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Automatic Dependent Surveillance-Broadcast / Cockpit Display of Traffic Information: Innovations in Pilot-Managed Departures

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16. Abstract:

Avionics devices that provide a cockpit display of traffic information (CDTI) enable pilots to acquire, verify, and maintain pre-defined spacing intervals from other aircraft. It is of interest to the Federal Aviation Administration to determine how the use of these displays influences pilot/controller operational communications. The operational evaluation of the CDTI in October 2000 provided an opportunity to examine some of these issues. Departure profiles (13 without CDTI, 32 with CDTI) were established to evaluate the ability of flight crews and air traffic controllers to manage long (6 nm) and short (4.5 nm) spacing intervals between departing aircraft during 3 day and 2 night operations. Subject-matter experts evaluated 15 hours of verbatim transcripts and audiotapes for benefits that may have resulted from pilot use of the ADS-B/CDTI. They also evaluated these communications for communication problems associated with misidentified aircraft, confusions, uncertainties, and operational concerns. Computed for each departure was the time the aircraft was under local control, runway ownership time, and the number and duration of messages. Approximately 4% of the departures conducted when CDTI was not used, and 9% when it was, involved communication problems. In particular, for pilot messages during CDTI departures, aircraft call signs were misstated or incorrect. However, when CDTI was not used, controller messages included the correct flight identifier but the wrong company name. In addition, more messages were exchanged during the short spacing interval. In contrast, when pilots executed CDTI departures, there was an overall increase in time on frequency, more time was spent under local control during the day, and departures were completed in less time when assigned the short spacing interval. Communication problems were associated with the call sign procedure that was designed to distinguish between aircraft being talked to versus talked about. Fortunately, controllers and pilots detected and corrected these problems in mid-stream, and statistically, communication efficiency was not affected. In light of the findings and comments from the controllers and pilots, alternative call sign procedures will be constructed and evaluated for the departure spacing application.

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AUTOMATIC DEPENDENT SURVEILLANCE - BROADCAST / COCKPIT DISPLAY OF TRAFFIC INFORMATION: INNOVATIONS IN PILOT-MANAGED DEPARTURES

"You on the cutting edge of technology
have already made yesterday's impossibilities
the commonplace realities of today"

— President Ronald Reagan,
White House, February 12, 1985

INTRODUCTION

The Automatic Dependent Surveillance-Broadcast (ADS-B)[1] is a data link application that will transmit from aircraft and vehicles equipped to emit surveillance data (such as position and identification) by means of a broadcast-mode to users who can receive these data. The Federal Aviation Administration (FAA) anticipates that ADS-B will provide many benefits — from extending the range and coverage of current ground-based secondary surveillance radar (especially around airport surfaces) to increasing air-to-air situational awareness. The FAA envisions that enhanced airborne and ground capabilities would provide for specific surveillance functions that would encourage co-operative air traffic management and collaborative decision-making among its users (Prinzo 2001).

ADS-B may also offer some innovative technology that could remove the delays attributed to low-ceiling/reduced visibility weather that currently restricts departure operations. For example, with improved airport surface surveillance, ADS-B supported avionics may provide synthetic or virtual digital-imaging of other aircraft, vehicles, or obstacles to the operator that would not be visible otherwise. This capability could potentially enhance safety.

Avionics devices that provide a cockpit display of traffic information (CDTI) enable pilots to acquire, verify, and maintain pre-defined spacing intervals from other ADS-B equipped aircraft. It is of interest to the FAA to determine how the use of these displays influences pilot/controller operational communications. For example, a pre-determined spacing interval could be included as part of an aircraft's (i.e., Ownship) pre-departure clearance (PDC). Following route taxi instructions, the pilot could taxi into position and monitor the distance between the nose of Ownship and the tail of the immediately departing aircraft using a CDTI. Once the spacing interval specified in the PDC was achieved, the pilot would begin the take-off roll and the next aircraft would taxi into position and hold. Under varying weather conditions, different aircraft types or sequences (e.g., a B727 behind a B757), and runway layouts, different spacing intervals might be desirable. The second operational evaluation of CDTI (OpEval-2) occurred in October 2000 and provided an opportunity to examine some of these issues.

The stated purposes of OpEval-2 were to *develop* and *evaluate* specific ADS-B air-air and air-ground applications, to *evaluate* controller use of ADS-B, and to *demonstrate* ADS-B technology.[2] Both the pilot and controller based concepts of departure spacing/clearance were assessed. Before proceeding any further, it must be pointed out, as it was during OpEval-1, that OpEval-2 provided an opportunity to demonstrate new air- and ground-based capabilities and systems at an FAA-controlled airport tower and terminal radar approach control facility. With that in mind, it is important to note that it was not possible to apply true experimental and control conditions comparable to that of laboratory-based experiments. In addition, the training that pilots and controllers received was uneven — making it impossible to exercise any statistical control over the data (e.g., treating the number of hours of training as a co-variant).

However, OpEval-2 provided an opportunity to gather field data that could be used to guide the development of ADS-B applications (e.g., approach spacing, departure spacing/clearance, runway and final approach occupancy awareness, and airport surface situational awareness). During that five-day event, objective and subjective data were collected from controllers and pilots, and a comprehensive report of

[1] In 1998, RTCA *SC-186 completed Minimum Aviation System Performance Standards for ADS-B. In addition to describing ADS-B, this document also provides information on applications that may use ADS-B information.*

[2] This was cited in the *Flight Crew Mission Guide* that was developed for OpEval-2 by the Operational Evaluation Coordination Group (OCG 2001).

the findings was prepared by the Operational Evaluation Coordination Group (OCG, 2001). Joseph, Domino, Battiste, and Bone (under review) provide a summary of the subjective flightdeck observer data. Reported here is a summary of several analyses performed on the audiotaped communications between pilots flying aircraft equipped with a CDTI device and local controllers who provided them with air traffic services. The objective of the voice tape analysis was to identify any change in operational communications, workload, or both that resulted when pilots were flying with and without the benefit of CDTI. This report provides a general description of the communication findings for the departure spacing application.

METHOD

Participants

Sixteen pilots, serving as a captain or first officer, flew aircraft equipped with CDTI while a local and ground controller along with a coordinator served as the OpEval-2 tower team who provided them with air traffic control (ATC) services. The pilot participants were paid volunteers who received briefings and participated in proficiency training exercises prior to the evaluation. The controllers, also volunteers, were on a temporary detail during training and on a regular schedule during the evaluation.

Materials

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

Procedure

Training on the Departure Spacing Application. Before OpEval-2, pilots and controllers participated in several pre-OpEval-2 simulations conducted at the Integration and Interaction Laboratory (I-Lab) of the MITRE Corporation Center for Advanced Aviation System Development (CAASD). During these simulations, pilots were instructed on how to respond to various types of ATC messages and listened to a combination of ATC and pseudo-pilot communications over a party line. They were to abide by the same requirement for pilot-managed and ATC controlled departure spacing. That is, at brake release, pilots were to say "MARK" on the tower radio frequency for data collection purposes.

Experimental OpEval-2 Departures. During the preflight briefings at the Air Guard (for pilots) and Tower (for controllers), all of the participants reviewed the flight scenarios and scripts. The facilitators reminded them to follow the established procedures and communication protocols. Afterwards, the pilots proceeded to their respective aircraft and the controllers went to their air traffic control positions in the tower or radar room.

For each flight period, the departure profiles were set up to evaluate the ability of the flight crew and controllers to manage a pre-determined spacing interval between departing aircraft. Typically, pilots taxied their aircraft along the assigned routes, held short of the active runway, and, following the receipt of the departure clearance flew a pre-determined pattern, landed the aircraft, taxied to the runway and departed again. The sequence of aircraft in the taxi pattern varied for each departure. Enumerated below are the procedures used to attain the OpEval-2 goals and ensure compliance with standard ATC procedures.

For the purpose of this study, the departure spacing interval was the distance between a pair of aircraft when the leading aircraft began its take-off roll down the runway. Each departure scenario defined the spacing interval as 6 nautical miles (nm, long) or 4.5 nm (short) between each pair of departing aircraft. Pilots managed the spacing interval between all but the final aircraft in the departure sequence. The local controller managed that aircraft.

Pilot-Managed Departure Spacing Interval. All participants used scenario cards that defined the departure spacing interval to be achieved for the flight period. As shown in Figure 1, once the lead aircraft was 6000 ft above the runway (Point A), local control provided a take-off clearance to the aircraft that was holding short of the active runway using standard phraseology and communication practices. The pilot positioned the aircraft onto the runway. By using information displayed on the CDTI (e.g., Ownship was 2.5 nm from the departing aircraft and it was at R=6000 feet elevation), the pilot determined when the scripted distance (either 4.5 nm or 6 nm) would be achieved and then began the aircraft's take-off roll down the runway. Local control protected the runway during the time the flight crew delayed the take-off roll.

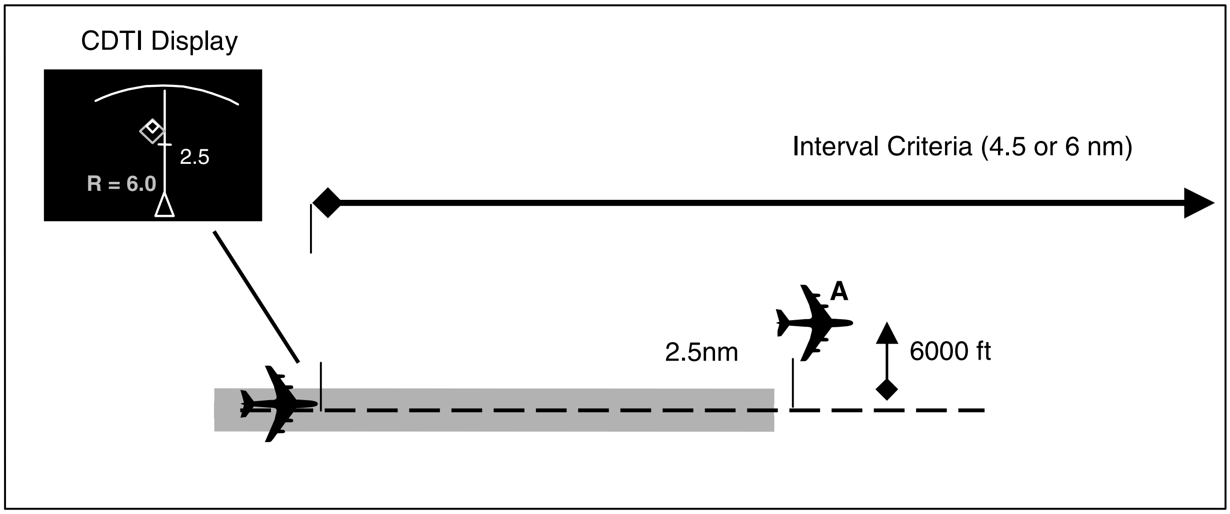

Figure 1. Departure Spacing Interval Criteria between Participating Aircraft.

Speaker	MESSAGE
N123	1. ACADEMY TOWER NOVEMBER ONE TWENTY-THREE' S HOLDING IN TURN BEHIND NOVEMBER FOUR FIFTY-SIX
ATC	2. NOVEMBER ONE TWENTY-THREE {NAME} TOWER ROGER
ATC	3. NOVEMBER ONE TWENTY-THREE RUNWAY ONE SEVEN RIGHT TURN RIGHT HEADING ONE NINER ZERO CLEARED FOR TAKE-OFF
N123	4. CLEARED FOR TAKE-OFF NOVEMBER ONE TWENTY-THREE
N123	5. NOVEMBER ONE TWENTY-THREE MARK
ATC	6. NOVEMBER ONE TWENTY-THREE CONTACT DEPARTURE
N123	7. NOVEMBER ONE TWENTY-THREE

Figure 2. Example of a Pilot-Managed Departure Communication Set.

Speaker	MESSAGE
N123	1. ACADEMY TOWER NOVEMBER ONE TWENTY-THREE ZERO READY FOR TAKE-OFF HERE ONE SEVEN RIGHT AT BRAVO
ATC	2. NOVEMBER ONE TWENTY-THREE {NAME} TOWER RUNWAY ONE SEVEN RIGHT TAXI INTO POSITION AND HOLD TRAFFIC STARTING SIX MILE FINAL
N123	3. POSITION AND HOLD ONE TWENTY-THREE
ATC	4. NOVEMBER ONE TWENTY-THREE RUNWAY ONE SEVEN RIGHT CLEARED FOR TAKE-OFF TURN RIGHT HEADING TWO FIVE ZERO WIND ONE EIGHT ZERO AT FIVE
N123	5. CLEARED FOR TAKE-OFF NOVEMBER ONE TWENTY-THREE AND TWO FIVE ZERO ON THE HEADING
ATC	6. NOVEMBER ONE TWENTY-THREE CONTACT DEPARTURE
N123	7. OVER TO DEPARTURE

Figure 3. Example of a Controller-Managed Departure Communication Set.

As shown in Figure 2, a pilot-managed departure communication set generally began when a pilot initiated the initial call up, as illustrated by message 1. When the runway was clear the controller issued the take-off clearance, and in some instances, issued a vector, or climb-out-instruction as was the case in message 3. The pilot taxied onto the runway and upon release of the break, responded with "MARK" (or similar words such as "Rolling") as in message 5. The inclusion of "MARK" indicated that the aircraft had begun its acceleration down the runway. The communication set ended when the local controller instructed the pilot to contact departure as illustrated by message 6.

Controller-Managed Departure Spacing Interval. Again, as with the pilot-managed departures, for the controller-managed departures all of the participants followed the scripted scenarios that defined the to-be-achieved departure spacing interval for the flight period. As shown in Figure 3, a controller-managed departure communication set generally began when the pilot initiated the initial call up, as illustrated by message 1. The local controller determined when to instruct the pilot to "taxi into position and hold." Then, when in the controller's judgment the anticipated scripted distance of 4.5 or 6 nm would be achieved, the take-off clearance was issued using standard phraseology and communications procedures. Similarly, the controller-managed communication set ended when the local controller instructed the pilot to contact departure, as illustrated by message 6.

Experimental Design

The TRACON and tower were divided into two sections, with the West portion of the airspace dedicated to OpEval-2. In addition, a portion of the airfield was set apart from normal operations and the tower controllers limited access to the West runway to participating aircraft. The OpEval-2 flight periods were scheduled during normally low airport activity. The participating aircraft made 69 departures that resulted in 54 departure pairs, of which two were lost to equipment failure and one to a loss of data.

This study used a two-factor within-subjects design. The within-subjects factors were Time of Day (Day, Night) and Spacing Interval (Short, Long). A between-groups comparison (Pilots, Controllers) was not attempted since there were more pilot participants than controllers, and pilots had access to ADS-B information and controllers did not.

Independent Variables. Departure profiles were established to evaluate the ability of flight crews and air traffic controllers to manage the 31 long (6 nm) and 20 short (4.5 nm) spacing intervals between departing aircraft during 3 day (flight periods 1, 2, and 4) and 2 night (flight periods 3 and 5) operations. The departure spacing application was performed by the pilots with the use of ADS-B distance information displayed on a CDTI or by the Local West controllers without benefit of ADS-B information. Forty-five departures began in initial contact and ended in a hand-off to the departure controller. Analyses were performed on 32 pilot-executed departures conducted with ADS-B/CDTI and 13 controller-managed departures conducted without ADS-B/CDTI.

Dependent Variables. To measure changes in workload and operational communication, (the primary variables of interest), the communications between local control and each aircraft for each departure were grouped into departure communication sets. Presented in Figure 4 is an example of one of the pilot-managed departure communication sets. Measures of workload included efficiency of communications and duration measures for communication sets. Measures of operational communication included communication problems and operational concerns. These measures were designed to provide the cost benefits subgroup of the OCG with a metric to help estimate the operational impact and the benefits of CDTI. They are described below.

Efficiency of Communications. Less time spent on frequency coupled with fewer departure-related transmissions to perform the departure spacing task may reflect improved efficiency in operational communication and a reduction in objective workload. Thus, efficiency of communications included the number of messages in a communication set that contained departure information and the duration of each of those calls. The duration of individual calls was the time spent on frequency (TOF) communicating. As shown in the example in Figure 4, TOF for the first message was 2s.

Duration Measures for Communication Set. Additional measures of objective workload were frequency occupancy time (FOT), runway ownership time (ROT), and the amount of time the aircraft was under local control (TLC). They were computed for each communication set that began with initial contact and ended in transfer of communication to the departure controller. Frequency occupancy time was the sum of all of the TOF for each communication set and in the example, FOT was 12s (FOT = S TOF = 2+2+4+2+0+2+0).

ROT was computed as the time lapsed from the onset of a message by local control that included a take-off clearance to the onset of a message by the controller for transfer of communication to the departure controller. In the example shown in Figure 4, 151s lapsed from the issuance of the take-off clearance in message 3 (078s) to the transfer of communications in message 6 (229s). During this time, the runway is active and, therefore, unavailable to local control for other vehicle movement or aircraft operations (runway crossing, landings, etc.). It is during this time that workload increases: For the local controller, additional effort is required to scan the airport surfaces for a potential runway incursion when there is a delay in the take-off roll. For pilots, monitoring the supplementary CDTI display may add workload while performing routine station-keeping tasks and preparing for take-off. Runway ownership time, as a by-product of ADS-B/CDTI use for pilot-managed departures task, was included as a measure of objective workload.

For each aircraft, the total time under local control (TLC) was computed as the time lapsed from the onset of the pilot's initial call-up in message 1 (at 007s) to the closing of the transaction in message 7 (at 232s). In the example TLC was 225s (232s-007s).

Communication Problems. SMEs identified communication problems as "any disturbance of routine communication, where controllers and pilots do not follow standard procedures, and/or where they must interrupt information transfer in order to clarify the communication" (Morrow, Lee, and Rodvold, 1990 pp. 36). Communication problems included inaccuracies, procedural deviations, and non-routine transactions that involved misunderstandings or other problems related to successful information transfer.

The use of the traffic-flight identifier in traffic-related messages by controllers during the Initial/Final Approach Spacing Application and Visual Acquisition Evaluation may have encouraged pilots to include it as part of their responses to those messages. Pilots who received messages in the form of "NOVEMBER ONE TWENTY-THREE TRAFFIC TWELVE O'CLOCK … NOVEMBER FOUR FIFTY-SIX" may have responded with … "NOVEMBER FOUR FIFTY-SIX IN SIGHT. " In fact, of the 889 pilot responses to traffic-related messages, 45% included either the full (362) or partial (40) call sign of the aircraft called as traffic (Operational Evaluation Coordination Group, 2001). Accordingly, inclusion of the traffic-flight identifier may have inadvertently migrated into pilots' communications with the local controller during the departure spacing application. Consequently, use of the traffic-flight identifier may have contributed to communication problems and added workload.

			Time (in seconds)				
Speaker		**MESSAGE**	**Start**	**End**	**TOF**	**ROT**	**TLC**
N123	1.	AND GOOD EVENING TOWER NOVEMBER ONE TWENTY-THREE IS IN SEQUENCE	007	009	2	151	225
ATC	2.	GOOD EVENING NOVEMBER ONE TWENTY-THREE ACADEMY TOWER ROGER NUMBER TWO	011	013	2		
ATC	**3.**	NOVEMBER ONE TWENTY-THREE **ACADEMY TOWER RUNWAY THREE FIVE LEFT FLY HEADING THREE THREE ZERO CLEARED FOR TAKE-OFF**	078	082	4		
N123	4.	CLEARED FOR TAKE-OFF THREE FIVE LEFT THREE THREE ZERO NOVEMBER ONE TWENTY-THREE	083	085	2		
N123	5.	MARK	176	176	0		
ATC	**6.**	NOVEMBER ONE TWENTY-THREE **CONTACT DEPARTURE**	229	231	2		
N123	7.	NOVEMBER ONE TWENTY-THREE	232	232	0		

LEGEND: TOF = Time on frequency per transmission
ROT = Runway occupancy time per aircraft
TLC = Time under local control per aircraft

Figure 4. Example of a Departure Communication Set.

Operational Concerns. SMEs also identified and categorized operational concerns into the "Traffic Advisory", "Position Operation", or both categories. For example, when pilots reported seeing traffic on the CDTI but not out-the-window, SMEs encoded these reports as a concern that the pilots may not be maintaining compliance with traffic advisory procedures. Similarly, SMEs encoded pilot self-separation from traffic as a concern in flight deck operation. As SMEs listened to the audiotapes and read the transcripts, they encoded their concerns and provided brief comments.

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

Data Extraction, Training, and Data Encoding Procedures

This section begins with a description of the qualifications of the Subject Matter Experts (SMEs), continues with the data extraction procedures and is followed by the procedures used by the lead SME to train the other SMEs. The section ends with an explanation of the data encoding process.

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

Data Extraction Procedures. Five sets of audiocassette tapes were dubbed from each digital audio tape (DAT). The transcribers used one copy to generate five sets of verbatim transcripts, and each message was typed onto an electronic copy of the Aviation Topic Speech Act Taxonomy-Coding Form (ATSAT-CF) like the one presented in Figure 5 (Prinzo, Britton, & Hendrix, 1995). Each message was preceded by its onset and offset time represented in hour (HH) minute (MM) and seconds (SS) and was followed by a column to record comments and a column to code operational concerns. Unlike the identifiers "N123" and "N456" that are presented in Figure 5, true aircraft identifiers and flight numbers were included as part of the OpEval-2 transcripts for all the aircraft that were present on the DAT.

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

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

RESULTS

Changes in operational communication that may have resulted from ADS-B/CDTI during OpEval-2 were evaluated from verbatim transcripts and digitized voice recordings provided by the TRACON facility. Although requests for the inclusion of baseline circuits during OpEval-2 were made during the planning of the event, none were conducted. Consequently, routine and OpEval-2 operational communications could not be compared since the baseline data necessary for comparison were not included as part of OpEval-2.

LINE	HH	MM	SS	HH	MM	SS	Speaker	Receiver	MESSAGE	COMMENT	CODE
1	16	5	46	16	5	49	N123	ATC	ONE SEVEN RIGHT POSITION HOLD FOR NOVEMBER ONE TWENTY-THREE		
2	16	6	38	16	6	40	ATC	N456	NOVEMBER FOUR FIFTY-SIX CONTACT DEPARTURE		
3	16	6	40	16	6	41	N456	ATC	FOUR FIFTY-SIX		
4	16	7	3	16	7	6	ATC	N123	NOVEMBER ONE TWENTY-THREE RUNWAY ONE SEVEN RIGHT TURN RIGHT HEADING ONE NINER ZERO CLEARED FOR TAKE-OFF		
5	16	7	7	16	7	11	N123	ATC	CLEARED FOR TAKE-OFF RUNWAY ONE SEVEN RIGHT HEADING ONE NINER ZERO NOVEMBER ONE TWENTY-THREE		
6	16	8	28	16	8	30	ATC	N123	NOVEMBER ONE TWENTY-THREE CONTACT DEPARTURE		
7	16	8	31	16	8	31	N123	ATC	ONE TWENTY-THREE		

Figure 5. Example of a Transcript.

Table 1. Pilot-Managed Departures Executed with ADS-B/CDTI

		Time (in seconds)				
Source	**(a) N Messages**	**(b) TOF**	**(c) FOT**	**(d) ROT**	**(e) TLC**	**N Sets**
Time of Day						
Day	6.38 (2.83)	2.47 (.64)	15.44 (7.06)*	135.81 (22.04)	201.00 (97.38)*	16
Night	5.13 (1.31)	2.19 (.53)	10.75 (2.02)	146.00 (12.26)	168.50 (45.24)	16
Spacing Interval						
Short Spacing	5.69 (1.70)	2.51 (.68)	14.12 (6.05)	128.81 (18.39)*	170.81 (80.46)	16
Long Spacing	5.81 (2.76)	2.15 (.44)	12.06 (5.17)	153.00 (6.43)	198.69 (72.14)	16

* statistically significant at p ≤ 05

Table 2. Controller-Managed Departures Executed without ADS-B/CDTI

		Time (in seconds)				
Source	**(a) N Messages**	**(b) TOF**	**(c) FOT**	**(d) ROT**	**(e) TLC**	**N Sets**
Time of Day						
Day	7.57 (1.72)	2.34 (.11)	17.71 (4.07)	60.14 (10.29)	213.29 (118.42)	7
Night	6.83 (1.72)	2.21 (.58)	14.67 (3.20)	77.17 (39.89)	184.00 (50.97)	6
Spacing Interval						
Short Spacing	8.67 (1.37)*	2.14 (.28)	18.67 (4.32)	58.17 (6.05)	224.50 (128.58)	6
Long Spacing	6.00 (0.58)	2.40 (.45)	14.29 (2.06)	76.43 (37.12)	178.57 (41.68)	7

* statistically significant at p ≤ 05

The local controller and pilots on the flight deck exchanged 278 messages. These messages comprised 45 departure clearance (DC) communication sets (one for each departure) that began with the pilot checking in (e.g., initial contact) and ended with a pilot acknowledging the hand-off (e.g., transfer of communications to departure control). For all practical purposes, the number of DC communication sets was approximately equal for day (n=23) and night (n=22) departures using a short or long spacing interval. Analyses were performed for pilot executed departures conducted with ADS-B/CDTI (32 departures) and for the controller-managed departures that were conducted without ADS-B/CDTI (13 departures).

Efficiency of Communications. As mentioned earlier, the measures of communication efficiency for the departure communication sets were (a) number of messages (N messages) and (b) mean time on frequency per message (TOF). To evaluate the effects of CDTI on communication efficiency during departure spacing, a Time of Day (Day, Night) by Spacing Interval (Short, Long) Analysis of Variance (ANOVA) was performed on the local control communication-data for Flight Periods 1-5. The results were evaluated using a criterion level set to $p = .05$. Presented in Table 1 and Table 2 are the mean (M) and standard deviation (SD) for each dependent variable.

The results of the separate ANOVAs revealed that when pilots executed ADS-B/CDTI departures, it did not matter whether they flew with a short or long spacing interval [$F(3,28)=2.40$] or if they flew during the day or night [$F(3,28)=2.37$] (see Table 1 columns a and b). When ADS-B/CDTI departures were conducted, pilots were instructed to say "Mark" as an indication that they were starting to move down the runway. These additional transmissions may have added to the number of messages transmitted and inflated the time data. However, upon re-analysis, the results did not change and only decreased the M and SD by a fraction of a second.

When ADS-B/CDTI was not in use, as was the case for controller-managed departures, the results revealed an increase in workload for controllers as indicated by more messages exchanged between local controller and the pilots on the flight deck during the short (but not long) spacing interval [$F(1,12)=16.54$] (see Table 2 column a). Time of day did not exert a statistically significant effect on controller workload when measured by either the number of messages exchanged or their mean duration (Table 2 columns a and b).

Duration Measures for Departure Clearance Communication Set. The duration measures of DC Communication Sets were c) total frequency occupancy time (FOT); (d) runway ownership time (ROT); and (e) total time that the aircraft was under local control (TLC). As shown in Table 1 for the time of day factor, the results indicated that for pilot-managed departures using ADS-B/CDTI, in addition to an increase in radio frequency occupancy time per departure (column c) [$F(1,28)=4.95$], longer periods of time were spent under local control (column e) during day but not night operations [$F(1,28)=4.24$]. For the spacing interval factor, flight crews executed the take-off clearance in less time (column d) when they were on a short, rather than long, spacing interval [$F(1,28) = 19.26$]. The absence of any significant interaction between spacing interval and time of day for the pilot-managed departures suggests that spacing interval alone accounted for the more than 20-second savings in transfer from local to departure control.

Displayed in Table 2 are the means and standard deviations of the duration measures for controller-managed departures conducted without ADS-B/CDTI. The results of the ANOVA revealed no statistically significant differences in workload for the time of day factor, the spacing interval factor, or their interaction.

Communication Problems. Using transcripts and cassette tapes, SMEs identified communication problems such as inaccuracies, procedural deviations, and non-routine transactions involving misunderstandings or other problems related to information transfer. Illustrated in Figure 6 are several examples. While these types of problems can contribute to frequency congestion and increase workload, they do not necessarily lead to operational errors or incidents.

An evaluation of the 278 messages involving the departure spacing application for ADS-B/CDTI revealed that approximately 2% contained communication problems involving five departures. When ADS-B/CDTI was in use, there were two departures in which the aircraft call sign was either misstated or incorrect and one departure in which the pilot requested a "say again."

As seen in Figure 6, the controller detected a communication problem of either a misspoken call sign or the potential for a stolen clearance. The problem was quickly resolved through the exchange of two additional messages. In another departure clearance readback, the pilot transposed the assigned heading with the numbers in the call sign, quickly discovered the problem and restarted the readback. "NOVEMBER THREE TEN OR UH NOVEMBER ONE TWO THREE TO THREE TEN ON A HEADING CLEARED FOR TAKE-OFF THREE FIVE LEFT." The last communication problem involved a pilot request for the controller to repeat the preceding

Speaker	ADSB IN USE
	Incorrect Call Sign
	1. NOVEMBER ONE TWENTY-THREE … CLEARED FOR TAKEOFF
PILOT	2. … CLEARED FOR TAKEOFF … **NOVEMBER ONE TWENTY-FIVE**
CONTROLLER	**3.** AND VERIFY THAT WAS **ONE TWENTY-THREE**
PILOT	**4.** UH **NOVEMBER ONE TWO THREE** UH CLEARED FOR TAKEOFF …
	Call Sign Midstream Correction
CONTROLLER	1. NOVEMBER ONE TWENTY-THREE … TAXI POSITION AND HOLD
PILOT	2. POSITION HOLD … NOVEMBER ONE TWENTY-THREE
CONTROLLER	**3. NOVEMBER ONE TWENTY-THREE** … TURN LEFT HEADING THREE ONE ZERO CLEARED FOR TAKEOFF
PILOT	**4. NOVEMBER THREE TEN OR THREE ONE THREE** TO THREE TEN ON A HEADING CLEARED FOR TAKEOFF …
	Say Again
CONTROLLER	**1. NOVEMBER ONE TWENTY-THREE RUNWAY**
PILOT	**2. SAY AGAIN** FOR NOVEMBER ONE TWENTY-THREE
CONTROLLER	3. NOVEMBER ONE TWENTY-THREE **DISREGARD HOLD SHORT** …
PILOT	4. HOLDING SHORT …
	ADS-B NOT IN USE
Speaker	**Call Sign Midstream Correction**
CONTROLLER	**1. NOVEMBER ONE TWENTY-THREE** … **CORRECTION DECEMBER ONE TWENTY-THREE** … TAXI INTO POSITION AND HOLD
PILOT	2. POSITION AND HOLD … **DECEMBER ONE TWENTY-THREE**
	Call Sign Midstream Correction
CONTROLLER	1. DECEMBER ONE TWENTY-THREE … TAXI INTO POSITION AND HOLD
PILOT	2. POSITION AND HOLD … **DECEMBER ONE TWENTY-THREE**
CONTROLLER	**3. NOVEMBER CORRECTION DECEMBER ONE TWENTY-THREE** … CLEARED FOR TAKEOFF
PILOT	4. CLEARED FOR TAKEOFF … **DECEMBER ONE TWENTY-THREE**

Figure 6. Examples of Communication Problems and Their Resolutions

transmission. When ADS-B/CDTI was not in use, there were several occasions when the controller referred to the aircraft with the correct flight numbers but with the wrong company name. Upon self-discovery of the problem, the controllers restated these transmissions using the correct call sign as shown in the lower half of Figure 6. No additional transmissions were required to clarify the misstated call signs since they were identified and corrected midstream by the controllers.

DISCUSSION

The analysis of voice communications from the departure spacing application suggests that neither the pilots who used the ADS-B/CDTI nor the controllers who applied current ATC procedures without the benefit of ADS-B information experienced a notable increase in workload. In particular, when pilots executed the ADS-B/CDTI assisted departures, neither the number nor duration of the messages exchanged between the flight deck and local control resulted in inefficient communications. In fact, the procedural changes instituted for the departure spacing application eliminated the instruction for the pilot to "taxi into position and hold, " without a decrease in total radio frequency occupancy time per departure. Unfortunately, OpEval-2 did not include conditions that would provide comparisons between this procedure and those used currently at the local control position. Consequently, a need exists for research to document the implications of eliminating the "position and hold" procedure on aircraft movement and airport capacity.

The findings from the duration measures indicated that pilots succeeded in using ADS-B/CDTI information to adjust their departure spacing interval from 4.5 to 6.0nm. Importantly, these specific spacing distances, as defined in the scripts and on pilot flight cards, were well coordinated and orchestrated. In fact, controllers managed the traffic in a manner that fully supported the local operation and the flight period spacing requirements to the extent possible. At times the operational priorities restricted the ability of the controllers to allow full conformance to scripted patterns, planned spacing intervals, or both. Fortunately, these occurrences were minimal.

Once the tower is provided with a display that includes ADS-B information, the departure spacing application will provide local controllers with a means of issuing take-off clearances that could specify variable wake-vortex minimums between aircraft equipped with ADS-B/CDTI. With the availability of an ADS-B/CDTI system onboard their aircraft, pilots could accept these clearances and begin their take-off roll at these prescribed minimums. The distance (or time interval) used to space aircraft for departures vary with the category of aircraft (Category I, Category II, or Category III), same runway versus intersecting or parallel runways, the potential for wake turbulence, and other factors.[3] ADS-B/CDTI systems developers could include these parameters as part of their algorithms and further optimize runway use with the added benefit of increased safety.

At noted earlier, controllers used standard phraseology to perform the departure spacing task (e.g., cleared for take-off) without specifying the pre-determined spacing interval to be established or maintained between aircraft. For some of the other applications that were evaluated, the controllers' inclusion of traffic flight identifiers was in accordance with FAA Order 7110.65, where "additional information" is allowed at the end of traffic information messages.[4] The controllers received flight strips that denoted the type of ADS-B equipage installed on the participating aircraft. Not surprisingly, on several occasions, pilot-use of the traffic flight identifier migrated to their communications with the local controller. For example, "TOWER {Ownship's} HOLDING IN TURN BEHIND NOVEMBER ONE TWENTY-THREE, " and "TOWER {Ownship's} READY BEHIND ONE NINER."

During preparation for this event, facility, regional and headquarters personnel focused on developing a phraseology and procedural environment that would address the issues noted in OpEval-1. This included a prototype phraseology that included the call signs of participating aircraft in all traffic calls and met the basic requirements of the operational environment. Unfortunately, a comprehensive evaluation of the operational concept for the departure spacing application and phraseology was not attainable during this operational event. Not surprisingly, significant work remains to address phraseology issues and safety concerns with flight crews occupying a runway for an extended time.

The lack of standardization in voice communications procedures was one of the operational concerns noted by the subject matter experts. To realize the full

[3] See FAA Order 7110.65M Air Traffic Control Section 8, Spacing and Sequencing for FAA authorized air traffic control procedures and phraseology for use by personnel providing air traffic control services.

[4] FAA Order 7110.65M Air Traffic Control Section 4 Para. 2-4-20 Aircraft Identification NOTE: "Air carrier and other civil aircraft having FAA authorized call signs may be pronounced using single digits if necessary for clarity."

benefits from ADS-B/CDTI, a more concise lexicon of air traffic phraseology would be helpful. A consideration of a data link for more routine communications, similar to what occurs for pre-departure clearances, would help keep the voice channel available should problems occur. Although pilots are *encouraged* to use the phraseology outlined in the *Aeronautical Information Manual* (FAA 2001) and *FAA Order 7110.65 The Handbook of Air Traffic Control* (FAA 2000), they are not *required* to use the phraseology. Air traffic controllers and pilots would benefit from precise, consistent, and standardized communications. Communication capability, pilot and controller workload, and system capacity all benefit from concise, standardized phraseology.

In addition to the phraseology and communication analysis, the subject matter experts expressed an operational concern that centered on the installation and commissioning of ADS-B at various airports. In particular, the pilot SME felt strongly that operational, procedural, and human factors considerations involving ADS-B/CDTI use for pilot-managed departures task and its affects on airport capacity, airport surface movement, and safety need a thorough evaluation. In particular, research is needed to determine the affect of increased "runway ownership time" on system safety and airport capacity. Specifically, runway ownership time represents the time the flight crew expends maneuvering the aircraft onto the runway, determining when the specified distance is achieved between Ownship and the preceding aircraft, and executing the take-off clearance. During this time, the runway is active and, therefore, unavailable to the controller for other vehicle movement or aircraft operations (e.g., runway crossing and landing).

More research is required to determine the affect of increased "runway ownership time" on airport movement, capacity, and safety during departure spacing. If the ADS-B/CDTI departure spacing application is implemented then a clear understanding is needed of the roles, responsibilities, procedures, and phraseology for pilots and controllers who use it.

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