.

Analysis of data from the questionnaires included frequency counts, descriptive statistics and analysis of variance on summary data, which was derived by combining groups of ratings for OpEval-2 applications. In addition, factor analyses were used to determine if usability ratings for usability statements could be grouped according to some underlying factor. Summary data was computed for each factor and analysis of variance was performed to determine if OpEval-2 platform types varied along these factors.

Responses to open-ended questions were analyzed to identify other issues that flight crewmembers thought were important. Open-ended responses from the two questionnaires were aggregated with responses from the structured interview to summarize the operational and human factors issues that flight crews identified for each platform type and OpEval-2 application.

Flight Crew Training

Thirty-four percent of the flight crews participating in Op-Eval-2 had some previous experience flying a CDTI-type platform. Approximately 82% of these flight crews stated that they flew CDTI on a test flight. This experience may have been gained during OpEval-1, in which some of the OpEval-2 flight crews participated. The mean number of hours flown using CDTI-type platform ranged from 1.0 hr to 275.0 hrs, with a mean of 19.1 hr and a median of 5.0 hr.

Table 5 shows the different methods of CDTI-type training to which flight crews were exposed. The I-LAB training consisted of simulation training at MITRE CAASD in preparation for OpEval-2. OpEval-2 training included the briefings provided flight crews immediately before OpEval-2 began. Formal training included classroom and flight instruction (simulation). Informal training included reading the platform-operating manual and other training included all types of training not covered by the training types previously listed. Table 5 reveals that flight crews who participated in OpEval-2 received most of their training from OpEval-2 briefings and from informal methods, such as reading the platform operating manual.

Table 5. Summary of CDTI training listed by OpEval-2 flight crews.

Training	Percent of Flight Crews Participating	Rating of Training by Flight Crews: Not Helpful	Somewhat Helpful	Very Helpful	Average/Median Number of Training Hours	Range of Training Hours
I-LAB Simulations	36%	36%	64%	0%	-----	-----
OpEval-2 Training	50%	6%	19%	75%	3.6 / 3.0	1.0 – 7.0
Formal Training	28%	11%	22%	67%	2.1 / 1.5	1.0 – 8.0
Informal Training	78%	3%	64%	33%	3.8 / 2.0	1.0 – 20.0
Other	19%	17%	17%	67%	0.2 / 0.10	0.05 – 0.5

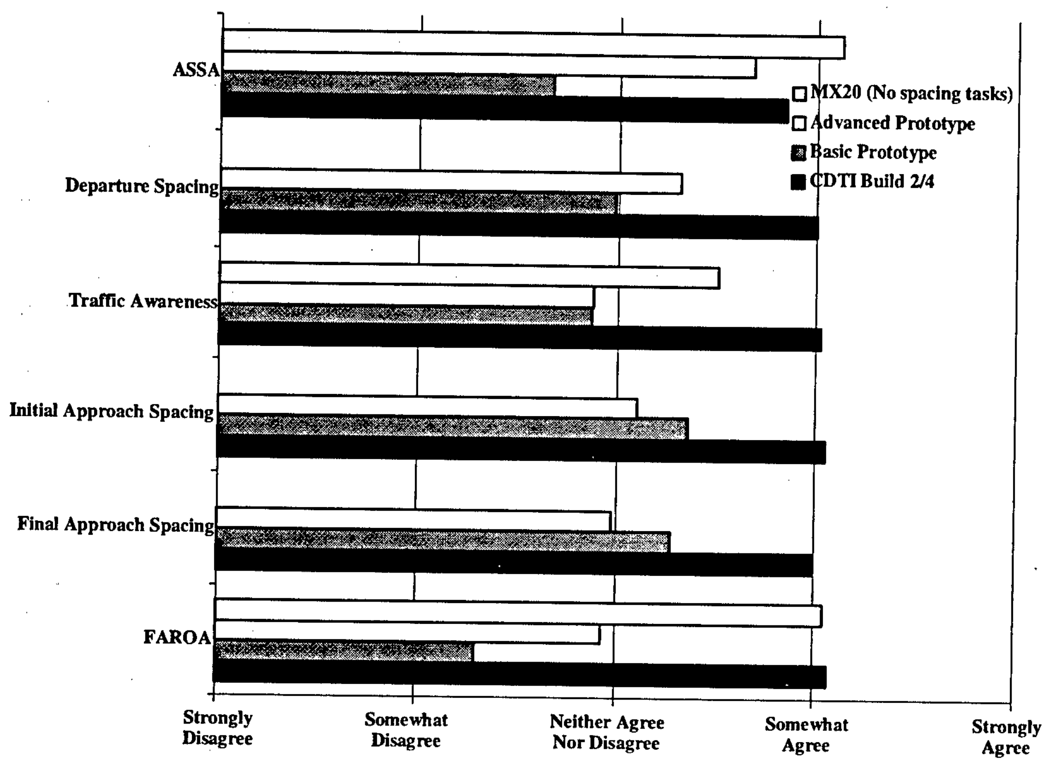


Figure 14. Average pilot rating for each OpEval-2 application by CDTI platform type.

OpEval-2 Applications

Flight crews rated their level of agreement to each questionnaire statement by using Likert-type scales (1=Strongly Disagree, 2=Somewhat Disagree, 3=Neither Agree Nor Disagree, 4=Somewhat Agree, 5=Strongly Agree). Pilot ratings were converted to a favorable - unfavorable scale to simplify interpretation. Ratings less than 2.75 were considered unfavorable and ratings greater than 3.25 were considered favorable.

Figure 14 presents the average pilot rating for each OpEval-2 application. The ratings are classified further by the CDTI platform type. The average rating for an application was derived by summing all ratings for that application and dividing this sum by the total number of ratings for that application. This method was used after analysis of ratings for individual questionnaire statements showed minimal variation in flight crew responses. A one-way analysis of variance (ANOVA) was performed for each application, using CDTI platform type as the independent variable and average rating for each OpEval-2 application as the dependent variable.

Table 6 includes the results of post-hoc tests for each of the OpEval-2 application average ratings. The ∩ indicates that one CDTI platform type was rated significantly higher than the CDTI platform type(s) with ∪ in the same row. For example, the ∩ and ∪ in the row for the ASSA application indicate that the CDTI Build 2/4 platform was rated significantly higher than the Basic Prototype platform. The MX-20 platform was used only for the ASSA and FAROA applications and to evaluate traffic awareness. It was not used during any of the spacing applications.

ASSA

The ASSA application portion of the questionnaire included statements that elicited flight crew responses about how well the CDTI Build 2/4, Basic Prototype and Advanced Prototype platform functions and features supported surface awareness, taxiing, and acquisition of ground traffic. The results of the ANOVA indicated that the highest ratings were associated with the CDTI Build 2/4 and MX-20 platforms, as shown in Figure 14. The flight crews agreed somewhat that these two platform types enhanced ASSA. Table 6 reveals that both the CDTI Build 2/4 and MX-20 platform were rated significantly higher than the Basic Prototype platform. All platform types received favorable ratings except the Basic Prototype platform. Examination of the individual item responses, however, indicated that most flight crews found clutter to be an issue for the ASSA application.

Departure Spacing (Not Applicable to MX-20)

The Departure Spacing application portion of the questionnaire included statements that elicited flight crews' responses about how well the CDTI Build 2/4, Basic Prototype and Advanced Prototype platform functions and features supported climb-out, traffic awareness, and range identification tasks during departure spacing. Figure 14 shows that the CDTI Build 2/4 and Advanced Prototype platform received favorable ratings. Although the Basic Prototype was not rated unfavorable, it did receive the lowest overall

Table 6. Tukey HSD post-hoc tests for flight crew questionnaire summary ratings by platform type and OpEval-2 application or Usability Factor.[1]

	CDTI Build 2/4[2]	Basic Prototype	Advanced Prototype	
ASSA	↑	↓	n.s.	↑
Departure Spacing	↑	↓	n.s.	-----
Traffic Awareness	↑	↓	↓	n.s.
Initial Approach Spacing	↑	↓	n.s.	-----
Final Approach Spacing	n.s.	n.s.	n.s.	-----
FAROA	↑	↓	n.s.	↑
Display Functions	↑	↓	n.s.	-----
Color and Symbology	↑	↓	↓	
		↓	n.s.	↑
Decision Making and Task Completion	↑	↓	n.s.	↑
Display Information	↑	↓	n.s.	-----
Head-Down Time and Workload	n.s.	↓	n.s.	↑
Aircraft Speed/Vector Information	↑	↓	n.s.	-----
Readability and Display Location	↓			↑
		↓	↓	↑
	↑	↓	↓	
Button Labeling, Layout and Size	n.s.	↓	↓	↑
Symbol Size	↑	↓	n.s.	-----
Button Cycling (e.g., Target Range/Selection)	↑	↓	↓	-----

[1] All post-hoc comparison tests were conducted using a significance criterion of 0.05. "↑" indicates that a given platform type was rated significantly higher than the platform type(s) with "↓" in the same row. Within rows, platform types with arrows in the same direction (e.g., CDTI Build 2/4 and MX-20 platforms for ASSA) are not significantly different. "n.s." indicates that a given platform type does not differ from the other platform types in the same row. "-----" is used to indicate that the MX-20 was not used for an OpEval-2 application or that the MX-20 was not rated on a given factor. Cells with "gray shading" indicate that more than one row was needed to explain the relationship between the ratings for platform types. For example, the comparisons for the "Color and Symbology" factor could not be represented using a single row. As shown in the first row for this factor, CDTI Build 2/4 platform ratings were significantly higher than those of the Basic and Advanced Prototypes. However, CDTI Build 2/4 platform ratings did not differ significantly from those of the MX-20, which, as shown in the second row for this factor, were significantly higher than ratings for the Basic Prototype.

[2] The CDTI Build 2/4 platform consistently was rated higher than the Advanced Prototype platform; however, statistical tests that included the latter platform had very low power.

rating for the Departure Spacing application. Also, Table 6 reveals that the ratings for the Basic Prototype platform were significantly lower than those for CDTI Build 2/4 platform.

Visual Acquisition and Traffic Awareness

The Visual Acquisition and Traffic Awareness application portion of the questionnaire included statements that elicited flight crews' responses about how well the CDTI Build 2/4, Basic Prototype, Advanced Prototype, and MX-20 platform functions and features supported locating and identifying proximate traffic. Figure 14 shows that the CDTI Build 2/4 and MX-20 platform received very favorable ratings, whereas the Basic Prototype and Advanced Prototype platform did not. Table 6 indicates that the Traffic Awareness ratings associated with the Basic and Advanced Prototype platform types were significantly lower than the ratings for the CDTI Build 2/4 platform.

Initial Approach Spacing (Not Applicable to MX-20)

The Initial Approach Spacing application portion of the questionnaire included statements that elicited flight crews' responses about how well the CDTI Build 2/4, Basic Prototype, and Advanced Prototype platform functions and features supported target selection, station keeping, and estimating distance and speed. Although Figure 14 shows that the CDTI Build 2/4 and the Basic Prototype platform received favorable ratings, the CDTI Build 2/4 platform was rated the highest. Table 6 indicates that the rating for the CDTI Build 2/4 platform was significantly higher than the rating associated with the Basic Prototype platform. The ratings for the Basic Prototype and Advanced Prototype platform were equivalent.

Final Approach Spacing (Not Applicable to MX-20)

The primary objective of the Final Approach Spacing application was to minimize the variability in spacing between aircraft on approach. The Final Approach Spacing application portion of the questionnaire included statements that elicited flight crews' responses about how well the CDTI Build 2/4, Basic Prototype, and Advanced Prototype platform functions and features supported target selection, station keeping, and estimating distance and speed. Figure 14 shows that the ratings for this application look very similar to the ratings for the Initial Approach Spacing application. The CDTI Build 2/4 and Basic Prototype platform received favorable ratings, whereas the Advanced Prototype platform did not. Table 6 indicates that, although the ratings for the CDTI Build 2/4 platform were higher than those for the Basic and Advanced Prototype platform, these differences were not significant.

FAROA

The FAROA application portion of the questionnaire included statements that elicited flight crews' responses about how well the CDTI Build 2/4, Basic Prototype, Advanced Prototype and MX-20 platform functions and features supported awareness, target detection in the runway environment, transition procedures, and estimation of runway threshold. The results of the ANOVA indicated that the highest ratings were associated with the CDTI Build 2/4 and MX-20 platforms. This finding is shown in Figure 14. The flight crews somewhat agreed that these two platform types enhanced final approach runway occupancy awareness. Table 6 reveals that ratings for the CDTI Build 2/4 and MX-20 platforms were significantly higher than ratings for the Basic Prototype platform. Ratings of the Basic Prototype platform were unfavorable. In fact, 80% of the flight crews gave an unfavorable rating of this platform type.

CDTI Platform Usability

Exploratory principal components analysis (using varimax rotation with Kaiser normalization) was used to analyze the pilot ratings of statements in the questionnaire. Principal components analysis is a statistical technique that is applied to a set of variables, such as questionnaire statements, to discern which variables in the set form coherent subsets, each of which are relatively independent of one another. Variables within subsets are correlated; however, subsets are largely independent of other subsets. For example, a group of statements within a section of the flight crew questionnaire (e.g., Location and Readability section) may be highly correlated and independent of other groups of statements within the same section. The correlation among statements within a given subset is interpreted as an underlying component or factor that can be used to describe the subset of statements. Principal components analysis was used in the present context to reduce a large number of questionnaire statements to a smaller number of usability factors on which OpEval-2 platform types could be compared. In addition, the definition of factors yields information that can be used to provide human factors guidance during the certification process (e.g., factors become checklist items in an HF supplement to a TSO).

Four principal components analyses were performed, one for each of the ergonomics sections in the questionnaire. The results of these analyses are summarized in the following list, which identifies 10 factors:

1: Display functions
2: Consistent and acceptable color and symbology
3: Enhanced decision making and task completion
4: Understanding of display information
5: Head-down time and workload
6: Display of aircraft speed information
7: Readability and display location
8: Button labeling, layout and size
9: Symbol size
10: Button cycling

Summary data were computed for each factor, and analysis of variance was performed to determine if OpEval-2 platform types varied along these factors. Figure 15 presents the average pilot rating for each usability factor. The ratings are further classified by platform type. The average rating for a given factor was derived by summing all ratings for that factor and dividing by the total number of ratings for that factor.

Factor 1: Display Functions (Not Applicable to MX-20). Flight crews were asked to rate the ease of use of particular display functions (e.g., display mode, target select, etc.) using a five-point, Likert-type scale (1= Difficult to use, 5=Easy to use) for questionnaire items 113 - 120. Figure 15 shows that flight crews rated the CDTI Build 2/4 platform easiest to use relative to the Basic and Advanced Prototype platform. Table 6 reveals that the CDTI Build 2/4 platform was rated significantly easier to use than the Basic Prototype platform.

Factor 2: Color and Symbology. The Color and Symbology portion of the questionnaire, which included items 122 - 128, elicited flight crews' responses about the appropriateness of the color and symbology used in the displays of the CDTI Build 2/4, Basic Prototype, Advanced Prototype and MX-20 platform. These items ranged from symbology scaling issues to consistency of color relative to other flightdeck displays. Figure 15 shows that the ratings for this usability factor were favorable for the CDTI Build 2/4 and MX-20 platforms and unfavorable for the Basic and Advanced Prototype platforms.

Table 6 indicates that ratings for the CDTI Build 2/4 and MX-20 platforms were significantly higher than the ratings for the Basic Prototype platform. In addition, the ratings for the CDTI Build 2/4 platform were significantly higher than the ratings for the Advanced Prototype platform. Written observations suggested that, overall, some flight crews reported difficulty in color discrimination between cyan and green.

Factors 3-6: Display Functions. Factor analyses of pilot ratings defined four underlying factors in this section of the questionnaire. Factor 3 included questionnaire items 142, 143 and 146, and this factor identified decision making and task completion issues. Figure 15 shows that ratings for the CDTI Build 2/4, Advanced Prototype and MX-20 platforms all were favorable. The rating for the Basic Prototype platform was unfavorable. The ANOVA results in Table 6 revealed that, for factor 3, the CDTI Build 2/4 and MX-20 platforms were rated significantly more favorable than the Basic Prototype platform.

Factor 4 included questionnaire items 132 -135, and was defined as types of display information (e.g., data tags, traffic altitudes, etc). This factor was not applicable to the MX-20 platform. Table 6 shows that the ratings for the CDTI Build 2/4, Advanced Prototype, and Basic Prototype platforms were favorable. Table 6 indicates that, for factor 4, the CDTI Build 2/4 platform was rated significantly more favorable than the Basic Prototype platform.

Factor 5 included questionnaire items 136, 144 and 145, and this factor revealed attentional issues (e.g., head-down time and workload). Figure 15 shows that only the MX-20 platform was rated favorably for this factor. Ratings for the CDTI Build 2/4, Basic Prototype, and Advanced Prototype platforms were unfavorable. Table 6 shows that, for Factor 5, the MX-20 platform was rated significantly more favorable than the Basic Prototype platform. These findings may indicate that, relative to the MX-20 platform, the CDTI Build 2/4, Basic Prototype and Advanced Prototype platforms were more novel to flight crews. Regardless of the explanation, issues related to attention should be explored and attempts should be made to mitigate the possibility of flight crews attending too much to OpEval-2 platform types.

Factor 6 included questionnaire items 131, 137 and 139. These items focused on display of aircraft speed and vector information (e.g., ground speed tag). This analysis was not applicable to the MX-20 platform. Figure 15 shows that ratings for the CDTI Build 2/4 platform were favorable, whereas ratings for the Basic Prototype and Advanced Prototype platforms were unfavorable. Table 6 indicates that, for factor 6, the CDTI Build 2/4 platform was rated significantly more favorable than the Basic Prototype platform.

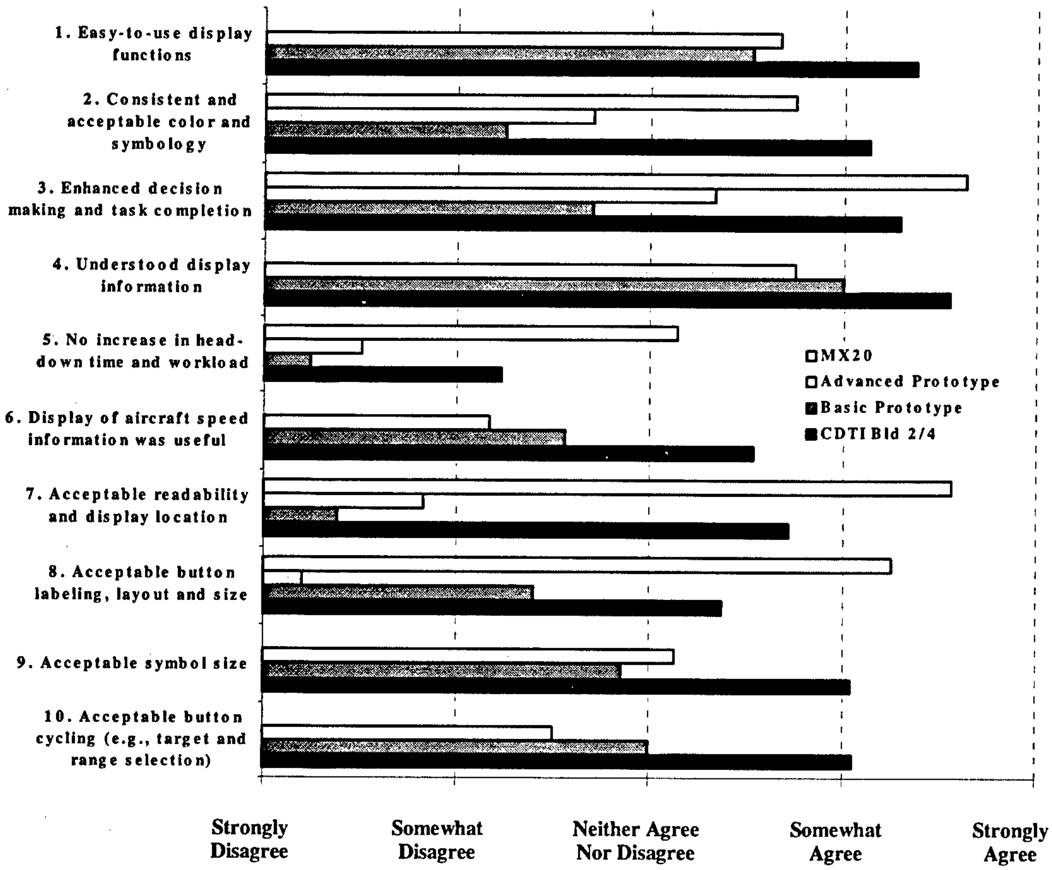


Figure 15. Average pilot rating for each usability factor by platform type.

Factors 7-10: Location and Readability. Factor analyses of pilot ratings also defined four underlying factors in this section of the questionnaire. Factor 7 consisted of questionnaire items 148, 150, 157 - 159, and 163 - 166. This factor seemed to reveal issues related to readability and display location. Figure 15 shows that ratings for the CDTI Build 2/4 and MX-20 platforms were favorable, whereas the ratings for the Basic Prototype and Advanced Prototype platforms were unfavorable. The ANOVA results in Table 6 revealed that, for factor 7, ratings for the MX-20 platform were significantly more favorable than the other three platforms. In addition, the ratings for the CDTI Build 2/4 platform were significantly more favorable than the Basic and Advanced Prototype platforms.

Factor 8 was defined by questionnaire items 153 - 156 and 167, all of which identified control button features (e.g., button labeling, button layout, and button size). Figure 15 again shows that the ratings for the CDTI Build 2/4 and MX-20 platforms were favorable, whereas the ratings for the Basic Prototype and Advanced Prototype platforms were unfavorable. The ANOVA results in Table 6 revealed that, for factor 8, ratings for the MX-20 platform were significantly more favorable than the ratings for the Basic and Advanced Prototype platforms.

Factor 9 consisted of questionnaire items 149 and 160 -162. These items identified issues related to display symbol size. The analysis was not applicable to the MX-20 platform. Figure 15 shows that the CDTI Build 2/4 platform was rated as favorable. Table 6 shows that, for factor 9, the CDTI Build 2/4 platform was rated significantly more favorable than the Basic Prototype platform.

Factor 10 included questionnaire items 151 and 152. This factor, although difficult to interpret, appeared to characterize issues associated with button cycling during target and range selection. The analysis was not applicable to the MX-20 platform. Figure 15 shows that ratings for the CDTI Build 2/4 platform were favorable, whereas ratings for the Advanced Prototype platform were unfavorable. Table 6 indicates that, for factor 10, the CDTI Build 2/4 platform was rated significantly more favorable than both the Basic and Advanced Prototype platforms.

CONCLUSIONS

The OpEval-2 flightdeck observer data supplements a corpus of evidence that contributes to the identification and resolution of human factors issues associated with the use of CDTI by flight crews. The following conclusions and recommendations, which are organized by OpEval-2 applications and CDTI certification issues, are drawn from analysis of the flightdeck observer data.

OpEval-2 Applications

ASSA

While navigating the airport surface along complex routes, flight crews who used electronic surface maps were able to easily perform taxi operations and identify taxiway locations relative to the crews who used paper surface maps. Nearly 67% of the flight crews with electronic surface maps used them for awareness of ownship position on the airport surface, and they were able to identify their location on the airport surface whereas crews with a paper surface map were not. All but one of the flight crews with an electronic surface map used the CDTI to support surface taxi operations at least some of the time. Also, flight crews unanimously agreed that awareness of airport surface operations was enhanced when the CDTI platform included an electronic surface moving map. Taken together, these findings indicate that a CDTI showing the position of own aircraft relative to an airport map appears to improve geographical and situation awareness.

Flightdeck observer data revealed that flight crews with electronic surface moving maps committed fewer errors than did flight crews with paper surface maps. Furthermore, when a taxi error was made, flight crews with electronic surface maps also were able to rejoin their assigned structured routes more readily than those with paper surface maps. Although statistical analysis of errors was not possible because there were too few, this evidence suggests that flight crew awareness can be enhanced by a CDTI with an electronic surface map. This evidence is compelling given that flight crews with paper surface maps were much more familiar with the airport used in this study than those with electronic surface maps.

Flightdeck observers reported that a higher percentage of crews with an electronic surface map used it to enhance awareness of the airport surface relative to those with a paper surface map. This enhanced awareness was accompanied by an increase in the use of the electronic surface map to assess traffic location on the airport surface, possible conflicts during taxi along the structured routes, locating TTF, and for general traffic awareness. Post-flight interviews indicated that the addition of traffic information was valuable for the ASSA application, and that this information was enhanced with the addition of an electronic surface map. When asked whether CDTI aided in traffic awareness, flight crews who used an electronic surface map agreed more strongly that it did relative to flight crews with a paper surface map.

In their responses to the post-flight questionnaires, all flight crews agreed that CDTI (with and without an electronic surface moving map) enhanced airport surface situation awareness. Overall, flight crews using the MX-20 platform, which included the moving map, did provide higher ratings for ASSA, but the difference was not statistically significant.

Flightdeck observer data indicated that the CDTI function known as Target Selection was used by approximately the same percentage of crews with electronic surface maps as those with paper maps. The function was used to aid surface navigation. The Ground Track Vector function was used by few crews during any task, regardless of whether these crews had an electronic surface map. The Range function was used twice as often by crews with electronic surface maps as crews with paper surface maps. These data indicate that, for the ASSA application, the Target Selection function may be valuable for CDTI with or without an electronic surface map, the Range function may be particularly valuable for CDTI with an electronic surface map, and the Ground Track Vector function does not appear to be useful. Flight crew comments from post-flight interviews indicated that use of the CDTI for the ASSA application could be enhanced by developing an effective means to control clutter, displaying runway and taxiway markings, using a track-up map orientation, providing NOTAM data (e.g. closed runways and taxiways), and including a pan and zoom function.

Flight crews were given a high-workload, surface navigation task during which their navigation, geographic and traffic awareness were evaluated. Flight crews that used CDTI platforms with electronic airport surface maps and those who used paper surface maps both agreed that it was easy to get oriented to the CDTI. These crews also reported that CDTI aided the tasks of locating and determining the positions of traffic, and that it aided their understanding of ATC communications. These findings imply that CDTI reduced the workload of flight crews during airport surface operations. Additionally, there was almost unanimous agreement by flight crews on the need for an electronic surface map on the CDTI to support the ASSA application.

Departure Spacing

The Departure Spacing application demonstrated that flight crews using CDTI and controllers using current procedures without ADS-B could minimize spacing variation and that it would not affect their workload. For example, post-flight interview data suggested that flight crews generally thought that tasks in the Departure Spacing application were easy to perform. This finding suggests that the Departure Spacing application would not affect flight crew workload. However, more research is required to determine the impact on airport capacity and safety of increased "runway ownership time," which represents the time allotted by the controller to the flight crew to maneuver the aircraft onto the runway and complete the departure roll after receiving a take off clearance from the controller. During this time, the runway is unavailable to the controller for vehicle or other aircraft operations (e.g., runway crossing, landings, etc.). Additionally, there is an increase in the potential for an accident because the aircraft remains on the active runway until appropriate spacing is achieved.

Initial and Final Approach Spacing

During the Initial Approach Spacing application, flightdeck observers reported high rates of compliance with OpEval-2 recommended CDTI function settings for Range Ring (79%), Vector Time (86%) and Select Target (78%). In many cases, these settings were made previously and simply retained by flight crews. Although adherence to these recommendations does not necessarily validate their use for initial approach spacing, it at least implies that the flight crews did not prefer other settings. These findings indicate that for initial approach spacing, flight crews were able to use the CDTI with the range ring, vector time, and target select functions. It should be noted that further work is needed before initial approach spacing can be performed by flight crews in the NAS.

Flightdeck observers also found that 85% of flight crews used the Select Target function during the Final Approach application. Flight crews and observers both reported that this function was the crews' primary source of information. Only half the crews complied with the Vector Time setting recommendation and this finding likely was due to the incompatibility of the vector indications (i.e., time) with the distance-based information provided for the spacing task (i.e., distance). The recommended Range Ring setting was observed 82% of the time during the Final Approach Spacing application.

Analysis of flightdeck observer data indicated that pilot workload during the Initial and Final Approach spacing applications varied by CDTI platform type. Cooper-Harper workload ratings for flight crews using the CDTI Build 2/4 CDTI platform revealed that mental effort was required to attain acceptable performance. Ratings associated with the Advanced Prototype platform indicated that high mental effort was needed to attain acceptable performance. Ratings for the Basic Prototype platform indicated that maximum mental effort was required to avoid large or numerous errors. Although these results indicate that the implementation of the Basic Prototype platform resulted in excessive workload levels, design efforts to reduce the workload associated with all platform types would be beneficial to flight crews.

During Final Approach Spacing, flight crews using the CDTI Build 2/4 platform reported competition for attention between the CDTI and the HUD, which provided primary flight control information. They commented in interviews that PNF workload was higher than would be acceptable in line operations, and that use of the CDTI caused distraction from other tasks, such as hearing ATC communications, monitoring airspeed and altitude, and checklist completion. Written comments by flight crews suggested that the use of CDTI resulted in two of the five checklist suspensions and five of the ten checklist interruptions.

Flight crews using the Advanced Prototype platform reported higher than expected workload during the Final Approach Spacing application. The higher workload was attributed to the frequency and magnitude of speed adjustments required by the advanced spacing algorithm commands. Reducing the frequency and magnitude of these speed commands may reduce the mental effort currently required to achieve acceptable performance. The relay of spacing information from PNF to PF created higher workload for the PNF. This issue could be mitigated by relocating the spacing information within the PF's primary field of view where the PF would be able to access it directly. Even with this solution, the CDTI-related responsibilities for the PF and PNF need to be integrated into existing flightdeck checklist procedures for the respective phases of flight.

FAROA

The FAROA Air application required flight crews to use CDTI while on final approach to determine whether the runway was occupied. During some restricted low approaches, vehicles were positioned on the runway. Eight flight crews with electronic surface maps identified vehicles were occupying the runway, whereas none of the crews with paper surface maps were able to identify these vehicles. Although these data appear to indicate that a CDTI with an electronic surface map enhances the ability of flight crews to detect runway intrusions, an appropriate comparison would be needed to establish the efficacy of using CDTI with a paper surface map for FAROA Air.

In their responses to the post-flight questionnaire, the flight crews using the CDTI Build 2/4 and MX-20 platforms agreed that the CDTI supported the FAROA Air application. The MX-20 platform included an electronic surface map, whereas the CDTI Build 2/4 platform did not. Flight crews using a CDTI platform that included an electronic surface map agreed that the CDTI aided in detecting traffic crossing the runway, traffic near the runway, traffic on the runway, and gauging when traffic exited the runway. Flight crews using a CDTI with a paper surface map agreed that the CDTI aided in determining when traffic was on the runway. Data from post-flight interviews indicated that flight crews noted difficulty in determining runway occupancy directly from the electronic surface map. Anecdotal data from flightdeck observers' suggested that flight crews became aware of possible incursion traffic by reference to the CDTI without an electronic surface map, after which they increased their visual search out the window to locate the traffic.

Overall, flight crews generally agreed that CDTI aided in taxiway, runway, final approach, and departure traffic awareness during takeoff. Additionally, they agreed that the color change from brown (on the surface) to green (when airborne) aided in awareness of aircraft status. Flightdeck observers reported evidence indicating that substantially more crews with an electronic surface map than crews without an electronic surface map used CDTI to assess runway occupancy as well as the approach and the departure corridors. These findings indicate that surface map capability appears to increase the use of CDTI for Final Approach Runway Occupancy Awareness (FAROA) Air and Ground.

The CDTI proved valuable for seeing properly equipped aircraft on or near the runway during the takeoff and approach phases of flight. However, as the TTF approached the runway, the symbol that represented it on the display merged momentarily with other aircraft symbols that were grouped as surface targets. Also, the absence of an electronic airport surface map and the inability to determine the precise position of traffic relative to the runway environments were problematic for flight crews on final approach. Many flight crews overcame these problems by using the Range function to manually adjusting CDTI range to one or two miles after passing the final approach fix, which is normally a time when crews devote full attention to landing.

Flightdeck observers also noted that the flight crews performing the FAROA Ground and Air applications with electronic surface maps used the CDTI to evaluate approach and departure corridors, and runways for possible conflicts. During final approach when flight crews were performing the FAROA Air application, observers reported that crews with an electronic surface map used different surface map modes. Although many crews used the Compass Rose mode and some used the Arc mode, most crews with a paper surface map used the Arc mode. The Range function was used to adjust the map range by most crews, especially those with electronic surface maps. A relatively small number of crews with and without electronic surface maps used the Ground Track Vector function for runway occupancy awareness during approach to display target speed. These data indicate that, for the FAROA Air application, Track-up 360 mode and the Range function may be used with an electronic surface map more than other modes, Arc mode may be used without an electronic surface map more than other modes, and that the Ground Track Vector function may be used both with and without the electronic surface map.

Visual Acquisition and Traffic Awareness

As much as possible, flight operations using CDTI in a mixed equipage environment should include the display of all aircraft on the CDTI. In post-flight structured interviews, a large majority of flight crews commented that the display of all aircraft would be necessary to achieve the full benefit of CDTI. One crewmember using the Advanced Prototype platform, which displayed all OpEval-2 aircraft, commented favorably on the utility of this feature. Some flight crews suggested that they would be required to maintain a robust visual search for aircraft that are not displayed in mixed equipage conditions.

CDTI Certification

One goal of the OpEval-2 test was to provide information to avionics manufacturers and the FAA Aircraft Certification Office to support certification of CDTI. For air transport category aircraft, the primary certification requirements are defined by the Code of Federal Regulations 14 Part 25. Part 25 addresses two primary issues: (1) Does the platform perform the intended function? and (2) Could the platform lead to hazardous situations? The following paragraphs summarize flightdeck observer data from OpEval-2 that will be used to address the two primary certification issues contained in Part 25.

Usability

Overall, flight crews rated the CDTI Build 2/4 platform functionality as easy to use and agreed that it enhanced decision making and task completion. Display information was considered understandable; symbol size, symbology, button cycling were considered acceptable; and, use of color was considered consistent and acceptable. Responses to the flight crew questionnaire for the MX-20 platform also indicated that it enhanced decision-making and task completion, the readability and display location, and that the button labeling, layout, and size were acceptable.

The Advanced and Basic Prototype CDTI platform were developed specifically for OpEval-2. The Advanced Prototype platform readability and display location were rated unfavorably; particularly its button labeling, layout, and size. The Basic Prototype platform readability and display location also were rated unfavorably. These responses may be related to the display-control interface and not the actual display interface. Flight crew questionnaire responses suggested that workload and head-down time increased most with the Advanced and Basic Prototype platforms, although responses indicated that they increased with the CDTI Build 2/4 platform as well. Collectively, these findings indicate that several usability issues remain with the Basic and Advanced Prototype platforms, which is to be expected given that both systems were still in the developmental stage.

CDTI in Flight Crew Field of View

An important certification issue pertains to whether the CDTI platform should be included in the flight crews' primary scan pattern. Aircraft participating in OpEval-2 had the CDTI platform mounted in the front panel of the flightdeck. The platform appeared to be scanned easily for all applications tested. However, none of the aircraft had the information from CDTI integrated with the Electronic Horizontal Situation Indicator or a Head-up Display (HUD), which are in the flight crews' primary scan pattern. Flight crews commented on this fact and they noted that traffic integration with the NAV display would provide the most effective tactical information for situation awareness. Furthermore, flight crews commented that the CDTI platform was out of the primary scan pattern during the Final Approach application. Apparently, the HUD, which was providing primary flight control information, and the centrally located CDTI competed for flight crews' attention. This phenomenon occurred despite a recommended technique that instructed only the PNF to attend to the CDTI platform. Finally, some flight crews noted that it was difficult to observe CDTI information from other locations on the flightdeck.

Display Presentation

Another important certification question pertains to CDTI platform display size and other display attributes that supported each OpEval-2 application. Data relevant to these issues were collected during OpEval-2 using post-flight, structured interviews and flight crew questionnaires. Overall, flight crews listed the following changes, which they thought would enhance display attributes such that the CDTI platform could be used efficiently for the applications tested during OpEval-2.

- A track-up, surface moving map and taxiway labels that are always in view and properly oriented.
- Better color differentiation- Selected target vs. background; also, written observations suggested that some flight crews reported difficulty in discriminating between cyan and green.
- Display feature priority (e.g., modify priorities for overlaying targets).
- Reduce size of ownship
- Include ownship velocity vector
- Develop a simpler means for de-cluttering display.
- Include target selection capability and display associated information in all traffic modes.

Crew Workload

Another important certification issue, crew workload, was assessed using the Modified Cooper-Harper workload scale, and by including several questions on the flight crew questionnaire related to workload (see items 67, 68, 70, 89, 90, 94, and 145 in Appendix B). The Cooper Harper ratings are valuable in that they partially address the flight crew workload certification issue. Comparisons of Cooper-Harper workload ratings and the overall average of the seven flight crew questionnaire items were performed to determine the extent of workload for two- and three-member crews. These comparisons were dependent upon and included ratings from all CDTI platform types. The Cooper-Harper ratings for CDTI platforms indicated that three-member crews (ave = 2.1) gave significantly lower workload ratings than two-member crews (ave = 6.5). A rating of 2.1 corresponds with the following statement on the Modified Cooper-Harper Workload Scale: "Mental effort is low and desired CDTI performance is attainable." A rating of 6.5 corresponds with "Maximum mental effort is required to attain acceptable CDTI performance."

Interpretation of the workload ratings is accompanied by several caveats. First, although flight crews explicitly mentioned workload in the context of the Final Approach Spacing application, flightdeck observers suggested that the PF appeared to give an overall rating for all of the spacing tasks. Hence, exactly what the PF rated is not entirely clear. Second, the workload ratings given by flight crews in two-and three-person crews are based on different tasks and different platforms. Furthermore, the flight crews in these crews had differing skill levels. Finally, it is important to remember that flight crews had minimal training on the CDTI platform (median = 5 hrs) and that operating environment and procedures associated with OpEval-2 were not the same as those experienced daily by line flight crews in normal revenue operations. Most crewmembers commented that the workload associated with each CDTI platform would be manageable with more experience, better procedures design, and training.

CDTI Clutter

The analysis of OpEval-2 applications provided an opportunity to evaluate the CDTI platform display for clutter. The flight crew questionnaire contained four items about clutter (see items 30, 31, 38, 50 in Appendix B). Although flight crews rated these four items favorably, suggesting that display clutter was not an issue for the CDTI platform, some of the crews did comment about display clutter. For example, they took issue with the momentary merging of the TTF target with a grouping of surface targets as TTF approached the runway. This phenomenon complicated the FAROA Air task for the aircraft following, and made the task of determining runway occupancy more difficult. Display clutter issues appeared to be dependent upon the type of OpEval-2 application; in particular, FAROA and ASSA. Generally, flight crews wanted a more effective way to configure the CDTI platform such that the information necessary to support the task was displayed and that which was unnecessary was eliminated.

Another important issue associated with the ASSA application is the evaluation of surface clutter on the traffic display. The ASSA application portion of the flight crew questionnaire included two statements (see items 30 and 31 in Appendix B) about surface clutter and its effect on flight crews' use of the CDTI platforms for airport surface situation awareness. Although a majority found clutter to be an issue, many did not, and most indicated that the CDTI de-clutter feature was effective for surface applications. However, post-flight structured interviews revealed that flight crews were affected by surface clutter during the FAROA Air task as previously described. This clutter-related phenomenon should be mitigated.

Display Symbology

Display Symbology, which was identified as a usability factor, focused on color coding of traffic symbols, consistency of color and symbology usage relative to other flightdeck displays, use of color to aid decision making, symbology used to identify ADS-B-equipped traffic, and the appropriateness of symbol sizes, including own-ship. Overall, the ratings for the Display Symbology factor were favorable for the CDTI platforms. Although flight crews rated the CDTI symbology favorably, the symbology for depicting obstructions on the airport map should be evaluated. No symbology for obstructions was used in OpEval-2, and standard symbology is needed for representing database obstacles.

Airport Map Attributes

Airport map database attributes must be evaluated to validate the accuracy, resolution, and integrity of the database. Characteristics of independently designed and developed databases (i.e., National Oceanic and Atmospheric Agency, Jeppesen, and others) should be compared, and chart designs and their functionality should be evaluated. Although the map survey group at NOAA indicated that they completed a limited validation prior to its use at OpEval-2, the electronic airport map database was not validated completely. Data collected during OpEval-2 ASSA and FAROA applications were limited to measures associated with the accuracy of aircraft position information within the aircraft map database.

Airport map database critical feature attributes must be specified, along with appropriate levels of accuracy, resolution, and integrity. Attributes that may be supported with lesser degrees of accuracy also must be determined. The RTCA Special Committee-193 (SC-193; 2001) is developing standards for airport databases and has suggested three levels of database accuracy: coarse, medium, and fine (see pp. 37 of SC-193 standards for a description of each level). Based on taxi task requirements for navigation and geographical orientation during OpEval-2, the fine resolution database was selected to support ASSA and FAROA tasks. Although no specific data was collected to determine whether the "fine" level of database accuracy was required, crew responses and performance during ASSA and FAROA applications provides some data pertaining to this issue. For example, during surface, final approach, landing, and departure operations, flight crews reported that the CDTI platform generally aided both airport surface situation and traffic awareness. Additionally, crews with an electronic surface map reported that the system accurately depicted their position, aided in maintaining geographical orientation during taxi, aided in understanding ATC taxi clearances, and aided in determining the position of traffic on or near runways and taxiways.

The level of accuracy and resolution represented by critical attributes in the airport map database used in OpEval-2 could be examined and evaluated for "completeness" by RTCA SC-193. The surface vehicle used to test the airport map database traversed many of the Standiford International Airport taxiways prior to OpEval-2 and personnel who performed this testing did not report any "incomplete" features. Furthermore, flight crews who participated in OpEval-2 indicated that the display of critical airport map features on the CDTI platform corresponded with what they observed on the airport surface. These findings are tempered because both flight crews and ground survey personnel were unfamiliar with criteria for determining which features were critical to surface navigation and airport surface situation awareness. Research on airport surface operations has not provided sufficient evidence to support identification of features critical to surface navigation and airport surface situation awareness. In an attempt to gather more information about critical features that may have influenced flight crew performance during OpEval-2 ASSA applications, day and night vehicle surveys of four basic taxi routes were completed immediately after OpEval-2. Initial results of these surveys led to the identification of some locations on the airport where airport signage and taxiway lines were either missing or confusing. Analyses of the OpEval-2 data from the ASSA application revealed that taxi errors were associated with airport surface locations where information was missing. Finally, additional research is needed to determine which airport and database features are critical to surface navigation and airport surface situation awareness, and to develop a hierarchy for including these features in electronic airport map databases.

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APPENDIX A

ACRONYMS

ADS-B	Automatic Dependent Surveillance – Broadcast
ANOVA	Analysis of Variance
ARTCC	Air Route Traffic Control Center
ASSA	Airport Surface Situation Awareness
ATC	Air Traffic Control
CAA	Cargo Airline Association
CAASD	Center for Advanced Aviation System Development
CDTI	Cockpit Display of Traffic Information
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FAROA	Final Approach and Runway Occupancy Awareness
GPS	Global Positioning System
HUD	Head-up Display
I-Lab	Integration and Interaction Laboratory
LDPU	Link and Display Processor Unit
NAS	National Airspace System
NM	Nautical Miles
NOTAM	Notice to Airmen
OCG	Operational Evaluation Coordination Group
OpEval	Operational Evaluation
PF	Pilot Flying
PNF	Pilot Not Flying
SDF	Louisville International Airport
SF21	SafeFlight 21
TCAS	Traffic Alert and Collision Avoidance System
TEMP	Test and Evaluation Master Plan
TIS	Traffic Information Service
TIS-B	Traffic Information Service-Broadcast
TRACON	Terminal Radar Control
TSO	Technical Standard Order
TTF	Traffic to Follow
UAT	Universal Access Transceiver
UPS AT	UPS Aviation Technologies

APPENDIX B: FLIGHTDECK OBSERVER DATA-COLLECTION TOOLS

CDTI BUILD 2/4 AND PROTOTYPE PLATFORMS FLIGHT CREW QUESTIONNAIRE

See Adobe Acrobat file (CDTI Questionnaire.pdf)

MX-20 PLATFORM FLIGHT CREW QUESTIONNAIRE

The purpose of this questionnaire is to evaluate flight crew human factors related to the use of the MX-20 for the applications evaluated in the second Safe Flight 21 Operational Evaluation (OpEval-2). Results of this questionnaire and data collected during the OpEval-2 may be published; however, your identity will be kept confidential in accordance with 45 CFR Part 46 of 1981, and 49 CFR Part 11 of 19915. Neither your employer nor any regulatory agency shall have access to your identity, as it appears in any of the data collected from this questionnaire or other sources for the purposes of this study.

Please use the following point of contact if you have questions about the data collection procedures or have related concerns.

B. Oscar Olmos
The MITRE Corporation
Center for Advanced Aviation System Development
1820 Dolley Madison Blvd
McLean, VA 22102-3481
(703) 883-5746

Date: October |___|___| , 2000
Example 2 5

Flight Event: |___|
Example 3

CDTI BUILD 2/4 AND PROTOTYPE PLATFORMS FLIGHT CREW QUESTIONNAIRE

Pilot Name: ______________________________

Aircraft Tail Number: ______________________

Crew Position (please indicate your response by placing a "X" on the appropriate line):
_____ Captain _____ First Officer

Flight Crew Information

1. FAA Certificates/Ratings (please indicate your response by placing a "X" on **ALL** applicable lines):
   _____ Private
   _____ Commercial
   _____ ATP
   _____ Instrument
   _____ CFI
   _____ CFII
   _____ Other (please write in your response →): ______________________

2. Aircraft Type Ratings (please write in your response):
   ____
   ____

Estimate the number of hours flown.

3. Total Hours Flown: [| | | |]
4. Total VFR: [| | | |]
5. Total IFR: [| | | |]
6. Last 12 months: [| | |]
7. Last 90 days: [| |]

Operational Experience (please *estimate* the percentage of time that you fly under each FAR part):
Items 8-11 should total 100%.

8. Part 121: [| |] %
9. Part 135: [| |] %
10. Part 91: [| |] %
11. Other: [| |] %

Previous MX-20/GX-60 Experience

12. Have you flown MX-20/GX-60 equipped aircraft before this date?

_____ No

_____ Yes ***If so, please answer the following by placing a "X" on ALL applicable lines.***

_____ as a test flight

_____ as part of revenue service

_____ other (please write in your response →): ______________________________

13. Please indicate the total number of hours flown using the MX-20/GX-60. [ ][ ][ ]

Example ***2*** ***5*** ***0***

'lease indicate any MX-20 training you have had by putting an "X" in front of the type of training.

_____ OpEval-2 training

A) Was this training helpful?_____ Not helpful_____ Somewhat helpful_____ Very helpful_____

B) Please indicate the number of training hours. _______________

_____ Formal training (e.g., course)

A) Was this training helpful?_____ Not helpful_____ Somewhat helpful_____ Very helpful_____

B) Please indicate the number of training hours. _______________

_____ Informal training (e.g., reading manual)

A) Was this training helpful?_____ Not helpful_____ Somewhat helpful_____ Very helpful_____

B) Please indicate the number of training hours. _______________

_____ Other (please write in your response): ______________________________________

A) Was this training helpful?_____ Not helpful_____ Somewhat helpful_____ Very helpful_____

B) Please indicate the number of training hours. _______________

Each of the following statements should be answered in relation to various aspects of both the GPS unit (GX-60) and the multi-function display unit (MX-20). Use the following scale to indicate your level of agreement with each statement.

0 = Not Applicable/Did Not Use
1 = Strongly Disagree
2 = Somewhat Disagree
3 = Neither Disagree nor Agree
4 = Somewhat Agree
5 = Strongly Agree

GX-60

	Statement	Startup	Creating Flight Plan	Editing Flight Plan	En Route Navigation	Responding to System Messages	Accessing Airport Information
15.	The equipment is easy to use.						
16.	The equipment operating procedures are easy to remember.						
17.	The equipment performs the functions necessary for my flying operations.						
18.	The equipment provides most of the information I need to conduct my flight.						
19.	The equipment allows me to perform all necessary flight functions without reference to operating manuals, etc.						
20.	The equipment provides easy access to the functions necessary for my flight.						
21.	The equipment operating manual clearly explains procedures.						
22.	When I press the wrong button, it is easy to undo.						
23.	I am never confused about which display page is active.						
24.	The equipment accommodates "canned" flight plans.						
25.	The menu choices or button formats are desirable.						
26.	The menus are easy to find.						

MX-20							
Statement		Accessing and Using Custom Map Function	Accessing and Using Terrain Function	Accessing and Using Traffic Function	Accessing and Using Flight Plan Function	Accessing and Using VFR Chart Function	Accessing and Using IFR Chart Function
27.	The equipment is easy to use.						
28.	The equipment operating procedures are easy to remember.						
29.	The equipment performs the functions necessary for my flying operations.						
30.	The equipment provides most of the information I need to conduct my flight.						
31.	The equipment allows me to perform all necessary flight functions without reference to operating manuals, etc.						
32.	The equipment provides easy access to the functions necessary for my flight.						
33.	The equipment operating manual clearly explains procedures.						
34.	When I press the wrong button, it is easy to undo.						
35.	I am never confused about which display page is active.						
36.	The PAN feature is desirable and easy to use.						
37.	The INFO mode is very useful.						
38.	The North-Up mode is preferred.						
39.	The Track-Up mode is preferred.						
40.	It's easy to adjust the map scale.						
41.	The available map scales were appropriate to my flight tasks.						
42.	The advisory flags (terrain or traffic) are easy to respond to.						
43.	The 360 mode is preferred.						
44.	The Arc mode is preferred.						
45.	The INVERT function is desirable.						
46.	The NAV data function is desirable.						
47.	The range and display formats are desirable.						
48.	Text message displays are appropriate and informative.						

Statement		GX-60	MX-20
49.	The response time of the equipment is adequate.		
50.	The equipment provides adequate feedback.		
51.	The display does not wash out in direct sunlight.		
52.	The display does not wash out in indirect sunlight.		
53.	The display is legible in night conditions.		
54.	The controls are easy to operate.		
55.	Control labels are easy to understand and remember.		
56.	The equipment allows for easy detection of alerting messages.		
57.	Alerting messages are appropriate and easily understood.		
58.	The equipment-operating manual is easy to use.		
59.	I feel confident using the equipment for VFR navigation.		
60.	I feel confident using the equipment to aid in the visual acquisition of other aircraft.		
61.	I feel confident using the equipment to aid in separation from terrain during VFR flight.		
62.	The equipment is helpful as a supplemental system during IFR flight.		
63.	The colors used to code the traffic symbols on the display were appropriate.		
64.	The color coding used on the display was consistent with that of other flight deck displays.		
65.	The colors used on the display aided decision-making.		
66.	The symbology used on the display was consistent with that of other flight deck displays.		
67.	The scale of the objects on the display was appropriate.		
68.	I was distracted from other flying tasks when using the equipment.		
69.	Overall, use of the equipment enhanced my decision-making.		
70.	Overall, use of the equipment did not increase head-down time.		
71.	Overall, use of the equipment did not increase workload.		
72.	Overall, the equipment contributed to the successful completion of tasks.		
73.	The physical layout of buttons allowed them to be used accurately.		
74.	The size of the buttons made them easy to use.		
75.	Button presses were accompanied by appropriate feedback.		
76.	The location of the equipment allowed it to be seen easily.		
77.	The reach required to use the equipment was acceptable from my seating position.		
78.	The readability of the text on the equipment display was acceptable from my seating position.		
79.	Having to read the text displays interfered with the performance of flight duties.		
80.	The addition of the equipment in the cockpit decreased the time available to scan instruments.		

Airport Surface Situation Awareness

Please indicate your level of agreement to the following by blackening the circle in the column of your choice.

	Statement	Not applicable/ Did not use	Strongly disagree	Somewhat disagree	Neither disagree nor agree	Somewhat agree	Strongly agree
81.	Overall, use of the MX-20 increased my ability to accurately locate other aircraft on the ground.	O	O	O	O	O	O
82.	Use of the MX-20 for airport surface situation awareness aided my ability to understand ATC communications.	O	O	O	O	O	O
83.	The relative position of other traffic was easy to interpret and understand on the MX-20.	O	O	O	O	O	O
84.	It was easy to get oriented to the surface map display.	O	O	O	O	O	O
85.	In general, enough information was provided on the MX-20 to be useful.	O	O	O	O	O	O
86.	In general, more information should be displayed on the MX-20 to aid in airport surface situation awareness.	O	O	O	O	O	O
87.	If you are in agreement with item 86, what additional information would be useful? ______						
88.	The MX-20 display accurately showed my position on the ground (taxiway).	O	O	O	O	O	O
89.	The display symbol for my aircraft was easy to identify.	O	O	O	O	O	O
90.	If you are in disagreement with item 89, please explain why? ______						
91.	The surface map was easy to bring up on the display.	O	O	O	O	O	O
92.	Use of the MX-20 during taxi increased the time available for crew duties.	O	O	O	O	O	O
93.	Use of the MX-20 during taxi increased the time available for completing checklists.	O	O	O	O	O	O
94.	Using MX-20 on the airport surface aided in locating targets visually.	O	O	O	O	O	O
95.	Use of the MX-20 aided in supporting traffic awareness while on the airport surface.	O	O	O	O	O	O
96.	Display clutter was not a problem during airport surface operations.	O	O	O	O	O	O
97.	Use of the MX-20 during airport surface operations did not increase head-down time.	O	O	O	O	O	O
98.	If in agreement with item 97, did using the MX-20 enhance or reduce the safety of airport surface operations? ______						
99.	Do you feel the MX-20 helped, hindered, or had no effect on your overall performance during departure spacing operations? ______						

Departure Spacing

Please indicate your level of agreement to the following by blackening the circle in the column of your choice.

	Statement	Not applicable/ Did not use	Strongly disagree	Somewhat disagree	Neither disagree nor agree	Somewhat agree	Strongly agree
100.	Use of the MX-20 for departure/climb-out aided in traffic awareness.	O	O	O	O	O	O
101.	The MX-20 range settings were adjusted to increase traffic awareness during departure.	O	O	O	O	O	O
102.	Display clutter was not a problem during departure spacing operations.	O	O	O	O	O	O
103.	Use of the MX-20 during departure spacing operations did not increase head-down time.	O	O	O	O	O	O
104.	If in agreement with item 103, did using the MX-20 enhance or reduce the safety of departure spacing operations? ______						
105.	It was easy to transition from final approach to surface operations using the MX-20.	O	O	O	O	O	O
106.	The procedure for using the MX-20 to transition from final approach to surface operations was acceptable.	O	O	O	O	O	O
107.	Do you feel the MX-20 helped, hindered, or had no effect on your overall performance during departure spacing operations? ______						

Visual Acquisition

Please indicate your level of agreement to the following by blackening the circle in the column of your choice.

	Statement	Not applicable/ Did not use	Strongly disagree	Somewhat disagree	Neither disagree nor agree	Somewhat agree	Strongly agree
108.	Use of the MX-20 aided in visually acquiring traffic before receiving an ATC call.	O	O	O	O	O	O
109.	Use of the MX-20 aided in visually acquiring traffic after receiving an ATC call.	O	O	O	O	O	O
110.	ATC traffic, when visually acquired, appeared at the same clock position as depicted on the MX-20.	O	O	O	O	O	O
111.	ATC traffic, when visually acquired, appeared at the same distance as depicted on the MX-20.	O	O	O	O	O	O
112.	Use of the MX-20 had no effect on maintaining awareness of multiple traffic targets.	O	O	O	O	O	O
113.	Display clutter was not a problem when trying to acquire aircraft visually using the MX-20.	O	O	O	O	O	O
114.	The Select function was useful for visually acquiring traffic.	O	O	O	O	O	O
115.	Use of the MX-20 to enhance visual acquisition did not increase head-down time.	O	O	O	O	O	O
116.	If in agreement with item 116, did using the MX-20 enhance or reduce the safety of visual acquisition procedures? ______						
117.	When using the MX-20, were you distracted when other pilots used your call sign? If so, please explain. ______						

Final Approach Spacing

Please indicate your level of agreement to the following by blackening the circle in the column of your choice.

	Statement	Not applicable/ Did not use	Strongly disagree	Somewhat disagree	Neither disagree nor agree	Somewhat agree	Strongly agree
118.	The amount of effort required to keep the traffic to follow displayed on the MX-20 was acceptable.	O	O	O	O	O	O
119.	The amount of effort required to keep the traffic to follow displayed on the MX-20 was acceptable.	O	O	O	O	O	O
120.	Minimal effort was required to keep other traffic displayed on the MX-20.	O	O	O	O	O	O
121.	The Select feature was used frequently to ID the traffic to follow.	O	O	O	O	O	O
122.	The Select feature was used frequently to ID other traffic.	O	O	O	O	O	O
123.	The workload (including speed/power changes, etc.) necessary to achieve separation was acceptable.	O	O	O	O	O	O
124.	The workload (including speed/power changes, etc.) necessary to maintain separation was acceptable.	O	O	O	O	O	O
125.	When using the MX-20, closure to final spacing occurred at what seemed a comfortable and appropriate rate.	O	O	O	O	O	O
126.	The final spacing achieved when using the MX-20 was comfortable and appropriate.	O	O	O	O	O	O
127.	The workload for gauging distance behind the aircraft to follow was acceptable when using the MX-20.	O	O	O	O	O	O
128.	The Select feature provided enough information to maintain the distance behind the traffic to follow when using the MX-20.	O	O	O	O	O	O
129.	The MX-20 did not distract from crew duties during final approach operations.	O	O	O	O	O	O
130.	The MX-20 did not distract from checklist completion during final approach operations.	O	O	O	O	O	O
131.	The MX-20 did not increase head-down time during final approach operations.	O	O	O	O	O	O
132.	If in agreement with item 131, did using the MX-20 enhance or reduce the safety of final approach operations? ____________________						
133.	The MX-20 increased traffic awareness during final approach operations.	O	O	O	O	O	O
134.	Do you feel that the MX-20 helped, hindered, or had no effect on your overall performance during final approach operations?	O	O	O	O	O	O
135.	Do you have any additional comments regarding the use of the MX-20 for final approach operations? ____________________						

Final Approach Runway Occupancy Awareness

Please indicate your level of agreement to the following by blackening the circle in the column of your choice.

	Statement	Not applicable/ Did not use	Strongly disagree	Somewhat disagree	Neither disagree nor agree	Somewhat agree	Strongly agree
136.	Use of the MX-20 effectively enhanced my awareness of final approach traffic.	O	O	O	O	O	O
137.	Use of the MX-20 effectively enhanced my awareness of departure traffic.	O	O	O	O	O	O
138.	Observing the target change color (e.g., brown to cyan) was helpful in determining the flight status of the target.	O	O	O	O	O	O
139.	When in take-off position, use of the MX-20 enhanced my awareness of aircraft clearing the runway.	O	O	O	O	O	O
140.	When in take-off position, use of the MX-20 enhanced my awareness of ground aircraft and vehicles on nearby taxiways.	O	O	O	O	O	O
141.	The MX-20 aided in gauging when the traffic to follow was over the runway threshold.	O	O	O	O	O	O
142.	The MX-20 aided in gauging when the traffic to follow was touching down.	O	O	O	O	O	O
143.	The MX-20 aided in gauging when the traffic to follow was clear of the runway.	O	O	O	O	O	O
144.	During low approaches, the MX-20 aided in detecting targets positioned on the runway.	O	O	O	O	O	O
145.	During low approaches, the MX-20 aided in detecting targets positioned near the runway.	O	O	O	O	O	O
146.	The MX-20 aided in detecting targets crossing the runway.	O	O	O	O	O	O

Please indicate your response to the following statements by using the scale below.

1 = Poor
2 = Fair
3 = Good
4 = Very good
5 = Excellent

How would you rate the MX-20 ***overall*** as an aid to…

147. …airport surface situation awareness? ____________

148. …departure spacing? ____________

149. …visual acquisition? ____________

150. …approach spacing? ____________

Comments/Suggestions

Each of the following statements should be answered in relation to various aspects of both the GPS unit (GX-60) and the multi-function display unit (MX-20). Comments will be summarized, so please print or write clearly and be concise.

151. Do you have any comments regarding the use of color and symbology on the GX-60?

152. Do you have any comments regarding the use of color and symbology on the MX-20?

153. Do you have any additional comments regarding specific problems you have encountered with the GX-60?

154. Do you have any additional comments regarding specific problems you have encountered with the MX-20?

155. What recommendations would you make for *improving the design* of the GX-60?

156. What recommendations would you make for *improving the design* of the MX-20?

157. What recommendations would you make for *improving the use* of the GX-60?

158. What recommendations would you make for *improving the use* of the MX-20?

This information is NOT required but would be appreciated. If we require clarification of any of your responses, may we contact you? If your answer is yes, please provide the following information.

Phone: (______)________________________

E-mail: ______________________________

Thank you for your participation!

CHECKLISTS FORM

Flight Event: ① ② ③ ④ ⑤ ____	**Aircraft Tail Number:** N_______	**Date:** 10/______/00
Circuit: ① ② ③ ④ ⑤ ⑥	**Page:** ① ②	**Flying Pilot:** O Captain O FO

G = Ground U = Upwind X = Crosswind D = Downwind B = Base F = Final

Checklist Name (1)	Status		Discuss CDTI Effects ONLY
	O Completed	O Missed by Crew	
	O Not Completed	O Missed by Observer	
Where completed (circle one):	O Interrupted	O Other	
G U X D B F	O Suspension		
Checklist Name (2)	**Status**		**Discuss CDTI Effects ONLY**
	O Completed	O Missed by Crew	
	O Not Completed	O Missed by Observer	
Where completed (circle one):	O Interrupted	O Other	
G U X D B F	O Suspension		
Checklist Name (3)	**Status**		**Discuss CDTI Effects ONLY**
	O Completed	O Missed by Crew	
	O Not Completed	O Missed by Observer	
Where completed (circle one):	O Interrupted	O Other	
G U X D B F	O Suspension		
Checklist Name (4)	**Status**		**Discuss CDTI Effects ONLY**
	O Completed	O Missed by Crew	
	O Not Completed	O Missed by Observer	
Where completed (circle one):	O Interrupted	O Other	
G U X D B F	O Suspension		
Checklist Name (5)	**Status**		**Discuss CDTI Effects ONLY**
		O Missed by Crew	
	O Completed	O Missed by Observer	
	O Not Completed	O Other	
Where completed (circle one):	O Interrupted		
G U X D B F	O Suspension		
Checklist Name (6)	**Status**		**Discuss CDTI Effects ONLY**
	O Completed	O Missed by Crew	
	O Not Completed	O Missed by Observer	
Where completed (circle one):	O Interrupted	O Other	
G U X D B F	O Suspension		

VISUAL ACQUISITION AND TRAFFIC AWARENESS FORM

Flight Event: ① ② ③ ④ ⑤ ____**Aircraft Tail Number:** N________

Date: 10/______/00 **Circuit:** ① ② ③ ④ ⑤ ⑥ **Flying Pilot:** O Captain O FO

Traffic 1	Traffic 2	Traffic 3	Traffic 4	Traffic 5	Traffic 6
Aircraft ID/Type	**Aircraft ID/Type**	**Aircraft ID/Type**	**Aircraft ID/Type**	**Aircraft ID/Type**	**Aircraft ID/Type**
______/______ –	______/______ –	______/______ –	______/______ –	______/______ –	______/______ –
Order	**Order**	**Order**	**Order**	**Order**	**Order**
Visual ① ② ③ CDTI ① ② ③ ATC ① ② ③	Visual ① ② ③ CDTI ① ② ③ ATC ① ② ③	Visual ① ② ③ CDTI ① ② ③ ATC ① ② ③	Visual ① ② ③ CDTI ① ② ③ ATC ① ② ③	Visual ① ② ③ CDTI ① ② ③ ATC ① ② ③	Visual ① ② ③ CDTI ① ② ③ ATC ① ② ③
Crew/ATC Queries	**Crew/ATC Queries**	**Crew/ATC Queries**	**Crew/ATC Queries**	**Crew/ATC Queries**	**Crew/ATC Queries**
① ② ③ ④ ⑤	① ② ③ ④ ⑤	① ② ③ ④ ⑤	① ② ③ ④ ⑤	① ② ③ ④ ⑤	① ② ③ ④ ⑤
Notes	**Notes**	**Notes**	**Notes**	**Notes**	**Notes**
Call sign used ? O Yes O No	Call sign used ? O Yes O No	Call sign used ? O Yes O No	Call sign used ? O Yes O No	Call sign used ? O Yes O No	Call sign used ? O Yes O No

Traffic 7	Traffic 8	Traffic 9	Traffic 10	Traffic 11	Traffic 12
Aircraft ID/Type	**Aircraft ID/Type**	**Aircraft ID/Type**	**Aircraft ID/Type**	**Aircraft ID/Type**	**Aircraft ID/Type**
______/______	______/______	______/______	______/______	______/______	______/______
Order	**Order**	**Order**	**Order**	**Order**	**Order**
Visual ① ② ③ CDTI ① ② ③ ATC ① ② ③	Visual ① ② ③ CDTI ① ② ③ ATC ① ② ③	Visual ① ② ③ CDTI ① ② ③ ATC ① ② ③	Visual ① ② ③ CDTI ① ② ③ ATC ① ② ③	Visual ① ② ③ CDTI ① ② ③ ATC ① ② ③	Visual ① ② ③ CDTI ① ② ③ ATC ① ② ③
Crew/ATC Queries	**Crew/ATC Queries**	**Crew/ATC Queries**	**Crew/ATC Queries**	**Crew/ATC Queries**	**Crew/ATC Queries**
① ② ③ ④ ⑤	① ② ③ ④ ⑤	① ② ③ ④ ⑤	① ② ③ ④ ⑤	① ② ③ ④ ⑤	① ② ③ ④ ⑤
Notes	**Notes**	**Notes**	**Notes**	**Notes**	**Notes**
Call sign used ? O Yes O No	Call sign used ? O Yes O No	Call sign used ? O Yes O No	Call sign used ? O Yes O No	Call sign used ? O Yes O No	Call sign used ? O Yes O No

MX-20 PLATFORM PROCEDURES FORM

Flight Event: ① ② ③ ④ ⑤ ____ **Aircraft Tail Number:** N________

Date: 10/______/00 **Flying Pilot:** O Captain O FO

Airport Surface Situation Awareness (ASSA)					
CDTI Used to...	**C1**	**C2**	**C3**	**C4**	**Notes**
1. ...determine taxi sequence?	Y N	Y N	Y N	Y N	
2. ...evaluate local traffic situations?	Y N	Y N	Y N	Y N	
3. ...locate targets relative to ground reference points (e.g., taxiways)?	Y N N/A	Y N N/A	Y N N/A	Y N N/A	
CDTI Features	**C1**	**C2**	**C3**	**C4**	**Notes**
1. Use **Select** to identify assigned taxi interval?	Y N	Y N	Y N	Y N	
2. Use **Time** (Vector lines) to evaluate target speed?	Y N	Y N	Y N	Y N	
Final Approach Runway Occupancy Awareness (FAROA) while on GROUND					
CDTI Used to...	**C1**	**C2**	**C3**	**C4**	**Notes**
1. ...evaluate runway occupancy?	Y N	Y N	Y N	Y N	
2. ...evaluate final approach corridor for possible conflicts?	Y N	Y N	Y N	Y N	
3. ...evaluate departure corridor for possible conflicts?	Y N	Y N	Y N	Y N	
CDTI Features	**C1**	**C2**	**C3**	**C4**	**Notes**
1. Which map orientation was used most frequently?	N-Up Trk-Up Trk-Up Arc Trk-Up 360 Desired Trk-Up	N-Up Trk-Up Trk-Up Arc Trk-Up 360 Desired Trk-Up	N-Up Trk-Up Trk-Up Arc Trk-Up 360 Desired Trk-Up	N-Up Trk-Up Trk-Up Arc Trk-Up 360 Desired Trk-Up	
2. Use **In** and **Out** to adjust range during taxi?	Y N	Y N	Y N	Y N	
3. Use **Time** (Vector lines) to evaluate target speed?	Y N	Y N	Y N	Y N	
Departure Spacing					
CDTI Used to...	**C1**	**C2**	**C3**	**C4**	**Notes**
1. ...determine spacing?	Y N	Y N	Y N	Y N	
CDTI Features	**C1**	**C2**	**C3**	**C4**	**Notes**
1. Use **In** and **Out** to adjust range prior to takeoff roll?	Y N	Y N	Y N	Y N	
2. Use **Traffic Altitude Filter** to set altitude range filter for departure spacing?	Y N	Y N	Y N	Y N	

Initial Approach Spacing (Crosswind, Downwind and Base Legs)					
CDTI Used to…	**C1**	**C2**	**C3**	**C4**	**Notes**
1. …establish and maintain spacing?	Y N	Y N	Y N	Y N	
CDTI Features	**C1**	**C2**	**C3**	**C4**	**Notes**
1. Use **Select** to identify target?	Y N	Y N	Y N	Y N	
2. Use **Time** (Vector lines) to aid in spacing?	Y N	Y N	Y N	Y N	
3. Use **Traffic Altitude Filter** to set altitude range filter for initial approach spacing?	Y N	Y N	Y N	Y N	
4. Use **Time** (Vector lines) to evaluate target speed?	Y N	Y N	Y N	Y N	

Final Approach Spacing					
CDTI Used to…	**C1**	**C2**	**C3**	**C4**	**Notes**
1. …establish and maintain spacing?	Y N	Y N	Y N	Y N	
2. …evaluate spacing by pilot not flying **ONLY**?	Y N	Y N	Y N	Y N	
CDTI Features	**C1**	**C2**	**C3**	**C4**	**Notes**
1. Use **Select** to identify target?	Y N	Y N	Y N	Y N	
2. Set **Time** (Vector lines) to aid in spacing?	Y N	Y N	Y N	Y N	
3. Use **Time** (Vector lines) to evaluate target speed?	Y N	Y N	Y N	Y N	

Final Approach Runway Occupancy Awareness (FAROA) while in AIR					
CDTI Used to...	**C1**	**C2**	**C3**	**C4**	**Notes**
1. ...evaluate the runway environment for possible conflicts?	Y N	Y N	Y N	Y N	
CDTI Features	**C1**	**C2**	**C3**	**C4**	**Notes**
1. Use **In** and **Out** to adjust range within runway environment?	Y N	Y N	Y N	Y N	
2. Which map orientation was used most frequently?	N-Up Trk-Up Trk-Up Arc Trk-Up 360 Desired Trk-Up	N-Up Trk-Up Trk-Up Arc Trk-Up 360 Desired Trk-Up	N-Up Trk-Up Trk-Up Arc Trk-Up 360 Desired Trk-Up	N-Up Trk-Up Trk-Up Arc Trk-Up 360 Desired Trk-Up	
3. Use **Time** (Vector lines) to evaluate target speed?	Y N	Y N	Y N	Y N	

Runway Incursion Scenarios (Flight Periods 1 and 2 ONLY)	Notes
1. Was **TRIOS1 Van** identified? CDTI ① ② Visual ① ② No O Distance ___________nm (check CDTI for distance)	
2. Was **FAA 727 (N40)** identified? CDTI ① ② Visual ① ② No O Distance ___________nm (check CDTI for distance)	

Surface Navigation

CDTI Used to...	C1	C2	C3	C4	Notes
1. ...evaluate the airport surface environment for possible conflicts?	Y N	Y N	Y N	Y N	
2. ...identify taxiways on airport surface?	Y N	Y N	Y N	Y N	

CDTI Features	C1	C2	C3	C4	Notes
1. Use **In** and **Out** to adjust range on airport surface?	Y N	Y N	Y N	Y N	
2. Which map orientation was used most frequently?	N-Up Trk-Up Trk-Up Arc Trk-Up 360 Desired Trk-Up	N-Up Trk-Up Trk-Up Arc Trk-Up 360 Desired Trk-Up	N-Up Trk-Up Trk-Up Arc Trk-Up 360 Desired Trk-Up	N-Up Trk-Up Trk-Up Arc Trk-Up 360 Desired Trk-Up	
3. Use **Time** (Vector lines) to evaluate target speed?	Y N	Y N	Y N	Y N	
4. Use **Select** to identify target?	Y N	Y N	Y N	Y N	
5. The Surface Map was used to taxi...	O Never O Sometimes O Always O N/A				

		Location?	Proximate AC ID?	(If Available)	
Outbound O Structured O Unstructured	Start ______ Stop ______	O Correct O Incorrect	AC Type ______ AC ID ______	**Taxi Speed** ______	
Inbound O Structured O Unstructured	Start ______ Stop ______	O Correct O Incorrect	AC Type ______ AC ID ______	**Taxi Speed** ______	

CDTI BUILD 2/4 AND PROTOTYPE PROCEDURES FORMS

Flight Event: ① ② ③ ④ ⑤ ____ Aircraft Tail Number: N________

Date: 10/______/00 Flying Pilot: O Captain O FO

Airport Surface Situation Awareness (ASSA)					
CDTI Used to...	**C1**	**C2**	**C3**	**C4**	**Notes**
1. ...determine taxi sequence?	Y N	Y N	Y N	Y N	
2. ...evaluate local traffic situations?	Y N	Y N	Y N	Y N	
3. ...locate targets relative to ground reference points (e.g., taxiways)?	Y N N/A	Y N N/A	Y N N/A	Y N N/A	
CDTI Features (BLD2)	**C1**	**C2**	**C3**	**C4**	**Notes**
1. Use **TGT (SEL)** to identify assigned taxi interval?	Y N	Y N	Y N	Y N	
2. Use **VEC** to evaluate target speed?	Y N	Y N	Y N	Y N	

Final Approach Runway Occupancy Awareness (FAROA) while on GROUND					
CDTI Used to...	**C1**	**C2**	**C3**	**C4**	**Notes**
1. ...evaluate runway occupancy?	Y N	Y N	Y N	Y N	
2. ...evaluate final approach corridor for possible conflicts?	Y N	Y N	Y N	Y N	
3. ...evaluate departure corridor for possible conflicts?	Y N	Y N	Y N	Y N	
CDTI Features (BLD2)	**C1**	**C2**	**C3**	**C4**	**Notes**
1. Which display mode was used most frequently? **DSP (ARC)**	Arc Comp Rose (No Arc/ No Rose)	Arc Comp Rose (No Arc/ No Rose)	Arc Comp Rose (No Arc/ No Rose)	Arc Comp Rose (No Arc/ No Rose)	
2. Use **R↑ and R↓** to adjust range during taxi?	Y N	Y N	Y N	Y N	
3. Use **VEC** to evaluate target speed?	Y N	Y N	Y N	Y N	

Departure Spacing (Events 1, 2, and 3 – Long 6.0 nm) (Events 4 and 5 – Short 4.5 nm)					
CDTI Used to…	**C1**	**C2**	**C3**	**C4**	**Notes**
1. …determine separation distance?	Y N	Y N	Y N	Y N	
CDTI Features (BLD2)	**C1**	**C2**	**C3**	**C4**	**Notes**
2. Set **RR** to separation distance? (Long = 6.0, Short = 4.5) (Build 4 ONLY)	Y N	Y N	Y N	Y N	
3. Use **R↑ and R↓** to adjust range prior to takeoff roll?	Y N	Y N	Y N	Y N	
4. Set **VEC** to 2 min Long or 1.5 min Short?	Y N	Y N	Y N	Y N	
5. Use **LVL (ALT)** to set altitude range filter for departure spacing?	Y N	Y N	Y N	Y N	

Initial Approach Spacing (Events 1, 2, and 3 – Long 9.0 nm) (Events 4 and 5 – Short 7.0 nm)					
CDTI Used to…	**C1**	**C2**	**C3**	**C4**	**Notes**
1. …establish and maintain separation distance?	Y N	Y N	Y N	Y N	
CDTI Features (BLD2)	**C1**	**C2**	**C3**	**C4**	**Notes**
2. Set **RR** to separation distance? (Long = 9.0, Short = 7.0)	Y N	Y N	Y N	Y N	
3. Select **TGT (SEL)** to identify target?	Y N	Y N	Y N	Y N	
4. Set **VEC** to 2 min Long or 1.5 min Short?	Y N	Y N	Y N	Y N	
5. Use **LVL (ALT)** to set altitude range filter for initial approach spacing?	Y N	Y N	Y N	Y N	
6. Use **VEC** to evaluate target speed?	Y N	Y N	Y N	Y N	

Final Approach Spacing (Events 1, 2, and 3 – Long 5.0 nm) (Events 4 and 5 – Short 3.0 nm)					
CDTI Used to...	**C1**	**C2**	**C3**	**C4**	**Notes**
1. ...establish and maintain separation distance?	Y N	Y N	Y N	Y N	
2. ...evaluate separation by pilot not flying **ONLY**?	Y N	Y N	Y N	Y N	
CDTI Features (BLD2)	**C1**	**C2**	**C3**	**C4**	**Notes**
1. Set **RR** to separation distance? (Long = 5.0, Short = 3.0)	Y N	Y N	Y N	Y N	
2. Use **TGT (SEL)** to identify target?	Y N	Y N	Y N	Y N	
3. Set **VEC** to 2 min Long or 1.5 min Short?	Y N	Y N	Y N	Y N	
4. Use **VEC** to evaluate target speed?	Y N	Y N	Y N	Y N	

Final Approach Runway Occupancy Awareness (FAROA) while in AIR					
CDTI Used to...	**C1**	**C2**	**C3**	**C4**	**Notes**
1. ...evaluate the runway environment for possible conflicts?	Y N	Y N	Y N	Y N	
CDTI Features (BLD2)	**C1**	**C2**	**C3**	**C4**	**Notes**
1. Use **R↑ and R↓** to adjust range within runway environment?	Y N	Y N	Y N	Y N	
2. Which display mode was used most frequently? **ARC (DSP)**	Arc Comp Rose (No Arc/No Rose)	Arc Comp Rose (No Arc/No Rose)	Arc Comp Rose (No Arc/No Rose)	Arc Comp Rose (No Arc/No Rose)	
3. Use **VEC** to evaluate target speed?	Y N	Y N	Y N	Y N	

Runway Incursion Scenarios (Flight Periods 1 and 2 ONLY)	Notes
1. Was **TRIOS1 Van** identified? CDTI ① ② Visual ① ② No O Distance __________nm (check CDTI for distance)	
2. Was **FAA 727 (N40)** identified? CDTI ① ② Visual ① ② No O Distance __________nm (check CDTI for distance)	

Surface Navigation					
CDTI Used to...	**C1**	**C2**	**C3**	**C4**	**Notes**
1. ...evaluate the airport surface environment for possible conflicts?	Y N	Y N	Y N	Y N	
2. ...identify taxiways on airport surface?	Y N	Y N	Y N	Y N	
CDTI Features (BLD2)	**C1**	**C2**	**C3**	**C4**	**Notes**
1. Use **R↑ and R↓** to adjust range on airport surface?	Y N	Y N	Y N	Y N	
2. Which display mode was used most frequently? **ARC (DSP)**	Arc Comp Rose (No Arc/No Rose)	Arc Comp Rose (No Arc/No Rose)	Arc Comp Rose (No Arc/No Rose)	Arc Comp Rose (No Arc/No Rose)	
3. Use **VEC** to evaluate target speed?	Y N	Y N	Y N	Y N	
4. Use **TGT (SEL)** to identify target?	Y N	Y N	Y N	Y N	
5. The Surface Map was used to taxi...	O Never O Sometimes O Always O N/A				

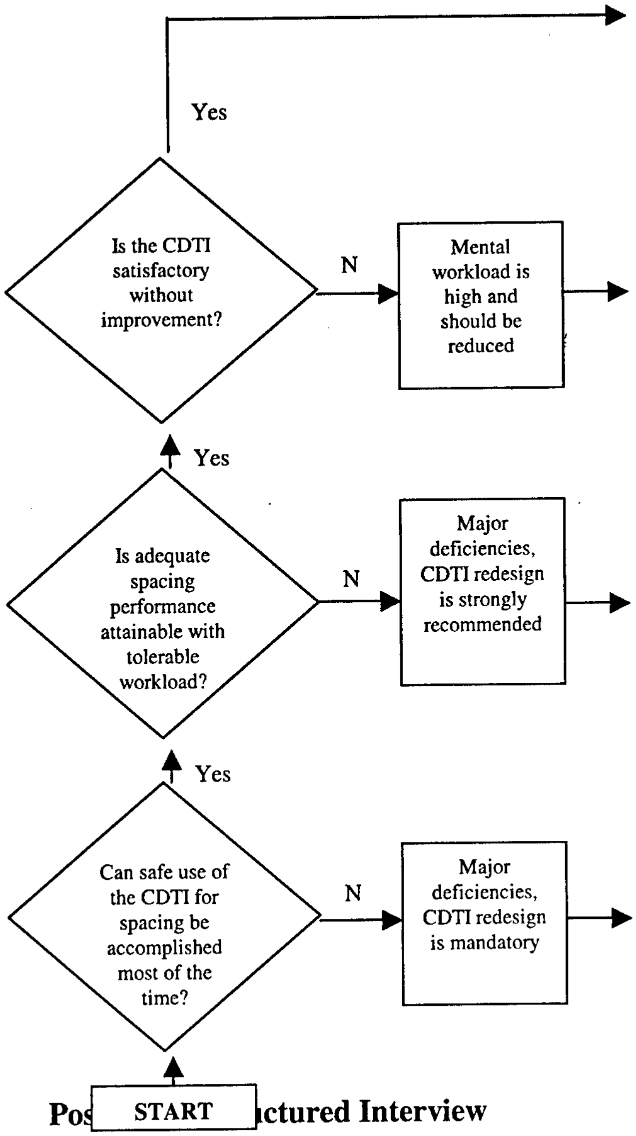
Taxi Time		**Structured Routes ONLY**		**Taxi Speed (If Available)**	**Notes**
		Location?	**Proximate AC ID?**		
Outbound O Structured O Unstructured	Start ______ Stop ______	O Correct O Incorrect	AC Type ______ AC ID ______	**Taxi Speed** ______	
Inbound O Structured O Unstructured	Start ______ Stop ______	O Correct O Incorrect	AC Type ______ AC ID ______	**Taxi Speed** ______	

Modified Cooper-Harper Workload Scale

Instructions: Begin in lower-left corner and follow arrows up and/or to the right. Darken the circles that correspond

Flight Event: ① ② ③ ④ ⑤ ____ Aircraft Tail Number: N__________ Date: 10/______/2000

Full Stop 1:	O PF	O PNF	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
Full Stop 2:	O PF	O PNF	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
Full Stop 3:	O PF	O PNF	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
Full Stop 4:	O PF	O PNF	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩



Difficulty level	Pilot demand level	Rating
Very easy, highly desirable	Mental effort is minimal and desired CDTI performance is easily attainable	1
Easy, desirable	Mental effort is low and desired CDTI performance is attainable	2
Fair, mild difficulty	Mental effort is required to attain acceptable CDTI performance	3
Minor but annoying difficulty	Moderately high mental effort is required to attain acceptable CDTI performance	4
Moderately objectionable difficulty	High mental effort is required to attain acceptable CDTI performance	5
Very objectionable but tolerable difficulty	Maximum mental effort is required to attain acceptable CDTI performance	6
Major difficulty	Maximum mental effort is required to bring errors to moderate level	7
Major difficulty	Maximum mental effort is required to avoid large or numerous errors	8
Major difficulty	Intense mental effort is required for acceptable CDTI performance, but frequent or numerous errors persist	9
Impossible	Acceptable CDTI performance cannot be accomplished reliably	10

Pos ctured Interview

Flight Event: ① ② ③ ④ ⑤ ____

Aircraft Tail Number: N__________

Date: 10/______/2000

Please answer these questions as they relate to the following OpEval-2 applications: Departure Spacing [*CDTI Build 2 and 4*], Approach Spacing, Airport Surface Situation Awareness, and Final Approach Runway Occupancy Awareness.

1. As a crew, were you adequately prepared for today's mission?

2. In general, please discuss the effect of the MX-20/GX-60 equipment on your interaction with ATC.

3. In general, please discuss the effect of the MX-20/GX-60 equipment on crew roles and communication (e.g., checklist completion).

4. In your opinion, what rules or procedures need to be developed and/or implemented to support the efficient use of the MX-20 for OpEval-2 applications.

5. Did you make a maneuver based on the CDTI only? If so, why?

6. Are there any general or specific issues (e.g., display, control panel, etc) about the MX-20/GX-60 equipment that you would like to discuss?

7. Would you like to see the MX-20/GX-60 equipment implemented in all aircraft that you fly?

8. Were you comfortable with your knowledge of the MX-20/GX-60 system?

9. Was there a tradeoff between the goal of increased traffic awareness for some other goal or task(s)?

[*CDTI Build 2 and 4 ONLY*]

10. What information should be available to ATC to support Departure Spacing using the CDTI?

Thank you for your time and candid responses to our questions.