COCKPIT DISPLAY OF TRAFFIC INFORMATION (CDTI) ASSISTED VISUAL SEPARATION (CAVS): PILOT ACCEPTABILITY OF A SPACING TASK DURING A VISUAL APPROACH[1]

Randall S. Bone (bone@mitre.org)
MITRE Corporation's Center for Advanced Aviation System Development, McLean, VA

Abstract

At many busy airports maximum efficiency and minimum delay occur when visual approaches are being conducted by pilots using visual separation from traffic for a portion of the approach. Pilot willingness to accept responsibility for visual separation also affords controllers maximum flexibility in traffic management under conditions of high traffic load. It may be possible to extend that efficiency to lower weather conditions if pilots are able to perform the same separation tasks by reference to a Cockpit Display of Traffic Information (CDTI) in lieu of visual contact out-the-window (OTW). This concept has been developed under the name CDTI Enhanced Flight Rules (CEFR); however, this paper will use the more descriptive and current term of CDTI Assisted Visual Separation (CAVS). Use of CAVS procedures may be applicable during visual or instrument approaches. This paper will mainly discuss the visual approach application since it will be the likely initial implementation. It will also review the maturity of the concept, including pilot objective and subjective results from four simulations. These results indicate positive pilot feedback and good performance.

Introduction

Visual separation can be used to separate two aircraft in terminal areas either by the tower controller, who sees both of the aircraft involved, or by the flight crew who sees the other aircraft involved. If the flight crew accepts a clearance by Air Traffic Control (ATC) to maintain visual separation, it must:

- Maintain constant visual surveillance,
- Maneuver the aircraft as necessary to avoid the other aircraft or to maintain in-trail separation,
- Avoid wake,
- Not pass the other aircraft until it is no longer a factor (traffic is no longer a factor when, during approach phase, the other aircraft is in the landing phase of flight or executes a missed approach), and
- Promptly notify ATC "if visual contact with the other aircraft is lost or cannot be maintained or if the pilot cannot accept the responsibility for the separation for any reason" ([1] sections 4-4-13 and 5-5-12).

When visual separation is to be used, a traffic advisory is issued by ATC to the flight crew. The flight crew then visually searches for the traffic and, when sighted, reports it in sight. The search for aircraft in a dense traffic environment, during reduced visibility, or at night can be challenging [2, 3, 4]. The flight crew may have difficulty visually identifying aircraft and may even identify the wrong aircraft as the traffic of concern. Such difficulties can be reflected in the number of traffic advisories that must be issued before the traffic is sighted. After reporting the aircraft in sight, the flight crew is assigned responsibility for visual separation and a visual approach clearance can be issued. Thereafter, the flight crew is responsible for maintaining visual separation from the Traffic To Follow (TTF) to the runway, while ATC continues to provide separation from all other aircraft.

While maintaining visual separation, the flight crew must adjust spacing as necessary to maintain a

---

[1] The contents of this material reflect the views of the authors. RTCA, the Federal Aviation Administration, and the Department of Transportation make no warranty or guarantee, or promise, expressed or implicit, concerning the content or accuracy of the views expressed herein.

© 2005 The MITRE Corporation. All right reserved.

safe arrival interval, and may have to detect and then respond to unexpected deceleration of the TTF, requiring them to adjust speed, reconfigure the aircraft, and in extreme cases perform a go-around (if the flight crew judges the separation to be unsafe) [5]. On occasion, the flight crew may lose sight of the preceding aircraft requiring ATC intervention to establish another form of separation.

Experience with Traffic alert and Collision Avoidance System (TCAS), as well as various studies, has shown that a display with traffic information is an effective enhancement to visual acquisition [6, 7, 8]. In fact, the concept of using a traffic display for enhanced visual acquisition is currently being practiced effectively in TCAS-equipped aircraft [9, 10]. Additionally, authors of a flight test report noted that when a CDTI was used to enhance airborne traffic awareness during day (with poor visibility) and night (with good visibility) operations, it was normally the first method used, followed by an ATC advisory or visual OTW sighting. In this flight test, approximately 75% of the traffic events involved use of the CDTI [11]. An early flight test also indicated that the CDTI was an effect tool to initially alert the flight crew to the presence of traffic for subsequent visual search [12].

The information available on the CDTI may also allow the flight crew to make more accurate spacing judgments and enhance the flight crew's ability to keep the aircraft in sight during less than ideal conditions through features such as closure rate, speed and distance information, as well as a range ring with a spacing alert [13, 14]. Such information is believed to be beneficial and necessary for a CDTI more capable than TCAS II for a near-term in-trail procedure [15].

Finally, when losing sight of the aircraft, Imrich [16] noted that the CDTI should assist in traffic awareness when transitioning in and out of clouds, at night, or during visual illusions. During an operational evaluation / flight test, flight crews reported that the CDTI helped in maintaining an awareness of the exact position of traffic when flying instrument approaches with visibility less than 5 miles and the TTF transitioned in and out of cloud layers [17].

If information on a CDTI can be used to perform the visual separation task, visual approaches could continue to be used during conditions under which visual OTW contact cannot be maintained, which would otherwise require visual approaches to be suspended with the subsequent loss of capacity [16].

Background

A CDTI using Automatic Dependent Surveillance-Broadcast (ADS-B) has been recognized as a need for a future ATM system [18, 19, 20]. Since the early studies of CDTI (e.g., [14, 21, 22]) and implementation of TCAS, RTCA standards for the CDTI and an associated link have been developed for a CDTI with additional capabilities over TCAS (e.g., [23]). Additionally, operational applications for the use of CDTI have been developed (e.g., [4, 23, 24]). However, only limited research has led to operational implementations of near-term applications (e.g., [25]). This line of research is directed at fielding a near-term application with current equipment (i.e., Garmin AT2000) and a customer (i.e., United Parcel Service (UPS)).

A joint United States and European group [26] developed four categories for Airborne Separation Assurance Systems (ASAS) applications: Airborne Traffic Situational Awareness, Airborne Spacing, Airborne Separation, and Airborne Self-Separation.

CAVS is an Airborne Separation application in which delegation of separation responsibility is applied to a designated aircraft (i.e., the TTF) and ATC maintains separation responsibility for all other aircraft. The concept is also similar to the notion of *extended delegation* as proposed by Hoffman, et. al. [27]. CAVS is not an Airborne Situational Awareness or Spacing application since the flight crew accepts responsibility for separation from one particular target. For the same reason, it is not an Airborne Self-Separation / free flight application in which the flight crew is responsible for separation from all aircraft [28, 29].

Other terminal Airborne Spacing or Separation applications such as Paired Approaches [30, 31] and Approach Spacing [23, 32, 33] have also been proposed. These applications provide the flight crew with speed commands to achieve a specified desired distance along the final approach. This is in contrast to CAVS where pilots use the CDTI to make spacing judgments and to achieve their self-determined spacing. These other terminal applications are expected to be implemented in a time frame beyond CAVS.

As a near term concept, Imrich [16] proposed CDTI use for current visual approach operations. He also recommended this CAVS application with the

© 2005 The MITRE Corporation. All right reserved.

expected benefits as defined herein. Others have defined this concept or one that is similar [4, 15].

Concept Description

The operational concept for CAVS is to use the information available from the CDTI for traffic identification and separation monitoring during single stream arrivals. It builds from the joint US and European application of Enhanced (Successive) Visual Approaches [23, 34]. CAVS makes the transition from pilots using the CDTI to assist with spacing judgments during visual approaches when the aircraft remains continuously in sight OTW (see [23]), to using the CDTI to maintain separation from another aircraft when it is lost OTW. In effect, the operational definition of "visual separation" is expanded to include the use of the CDTI to substitute for OTW visual contact when maintaining pilot-determined separation. Requirements for the conduct of the visual approach are unchanged except for pilot use of the CDTI for visual separation.

The source of traffic information is assumed to be from aircraft equipped with ADS-B data link. ADS-B is a function on an aircraft or surface vehicle that periodically (approximately once or twice a second) broadcasts its three dimensional position and velocity as well as other information such as call sign and weight category (see Figure 1).

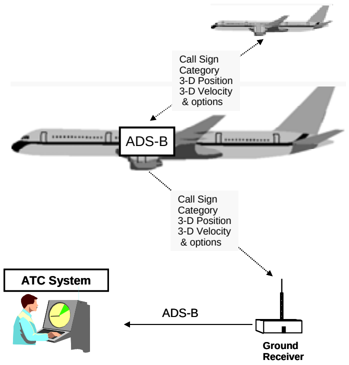

Figure 1. ADS-B air to air and air to ground transmission.

While conducting CAVS, pilots use the information from the CDTI for traffic identification and separation monitoring during visual approaches in Visual Meteorological Conditions (VMC). Use of the CDTI is expected to occur in a manner that is functionally equivalent to using similar information derived from scanning the external visual scene while performing visual separation. For example, flight crews assigned visual separation while following another aircraft are expected to detect closure on the TTF by changes in the apparent size of the target OTW and to adjust ownship speed or path so as to maintain a safe interval. The CDTI provides analogous information in the form of traffic position, range, and ground speed, and in some implementations, closure rate (see Figure 2). Changes in distance or speed, therefore, are directly observable on the display in the form of both graphical relative distance and alphanumeric information. Use of the CDTI should make it possible to detect such changes well before they would be apparent using visual cues alone, thus improving pilot traffic awareness. The availability of flight identification on the CDTI also aids in traffic awareness and enables more reliable and less ambiguous traffic identification.

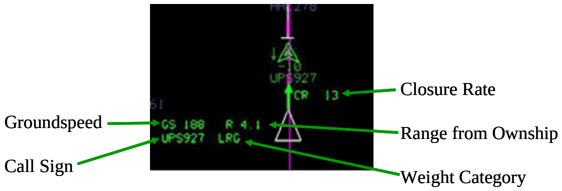

Figure 2. Inset of CDTI Showing an ADS-B selected target and the associated target information.

CAVS operations during visual approaches will occur anywhere current visual separation and visual approaches are acceptable [35]. Many different aircraft with different equipage and speeds will be operating within this environment. For a visual approach, the weather conditions at the field must be at least VMC (ceiling at or above 1000 feet and visibility 3 miles or greater). Additionally, in order for ATC to vector for the approach, the reported ceiling at the airport of intended landing must be at least 500 feet above the Minimum Vectoring Altitude / Minimum Instrument Flight Rules (IFR) Altitude (MVA / MIA). It is expected that each airport will determine the weather conditions and the airspace appropriate for the CAVS procedure.

Under CAVS, controllers can apply visual separation (with flight crew concurrence) based on visual OTW contact and / or use of the CDTI. This would extend the flexibility of operations to the use of visual separation standards during reduced visibility (e.g., haze) or difficult sighting and tracking

© 2005 The MITRE Corporation. All right reserved.

conditions (e.g., clear nights) based on the information provided to the flight crew via the CDTI.

The initial implementation requires that the flight crew first establishes visual OTW contact with TTF, then correlates that traffic with the corresponding CDTI traffic symbol before using the CDTI to maintain separation. If the visual contact is subsequently lost (for example, as TTF blends with ground lights), the CDTI could then be used to monitor and maintain separation. A later stage of the concept may authorize CDTI based-separation based solely on identification of the displayed target on the CDTI.

Procedures and Responsibilities

Current ATC and flight crew procedures would be used, including the use of visual separation. Flight crews would be expected to continue to comply with company visual approach procedures including use of lateral and vertical path guidance when on visual approach to a runway so equipped. Flight crews will also be trained on the wake separation criteria set forth in the ATC Handbook, 7110.65 [35] and Aeronautical Information Manual (AIM) Section 7-3-9 [1]. It is expected that the flight crew would use these values as guidance for safe distances to maintain behind other aircraft. However, the flight crew would be expected to make safe spacing judgments based on the particular conditions of each approach and, when necessary, apply other avoidance procedures as specified in AIM Section 7-3-7.

As with current visual approach operations, after accepting a clearance to maintain visual separation, flight crews will be responsible for adjusting spacing to maintain a safe separation, maintain visual surveillance, and avoid wake. Also as with current operations, it is expected that the controller will vector aircraft to a position, including appropriate speed instructions, such that the approach will result in a landing with an appropriate spacing between aircraft. With this set-up, the flight crew will make speed adjustments to achieve its desired spacing from the aircraft ahead.

Controllers are expected to maintain control of the arrival flow to the airport, just as they do today when conducting visual approaches with the use of visual separation. Pilots should not try to “second guess” controller decisions based on the limited view of traffic that they have on the CDTI. The conduct of CAVS is intended to be a collaborative use of traffic information in which both pilots and controllers are more effectively able to perform their historic roles and responsibilities in the context of visual approaches using visual separation.

A quote from Connelly [13] summarizes the pilot / ATC relationship quite well “Employment of the [CDTI] by no means implies ATC by committee or a free-wheeling, laissez-faire operation. Traffic flow would still be organized and monitored from the ground...the [CDTI] will be used by the pilot primarily to...fine-tune spacing in trail...In other words, the [CDTI] would be used to enhance the performance of the pilot in carrying out the objectives of the ATC system” (p. 20-21).

Controller responsibilities are not expected to change with the use of a CDTI for visual separation. In regards to procedures, since call sign is available on the CDTI, controllers can include TTF call sign when issuing a traffic advisory, when appropriate. This will enable flight crews to correlate the traffic sighted visually with its target on the CDTI. In a mixed equipage environment, ATC may need to know which aircraft are equipped with a CDTI and capable of maintaining visual separation based on the display.

Infrastructure requirements

The necessary aircraft equipment will include the traffic display, a pilot interface, and the associated processing systems. An expected CDTI function is target selection (highlighting the target and the display of selected target ground speed, weight category, call sign, as well as range and closure rate in regards to ownship) (see Figure 2).

As for ATC, additional infrastructure may not be necessary. Teams have been formed to develop the human-machine interface requirements for ADS-B on ATC displays (e.g., update rates for ADS-B targets and display of aircraft equipage levels). While ADS-B information may be displayed to the controller, this concept mainly requires controller knowledge of the aircraft and flight crew capability to perform CAVS. The most practical method of identifying capable aircraft to controllers is currently under evaluation. However, the most desirable method is to have this information on the ATC surveillance display.

Purpose

The purpose of CAVS is to delay the transition from visual approach and visual separation operations to instrument approach operations as weather conditions deteriorate. CAVS is expected to

© 2005 The MITRE Corporation. All right reserved.

enable arrival rates closer to those during visual approaches by allowing for the use of the CDTI by the flight crew to maintain separation from traffic and by providing ATC the flexibility allowed by visual separation procedures. Use of visual separation by flight crews is an underlying factor for the maintenance of VMC arrival rates during periods of high demand at many airports. However, visual approaches are often discontinued above the prescribed facility minimums due to the difficulties inherent in visual approaches, e.g., pilots not being able to consistently achieve and maintain visual OTW contact. By continuing "visual" separation operations to the actual visual approach minimums, airport capacity may be improved and delays reduced [36] (see Figure 3). The need to increase airport capacity to meet projected demand was identified in the Federal Aviation Administration (FAA) Flight Plan for 2004 to 2008 [37].

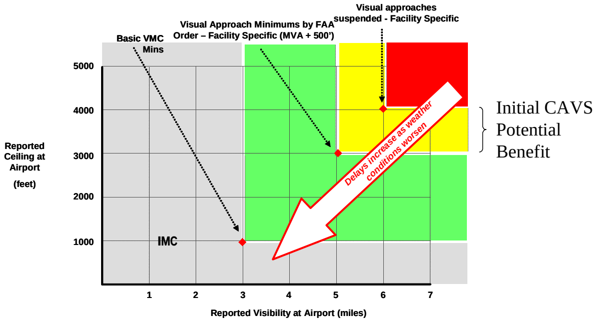

Figure 3. Weather conditions in relation to visual approach operations.

A cost benefit analysis of CAVS operations was conducted for 31 large airports [38]. The operational impacts considered airborne and ground delays, missed connections, and cancellations. The benefits were converted into economic terms by evaluating the aircraft direct operating costs and passenger value of time. The total benefit case for CAVS for aircraft direct operating cost savings was $62 million per year for the 31 airports, while passenger value of time was $315 million per year. When these results are segmented by ceiling and visibility weather conditions, $196 million (62%) of the total benefits are attributable to visibility alone. These results indicated that the CAVS application alone does not provide a strong business case for avionics equipage. However, there are additional potential benefits provided by ADS-B / CDTI technologies as those proposed by the Safe Flight 21 (SF-21) set of nine operational enhancements [39]. These include enhancements such as the display of surface traffic to ATC, pilots, and airline operations, as well as surveillance coverage in non-radar airspace. A comprehensive business case for avionics equipage should also consider potential safety and efficiency benefits provided by all nine enhancements and at more than just the 31 airports examined.

Maturity

CAVS is currently in a developmental stage. It is being developed by the FAA SF-21 program and is being considered for inclusion in a joint United States (i.e., RTCA Special Committee 186) and European (i.e., EUROCAE Working Group 51) ADS-B / CDTI technical requirements document (i.e., a version of [23]). CAVS is also identified as a terminal application under the Operational Evolution Plan (OEP) - Airport Weather Conditions: AW-2, Space Closer to Visual Standards [40]. It builds from the joint United States and European application of Enhanced (Successive) Visual Approaches, which has been renamed Enhanced Visual Separation in Approach [41, 42]. An initial safety analysis has been completed [43]. Numerous organizations have been involved in the definition of CAVS, e.g., National Air Traffic Controllers Association (NATCA), Air Line Pilots Association (ALPA), FAA Flight Standards and Certification, as well as the Independent Pilots Association (IPA).

The traffic information is assumed to be transmitted from other ADS-B-equipped aircraft. Therefore, implementation of CAVS will require that a sufficient number of aircraft be equipped to broadcast ADS-B. From an avionics perspective, manufacturers are currently building ADS-B capable equipment. Additionally, Boeing and Airbus are delivering new aircraft with the capability to broadcast ADS-B information. UPS has equipped all 107 of their 757 and 767 aircraft with ADS-B / CDTI avionics. UPS has a Supplemental Type Certificate (STC) for use of the avionics in support of traffic awareness. This same equipment may be able to support CAVS, and UPS has indicated that they will be an applicant for CAVS during visual approach in early 2005.

Simulations

A series of four medium fidelity cockpit simulations [44, 45, 46, 47], with pilots and controllers, were conducted at MITRE Center for Advanced Aviation System Development (CAASD) to refine the application description and the associated procedures previously developed within the SF-21 Program. The simulation facility is an end-

© 2005 The MITRE Corporation. All right reserved.

to-end, human in-the-loop simulation consisting of a generic transport cockpit with a visual display system, controller stations similar to Automated Radar Terminal System (ARTS) IIIE, pseudo pilot capability, and the associated simulated radio communications (for more detail on the simulation facility see [48]).

The simulations examined numerous variables: power control (autothrottle or the higher workload method of manual speed control), approach types (parallel visual and single stream instrument), weather conditions (day, night, haze, and cloud layers), aircraft types (large, 757, and heavy), CDTI locations (primary field of view and throttle quadrant forward console), different periods using only the CDTI for separation, spacing instructions and alerts, as well as target failure conditions. Fifty-six pilots from various airlines participated in the simulations.

Data collection methods included questionnaires, workload forms, and informal debrief questions, as well as aircraft to aircraft spacing and closure rate data.

This section serves as a summary across the entire series of CAVS flight simulations. Results indicated that the CAVS concept of visual separation based on a CDTI is viable. This conclusion is based on subjective feedback from pilots, objective simulation data, as well as participation in the development of the concept by NATCA, ALPA, IPA, as well as select FAA offices. Select results from the four simulations follow.

CAVS concept / CDTI use for spacing and separation

All pilots agreed that they would routinely perform the CAVS procedure and that their performance in the simulations reasonably reflected how they would fly CAVS in actual operations. Pilots agreed that they would accept responsibility for separation from the TTF by reference to the CDTI and that any associated spacing alert should be advisory in nature with the pilot determining the appropriate action. Pilots strongly agreed that they would perform CAVS under any of the weather conditions simulated, i.e., various visibilities, cloud layer thicknesses [44], as well as day [44, 45, 46] or night conditions [47]. Additionally, the cloud thicknesses / durations on the CDTI for separation presented in the simulations did not appear to be an issue for the pilots based on the spacing data. Spacing data in [44] also indicated that pilots did not have difficulty with anomalous speed behavior of the TTF and were able to detect and respond appropriately using solely the CDTI. Finally, pilots were able to manage a failure condition on the CDTI of a TTF degrading to a condition where it was unusable for CAVS.

Pilots agreed that the necessary CDTI elements were available and those elements were beneficial in performing CAVS (for a sample of the elements, see Figure 2). Pilots preferred a CDTI located in the primary field of view but found a CDTI located in the throttle quadrant forward console area (the same location typically used in some weather radar installations) to be an acceptable implementation. As for the objective data, no effect was found for CDTI location either on spacing or closure rates between ownship and the TTF, whether traffic was visible or not [45].

Pilots were able to use the information available on the CDTI to allow for higher closure rates when spacing between aircraft was greater and lower closure rates when spacing between aircraft was reduced [45, 46, 47]. As an example of this, Figure 4 depicts the relationship between mean closure rate and distance from a spacing reference during the approach in the fourth simulation [47]. It is clear from the figure that pilots were able to use the information available on the CDTI to allow for higher closure rates when spacing between aircraft was greater and lower closure rates when spacing between aircraft was reduced.

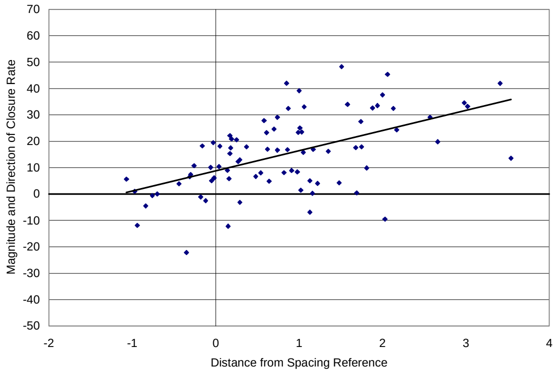

Figure 4. Relationship between derived distance from spacing reference and mean closure rate across the entire approach.

Pilots consistently strongly agreed that they were more confident with the use of the CDTI as compared to using OTW visual cues for establishing appropriate spacing. Across all simulations, pilots

© 2005 The MITRE Corporation. All right reserved.

either strongly or somewhat agreed that the CDTI enhanced the safety of approach operations.

In all simulations, when following different aircraft types, final spacing between ownship and the TTF increased as initial spacing increased. These results indicate that controllers will continue to have a key role in the successful implementation of CAVS procedures. Tighter initial spacing or an instruction to maintain a certain speed or greater[2] will permit pilots to "fine tune" their spacing intervals. Figure 5 depicts the relationship between initial spacing and final spacing when the simulation flight crew was following another large aircraft during the fourth simulation [47]. The graphs for following 757 and heavy aircraft show similar trends. When examining the figure, it should be noted that some pilots employed wake avoidance techniques (such as flying high on the glideslope) when flying the approaches.

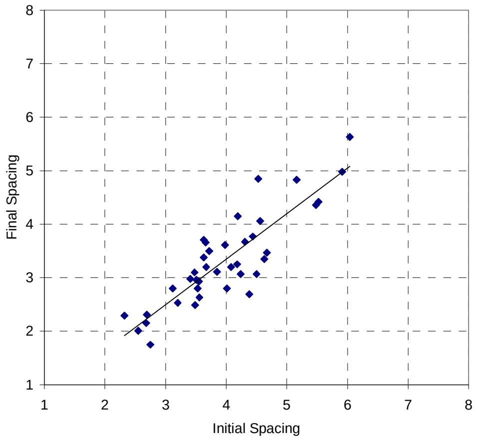

Figure 5. Relationship between initial spacing and final spacing when following large aircraft.

Air traffic controllers participated in the development and execution of the simulations. During the simulations, they provided feedback on the concept and associated operational issues. Their feedback aided in the development of the simulations as well as the continued development of the concept. Discussions with some of the air traffic controllers who participated in the simulations indicated initial uncertainty and apprehension about the procedure. However, NATCA supports continued research of the concept and discussions continue with air traffic controllers to identify potential concerns.

Workload

Across all simulations, pilots agreed that all cockpit tasks were successfully completed. Pilots in the final two simulations agreed that overall workload while performing CAVS during visual approaches was acceptable and approximately the same as that currently experienced with visual approaches [46, 47]. The objective results also indicate that pilots are willing and able to perform the CAVS procedure, using either the autothrottle to control airspeed or the higher workload method of manual speed control. While there were differences between manual and autothrottle speed control for closure rate, final spacing was not affected, thereby indicating that the closure rate differences, while interesting, may not be operationally relevant [46]. In regards to crew operations, the final simulation indicated no workload differences between the pilot flying and the pilot not flying.

Head down time

Pilots generally agreed that the amount of head down time did not impact on safety. However, pilot responses did vary on some questions of head down time. Some of the head down issues may be resolved once pilots become more familiar with the procedure and the CDTI, as well as when they are flying the aircraft they have been trained on and not a generic simulator.

General difficulty

Across all simulations, pilot responses were either that the CAVS procedure was "no more difficult than most precision approaches" or "more difficult than most precision approaches but the average line pilot can do it." No pilots said it was "very", "extremely", or "too" difficult.

Conclusion

Efforts over the past year indicate that performing CAVS (i.e., visual separation via a CDTI) during visual approaches is technically and operationally possible. MITRE pilot simulations indicate that the concept is viable and key

---

[2] Air traffic control issuing a speed to maintain for spacing to the flight crew, when the flight crew is responsible for separation, can seem contradictory. However, this is a common current practice during visual separation and / or visual approaches to achieve a desired operational spacing to the same runway. If necessary, pilots are able to initially refuse or subsequently report unable.

© 2005 The MITRE Corporation. All right reserved.

stakeholders support continued research. While there is not a compelling standalone CAVS business case for avionics equipage, other operational enhancements may provide the necessary benefits for such a case. UPS plans to seek operational approval of CAVS and has installed avionics that have the necessary display elements.

Acknowledgements

David Domino and John Helleberg were two other main contributors to this line of research. Other key participants to be recognized are the MITRE ATM lab staff for the efforts that allowed the simulation to be conducted, NASA AMES for providing human factors review and support, as well as the participants in the SF-21 Working Groups for the continued development of the concept and the simulation reviews.

References

[1] FAA (2004). *Aeronautical Information Manual*, DOT FAA, Washington, DC.

[2] FAA (1983). *Pilots' Role in Collision Avoidance*, Advisory Circular AC 90-48C, Department of Transportation (DOT) FAA, Washington, DC.

[3] Popp, P. T. (1995). The Physical Limitations of the "See and Aviod" Concept for Separation of Air Traffic, *International Society of Air Safety Investigators (ISASI) Forum*, September, 1995, Sterling, Virginia: ISASI.

[4] Stassen, H. P. (1998). *Enhancing the Safety and Efficiency of Runway Approaches Using a Cockpit Display of Traffic Information*, MITRE Working Note WN98W0000005 , The MITRE Corporation Center for Advanced Aviation System Development, McLean VA.

[5] Keller, J. and Leiden, K. (2002). *Information to Support the Human Performance Modeling of a B757 Flight Crew during Approach and Landing: RNAV*, prepared by Micro Analysis and Design, Inc. for NASA Ames, Moffett Field, CA.

[6] Moore, S. M. (1997). *Comparison of alerted and visually acquired airborne aircraft in a complex air traffic environment*, Society of Automotive Engineers, 98ASC-32, Warrendale, PA.

[7] Andrews, J. W. (1984). *Air-to-Air Visual Acquisition Performance with TCAS II*, Project Report ATC-130, DOT/FAA/PM-84/17, Massachusetts Institute of Technology Lincoln Laboratory, Lexington, MA.

[8] Andrews, J. W. (1991). *Unalerted Air-to-Air Visual Acquisition*, Project Report ATC-152, DOT/FAA/PM-87/34, Massachusetts Institute of Technology Lincoln Laboratory, Lexington, MA.

[9] FAA (1993). *Air Carrier Operational Approval and Use of TCAS II*, Advisory Circular AC 120-55A, DOT FAA, Washington, DC.

[10] Mundra, A., Cieplak, J. J., Domino, D., and Peppard, K. (1993). *Enhancing Visual Approaches with the TCAS Traffic Display*. MITRE Paper MP-93W0000052. McLean, VA: MITRE Corporation.

[11] Joseph, K. M., Domino, D. A., Battiste, V., Bone, R. S., and Olmos, B. O. (2003). *A Summary of Flightdeck Observer Data from SafeFlight 21 OpEval-2*. DOT/FAA/AM-03/2 FAA CAMI, Oklahoma City, OK.

[12] FAA (1966). *Feasibility Test of Televised Radar*. NAFEC Project 241-023-01X, RD-66-1. Atlantic City, NJ.: National Aviation Facilities Experimental Center.

[13] Connelly, M. E. (1972). *The Role of the Airborne Traffic Situation Display in Future ATC Systems*. ESL-P-483. Cambridge, MA: Massachusetts Institute of Technology.

[14] Abbott, T. S., Moen, G. C. Person, L. H. Jr., Keyser, G. L. Jr., Yenni, K. R., Garren J. F. Jr. (1980). *Flight Investigation of Cockpit Display of Traffic Information Utilizing Coded Symbology in an Advanced Operational Environment*, NASA Technical Paper 1684. Hampton, VA: NASA Langley Research Center.

[15] Hollister, W., and Sorensen J., (Eds.) (1990). *TCAS – Cockpit Display of Traffic Information (CDTI) Investigation Phase I Report*. Seagull Technical Report 90112b-01. Sunnyvale, CA: Seagull Technology, Inc.

[16] Imrich, T. (1971). *Concept Development and Evaluation of Airborne Traffic Displays*, MIT FTL Report R71-2. Cambride, MA: MIT Department of Aeronautics and Astronautics.

[17] Battiste, V., Ashford, R. and Olmos, B. O. (2000). *Initial Evaluation of CDTI / ADS-B for Commercial Carriers: CAA's Ohio River Valley Operational Evaluation*. Presented at the 5th World Aviation Congress and Exposition, San Diego, CA, October 10-12, 2000. SAE Paper Number 2000-01-5520.

© 2005 The MITRE Corporation. All right reserved.

[18] RTCA (1995). *Final Report of RTCA Task Force 3: Free Flight Implementation.*. Washington, DC: RTCA.

[19] FAA (1999). *Blueprint for NAS Modernization: An Overview of the National Airspace System (NAS) Architecture Version 4.0*, January 1999. DOT FAA, Washington, DC.

[20] RTCA (2002). *National Airspace System: Concept of Operations and Vision for the Future of Aviation*. Washington, DC: RTCA.

[21] Connelly, M. E. (1977). *Simulation Studies of Airborne Traffic Situation Display Applications*. ESL-R-751. Cambridge, MA: Massachusetts Institute of Technology.

[22] Hart, S. G., and Loomis, L. L. (1980). Evaluation of the Potential Format and Content of a Cockpit Display of Traffic Information, *Human Factors*, 22(5), 591-604.

[23] RTCA (2003). *Minimum Aviation System Performance Standards (MASPS) For Aircraft Surveillance Applications (ASA)*, Document No. RTCA/DO-289, Washington, DC.

[24] Hoffman, E., Zeghal, K., Cloerec, A., Grimaud, I., Nicolaon, J-P. (1999). *Operational Concepts for Limited Delegation of Separation Assurance to the Cockpit*. Air Traffic Management 1999 Workshop, Capri, Italy.

[25] Olmos, B. O., Mundra, A.D., Cieplak, J. J., Domino, D. D., and Stassen, H. P. (1998). Evaluation of Near-Term Applications for ADS-B/CDTI Implementations, *Proceedings of the 1998 World Aviation Conference*. Warrendale, PA: SAE International.

[26] FAA / EUROCONTROL Cooperative Research and Development, (2001). *Principles of Operation for the Use of Airborne Separation Assurance Systems*, Version 7.1, 19 June 2001 http://human-factors.arc.nasa.gov/ihh/cdti/DAG_TM_WEB/Documents/ ASAS_report (0601).pdf.

[27] Hoffman, E., K. Zeghal, A. Cloerec, I. Grimaud, and J. Nicolaon (2000). Is limited delegation of separation assurance promising? *Proceeding of 3rd USA / Europe ATM R& D Seminar*, Napoli, 2000.

[28] Johnson, W., V. Battiste, S. Delzell, S. Holland, S. Belcher, K. Jordan (1997) Development and demonstration of a prototype free flight CDTI, *Proceedings of the* 1997 *SAE/AIAA World Aviation Congress*.

[29] Ruigrok, R., R. Van Gent, J. Hoekstra (1999). The transition towards free flight: a human factors evaluation of mixed equipage, integrated air-ground, free flight ATM scenarios, *Proceedings of the 1999 SAE/AIAA World Aviation Congress*, San Francisco.

[30] Bone, R., O. Olmos, A. Mundra, J. Hammer, H. P. Stassen, M. Pollack (2000). *Paired Approach Operational Concept*. MITRE Paper 00W0000210, The MITRE Corporation Center for Advanced Aviation System Development, McLean, VA.

[31] Stone, R. (1998). *Paired Approach Concept, Increasing IFR Capacity to Closely Spaced Parallel Runways*. United Airlines World Headquarters, Chicago, IL.

[32] Abbott, Terence S. (2002). *Speed Control Law for Precision Terminal Area In-Trail Self Spacing*, NASA TM 2002-211742, NASA Langley Research Center, Hampton, VA.

[33] Olmos, B. O., R. S. Bone, and D. A. Domino (2001). *Cargo Airline Association & Safe Flight 21 Operational Evaluation-2 (OpEval-2). Proceedings of Proceeding of the 4th USA / Europe ATM R& D Seminar*, Orlando, 2001.

[34] Eurocontrol (2002). *CARE/ASAS Activity 5. Proposal for a first package of GS/AS applications*, Brussels, Belgium.

[35] FAA (2004). *7110.65 Air Traffic Control*, DOT FAA ATO-100, Washington, DC.

[36] Bone, R., Domino, D., Hahn, E., and Narkus-Kramer, M. (2002). Cockpit Display Of Traffic Information (CDTI) Enhanced Flight Rules (CEFR). *Proceedings of the 2002 IEEE/AIAA 21st Digital Avionics Systems (DASC) Conference*, Oct. 2002, Irvine, CA: IEEE Press, 2002.

[37] FAA (2003). *Flight Plan 2004-2008*, DOT FAA, Washington, DC.

[38] FAA (2003). *Safe Flight 21 CDTI Enhanced Flight Rules (CEFR) Initial Benefit Analysis (Version 3)* May 2003, DOT FAA, Washington, DC.

[39] FAA (2002). *Safe Flight 21 Master Plan*, Version 3.0, June 2002, DOT FAA, Washington, DC.

[40] FAA (2001). *Operational Evolution Plan*. Available URL: http://www2.faa.gov/programs/oep/AW-2.htm, DOT FAA, Washington, DC.

[41] Eurocontrol (2002). *CARE/ASAS Activity 5. Proposal for a first package of Ground Surveillance /*

© 2005 The MITRE Corporation. All right reserved.

Airborne Surveillance Applications, Brussels, Belgium.

[42] RTCA (2000). *Application Descriptions for Initial Cockpit Display of Traffic Information (CDTI) Applications*, Document No. RTCA/DO-259, Washington, DC.

[43] FAA (2003). *CDTI Enhanced Flight Rules (CEFR) Design Analysis Report: Approach Spacing for Instrument Flight Rule Instrument Approaches Operational Safety Assessment*, DOT FAA, Washington, DC.

[44] Bone, R. S., Domino, D. A., Helleberg, J., and Oswald, A. (2003). *Cockpit Display Based Visual Separation During an Instrument Approach: Pilot Performance and Acceptability. An Implementation of Cockpit Display of Traffic Information (CDTI) Enhanced Flight Rules (CEFR)*. MITRE Technical Report (MTR 03W0000011), The MITRE Corporation Center for Advanced Aviation System Development, McLean, VA.

[45] Bone, R. S., Helleberg, J., Domino, D. A., and Johnson, N. (2003). *Effects of Traffic Display Size and Location During an Instrument Approach Spacing Task: Cockpit Display of Traffic Information (CDTI) Enhanced Flight Rules (CEFR) Simulation 2*. MITRE Technical Report (MTR 03W0000030), The MITRE Corporation Center for Advanced Aviation System Development, McLean, VA.

[46] Bone, R. S., Helleberg, J., Domino, D. A., and Johnson, N. (2003). *Pilot Use of a Traffic Display to Supplement Visual Separation during Visual Approaches: Cockpit Display of Traffic Information (CDTI) Enhanced Flight Rules (CEFR) Simulation 3*. MITRE Technical Report (MTR 03W0000068), The MITRE Corporation Center for Advanced Aviation System Development, McLean, VA.

[47] Bone, R. S., Helleberg, J., Domino, D. A., and Johnson, N. (2003). *Flight Crew Use of a Traffic Display with Range Alerting to Supplement Visual Separation during Visual Approaches: Cockpit Display of Traffic Information (CDTI) Enhanced Flight Rules (CEFR) Simulation 4*. MITRE Technical Report (MTR 03W0000099), The MITRE Corporation Center for Advanced Aviation System Development, McLean, VA.

[48] Oswald, A. and Bone, R. S. (2002). Integrated Terminal Area And Flight Simulation Capabilities, *Proceedings of the AIAA Modeling and Simulation Technologies Conference*, Monterey, California 2002.

Key Words

Airborne Separation application, Airborne Separation Assurance Systems (ASAS), Automatic Dependent Surveillance-Broadcast (ADS-B), ATM lab, Cockpit Display of Traffic Information (CDTI), CDTI Enhanced Flight Rules (CAVS), flight simulation, MITRE CAASD, Safe Flight 21 (SF21), spacing, terminal area.

Biography

RANDALL BONE earned a M.S. in Engineering Psychology in 1998 from the University of Illinois at Urbana-Champaign. He has worked in the field of aviation operations / concepts, human factors, and safety. He is an instrument flight instructor as well as an advanced and instrument ground instructor. He is currently an Operations / Human Factors Specialist at the MITRE Center for Advanced Aviation System Development (CAASD) working mainly on operational applications of Automatic Dependent Surveillance-Broadcast. He also co-chairs the Operations Working Group of RTCA Special Committee 186.

© 2005 The MITRE Corporation. All right reserved.