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A Piloted Simulation Study of Data Link ATC Message Exchange

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Summary

Digital data link air traffic control (ATC) and air traffic service message and data exchange offers the potential benefits of increased flight safety and efficiency by reducing communication errors and allowing more information to be transferred between aircraft and ground facilities. Digital communication also presents an opportunity to relieve the overloading of ATC radio frequencies, which hampers message exchange during peak traffic hours in many busy terminal areas.

A piloted-simulation study to develop pilot factor guidelines and assess potential flight crew benefits and liabilities from using data link ATC message exchange has been completed on the NASA Langley Transport Systems Research Vehicle simulator. The data link ATC message exchange concept, implemented on an existing navigation computer control display unit (CDU) in this advanced flight deck simulator, required maintaining a voice radiotelephone link with an appropriate ATC facility as a part of the operational protocol. Pilot and copilot comments and scanning behavior, and measurements of time spent in ATC communication activities for data link ATC message exchange were compared with similar measurements made during simulated conventional voice radio operations. The results show crew preference for the quieter flight deck environment and a perception of lower communication workload. Based on the test results, some suggested guidelines addressing flight crew information requirements are presented.

Introduction

Digital data link air traffic control (ATC) and air traffic service message and data exchange offers the potential benefits of increased flight safety and efficiency by reducing communication errors and allowing more information to be transferred between aircraft and ground facilities. Digital communication also presents an opportunity to relieve the overloading of ATC radio frequencies, which hampers message exchange during peak traffic hours in many busy terminal areas.

Exchange of information and messages by digital data link is likely to become a more frequent means of air-ground communication in future aircraft operations. Several data link facilities for aeronautical use, including the Mode S data link incorporated in the upgraded radar surveillance system (part of the Federal Aviation Administration's National Airspace System plan), satellite data links such as AvSat (ref. 1), and an upgraded ACARS (Aeronautical Radio Incorporated (ARINC) Communications Addressing and Reporting System), are either operational or expected to become operational within the next few years. The possibility of transmitting air traffic control messages over such a data link offers an opportunity to reduce voice radio channel clutter, which hampers air-ground ATC message exchange in many busy terminal areas. Also, data link ATC message exchange could possibly enhance system safety and efficiency and reduce flight crew workload. Reference 2 cites several examples of ATC system safety violations resulting from misunderstood communications over the voice radio system. Digital data and message exchange using discrete aircraft addressing could reduce this problem.

The overall goal of the subject research at Langley is to develop an information and technology data base applicable to deriving guidelines for the user data link interface hardware and software.

Consideration was given to the findings of earlier related research in developing the present study. The FAA published a study in 1975 that investigated several parameters affecting data link ATC message exchange in the flight deck and provided strong evidence of its feasibility from the aircrew's vantage point (ref. 3). The feasibility and desirability in a single-pilot operation was demonstrated in a study sponsored by Langley in 1982 (ref. 4). A recently completed study, also sponsored by Langley, developed a data link message exchange concept applicable to a wide range of present-day transport flight regimes (ref. 5). That concept addresses air traffic control and air traffic service message exchange by digital data link used in conjunction with conventional voice radiotelephone operations. Reference 6 presents the results of a general aviation, single-pilot, data link ATC message exchange study completed on a Langley simulator.

None of the previously published studies have tested an ATC message exchange concept, in a realistic representation of an ATC environment, using flight deck interface technology of the type available in modern aircraft. The objective of the present study was to compare data link and conventional voice ATC message exchange and to make an initial assessment of potential data link operational benefits and liabilities from the flight deck perspective. This objective included determining preliminary guidelines for using data link ATC message exchange, such as which message types are suitable for data link operations. A baseline concept that could be conveniently implemented on an existing simulation facility was assumed. This concept incorporated several features proposed in reference 5, including establishing and maintaining a voice radiotelephone link with an appropriate ATC facility, presenting a summary of ATC clearances on a separate page for quick reference, and presenting Automatic Terminal Information Service (ATIS) reports in a data link format. The concept also included visual and aural alerting of the flight deck crew upon arrival of new messages and a two-keystroke reply capability.

Abbreviations

ACARS	ARINC Communications Addressing and Reporting System
ARINC	Aeronautical Radio Incorporated
ATC	air traffic control
ATIS	Automatic Terminal Information Service
CDU	control display unit
CRT	cathode-ray tube
ENT	enter
FAA	Federal Aviation Administration
IFR	Instrument Flight Rules
IVSI	instantaneous vertical speed indicator
MSSG	message
NASA	National Aeronautics and Space Administration
NAV DATA	navigation data
ND	navigation display
NM	nautical mile
PFD	primary flight display
PMC	panel-mounted controller
PPI	plan position indicator
ROG	roger
TSRV	Transport Systems Research Vehicle
UNA	unable

Simulator Description

This study was conducted on the Transport Systems Research Vehicle (TSRV) simulator shown in figure 1. This fixed-based simulation facility is controlled through the Langley central digital computing system operating in a real-time mode with computations updated 32 times per second. The airplane model represented a two-engine, commercial class jet transport. The flight deck layout (fig. 1) was a two-crew-member arrangement with similar instrumentation in both flight stations. No out-of-the-window visual scene was used.

Flight Instruments

The flight instruments in both the right and the left 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). Electronic CRT displays of engine status were presented on a center instrument panel. A navigation computer control display unit (CDU), consisting of a CRT and a keyboard, was located at each flight station. Although normally used for interfacing with the flight management computer, the CDU's were adapted for the additional function of providing the flight crew interface with the data link communication channel for ATC message exchange.

Primary flight display. Figure 2 presents a drawing of the PFD with the symbols labeled. Graphic representation of localizer deviation, glide slope deviation, airspeed deviation from a reference value, and aircraft attitude are presented. Also, a scaled perspective runway is presented as the simulated aircraft nears landing.

The flight path angle wedges presented the inertia flight path angle of the airplane as vertical displacement from the artificial horizon, and drift angle as lateral displacement from the attitude symbol. The flight path angle reference wedges presented a display of the flight path angle that the control system was attempting to capture and maintain as a result of pilot control inputs. The flight path angle wedges and flight path angle reference wedges complemented the capabilities of the velocity vector control-wheel-steering control mode of the modeled airplane.

Navigation display (ND). The navigation display, an electronic CRT instrument illustrated in figure 3, presented lateral path information in a dynamic map configuration with aircraft track up. The map scale was individually selectable at each flight deck station, with values of 1, 2, 4, 8, and 32 n.mi./in. available. The apex of the 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 magnetic track of the aircraft. The straight trend vector extending from the apex of the aircraft symbol indicated the path the airplane would follow if its current track was maintained.

The planned flight path was displayed on the map as a series of connected straight and curved line segments with each way point represented by a four-pointed star symbol and an alphanumeric name. The flight plan data were assumed to have been entered into the navigation computer by the crew before the flight, but were actually fixed in the software that supported this simulation.

Flight Controls

The flight controls included a pair of panel mounted controllers (PMC's) at both flight deck stations; the PMC's extended from the instrument panel and functioned as an adaptation of the conventional wheel and column arrangement. A thumb switch on one of the two PMC's at each station allowed small commanded flight path angle changes. Throttle control levers were located on the center console between the two flight stations along with the flap control lever and the speed brake lever. The landing gear control extended from the center instrument panel, and the rudder pedals with toe brakes were active.

The nominal control mode used during this study, velocity vector control wheel steering, provided highly augmented longitudinal and lateral control with pilot manual control inputs made through the PMC's. In the longitudinal axis, pilot inputs controlled rate of change of commanded flight path angle. In the lateral axis, pilot control inputs commanded rate of change of bank angle. The lateral-axis flight control system maintained track angle if the control input was removed with a bank angle of less than 5°, and maintained bank angle if the input was removed with a bank angle greater than 5°. Both autothrottle and manual throttle capabilities were available during the entire scenario; however, the pilots generally used the autothrottle.

Data Link Message Exchange Concept

For this study, messages were formatted so that they could be presented on the six lines of the CDU available for message display. The study concentrated only on crew and flight deck issues; therefore, issues related to composing and transmitting these messages from the ATC station were beyond the scope of the present study. Since the flight scenarios used were limited to a descent into the Denver Stapleton terminal area from the northeast following a standard route, a limited set of clearances and advisories, presented in table I(a) along with brief explanations, was selected. Also, three Automatic Terminal Information Service (ATIS) reports were used and are presented in table I(b). In developing the subject message exchange concept an attempt was made to adhere as closely as reasonable to current ATC practices, with the obvious exception of employing digital ATC message exchange. Significant features of the message exchange concept included a message page, an ATIS page, and a clearance summary page.

Another element of the subject data link message exchange concept was that continuous voice radio contact was maintained between the crew and the controller, as is the case in current flight operations. Voice radio control-sector check in on hand-off or initial entry into a sector would remain a requirement under the subject concept. In addition to providing a backup to the data link in the event of a malfunction, urgent or time-critical messages could require the use of the voice channel because of expected data link message delivery delays. Less routine message changes and aircrew-controller negotiations could also be conducted over the voice radio.

Flight Deck Data Link Interface

The control display units (CDU's), nominally the flight crew's interface with the navigation and control computer, were adapted to provide the crew's data link interface. A separate unit at each of the two flight stations consisted of a 4 1/4- by 3 1/4-in. CRT and a 7- by 7-key, backlighted array (fig. 4). The units at the two flight stations were slaved together and, depending on the positions of crew-operated switches on the two units, only one keyboard could be active at a time. Although several keyboard modifications, including the addition of ATC-related symbols and character strings, were made to the CDU for possible use in the message exchange process, only a few were actually used in the subject tests: a roger (ROG) was added to the "6" key, an unable (UNA) was added to the "0" key, and a message (MSSG) page was given a CDU page selection key location of its own on the bottom row of keys. Also, the page selection function of the key labeled "NAV DATA" was modified to make the first page selected by depressing it the ATC clearance summary page, and the second, the ATIS report page. Subsequent pages selected by repeatedly depressing the NAV DATA key were the normal navigation data pages opened by that key, with circular return to the first page. A shift key (not visible in fig. 4), functional only when the message page was selected, was mounted on the side of each CDU and enabled typing individual alphanumeric characters.

The CRT of the control display unit had 8 lines with 24 character positions in each. When used in the data link mode, with the message page selected, the first line was used to label the page "MESSAGE." The next six lines were used to present messages, and the eighth line, at the bottom of the CRT, was a scratch pad line that echoed characters and symbols as they were keyed in by the crew.

The ROG (roger) and UNA (unable) keys had a special feature when activated with the CDU cursor in the first column of the scratch pad line; the echoed string (characters displayed in response to depressing the key) was "ATC: ROGER xx" or "ATC: UNABLE xx," accepting or rejecting a message with flight deck local numbering xx. Activating these keys with the cursor display in columns 2 to 22 generated only the character strings ROG and UNA, respectively.

Incoming messages were printed below the previous message, with a one-line margin between it and the previous message, or on the second line of the CRT when there were no previous messages. When the page was filled down to the scratch pad line, previous messages were automatically scrolled up to make space for new messages. Displayed messages could also be scrolled manually by activating the UP and DOWN keys located in the upper right portion of the keyboard. A single keystroke moved an entire message onto or off the display, whether it was single lined or multilined in composition, and appropriately repositioned adjacent messages.

A scratch pad line was used to compose single-line messages (fig. 4). These messages could then be transmitted over the simulated data link to the appropriate destination indicated by the first three characters of the message field, ATC in the example shown in figure 4. Depressing the ENT (enter) key in the upper left corner of the keyboard dispatched the message to its destination and cleared the scratch pad line. In concept, messages could be dispatched to the airline company, air traffic services, and ATC. However, only the ATC station destination was actually used in this study. Messages composed in the cockpit were limited to one 24-character scratch pad line.

Message Page

A single page of the CDU was used to display tactical messages received from the air traffic controller. This page, an example of which is shown in figure 4, could be viewed by the crew any time during the simulated flight. If a page other than the message page was being displayed when an ATC message was uplinked, the crew was required to manually select the message page to view that message. If the message page was already selected, the incoming message was displayed immediately. Selecting the message page was also necessary in order to compose and dispatch messages, including roger and unable responses, to the ATC station.

Uplinked messages used in this study were formatted similarly to standard practices used in current voice radio ATC communications. The downlinked reply consisted of a "roger" or "unable" and a playback of the message. The method of generating such a reply with two keystrokes was described in a previous section. An example of a roger reply is shown in the scratch pad line of figure 4.

Message Alerting

When a new message was received in the flight deck, a visual and an aural signal alerted the crew. The visual alert consisted of the characters "MSSG" flashing in the centers of the PFD and the ND at both flight stations (fig. 5). When the message was routine in nature, the alphanumeric MSSG presentation was amber, while for time-critical messages, requiring the crew's immediate attention, the MSSG flashed in red. In either case, the alerting signal continued flashing until the MSSG key on the bottom row of the CDU keyboard was depressed or a roger or unable message was transmitted to the ATC station by depressing the appropriate CDU keys. The aural alerting tone, signaling arrival of a new message into the flight deck, was a 230 Hz buzz that sounded once for 2 sec when a routine message was received and repeated every 3 sec with the flashing red MSSG signal for urgent messages.

ATC Clearance Summary Page

The tactical ATC clearances were presented in a summary format on a separate page labeled "ATC Clearance." Figure 6 presents an example of that page, which includes current route, altitude, airspeed, heading, and radio frequency clearances. This page could be displayed at the crew's command by depressing a single key on the keyboard of the CDU and was intended to provide a quick reference for the crew. The displayed information was automatically updated whenever a new clearance was issued over the data link and a roger response was downlinked.

ATIS Page

The Automatic Terminal Information Service (ATIS) report was available on a separate page of the CDU and could be displayed at the aircrew's command. Figure 7 presents an example, information November (N), displayed on the CDU. An ATIS message was transmitted to the flight deck at the start of each simulated descent and could be reviewed at the crew's convenience. Since present-day protocol was adhered to where practical, the crew was required to report having the current ATIS when checking into the first approach sector by voice radio.

Test Procedure

Each run consisted of a simulated descent into the Denver Stapleton terminal area from the northeast, initiated at the SMITY intersection approximately 60 miles from the airport, straight and level at flight level 260 (FL260), and 280 knots indicated airspeed. The flight conditions were instrument meteorological conditions in smooth air with no out-of-the-window visual scene provided. Figure 8 presents a perspective view of the nominal descent and approach route used to the simulated runway 26L. The approach route involved several ATC jurisdictions: Denver Center, Denver Approach Control, and Denver Tower. The simulated flights were terminated at touchdown except when a go-around procedure was required. These runs were terminated approximately 45 sec after the go-around instruction was received in the flight deck. Each run required approximately 15 min for completion.

Nine pilots with a wide range of experience participated in the tests: three airline pilots, four U.S. Air Force pilots, and two NASA test pilots. Table II presents a coded list of these pilots along with their respective number of flight hours and aircraft types. Also a NASA engineer with piloting experience, on whom data were not taken, assisted as the second crew member with pilot P9. The pilots were paired, and the same pair worked together as a crew throughout the entire set of tests, alternating roles as pilot and copilot. The simulation testings comprised a total of 60 data runs with each of the 10 pilots performing 3 replications in each of 2 modes, voice and data link. When adjusted for the pilot who was not a subject, the test matrix consisted of 54 runs (9 subjects by 2 conditions by 3 replications). Each run (except when the "fill-in" pilot was used) generated a set of data taken on the pilot and a set taken on the copilot. One voice radio message, "Depart FLOTS heading xxx," was included in each data link run to test the acceptability of mixing voice and data link exchanges for traffic control operations.

Before the start of the tests, each crew was briefed on the operation of the simulator, including the radios, data link interface, operational protocols, and the control system and instruments. The crew was then allowed to practice on the simulator until they became comfortable with its operation. The time required for familiarization varied from 1 to 8 hr of operation per crew, depending on the background of the pilots and their previous experience with the TSRV simulator.

The pilot was in command and actively controlled the simulated transport airplane while the copilot handled the communication task and other conventional duties such as instrument cross-checks and call outs. This terminology, "pilot" and "copilot," will be used throughout the remainder of this report.

At the end of the tests, the subjects completed a debriefing form consisting of 24 questions and space for comments (appendix A). Comments were also recorded during the sessions and during informal debriefing sessions after the testing of each crew.

Results

Subjective Evaluations

The pilots were asked on the debriefing questionnaires to evaluate the overall acceptability of the data link ATC message exchange operation. The possible responses were (a) very acceptable, (b) somewhat acceptable, (c) neutral, (d) somewhat objectionable, and (e) very objectionable. The responses split between the very acceptable and somewhat acceptable evaluations. All the subjects indicated in written or oral comments that the data link message exchange capability was a beneficial addition. The data link capability greatly reduced voice channel activity, and the crew was unaware of data link messages going to other aircraft. The number of ATC voice messages to other aircraft was reduced and consequently the communication workload associated with monitoring voice radio messages for their own call sign was reduced. The crews applauded the resulting quiet flight deck environment. Their comments regarding the CRT alphanumeric display of uplinked routine ATC clearance messages were very favorable. They cited the availability of the alphanumeric displayed messages for review and the obviated need to take notes. The crew members expressed increased confidence in message accuracy as compared with having to listen and understand in real time in the voice case. Although data link messages were displayed at both flight deck stations, the pilots indicated that they preferred that the copilot read all incoming messages aloud. Even though this was done, scanning behavior measurements, which will be discussed below, indicated that pilots spent significant time looking at the messages.

Party line effect. The party line effect is the ability of all users of a particular ATC frequency to overhear messages intended for other users. It is commonly used by pilots to acquire information on the environment in which they are operating. Several pilots commented on the reduced party line effect in the data link environment. In particular, they indicated that their ability to plan ahead for absorbing delays, as an example, would possibly be diminished in a data link environment. The substance of the comments appeared to be that the crews wanted to retain a capability to receive traffic density and possible delay information for planning purposes, information currently gleaned from the party line capability in voice radio operations.

Several pilots also stated that in the voice radio case they heard the controller's conversation with other aircraft and received lead information that a "go around" or other critical situation was developing. This was true to a lesser extent in the data link cases, since there was reduced communication activity on the voice radio frequency.

They indicated some additional concern about the loss of information on the location of other traffic in the sector and their diminished ability to cross-check ATC clearances for separation assurance. Comments also indicated a desire of the crews to know how busy the sector controller was. In spite of these concerns, the crew members indicated a strong preference for the quiet flight deck environment of the data link message exchange operation and stated that they were not certain that the party line benefits were as important to them. It is recognized, however, that these tests included limited operational conditions and more extensive testing could be beneficial.

Hard copy printer. The subjects were asked if they felt that a hard copy printer would be a beneficial addition to the data link interface. Although the subjects liked the CRT presentation of incoming data link messages, the debriefing responses indicated that they were split on the question of whether they preferred the addition of a printer to the operation. The reason for the split was not clear; however, one of the subjects who had responded that a printer was needed, when questioned in more detail, indicated that he had forgotten about the message review capability of the CDU.

Other factors are important however. The CDU is a multifunction device in the subject simulator flight deck. Although used as the interface for data link ATC message exchange, it is also the crew's interface with the flight management computer. If a crew member wanted to use the flight plan information received from ATC by data link to manually modify flight management data in the computer, it is quite likely that he would want to print the information from the ATC message page for reference before changing the CDU to the appropriate flight management data page. Another consideration is that the viewing position of the CRT is fixed. If a pilot is performing a primary task such as heads-up flying or monitoring flight instruments, he will frequently prefer to move information he has to read into the vicinity of the visual field of his primary task rather than having to shift his vision back and forth over relatively large distances.

Information not appropriate for data link exchange. Several questions on the debriefing form addressed the issue of which information should be presented on the data link and which should be transmitted by voice radio. All the subjects expressed a high degree of satisfaction with routine messages such as "Turn left heading 270" or "Cleared to land runway 26L" being transmitted over the data link. The required two keystroke response presented no problem. Having these messages displayed on the CRT for viewing at their own convenience was a favorable feature in the data link operation.

When the subjects were asked about the use of data link for priority or time-critical messages in the manner implemented in these tests, all responded that this was an unacceptable operation. They preferred to have such messages transmitted over the voice radio and expressed doubt about whether the air traffic controller could input urgent messages in an alphanumeric form in a timely manner. In addition, they expressed concern over whether the crew could, or would, read such messages immediately. The majority opinion was that priority messages should be annunciated over the voice radio and data linked for alphanumeric display. However, some question was raised by the pilots regarding the wisdom of using both modes simultaneously, a procedure that was used with half the data link priority message transmissions in this study. Some pilots reported responding to the directives of the priority voice radio messages while wondering whether the incoming data link message, which they had not yet read, contained the same clearance.

Four elements of voice radio transmission of priority messages were highlighted as favorable features: (a) crew confidence in timely message dispatching, (b) real time transmission with no transmission delay, (c) aural message annunciation, and (d) party line-derived lead information. The subjects expressed lack of confidence as to whether these qualities could be included in a data link message exchange operation without using voice radio for highly time-critical transmissions.

ATIS report. The subjects were asked about their preference for transmission of the arrival ATIS information. All but two of the subjects stated that the data link ATIS presented in alphanumeric form on the CRT was highly preferred over the conventional voice radio transmission. One of the two dissenters, who had approximately 1000 flight hours, stated that he was indifferent and saw no particular advantages to the data-linked report. The second dissenter was a subject with more than 8000 flight hours who commented that he somewhat preferred the conventional recorded-voice ATIS report. This subject commented that he had some difficulty understanding the printed ATIS messages, in particular the abbreviations used. He also stated that additional experience with the formats and abbreviations might change his preference.

Workload perception. When the subjects were asked about their perception of the impact of the data link ATC message exchange on workload when operating in the copilot role, and therefore handling the ATC communications, they reported significantly lower communication task workload and generally a reduction in overall workload. The subjects were generally in good agreement on this point.

In the pilot role, however, the subjects gave a mixed response on the workload questions. Several subjects pointed out that in the data link case their eyes were distracted from the primary task of flying the airplane, and therefore they felt that their communication and overall workloads were somewhat higher with the printed messages displayed on the CRT. These pilots stated that when actively flying the airplane they preferred having the ATC messages aurally annunciated. Several other pilots expressed an exact opposite opinion, preferring the data link presentation even when actively flying.

In considering these opposing responses in some detail, there was clear evidence that piloting experience level was a determinant as to which pilots, when actively flying, judged the workload was higher or lower with the data link ATC message exchange operations. The high-time pilots felt that overall and communication workloads were lower when using the data link message exchange. The low-time pilots invariably expressed an opposite opinion. It is emphasized that the subjects who judged that their workload was increased by the data link message exchange stated that the reason was increased demands on their visual attention.

Tactical ATC clearance page. This page was not given a significant amount of use by the subjects during these tests. Some of the subjects did not respond to the questions about this feature of the interface, possibly indicating that they had forgotten about it. Two subjects suggested that this page might be a more useful feature if it were continuously displayed as a window in one of the CRT's available in the cockpit so that it could be viewed without requiring the crew to change the CDU page.

Another element of the flight deck operation might well have affected the usefulness of the tactical ATC clearance page. The control panel for the autopilot functions had dial knobs and display windows for commanded altitude, airspeed, and track angle. Whether or not these autopilot functions were used, when tactical clearances were given, changing the desired value of these parameters, the crew generally dialed in the values as a reminder. The pilots invariably commented during the familiarization sessions that they were used to having such a feature and looked for it in the subject flight deck. The radio frequency changes were usually dialed immediately upon receipt; the message page was used for reference during that process when needed.

Reference 5 suggests that a display similar to the ATC clearance page be included, and that it would provide the primary tactical clearance information storage. Based on the present study, more consideration will need to be given to what should actually be made available in any given implementation of a page summarizing ATC clearances.

Mixed data link and voice radio operations. The data link operation used in these tests required that voice radio contact with an appropriate ATC facility be maintained throughout the flights. As expected, the subjects strongly endorsed this feature. In addition, in the data link test cases one tactical message, an instruction to depart the FLOTS intersection at a specified heading, was transmitted by voice radio several minutes prior to the FLOTS intersection. The pilots invariably objected to this practice, commenting that if data link is understood to be the primary mechanism for tactical clearance negotiation, they preferred that all routine messages be transmitted over the data link, or otherwise a convenient means of entering voice radio-derived clearance agreements into the CRT-displayed list of messages should be provided.

Instrument Scanning Behavior

The scanning behavior of both the pilot and the copilot was recorded during these tests; however, because of measurement difficulty with subjects wearing glasses, only the data for the low-time pilots were successfully acquired and analyzed, since they did not wear glasses during the tests.

Table III presents the percentage of total run time spent viewing each of several flight parameters displayed on the instrument panel. The entries in the table are averaged over the four low-time-pilot subjects and show that the scanning behavior of the copilot was characteristically different from that of the pilot.

When the data link ATC message exchange operation was introduced, the pilot tended to at least maintain his vigilance on the PFD, perhaps even increasing it. This was possibly in an effort to avoid having his primary flying task, and the instrument scanning behavior associated with it, affected by the data link ATC message exchange. Each of the low-time pilots in debriefing comments indicated possible objectionable interference of the data link operation with their scan pattern when actively flying the airplane. In this role the subjects spent less than 2 percent of their time viewing the CDU. It is questionable whether this was enough time to read each message as it came in, but clearly there was some time spent viewing messages.

In the data link operation, the copilot spent approximately 7 percent of his time in ATC message exchange activity, based on scanning behavior measurements. Comparisons with the voice radio case indicate that approximately 75 percent of this time would have been spent viewing the PFD or the ND and the remainder viewing other instruments.

In the conventional voice message exchange case, the copilot spent 40 to 50 percent less time than did the pilot viewing information in the PFD and more time on other instruments: the altimeter, the ND, the vertical speed indicator, and the airspeed indicator. Thus, the copilot's scan pattern indicated that he spent more time cross-checking instruments than did the pilot, as might have been expected. It is noted that since most flight crew scanning behavior studies conducted in the past have focused on the pilot, measurements of differences between the scanning behavior of the copilot and the pilot are at best sparsely documented in operator scanning behavior literature. The copilot scanning behavior measurements included in table III could possibly have significance beyond the immediate objectives of this study.

Response Time

Measurements were made on the response time of the crew in replying to messages uplinked from the ATC facility. The response time was taken as the time between the first alerting signal indicating the arrival of a new message in the cockpit and the copilot depressing the ENT (enter) key to downlink a roger or unable response. A histogram showing the distribution of the response time measurements is presented in figure 9. To facilitate this analysis, 45 sec was set as the upper limit for nonfaulty responses. A few responses came later than this limit, and were considered as faulty replies, as were a few cases in which responses were never downlinked. The measurements were pooled across subjects. The mean response time for all (nonfaulty reply) messages was 10.51 sec and the standard deviation was 6.7 sec; 70 percent of the measurements were clustered between 4 and 13 sec.

Table IV presents the mean and standard deviation of the response time for the individual messages. The messages are generally in the order in which they were dispatched from the ATC station, although there were some variations from run to run. The number of times each message was included in the data and the number of times each message was not followed by a reply within 45 sec (and consequently not included in the mean and standard deviation computation) are also presented.

Although no strong trends are apparent, most of the longest mean response times correspond to the longer messages. If the mean response times are adjusted for the message length, it appears the means would generally decrease with altitude and distance to the runway. Also, the standard deviations of the response times appear to decrease as the altitude and distance to the runway decreased, indicating more consistent behavior as the aircraft approached the runway threshold. The "Go around" message has one of the lowest mean response times of the messages considered, 7.06 sec, with a standard deviation of 2.8 sec. However, the other priority message, an instruction to level off at a specified altitude, typically received between an altitude of 16 000 and 14 000 ft during the descent, exhibited a conspicuously higher response time, with a mean of 11.17 sec and a standard deviation of 7.45 sec. After both priority messages, however, pilots invariably initiated a maneuver to comply with the ATC instruction within 2 to 3 sec of receiving it. In general these maneuvers to comply with all ATC priority instructions were begun before the copilot dispatched a response. This same order of events was typically observed in operations with routine messages as well. Similar results were reported in the single-pilot data link message exchange study of reference 6.

The column labeled "faulty replies" in table IV presents the number of times no reply was received within the 45 sec time limit; 8 of the total of 12 faulty replies were cases of replies never being dispatched from the cockpit. These faulty replies represented approximately 4 percent of the data. In the eight in which absolutely no reply was dispatched, the flashing MSSG alerting signal was left on in several cases. This indicates that consideration should be given to repeating the message alert tone at some regular interval until a reply has been dispatched, perhaps after 15 sec. Four of the 12 faulty replies were made by 1 low-time-pilot subject, while 2 additional faulty replies were made by the subject paired with him. Another two of these errors were made by a high-time pilot.

Message Exchange Session Lengths

For the purpose of this discussion, a message exchange session will be considered as the set of activities including (1) controller initiation of a message; (2) the crew operations required to receive, interpret, and reply to the message; and (3) the display of the reply at the controller's station. The session length will be considered as the time from start to completion of a message exchange session.

Voice radio sessions measurements. Using audio-video tape recordings of the simulation runs, stopwatch measurements were made of the time from the start to completion of voice message-exchange sessions from eight randomly chosen data runs, during which each of the messages listed in table V were exchanged. This table presents the means and standard deviations of the corresponding session lengths. For voice radio operations, the pooled average session length is 8.22 sec, with a standard deviation of 3.32 sec. Figure 10 includes a histogram of the distribution of these data.

Data link sessions measurements. Table V also presents estimates of the session lengths for transmitting the same messages with the simulated data link. The characteristics of the simulated data link resulted in a message transmission time mean of 4.0 sec with a standard deviation of 1.1 sec for uplinked messages, and a mean of 4.2 sec with a standard deviation of 1.1 sec for the downlinked messages. The estimates for the data link session lengths in table V were derived by adding the uplink and downlink transmission time means, totaling 8.2 sec, to the mean response times given in table IV. The corresponding standard deviations were estimated by combining the transmission time standard deviations with the values given in table IV for the crew's response time. The estimates were made assuming that the uplink and downlink transmission times were uncorrelated to each other and to the response times. Figure 10 includes histograms of the distribution of the data link session length estimates and the voice radio session measurements.

Comparison of session lengths. The data link message exchange sessions averaged around 19 sec, more than twice the average of about 8 sec for the voice operations. Furthermore, the standard deviation estimates in the data link case are much larger than those for the voice radio case, indicating more inconsistent behavior. It appears that this longer message exchange time is possibly related to the lower workload perception referred to by several crew members. Related to this point, the subjects commented that one of the benefits of the data link operation was that they were not so compelled to immediately decrease concentration on the task they were performing at the moment a data link message arrived to listen to the message, as was the case in the voice radio operation. It should also be recognized that approximately 8 sec of the total 19 sec average time required for data link message exchange sessions were due to the transmission time required. The average data link message exchange session time could be reduced if a link with a faster transmission time was used.

Controller comments on the impact of the data link ATC message exchange on the controller station operations are included in appendix B. These comments were offered by a single controller who has several years of field experience and was responsible for providing the air traffic control operation in this study.

Concluding Remarks

The objective of these tests was to assist in developing the data base to be used in establishing flight-deck guidelines for data link air traffic control (ATC) message exchange. The results indicated that both the pilot and the copilot favored the data link operations for routine ATC message exchange. When messages are time critical, however, conventional voice radio operations were highly preferred.

In the limited test scenarios used in this study, the subjects stated that the absence of the party line effect in the data link operation presented no problem, but suggested that a wider range of scenarios could lead to a somewhat different conclusion. The tests simulated a fairly low density Instrument Flight Rules environment. A scenario involving aircraft being vectored around a thunderstorm, for example, or a high traffic density Visual Flight Rules environment, could have different implications. More testing of the lack of the party line in the data link environment is recommended. In such testing, consideration should be given to providing the pilot, by data link, with information normally derived from the party line. Such information could include density and proximity of other traffic and information on the traffic flow and probable delays.

In the copilot role, the subjects unanimously reported a perception of lower workload when operating with data link communication. In contrast, when actively flying in the pilot role, the subjects' workload perception divided according to experience level. High-time pilots reported that the workload was reduced with the data link operation, while low-time subjects sensed a slight increase because of increased demands on their visual attention. Pilots spent about one-third the time viewing the data linked messages as did copilots, who generally read the messages aloud and dispatched the replies.

If voice radio and data link ATC message exchange are to be used in some combination, careful consideration should be given to the protocols. For routine messages, in non-time-critical situations, the need for a voice backup of messages transmitted by data link is doubtful, and would probably increase the controller's, as well as the crew's, workload. Also, in routine operations, if some messages will be delivered by data link and others by voice radio, a "note pad" feature allowing the flight crew to add voice-derived clearance information to the display of data-link-derived clearances should be considered. Furthermore, backing up priority messages transmitted by voice radio with data link transmissions should be given more careful testing before being considered for use in an operational environment. Some of the pilots indicated that some uncertainty was introduced when they initially received a voice message to "Go around," and a second or two later, after they had begun to execute the required maneuver, a data link message alert was sounded.

The data-linked alphanumeric display of Automatic Terminal Information Service (ATIS) information was generally preferred by the subjects over the conventional voice format, and no complaints about its presentation on a separate page were raised. However, pilot and copilot comments indicated that if a summary of tactical ATC clearances is maintained, it should perhaps be continuously displayed. When presented on a separate page of the data link interface in this study, the crews' use of this page was minimal.

The average data link message exchange session required about 19 sec for completion, including 8 sec of two-way transmission time. An average of 8 sec total was required to exchange similar messages by voice radio. Since delays in controller reception of flight crew replies to data-linked advisories are relatively large compared with conventional voice operations, the impact of data link operations on controller duties should be carefully considered. There was evidence that some of the large crew response times resulted from the crews having forgotten to complete the message handling process in a timely fashion. In some of the faulty message handling cases, the visual alerting signals continued to flash in the centers of the primary flight display and the navigation display without attracting the crew's attention. Therefore, additional means of prompting crews for timely responses should be researched.

NASA Langley Research Center
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December 6, 1988

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Appendix A

Test Subjects Debriefing Form

Directions:

Please answer as many of the questions as you can. Circle the letter preceding the one answer you prefer in the multiple choice questions. Use the back of the pages for comments when more space is needed. Please make comments on any questions you wish.

1. The data link ATC message exchange used in the simulated descents and approaches were

   a. Very acceptable
   b. Somewhat acceptable
   c. Not particularly acceptable or objectionable (neutral)
   d. Somewhat objectionable
   e. Very objectionable

2. Discuss any particular advantages of ATC message exchange operation using digital data link over voice radio communication noted during the tests.

3. Discuss any particular advantages of the conventional voice radio communication over data link operation for ATC message exchange noted during the tests.

4. Same as 2 above, however not particularly noted in the test scenarios.

5. Same as 3 above, however not necessarily observed in the test scenarios.

6. Discuss any message transmissions (data link or voice radio) and/or practices used in the data link scenario which presented a problem. Suggest any solutions which come to mind.

7. How do you view the concept of transmitting priority messages over the data link (e.g., "go around")?
   a. Very acceptable
   b. Somewhat acceptable
   c. Neutral
   d. Somewhat objectionable
   e. Very objectionable

   Comments:

8. How did you view receiving the ATIS reports over the data link compared to the conventional radio protocol?
   a. Data link ATIS highly preferred
   b. Data link ATIS somewhat preferred
   c. Either method is okay, neutral
   d. Conventional radio is somewhat preferred
   e. Conventional radio is highly preferred

9. I found the tactical ATC clearance summary page on the CDU
   a. To highly negatively impact cockpit operations
   b. To somewhat negatively impact cockpit operations
   c. Leaves one uncertain of benefits, neutral
   d. Somewhat beneficial
   e. Highly beneficial

10. Compared to conventional voice radio, ATC message exchange using the data link made the pilot's (pilot flying)
    a. Communication workload
       1. Much lower
       2. Somewhat lower
       3. About the same
       4. Somewhat higher
       5. Much higher
    b. Overall workload
       1. Much lower
       2. Somewhat lower
       3. About the same
       4. Somewhat higher
       5. Much higher

11. Same as 10 above except for first officer's or copilot's
    a. Communication workload
       1. Much lower
       2. Somewhat lower
       3. About the same
       4. Somewhat higher
       5. Much higher
    b. Overall workload
       1. Much lower
       2. Somewhat lower
       3. About the same
       4. Somewhat higher
       5. Much higher

12. Interpreting messages transmitted over the data link (compared to conventional voice radio protocol) was

   a. Much easier
   b. Somewhat easier
   c. Of approximately the same difficulty level
   d. Somewhat more difficult
   e. Much more difficult

13. My perception of the number of mistakes made in the message exchange (including those detected and corrected) was that

   a. The data link operation was much more reliable
   b. The data link operation was somewhat more reliable
   c. The data link operation was about the same as voice radio
   d. The voice radio protocol was somewhat more reliable
   e. The voice radio protocol was much more reliable

14. My confidence in the data link for nonpriority or standard ATC message exchange during the test scenario was

   a. Much higher than for voice radio
   b. Somewhat higher than for voice radio
   c. About the same as for voice radio
   d. Somewhat less than for voice radio
   e. Much less than for voice radio

15. Same as 14 above but priority messages

   a. Much higher than for voice radio
   b. Somewhat higher than for voice radio
   c. About the same as for voice radio
   d. Somewhat less than for voice radio
   e. Much less than for voice radio

16. During the simulated flight with data link the reduced amount of voice communication between the ATC controller and other aircraft (on the same frequency)

   a. Was a very desirable feature
   b. Was a somewhat desirable feature
   c. Was a feature which I am neutral about
   d. Was a somewhat undesirable feature
   e. Was a very undesirable feature

   Comments:

17. Receiving priority messages over the data link with no voice radio backup was

   a. Quite satisfactory
   b. Somewhat satisfactory
   c. Presented no problem, neutral
   d. Somewhat unsatisfactory
   e. Very satisfactory

18. Compared to data link transmissions only, receiving a priority message over the data link with a voice backup was

a. Much more satisfactory
b. Somewhat more satisfactory
c. No preference
d. Somewhat unsatisfactory
e. Very unsatisfactory

19. For priority messages I prefer

a. Data link only
b. Data link followed by voice backup
c. Voice radio followed by data link backup
d. Voice only
e. No clear preference

20. For the tasks required in the test scenario, the cockpit data link interface was

a. Very satisfactory
b. Somewhat satisfactory
c. Neutral
d. Somewhat unsatisfactory
e. Very unsatisfactory

Comments:

21. When flying the airplane, I prefer that the first officer read the data link messages aloud.

a. yes b. no

Comments:

22. Would there be a significant advantage in having ATIS messages on both voice radio and data link?

a. yes b. no

23. With the CRT interface for data link messages as in this study available, a hard copy printer in addition would be

a. Very helpful
b. Somewhat helpful
c. Neutral (of questionable necessity)
d. Somewhat unnecessary
e. Very unnecessary

24. My reaction time to messages transmitted over the data link as compared to voice radio was

a. Very much improved with data link
b. Somewhat improved with data link
c. About the same
d. Somewhat worse with data link
e. Very much worse with data link

Appendix B

Air Traffic Environment Simulation and Controller Observations

The emphasis of this study was on flight deck considerations for data link ATC message exchange operations. The ATC simulation used was therefore 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 ATC station human interface, nor to perform a rigorous study of the controller's activities during these tests. Nevertheless, the controller who participated in this simulation, having had several years of ATC experience, made a number of observations concerning the data link operation that will possibly be of interest to designers of the National Airspace System. This appendix presents a brief description of the air traffic environment and controller station simulations as well as relevant observations made by the controller. No assumption is made in this discussion regarding the manner in which a data link message exchange system might be supported in ATC facilities of the future, nor about the degree of automation envisioned and the probable role of the human controller in the system.

Air Traffic and ATC Simulation

The operational and procedural air traffic environment simulated that of the Denver Air Route Traffic Control Center and Denver Approach Control for arrivals inbound to Stapleton International Airport from the northeast and northwest (fig. 11). The simulated flight deck always approached from the northeast. This route involved sequentially a Denver Center high altitude sector, a Denver Center low altitude sector, two Denver Approach Control sectors, and the Denver Tower.

The simulated air traffic was generated by a special purpose software package that operated in real time on a time-shared computer and generated dynamic, point-mass-modeled air traffic whose state could be controlled by keyboard entries at a "pseudopilot" station. This software package also interfaced with the primary aircraft simulation software and allowed the test airplane, the TSRV simulator arriving from the northeast, to operate as one of the aircraft in the air traffic environment. New traffic was programmed to arrive at the metering fix, the SMITY intersection northeast of the airport, at an average rate of 17 aircraft per hour. This traffic was eventually merged with traffic from the northwest that was introduced at a similar frequency to generate a simulated IFR arrival rate of approximately 34 aircraft per hour. The resulting traffic pattern was displayed at a simulated ATC controller station in the Langley Mission-Oriented Terminal-Area Simulation Facility (MOTAS, ref. 7).

Figure 12 presents a photograph of the simulated ATC station. The plan position indicator (PPI), a 20-in-diameter circular monochromatic CRT, presented a display of simulated radar-tracked air traffic superimposed on a scaled map of the Denver terminal area. Figure 13 presents a photograph of the PPI. The triangular symbols represent the radar return from aircraft operating in the area, and adjacent data blocks present the aircraft call sign, type, altitude, and ground speed. Three separate areas, located on the left side of the display, were dedicated to data link information. These areas were (a) a scratch pad area that echoed messages as they were composed, (b) an area for displaying previously dispatched messages, and (c) an area displaying messages received from the flight deck simulator. The uplink and downlink message areas are shown in Figure 13. The numbers that appear to the right of each message are indices used to correlate a given message to its response.

The air traffic environment representation required a trained controller and a pseudopilot. The controller assumed the role of each ATC controller with whom the crew would have communications during the flight, i.e., two center controllers, two approach controllers, and one tower controller. The pseudopilot assumed the piloting role for all pseudoaircraft and was required to type computer control instructions to maneuver the simulated aircraft and to conduct voice radio message exchange activities with the controller. To enhance realism, an electronic voice-disguising device was used to generate different vocal qualities as the pseudopilot assumed the identity of different pilots. A realistic and consistent communications rate was maintained by addressing appropriate control instructions and advisories to each of the simulated aircraft, including the manned TSRV flight deck simulator.

In the data link operation, the controller, using a standard computer keyboard, composed the body of the ATC messages presented in table I by entering a three-character code followed by appropriate numerical data. After the newly composed message, echoed in the scratch pad area of the PPI was reviewed, it was transmitted by depressing the enter key.

Controller Comments on the Data Link Operation

These observations are made fully realizing that the controller interfaces and message set used in this study may, and probably will, vary significantly from those used in future operational systems.

There were two specific characteristics of the data link operation that were favorable from the controller's standpoint. First, visually reviewing data link commands prior to sending resulted in a high confidence level that the command or advisory was correctly sent; this was particularly true of commands that included variables such as speeds, headings, and altitudes. This confidence level was reinforced by the awareness that, in this study, the flight crew could refer back to previous clearance information. Therefore, consideration should be given to providing the airborne crew, through the data link interface, the capability to refer back to data link messages previously received. Second, the quieter environment created by the reduced voice radio communications level was appealing to the controller.

The voice responses that a controller, based on experience, associates with the assurance that a command will be executed, were missed in the data link message exchange operation. Upon receiving the data link response, there was a tendency to pay more than normal attention to that particular aircraft target to ensure pilot compliance with the command. This was probably because of limited operational experience with the data link, and it may be that the controller's confidence in the data link operation would increase with additional use.

A major problem with data link communications from a controller's perspective is the comparatively long time associated with a data link exchange. For the purpose of this discussion, a data link exchange time is considered to be measured from the time a message transmission is initiated by the controller until a reply to that message appears on the controller's display. Because the control of air traffic can be intensely time critical, careful consideration should be given to this factor. A comparison of message exchange times (session lengths) associated with voice and data link communications in this study indicates a considerable difference. The average time for data link exchanges was approximately 19 sec, while the average message exchange time for voice radio was approximately 8 sec.

The significantly longer time required for data link exchanges creates several problems for the controller. First, by the inherently dynamic nature of air traffic, clearances need to be issued and responses received in a timely manner to provide a safe and orderly flow of air traffic. When average message exchange times are on the order of 20 sec, as with data link, the controller is forced to plan 10 to 12 sec further in advance to achieve the same results as in conventional voice radio operations. Second, because many control instructions issued to an aircraft are predicated on responses to instructions previously issued to other aircraft, the cumulative delay of message exchanges could potentially create a backlog of messages. Consequently, an unassisted controller would be unable to issue timely instructions to aircraft. In conjunction with this problem, if a controller decides to send a follow-up message soliciting a reply to an unanswered message, it can create confusion and consume valuable data link time if the crew has already replied to the first message. As automation plays an increasing role in assisting the controller, the impact of lengthy message exchange times associated with data link communications may become less critical. In addition, the variability of the response time made the control task more difficult. This variability was found to disrupt the natural rhythm of the controller communications and required that more attention be paid to the area of the display where message acknowledgments are presented.

For priority messages, the delays in receiving replies from the simulated aircraft were cause for increased concern. The controller did not know whether the time-critical message had been received in the aircraft. The data presented in table IV show that for the priority message "↓ (alt) * " (to level off at a specified altitude), the average reply time exceeded 11.2 sec. This value was greater than the average reply time of 8.8 sec measured for nonpriority exchange of similar messages. As reported in the main text, further analysis of the data showed that the control instructions were frequently executed before the reply was received at the ATC station. In contrast, when voice transactions were used for priority messages, a prompt verbal acknowledgment was normally received, thereby leaving no question in the controller's mind that the instruction had been received. Clearly, from the controller's perspective gained in this study, voice radio should be used anytime an instruction requiring expeditious compliance is issued.

Finally, the traditional freedom of being able to direct attention away from the PPI is not permitted with data link communications without some sort of aural alert to signal incoming messages. Sometimes downlinked messages appeared and initially went unnoticed while the controller's attention was directed away from the display.

In summary, it is recognized that the emphasis of this study was on the flight deck operation and that no attempt was made to optimize the controller station data link interface. However, several controller station issues that might be important in evolving a practical data link ATC message exchange system became apparent. Having the messages in alphanumeric form for review and reference was highlighted as a benefit to the controller. But, the delay in receiving replies acknowledging receipt of messages was a liability from the controller's perspective. This delay forced the controller to wait for responses to previously issued messages before transmitting instructions to other aircraft, thereby making the controller's task more difficult. Clearly, the successful evolution of a data link ATC message exchange system will require extensive consideration of the controller's interface and solutions to problems such as those discussed above, as well as careful consideration of flight deck issues.

Table I. Data Link Messages Used in the Study

(a) Clearances and Advisories Implemented for Data Link Transmission

Messages	Explanation
ALTIMETER #### CLRD PRFL DCNT	Altimeter #### Cleared for profile descent
CNTC CEN 125.95	Contact center on 125.95
X KEANN ⤈FL### CNTC DEN APPRCH 120.2	Cross KEANN at or below flight level ### Contact Denver Approach on 120.2
↓ (alt) *	Descend and maintain (altitude)
↓ (alt)	Descend and maintain (altitude)
TL HDG (hdg)	Turn left heading (new heading)
TR HDG (hdg)	Turn right heading (new heading)
CNTC APPRCH 125.3	Contact approach control on 125.3
RDC TO (spd)KTS	Reduce to (speed) knots
INC TO (spd)KTS	Increase to (speed) knots
(miles) MI FRM ARP MTN 7200 UNTIL ESTB ON LOC	(distance) Miles from the airport. Maintain 7200 until established on the localizer
CLRD ILS RNY 26L	Cleared to ILS runway 26 left
CNTC TOWR 118.3 @ OM	Contact the tower on 118.3 at the outer marker
WIND (hdg) @ (spd)	Wind (heading) at (speed)
GO AROUND *	Go around

* priority messages

Table I. Concluded

(b) ATIS reports used

Report	Read as
ATIS:DEN ARR INFO K 2100UTC WX: E15 BKN 45 OVC 6 RW- 77/66 2920G36 2997 EXPCT PRFL DSCNT AND VEC ILS 26L. K	Denver arrival ATIS information kilo. 2100 coordinated universal time. Weather: estimated ceiling 1500, broken, 4500 overcast, visibility 6, light rain showers, temperature 77, dew point 66, wind 290 at 20 gusting to 36, altimeter 2997. Expect profile descent and vectors ILS 26 left. Information kilo.
ATIS:DEN ARR INFO N 2100UTC WX: E10 BKN 23 OVC 3 RW- 70/66 2715G30 2999 EXPCT PRFL DSCNT AND VEC ILS 26L. N	Similar to above
ATIS:DEN ARR INFO L 1600UTC WX: E11 BKN 30 OVC 2 RW+ 68/66 2612G25 2992 EXPCT VEC ILS 26L. L	Similar to above (RW+ implies heavy rain showers)

Table II. Experience Levels of the Test Subjects

Pilot	Experience	Total flight hours	Recent aircraft
1	NASA test pilot	8000	Boeing 737
2	NASA test pilot	8000	Boeing 737
3	Military	1000	C12[a]
4	Military	1000	C21[b]
5	Military	1000	C21[b]
6	Military	1000	C12[a]
7	Airline	30 000	Boeing 707, 747
8	Airline	24 000	Boeing 707, 727 Boeing 767, 757
9	Airline	10 000	Boeing 727, 737

[a] Military version of the Beech Super King Air.
[b] Military version of aircraft manufactured by Gates Learjet.

Table III. Instrument Dwell Percentages

	Viewing time as percent of total run time for—			
	Voice radio case		Data link case	
Parameter	Pilot	Copilot	Pilot	Copilot
PFD center	35.91	20.51	40.31	18.59
Roll	6.38	3.47	6.57	2.28
Glide slope	3.24	2.57	2.53	2.97
Localizer	.88	.57	.76	.62
Total PFD	46.41	27.12	50.17	24.46
ND	11.57	14.23	9.13	11.57
PFD + ND	57.98	41.35	59.30	36.03
Altimeter	9.18	17.53	8.01	16.08
Airspeed	7.16	9.78	6.06	9.53
Engine instruments	1.23	5.10	1.31	3.48
IVSI	2.11	2.14	1.82	1.94
Peripheral instruments (total)	19.68	34.55	17.20	31.03
CDU			1.74	6.99

Table IV. Data Link Response Times

Uplinked message	Mean response time, sec	Standard deviation†, sec	Sample size	Faulty replies
ALTIMETER #### CLRD PRFL DCNT CNTC CEN 125.95	14.46	9.62	31	3
X KEANN ⤈FL### ↓ (alt)	11.99	5.44	34	0
CNTC DEN APPRCH 120.2	11.40	12.06	30	2
↓ (alt) *	11.17	7.45	11	1
↓ (alt)	8.77	3.52	29	1
TL HDG (hdg)	7.90	1.54	5	1
TL HDG (hdg) CNTC APPRCH 125.3	13.75	8.09	8	0
CNTC APPRCH 125.3	7.62	3.30	11	0
RDC TO (spd) KTS	8.16	3.56	7	1
↓ 7200	10.45	7.87	25	1
TR HDG (hdg)	6.33	2.10	11	0
(miles) MI FRM ARPT MTN 7200 UNTIL ESTB ON LOC CLRD ILS RNY 26L APPRCH CNTC TOWR 118.3 @ OM	13.08	6.44	12	0
TR HDG (hdg) (miles) MI FRM ARPT MTN 7200 UNTIL ESTB ON LOC CLRD ILS RNY 26L APPRCH CNTC TOWR 118.3 @ OM	14.21	6.32	20	1
WIND (HDG) @9 CLRD TO LAND 26L	6.96	2.37	31	0
GO AROUND *	7.06	2.80	18	1

†The reader is cautioned that the distributions are probably not normal.
*Priority message.

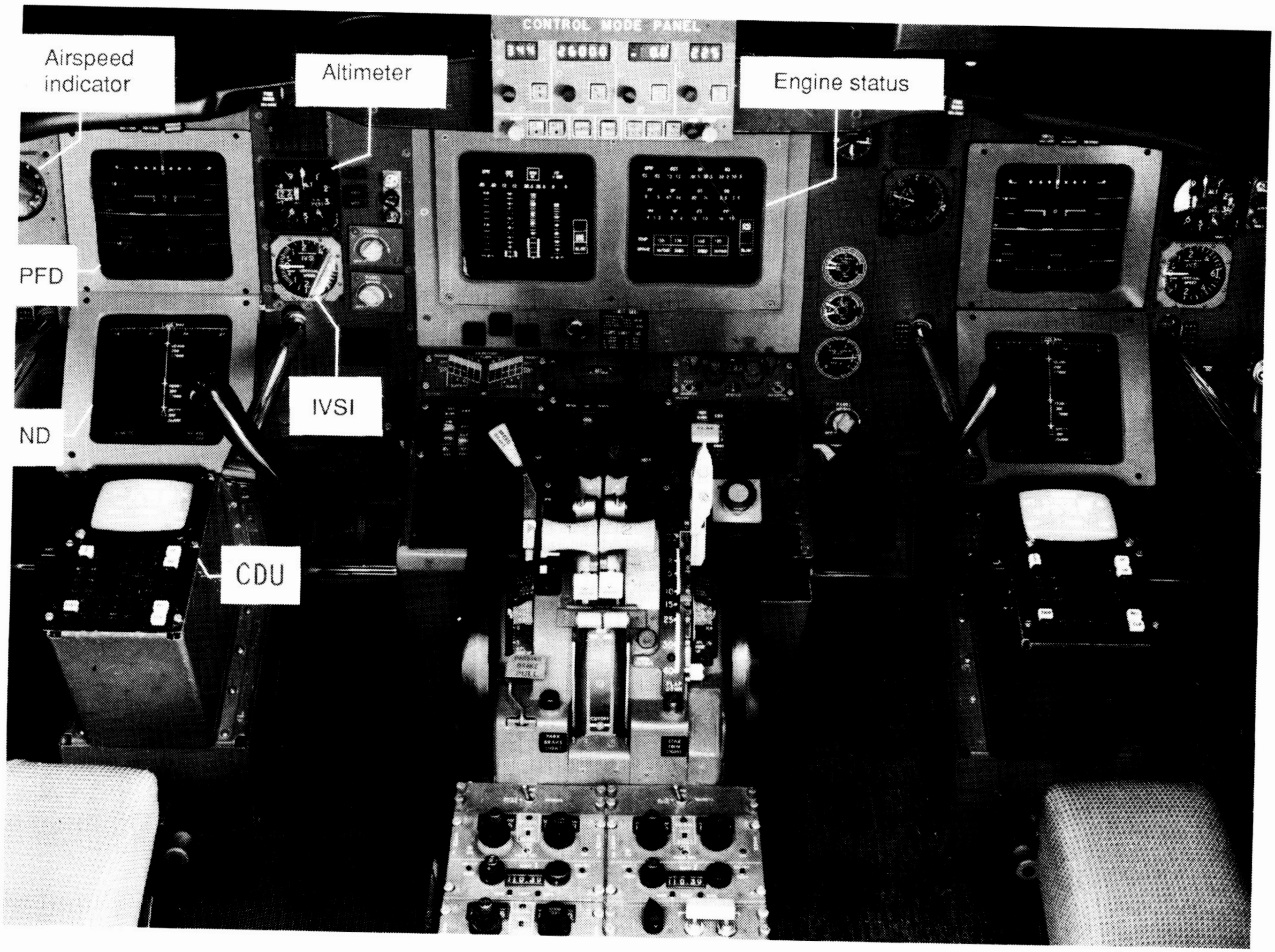
Table V. Message Transmission Session Length

ATC initiated message	Voice session length, sec		Data link session length, sec	
	Mean	Standard deviation	Mean	Standard deviation
ALTIMETER #### CLRD PRFL DCNT CNTC CEN 125.95	10.22	1.73	22.7	9.7
X KEANN ⤈FL### ↓ (alt)	9.04	1.12	20.2	5.7
CNTC DEN APPRCH 120.2	7.41	1.34	19.6	12.1
↓ (alt) *	12.08	[a]2.04	19.4	7.6
↓ (alt)	5.10	.86	17.0	3.8
TL HDG (hdg)	6.11	1.38	16.1	2.2
TL HDG (hdg) CNTC APPRCH 125.3	9.60	1.36	22.0	8.2
CNTC APPRCH 125.3	5.33	.48	15.8	3.6
↓ 7200	7.01	.90	18.7	7.9
TR HDG (hdg)	6.34	.96	14.5	2.6
(miles) MI FRM ARPT MTN 7200 UNTIL ESTB ON LOC CLRD ILS RNY 26L APPRCH CNTR TOWR 118.3 @ OM	16.02	1.59	21.3	6.6
GO AROUND *	7.40	1.83	15.9	3.2

*Priority message.

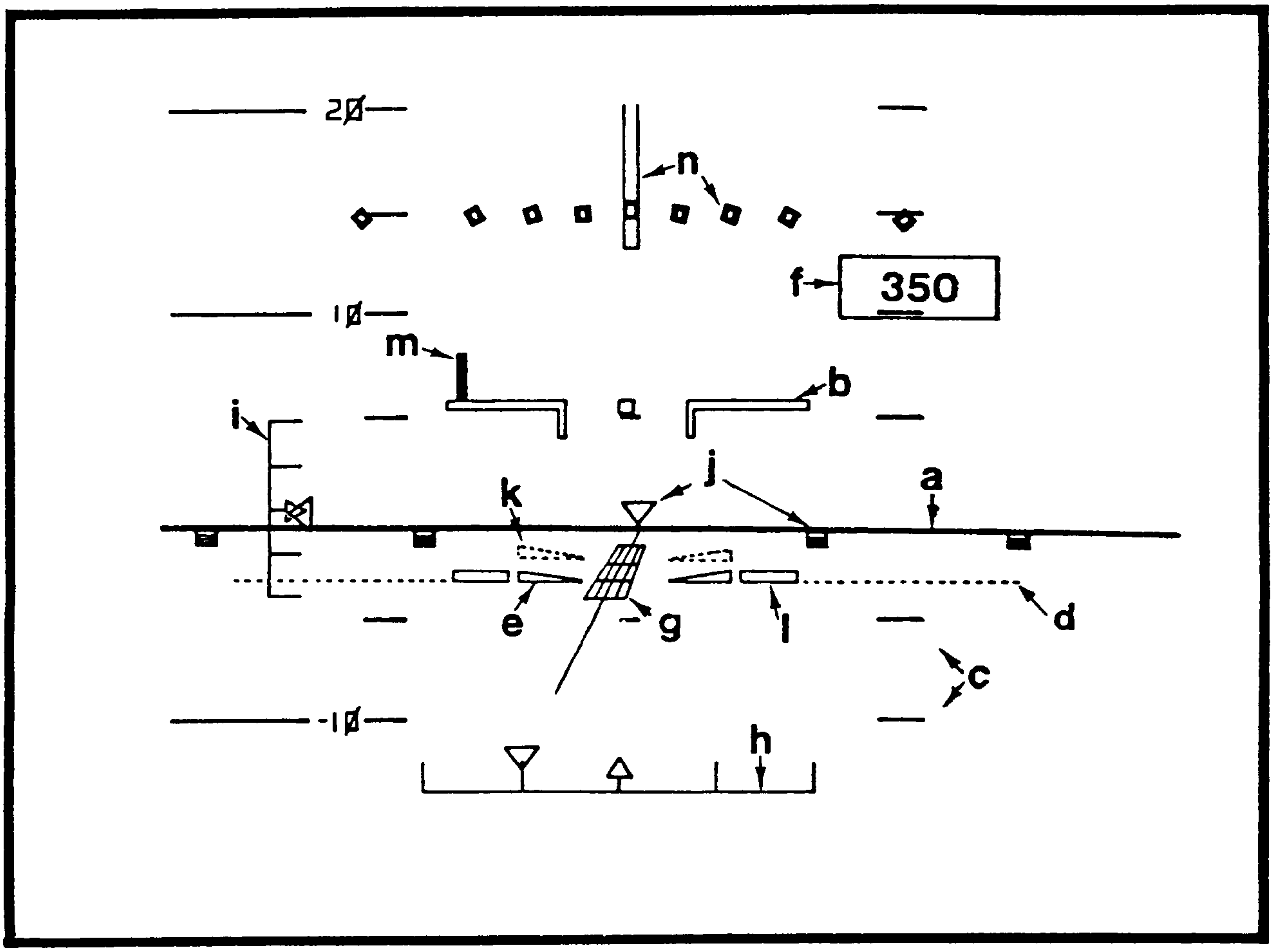
[a] The voice priority message included a reason that contributed to the lengthy message exchange time.

ORIGINAL PAGE IS
OF POOR QUALITY



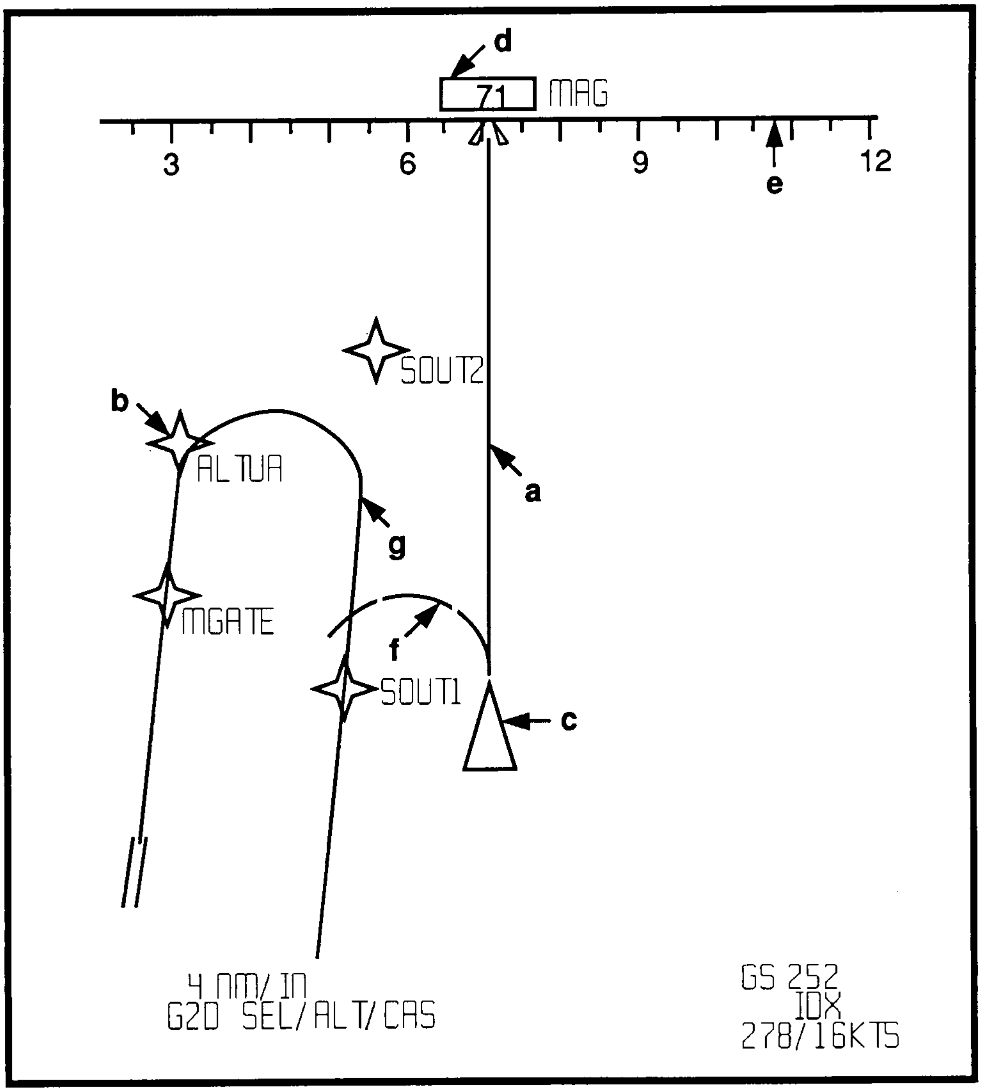
L-86-10,535

Figure 1. Transport Systems Research Vehicle flight deck simulator.



a	horizontal line
b	attitude symbol
c	pitch scale
d	pitch reference line
e	flight path angle wedges
f	radar altitude
g	runway perspective and extended centerline
h	localizer scale and pointer
i	glide slope scale and pointer
j	track pointer and scale
k	flight path angle reference wedges
l	flight path acceleration bars
m	speed error bar
n	bank angle scale and pointer

Figure 2. Sketch of the primary flight display.



a straight trend vector

b way point

c airplane symbol

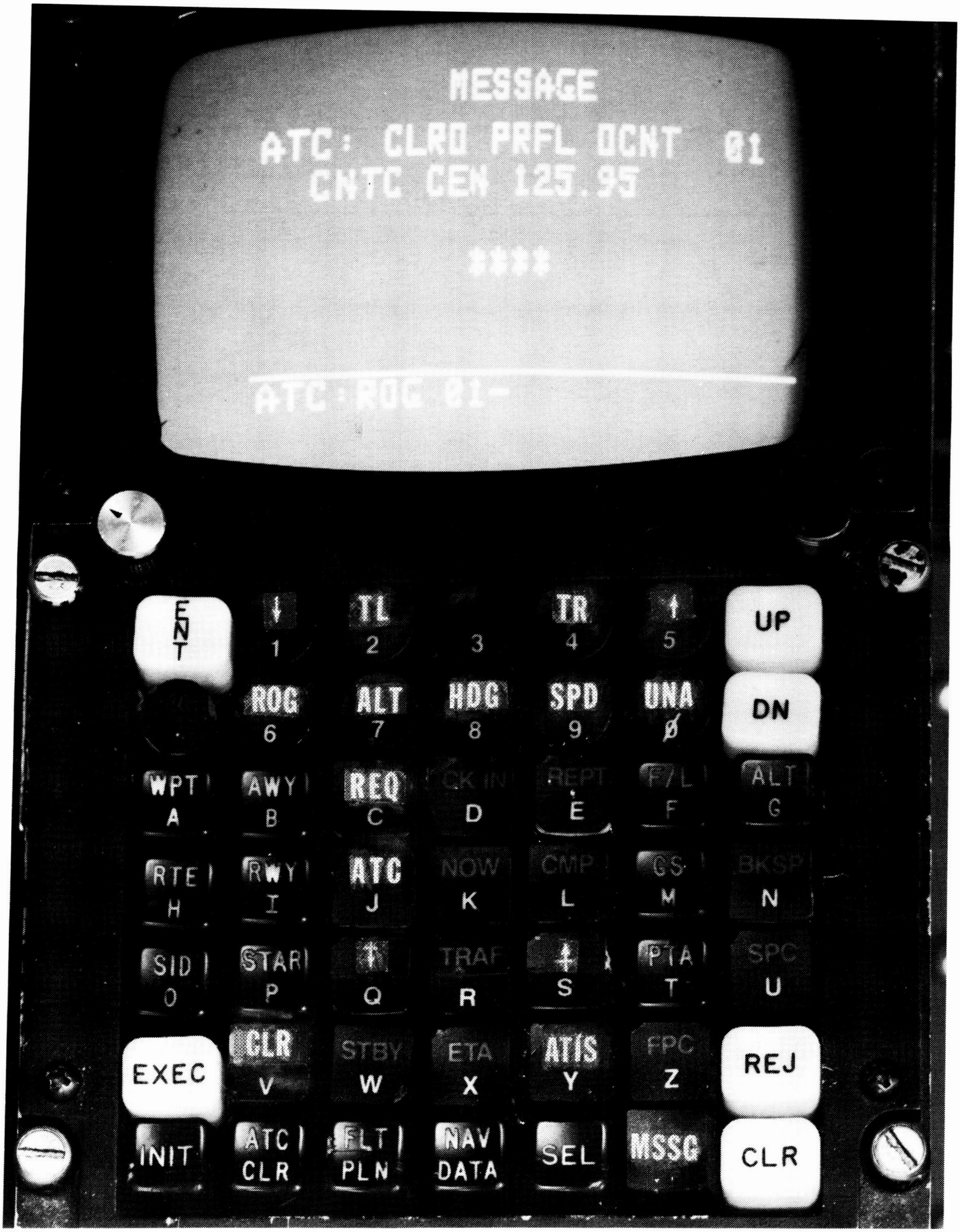
d track box

e track scale

f curved trend vector

g planned flight path

Figure 3. Sketch of the navigation display.



```
MESSAGE
ATC: CLRD PRFL OCNT  01
  CNTC CEN 125.95

         ****

ATC:ROG 01-
```

Figure 4. The control display unit (CDU) and data link interface.

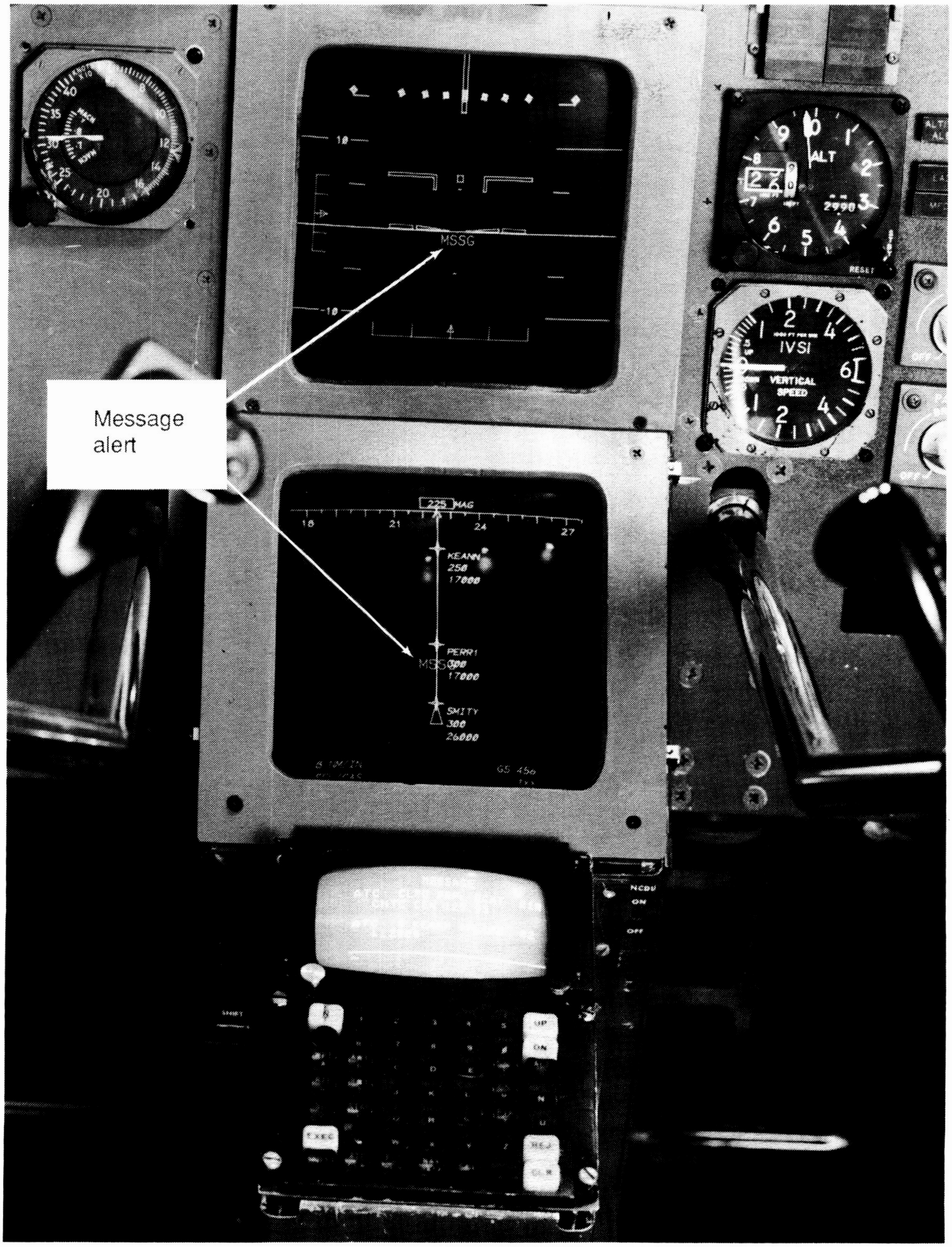


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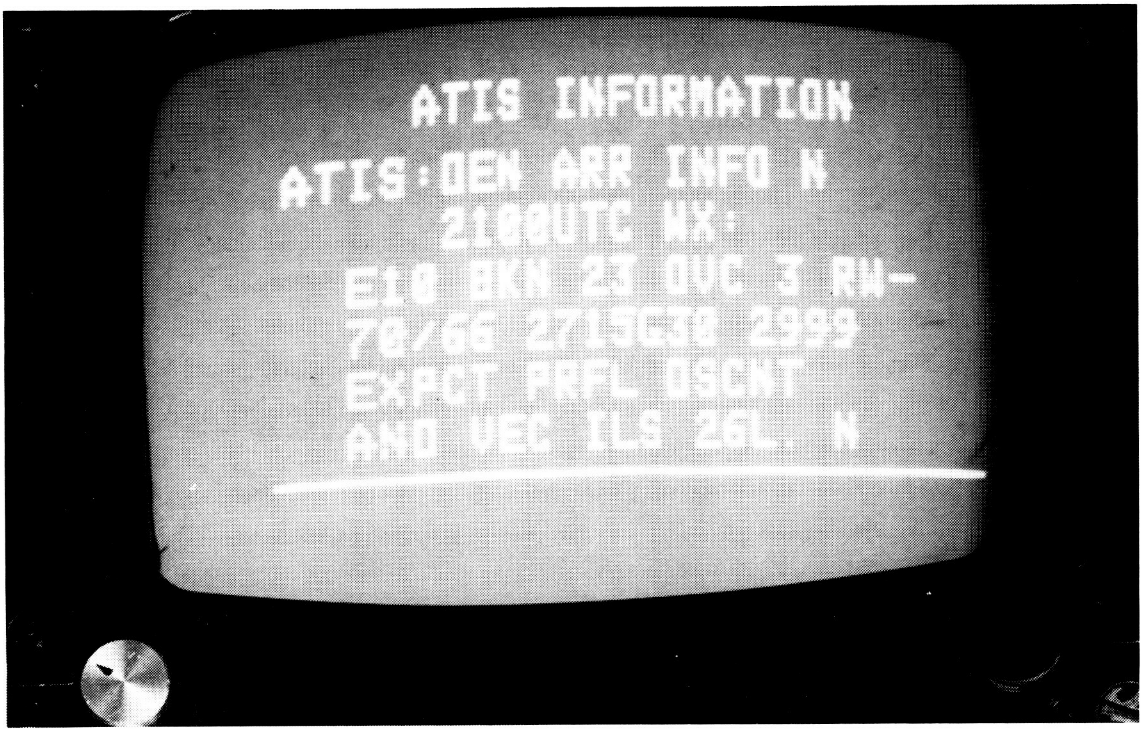
Figure 5. The message alert signal displayed on the primary flight display (PFD) and the navigation display (ND).

```
ATC CLEARANCE (TACTICAL)

RTE: KEANN   FLOTS
ALT: FL260
SPD: MACH  .68
HDG:
 FQ: 133.75
```

Figure 6. The air traffic control clearance page (tactical agreements).



```
     ATIS INFORMATION
ATIS:DEN ARR INFO N
     2100UTC WX:
   E10 BKN 23 OVC 3 RW-
   70/66 2715G30 2999
   EXPCT PRFL DSCNT
   AND VEC ILS 26L. N
```

Figure 7. ATIS information November (N) displayed on the CDU.

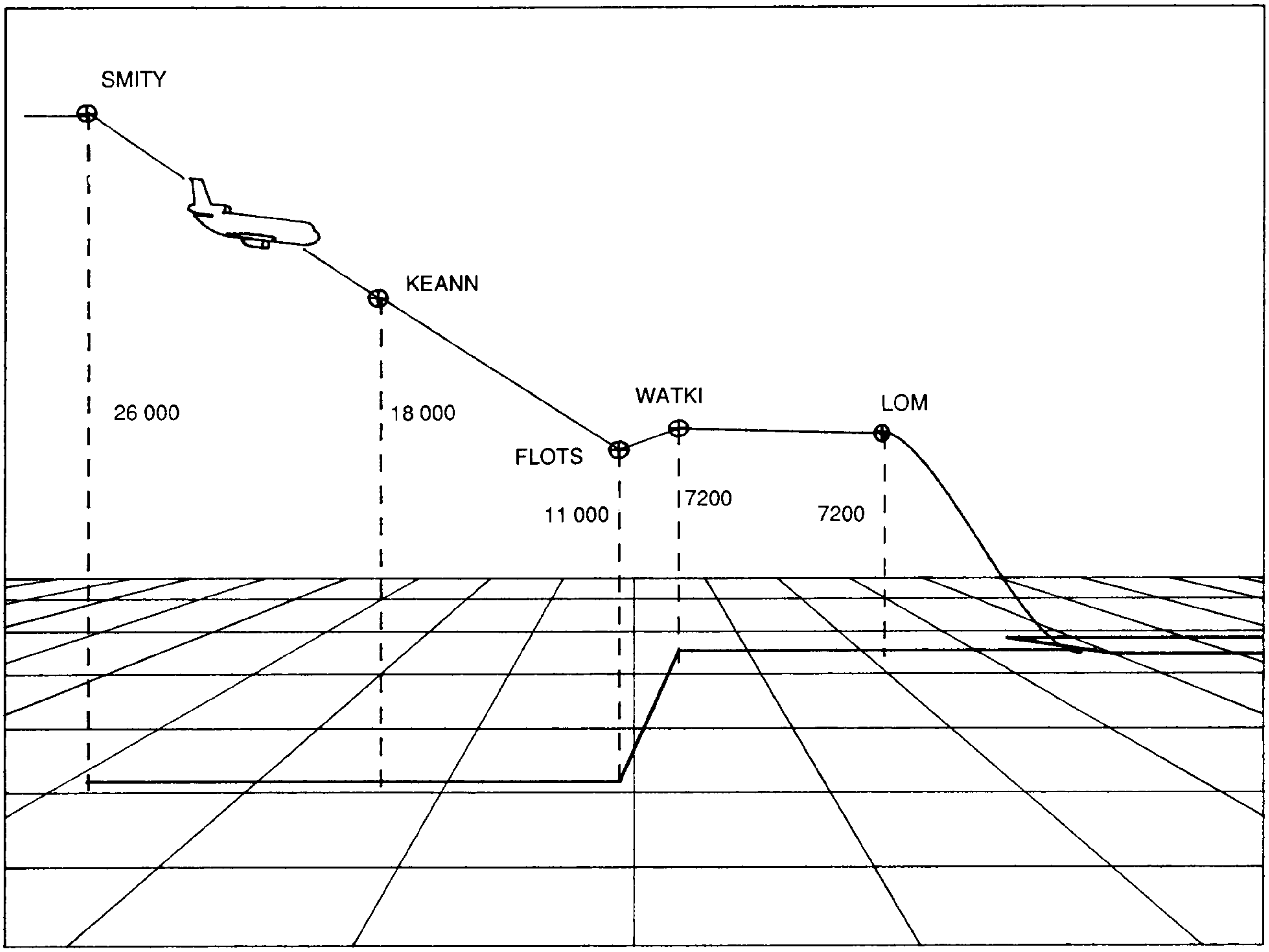


Figure 8. The nominal descent and approach path used. (Altitudes are in feet.)

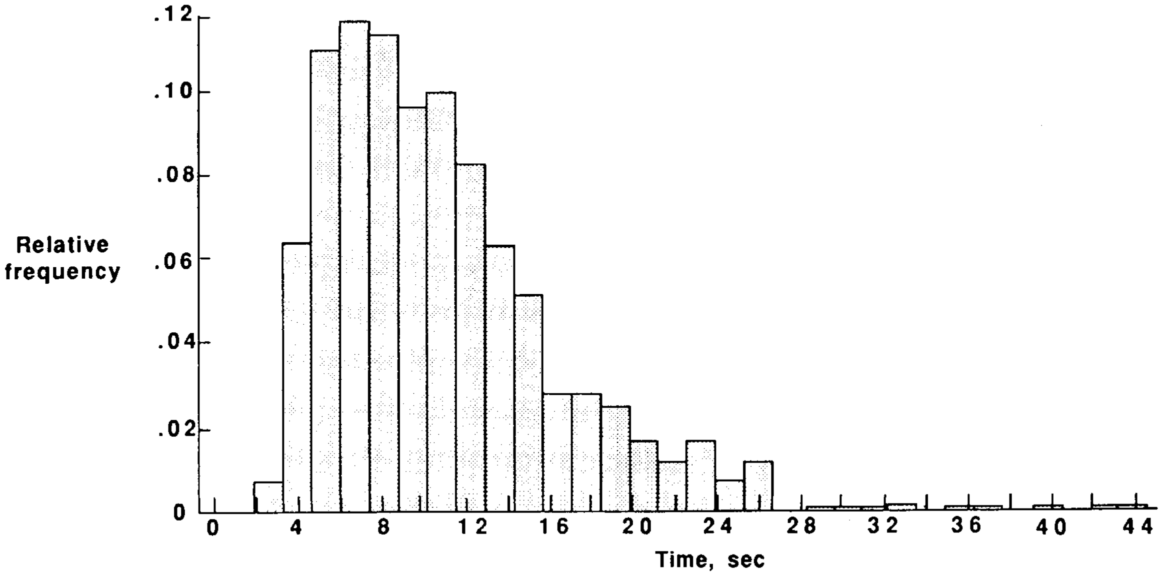
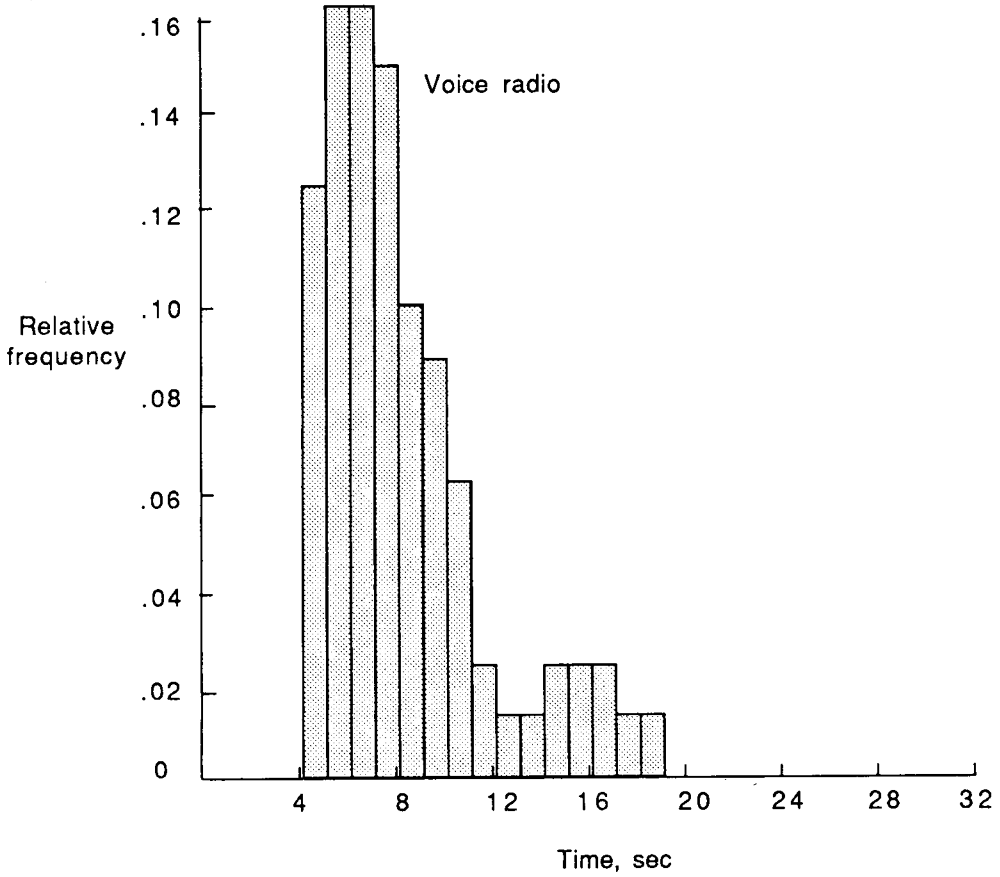


Figure 9. Histogram of the response times for all data link messages pooled across subjects.



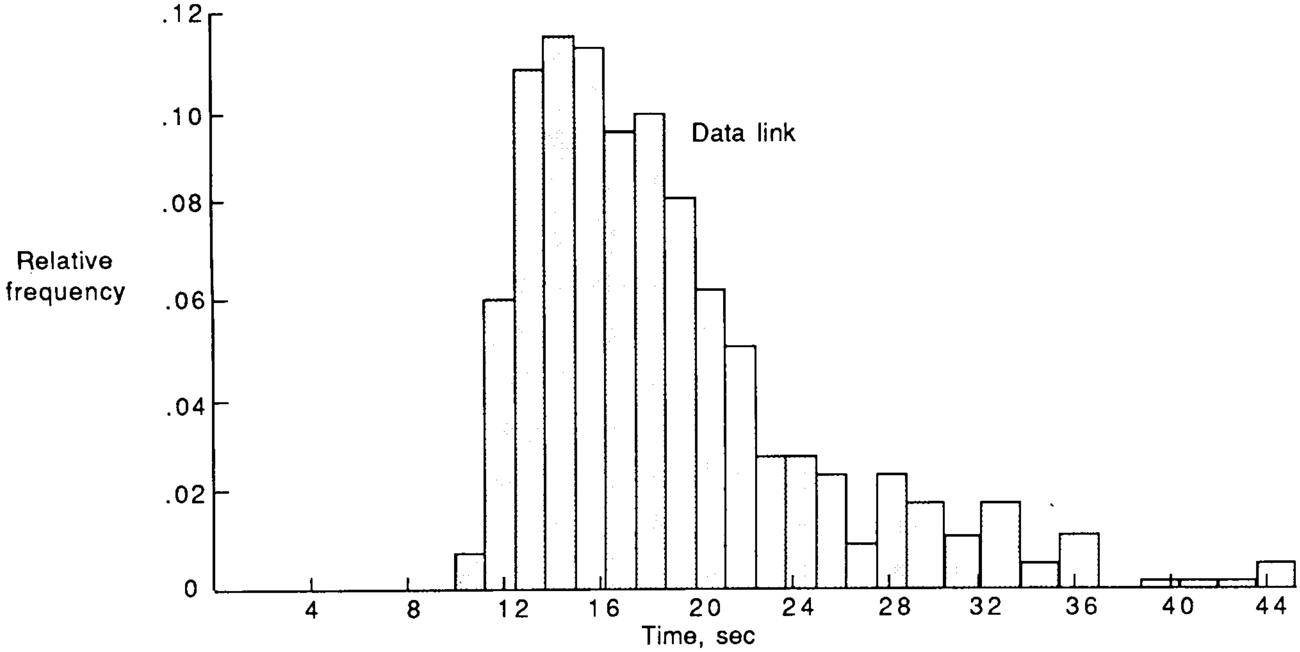


Figure 10. Histograms of message exchange session lengths.

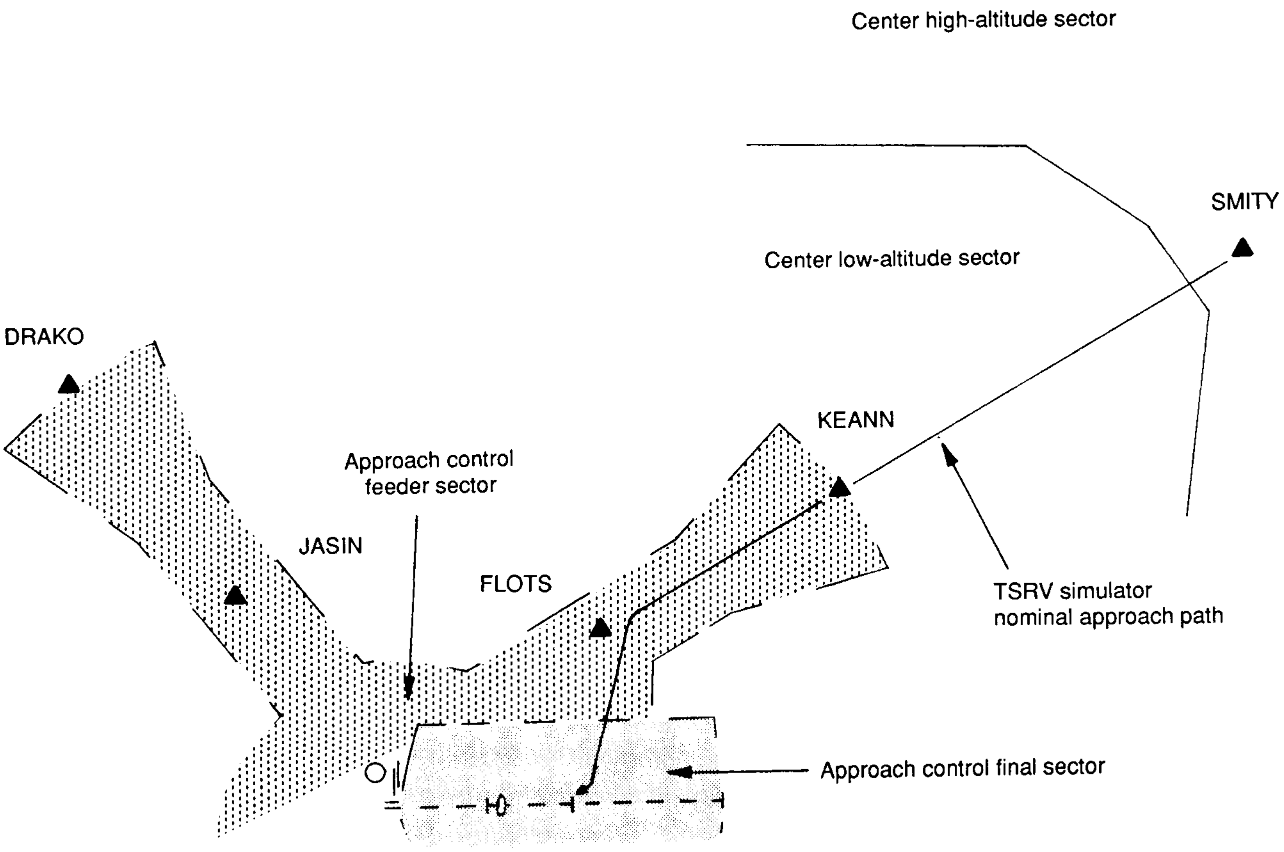


Figure 11. Simulated Denver Center and terminal airspace.

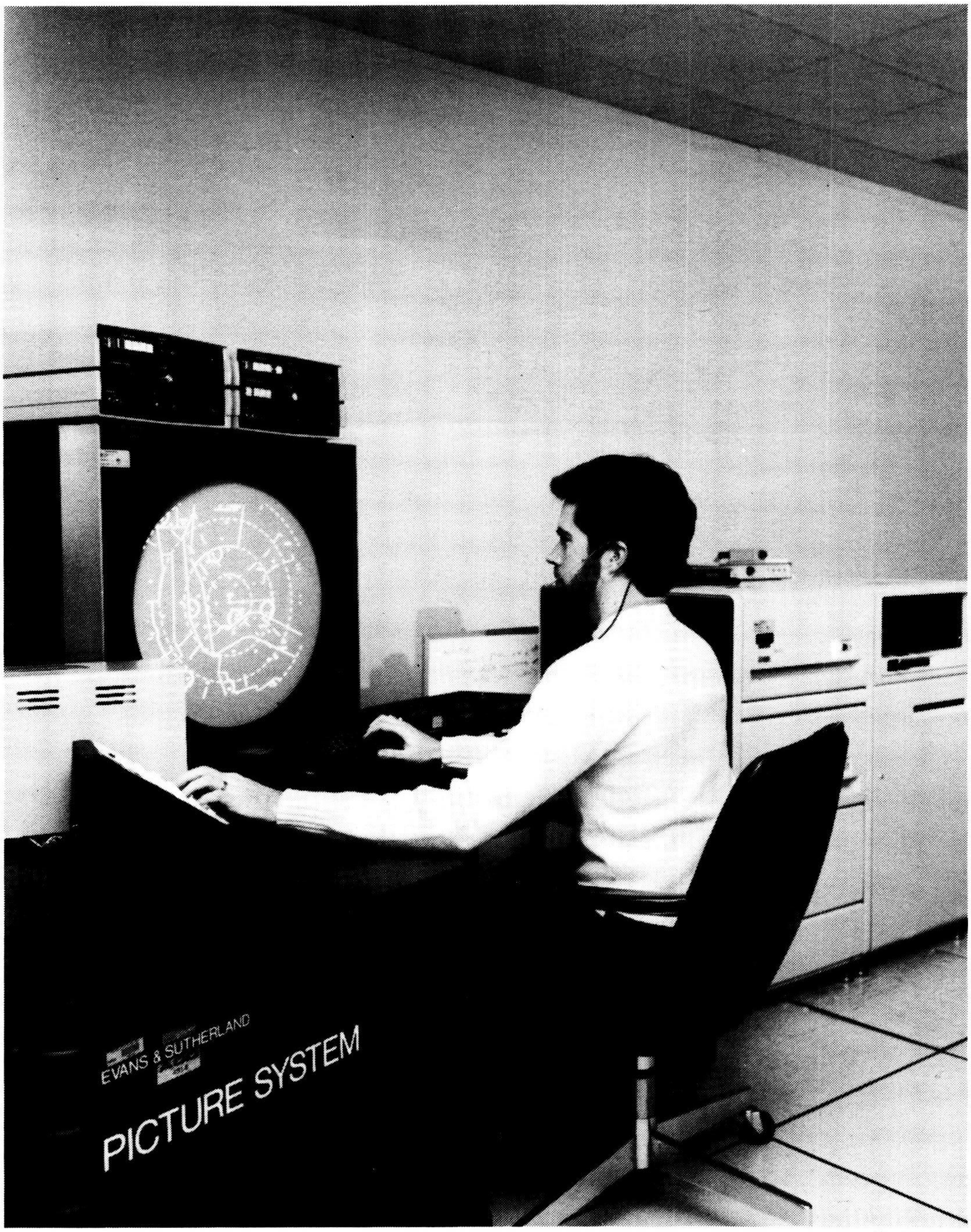


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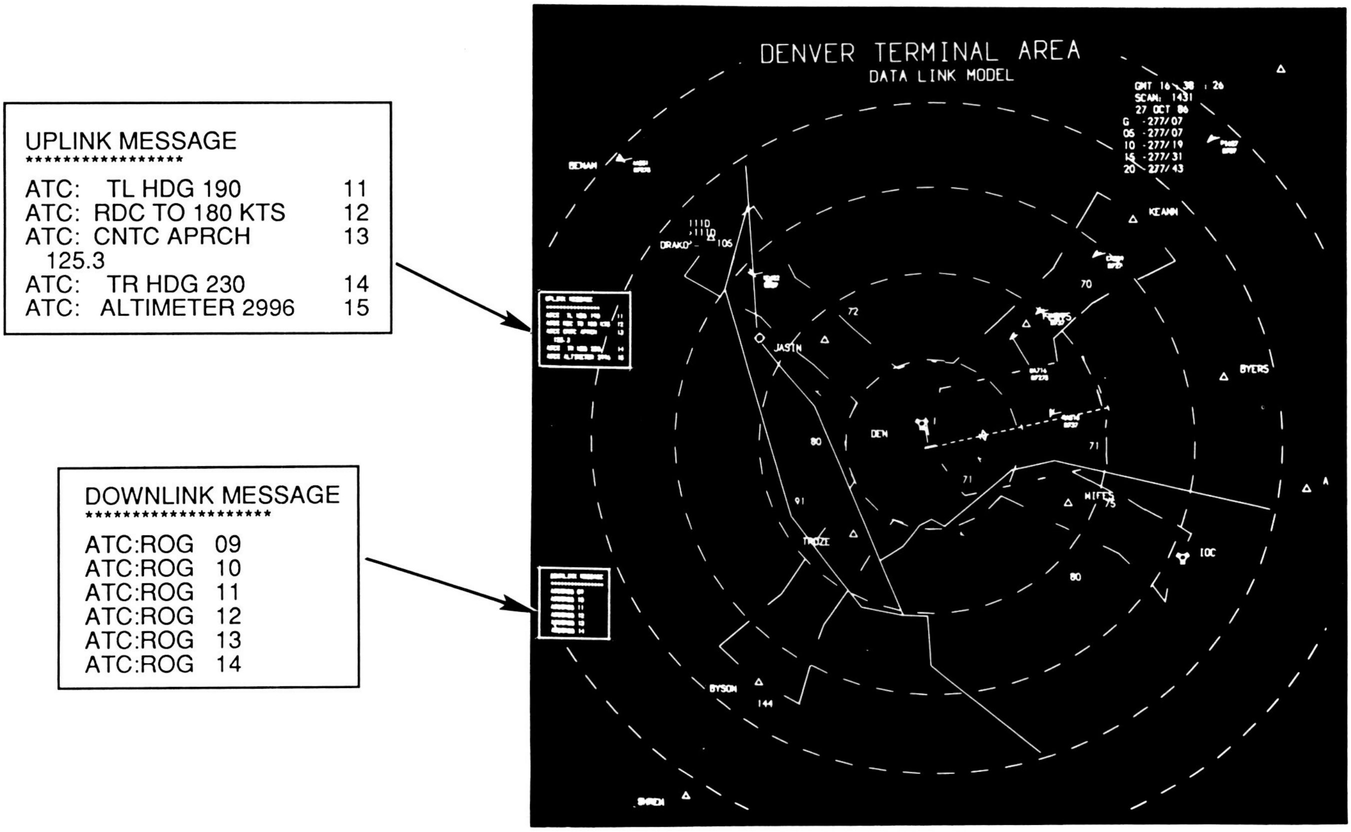
Figure 12. Langley Mission-Oriented Terminal-Area Simulation Facility air traffic controller's station.



UPLINK MESSAGE

```
*****************
ATC:   TL HDG 190          11
ATC:  RDC TO 180 KTS       12
ATC:  CNTC APRCH           13
   125.3
ATC:   TR HDG 230          14
ATC:   ALTIMETER 2996      15
```

DOWNLINK MESSAGE

```
*********************
ATC:ROG  09
ATC:ROG  10
ATC:ROG  11
ATC:ROG  12
ATC:ROG  13
ATC:ROG  14
```

Figure 13. Controller station plan position indicator (PPI) with magnified views of the data link message areas.

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16. Abstract

Digital data link air traffic control (ATC) and air traffic service (ATS) message and data exchange offers the potential benefits of increased flight safety and efficiency by reducing communication errors and allowing more information to be transferred between aircraft and ground facilities. Digital communication also presents an opportunity to relieve the overloading of ATC radio frequencies, which hampers message exchange during peak traffic hours in many busy terminal areas. A piloted-simulation study to develop pilot factor guidelines and assess potential flight crew benefits and liabilities from using data link ATC message exchange has been completed. The data link ATC message exchange concept, implemented on an existing navigation computer control display unit (CDU) required maintaining a voice radiotelephone link with an appropriate ATC facility. Flight crew comments, scanning behavior, and measurements of time spent in ATC communication activities for data link ATC message exchange were compared with similar measurements for simulated conventional voice radio operations. The results show crew preference for the quieter flight deck environment and a perception of lower communication workload.

17. Key Words (Suggested by Authors(s))
Flight deck data link interfaces
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Air traffic control
ATIS
Data link message exchange
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