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Abstract

A fixed-base, piloted simulation study was conducted to determine the operational benefits that result when air traffic control (ATC) instructions are transmitted to the flight deck of a transport airplane over a digital data link. The ATC instructions included altitude, airspeed, heading, radio frequency, and route assignment data. The interface between the flight deck and the data link was integrated with other subsystems of the airplane to facilitate data management. Data from the ATC instructions were distributed to the flight guidance and control system, the navigation system, and an automatically tuned communication radio. The copilot initiated the automation-assisted data distribution process.

Digital communication and automated data distribution were compared with conventional voice radio communication and manual input of data into other subsystems of the simulated aircraft. Less time was required in the combined communication and data management process when data link ATC communication was integrated with the other subsystems. The test subjects, commercial airline pilots, provided favorable evaluations of both the digital communication and data management processes.

Summary

Insufficient capacity for air-ground information exchange and communication errors limit the effective use of ground-station and airborne automation in the current air traffic control (ATC) system. To alleviate this problem, air-ground ATC communication via data link is being phased into the airspace system. Thus, aeronautical system designers and flight crews are concerned with how to best design flight deck interfaces for data link communication.

A fixed-base, piloted simulation study was conducted to determine the operational benefits that result when altitude, airspeed, heading, radio frequency, and route data were transmitted to a transport flight deck over a digital data link. A touch-sensitive CRT mounted in the center panel of the glass flight deck was used as the interface between the flight crew and the data link. This interface was integrated with the subsystems of the airplane to facilitate data management. The data received in the flight deck and displayed on the CRT were distributed to the flight guidance and control system, the navigation system, and an electronically tuned communication radio. A crew member touched a designated key to initiate the data distribution process. In the study, commercial airline pilots flew simulated flights from Chicago to Denver.

Digital communication and automation-assisted data management were compared with conventional voice radio communication and manual data input. The pilots spent less time in the combined communication and data management process when data link ATC communication was integrated with other subsystems of the simulated aircraft. The pilots provided favorable evaluations of both the digital communication and data management processes. They also emphasized that, as in this study, the flight deck crew must actively approve all data entry into the subsystems of the aircraft.

Introduction

The use of digital data link systems for air-ground communication and data transfer in the airspace system is expected to become more common in the next decade. The impetus to make data link information transfer a reality in the air traffic control (ATC) system is being provided in part by the commitment of the Federal Aviation Administration (FAA) to develop a Mode-S data link system. Expected benefits of data link communication in the ATC system include reduced demand on the ATC voice radio communication frequencies, increased communication efficiency, and reduced information-transfer error rate.

The objective of this study was to evaluate the effects that occur when ATC information transmitted by data link is entered into the relevant subsystems of the airplane. The information included in the automatic data-input process that was initiated by the flight crew was altitude, airspeed, heading, route, and radio frequency. With this process, the flight crew did not have to dial data into the autopilot display windows, tune the radios, or manually modify route data in the flight management computer control display unit (CDU). Pilot-initiated automatic data entry of this nature was expected to reduce the work load of the flight deck crew.

This study was conducted in the Transport Systems Research Vehicle (TSRV) Simulator at the Langley Research Center and consisted of fixed-base simulation tests, which used commercial airline pilots as subjects. This report documents the results of those tests.

Abbreviations

ADS	automatic dependent surveillance
AGCS	automatic guidance and control system
ALT	altitude, ft
ATC	air traffic control

ATIS	automatic terminal information service
BKN	broken
CAS	calibrated airspeed, knots
CDU	control display unit (FMS computer interface)
CHNG	change
COMM	communication
CONT	controller
CPLT	copilot
CRT	cathode ray tube
DBQ	three-letter identifier for Dubuque VOR
DEN	three-letter identifier for Denver VOR; also Denver Stapleton International Airport
DSCND	descend
DSM	three-letter identifier for Des Moines VOR
EXPCT	expect
FAA	Federal Aviation Administration
FL	flight level (e.g., FL260)
FMS	flight management system
FQ	frequency
HDG	heading, deg
ILS	instrument landing system
INFO	information
IOW	three-letter identifier for Iowa City VOR
IVSI	instantaneous vertical speed indicator
J###	jet route (e.g., J114, jet route 114)
LOM	compass locator at ILS outer marker
MAG	magnetic heading, deg
MAINT	maintain
MSSG	message
ND	navigation display
NM	nautical miles in table 1
OAC	other aircraft
OBH	three-letter identifier for Wabash VOR
OM	our message
ONL	three-letter identifier for O'Neill VOR
ORD	three-letter identifier for Chicago VOR; Chicago O'Hare International Airport
ORD7	O'Hare runway 7
OVC	overcast
PFD	primary flight display
PG	page
PIREP	pilot weather report
PMC	panel-mounted controller
PPI	plan position indicator
R	roger
RWY	runway
SCT	scattered
SIGMET	significant meteorological information
SPD	airspeed, knots
STNBY	standby
SUR OBS	surface observations
TL	turn left
TR	turn right
TRCK	track angle, deg
TSRV	Transport Systems Research Vehicle
U	unable
VECTRS	vectors
VHF	very high frequency
VLDS	Visual Landing Display System
VOR	very high frequency omnidirectional radio range navigation aid
VVCWS	velocity vector control wheel steering
WX	weather

Background

The Mode-S data link system is being developed for air traffic control and air traffic service applications in the national airspace system. The feasibility of using other data link systems, along with the

Mode-S link, in ATC and other aeronautical applications is also being vigorously explored. Reference 1 provides a comprehensive review of worldwide data link applications in air traffic control and other elements of flight operations, such as weather services. Several airlines are using a commercially available very high frequency (VHF) data link for fleet management. Along with the FAA, at least three airlines are experimenting with using that same VHF data link for preflight clearance delivery. Also, a satellite data link system is being used, at least on an experimental basis, for automatic dependent surveillance (ADS) in transoceanic flight applications (ref. 2). The ADS system is expected to be fully operational within 2 years.

Several studies have addressed the subject of using data link in air traffic control and air traffic service applications. Reference 3 presents the results of a study sponsored by the FAA that was completed in 1975 and addressed elements of optimizing the pilot interface to the data link system in ATC applications. That study addressed issues, such as character size and abbreviations in message displays. Reference 4 presents the results of a NASA-sponsored study of ATC message exchange with data link in a single-pilot operation; data link communication was found to be desirable and beneficial in single-pilot operations.

A NASA-sponsored, comprehensive research and development effort derived a general concept for ATC message exchange with data link (ref. 5). This concept included operational protocols and elements of a message set that laid the foundation for follow-on studies. Reference 6 presents the results of a recent simulation study of an application of that concept. This study, which was conducted at Langley Research Center, compared a CDU-based data link interface for ATC message exchange with conventional voice operations; the study was conducted from the perspective of the transport flight deck. The study concluded that pilots prefer ATC message exchange with data link for routine communication when time is not a critical factor. Conventional voice was preferred when message exchange operations were time critical. Measurements of pilot-scanning behavior showed that pilots spent less than 2 percent of their time viewing the data link interface. Copilots, however, spent about 7 percent of their time viewing the data link interface during the simulated descent into the Denver terminal area.

Similar results were obtained in another Langley simulator-based study that addressed single-pilot operation and concluded that the total number of ATC message exchange operations decreased when data link was the primary ATC communication mode. (See ref. 7.) A study conducted in an advanced flight deck simulator at Ames Research Center (ref. 8) also showed that pilots favored data link for routine ATC communication and emphasized pilot concern for the amount of "heads down" time required in data link operations.

The results of the previous studies completed at NASA indicate three areas that need additional research. The first area is the loading of the pilots' busy visual channel with a communication task, which has traditionally been an audio task, and its interference with vigilance; this is the issue of heads-down time. The second area is the loss of party-line benefits by which pilots overhear communication between other flight crews and the air traffic controller and deduce lead information about their own operation. The third area is the pilots' suggestion that much of the ATC information and numerical data received on the data link be fed directly into other aircraft subsystems on pilot approval. This third area, pilot-initiated automatic input of uplinked data into the subsystems of the aircraft, is the subject of this study.

Simulator Description

This study was conducted in the Transport Systems Research Vehicle (TSRV) Simulator. (See fig. 1.) This fixed-based flight deck simulation facility is controlled through a central digital computing system that operates in a real-time mode with computations updated 33 times per sec. The airplane model represented a two-engine, commercial jet transport. The flight deck layout (fig. 1) was a two-crew-member arrangement with similar instrumentation in both flight stations. An out-the-window visual scene was provided for only the left flight deck position.

Flight Instruments

The flight instruments in both the left and right flight deck stations consisted of a primary flight display (PFD), a navigation display (ND), an airspeed indicator, a drum-and-dial altimeter, and an instantaneous vertical speed indicator (IVSI). An electronic CRT display of the engine status and the data link interface, also an electronic CRT, were located on the center instrument panel. A navigation computer control and display unit (CDU), which consisted of a CRT and a keyboard, was located at each flight station. The CDU is the interface between the flight deck crew and the flight management computer.

Primary flight display. Figure 2(a) is a drawing of the PFD. This configuration was tailored to

the velocity vector control wheel steering (VVCWS) flight control system. The display format was centered about the velocity vector of the airplane. The major information elements were velocity vector, altitude, horizon, roll angle, pitch angle, and path deviation. References 9 and 10 provide more detailed descriptions of the display features.

Navigation display. Figure 2(b) is a drawing of the navigation display. This color CRT instrument presented lateral path information in a dynamic map configuration with aircraft track up. The map scale was a pilot option with values of 1, 2, 4, 8, or 32 n.mi./in. The apex of the triangular aircraft symbol represented the present aircraft position and remained stationary on the CRT while the other dynamic symbols moved relative to it. The track box, a window at the top of the ND, presented a digital display of the aircraft magnetic track. The straight trend vector that extended from the nose of the aircraft symbol indicated the path the airplane followed when its current track was maintained.

The planned flight path was displayed on the map as a series of connected line segments with each way point represented by a four-point star symbol and an alphanumeric name. In simulating conventional operations with voice radio ATC communication, the planned route data were assumed to have been entered into the navigation computer by the crew prior to the flight but were actually provided by the software that supported this simulation. A second route or route change, called a provisional route, could be typed into the navigation computer through the CDU keyboard. The provisional route was displayed on the navigation display as a series of way-point symbols connected by dashed white lines. The pilots could make the provisional route the active route by pressing the execute key on the CDU keyboard. During the data link operations, the provisional route could also be provided through the data link interface. That process is described in the section "Data Link Interface."

Flight Control System

The nominal control mode used during this study, VVCWS, provided highly augmented longitudinal and lateral control with pilot manual control inputs made through the panel-mounted controller (PMC). In the longitudinal axis, pilot control inputs controlled the rate of change of the commanded flight path angle. In the lateral axis, pilot control inputs commanded the rate of change of the bank angle. The flight control system for the lateral axis maintained track angle when the control input was removed with a bank angle less than 5° and maintained bank angle when the input was removed with a bank angle greater than 5°.

Panel-mounted controllers were located at both flight deck stations and extended from the instrument panel. The PMC's functioned as an adaptation of the conventional wheel and column arrangement. A thumb switch on one of the two PMC's at each flight station allowed pilots to command small changes in flight path angle. Along with the flap control lever and the speed brake lever, throttle control levers were located on the center console between the two flight stations. The landing-gear control extended from the center instrument panel. The rudder pedals were active.

Mode Control Panel for Automatic Guidance and Control System

The mode control panel for the automatic guidance and control system (AGCS) (fig. 3) was located on the glare shield just above the center instrument panel and allowed the pilots to select the automatic and manual modes for aircraft control. Whether the airplane is in an automatic mode or not, the normal flight procedure in commercial and military operations is to enter altitude, heading, and airspeed numerical clearance data when they are received from the air traffic controller. This data entry process is required in many commercial aircraft operations. The AGCS mode control panel in this simulator had a fourth dial for flight path angle. As the data for these four parameters were dialed into the panel, the parameters were displayed in the panel windows and became available for use in the automatic control system functions. The airspeed and altitude values were also automatically displayed in the reference areas of the primary flight display. During manual flight control mode, the pilots used the panel display as a note pad. In some simulated flights, the uplinked altitude, airspeed, and heading data (changed to track) were automatically copied into the mode control panel when the copilot touched a key to initiate the data transfer process.

The mode control panel had an additional function that enabled the pilots to select the various control system modes. The details of that function will not be discussed in this document, since the flights were all flown with velocity vector control wheel steering. The pilots were able to select the autothrottle feature at their own discretion by pressing a key on the mode control panel. They usually used the autothrottle except during takeoff and landing operations.

Out-the-Window Visual Scene

The Langley Visual Landing Display System (VLDS) was used to provide an out-the-window visual scene for the crew member in the left flight deck position. During takeoff and landing operations, the scene consisted of the runway and area around the airport. As the aircraft climbed to an altitude of 1600 ft, it entered a cloud cover and emerged through the top of the clouds at approximately 5000 ft. The scene for the duration of the flight above 5000 ft represented the horizon generated by the intersection of the cloud cover and sky. Reference 11 provides a more detailed description of the VLDS.

Air Traffic Environment

The ATC simulation was designed to provide a realistic air traffic and ATC-operating environment for the simulator flight deck. For this reason no attempt was made to optimize the human interface of the ATC station.

The air traffic environment was script based. Current U.S. airspace ATC sector boundaries were modeled and formed the basis for the simulated ATC environment. The communications heard in the simulator flight deck over the voice radio were designed to be representative of normal communications. Pseudo pilots and pseudo airplanes represented other air traffic on the same radio frequency. The nominal communication protocol required the flight deck crew to contact the sector controller over the voice radio when they entered a new sector in each of the communication modes tested. The controller was in an ATC station simulator in a separate location from the flight deck simulator. A description of the ATC simulation facility is presented in reference 12.

In the data link operation, the controller used a standard computer keyboard to compose the body of the ATC messages. The process consisted of entering a three-character code followed by the appropriate numerical data. Table 1 presents a list of the messages available to the controller. A newly composed message was displayed in the scratch pad area of the controller's CRT display for review. On approval, it was transmitted to the simulator flight deck.

Data Link Interface

The 6-in. by 6-in. CRT on the right-hand side of the center panel in the simulator flight deck (fig. 1) had a touch-sensitive screen and was used as the data link interface. Figure 4 is an illustration of the display format. Reference 5 provided the basis for this design. The touch-sensitive screen comprised three windows. The upper window displayed messages as they entered the flight deck and maintained a log of the data-linked messages. The display protocols used in the upper window closely matched those used in reference 6. In that study, the same flight deck simulator was used; however, the flight management system (FMS) CDU was used as the data link interface.

The middle window, on which automated terminal information service (ATIS) information is displayed in figure 4, was used to compose downlinked messages and to select and display a variety of information stored in on-board buffers (ref. 5). The lower window of the display, the clearance summary area, displayed the approved route, heading assignment when being vectored, ATC communication frequency assignment, altitude, and airspeed clearances. This lower window also provided a mechanism for interfacing select uplinked data with appropriate flight subsystems. A more detailed discussion of the three window functions is presented in appendix A.

Synthetic Voice Annunciation of Uplinked Messages

Several pilots who participated in a previous study (ref. 6) were concerned that ATC message exchange with the data link might have had a negative effect on their instrument scan patterns. Synthetic speech technology was suggested as a means to alleviate such problems. Therefore, in this study, a commercially available digitally recorded speech device was used. It "spoke" newly arriving data-linked messages as they were simultaneously displayed in alphanumeric form on the touch-sensitive CRT. In addition, a SPEAK key on the touch-sensitive screen allowed the last message received in the flight deck to be repeated when the message page was displayed. This key also enabled the option to speak the ATIS message when the ATIS page had been selected for display in the middle window of the screen.

Route and Route Change

When the air traffic controller uplinked a route or a route change to the flight deck, it automatically appeared on the navigation display in a graphical format. An alphanumeric display of the route change instruction simultaneously appeared on the touch-sensitive CRT. The graphical route display was similar in appearance to the dashed provisional route illustrated in figure 2(b). However, the provisional route was displayed in white, and a newly proposed route uplinked from the air traffic controller was displayed in amber. Since the proposed route was displayed simultaneously with the alphanumeric presentation and the spoken message presentation, it

provided a graphic presentation that helped the pilots decide whether the route changes were acceptable. Touching the ROUTE key on the CRT data link interface moved the uplinked route to the provisional-route status in the navigation system.

Test Procedures

The tests comprised simulated flights from Chicago O'Hare International Airport to Denver Stapleton International Airport. The en route portion of the simulated flights was shortened to limit the run time to 40 min for each flight. The nominal scenarios that were followed during the testing were based on scenarios presented in reference 5.

At the beginning of the simulated flights, the pilots contacted clearance delivery on the communication radio or by data link and requested clearance to Denver. Clearance via one of the following three routes was given (fig. 5(a)):

1. ORD7.ORD.DBQ.J94.ONL.J114.....DEN (O'Hare 7 departure to Dubuque VOR J94 to O'Neill VOR J114 to Denver)
2. ORD.IOW.DSM.J10.....DEN (O'Hare direct to Iowa City VOR direct to Des Moines VOR J10 to Denver)
3. ORD.DBQ.J100.OBH.J10...DEN (O'Hare direct to Dubuque VOR J100 to Wabash VOR J10 to Denver)

After receiving a preflight clearance, the flight crew contacted the Chicago Tower (simulation) and requested a taxi clearance. After acknowledging the clearance, the simulated aircraft was relocated to the takeoff position on runway 32R, and an appropriate visual scene was displayed. The taxi operation was not simulated. After receiving a takeoff clearance from the tower, the flight crew executed the takeoff procedures. Control was transferred to Chicago Departure Control and then to the Chicago Air Route Traffic Control Center. Clearance to cruise altitude followed. Figure 5 presents maps of the routes used in these tests, and table 1 presents the data link messages available to the air traffic controller.

On arrival at the Denver terminal area, the Denver Center controller transferred control of the flight to the Denver northeast approach sector controller. Then, the flight descended into the Denver terminal area by using the published profile descent procedure and by using instrument landing system (ILS) on runway 26L.

Five two-member flight crews participated in the tests. One crew member acted as the pilot (flying) during half of each flight and as first officer (copilot) during the other half; the pilot and first officer switched roles at the direction of the experimenter. The crew changed roles as the simulated airplane neared the Denver terminal area, just as the aircraft position was changed to shorten the flight. Each crew member was debriefed after each flight. At the end of the tests, the subjects were also asked to complete a written questionnaire about the experiment.

Tests were conducted with conventional voice radio for ATC communication and with data link for ATC message exchange. The data link flights used voice radio contact with the air traffic controller for backup and for lengthy or nonroutine negotiations. Nine simulated flights were completed with conventional voice radio ATC communication, and 15 were completed with data link communication integrated with other subsystems of the aircraft.

The recorded data included time histories of the aircraft variables, pilot control activities, and discrete events in the simulated flight deck, such as mike switch closures. Also, the mike switch closures of the simulated air traffic controller and the pseudo pilot were recorded. The time-history data provided a record of the pilot and copilot activities that were related to the task under investigation. In addition to the systems information, an open-mike videotape was made of each flight. The camera recorded a view of the flight deck from behind the pilot and captured an image of the instrument panel, the pilot interactions, communications, and control activities. The videotapes supplemented the digital data records and were useful for clarifying difficult-to-interpret sequences in the digitally recorded time histories.

Results

Data Link Interface

This study was focused on the integration of the data link message exchange process with the flight management and guidance and control systems of the aircraft. Although optimizing the interface was not the primary purpose, pilot acceptance of the interface and its operability could affect the results of the experiment. Therefore, some evaluation of the interface is pertinent.

The flight crews felt that the interface was not difficult to understand and operate. After a 30-min briefing and two flights that used the interface, the subjects reported that they were comfortable with the interface features used in this study.

The pilots, however, commented on one problem. Because of hardware limitations and the location of

the CRT, a significant amount of parallax occurred with the touch-screen CRT. A cross-hair cursor was included on the touch-sensitive CRT display to lessen the impact of parallax. This ¾-in. by ¾-in. illuminated cursor displayed the location where the screen was being touched, and it was turned off 1 sec after the touch was released. Several pilots commented that the cross-hair cursor significantly reduced the parallax problem. One subject, however, commented that seeing the cross hairs at a spot slightly offset from where he was touching disturbed him.

The subjects commented that the concepts used in the data link communication process were good, but the size of the touch areas (1.25 in. by 0.38 in.) and the parallax presented some difficulty. This limitation annoyed some subjects more than others, and their comments about the operation highlighted this aspect. Several pilots stressed that they had little problem operating the interface in the fixed-base simulator, but turbulence in an actual flight environment may require bigger touch buttons for the operation.

The panel-mounted controller switches that allowed "roger" replies without touching the display was a favorable feature of the experimental interface. (See appendix A.) The subjects liked this feature and suggested that researchers consider applications in which the switch automatically initiates the data transfer to the subsystems or in which a second position of the switch initiates the data transfer. With such an implementation, pilots would not have to touch the screen to initiate the data transfer. Pilot comments about this switch were primarily concerned with the need for the copilot to reach the center panel to complete the operation. However, the PMC switch also avoided parallax and difficulty with pointing accuracy when sending roger replies.

Message-Processing Time

Measurements were made of the time required to receive and input uplinked numerical data into the subsystems of the airplane. A comparison was made between the conventional voice operation and the data link operation. The data link operation incorporated pilot-initiated automatic input of airspeed, track angle, altitude, and radio frequency data into the aircraft subsystems. The examples presented in the following discussion illustrate the differences in the two ATC message handling processes. These examples are actual cases from the data set. The mean and standard deviation of the measurements are also presented.

Appendixes B and C present, in a coded format, event-driven time histories of sample flights in the two communication modes tested. Appendix B is an example of a flight that used conventional voice, and appendix C is an example of a flight that used data link communication integrated with elements of the flight management system as previously discussed.

These appendixes present examples of typical flights from a number of simulated flights, and consideration of the entire data set is included in the discussion and selection of the examples. These examples are used to emphasize trends identified over the data set. Clearly, some events in lengthy sample time histories, such as these appendixes, do not support all generalizations made from the entire data set.

In all these examples and in the statistical analysis in which altitude, heading, airspeed, radio frequency, or route ATC instructions were exchanged, the measurements indicated time savings for the flight crew when the data link communication process was integrated with the subsystems of the airplane.

Altitude instructions. Figure 6 presents sample time-history plots of pilot activities when the crew received an altitude assignment message from the air traffic controller. The same pilots and flight phases are presented in both parts of the example. A sample conventional voice case is presented in figure 6(a). The controller spoke an 8-sec instruction over the voice radio: "NASA 515 radar contact. Climb and maintain one seven thousand." After about 7 sec, the copilot began to dial 17 000 into the altitude window of the mode control panel to store the data and radioed an acknowledgment while dialing the assigned altitude. The copilot completed the process in about 23 sec.

Figure 6(b) presents the time history of a similar transaction conducted by data link. The same pilots and flight phase were selected as those selected for figure 6(a). The data link message was "...climb and maintain 17 000." The processing time was about 10 sec from the time the message entered the flight deck until the copilot dispatched a roger reply by depressing the yoke-mounted switch. The copilot then reached over to the CRT screen of the data link interface and touched the ALT key to swap the altitude data into the active area of the data link interface and simultaneously copy it into the altitude window of the autopilot mode control panel. This entire process required less than 12 sec, which was about half the time required in the conventional voice radio example. (See fig. 6(a).)

Heading instructions. Figure 7 presents a similar comparison of a heading change message that

was received by conventional voice radio and by data link. In figure 7(a), the conventional voice message was "NASA 515, turn left heading ###" and required the controller's mike key to be activated for 4 sec. The flight crew's reply used 1.5 sec, and the track dial adjustment required 9 sec. This whole process required about 14.4 sec.

In the data link case in which the heading data were interfaced with the autopilot mode control panel by a single touch of the data link screen by the copilot (fig. 7(b)), the message entered the flight deck and required 4 sec for the pilots to read it, make a decision to transmit a roger reply, and depress the reply switch. Entering the data into the autopilot mode control panel occurred 6.67 sec after the message entered the flight deck. The process was completed in less than 7 sec. In this example, about half the time was required when data link was combined with pilot-initiated automation features.

Airspeed instructions. Figures 8(a) and (b) are time histories of events for which airspeed instructions were processed in the simulated flight deck. A conventional voice operation is presented in figure 8(a). The speed change instruction "...when able reduce to 210" required 4 sec of controller mike key activation. The copilot's reply required 4 sec, and dialing the airspeed into the autopilot panel required about 5 sec. Completing the transaction in this example required less than 15 sec.

Figure 8(b) presents the results of an example for which data link was used to deliver a similar airspeed change instruction. In this case, in which the airspeed data were interfaced with the autothrottle system by a single touch of the data link screen, the processing time was 12 sec. In this example, data link required about 3 sec less time than conventional voice radio.

Radio frequency change instructions. Examples of instruction processing for radio frequency change are presented in figure 9. In figure 9(a), the conventional voice radio was used to communicate the ATC instruction. The time required to receive the instruction, acknowledge it, and tune the voice radio was 14 sec. Using the data link application, the copilot required 7 sec to complete these actions. In this example, the process of integrating the data link communication system with the FMS by automatically tuning the radio at the flight crew's command halved the processing time.

The event time history in appendix B reflects an operator error related to tuning the radios at time 1935.76 sec. After tuning the correct radio frequency, the copilot attempted to contact the Denver center controller but forgot to select the correct radio on which to transmit. Automating the radio-tuning process could alleviate this type of error and reduce crew work load.

Statistics of data management times. Figures 10(a) and (b) are histograms of the relative frequency of message processing times used by the flight deck crew. Data for altitude, airspeed, heading, and radio frequency assignments are presented using 5-sec time intervals. Several factors limited the sample sizes in the histograms. First, to select events in the sample required that no evidence indicate that the pilots were involved in and gave priority to completing another activity as the ATC instruction with the data was introduced into the flight deck. Second, only simple instructions that involved one data entry requirement were included. Also, in the data link cases, the copilot sometimes dialed the data into the mode control panel or the radio head and did not use the automation feature. Finally, especially in the conventional voice cases, the sequence of events in the digital records was not always clear enough to conclude that the dial adjustment was made in direct response to an ATC instruction. Usually in these cases, the voice reply signals of the flight crew were not timely, which left questions about what really transpired.

Figure 10(a) is a histogram of conventional voice operations. In the conventional voice case, air traffic control instructions were given over the simulated voice radio. As in conventional transport aircraft operations, the pilot then manually dialed the altitude, airspeed, heading, and radio frequencies into the autopilot mode control panel or the communication radio head. The mean time required to receive the data over the voice radio and dial it into the appropriate subsystem of the aircraft was 16.80 sec with a standard deviation of 6.20 sec. Three percent of the measurements exceeded 30 sec. Approximately 30 percent of the measurements exceeded 20 sec.

In the data link case, ATC messages were displayed in alphanumeric form on the touch-sensitive CRT screen. The pilots touched a key on the CRT to automatically copy the uplinked altitude, heading, airspeed, or radio frequency assignment data into the appropriate subsystem of the airplane. Figure 10(b) presents the measurements for data link communication with pilot-initiated automation features used to input the data into the subsystems of the airplane. The mean time for receiving data and completing the input to the aircraft subsystem was 12.50 sec with a

standard deviation of 3.39 sec. Only one measurement exceeded 20 sec.

The statistical significance of the difference between the means in the conventional voice and data link operations was tested by using the Kolmogonov-Smirnov nonparametric statistic (ref. 13). The results indicate that the 4.3-sec average time savings measured when data link ATC communication was integrated with select aircraft subsystem functions is significant at the 0.01 level. The histograms presented in figure 10, along with the mean and standard deviation estimates, indicate that data link operation with pilot-initiated automatic data entry is faster and less prone to lengthy data management time requirements than the conventional voice operations.

Route modification. A simulated storm cell was displayed on the ND (fig. 2(b)) to create a situation that used the rerouting feature of the data link interface in the flight deck. A time history of events during which the simulated flight was rerouted around the hazardous weather in the Denver terminal area is included in appendix C. The ATC-initiated message to reroute arrived in the flight deck at time 1163 sec. The proposed new route was simultaneously displayed in a graphical format on the moving-map navigation display. The pilots reviewed the displayed route and entered a roger reply after 15 sec. Since the new route was displayed on the ND, the pilots could manually follow it immediately. A crew member had to touch the ROUTE key on the lower window of the data link interface to complete the process of entering the route change data into the FMS. In this example (initiated at time 1163 sec in appendix C), the route key was touched and the route was copied into the CDU at time 1206 sec. The required pilot actions to input the rerouting data into the navigation computer were completed 45 sec after the route change data were received from ATC.

No cases were conducted with the conventional manual method of entering route change data into the FMS CDU. The process of instructing the subject pilots to use the CDU was considered too time consuming. However, pilots who have experience with FMS CDU's stated that a similar change that used manual data input would require considerably more time.

In appendix B, rerouting by vectoring around a storm in the terminal area was initiated at time 1044.54 sec from the start of the simulated flight. This vectoring process, along with a significant increase in the controller's work, required five voice radio communication exchanges between the controller and the flight crew, one each at times 1044.54, 1217.97, 1257.96, 1268.04, and 1369.29 sec. Relieving this type of voice radio frequency load during weather conditions that require rerouting a number of aircraft can reduce radio frequency congestion.

Pilot Evaluation of Data Management Process

At the end of the simulated flights, the test subjects were asked (on the questionnaire form) several questions about the manner in which the data link communication process was integrated with the subsystems of the airplane. Although most responses were favorable, some reactions were mixed. Figures 11 to 15 present the pilots' evaluations in a graphical format.

Figure 11 presents the results when the pilots were asked to evaluate the altitude assignment of the data management process. The evaluations offered by the pilots favored the process. Six of the ten subjects rated the process as very beneficial. One pilot commented that this data management process would eliminate errors. Another pilot suggested that these data should also be an automatic input into the altitude alert system.

In the heading assignment case (fig. 12), the ratings were again mixed but also favored the semiautomatic data input process. Five subjects rated the process as very beneficial.

The subject pilots were asked about the semiautomatic entry of uplinked airspeed data into the autothrottle subsystem and AGCS panel display. Figure 13 shows that the replies to that question were mixed but favored the process; four subjects responded that the process was very beneficial. One subject commented that this process would eliminate errors. Another subject emphasized that the pilot should have the final authority in any implementation of this feature. The pilot who rated the altitude data management process as undesirable also rated the airspeed data management process as undesirable.

The subjects were asked about the radio-tuning process, in which the uplinked ATC communication radio frequency was used to automatically tune and select the radio channel. (See fig. 14.) The flight crew initiated the process by touching the radio key on the data link interface. All subjects felt that this was a beneficial feature of the data link communication process. One subject recommended that the radio change automatically on the roger reply rather than change by a separate touch of the display. A second subject expressed his concern that the assigned radio frequency would be lost in the event of a CRT failure.

The subjects were asked about the semiautomatic entry of uplinked route data. Figure 15 shows that most subjects liked this feature and felt that it was very beneficial to flight deck operations.

The pilots' concern that the flight crew remain in control of any data input into the subsystems of the airplane was a highly emphasized issue in the written and oral debriefings. One pilot, who was neutral about the data management method under investigation, stated in an oral debriefing that he feared this was possibly the start of a process in which the aircraft could be flown from the ground. This concern persisted, even though, in this study, pilots had total control of the data management and automation applications.

Concluding Remarks and Recommendations

In this study, aircraft data link communication with air traffic control (ATC) was integrated with flight management functions of the aircraft. The uplinked ATC instructions were initially displayed to the pilots on a touch-sensitive CRT used as the data link interface. After approving the instructions, the flight crew touched a designated CRT-displayed key to initiate the automatic distribution of data to the subsystems of the simulated aircraft. In particular, data-linked altitude, airspeed, and heading clearances were directed to the automatic guidance and control system and were displayed in the window of the mode control panel. Also, route data were sent to the navigation computer through the control display unit (CDU), and the assigned radio frequency was used to automatically tune the communication radio.

Integrating the data link communication process with the subsystems of the airplane provided benefits to the pilots. The time required to process selected ATC data that arrived in the flight deck from the air traffic controller was reduced. An average time savings of approximately 25 percent occurred when altitude assignments, heading changes, airspeed changes, and radio frequency changes were processed. The mean time in the data link case was 12.5 sec as opposed to 16.8 sec in the voice case. Significant savings also occurred in processing route changes that were uplinked from the air traffic controller.

In general, the subject pilots gave favorable evaluations to the data link information exchange and pilot-initiated automatic data distribution processes. Some pilots, however, noted reservations that were related to the size of the touch keys and the parallax in the CRT touch-screen hardware. The pilots' concern that the flight crew remain in control of any data input into the subsystems of the airplane was a highly emphasized issue in the written and oral debriefings.

The data link interface, particularly the hardware implementation, was a problem for some pilots. Most subjects recognized that the parallax problems could be remedied and that some of the implementation details could be improved without great difficulty. The panel-mounted controller (PMC) switch used to initiate roger replies proved to be a beneficial aspect of the interface.

Previous studies indicate that some increases in pilot visual work load may result from data link communication. The results of this study suggest that data processing time for pilots is reduced when the tasks are examined in a broader sense and when the advantages of digital ATC communication integrated with the subsystems of the airplane are exploited.

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Appendix A

Details of Data-Link Interface Windows

The touch-sensitive CRT of the data link interface was composed of three windows: an upper, a middle, and a lower window. The functions and operating procedures of these windows are discussed in this appendix.

Upper Window: Display of and Reply to Uplinked Messages

The upper window (fig. 4) immediately displayed the uplinked ATC messages as they were received in the flight deck. Air traffic control messages were prefixed with a source identifier followed by a colon (e.g., ATC:). An aircraft-local identification number was displayed on the first line and on the immediate right of each message (e.g., 01 and 02). This number reflected the order in which the messages were received or generated in the flight deck. A suffix, "R" or "U," attached to the identification number indicated that a roger or unable response had been dispatched to the originator.

The first line of each message was aligned with a magenta touch-sensitive, rectangular key, which was used to expedite editing and referencing that message (white-outlined areas in figs. 4, 16 to 18, and 20). When a new message arrived in the flight deck, it was displayed below the messages already in the window. When space was needed, the new message caused earlier messages to scroll up and off the screen. Pilots used touch-sensitive scroll keys to move messages in this window up and down for review.

Figure 16 shows the upper window with uplinked messages displayed. A new message has been received in the flight deck, message number 23: Descend and maintain 17 000 (ATC: DSCND & MAINT 17000). As the message was displayed, a tone sounded to annunciate its arrival. Also, a visual-alerting signal (MSSG) blinked near the center of both the primary flight display (PFD) and the navigation display (ND). The audio-alerting signal was repeated every 10 sec until the crew dispatched a response. The visual-alerting signal in the PFD and ND also blinked until the crew dispatched a response. The repeated audio-alerting tone was used because reference 6 stated that crews occasionally failed to reply promptly when only the visual-alerting signal blinked.

When an uplinked message arrived in the flight deck, one of three actions caused the middle window to display the latest message (default case) or the selected message (when a key beside a message is touched) in the roger response configuration. (See fig. 17.) The three actions are

1. Touching the key (touch-sensitive area) on the left or right of the first line of a message
2. Pressing the trigger switch mounted on the panel-mounted controller
3. Touching the message page key (MESSAGE PG)

Once one of these actions was taken and the middle window of the display changed to the configuration shown in figure 17, touching the SEND key downlinked the roger response message to the air traffic controller and updated the data in the clearance summary display. Similarly, touching the UNABLE key switched the message to the unable configuration.

Actions 1 and 2 had an associated time-out–autosend feature. The time-out parameter was set to 1.5 sec. After action 1 or 2 was taken to initiate the reply process, the display in the middle window changed to the format illustrated in figure 17 for 1.5 sec, and a roger reply was then automatically transmitted. Immediately after the send function downlinked the reply, the middle window returned to its original display configuration, so the pilots could continue any operation that may have been in progress. Also, an "R" denoting the roger reply was affixed to the local message number on the display. Finally, the altitude data were relayed to the lower window of the interface in support of data management and integration processes. These processes are discussed in the section that describes the lower window. Figure 18 illustrates the display configuration when the reply process is completed.

Because of the 1.5-sec time-out feature previously discussed, action number 3, touching the MESSAGE PG key (fig. 16), was the only practical method to access the UNABLE reply key. Under such a scenario, the copilot touches the MESSAGE PG key to change the display to the roger configuration. (See fig. 17.) Next, the copilot touches the UNABLE key, which causes it to turn green. If satisfied, the copilot then touches the SEND key to dispatch the unable reply. If the copilot decides not to dispatch the message before touching the SEND key, the ROGER key can be touched to return to the roger configuration. As a matter of protocol, sending the unable reply message requires further negotiation between the flight crew and the air traffic controller by means of the voice radio. The negotiation process should result in a new clearance being uplinked to the aircraft. Downlinking a roger or unable response to any uplinked message received in the flight deck

usually ends the session (i.e., the sequence of actions required to complete the exchange of a message).

Middle Window: Data Display and Downlink Message Editing

Besides its role in the uplinked message reply process, the middle window of the touch-sensitive CRT interface offered the crew a variety of options to access and manipulate information. This portion of the interface was organized in a menu selection format following the scheme illustrated in figure 19.

The main menu, which was displayed at the start of each simulated flight, was the beginning of the menu selection scheme and allowed the crew to select either the DISPLAY or EDIT option. Under the DISPLAY option, the left branch from the main menu in figure 19, the crew could display information, for viewing only, from either of two classifications: strategic or noncontrol.

The options of display noncontrol information selection included a series of weather products, which included ATIS, winds and temperatures aloft, airport surface observations, and PIREP. (See fig. 19.) The airport surface observations and PIREP pages were inactive in this study and were simply place holders that displayed "No data available" notes to the pilots.

Selecting the EDIT option from the main menu activated the process by which the crew could use menu selection and incorporated touch-controlled switching schemes to compile messages and downlink them to the simulated ATC station. The EDIT options were available to the crew through three subbranches: strategic, tactical, and noncontrol.

The edit strategic path allowed the crew to transmit a request for a preflight clearance and to request a clearance or clearance change either in the preflight condition on the ground or en route. The route and route-change requests were selected from a menu of choices, which were assumed to be crew- or company-preferred alternates stored at an earlier time.

Lower Window: Clearance Summary and Data Link–Flight Management System Integration

The lower window of the data link interface (fig. 4) provided two functions. The first was a continuously available summary of clearances that pilots used to recall route, altitude, heading, and airspeed clearance information. The second function allowed the pilots to supervise the semiautomatic input of uplinked data into the flight management system; thus, this function provided a communication system and flight management system integration function.

When messages that contained route, altitude, heading, airspeed, or radio frequency assignments were received in the flight deck and a roger reply was downlinked, the associated numerical data were automatically copied into the appropriate standby area of the lower window of the display. By touching the magenta key on the screen (white-outlined area in figs. 4, 16 to 18, and 20) associated with that parameter, the data were automatically shifted to the active area of the display and simultaneously copied into the appropriate flight subsystem. The route or route-change information was copied into the provisional-route facilities of the navigation computer and displayed on the ND as a provisional route. The radio frequency information automatically tuned the selected communication radio, and the airspeed, heading, and altitude data were activated in the autopilot mode control panel. The autopilot mode selection was not changed by this activity. Reference airspeed and altitude values in the PFD were automatically changed.

Reviewing the process, beginning with figure 16, provides an example of the data-linked altitude assignment process that incorporates data integration into the flight management system. An altitude assignment message has been uplinked to the flight deck. Subsequently, the copilot has touched the screen to send a roger reply to the air traffic controller (fig. 17), the altitude data have been recorded in the standby altitude area of the lower window (fig. 18), and the reply process is completed as the display configuration changes as shown in figure 18.

In figure 20, the copilot has touched the magenta area labeled ALT to move a copy of the new altitude assignment data to the active line of the display and simultaneously to the altitude display window of the autopilot mode control panel. (The autopilot mode is not changed by this action.) In the clearance summary area of the data link interface (lower window), the previously active altitude assignment is changed to the standby area. A second touch of the same key reverses the data-swapping process. The asterisk, which immediately follows any parameter in this window, indicates that the parameter is the most current clearance agreement completed by data link.

Appendix B

Time History of Sample Flight That Used Conventional Voice Radio

This appendix presents a time history of the events that occurred during a simulated flight that used conventional voice radio communication (table B1).

The column entries include the following: times from the start of the simulated flight (TIME), copilot mike switch closures (CPLT MIKE), controller mike switch closures (CONT MIKE), other aircraft (pseudo pilot) mike switch closures (OAC MIKE), altitude autopilot dial movements (ALT AGCS DIAL), airspeed autopilot dial movement (CAS AGCS DIAL), track autopilot dial (TRCK AGCS DIAL), aircraft altitude (ALT), airspeed (SPD), and communication frequency change (COMM FQ CHNG).

In the first five columns that follow the time column, "1" indicates that an input was initiated and "0" indicates that the input process has terminated or the device is no longer activated. In the radio frequency change column, "1" indicates that a new frequency has been tuned and activated by the flight crew.

Table B1. Time History: Conventional Voice Radio

Time, sec	CPLT MIKE	CONT MIKE	OAC MIKE	ALT AGCS KNOB	CAS AGCS DIAL	TRCK AGCS DIAL	ALT, ft	SPD, knots	COMM FQ CHNG	Comment
125.01	1						677	0		
128.31	0									
152.49	1									
155.40	0									
165.12	1									
165.48	0									
171.66									1	Radio frequency switched to tower
186.21				1						
189.69				0						
220.38	1									
221.88	0									
253.59	1									
254.79	0									
281.97		1								Cleared for takeoff
287.52	1									
289.05	0									
289.98		0								
305.97			1							
313.98			0				677	0		
321.96		1								Contact departure
325.98		0					723	157		
346.05	1						1 988	138		
346.32	0									
353.97			1							
361.98			0							
365.55									1	
365.97		1								
369.66	1									Call to departure
369.96		0								

Table B1. Continued

Time, sec	CPLT MIKE	CONT MIKE	OAC MIKE	ALT AGCS KNOB	CAS AGCS DIAL	TRCK AGCS DIAL	ALT, ft	SPD, knots	COMM FQ CHNG	Comment
374.31	0									
377.97		1								
380.40	1		1							
381.96		0					2 693	212		
381.99	0									
382.02				1						
389.97			1							
392.22				0						
397.98		1	0							
401.97		0								
405.96			1							
409.98			0							
425.97		1								Climb and maintain 16 000
426.12				1						
426.96	1						3 668	319		
428.52	0									
429.90		0		0						
433.98			1							
441.96		1	0							
445.98	0									
449.97			1							
453.96			0							
457.98		1								
461.97		0								
465.96		1								
473.97		0	1							
477.96		1	0							Turn left 300°
479.91						1				
482.16						0				
483.15	1									
485.37	0									
485.97		0					10 084	252		
489.96			1							
497.97		1	0							
501.96		0								
506.16					1					
514.26					0					
525.96			1				12 000	298		
533.97			0							
537.96		1								
541.98		0								
589.98			1							
597.96		1	0							
601.98		0								
605.97		1								
609.96		0	1							

Table B1. Continued

Time, sec	CPLT MIKE	CONT MIKE	OAC MIKE	ALT AGCS KNOB	CAS AGCS DIAL	TRCK AGCS DIAL	ALT, ft	SPD, knots	COMM FQ CHNG	Comment
613.98		1	0							Contact Center on 132.75...
617.97		0								
625.98		1					16 000	334		Contact Center...(repeated)
627.15	1									Acknowledged
628.56	0									
629.97		0								
632.70									1	
633.96			1							
638.64						1				
640.68						0				
641.97		1	0							
644.46	1									Call to Chicago Center, ...FL260
645.96		0								
646.68	0									
649.98		1								Acknowledged, climb...FL280
651.27	1									
651.84				1						
652.26	0									
653.97		0								
663.99				0						
677.97			1							
685.98		1	0							
697.98		0	1							
701.97		1	0							Listen for your call sign... NASA 515 on frequency
703.62	1									
704.28	0						20 800	286		
705.96		0								
737.97		1								
741.96		0	1							
745.98			0							
757.98		1								
761.97		0								
765.96			1							
769.98			0							
785.97		1								
793.98		0	1							
797.97			0							
809.97			1							
817.98		1	0							
825.96		0	1							
829.98		1	0							
833.97		0								
885.96			1							
892.92										Map scale change

Table B1. Continued

Time, sec	CPLT MIKE	CONT MIKE	OAC MIKE	ALT AGCS KNOB	CAS AGCS DIAL	TRCK AGCS DIAL	ALT, ft	SPD, knots	COMM FQ CHNG	Comment
893.97			0							
913.98		1								Contact Denver Center
919.02	1									
921.96		0								
922.65	0									
929.97			1							
933.96			0							
935.76	1									Call to Denver Center
940.02	0						27 000	287		(Dialed but did not switch radio frequency)
941.97			1							
942.66									1	
943.86	1									Call to Center
947.82	0									
949.98		1	0							
953.97		0	1							Expect vectors for weather...
961.98			0							
962.37	1									
967.44	0									
969.96		1								
981.36	1									
981.96		0								
982.32	0									
1005.96		1								ATIS update...November
1029.96		0								
1033.98		1								NASA 515 acknowledge ATIS
1035.39	1									Acknowledge ATIS
1036.11	0									
1037.97		0								
1041.96		1								Depart SMITY 190..., weather, cleared profile descent
1044.54						1				
1048.62	1									
1049.97		0								
1050.54						0				
1055.28	0						27 900	310		
1061.97			1							
1065.96			0							
1069.98		1								
1074.60				1						
1077.96		0	1				27 800	306		
1080.00				0						
1081.98			0							
1114.59						1				

Table B1. Continued

Time, sec	CPLT MIKE	CONT MIKE	OAC MIKE	ALT AGCS KNOB	CAS AGCS DIAL	TRCK AGCS DIAL	ALT, ft	SPD, knots	COMM FQ CHNG	Comment
1117.86						0				
1121.97			1							
1129.98			0							
1133.97		1								
1137.96		0	1							
1145.97			0							
1189.98		1								Descend...FL180, contact Denver approach on 132.5
1192.74				1						
1195.59	1									
1197.03				0						
1197.96		0								
1200.84	0									
1205.97			1						1	
1209.96			0							
1211.85	1									Call to approach...for FL180
1216.41	0									
1217.97		1								...Turn right heading 220°
1221.63	1						20 100	320		
1221.96		0								
1222.95						1				
1223.31	0									
1225.98		1								Do you have current ATIS?
—		0								
1226.97	1									We have November
1229.34	0									
—		1								Disabled aircraft on runway, expect holding at KEANN
1232.37						0				
1236.39	1									
1237.98		0								
1238.67	0									
1241.97		1								
1253.97		0	1							
1257.96		1	0							Can you navigate to KEANN...?
1260.09	1									Affirmative
1262.94	0									
—		0								
—		1								Proceed direct to KEANN, maintain 17 000
1268.04	1									
1269.96		0								
1270.56	0									
1279.62				1						
1283.28				0						
1297.98		1					18 000	292		

Table B1. Continued

Time, sec	CPLT MIKE	CONT MIKE	OAC MIKE	ALT AGCS KNOB	CAS AGCS DIAL	TRCK AGCS DIAL	ALT, ft	SPD, knots	COMM FQ CHNG	Comment
1301.97		0	1							
1305.96			0							
1313.97		1								
1317.96		0	1							
1325.97			0							
1326.33					1		17 000	282		(Copilot: I'll put 250 on the airspeed here)
1331.13					0					
1353.96			1							
1357.98			0							
1361.97		1								Descend...16 000, TL...direct FLOTS
1369.29	1									
1369.98		0								
1375.65	0									
1425.96			1							
1429.98			0							
1431.57						1				
1433.94						0	16 000	258		
1433.97			1							
1437.96			0							
1453.98		1								
1457.97		0	1							
1461.96		1	0							Descend...11 000
1464.12	1									
1465.98		0								
1466.25				1						
1467.37	0									
1471.32				0						
1473.96		1								
1477.98		0	1							
1485.96			0							
1489.98			1							
1493.97			0				15 600	230		
1501.98		1								
1506.21		0								
1514.19		1								Fly heading 190, contact approach on 125.7
1518.21		0								
1518.48	1									
1522.71	0									
1527.15						1				
1531.74						0				
1531.98									1	
1533.24	1									Calls Denver approach control
1537.68	0									No reply from Denver approach

Table B1. Continued

Time, sec	CPLT MIKE	CONT MIKE	OAC MIKE	ALT AGCS KNOB	CAS AGCS DIAL	TRCK AGCS DIAL	ALT, ft	SPD, knots	COMM FQ CHNG	Comment
1548.87	1									Repeats call to Denver approach control
1553.07	0									
1554.21		1								...Descend to 7200 when able reduce to 190 knots
1561.47	1									Roger...Which do you want first?
1562.19		0								
1567.92	0									
—		1								Descent please (recorded on audio tape but did not appear in digital records)
—		0								
1570.53	1						12 700	246		Acknowledgment
1574.85	0									
1578.21			1							
1586.19			0							
1590.21		1								
1598.19		0	1							
1602.21			0							
1606.20		1					11 000	252		
1610.19		0								
1614.21			1							
1617.87				1						
1618.20			0							
1623.63				0						
1634.19		1								
1638.21		0	1							
1642.20			0							
1670.19			1							
1678.20			0							
1682.19		1								
1686.48					1					
1690.20		0	1							
1692.03					0					
1694.19		1	0							TR 230...join localizer...
1696.83	1									
1698.21		0								
1699.83	0									
1708.35					1		7 400	217		
1709.58					0					
1710.21		1								
1714.20		0	1							

Table B1. Concluded

Time, sec	CPLT MIKE	CONT MIKE	OAC MIKE	ALT AGCS KNOB	CAS AGCS DIAL	TRCK AGCS DIAL	ALT, ft	SPD, knots	COMM FQ CHNG	Comment
1718.19		1	0							5 miles from OM...
1722.09	1									
1722.21		0								
1725.42	0									
1730.19		1								If able, maintain 180 knots... until OM. Tower 118.3
1734.21		0								
1734.33	1									Readback error...118.1
1739.28	0									
—		1								(audio recording gives controller correction)
—		0								
1740.78	1									
1742.16	0									
1746.21			1							
1750.20			0							
1774.20			1							
1782.21		1	0							
1786.20		0								
1789.59									1	
1790.31	1						7 071	169		Call to tower
1794.27	0									
1802.19		1								Tower acknowledged... cleared to land...
1802.46					1					
1802.58					0					
1802.79					1					
1802.88					0					
1807.80										Acknowledged
1810.20		0								
1811.04	0						7 049	131		
1818.21			1							
1822.20		1	0							
1826.19		0								
1838.19		1								
1842.21		0	1							
1846.20			0							
1850.19		1								
1854.21		0	1							
1866.21			0							
1874.19		1								
1878.21		0								
1882.20			1							
1886.19			0							
1950.21		1					5 411	135		

Appendix C
Time History of Sample Flight That Used Data Link

This appendix presents a time history of the events that occurred during a simulated flight that used data link as the primary ATC communication mode (table C1).

The column entries include the following: times from the start of the simulated flight (Time), copilot mike switch closures (CPLT MIKE), controller mike switch closures (CONT MIKE), other aircraft (pseudo pilot) mike switch closures (OAC MIKE), altitude autopilot dial movements (ALT AGCS DIAL), airspeed autopilot dial movement (CAS AGCS DIAL), track autopilot dial (TRCK AGCS DIAL), aircraft altitude (ALT), and airspeed (SPD).

In the first five columns that follow the time column, "1" indicates that an input was initiated and "0" indicates that the input process has terminated or the device is no longer activated. In the frequency change column, "1" indicates that a new frequency has been tuned and activated by the flight crew.

Table C1. Time History: Data Link Integrated With FMS

Time, sec	CPLT MIKE	CONT MIKE	OAC MIKE	ALT AGCS KNOB	CAS AGCS DIAL	TRCK AGCS DIAL	ALT, ft	SPD, knots	Comment
0.00							676	0	Main menu
11.82									Touch edit page key
16.65									Touch noncontrol key; edit page
19.17									Touch ATIS
31.38									Touch speak key
60.81									Main menu key; ATIS page
65.31									Edit key; main menu page
68.64									Strategic key; edit page
73.68									Request clearance key; edit strategic page
76.02									Send key; edit strategic page
176.04									MSSG: Clearance to Denver
195.27									Roger
199.58									Auto route key
230.19									Main menu key
233.64									Edit key: main menu
236.04									MSSG: contact tower...
238.62									Noncontrol key: edit menu
243.81									ATIS key: noncontrol page
246.99									Roger
266.88									Main menu key
267.75			1						
273.93	1								
274.86	0								
275.25			0						
280.68	1								
282.75	0								
294.45									Map scale change to 1 n.mi./in.
296.58	1								
298.44									Map scale set to 4 n.mi./in.
298.86	0								
301.50		1							
305.25		0							

Table C1. Continued

Time, sec	CPLT MIKE	CONT MIKE	OAC MIKE	ALT AGCS KNOB	CAS AGCS DIAL	TRCK AGCS DIAL	ALT, ft	SPD, knots	Comment
308.76									MSSG: taxi into position and hold
316.77									Roger
331.26									MSSG: ...cleared to takeoff
339.93									Roger
357.75			1				676	43	
365.25		1	0						
369.00		0					676	91	
410.25			1						
412.62					1				
413.82					0				
414.00			1				1 536	197	
421.76									MSSG: contact departure on 125.40
425.37									Roger reply
427.05									Radio autotune key
432.75			1						
440.25		1	0						
444.00		0							
449.73				1					
462.75		1							
466.50		0							
467.70				0					
521.34						1			
530.22						0			
533.76									MSSG: fly heading 300°
545.49									Roger
552.75		1							
556.50		1							
559.02						1			
575.25			1						
581.67						0	10 000	260	
582.75			0						
586.50		1							
590.25		0							
622.53									Scroll up upper window
626.67							12 000	306	Scroll down upper window
642.33						1			
642.75			1						
643.05						0			
646.49									MSSG: contact Chicago Center on 132.75
646.50			0						
650.79									Roger
653.49									Radio autotune key
657.57	1								
661.11	0								
665.25			1						
669.00			0						
677.34	1								

Table C1. Continued

Time, sec	CPLT MIKE	CONT MIKE	OAC MIKE	ALT AGCS KNOB	CAS AGCS DIAL	TRCK AGCS DIAL	ALT, ft	SPD, knots	Comment
681.36	0								
684.00		1							
687.75		0							
691.50			1						
695.25			0						
699.00		1							
702.75		0							
710.25			1						
717.75	1		0						
721.50			1						
729.00			0						
736.50			1						
744.00			0						
747.75		1							
751.50		0					18 000	306	
766.50			1						
774.00		1	0						
777.75		0							
796.26									MSSG: Contact Minneapolis Center
804.00			1						
804.72									Roger
808.17									Radio autotune key
811.50			0						
815.25		1							
821.97	1								
822.75		0							
827.10	1								
834.00			1						
841.50		1	0						
852.75			1						
860.25			0						
886.50			1						
897.75		1	0						
901.50		0							
927.75			1						
931.50			0						
935.25		1							
939.00		0	1						
942.75			0						
950.46									Roger touch key
976.26									MSSG: contact Denver Center
984.00			1						
984.21									Roger
988.53									Radio autotune key
991.50			0				26 000	303	

Table C1. Continued

Time, sec	CPLT MIKE	CONT MIKE	OAC MIKE	ALT AGCS KNOB	CAS AGCS DIAL	TRCK AGCS DIAL	ALT, ft	SPD, knots	Comment
992.10	1								
997.80	0								
1002.75		1							
1007.43	1								
1008.63	0								
1012.41	1						26 000	303	
1014.00		0							
1015.05	0								
1017.75			1						
1025.25			0						
1032.51									MSSG: SIGMET...
1036.50		1							
1040.25		0							
1044.06									Roger
1066.50		1							
1070.01									MSSG: expect delays...weather
1070.25		0							
1076.91									Roger touch key
1081.50			1						
1100.91			0	1					
1103.40				0					
1108.74									ALT key
1119.00		1							
1122.75		0							
1126.26									MSSG: cleared for profile descent
1134.30									Roger
1144.86				1					
1150.95				0					
1163.76									MSSG: reroute for weather
1178.52									Roger
1182.75			1						
1190.25			0						
1197.60									Map scale change
1206.33							26 000	295	Route auto data entry key
1209.00			1						
1212.75			0						
1216.50		1							
1220.25		0							
1265.25			1						
1272.75		1	0				23 000	300	
1276.50		0							
1302.75			1						
1310.25			0						
1317.75			1						
1325.25			0						
1336.26									MSSG: contact Denver approach on 120.50
1341.60									Roger
1346.94									Radio autotune key

Table C1. Continued

Time, sec	CPLT MIKE	CONT MIKE	OAC MIKE	ALT AGCS KNOB	CAS AGCS DIAL	TRCK AGCS DIAL	ALT, ft	SPD, knots	Comment
1355.25			1						
1359.00			0						
1362.75		1							
1366.50		0							
1374.69	1								
1380.18	0								
1381.50		1							
1385.25		0							
1392.75		1							
1396.50		0							
1397.01					1				
1400.10							17 000	300	MSSG: traffic is light...
1408.02									Roger
1412.40			1		0				
1415.25			0						
1419.00		1							
1422.75		0							
1458.39				1					
1460.25		1							
1464.00		0					17 000	246	
1469.07				0					
1677.51									MSSG: descend and maintain 7200
1682.22									Roger
1501.50			1						
1509.00			0						
1539.00			1						
1542.75			0						
1576.26									MSSG: reduce to 230...headway 190°
1583.22									Roger
1591.41									Speed auto key
1594.38									HDG auto key
1628.76									MSSG: contact approach...
1634.49									Roger
1637.19									Radio autotune key
1644.00			1						
1647.75			0						
1652.19	1								
1657.05	0								
1659.00		1							
1662.75		0							
1677.75			1						
1681.50			0						
1730.25			1						
1737.75		1	0						
1741.50		0							
1756.50			1						

Table C1. Concluded

Time, sec	CPLT MIKE	CONT MIKE	OAC MIKE	ALT AGCS KNOB	CAS AGCS DIAL	TRCK AGCS DIAL	ALT, ft	SPD, knots	Comment
1764.00		1	0						
1767.75		0							
1786.50			1						
1794.00		1	0				7797	217	
1797.51									MSSG: ...TR heading 230°...cleared 26L
1797.75		0							
1802.01									Roger
1810.17									Heading touch key
1854.00		1							
1857.75		0							
1872.75			1						
1880.25		1	0						
1884.00		0	1						
1887.75			0						
1898.76									MSSG: contact tower on 118.30
1903.08									Roger
1903.86									Radio autotune key
1907.73	1								
1911.12	0								
1942.05	1								
1946.10	0								
1947.75		1							
1948.50						1			
1950.03						0			
1951.50		0	1						
1955.25		1	0						
1959.00		0							
1966.26									MSSG: ...cleared to land
1970.25			1						
1971.42									Roger
1977.75		1	0				6619	137	
1981.50		0							
2007.75			1						
2015.25		1	0						
2019.00		0							
2045.25			1						
2049.00		1	0						
2052.75		0							
2094.00			1						
2101.50		1	0						
2105.25		0							

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Table 1. Simulation Study of Data Link Messages

Messages	Comments
(Blanks (_ _ _ _) embedded in the messages indicate data to be typed by the air traffic controller.)	*(An explanation of selected messages and abbreviations is provided so that the reader can extend interpretation to other messages.)*
ATIS: ORD DEP INFO F 1745Z WX: 30 OVC 5R-78/70 260/10 2998 DEP RWYS 27L & 32L NOTAM: TXWAY 1 CLSD	ATIS information Foxtrot: 1745 Zulu Weather: 30 ft ceiling, overcast, visibility miles, light rain showers, temperature 78°F, dew point 70, winds from 260° at 10 knots. Altimeter 2998 departure runways 27 left and 32 left. Notice to Airmen: taxiway 1 closed.
ATC: CLRD TO DEN VIA ORD7 DEP.IOW.DSM.J10, MAINT _ _ _ _, DEP FREQ 125.40, SQWK 4614	Cleared to Denver via Chicago Departure 7 to Dubuque VOR, then as filed. Maintain (altitude). Departure frequency 125.40. Squawk 4416.
ATC: CLRD TO DEN VIA ORD7 DEP.DBQ THEN AS FILED, MAINT _ _ _ _, DEP FREQ 125.40, SQWK 4416	
ATC: CLRD TO DEN VIA ORD7 DEP.DBQ.J94.ONL. J114, MAINT _ _ _ _, DEP FREQ 125.40, SQWK 4164	
ATC: CLRD TO DEN VIA DIRECT DBQ.J100.OBH.J10, CLMB & MAINT	Cleared to Denver via Direct Dubuque VOR, J100 to Wabash VOR, J10. Climb and maintain (altitude).
ATC: CHANGE TO CLRNC-CLRD TO DEN VIA DIRECT DBQ.J94.ONL.J114, CLMB & MAINT_ _ _ _	Change to clearance...
ATC: CNTC TOWR 118.10 FOR DEP	Contact tower 118.10 for departure.
ATC: TAXI INTO POSIT & HOLD	
ATC: RNWY 32L, CLRD FOR TAKEOFF	
ATC: CNTC DPTURE 125.40	
ATC: RADAR CONTACT, CLMB & MAINT_ _ _ _	

Table 1. Continued

Messages	Comments
ATC: CNTC CHICAGO CENTER, 132.75	
ATC: CNTC MINNEAPOLIS CENTER, 133.55	
ATC: CNTC DENVER CENTER, 135.20	
ATIS: DEN ARR INFO K 1800Z WX: 15 BKN 45 OVC 6RW 77/76 290/20 2997 EXPCT PRFL DSCNT AND VECTRS ILS RWY 26L	
ATIS: DEN ARR INFO L 1800Z WX: 11 BKN 28 BKN 7 76/68 260/10 2994 EXPCT VECTRS ILS 26L. NOTAM: TXWAY F CLSD	Denver arrival information Lima: 1800 Zulu. Weather: 1100 broken, 2800 broken, visibility 7 miles, temperature 76°F, dew point 68, winds from 260° at 10 knots. Altimeter 2994. Expect vectors to ILS runway 26 left. Notice to Airmen: taxiway Foxtrot closed.
ATIS: DENN ARR INFO N 1900Z WX: 8 SCT 12 BKN 20 OVC 7 77/67 270/15 2999	
ATC: DSCND & MAINT _ _ _ _, THEN RDC TO _ _ _ _KTS	Descend and maintain (altitude). Then reduce to (speed) knots.
EXPCT VECTRS ILS RWY 26L	
ATC: CNTC CENTER, 125.95	
ATC: SIGMET GOLF 7 LOCALIZED T-STORMS BETWEEN 30NM and 60NM NE OF DEN	
ATC: ACFT INBND TO DEN FROM THE NE–EXPCT DELAYS DUE TO WEATHER	Aircraft inbound to Denver from the northeast, expect delays due to weather.
ATC: CLRD PRFL DSCNT, DEN ALTMTR _ _ _ _	
ATC: CROSS KEANN AT OR BELOW _ _ _ _, DSCND & MAINT _ _ _ _	

Table 1. Continued

Messages	Comments
ATC: HOLD AT SMITY INTXN AS PUBLSD, 15 MI LEGS. MAINT _ _ _ _, EFC AT _ _ _ _Z.	Hold at the SMITY intersection as published. 15 mile legs. Maintain (altitude). Expect further clearance at (time) Zulu.
ATC: TURN INBND TO SMITY NOW, CONTINUE PRFL DSCNT, DSCND & MAINT _ _ _ _	
ATC: CLRD INBND TO DEN DSCND & MAINT _ _ _ _	
ATC: ACFT INBND TO DEN FROM THE NE–DELAYS NO LONGER EXPECTED	
ATC: IF ABLE MAINT _ _ _ _KTS FOR IN TRAIL SPACING	
ATC: EXPCT VECTRS SOUTHEAST OF ROUTE IN 15NM FOR WEATHER	
ATC: TL HDG _ _ _ _. VECTRS AROUND WEATHER	Turn left (heading in degrees). Vectors around weather.
ATC: TR HDG _ _ _ _. JOIN THE DEN046R	
ATC: REROUTE FOR WX–CLEARED TO DEN VIA SMITY PPT01 KEANN FLOTS DEN	
ATC: EXPCT POSSIBLE VECTRS FOR WEATHER IN 20NM	
ATC: WEATHER DOES NOT APPEAR TO BE A FACTOR	
ATC: CNTC DENVER APRCH, 120.50	
ATC: TRAFFIC IN THIS SECTOR IS LIGHT	
ATC: TRAFFIC IN THIS SECTOR IS MODERATE	
ATC: TRAFFIC IN THIS SECTOR IS HEAVY	

Table 1. Continued

Messages	Comments
ATC: CNTC APRCH, 125.70	
ATC: RDC TO _ _ _ _KTS, DEPART FLOTS HDG _ _ _ _, VECTRS ILS RWY 26L	
ATC: RDC TO 160 KTS, TR HDG _ _ _ _, DSCND & MAINT 7200	
ATC: _ _ _ _MI FRM ALTUR, TR HDG _ _ _ _, MAINT 7200 UNTIL ESTAB ON LOC, CLRD ILS 26L APRCH	
ATC: _ _ _ _MI FRM ALTUR, TR HDG _ _ _ _, MAINT 7200 UNTIL ESTAB ON LOC, CLRD ILS 26L APRCH	
ATC: RDC TO APRCH SPEED	
ATC: CNTC DENVER TOWR 118.30	
ATC: WIND 270/10, CLRD TO LAND	
ATC: WHEN ABLE, TR CNTC GROUND 121.90	
ATC: ROGER	
ATC: RDC TO _ _ _ _KTS	
ATC: INC TO _ _ _ _KTS	
ATC: CLMB & MAINT _ _ _ _	
ATC: TL HDG _ _ _ _	Turn left heading (direction in degrees).
ATC: TR HDG _ _ _ _	Turn right heading (direction in degrees).
ATC: FLY HDG _ _ _ _	
ATC: VERIFY ALTITUDE	

Table 1. Concluded

Messages	Comments
ATC: TRAFFIC _ _ _ _O'CLOCK, _ _ _ _MI SOUTHBOUND, ALTITUDE UNKNOWN	
ATC: ALTIMETER _ _ _ _	
ATC: UNABLE TO APPRV	
ATC: DSRGD LAST MSSG	Disregard last message.
ATC: AFFIRMATIVE	
ATC: NEGATIVE	

L-90-14721

Figure 1. Transport Systems Research Vehicle Simulator.

(a) Primary flight display.

(b) Navigation display (ND).

Figure 2. Electronic flight instrument system.

L-87-9156

Figure 3. Mode control panel.

Figure 4. Display format of three-window data link interface.

(a) Chicago to Denver routes.

(b) Denver Center and terminal airspace.

(c) Nominal descent and approach path. (Altitudes are in feet.)

Figure 5. Simulated flight routes and airspace.

(a) Conventional voice radio.

(b) Data link integrated with AGCS.

Figure 6. Examples of altitude assignment.

(a) Conventional voice radio.

(b) Data link integrated with AGCS.

Figure 7. Examples of heading assignment.

(a) Conventional voice radio.

(b) Data link integrated with AGCS.

Figure 8. Examples of airspeed instruction.

(a) Conventional voice radio.

(b) Data link integrated with autotune radio feature.

Figure 9. Examples of radio frequency assignment.

(a) Conventional voice and manual data input. Mean = 16.80 sec; Standard deviation = 6.20 sec; Count = 56.

(b) Data link and automatic data entry into subsystems. Mean = 12.50 sec; Standard deviation = 3.39 sec; Count = 73.

Figure 10. Distribution of data management times.