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Safe Flight 21: The 1999 Operational Evaluation of ADS-B Applications*

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Abstract

Safe Flight 21 is a cooperative government/industry effort to develop enhanced capabilities for Free Flight based on evolving Communications, Navigation and Surveillance (CNS) technologies. Safe Flight 21 will demonstrate the in-cockpit display of traffic, weather and terrain information for pilots and will provide improved information for controllers. The new technologies on which this program is based include the Global Positioning System (GPS), Automatic Dependent Surveillance – Broadcast (ADS-B), Flight Information Services -- Broadcast (FIS-B), Traffic Information Service – Broadcast (TIS-B), and their integration with enhanced pilot and controller information displays. Safe Flight 21 will evaluate the safety, service and procedure improvements these technologies make possible.

The primary objective of the Safe Flight 21 program is to enable and expedite decisions by stakeholders on implementing nine operational enhancements identified by this forum. The program will do this by working with industry to demonstrate and evaluate these enhancements. Prior to committing the FAA and the users to a full scale implementation of these enhancements, there needs to be consensus among the FAA and industry on the feasibility and business case for the enhancements.

On July 10, 1999 a year's worth of work in developing ADS-B technology and procedures was culminated in an operational evaluation in Wilmington, Ohio. That evaluation brought together 24 aircraft comprised of general aviation, commercial, military and government aircraft. Specific scenarios were flown that day to allow data to be taken to support the eventual implementation of this technology.

This paper will focus on the results from the Ohio Valley evaluation, including the benefits of enhanced visual acquisition and enhanced visual approaches using ADS-B and the data that will be used to support the ADS-B link decision.

Operational Evaluation 1999

The primary operational objectives of the Cargo Airline Association / Safe Flight 21 Operational Evaluation ("OpEval") for 1999 were to: (1) to demonstrate ADS-B technology, (2) to evaluate specific air-air and air-ground applications, and (3) to develop a wide support base within the aviation community for the advancement of ADS-B implementation. These objectives were be met by a series of high and low altitude flight tests consisting of multiple aircraft types, avionics platforms, and a government/industry ground station configuration.

Other goals included the demonstration of a prototype version of Lockheed-Martin's MicroEARTS ground system to give the controller the benefit of improved surveillance via ADS-B, the demonstration of the compatibility of ADS-B with TCAS systems, and an attempt to stimulate industry toward the production of certified air and ground systems.

In brief, the following was accomplished in the OpEval on 10 July 1999:

- 24 aircraft and 1 ground vehicle were equipped with avionics from UPS Aviation Technologies, AlliedSignal, Rockwell-Collins, Honeywell, and BF Goodrich. The various aircraft included:
  - 12 cargo airline
  - 4 avionics industry test aircraft
  - 3 FAA test aircraft
  - 3 General Aviation / Universities
  - 1 NASA research aircraft
  - 1 US Navy flight test aircraft
- 600+ hours of flight time logged leading up to and including 10 July 1999
- 3 ADS-B ground stations were operational (McLean,

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*This paper is based on information reported in the Phase I Operational Evaluation Final Report [FAA, 2000]
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VA; Wilmington, OH; Louisville, KY)

- Integration of ADS-B and radar surveillance data on controller-display equipment by a consortium including Lockheed-Martin, Sensis Corporation, and Harris Corporation

MITRE/CAASD's roles in the planning and execution of OpEval were extensive. First, MITRE/CAASD is the of the Safe Flight 21 Master Plan, which lays out the multi-year schedule and priorities for evaluating the Safe Flight 21 applications. The CAASD Integration and Interaction Simulation Laboratory was used during the spring of 1999 to develop the final ATC and pilot procedures that were flown during the July 10 test. CAASD also developed and coordinated the overall flight profiles and schedules that were flown. The Ground Broadcast Servers (GBSs) were developed and installed by MITRE, and were manned by CAASD personnel during the integration flight tests and the actual OpEval. Finally, CAASD personnel monitored all 24 aircraft and updated the flight schedule during the OpEval. All of these activities were performed in close coordination with the CAA, FAA headquarters, NASA, RTCA, and union and staff controllers from Dayton Terminal Radar Approach Control (TRACON), Indianapolis Air-Route Traffic Control Center, and Wilmington Tower.

Flight activities during OpEval were prioritized to focus on near term CDTI applications that may provide benefits in a relatively short time period with few, if any, changes to current ATC procedures. The scenarios were designed to assess crew performance, operational procedures/benefits, and data link technical performance. The CDTI applications were prioritized in the following manner (from highest to lowest priority):

- Formal Evaluation of Enhanced Visual Acquisition for "See & Avoid"
- Formal Evaluation of Enhanced Visual Approaches
- Demonstration of Airport Surface Situation Awareness
- Demonstration of Enhanced In-Trail (or Lead) Climbs/Descents
- Demonstration of Station Keeping
- Demonstration of Departure Spacing
- Demonstration of Final Approach Spacing

System Description – Airborne Elements

The CDTI, depicted in Figure 1, is a flight deck display that presents relative position of other traffic in the vicinity with respect to own aircraft. In addition to aircraft position, other information, such as navigational aids and obstructions, may be displayed. Traffic information for the CDTI may be obtained from various sources, including ADS-B, Traffic Information Service (TIS), or an on-board traffic alert and collision avoidance system (TCAS). To display traffic information, the CDTI may use a dedicated display device or a shared multi-function display (MFD). Even though a visual, graphical presentation of the traffic on a heads-down display will be the most common in the near term, other types of presentation (e.g. aural, graphical, heads up) are also possible.

The Link and Display Processor Unit (LDPU), manufactured by United Parcel Service Aviation Technologies (UPSAT) of Salem, Oregon, receives traffic surveillance data from each of the three candidate ADS-B data links: Mode Select (Mode S) transponder (1090 MHz), Universal Access Transceiver (UAT) (966MHz), and Very High Frequency (VHF) Data Link Mode 4 (108-136 MHz range). It then transfers the data to the CDTI for display in the cockpit. A block diagram of the LDPU can be found in Figure 1.

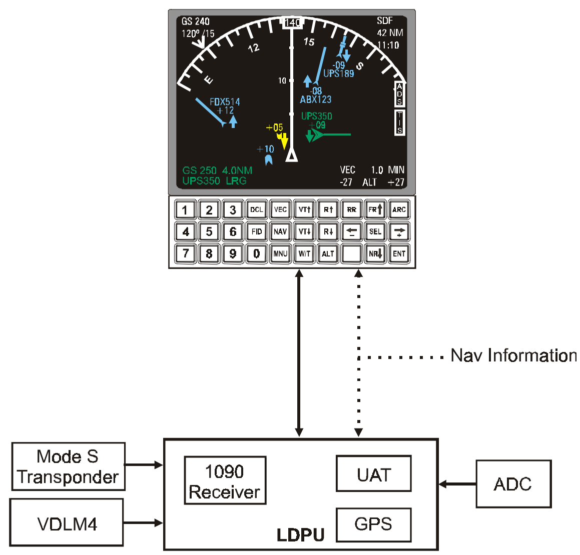

Figure 1: LDPU and CDTI Display

The LDPU contains a 1090 MHz receiver, a UAT transceiver, and an embedded Global Positioning System (GPS) card for position information. Each aircraft is equipped with a Mode S transponder which is used for transmitting the ADS-B "extended squitter" on 1090 MHz and receiving Traffic Information Service information on 1030 MHz. The VDLM4 radio is also separate from the LDPU.

System Description – Ground Elements

A ground system including receivers of the three data link candidates and an air traffic management system was located at Wilmington to receive and record ADS-B data. The ground system also demonstrated that existing ground technologies can accommodate ADS-B information. The ground system consisted of an SF21 ADS-B Ground Station and an Air Traffic Management Demonstration

System (ATMDS).

The SF21 ADS-B Ground Station (Figure 2) is a proof-of-concept ADS-B implementation integrated and installed by the MITRE Corporation. It received broadcasts from all three-candidate links and logged and output the data for processing by the ATMDS. During OpEval, two SF21 ADS-B Ground Stations were utilized; one at Wilmington Airpark (ILN) and another at Louisville International Airport (SDF).

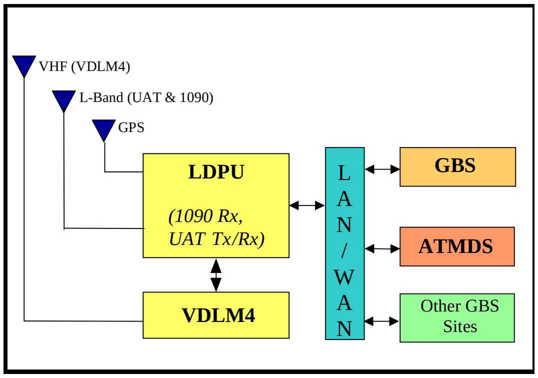

Figure 2: SF21 ADS-B Ground Station General Architecture

The CAA invited industry participation in the OpEval. The OpEval industry team was led by Lockheed Martin Air Traffic Management (LMATM) and included Harris Information Systems Division (ISD) of Melbourne, FL and Sensis Corporation of Syracuse, NY. The ATMDS received ADS-B data from the SF21 ADS-B Ground Station and from two additional 1090 MHz receivers supplied by Harris and Sensis. The system also received terminal radar data from the Airport Surveillance Radar – Model 9 and Monopulse Secondary Surveillance Radar (ASR-9/MSSR) on site at Wilmington and fused the two data types for display.

The ATMDS was intended to support the OpEval and to:

- Demonstrate that existing ground system technologies can accommodate ADS-B
- Provide a basis for planning evaluation of ADS-B operational concepts and procedures
- Demonstrate the benefits of ADS-B to air traffic management
- Demonstrate ability to use ADS-B in transitional environment
- Provide early visibility into requirements for implementation of ADS-B into the NAS.

It should be noted that FAA controllers provided air traffic services during the evaluation from FAA Dayton Terminal Area Control Center (TRACON) using existing ATC systems which do not have ADS-B capability. In parallel the ATM demonstration system processed ADS-B data for observers, who included air traffic controllers. Feedback from observers is included in lessons learned from demonstrations.

Flight Profiles

The OpEval consisted of three major flight periods, a morning, mid-day, and afternoon flight period. The CAA aircraft primarily flew during the morning and afternoon flight periods. Flight profiles consisted of multiple approaches at the Wilmington airport and also a high altitude en-route segment.

Method of Test

Operational Concepts

One product of the OpEval was the validation of the CDTI operational concepts as developed by RTCA SC-186. This section documents the feedback from OpEval into the RTCA CDTI operational concept document, which was used to identify the "near term" CDTI applications that were evaluated or demonstrated during OpEval. OpEval experience was provided as input to the document at a Working Group 1 meeting in October 99. The following is a brief description of that input for the main applications under consideration.

Enhanced Visual Acquisition: The CDTI enhanced visual acquisition application is a capability that aids pilots in visually acquiring other proximate traffic as well as increasing their traffic awareness. The feasibility of this concept was validated in the OpEval flight environment with multiple equipped aircraft of various types.

The CDTI *assists* the pilot with this "*see-and-avoid*" visual scan by providing a display of traffic. From the pilot's point of view, this capability should be considered as a complement to the traffic advisory service provided by air traffic controllers (ATC). CDTI can also enhance the pilot's ability to visually acquire traffic called out by ATC. The CDTI is currently intended only to assist in visual acquisition of other aircraft in Visual Meteorological Conditions (VMC). It does not relieve the pilot responsibility to "see-and-avoid" other aircraft. Currently, there are no aircraft evasive maneuvers recommended, authorized, or provided for as a sole result of the CDTI or CDTI alerts.

One finding of OpEval and was further discussed at SC-186 WG1 is the benefit of having an aural/visual alert to draw the pilots attention to the CDTI when there is visual acquisition traffic of interest. This could increase the utility/benefit of the application. However, also noted at OpEval and further discussed is the need for carefully designed alerting logic that minimizes false or nuisance alerts. WG1 felt alerts were not a minimum requirement for this application, but is adding it as an option in the operational concept.

Enhanced Visual Approaches: The OpEval also validated the feasibility of this application and provided feedback to refining the Ops Concept. The normal conduct of visual approaches was enhanced with the use of the CDTI (see Human Factors). In addition the concept feasibility of allowing the pilots to respond with traffic call-sign, was validated, however concerns were brought up on specific phraseology, voice communication clutter/misinterpretation, and the controllers potential use to call out traffic by flight ID. This last point is in the RTCA CDTI operational concept, but was not formally implemented during this OpEval. These issues will need to be addressed during further procedure development. Allowing the pilots to close-up spacing once cleared for a visual approach was not in the original CDTI Ops Concept for enhanced visual approaches, but was part of the Ops Concept for final approach spacing. Given the pilots ability to perform this task, it has now been added to the SC-186 concept for enhanced visual approaches, with specific references to monitoring and closing up spacing during visual approaches.

Operational Procedure Development

OpEval procedures were specifically designed to replicate commercial air carrier "line" operations to the maximum extent possible. Likewise, no waivers to existing procedures in FAA Order 7110.65L (1999) were requested. All separation criteria and communication procedures were per current operational guidelines. These restrictions were established to ensure a more line oriented evaluation of the ADS-B/CDTI system. In addition, the results can more easily be extrapolated into current line operations if the test environment was representative of present day NAS operations.

While OpEval was specifically designed to minimize changes to current ATC procedures there was, nonetheless, a need to provide flight crews with guidance on procedures for the various CDTI applications. In addition, a departure from normal pilot responses to an ATC traffic call-out was developed that allowed flight crews to use the aircraft call sign. Both of these items are discussed below.

Procedure Development and Flight Crew Maneuver Cards: The process for developing the OpEval procedures began by reviewing the RTCA SC-186's CDTI Operational Concepts document. This document helped to establish the required procedures and tasks that a pilot must be able to perform in order to use the CDTI effectively[2]. Upon considering those tasks, and in conjunction with input from the I-Lab simulations, a set of flight maneuver cards was developed. The purpose of the flight maneuver cards was to assist flight crews during training, briefing, and as an in-flight reference for OpEval procedures, tasks, and techniques.

Flight ID Phraseology: During the planning of OpEval, concerns were expressed by both pilots and controllers regarding the potential for confusion with respect to one flight crew being able to use the call sign of another aircraft. From the pilot's perspective, they are highly attuned to their own call sign, and might assume that any transmission including their call sign was for them, probably adding to their workload, and to frequency congestion and controller workload as they resolved the confusion. From the controller's perspective, they might not be sure if the call was from the call sign aircraft or from another aircraft about the identified aircraft, again increasing frequency congestion and workload while the confusion was resolved. Augmenting these concerns were reports of those situations actually occurring during some of the I-Lab simulations. As a result of the simulation work, communications procedures were developed for OpEval to minimize call sign confusion.

Collected Data

The objectives of the CDTI Human Factors analysis, which was primarily conducted by personnel affiliated with the NASA Ames Research Center, were as follows:

- Evaluate CAA specified applications
- Evaluate flight crew and controller aspects of workload and traffic situational awareness
- Evaluate potential traffic management and procedure implications
- Evaluate effects of demonstration/evaluation on resulting data

The Human Factors data collection plan identified observer records, flight crew and controller feedback, GBS track data, and ATC facility radar track and voice communications tapes as data sources. It further identified the following avenues for soliciting and obtaining flight crew and controller feedback: (1) during simulation studies at MITRE, (2) in-flight data collection with flight crews, (3) controller workload ratings and questionnaires and (4) post flight debriefing of the OpEval flight crews and controllers.

Based on the planned flight schedule detailed in the Test

[2] The CDTI tasks performed by the flightcrews were additional to and augmented normal flight tasks (e.g., flight crew must visually acquire aircraft, but can reference the CDTI to assist in the visual search).

and Evaluation Master Plan (TEMP), there were ninety-six scheduled observable trials planned consisting of 32 baseline and 64 CDTI. Crews flew as within-subjects in cells that were counterbalanced for runway, flying pilot, order effects, baseline, CDTI and for two (AM and PM) visibility factors.

Table 1 provides a description of the data resources and the applicable performance measures that were collected and summarized in this report.

DEPENDENT MEASURE	DATA RESOURCE
Visual Acquisition Time	ATC Voice Tapes Observer Reports
Flight Crew and ATC Workload	ATC Voice Tapes Questionnaires
Aircraft Spacing, Terminal & En-Route	Dayton TRACON Radar Track Data MITRE GBS
CDTI Feature Preferences	Questionnaire and Debrief
ATC Responses to CDTI	Questionnaire and Debrief
Flight Crew Response to CDTI	Questionnaire and Debrief
Flight Crew Traffic Awareness	Observer Records Questionnaire and Debrief
Flight ID Phraseology	ATC Voice tapes

Table 1: OpEval Performance Measures

Flight Crew Human Factors Observers: NASA selected, trained and scheduled observers who observed the flight crews' interaction with and without the CDTI during the OpEval flights.

The observers took notes on the observer forms, administered the questionnaire, and debriefed the flight crews after the test scenarios were completed. The observer records were used to support the collection of:

- Response time to each traffic call
- Assessment of CDTI use during visual traffic acquisition
- Assessment of the impact of CDTI on normal cockpit duties

Flight Crew HF Post Event Questionnaire: The flight crew questionnaire was designed to elicit a variety of responses from flight crews on a number of CDTI related issues. In the results we report on questions relevant to each application.

Pilot opinion ratings were gathered during the post-flight debriefing, after each crew completed their post flight duty requirements. The questionnaires were completed prior to a structured interview and the combined activity lasted about one hour. Each question was designed to elicit specific information from the flight crews on the usefulness of individual features and functions of the CDTI, and the impact of the CDTI on specific flight related tasks. Items in the questionnaire were scaled from 1 to 3 or from 1 to 5 to support a Likert scale analysis. Additionally, a selection of "Not Applicable/Did Not Use" was an available choice.

Air Traffic Control Observers and Post Event Questionnaires: A separate controller was assigned to each runway, with responsibility for aircraft up to 5,000 feet. A separate radio frequency was used for each runway. In accordance with standard operating procedures, there was a relief shift provided by a third controller partway through the morning and afternoon sessions. A fourth controller and the operations manager performed high level coordination of the OpEval aircraft.

Two human factors specialists collected data at the Dayton TRACON during the ADS-B OpEval exercise, focusing on the low altitude flights. As each set of aircraft completed a full cycle around the traffic pattern (i.e., all aircraft in the pattern had executed a missed approach or landed), a specialist asked the controller to estimate his or her workload during that cycle on an 8-point scale. The scale ranged from 1 = very low workload through 4-5 = moderate workload to 8 = very high workload. They were also able to add comments about why their workload was at its current level. After the morning low altitude session, and then again following the afternoon session, the three controllers who had worked the traffic completed a three-part questionnaire.

After the questionnaires were completed independently by each controller, the human factors specialists conducted an oral debriefing of the three controllers who worked the traffic and the controller who worked as a coordinator. The four were debriefed as a group. The debriefings provided an opportunity for the specialists to ask questions about specific events that occurred during the session and for the controllers to discuss their experiences.

Air Traffic Control Voice Tapes: Five hours of audio taped pilot/ATC communications were provided by the Dayton Terminal Radar Approach Control (TRACON) facility. The two-channel tapes included all calls made on the recorded radio frequency on one tape channel and the Universal Time Coordinated (UTC) time code on the other channel expressed in terms of date, hour, minute, and whole second.

Aircraft Track Data: Post-processed computer recordings of aircraft track data were obtained from Indianapolis ARTCC and Dayton TRACON radar tapes, and from ADS-B Surveillance data.

This track data was used to calculate statistics showing both the accuracy and variance of CDTI-based spacing, in both ARTCC and TRACON airspace. Track time-tags also permitted the correlation of aircraft position with concurrent time-tagged events recorded in other data. Inferences from these statistics pertained to the same objectives for which the other indices were obtained, namely insight into effects of CDTI on workload, and traffic throughput, implications for future procedures, and effects of test conditions.

Results

Human Factors

This section presents a synopsis of the results presented in the Phase I – Operational Evaluation Final Report and their implications for CDTI applications. OpEval has provided a unique opportunity for investigators to evaluate CDTI in an operational flight environment. A considerable amount of flying time was achieved, allowing for the collection of a large quantity of objective performance data. There are clear trends in the performance data showing operational benefits of the CDTI. However, due to operational flight issues (weather, maintenance, etc.), a balanced data collection protocol could not be maintained and therefore most data were not subjected to standard statistical tests. In addition to the objective data, both controllers and flight crews were very willing to share their experience and opinions after the event, resulting in a wealth of subjective opinion data. Analysis of the performance and subjective data has provided valuable insight into the benefits and issues surrounding CDTI.

Collectively, a review of both the performance and subjective data revealed no "showstoppers" that would indicate serious obstacles towards the implementation of CDTI for the applications evaluated and demonstrated at OpEval. Comments from both flight crews and controllers were generally positive, although the performance data did not always support their positive opinions. Overall, flight crews agreed that the CDTI aided visual acquisition, visual approaches, station keeping, in-trail climbs/descents, and high altitude departure flights[3]. Crews ratings were mixed on the use of CDTI as an aid to surface awareness (mean rating 2.88, $p>.05$, df=24). In addition, controller opinions suggested that the CDTI aided the enhanced visual acquisition and enhanced visual approach applications, and they were generally positive about the use of CDTI.

We should note that controllers did express some concerns over potential CDTI effects in an operational environment (e.g., flight crews having too much discretion over how closely to follow traffic). It is, however, important to differentiate between concerns over what might happen and what actually happened during OpEval. Most of their concerns were not apparent in the OpEval data, but we cannot state whether these concerns would be substantiated under different operational conditions.

General Issues: Flight crews identified three issues, which need to be considered as we proceed with the design and use of CDTI to support visual traffic acquisition and other ADS-B applications. Crews identified display integration, clutter, and heads down time as issues that need to be addressed in future CDTI implementations.

Display Location and Integration: Overall, flight crews reported using the CDTI effectively during the approach phase of flight, although some flight crews reported that display integration was an issue. Specifically, flight crews reported that the location of the display outside the primary visual scan made it difficult to integrate it into the normal scan, and that this location may have caused additional intra-cockpit communication. Intuitively, integrating the CDTI with the NAV display in a glass cockpit aircraft should improve CDTI usability and reduce heads-down time; however, this remains to be demonstrated. Regardless, flight crews reported the present CDTI implementation to be effective as an aid to visual acquisition, either with or without an ATC traffic call, and that maintaining awareness of multiple traffic targets was less difficult with the CDTI. This would suggest that the CAA's initial CDTI implementation, on a stand-alone display, was adequate for both the enhanced visual acquisition and enhanced visual approach applications.

Some crews identified issues with the location of the CDTI. It was difficult for the second officer in B-727 aircraft to see and use the CDTI which was located forward of the throttles, and he or she could not reach it without leaving his or her seat. The DC-9 First Officers also had less access to the CDTI, which was located nearer to the Captain's side. The impact of the placement of the display is dependent on flight crew procedures for operation of the CDTI. Overall, the display location required flight crews to develop alternatives to their usual cockpit scan to include the CDTI and make use of the information being presented.

Display Clutter: In general, display clutter was reported to be manageable during airborne operations, even in the

[3] (A majority of crewmembers agreed that overall the CDTI System was an aid to: (1) high altitude departure flight (mean 1.6, $p<.05$, df=3); (2) station keeping (mean rating 1.2, $p<.05$, df=3); (3) in-trail or lead climbs and descents (mean 1.4, $p<.05$, df=3); (4) visual approach (mean 1.4, $p<.05$, df=24); and (5) visual acquisition (mean 1.4, $p<.05$, df=23).

relatively densely populated low flight scenarios where aircraft were conducting visual approaches. Display clutter was, however, especially evident during airport surface operations, where a large number of targets were located in close proximity. This combined with large target and data tag size, as well as lack of a surface map, contributed to a number of adverse remarks about the CDTI's usability on the airport surface. Since the CDTI was not designed for use on the airport surface, these adverse comments are not surprising. A surface map will be added to the CDTI and evaluated in future Operational Evaluations. This may introduce other issues which will be addressed during that evaluation.

Heads Down Time: Many flight crews commented on the increase in heads down time while using the CDTI, while at the same time suggesting it was an effective aid to visual acquisition and visual approaches, both currently out the window tasks. One possible explanation for this reported increase in heads down time is that flight crews were relatively inexperienced with the CDTI and received only moderate instruction in its operation. There was, however, some evidence that flight crews' confidence in and efficiency with the CDTI improved over the course of the day (Figure 3). This would suggest that the increased heads down time may be mitigated with training and experience.

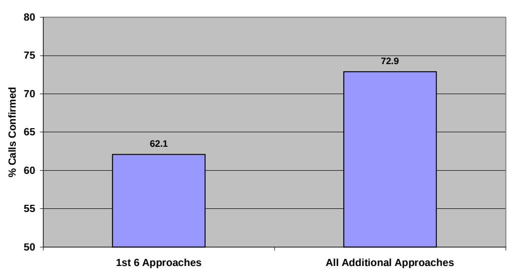

Figure 3: Percentage of Calls Confirmed During PM Visual Approaches

Previous research on visual target acquisition during low visibility surface operations suggests that, for visual search, the increase in CDTI heads down time may, in fact, have a positive impact on visual acquisition performance (Battiste, Mccann & Downs). That is, the time spent heads-down may translate to a more effective visual scan in the out the window view. However, the determination of the extent to which any improved efficiency for visual acquisition would be offset by increased heads down time would require a controlled experiment.

Enhanced Visual Acquisition: Crew comments on the use of the CDTI for enhanced visual acquisition were positive. Flight crews reported that the CDTI was very useful as an aid to visual traffic acquisition during MVMC and in VMC conditions. Flight crews also reported that the CDTI improved the efficiency of the visual acquisition task, and that they found the workload associated with the use of the CDTI acceptable. In addition, they reported that the CDTI was useful as an aid to maintaining awareness of multiple targets and to reacquire previously acquired traffic when needed.

Figure 4 shows that in the absence of an ATC traffic call, flight crews acquired traffic 76% of the time using the CDTI, either before, after, or without acquiring the traffic out-the-window (OTW). Only 24% of the time was traffic acquired without the aid of the CDTI. These data strongly supports the flight crews' assertions that the CDTI was an aid to visual acquisition. After an ATC traffic call (Figure 5), almost half the responses are OTW visual acquisitions only, but CDTI was still used for acquisition in the remaining responses, including 33% of the total responses where traffic is first acquired on the CDTI. This suggests that while many responses to an ATC call are traditional OTW visual acquisitions, the CDTI is still a significant aid in that process.

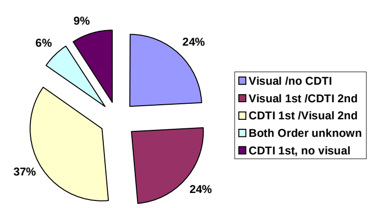

Figure 4: Distribution of Traffic Acquisitions without an ATC Traffic Call - Total number of acquisitions confirmed and coded n=33

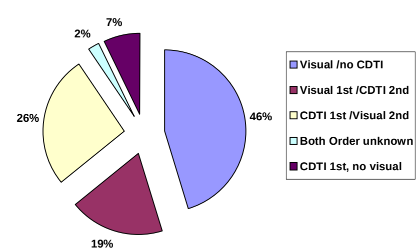

Figure 5: Distribution of Traffic Acquisitions After ATC Traffic Call - Total number of acquisitions confirmed, and coded N = 42

Controllers also reported that the CDTI enhanced visual acquisition in ways beneficial to ATC. However, much of the time they reported being unable to determine when CDTI was in use. They thought CDTI was in use all of the time after the first Baseline approach when in fact it was not. Nonetheless, they suggested that the CDTI increased situational awareness for both pilots and controllers when traffic was called out.

The controllers stated that CDTI allowed them to call traffic earlier than normal. For instance, one controller reported that on two successive departures he was able to call traffic to follow on the crosswind leg, and the subject aircraft followed without incident. This would appear to enable controllers to better manage and reduce their workload by reducing time. However, this statement is not supported by the data presented in Figure 6, which does not indicate greater call out distances for CDTI aircraft. Additionally, no evidence indicated that CDTI reduced the duration or the number of messages that comprised the ATC communication sets, so we were not able to confirm the controllers' perceived reduction in workload.

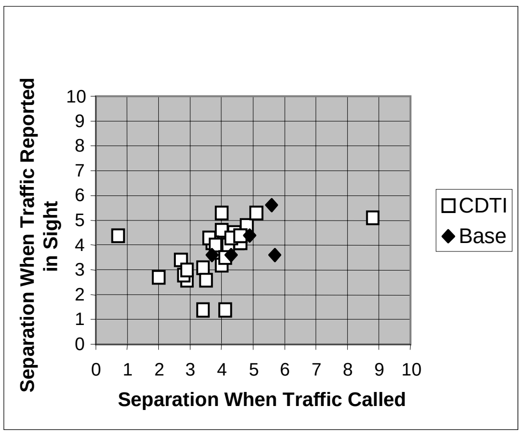

Figure 6: Visual acquisition distances

Visual Acquisition Time: In light of findings from previous simulation studies (Wickens, 1999; Olmos, 1998), we expected that visual acquisition time would be reduced with the aid of the CDTI. Two independent ways of measuring visual acquisition time were developed. The first was the flight deck observer measuring the time between an ATC call and the first indication by any member of the flight crew that they had acquired the traffic. This indication could take the form of a reply to ATC, or an intra-cockpit communication or gesture. A second measure came from analysis of the ATC communication voice tapes and was the time interval between ATC calling traffic and the flight crew responding to ATC. Analysis of the data shows that neither metric indicated a significant difference in acquisition time.

For the acquisition times measured by the observer, the average is about 20 seconds both with and without the CDTI. ATC communication tape responses were analyzed both for all responses, and then for only those responses indicating "traffic in sight". The "traffic in sight" responses show no significant difference between baseline and CDTI conditions, although there is a slight trend towards reduced response time with the CDTI. Also, there is a trend towards longer "looking" or "not in sight" response times with the CDTI than without. This may indicate crews with the CDTI used it as part of their search before replying to ATC, as is also indicated by the observer data reported in Figure 4. The ATC communication tape data set for all responses show that CDTI aircraft had a higher frequency of responses less than 3 seconds (Figure 7). These are practically immediate responses, expected to reflect the pilots' OTW perception at the time of the ATC call, either "traffic in sight" (i.e., previously acquired), "looking" or "not in sight". More crews with the CDTI chose to give an immediate reply, rather than looking for the traffic before replying. This may imply some additional level of comfort due to the improved situational awareness afforded by the CDTI, so the first reaction is to reply to the ATC call before looking for or reconfirming the traffic.

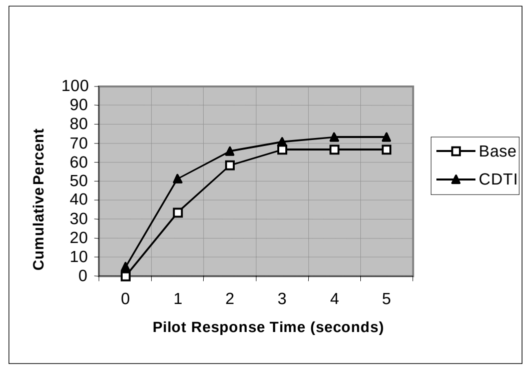

Figure 7: Cumulative Distribution of Time for All Pilot Responses to ATC traffic Call-Outs (within 5 sec).

Analysis of visual acquisition time is confounded by the fact that each ATC traffic call is for a unique separation distance and encounter geometry. One would expect faster acquisition performance for closer aircraft, and for aircraft called out near the 12 o'clock position. Acquisition time proved to be correlated to separation distance at the time of the ATC call, for the combined CDTI and baseline data. Inspection of the data in Figure 6 shows that most traffic was called out at distances ranging from two to six miles. It is clear that there are too many uncontrolled variables, including range, geometry, visibility conditions, and flight crew workload, all of which could affect acquisition time, for us to evaluate the true effect of the CDTI on visual acquisition performance.

The data showed an apparent increase in use of the CDTI as the day progressed (Figure 3). Traffic was acquired using the CDTI more frequently during the later afternoon approaches, and less frequently visual only. This suggests flight crews were learning to integrate the use of CDTI into their usual procedures, and that some training may be required to develop optimal patterns of use.

Pilot-Initiated Visual Acquisition Reports: There were eight occasions when flight crews initiated a traffic call. At least some appeared to represent implicit requests to follow the traffic reported in sight. This was a concern expressed by all three controllers, since responding to pilot-initiated requests in terminal airspace can potentially increase controller workload and might impact their plans for handling the traffic. Of the eight calls, four came from one aircraft, and four were in the late afternoon, suggesting that possibly these calls are not representative of the frequency of pilot-initiated requests that would be experienced under normal operational conditions.

Enhanced Visual Approaches: Generally, both flight crews and controllers commented that the CDTI was a positive aid for visual approaches, in that it aided overall traffic awareness and in closing to a comfortable and appropriate final approach spacing. Flight crews perceived the workload for gauging the distance behind the aircraft ahead to be acceptable, although heads downs time was reported to increase.

Spacing from Lead Aircraft: Analysis of the spacing data obtained from radar tracks and ADS-B for Baseline and CDTI approaches shows a clear trend towards spacing reduction with the CDTI, although this difference was found to be only marginally significant. Specifically, analysis of the radar track data indicates an approximate 6% probability that the 1.4 mile mean reduction in the median spacing with the CDTI was due to chance and would not be repeated if the same flight scenarios were flown again. Again, the operational conditions and limited data sample may have contributed to this trend not reaching significance. The mean approach times with and without CDTI show a 15% reduction (72.5 to 65.8 sec) with the CDTI. While not conclusive, this data strongly suggest the CDTI is aiding the efficiency of visual approaches.

The test scenario may have affected spacing, since each flight crew was aware that the aircraft ahead would go around and not land. This could induce a spacing comfort level well below what would be comfortable were the lead aircraft to land. During normal VMC operations, an aircraft cleared for a visual approach behind another aircraft will maintain spacing sufficient to ensure the lead aircraft has cleared the runway before it crosses the threshold, allowing for the lead aircraft to land long and/or delay it's turn off. This distance is usually not less than about 1 1/2 to 2 miles, but for other reasons (e.g., wake vortex considerations or the spacing that existed when the trailing aircraft was cleared for the visual approach) may be much larger. The approach spacing data indicate that aircraft did not get closer than 2 miles in almost all cases, suggesting that flights did not get close enough with the CDTI that they would have risked having to go-around because the lead aircraft had not cleared the runway. However, it is still possible that flight crews were more comfortable with closer spacing on approach than they would have been if the aircraft were landing instead of going around. A controller commented that flight crews closed up less when coming in for a landing than when performing low approaches. Analysis of the spacing data to evaluate whether this was in fact true was not attempted since there were insufficient numbers of approach events that ended in a landing.

CDTI usage appeared to increase over the course of the day, so one might presume that spacing might also be reduced as pilots became more familiar with the CDTI (Figure 3). However, no trend towards greater spacing reduction over the course of the afternoon was observed.

ADS-B and radar data show that aircraft spacing was closer between CDTI aircraft when the aircraft were cleared for the approach (Figure 8). The exact reason for this is unclear. CDTI aircraft, being closer when turning on to the final approach course, had less time to reduce spacing, and less spacing distance to reduce in that time. Even with the reduced closure opportunity, CDTI aircraft closed by about the same percentage as baseline aircraft, possibly suggesting the CDTI had a beneficial effect on spacing over the flight pattern. There were no statistically or operationally significant differences in spacing variability between CDTI and baseline aircraft.

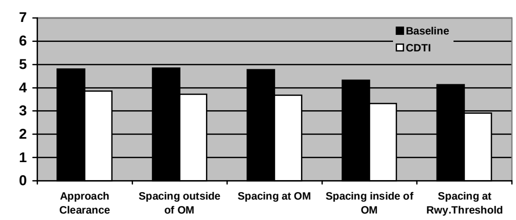

Figure 8: Baseline and CDTI Spacing for aircraft cleared to follow lead aircraft

Figure 9 shows the distributions of all approach event spacing distances. The CDTI distribution shows evidence of a positive skew, whereas the Base distribution assumed a bimodal shape.

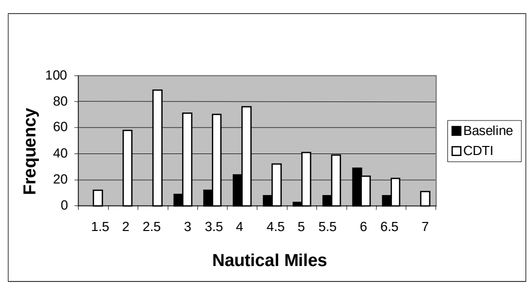

Figure 9: Frequency distribution of spacing measurements for the PM session

Flight ID Phraseology Potential Pilot/Controller

Confusion: Confusion over hearing their call sign repeated by another fight crew was not mentioned by any flight crew or controller during the debrief sessions. Examinations of complete call sign use, non-standard communication practices, call-sign location in pilot replies to traffic call-outs, and confusions in pilot replies, failed to find statistically robust evidence of problems that could be attributed to CDTI. Procedures to utter the own ship call sign first, and traffic call sign in the middle or end of the message were generally followed, although a few instances of pilots and controllers confusing traffic and own ship call signs were nonetheless recorded. No aircraft whose call sign was used in a traffic reference mistakenly responded. There was one instance when ATC used a traffic call sign when communicating with a plane that did not have access to CDTI. This illustrates the need for ATC to know whether aircraft have CDTI available (not the case at OpEval). While communications problems occurred in the low to moderate workload OpEval environment at a rate comparable to normal TRACON operations, communications problems and their antecedents in pilot and controller use of flight ID should continue to be studied, especially under higher workload conditions.

Aid to Positive Identification: One problem that is often reported during visual approach operations is that of flight crews misidentifying the traffic called out by ATC (Stassen, 1998; Monan, 1983). As a result, a primary objective of the Enhanced Visual Approach application is to minimize these instances of misidentification (described in the application description as "Aid to Positive Identification"). A review of the data shows three or four occasions when a flight crew's use of call sign alerted the controller to the fact that the wrong aircraft had been identified, thus indicating that the CDTI is, in fact, acting as an Aid to Positive Identification. This suggests a major CDTI benefit in providing early warning to ATC if an incorrect aircraft has been identified. This information will allow the controller to correct the situation well before it can become a potential conflict. This benefit was reflected in both pilot and controller comments.

ATC Communications Workload: Overall, controller workload was perceived as low to moderate during OpEval. This was largely because a controller was assigned to each runway, resulting in an average of less than three aircraft on frequency, much lower than many terminal operations. A statistically significant increase in the number of transmissions when aircraft were using the CDTI was found. This is possibly attributable to the higher throughput for aircraft using CDTI, resulting in less time for the communications to occur. The communications rate decreased slightly with increasing exposure to CDTI. Messages were slightly longer and more complex with the CDTI, although these differences did not reach statistical significance. Increases in complexity and duration may have been due to the addition of traffic call signs in pilot messages. Lack of sufficient baseline data inhibits further analysis of this trend. It is possible that the apparent increase in communications frequency and complexity with the CDTI was due to flight crews and controllers attempting to maximize CDTI usage. While no definite implications can be drawn about CDTI's effects on communications workload, if CDTI increases throughput, it may also increase communications workload.

Use of CDTI in IMC and MVMC: ILS approaches were flown during the morning low flight scenarios. Aircraft were vectored onto the final approach course outside the outer marker, resulting in longer final approaches than were flown for the afternoon visual scenarios. The data show a distinct trend towards reduced separation with the CDTI (Figure 10), but the results did not meet the normal criteria for statistical significance. Specifically, there is an 11% probability that the 1.1 mile measured reduction in median spacing with the CDTI is merely due to chance, and would not be repeated if the same flight scenarios were to be flown again. Again, the observed spacing difference between baseline and CDTI aircraft existed before the aircraft were vectored onto the final approach course.

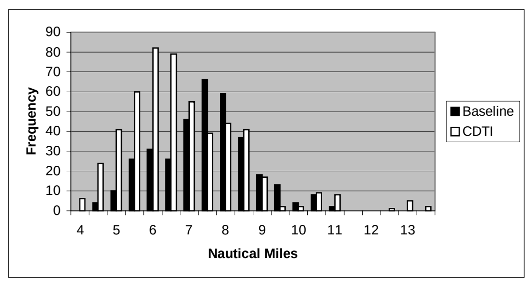

Figure 10: Frequency distribution of spacing measurements for the AM session

Crews commented that the CDTI increased their confidence in maintaining awareness of traffic that passed in and out of clouds. Since crews are generally searching the visual scene for traffic in both IMC and VMC conditions, this type of system should aid them in this task. Overall, the value of CDTI for traffic situational awareness was reported to be very positive.

Assessment of the Maturity of Concepts and Technology

Per the RTCA "Development and Implementation Planning Guide for ADS-B Applications," the paragraphs below summarize the implementation feasibility and the technology availability of the applications investigated during OpEval.

Maturity of ADS-B Applications: The OpEval afforded the look into the feasibility of several of the ADS-B applications. The OpEval Coordination Group makes the following conclusions about the ADS-B applications evaluated/demonstrated at OpEval:

- Evaluate Enhanced Visual Acquisition for "See & Avoid" - As one of the main applications being evaluated at OpEval, this application is seen as very feasible. The operational concept for this application is mature and has been approved by the RTCA SC-186. The operational concept and CDTI requirements have been evaluated within the OpEval.

- Evaluate Enhanced Visual Approaches - The operational concept for this application is mature and has been approved by the RTCA SC-186. The majority of this application and its associated CDTI requirements have been evaluated at OpEval. The remaining item from the operational concept that has not been demonstrated is the controller use of call sign. However, this procedure will be evaluated in FY00 as part of the SF21 program.

Summary

The CAA's initial CDTI implementation was evaluated with respect to several near-term applications. For the Enhanced Visual Acquisition evaluation, the mature operational concept and associated CDTI requirements were tested. Both pilots and controllers felt the CDTI augmented the visual acquisition task and improved pilot awareness of surrounding traffic. No significant problems with respect to the operational approval of this application were revealed. One potential issue that was raised, which needs to be addressed as part of future CDTI training programs, is that of flight crews initiating unwarranted requests from ATC. For the Enhanced Visual Approach Evaluation, the CDTI requirements as outlined in the operational concept were tested. The results have revealed significant performance benefits in the form of enhanced spacing awareness and a reduction in the misidentification of aircraft called out by ATC. As with Enhanced Visual Acquisition, both pilots and controllers felt the CDTI augmented flight crew performance during visual approaches and no significant problems with respect to the operational approval of this application were revealed. The remaining applications were demonstrated and the findings will feed into future operational concept development and evaluations.

Although the airborne applications were the primary focus of the Operational Evaluation, the ground system demonstrated the potential to support air – ground ADS-B applications. The ADS-B MASPS (RTCA DO-242), identifies a number of potential near-term ADS-B Air Traffic Services surveillance applications. Many of these are reflected in Safe Flight 21's near-term plans.

Selected Bibliography

Many of the following documents are available on the FAA website for Safe Flight 21 http://www.faa.gov/safeflight21/. Additional background on ADS-B applications can be found on the MITRE/CAASD website at http://www.caasd.org/cdti/.

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