NASA
Technical
Paper
2837

December 1988

Simulator Investigation of Digital Data-Link ATC Communications in a Single-Pilot Operation

David A. Hinton
and Gary W. Lohr

(NASA-TP-2837) A SIMULATOR INVESTIGATION OF THE USE OF DIGITAL DATA LINK FOR PILOT/ATC COMMUNICATIONS IN A SINGLE PILOT OPERATION (NASA) 41 p CSCL 17B
N89-11726
Unclas
H1/04 0156104

NASA

NASA
Technical
Paper
2837

1988

Simulator Investigation of Digital Data-Link ATC Communications in a Single-Pilot Operation

David A. Hinton
Langley Research Center
Hampton, Virginia

Gary W. Lohr
Embry-Riddle Aeronautical University
Daytona Beach, Florida

National Aeronautics
and Space Administration

Scientific and Technical
Information Division

Summary

Previous studies have shown that radio communications between pilots and air traffic control contribute to high pilot work load and are subject to various errors. These errors are caused by congestion on the voice radio channel and result in missed and misunderstood messages. The use of digital data link has been proposed as a means of reducing the work load and error rate. A critical factor, however, in determining the potential benefit of data link will be the interface between future data-link systems and the operators of those systems, both in the air and on the ground. The purpose of this study was to evaluate the pilot interface with various levels of data-link capability in simulated, general-aviation, single-pilot, instrument-flight-rule operations. The study was conducted in a light, twin-engine-airplane simulator equipped with a motion base and an out-the-window visual scene. The scenarios included all flying, navigational, and communications tasks associated with arrival and departure operations.

During the simulated flight operations, the data link reduced demands on the pilots' short-term memory, reduced the number of communication transmissions, and permitted the pilots to more easily allocate time to critical cockpit tasks while receiving air-traffic-control messages. The pilots who participated in the study unanimously indicated a preference for data-link communications over voice-only communications. There were, however, situations in which the pilots preferred the use of voice communications. These situations included takeoff clearance, messages received with the airplane at a low altitude, and pilot requests for altitude or heading changes. A disadvantage of the data link was an increased time delay in the acknowledgment of messages to air traffic control, that was the result of a tendency of the pilots to delay the processing of data-link messages during high-work-load events.

Introduction

Prior research has shown general-aviation, single-pilot, instrument-flight-rule (IFR) operations to be very challenging for a pilot. Most tasks in terminal airspace are time-critical, and during periods of high work load the pilot may not be able to perform all tasks with the desired precision or cross-checking. The study described in reference 1 showed that when a copilot was introduced into flight operations and was allowed to perform only certain tasks for the pilot, the most beneficial task was communicating with air traffic control (ATC). An analysis of actual operational problems (ref. 2), as reported to the Aviation Safety Reporting System, also showed ATC and pilot communications to be a major problem area in single-pilot IFR operations. These communication problems included misunderstood instructions, frequency congestion, and excessive frequency changes. These problems suggest that improvements in communications between pilots and ATC may reduce errors and increase the safety and utility of general-aviation aircraft.

The use of digital data-link communications between pilots and ATC has been proposed as a means of improving the communications link. Data link was previously evaluated in a simple general-aviation training simulator (ref. 3) with favorable results. An in-flight study of a simulated data-link capability was also conducted in a light, twin-engine airplane (refs. 4 and 5), and comments from the pilots were generally favorable. The use of data link for air-carrier aircraft has also been proposed and studied (refs. 3 and 6). With the introduction of the discrete-address Mode-S transponder and proposals for other data-link channels, such as satellite data link and radio links similar to the Arinc communications addressing and reporting system (ACARS), data-link communications between pilots and ATC have become feasible. A critical factor in determining the utility and acceptance of data link will be the interface between future data-link systems and the operators of those systems, both in the air and on the ground.

The purpose of this study was to evaluate the pilot interface with various levels of data-link capability in a realistic IFR environment. Determining the relative benefits of various levels of capability was desirable, since previous research (ref. 1) has shown simplicity of equipment operation to be an overriding consideration in single-pilot operations. This study was conducted in a general-aviation, light, twin-engine-airplane research simulator equipped with a motion base and an out-the-window visual scene. A simulation of an ATC facility was used to represent the ATC environment in the vicinity of Denver, Colorado, during arrival and departure scenarios from Stapleton International Airport. The scenarios included all flying, navigational, and communications tasks associated with operations between the runway and en route cruise. For each data-link level, measurements were made of voice and data-link activity and of the time required for pilot response to ATC messages. Pilot acceptance and operational advantages and disadvantages of each data-link level were also determined.

Abbreviations

ABV	above

ACARS	Arinc (Aeronautical Radio, Incorporated) communications addressing and reporting system
ADF	automatic direction finder
ALT	aircraft altitude, ft above mean sea level; also altimeter setting, inches of mercury
APPR	approach
ARR	arrival
ATC	air traffic control
ATIS	automatic terminal information service
ATISA	approach ATIS information
BACK SPC	backspace
BKN	broken
CDI	course-deviation indicator
CLRD	cleared
CLRNC DELIV	clearance delivery
CO	Colorado
COMM	communications
CRT	cathode ray tube
DEN	three-letter identifier for Denver's Stapleton International Airport; also DENVER VORTAC
DEP	departure
DIR	direct
DME	distance measuring equipment
EXPT	expect
FAA	Federal Aviation Administration
FT	feet; also terminal forecast
GA	general aviation
GLD	three-letter identifier for GOODLAND VORTAC
HDG	aircraft heading from magnetic north, deg
HSI	horizontal situation indicator
ICG	icing
IFR	instrument flight rules
ILS	instrument landing system
INFO	information
IOC	three-letter identifier for KIOWA VORTAC
KS	Kansas
LOC	ILS localizer
MIN	minutes
MOD	moderate
MOTAS	mission-oriented terminal-area simulation
MSG	message
MTN	maintain
N/A	not applicable
NAV	navigation
NDB	nondirectional radio beacon
NE	Nebraska
OCNL	occasionally
OM	ILS outer marker
OVC	overcast
PIREP	pilot weather report
REQ	request
RWY,RWYS	runway(s)
S	standard deviation
SIGMET	significant meteorological information
SVR	severe
TACAN	tactical air navigation
TEMP	temperature, °F
TERM	terminal
TWR	air-traffic-control tower (local controller)
TXC	three-letter identifier for THURMAN VORTAC
UA	pilot report
VIS	visibility
VLDS	visual landing display system
VOR	very high frequency omnidirectional radio range
VORTAC	combined VOR and tactical air navigation

WILCO	will comply
WX	weather

Description of Equipment

Airplane Simulation

The Langley General Aviation Simulator was used in this study. The hardware consisted of a fully enclosed cockpit mounted on a two-degree-of-freedom motion-base platform. The motion base provided pitch and roll cues. The Langley Visual Landing Display System (VLDS) provided out-the-window visual cues for taxi, takeoff, approach, and landing. A collimating lens focused the image at infinity, and various weather-ceiling and visibility conditions were simulated. The cockpit instrument panel was configured as a generic, general-aviation, multiengine airplane (fig. 1). The instruments included a horizontal situation indicator (HSI), a course-deviation indicator (CDI), an automatic direction finder (ADF), and distance measuring equipment (DME). The avionics were representative of state-of-the-art equipment, with active and standby frequencies for all radios. This feature permitted the pilot to select the next frequency in the standby window during low-work-load periods and to activate that frequency when needed by pushing one button. The control yoke and rudder pedals in the simulator were hydraulically loaded to provide the appropriate force gradients with changes in airspeed and configuration. A sound system in the simulator cockpit provided engine- and wind-noise cues. The engine sound varied with engine speed, and the wind noise varied with airspeed. The simulator and VLDS were driven by a CYBER 175 digital computer.

The simulator software modeled a Cessna 402B airplane. The model included wing-flap and landing-gear effects on airplane stability and performance, instrument and engine lags, and an atmospheric wind model. No atmospheric turbulence was used in this study. A navigational data base, which simulated the environment in the area of Stapleton International Airport in Denver, Colorado, was used. The data base extended to the en route environment, about 60 miles east of Denver, and included the instrument landing system (ILS), nondirectional radio beacon (NDB), omnirange/TACAN (VORTAC), marker beacon, and DME facilities that were applicable to the scenarios defined for this study.

Air-Traffic-Control Simulation

The ATC simulation was provided by one individual, assuming the role of all controllers and pseudo pilots, using an ATC station (fig. 2) located in the Langley Mission-Oriented Terminal-Area Simulation (MOTAS) Facility (ref. 7). Pseudo aircraft were simple representations of aircraft accomplished by displaying the software-modeled aircraft on the controller's display. The sole purpose of the pseudo aircraft was to provide realism to the subject pilot, in the form of audio communications between ATC and other aircraft. Voice communications between the subject pilot and the controller were achieved only when both were tuned to the same radio frequency. An automatic terminal information service (ATIS) message capability was provided with a tape player. The pilot could receive ATIS messages by tuning either communication radio to the ATIS frequency. The various ATIS messages used are shown in the appendix. A voice disguiser was used to permit one person to act as the ATC controller and pseudo pilots, and present to the subject pilot a different voice for each of those roles. The voice disguiser was manually set for each voice setting as required.

The operational environment for the ATC simulation was the Stapleton International Airport and the surrounding terminal area. The terminal area, or approach-control airspace, was centered around the Stapleton International Airport and extended from the surface to 20 000 ft. The airspace configuration included four arrival corridors; the areas separating the arrival corridors were used for departures and are called departure gates. At Denver, the flow of arrivals is normally through the arrival corridors; however, in the case of light twin-engine and single-engine propeller-driven aircraft, low-altitude inbound routings through the departure gates are frequently used. These routings allow slower and faster traffic to merge closer to the airport, which produces a more efficient flow of traffic. During the simulations, the subject aircraft received inbound routings through both the arrival corridors and through the departure gates.

Control instructions issued to the subject aircraft were similar to those actually used at Stapleton International Airport for arriving light commuter aircraft and general-aviation aircraft, including techniques commonly used to lessen the impact of slower aircraft on the traffic flow. Specific examples include requests to maintain the best possible speeds and vectors to join the final-approach course at the final-approach fix.

During arrivals, the subject airplane encountered a total of five controllers: a center controller, two approach controllers, a tower controller, and a ground controller. During departures, the airplane was handled by a ground controller, a tower controller, a departure controller, and a center controller.

Communications were provided between the ATC controller in the MOTAS facility and the pilot in the cockpit by both voice link and data link. The voice link consisted of a headset and push-to-talk switch for the pilot, communication radios and audio controls in the cockpit, and a voice line to the MOTAS facility. From the pilot's point of view, the voice-system operation was nearly identical to the real-world environment. The cockpit audio panel allowed the pilot to select which of the two communications radios would be used for transmitting and which radios would be connected to the pilot's earpiece or cabin speaker. Selecting the audio from a navigation receiver gave the morse-code identification for the selected station. The two communications radios had individual volume controls and were individually tuned. As in the real world, it was necessary for the pilot and the ATC controller to be on the same frequency for communications to take place. Unlike the real world, only one controller was present in the simulation, and the pilot was able to communicate only with the current control facility.

Data-Link Simulation

Data-link messages were presented to the pilot on a data-link panel (fig. 3) which was installed on the cockpit instrument panel immediately to the right of the flight instruments (fig. 1). A cathode ray tube video screen (CRT) was provided to display ATC and weather messages to the pilot, and a keyboard enabled the pilot to acknowledge ATC messages and down-link messages to ATC. Major components of the display format were an 8-line by 30-character text area in the center of the screen, for weather and ATC messages; two dedicated windows at the bottom of the screen, which showed the last assigned heading and altitude; and a scratch pad between the text area and the dedicated windows, for composing down-link messages. The up link of an ATC message was annunciated with a light located just above the attitude indicator and with an audio tone. New messages appeared in inverse video (black on a white background) until that message was acknowledged. The message then changed to normal video (white on a black background). In certain data-link runs, a small cockpit printer was available to the pilot. Pressing a button on the data-link panel caused the contents of the CRT to be printed.

Four levels of communication capability were tested in this study. Level 1 was a baseline, voice-only communication capability. No data-link communications were possible. The voice communication capability was retained in all data-link levels. Level 2 provided one-way data link, from the controller to the pilot, of heading and altitude to fly. One-way data link indicates that no messages could be sent over the data link by the pilot, except for acknowledgment of ATC messages. Only the dedicated windows at the bottom of the CRT were used, and no textual information was transmitted. Level 3 provided the capability of level 2, plus one-way data link of textual information. The textual information was used for such tasks as initiating hand-offs, vectors, and approach and landing clearances. Level 3 also included the use of the cockpit printer. Level 4 provided the capabilities of level 3 plus the capability of the pilot to send messages to ATC and to request weather information on a separate weather page. The messages that could be sent to ATC were "Request clearance" for the initial IFR route clearance, "Request taxi," "Request takeoff," "Request altitude ___," and "Request heading ___." The last two messages required the use of the numeric keys to enter the desired altitude or heading. The weather page permitted the pilot to request arrival and departure automatic terminal information service (ATIS) information, pilot weather reports (PIREPS), significant meteorological information (SIGMET) advisories, and the local terminal forecast. The data-link levels are summarized as follows:

Data-link level	Data-link features
1	None (voice only)
2	Level 1 + heading and altitude windows and acknowledgment down link
3	Level 2 + textual-data up link and printer
4	Level 3 + textual-data down link and weather page

Detailed information on the implementation of the data-link simulation and the pilot and controller operation of the data link is presented in the appendix.

Description of Task

Several assumptions were made during the design and performance of this study. The primary assumption was that the data link was intended to coexist with, not replace, the voice channel. This arrangement was intended to permit routine ATC communications, which encompass the majority of ATC transmissions, to be handled with a simple data-link interface. The voice channel remained available for nonroutine communications. The protocol for data-link usage was designed to coexist with voice-link usage. For example, a hand-off from one controller to another would begin with a data-link message such as "Contact DEN approach 119.45." The pilot would use the data-link "YES" button to acknowledge the message and would then tune the communication transceiver to the next controller frequency, 119.45. Standard voice phraseology, such as "Denver approach, NASA 402 with you, 9000 ft," would then be used to establish contact with the second controller. The second controller would acknowledge the voice transmission via voice and would then use the data link for later messages. The protocol was designed so that a listening watch would always be maintained with the current ATC controller. Data-link messages were acknowledged via the data-link and voice messages were acknowledged via voice.

A second assumption was that the procedures in use in the ATC system of today (ref. 8) would initially be used with data link. Although the use of data link for tactical messages is probably not possible without significant ATC automation, the form of this automation is not known at present and could be transparent to the pilot. Present-day procedures were therefore used in this effort. For example, the pilot was required to inform the initial approach controller that the current ATIS information had been received and to provide controllers with the airplane altitude on the first voice contact. No advanced ATC procedures or automation were assumed, other than the presence of data link. It was further assumed that not all aircraft would be data-link equipped; the voice communications overheard by the subject pilot therefore included other aircraft.

This effort was intended to be a study of the use of the data link in a general-aviation, single-pilot operation. Work load and the pilot interface with controls and displays are especially critical in this type of operation (ref. 1); therefore, no copilot was used, nor was the use of the simulator autopilot permitted.

Arrival Scenarios

The piloting task consisted of both arrival and departure scenarios. The arrival scenarios began with the simulated airplane about 30 n.mi. from Denver, in Denver Air Route Traffic Control Center (Denver Center) airspace. Four arrival scenarios, based on two basic arrival routes, were used. The four scenarios are depicted in figure 4. In the first arrival route (used for scenarios A1 and A2), the airplane was initialized on victor airway 4 (V4), at the BYERS intersection at an altitude of 12 000 ft on a heading to track the airway westbound. The pilot was told before the run, in this case, that the current clearance was to track V4 to the DENVER VORTAC at 12 000 ft. In the second arrival route (used for scenarios A3 and A4), the airplane was initialized on victor airway 148 (V148), 10 n.mi. northeast of the KIOWA VORTAC at an altitude of 12 000 ft on a heading to track the airway to KIOWA. The pilot was told before the run that the current clearance was to track V148 to KIOWA and victor airway 19 (V19) to DENVER and to maintain 12 000 ft.

The four arrival scenarios were used to prevent the pilots from knowing the vectors and altitudes to expect on each run; they are labeled A1 through A4. Scenario A1 used the first arrival route and involved an approach and landing on runway 35R. Scenario A2 also used the first arrival route but used runway 26L for the landing. Scenario A3 used the second arrival route and terminated with a landing on runway 26L. Scenario A4 also used the second arrival route but terminated with a landing on runway 35R. The length of each run was approximately 20 min, and the four arrival scenarios were considered equivalent for data analysis purposes.

In each of the arrival scenarios, the pilot began the run under the control of Denver Center. The pilot was required to acquire the current ATIS information from Stapleton International Airport in anticipation of the hand-off from the Denver Center controller to a Denver Approach controller. After the hand-off to Denver Approach, the pilot began to receive altitude assignments and vectors to one of the two ILS approaches used in the study. The instrument approach charts for the approaches are shown in figures 5 and 6. The runs were terminated after the landing, while the airplane was still on the runway. During the vectoring operation, hand-offs to other controllers were accomplished as the airplane flew from one ATC sector to another.

Departure Scenarios

Three departure scenarios, based on two basic departure routes, were used. The three scenarios are depicted in figure 7. The pilot was told prior to the runs that a flight plan to Goodland, Kansas, had been filed with a requested cruising altitude of 11 000 ft. This destination is approximately 150 n.mi. east of Denver, and the pertinent airways and navigation facilities are shown in figure 8. The flight-plan route was V4 to GOODLAND. The first departure route used was the flight-plan route. The other route was V19 to KIOWA, V148 to THURMAN, and V4 to GOODLAND. Both runways, 26L and 35R, were used for departures in the V4 scenarios. Only runway 26L was used in runs that involved the V19 departure route. Therefore, there were three departure scenarios, labeled D1 through D3. Scenario D1 used runway 35R for takeoff and used the V4 departure route. Scenario D2 began with a takeoff on runway 26L and also used the V4 departure route. Scenario D3 also began on runway 26L, but the airplane used the second departure route. Each scenario required approximately 20 min and is considered equivalent to the others for data analysis purposes.

The departure scenarios began with the airplane on the ground. The airplane was positioned on a taxiway at the entrance to the departure runway in use. After beginning the run, the pilot was required to obtain the current ATIS information and the IFR clearance to Goodland. The IFR clearance generally included climb restrictions rather than allowing an uninterrupted climb to the requested altitude. After accepting the clearance, the pilot contacted the tower and was cleared for takeoff. For added realism, the pilot was randomly given a direct takeoff clearance, was told to hold for landing traffic, or was told to taxi into position and hold.

After takeoff, the pilot was given a hand-off from the tower to departure control and was provided with vectors to the airway. In the case of a departure to V4, the pilot was given vectors that paralleled the airway to the north. This procedure kept the departure path clear of the arrival flow to runway 26L. The airplane altitude was restricted to 10 000 ft until after passing a routine flow of arrival traffic that departed the FLOTS intersection southbound. Once clear of the arrival traffic, the pilot was given a vector to intercept V4. In the vicinity of the BYERS intersection, the pilot intercepted V4, and was given a hand-off to Denver Center. The run terminated after the hand-off. In the case of a departure to V19, the pilot was vectored to the southeast of the airport and then given a clearance to either intercept V19 or to proceed direct to KIOWA. Shortly after passing the KIOWA VORTAC, the airplane was given a hand-off to Denver Center, and the run was terminated. In both runs, the airplane was given hand-offs to other controllers as it entered the various ATC sectors.

Weather Conditions

The VLDS system was used to provide ceiling and visibility limitations. Two basic weather conditions were used. One was a ceiling of 450 ft with a visibility of 2 mi. The second was a ceiling of 700 ft with a visibility of 5 mi. The recorded ATIS information reflected these conditions with reported ceilings between 400 ft and 1000 ft. An additional condition with zero ceiling and zero visibility was used on one arrival run for each pilot to force a missed approach. When the airplane was above the ceiling set for each run, no visual scene was available out the simulator window. Below the ceiling, the outside world became visible. The wind in each run was from the northwest and was either 3 or 8 knots in any given scenario. No atmospheric turbulence was used in the simulation.

Abnormal Situations

Two aircraft abnormal situations were introduced in the simulation to evaluate the pilot acceptance of data link in those situations and to prevent the runs from becoming completely routine. The pilots were not told that any particular abnormal situation would occur and were told to operate the simulator as they would an actual airplane, during the scenarios, until the runs were terminated by the researcher. The abnormal-situation runs were considered separately from the normal runs for data analysis purposes.

One abnormal situation, included in one of the arrival scenarios, involved a complete loss of voice communications during the hand-off from Denver Center to Denver Approach. This abnormal situation was only introduced with the two highest levels of data-link capability, levels 3 and 4. In these runs, normal communications took place until the pilot attempted to contact the first approach controller. From that time, the controller in the MOTAS facility ceased to call or respond to the pilot over the voice link, or to communicate with the pseudo aircraft. The remainder of the run was conducted with only the data link; ATC continued to send appropriate data-link instructions.

The other abnormal situation involved a failed engine during a departure scenario. This abnormal situation was also only introduced with the two highest levels of data link. The departure scenario used was a runway 26L takeoff and vectors to parallel V4 in preparation for joining V4 eastbound. Approximately 10 n.mi. northeast of the airport, in level cruise flight, the right engine was failed by simulating an idle throttle setting in software. The scenario was designed with the expectation that the pilot would respond to the engine failure and request a return to Denver for a landing. Air traffic control, upon being advised of the problem, made the standard requests for the number of people on board, fuel remaining, and the nature of any assistance required. After the pilot requested a return to Denver, the controller provided vectors for an ILS approach to runway 26L. The run was terminated after landing. Although the pilot was expected to use the voice channel to report the situation and the ATC controller used voice for acknowledgment and the initial questions, the scenario called for ATC to return to the data link for the remainder of the flight.

In addition to the planned abnormal situations, several simulator hardware problems affected the runs. One problem involved the tuning of the avionics. The hardware that detected the movement of the rotary tuning knobs on the avionics panel would occasionally misread pilot input and would cause difficulty in frequency setting. Since this problem had the potential to artificially increase pilot work load, the pilots were briefed on this difficulty and told that the researcher in the cockpit would assist in clearing the malfunction when requested. The pilot was required to attempt to tune the radio in each case. A second problem involved the matching of the frequency tuned on the cockpit radio and the frequency on the frequency-select box in the MOTAS facility. Occasionally during a hand-off, the hardware would not detect that the pilot had switched frequencies, which would prevent contact with the next controller. When this happened, the pilot would generally return to the previous ATC frequency to report the inability to contact the next controller. The researcher in the cockpit, in this case, used a separate, non-ATC line to advise the controller to return to the previous frequency. In other cases, the researcher in the cockpit cleared the problem and used the non-ATC line to advise the controller that the pilot had attempted a call. The controller would then call the pilot with a message such as "Last aircraft calling, say again." The pilots participating in the study reported that this problem actually increased the realism of the simulation, since similar difficulties and corrective actions occur in the real world. Finally, the airplane math model provided very little pitch stability and required the pilot to spend more time on basic attitude control than would be necessary in an actual airplane. The low pitch stability was considered desirable (by the researcher) from the aspect of using increased pilot work load to increase the sensitivity of the study to differences in work load with and without data link.

Experiment Matrix and Test Procedure

Prior to any data runs, each pilot was given a minimum of 3 hr of familiarization with the simulator, the Denver ATC environment, and the data-link levels. The practice sessions included complete arrival and departure runs, with the data link, over routes that were different from the ones used in the data runs. The experimental matrix is shown in table 1. Each pilot flew a total of 10 data runs. Two runs introduced abnormal conditions involving aircraft system malfunctions. The remaining eight runs were equally divided between arrivals and departures. The first run for any pilot was with voice only, to provide additional familiarity with the environment, and the data-link levels were presented in order of increasing levels of capability. Four pilots participated in the study, two of which were NASA research test pilots. All pilots were qualified for the operation being simulated and held at least a commercial certificate with multiengine and instrument ratings.

Data

The data collected during the study included the number of data-link messages sent by ATC and by the pilot, the time taken by the pilot to acknowledge data-link messages, and the time and duration of controller and pilot voice transmissions. Only ATC transmissions to the subject airplane were counted; a separate controller headset was used for transmissions to other aircraft. Data for controller voice transmissions were derived from a voice-activated discrete signal. The data were filtered so that ATC transmissions to the subject airplane that were less than 1 sec apart were counted as one message. The voice data for pilot transmissions were derived from the pilot's push-to-talk switch, which was not subject to this problem. Information on the number of times the cockpit printer was used, the time used by the pilot to compose down-link messages, and the use of the data-link weather page were also included in the data set. Pilots were encouraged to make brief comments during the data runs, when appropriate, and a list of questions were asked of the pilots after the data runs. Finally, researcher observations of pilot/data-link interaction were included in the analysis. The data set collected made possible an analysis of the effect of the different levels of data link on voice communications and on pilot response time to ATC. The observations and pilot comments made possible an analysis of the impact of the data link on the piloting task.

Results and Discussion

The data were examined to determine how the data link affected the communication activity between the pilot and controller. The time required for pilot response to ATC data-link and voice messages and the number of data-link and voice messages for each data-link level were determined. The interaction of the use of data link with other cockpit tasks and pilot acceptance of the data link were examined.

Response Time to ATC

The pilot response time to messages is defined as the interval between receipt of a message by the pilot and the acknowledgment of that message by the pilot.

The time interval between pilot receipt of a message and the performance of any action required by that message, such as initiating a turn, is not considered in the response time. For voice transmissions, the response times were determined by manually timing the interval between the end of an ATC transmission and the beginning of the pilot response. This determination was made using voice recordings for a small sample of the data runs after all runs had been completed. For data-link transmissions, the response times were recorded digitally during all data runs and are the intervals between a message being received in the cockpit and the pilot pressing either the "YES" or "NO" button. This time interval includes the time required for the messages to be written on the CRT, which may vary from 0.5 sec to 6 sec. A detailed discussion of data-link hardware time delays is presented in the appendix. No effort was made to adjust the response times for this factor, since the pilots generally did not begin to read and comprehend the messages until the messages had been completely written; voice messages could be comprehended while the controller was still speaking.

A breakdown of data-link response times, as a function of scenario type and data-link level, is presented in table 2. The mean and standard deviation of voice response times, for a sample of all runs, were 0.9 sec and 0.7 sec, respectively. The response times were significantly greater with data link; response time began with a mean of 5.8 sec for level 2 and increased to a mean of 11.6 sec for level 3. In data-link level 2, the message writing time was only 0.5 sec. The variation in data-link response times was also large. Of the total of 297 data-link messages sent to the airplane during the study, 20 of the responses took longer than 20 sec, 9 exceeded 30 sec, 4 exceeded 40 sec, and 2 took longer than 1 min. The longest response time was 69 sec.

Several factors appear to be involved in the response delays. One is that the pilots generally did not read a message immediately if another task was in progress when the message was received. An example would be a message received just as the pilot was leveling at a new altitude and resetting power and pitch trim. In this type of situation, the pilots tended to complete the maneuver prior to reading the data-link message. Another factor is that the pilots would frequently perform the action required by a message prior to acknowledging the message. An example of this would be receiving a clearance to turn to a new heading. The pilots frequently set the HSI heading bug to the new heading and began the turn prior to acknowledging the message.

Another factor in the response delays was the occasional reluctance of a pilot to acknowledge a clearance until the pilot had considered the implications of the clearance and had decided that the clearance was acceptable. This situation frequently occurred after receiving the initial IFR departure clearance. In present-day voice operations, pilots acknowledge receipt of that clearance, then consider the routing, and call the controller back if there is an objection or question. The protocol for replying to messages may have contributed to this factor. The "YES" button performed the dual functions of acknowledging and accepting clearances (roger and will comply, WILCO). The "NO" button performed the dual functions of acknowledging and refusing clearances (roger and unable). It is possible that had a "STANDBY" feature been provided, the pilots would have more quickly acknowledged receipt of messages during busy situations. During the entire set of data runs, the "NO" button was only used in four situations, twice to refuse an altitude assignment and twice to refuse a vector given shortly after takeoff.

Yet another factor that contributed to response delays in a few cases was the requirement for the pilot to switch from the weather page to the ATC page, in data-link level 4, if the weather page was active when an ATC message was received. The visual and aural annunciations of message receipt were not factors in the delays. The annunciations provided adequate notification, and none of the pilots reported being unaware that a message had been received.

A common trend in most of the delays was that the pilot processed the data-link information when time permitted, rather than as the data were being received, as must be done in voice communications. When using the data link, pilots had less interaction with a person and more interaction with a machine. The urgency of responding to a person on the ground appeared to diminish. The pilots reported liking the fact that the message stayed on the CRT for later reference. The pilots also cited the priorities taught in flight training—to aviate, navigate, and communicate, in that order. The data link enabled the pilots to push the communication task farther back in time during busy periods.

Communication Errors

One objective of the effort was to determine how the rate of communication errors, such as misunderstood altitude assignments, would be affected by data link. A few errors occurred during the study, but they were too few in number for a statistical analysis. For voice transmissions, there were several cases of pilots requesting that heading or frequency assignments be repeated. Examples of errors include the case of a pilot who was given an initial clearance that included V19; the pilot searched the chart for a

V191. In another initial clearance, a pilot was given a transponder code of 5263, but he copied it as 4263. Finally, while being vectored during an arrival run, a pilot was told to expect an ILS approach to runway 35R; the pilot understood and read back runway 26L.

During the data-link runs, a pilot misunderstood a message to change radio frequency and acknowledged an old heading assignment that was being scrolled up on the CRT to make room for the new message. The pilot then reset the heading bug to the erroneous value. The opportunity for the pilot to read and execute a previous message when receiving a new message could be reduced by displaying only the most recent clearance or by modifying the interface to instantaneously write the new message display. In another incident, the controller accidentally sent a data-link message requesting a descent to 1000 ft, but 10 000 ft was the intended message. The pilot accepted this clearance before realizing the error. Terrain elevation in the simulated area was above 5000 ft. Although the pilots generally did not acknowledge messages until after reading them, there were many cases of the pilot pressing the "YES" button prior to a message being completely written on the CRT. In yet another situation, a 500-ft altitude deviation occurred when the airplane passed through an assigned altitude, in a descent, while the pilot was occupied with getting ATIS information on the data link.

Pilot comments suggest that misunderstood messages would occur less often with data link than with voice only. All pilots reported frequent use of the data link, especially the dedicated heading and altitude display, as a reminder of the last clearance received. One pilot indicated that the data link took the place of a separate altitude-reminder device.

Communication Activity

For each run, the total number of voice and data-link messages and the duration of the voice messages were recorded. Table 3 shows the average number of ATC voice messages to the airplane per run and the average duration of those transmissions for each data-link level. The data are broken out by scenario type: arrival, departure, communication failure, engine failure, and all nonemergency runs. Except for the engine-failure scenario, all data runs were of approximately the same length of time and flight distance, so the number of transmissions per run can be directly compared.

The number of voice transmissions per run steadily decreased as the data-link capability increased. In the baseline voice runs, ATC made about 21 transmissions to the airplane per run. This fell 31 percent, to about 14.5 calls per run, with the up link of only heading and altitude to the airplane. A large reduction in voice activity occurred when the ability to send text messages was used. The number of ATC voice transmissions to the airplane fell to about seven per run in data-link level 3, for a reduction of 67 percent from the baseline level. A very small additional reduction in the number of calls occurred when the pilot was given the down-link capability of level 4, to about six calls per run. The average duration of the ATC transmissions to the airplane remained almost constant between data-link levels; it varied from about 4.5 sec per transmission with levels 1 and 2 to about 3.5 sec per call with levels 3 and 4.

The data-link activity from ATC to the subject airplane is shown in table 4. The average number of data-link messages per run was at 6.4 for data-link level 2 and increased to about 10 for the highest data-link level. In level 4, any weather data up linked to the airplane, that was requested by the pilot using the weather page, was not considered to be an ATC message and is not included in the count. The number of data-link transmissions per run did not increase with increased data-link levels as rapidly as the number of voice transmissions decreased. This trend is indicated by the data in table 5, which lists the average number of ATC transmissions, both data link and voice, per run. The total number of messages began at 21.3 per run for level 1 and gradually decreased to 15.6 for level 4. Therefore, there were 26 percent fewer ATC messages to the airplane than with the voice baseline at the highest data-link level. Possible reasons for the reduction include fewer missed calls, fewer requests to repeat information, and fewer multiple-transmission "conversations" between the pilot and ATC because of the concise nature of the data-link messages.

The voice activity by the pilots is summarized in table 6, which shows the number of pilot transmissions per run and the average length of those messages. The trend is similar to the ATC voice activity; there is steadily decreasing voice activity with increases in the data-link capability. The pilot voice activity was reduced 67 percent from the baseline with data-link level 4.

Mixing of Voice and Data-Link Messages

The voice channel of communication was retained and used in the data-link runs. Each hand-off to a new controller involved a voice communication with the receiving controller, and any unusual requests or negotiations were handled by voice. A general rule in the study was that any given message would be sent either via voice or data link, but not by both. Exceptions occurred in data-link level 2, where messages such as the instrument-approach clearance had to be sent via voice and where the clearance contained a heading and/or altitude to fly. In that case, the heading and/or altitude portion of the clearance was also transmitted via the data link. Exceptions also occurred, in all data-link levels, for situations in which the pilot negotiated a new heading or altitude verbally with the controller. Once the negotiation was begun with voice, it was completed with voice, but the new clearance was then sent up via the data link.

The pilots, with a few exceptions, reported that the mix of voice and data-link communications seemed completely natural. Exceptions to the positive comments on the mix of voice and data link included situations that involved critical weather and communications with the local controller (control tower). With respect to weather, one pilot commented that any requests for deviations, for example, a heading to avoid thunderstorms, should be handled by voice to minimize pilot work load and to let other pilots in the vicinity know what is happening. The pilots generally reported that they liked the reduced activity on the radio, but that they would miss the "party-line" effect in critical weather situations. With respect to communication with the local controller, all four pilots strongly recommended the use of voice for receiving the clearances to taxi onto the runway and to takeoff. The data-link capability in level 4 enabled the pilot to request and receive takeoff clearance without talking to the local controller, and a few takeoffs were made that way. The pilots believed that the takeoff clearance was so critical, and that establishing radio contact with the tower was important enough, that the data link should not be used as the sole channel for takeoff clearance. Use of the data link to confirm the clearance (ATC sending the clearance on both voice and data link) was reported to be acceptable, as was the use of only data link for landing clearance. For landing, however, the pilots were occasionally given clearance via the data link when they were close to the airport and at low altitude. The pilots reported that a late landing clearance should be given via voice, since the visual channel is already heavily loaded from tracking the ILS display. With respect to receiving a message on both the voice and data-link channels, one comment indicated that it seemed strange to receive the data-link message after the voice message. With a time delay between the voice and data-link messages of only 5 to 10 sec, a pilot may initially believe that the data-link message represents a change from the voice message that was just given.

The results suggest that the data-link and voice channels of communication with ATC can be integrated, in single-pilot operations, in a manner that seems natural to the pilot. The data link can assist the pilot with most routine, highly structured messages, and the voice channel is available for negotiations and less-structured messages.

Data-Link Interface Effects

The pilot interface with the data-link capability influenced the use of that capability and the pilot comments. The interface was examined with respect to message alerting, screen display, speed of operation, and keyboard layout.

The audio tone and annunciator light were adequate for alerting the pilot that a new message had been received. There were no occurrences of a pilot not being aware that a message had been received. One pilot reported, however, that the audio alert tone could possibly be confused with the audio from a marker beacon during an ILS approach. Other comments were received requesting that the data-link interface permit the pilot to silence the audio alert prior to reading or acknowledging the message.

The CRT display format generally provided the up-linked messages in an easy-to-read manner. The pilots commented that the print was easy to read, that the use of inverse video made the new, unacknowledged messages obvious and easy to pick out, and that the messages and abbreviations were easy to interpret. A few problems were found, however, with the retention and scrolling of old textual messages on the display. Pilot comments indicated that, although the indentation used to group messages helped declutter the display, the old messages were jumbled together. One pilot suggested that a blank line be used between messages. Another pilot reported that the display was excessively cluttered with old messages and that he wanted an interface feature to erase all the old messages. As noted in the section "Communication Errors," one error occurred when a pilot read an old message and believed it to be the current clearance. Other comments suggested that only the most recent message remain on the CRT and that all old messages be sent either to a buffer or to the cockpit printer.

As noted previously, there were time delays between the annunciation of an incoming textual data-link message and the actual display of that message. Most pilots reported that during the delay between message alert and completion of writing, they temporarily ignored the data link and then included it in their instrument scan until the presence of inverse video indicated that the message had been written. On a few occasions, however, a pilot stared at the data-link display while old messages were being scrolled up and the new message was being written. The resulting interruption in the primary instrument scan resulted in deviations from assigned altitudes and paths and, in one case, occurred while tracking an ILS. These results suggest that a data-link interface should have very short display-write times and should not alert the pilot to a new message until the message is actually being displayed. The time required to send the contents of the data-link display to the cockpit printer, 31 sec, affected the utility of the printer. During that write time, the data-link system could not be used for any other function. The pilots indicated that this was not completely satisfactory and that the printer would have been used more often if the delay had not been present.

The keyboard interface with the data link worked well and generally received positive comments. Since only very simple down-link messages were possible, keyboard use was kept to a minimum. The keyboard buttons applicable to each data-link level were internally illuminated for runs with that level, which effectively decluttered the keyboard for the runs with the lower data-link capability levels. Pilot comments indicated that the keyboard arrangement was easy to use, but one pilot suggested an alternate layout with ATC message buttons in one group and a separate group of weather-product buttons. The proposed weather information group included a dedicated button for each weather product available, such as the ATIS information; this group could eliminate the need for a separate weather data page on the CRT. Other pilot comments suggested that the "YES" acknowledgment button could be more quickly and easily used if it were placed on the pilot's control yoke. Other comments questioned the protocol used to send a down-link message, where one button was pressed to select the message and display it in the scratch-pad area, and then the "SEND" button was pressed. The comments suggested that the message should be selected and sent with only one push of a button.

Overall, the pilot interface with the data-link capability was sufficiently simple and easy to use for general-aviation, single-pilot operations. An operational unit, however, would require improvement in the speed of operation and a reduction in display clutter, possibly by displaying only the most recent message.

Data-Link Use/Cockpit Task Interaction

The pilot comments indicated that, in general, the use of the data-link device did not interfere with other cockpit tasks. Exceptions occurred when the pilot was heavily loaded with other tasks, especially in the visual channel, when the data-link message was received. Examples include receiving a data-link message while in the process of intercepting a localizer, while close to the ground during an ILS approach, while taxiing onto a runway for takeoff, or while still at low altitude shortly after takeoff. In these cases, pilot comments indicated that the data-link messages interfered with the primary task. In a few such cases, flight-path deviations resulted.

Although the data link rarely interfered with the performance of cockpit tasks, the cockpit tasks often interfered with the use of the data link. As described previously, messages received while the pilot was busy with such tasks as capturing an altitude were often ignored until the task was completed.

Utility of Data-Link Levels

The pilots were asked for their assessments of the relative utility of the various data-link levels. The answers generally indicated that the most basic data-link capability, level 2, created a large improvement in ATC communications over the voice baseline. Pilots reported the improvements by saying that they were "much more relaxed" and that the data link "made life easier" during the flights. The data-link benefits increased as the data-link level increased beyond level 2, but at a lower rate. One comment indicated that simply having the heading, altitude, and weather information on a data link would make for a very useful capability level.

At the highest level of data-link capability, level 4, the pilots indicated that the complexity and capability had become more than was necessary. One pilot stated that he did very little with the down-link capability and that most of the benefits existed only with up link. Another comment was that level 4 was excessive for a single-pilot operation. Yet another opinion was that level 3 was best and that level 4 was too complex. No comments were received to indicate that level 3 was too complex. The only difference between the two levels was the ability to down link messages in level 4. The use of terminal-area operations for this study may have affected this result, as some pilot comments indicated that more use would be made of the down-link capability in the lower work load, en route phase of flight, especially for acquiring weather data. The overall results suggest that as the up-link capability increased, the benefits to the pilot increased by reducing demands on the pilot's short-term memory and by allowing the pilot to delay responding to ATC during high-work-load events. The down-link capability, however, increased the pilot's work load.

Concluding Remarks

The use of digital data link for communications between pilots and air traffic control (ATC) provided benefits to pilots in simulated, general-aviation, single-pilot operations. The data link reduced demands on the short-term memory of the pilots, reduced the number of communication transmissions, and permitted the pilots to more easily allocate time to critical cockpit tasks while receiving ATC messages. The four pilots who participated in the study unanimously indicated a preference for data-link communications over voice-only communications. In particular, the use of the data link to receive initial instrument-flight-rule (IFR) route clearances and automatic terminal information service (ATIS) messages, and as a reminder of the most recently assigned heading and altitude, was preferred by the pilots. A mix of voice and data-link communications was used in the data-link runs, and the protocol used to mix the communications was reported by the pilots as acceptable and natural to use.

The pilots perceived benefits with even the simplest data-link capability level and preferred the higher data-link capabilities, which accommodated the up link of textual data. The pilots had little use, however, for the capability to down link messages to ATC; they preferred to use voice for negotiating clearances or making requests. For this reason, and because of the fact that the scenarios did not require in-flight gathering of en route weather information, the down-link capability was primarily used for requesting initial IFR route clearances and ATIS information.

The use of data link caused concern or problems for the pilots in certain situations. Communication with the local controller during taxi onto a runway and during takeoff was judged, by all four pilots, to be too time critical to be received by only data link. The strong preference was for clearance to be given by voice, but data-link was acceptable as a backup. Reception of messages by data link was also not considered acceptable when the pilot was heavily loaded visually with a control task; such as intercepting the instrument landing system (ILS), tracking the ILS at low altitude, landing, taking off, or taxiing.

Data-link communications, as simulated in this effort, have the potential to create problems for the ATC system. The time required to transmit a message was greater than with voice. Additional delays in the action taken on tactical messages by the pilot occurred when the pilot delayed reading messages during high-work-load tasks. Another delay, in the acknowledgment of ATC messages, occurred when the pilot accomplished the task required by a message before giving an acknowledgment. When using the data link, pilots had less interaction with a person and more interaction with a machine, and the urgency of responding to a controller's message tended to disappear. No attempt was made in this research to investigate the interface between controllers and a data-link capability; research in this area is needed to ensure the development of an effective system.

NASA Langley Research Center
Hampton, VA 23665-5225
September 15, 1988

Appendix

Details of Data-Link Displays, Keyboard, and Messages

Patricia B. Naftel
Research Triangle Institute
Research Triangle Park, North Carolina

Data-Link Screen and Keyboard Format

Data-link messages received in the cockpit were displayed on a black and white, rectangular cathode ray tube (CRT) mounted in the center of the cockpit instrument panel (fig. 1). Responses to up-link messages, as well as to pilot-initiated down-link messages, were achieved via a keyboard below the CRT. The CRT and keyboard are shown in figure 3. Details of the data-link display vary as a function of the data-link capability level. Some displays contain only a minimal amount of information for the pilot, while others provide controller commands in full detail.

The large central section of the CRT (see fig. 9) displayed data-link messages in textual form and is referred to herein as the text area. This area could accommodate up to eight lines of text, with each line containing a maximum of 30 characters. Multiple-line messages were indented slightly after the first line to enhance message recognition. New messages were displayed in inverse video until the pilot acknowledged them.

At the bottom of the text area were two boxes dedicated to showing the most recent heading and altitude assignments. These areas are referred to herein as the dedicated windows. The heading was displayed in degrees from magnetic north, and the altitude was displayed in feet. If an air traffic control (ATC) message instructed the pilot to turn left or right to a heading, then a letter L or R, respectively, also appeared in the heading window. An up or down arrow, as appropriate, appeared in the altitude window to command the pilot to climb and maintain, or descend and maintain, an assigned altitude.

Flanking the text area were two vertical rectangular regions which contained display status information for the pilot. The left area contained either "ATC" or "WX" to indicate that the current display "page" contained controller messages or weather information, respectively. The right area was blank when the current ATC or weather page was displayed, and was filled with a column of B's when an information "buffer" was being viewed. These buffers contained previous messages which were scrolled off the primary ATC or weather page as those pages were filled with information.

Data-link level 4 featured a single-line work area, or scratch pad, between the text area and the dedicated windows. This scratch pad provided the pilot with a space in which to generate down-link messages. These messages were kept simple in structure and consisted of requests for clearances, taxi, takeoff, heading changes, altitude changes, and weather information. The scratch pad allowed the pilot to preview and make corrections to the message before it was sent or to cancel the message altogether.

Data-Link Levels

The complexity of the data-link display varied as a function of the data-link capability level. An example of the display, for data-link level 4, is shown in figure 9. Lower data-link levels show subsets of the display components that are used in level 4. There were four distinct data-link levels. Data-link level 1 was a baseline, voice-only mode. No information appeared in any of the screen viewing areas, and the keyboard was inoperative.

In data-link level 2, heading and altitude information only was extracted from the ATC messages and was depicted in the dedicated windows at the bottom of the CRT. No other data-link information or capabilities (i.e., weather-product data, printer function, pilot down link) were available to the pilot in this level. Only the "YES" and "NO" buttons on the cockpit keyboard were operative.

In data-link level 3, the same heading and altitude information described in level 2, with several enhancements, was shown. Along with the heading and altitude information, ATC messages appeared in the text area of the CRT. The text area also provided the pilot with buffers of previous messages. As the text area of the display became filled, prior messages were automatically scrolled into the buffers to make room for new messages. The buffers were accessed via the "LAST MSG" button on the data-link keyboard. Each depression of this button caused a prior time-history buffer of information to be displayed on the CRT. Buffer data were flagged by a column of B's in the panel flanking the right side of the text area. Figure 10 provides an example of a buffer display. After viewing buffer information, the pilot could return to the current ATC message display via the "ATC PAGE" button.

Data-link level 3 also provided the pilot with the ability to obtain a hard-copy printout of the CRT display. This was accomplished by pressing the "PRINT" button on the data-link keyboard. This button activated a small printer installed beneath the copilot's side of the instrument panel. Because the printer had no data buffer, the other functions of the data link were temporarily suspended during printing.

Data-link level 4 included all the features of level 3 plus the ability to down-link requests to the ground, including requests for weather information. The CRT display format was modified by the addition of a one-line scratch pad that separated the dedicated windows from the text area. This scratch pad was used by the pilot to compose down-link messages to the controller. Message composition was accomplished via specific buttons on the cockpit keyboard and included requests for the initial route clearance, taxi, takeoff, and for heading and altitude changes.

Data-Link Keyboard

The data-link keyboard consisted of a four-column, eight-row rectangular matrix of buttons which, when pressed, triggered various functions. The buttons had a white background with black lettering. The keyboard was organized so that the buttons to be used most often, and that were used with each data-link level, were closest to the CRT display. These were the "YES" and "NO" buttons used for acknowledgment of ATC messages. Pressing the "YES" button performed the dual functions of acknowledging and accepting a clearance. Pressing the "NO" button acknowledged the message and indicated to the controller that the pilot could not comply. In that case the pilot or controller would use the voice-communications channel to negotiate a clearance. The "YES" and "NO" buttons were placed at opposite ends of the top row of buttons to reduce the possibility of a pilot inadvertently pressing the wrong one. Immediately between and below the "YES" and "NO" buttons were those buttons used to control the data-link display. These buttons selected the current ATC page, weather page, or last-message buffer pages, cleared the text area of the display, and activated the printer. Except for the weather-page select, all these buttons were active in data-link level 3. The down-link capability of data-link level 4 required buttons for selecting the desired message, a button for selecting the weather page, and a "SEND" button. In an attempt to simplify operation of the data link, a full alphanumeric keyboard was not implemented, and a menu and a fill-in-the-blank method of composing down-link messages were used. The buttons used to select messages that required no additional input prior to being sent were arranged to the left of the "SEND" button and above the numeric keyboard. The buttons used to select messages that did require additional input, such as altitude requests, were arranged below the "SEND" button and to the right of the numeric keyboard. Details of message composition and down link are given in the sections "Sending Messages From the Cockpit" and "Weather-Product Page."

The buttons that were active for any particular data-link level were illuminated with an internal light during that run. In level 1 (voice only), none of the buttons were illuminated. In level 2, only the "YES" and "NO" acknowledgment buttons were illuminated. In data-link level 3, the "YES," "NO," "ATC PAGE," "PRINT," "LAST MSG," and "CLEAR" buttons were illuminated. In data-link level 4, all the labeled buttons were illuminated. Several unlabeled buttons, provided as spares for future development, were never used or illuminated.

Cockpit Message Reception and Acknowledgment

Reception of an ATC message in the cockpit sounded an audio alarm and turned on an annunciator light above the attitude indicator on the cockpit instrument panel. The audio alert sounded when a message was received, then went silent. If the message were not acknowledged within 10 sec, the audio tone would sound again. This sequence continued until the message was acknowledged. The annunciator light remained illuminated until the pilot acknowledged the new message. Newly received messages were displayed in inverse video to visually highlight those messages on the CRT. If the new message contained new heading or altitude assignments, this information was also extracted and appeared in inverse video in the dedicated windows. The pilot acknowledged the message by pressing either the "YES" or "NO" button on the keyboard, depending upon whether the pilot accepted or rejected the ATC command. Depression of the "YES" button caused the new message information, including any new heading or altitude assignments associated with the message, to be displayed in normal video. A "NO" erased the new message from the screen and caused backscrolling of the ATC buffers, as necessary, to restore the ATC page display to its original contents prior to message reception. A "NO" also erased any new heading and/or altitude information in the dedicated windows and restored the previous data depicted in those windows.

In data-link levels 3 and 4, it was possible for an ATC message to be received while the pilot was viewing another page, such as a buffer or a weather page. In this case, both the audio and visual annunciations were given, and the pilot could see new information in the dedicated windows, which were always visible. To view the textual component of the new message, it was necessary for the pilot to manually select the ATC page by pressing the "ATC PAGE" button. It was possible to acknowledge the new message, however, without selecting the ATC page.

As the text area filled with new messages, automatic scrolling occurred which placed former messages into buffers which could later be recalled for review by the pilot. Scrolling was based on message length; that is, if the current display consisted of two messages, the first containing four lines and the second containing three lines, a new two-line message (which would exceed the maximum eight-line limit) would cause all four lines of the first message to scroll into the buffer. Thus, the new display that was produced consisted of the previous three-line message plus the new two-line message.

Sending Messages From the Cockpit

Level-4 data-link operations provided the pilot with the capability of composing and sending down-link messages to the controller. Messages to be down linked were selected from the menu provided on the keyboard and appeared in the one-line scratch-pad area for additional composition or review by the pilot. Messages to be down linked appeared in inverse video while being composed. After composing a message, the pilot could transmit it to ATC by pressing the "SEND" button. Depression of this button simultaneously changed the scratch-pad display of the down-link message to normal video.

Three of the available down-link messages required no additional composing after being selected. These were requests for the initial route clearance ("REQ CLEARANCE" button), requests for ground taxi clearance ("REQ TAXI" button), and requests for takeoff clearance ("REQ TAKEOFF" button). Pressing the appropriate button caused the corresponding message to appear in the scratch pad, ready to be sent.

Heading and altitude requests further required the numeric input of the desired heading or altitude. Pressing the "REQ HDG" button or the "REQ ALT" button placed the appropriate message in the scratch pad with either three or five blank spaces, respectively, which were filled in by the pilot. The numeric keypad was used to type in the desired heading, in degrees, or the desired altitude, in feet. The entire scratch-pad area remained in inverse video while the message was being composed.

If the pilot made a mistake while entering information, or decided not to send the message, the "BACK SPC" button could be used to erase incorrect information. One numeric digit was erased each time "BACK SPC" was pressed, and data items were erased in the reverse order in which they had been entered. Multiple depressions of the "BACK SPC" button could be used to erase all the incorrect heading or altitude numbers. Pressing the "BACK SPC" button canceled the message under composition (and cleared the scratch pad) once all numeric information had been erased, or if the message required no numeric entry.

Weather-Product Page

Data-link level 4 also gave the pilot the capability of sending requests, for various weather products, to the ground. This was done using the weather page of the data-link device. Upon depression of the "WX PAGE" button, the screen display changed to depict a weather-product menu (fig. 11). The weather-page display retained the heading- and altitude-dedicated windows and showed "WX" in the left panel flanking the text area to signal the display of weather information. The menu consisted of the following numbered choices: 1. departure automatic terminal information service (ATIS) messages, 2. arrival ATIS messages, 3. pilot weather reports (PIREPS), 4. significant meteorological information advisories (SIGMETS), and 5. the local terminal forecast. The pilot selected the desired weather product by pressing the corresponding number on the numeric keypad; the weather-product choice was displayed in inverse video in the scratch-pad area. If the pilot was satisfied with the choice, pressing the "SEND" button would down link the request. Depression of "SEND" also caused the request in the scratch pad to appear in normal video, to signal to the pilot that down link of the request had occurred. After a delay of about 6 sec, the requested weather information would appear in the text area. A down-link request could be canceled, prior to sending it, by pressing the "BACK SPC" button. Another selection could then be made. The weather information that was up linked for each product request is shown in table 7.

When viewing the weather-product menu, the pilot could also view previously up-linked weather information by pressing the "LAST MSG" button. This displayed the weather-information buffer page, along with a column of B's in the area to the right of the text area. Repeated pressing of the "LAST MSG" button would display older buffers of up-linked weather data, and the pilot could return to the weather-product menu by pressing the "WX PAGE" button. The weather-buffer pages and the ATC buffer pages were maintained separately, so only weather messages were seen on the weather-buffer pages.

There were three versions of the arrival ATIS message. The one that was relevant to a particular run was selected at run setup time and remained current for the duration of the run, unless it was changed via physical input at the controller workstation. One data-link scenario involved an emergency situation in which the arrival ATIS was up linked, by the controller, to accommodate an emergency return to the airport. Otherwise, the functioning of the weather-product data-link service was strictly automatic and required no response from the controller. The process was intended to simulate the pilot querying a central weather facility and automatically receiving the requested information. Also, since no alpha keyboard was provided, it was not possible with this particular data-link interface to specify an airport when requesting a terminal forecast. For the purposes of this study, it was sufficient to simply provide the terminal forecast for Denver.

Since the controller was not involved with the up link of weather products that were requested on the weather page, the up-link information appeared in normal video and no "YES" or "NO" acknowledgment of that up-link weather information was required. No audio or visual alarms were given upon receipt of the requested weather information. On the other hand, the controller could send an up-link message containing any of the weather-product items. These messages then became part of the controller message display in the cockpit; they were accompanied by both the light and sound annunciators and were displayed in inverse video until acknowledged by the pilot.

Use of Cockpit Printer

A small thermal printer (4.5 in. wide by 2.7 in. high by 5.7 in. deep) was mounted beneath the cockpit panel on the copilot's side of the cockpit for use in the level 3 and level 4 data-link scenarios. The paper width was 3.125 in. The printer function was activated via the keyboard "PRINT" button and provided a hard copy of the contents of the current page. This hard copy included: a header of either ATC or WX designation to indicate whether ATC data or weather data were being viewed; a rightmost column of B's when a buffer was being viewed; the dedicated-window heading and altitude assignments; and the contents of the text area. When the screen display had been printed, the pilot could read it by tearing off the hard copy from the printer.

Two drawbacks of the utilization of the printer were the slow speed with which the printer performed its task and the lack of data buffering in the printer itself. The printer took about 31 sec to provide its output, and the lack of buffering suspended other data-link functions until the printer output was completed.

Controller Operation of Data Link

Data-link messages were sent to the cockpit, via an RS-232 interface and a video cable, from an IBM AT computer located in the Langley Mission-Oriented Terminal-Area Simulation (MOTAS) Facility. The RS-232 interface connected the cockpit data-link keyboard to the IBM AT computer, where the pilot inputs were actually processed. The cockpit data-link display was an image of the IBM AT graphic display, which was also being shown in the MOTAS facility at the controller's workstation. By viewing the display, the controller could see when an up-link message had been acknowledged (inverse video changing to normal video) and could see the pilot composing and sending down-link messages.

Controller up-link messages were generated by coded input at the IBM AT keyboard with the aid of a controller assistant. The code subsequently activated the audio and visual message annunciators in the cockpit and generated the appropriate cockpit screen updates.

At the beginning of each data-link run, certain initialization procedures were performed. Run and pilot identification numbers were entered into the IBM AT computer to establish predetermined scenario conditions for the run. These conditions included such items as the runway to be used in the scenario, the arrival ATIS to be activated for the run, and a coded description of the particular scenario itself. The pilot was prompted to press a time-synchronization button located above and to the right of the data-link keyboard buttons. This generated a simultaneous signal to both the IBM AT (data-link simulation) and CYBER 175 (airplane simulation) computers, so that the timing of events in the data-link run could later be synchronized for data-analysis purposes.

Data-Link Message Set

The entire data-link message set was predefined for the data-link experiment. Free-form entry of messages was not possible. A message to be sent to the airplane was entered at the controller workstation as a four-letter code followed by additional numeric data if needed to specify altitude, heading, radio frequency, or runway assignment. To enhance the pilot interface with the data link, the development of the message set considered the space available for message display, standard ATC phraseology, and standard abbreviations (ref. 9). The message set is shown in table 8. Tables 7 and 8 provide a complete list of the messages that could be transmitted to the cockpit data-link display from the controller station. The messages are shown as they appeared on the data-link display.

Data-Link System Delays

The time required by the data-link simulation hardware to perform various functions affected the data-link interface with the pilot and was a component in the response delays to ATC messages. Those times were determined for various combinations of ATC and weather-message reception, with clear and full screens, with scrolling, and with ATC and weather pages displayed. The results are shown in table 9.

The time delay from the controller sending a message to activation of the annunciation in the cockpit was almost zero. The dedicated windows that show heading and altitude were also updated quickly; there was a delay of about 0.5 sec. The time between the transmission of a message by ATC and the beginning of the writing of that message, however, varied with the amount of text already displayed in the text area. With an empty text area, the new message began to appear less than 1 sec after being sent and took about 0.8 sec per line to be written. With a full screen, the old messages were first scrolled up to make room for the new message. This scrolling process required just over 6 sec, for eight lines of text. In general, the data-link interface required about 0.8 sec per line for scrolling messages and writing messages.

Switching between the ATC page and the weather page required about 7.6 sec in either direction. The time was used to write out the weather menu or the ATC messages. The only weather product routinely requested during the study was ATIS information. The time required to finish writing the ATIS information, after the pilot pressed the "SEND" button to down link the request, was just under 6 sec.

When a buffer of previous ATC messages was selected with the "LAST MSG" button, about 7 sec were required to write out the buffer on the CRT. About 7.6 sec were required to return to the ATC page. The printer, used to produce a hard copy of the contents of the CRT screen, required 31 sec from the time that the "PRINT" button was pressed to complete printing.

References

1. Hoh, Roger H.; Smith, James C.; and Hinton, David A.: *The Effects of Display and Autopilot Functions on Pilot Workload for Single Pilot Instrument Flight Rule (SPIFR) Operations.* NASA CR-4073, 1987.
2. Bergeron, Hugh P.: *Analysis of General Aviation Single-Pilot IFR Incident Data Obtained From the NASA Aviation Safety Reporting System.* NASA TM-80206, 1980.
3. Hilborn, Edwin H.: *Human Factors Experiments for Data Link.* Rep. No. FAA-RD-75-170, Nov. 1975. (Available from DTIC as AD A019 299.)
4. Parker, James F., Jr.; Duffy, Jack W.; and Christensen, Diane G.: *A Flight Investigation of Simulated Data-Link Communications During Single-Pilot IFR Flight. Volume I—Experimental Design and Initial Tests.* NASA CR-3461, 1981.
5. Parker, James F., Jr.; and Duffy, Jack W.: *A Flight Investigation of Simulated Data-Link Communications During Single-Pilot IFR Flight. Volume II—Flight Evaluations.* NASA CR-3653, 1982.
6. Flathers, G. W., II: *Development of an Air Ground Data Exchange Concept: Flight Deck Perspective.* NASA CR-4074, 1987.
7. Kaylor, Jack T.; Simmons, Harold I.; Naftel, Patricia B.; Houck, Jacob A.; and Grove, Randall D.: *The Mission Oriented Terminal Area Simulation Facility.* NASA TM-87621, 1985.
8. *Air Traffic Control.* 7110.65E, Federal Aviation Adm., Apr. 9, 1987.
9. *Contractions.* 7340.1K, Federal Aviation Adm., June 1, 1988.
10. *Aviation Weather Services (A Supplement to Aviation Weather AC 00-6A).* EA-AC-0045B, U.S. Dep. of Transportation, Revis. 1979.

Table 1. Data-Run Experimental Matrix

Run	Scenario	Data-link level	ATIS message	Cloud ceiling, ft	Visibility, n.mi.
Pilots 1 and 2					
1	A4	1	Echo	700	5
2	A3	2	Bravo	450	2
3	A2C[1]	3	Echo	700	5
4	A1	4	Echo*[2]	700	5
5	A2	3	Bravo	0	0
6	D3	1	Delta	450	2
7	D2	2	Delta	450	2
8	D1	3	Delta	450	2
9	D2E[3]	4	Delta	700	5
10	D3	4	Delta	450	2
Pilot 3					
1	D1	1	Delta	450	2
2	D2	2	Delta	450	2
3	D3	3	Delta	700	5
4	D1	4	Delta	450	2
5	D2E[3]	4	Delta	450	2
6	A1	1	Echo	700	5
7	A2	3	Bravo	0	0
8	A3C[1]	4	Echo	700	5
9	A4	3	Bravo	450	2
10	A3	3	Echo*[2]	700	5
Pilot 4					
1	D1	1	Delta	450	2
2	A1	1	Echo*[2]	700	5
3	D2	2	Delta	450	2
4	A2	2	Bravo	450	2
5	D3	3	Delta	450	2
6	A3	3	Echo	700	5
7	D2E[3]	3	Delta	450	2
8	A4	4	Bravo	0	0
9	D1	4	Delta	450	2
10	A1C[1]	4	Echo	700	5

[1] Suffix "C" on scenario label indicates that scenario included lost communications.

[2] Echo* indicates that the first ATIS information received by the pilot was Echo and that information FOXTROT became current during the run.

[3] Suffix "E" on scenario label indicates that scenario included engine failure.

Table 2. Mean and Standard Deviation of Pilot Response Times to ATC Data-Link Messages

Scenario	Mean and standard deviation, sec, at— Data-link level 2	3	4
Arrival	7.2 and 7.0	9.0 and 7.4	9.5 and 8.3
Departure	5.8 and 4.6	11.6 and 13.3	11.2 and 7.6
Communication failure	N/A	8.8 and 4.1	10.6 and 5.3
Engine failure	N/A	12.8 and 5.3	12.8 and 10.7
All nonemergency	6.5 and 5.9	10.1 and 10.2	10.4 and 7.9

Table 3. Average Number of ATC Voice Transmissions Per Run to Subject Aircraft and Average Length of Transmissions

[Except for engine-failure scenario, all runs were approximately the same length in time and distance]

Scenario	Transmissions per run and length of transmissions, sec, at—			
	Data-link level			
	1	2	3	4
Arrival	22.3 and 4.3	14.5 and 4.4	7.8 and 3.6	7.0 and 3.4
Departure	20.3 and 4.5	14.8 and 5.0	6.3 and 3.4	5.0 and 3.3
Communication failure	N/A	N/A	1.0 and 2.8	1.0 and 1.2
Engine failure	N/A	N/A	17.0 and 3.2	12.3 and 4.6
All nonemergency	21.3 and 4.4	14.6 and 4.7	7.1 and 3.5	5.9 and 3.3

Table 4. Average Number of ATC Data-Link Transmissions Per Run to Subject Aircraft

[Except for engine-failure scenario, all runs were approximately the same length in time and distance]

Scenario	Transmissions per run and length of transmissions, sec, at— Data-link level 1	2	3	4
Arrival	N/A	6.0	9.8	10.7
Departure	N/A	6.8	8.8	9.0
Communication failure	N/A	N/A	9.0	11.0
Engine failure	N/A	N/A	14.0	14.0
All nonemergency	N/A	6.4	9.3	9.7

Table 5. Average Number of Total ATC Transmissions Per Run to Subject Aircraft

[Except for engine-failure scenario, all runs were approximately the same length in time and distance]

Scenario	Transmissions per run and length of transmissions, sec, at— Data-link level 1	2	3	4
Arrival	22.3	20.5	17.6	17.7
Departure	20.3	21.6	15.1	14.0
Communication failure	N/A	N/A	10.0	12.0
Engine failure	N/A	N/A	31.0	26.3
All nonemergency	21.3	21.0	16.4	15.6

Table 6. Average Number of Pilot Voice Transmissions Per Run and Average Length of Transmissions

[Except for engine-failure scenario, all runs were approximately the same length in time and distance]

Scenario	Transmissions per run and length of transmissions, sec, at—			
	Data-link level			
	1	2	3	4
Arrival	21.3 and 2.5	17.5 and 2.4	7.4 and 2.7	9.3 and 2.7
Departure	22.8 and 2.8	19.3 and 2.7	9.5 and 2.8	5.8 and 2.7
Communication failure	N/A	N/A	7.5 and 2.6	5.5 and 3.7
Engine failure	N/A	N/A	15.0 and 2.9	17.0 and 2.8
All nonemergency	22.0 and 2.7	18.4 and 2.6	8.3 and 2.8	7.3 and 2.7

Table 7. Weather-Product Set

[See ref. 10 for description of weather products]

Pilot request	Weather Product
REQUEST DEPARTURE ATIS	DEN DEP INFO DELTA, 1400Z WX CEILING 4 BKN 10 OVC, VIS 3L, WIND 340/8, ALT 29.92, TEMP 53/51, DEP RWYS 35L & 35R, CONTACT CLRNC DELIV 127.6
REQUEST ARRIVAL ATIS	DEN ARR INFO BRAVO, 1400Z WX CEILING 4 BKN 10 OVC, VIS 3L, WIND 340/8, ALT 29.92, TEMP 53/51, ILS 26L AND 35R IN USE or DEN ARR INFO ECHO, 1400Z WX CEILING 7 OVC, VIS 6, WIND CALM, ALT 29.92, TEMP 68/64, EXPT VECTORS ILS 26L or DEN ARR INFO FOXTROT 1500Z WX CEILING 8 OVC, VIS 10, WIND 350/5, ALT 29.92, TEMP 76/65 ILS 26L AND 35R IN USE
REQUEST PIREPS	UA 1350Z B80 MOD RIME ICG AT 12000 FT, 20 DME NORTH DEN
REQUEST SIGMETS	SIGMET PAPA 1300Z MOD TO SVR ICG ABV 11 000 FT OVER CO, NE, KS
REQUEST TERMINAL FORECAST	DEN FT 1200Z C5 BKN 10 OVC 4R- 3510G15, OCNL C2 OVC 1R

Table 8. Data-Link Message Set

CLEARANCE ON REQ	
CLRD TO GLD AS FILED, MTN 8000 FT, EXPT 12 000 FT 10 MIN AFTER DEPARTURE, DEP 128.05, SQUAWK 4324	
CLRD TO GLD AS FILED, MTN 10 000 FT, EXPT 11 000 FT 10 MIN AFTER DEPARTURE, DEP 128.05, SQUAWK 5735	
CLRD TO GLD VIA V19 IOC V148 TXC V4, MTN 9000, DEP 123.85, SQUAWK 5263	
HOLD FOR LANDING TRAFFIC	
TAXI INTO POSITION & HOLD	
FLY RWY HEADING, CLRD FOR TAKEOFF	
CONTACT DEP	
CALL ATC ON _ _ _ · _ _	(Blanks contain a frequency assignment)
VOICE COMM LOST	
STANDBY	
UNABLE	
CONTACT GROUND .9 WHEN CLEAR	
TAXI TO GA RAMP	
TURN RIGHT HDG _ _ _	(Blanks contain a heading assignment)
TURN LEFT HDG _ _ _	
FLY HDG _ _ _	

Table 8. Concluded

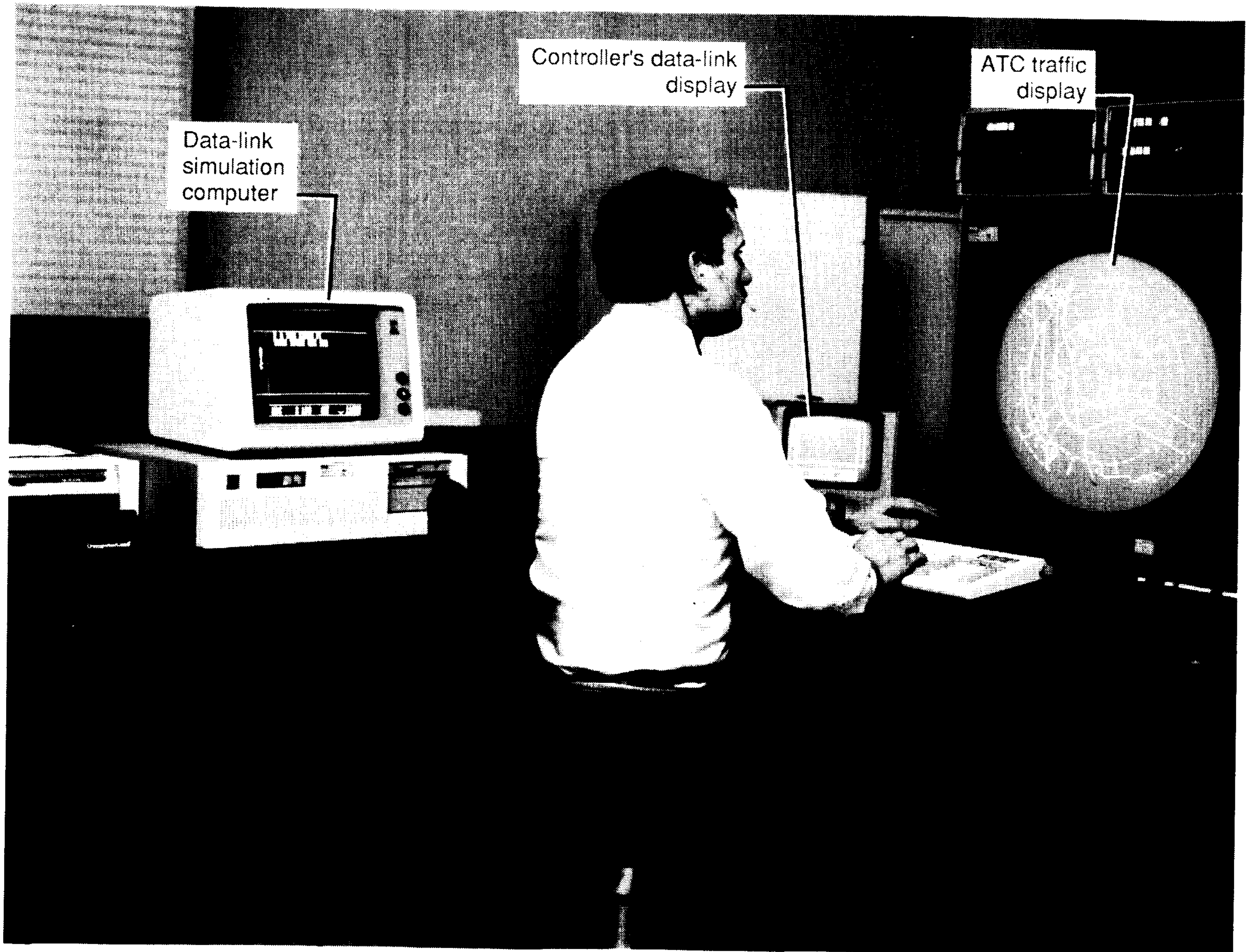
C & MTN - - - - - FT	(Indicates "climb and maintain" an altitude)
D & MTN - - - - - FT	(Indicates "descend and maintain" an altitude)
RADAR CONTACT	
TRAFFIC, NUMEROUS ARRIVALS DEPARTING FLOTS SOUTHBOUND AT 11 000 FT	
PROCEED DIR KIOWA	
FLY HEADING - - -, INTERCEPT DEN 118 RADIAL INBOUND	(Blanks contain a heading assignment)
FLY HEADING - - -, VECTORS TO FINAL APPROACH COURSE	
TURN RIGHT HEADING 120, INTERCEPT V4, RESUME OWN NAV	
CONTACT DEN CENTER 127.5	
CONTACT DEN APPR 120.8	
CONTACT APPROACH 125.3	
WIND 330/10, ALT 29.92	
FLY HEADING - - -, MTN 7200 FT TIL ON LOC, CLRD ILS RWY 26L, CONTACT TWR 118.3 AT THE OM	(Blanks contain a heading assignment)
FLY HEADING - - -, MTN 7500 FT TIL ON LOC, CLRD ILS RWY 35R, CONTACT TWR 119.5 AT THE OM	
CLRD TO LAND - - -	(Blanks contain a runway specification, either 26L or 35R)
GO AROUND	
IF ABLE, MTN 160 KNOTS TO THE OUTER MARKER	

Table 9. Data-Link System Time Delay

	Time delay, sec, with—	
	Clear screen	Full screen (1-line messages)
ATC transmit to cockpit annunciation	Almost 0	Almost 0
ATC transmit to display in dedicated window	0.5	0.5
ATC transmit to beginning of text writing	0.7	6.2
Time required to write text:		
1-line message	0.8	0.8
2-line message	1.5	1.5
4-line message	3.2	2.9
Time required to clear a full screen		6.1
Time required to print ATC page	31	31
Weather:		
Time required to write weather-page menu	7.5	7.5
Time from pressing "SEND" to finish writing ATIS	5.6	5.6
Time to switch from weather page to display of full ATC page	7.6	7.6
Buffer page:		
Time to switch from ATC page to display of full buffer page	6.8	6.8
Time to return to and display a full ATC page	7.6	7.6

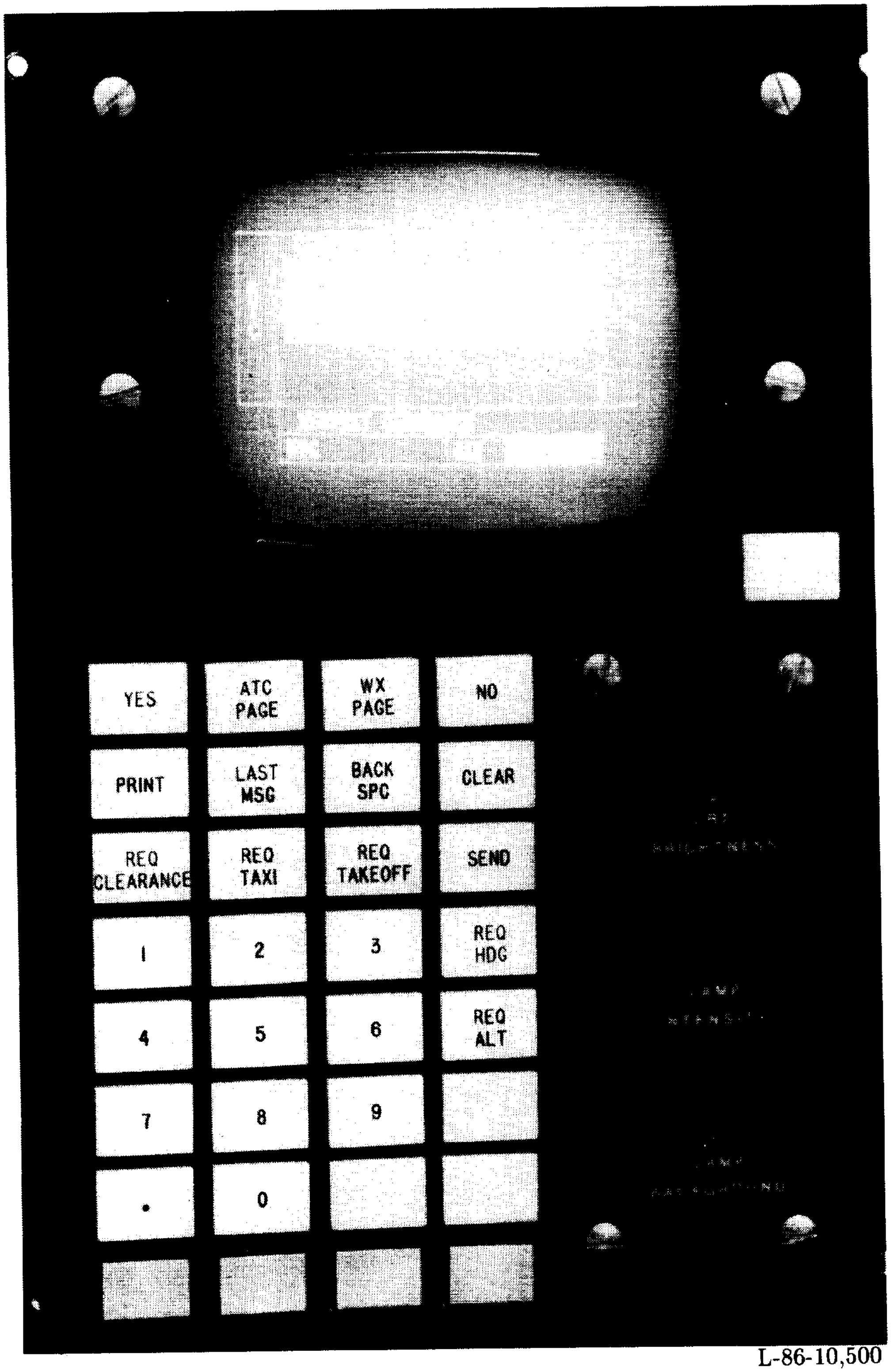
L-87-7940

Figure 1. Instrument panel of Langley general-aviation simulator.



L-86-11,513

Figure 2. Langley Controller Station for Mission-Oriented Terminal-Area Simulation Facility.



L-86-10,500

Figure 3. Cockpit data-link display and keyboard.

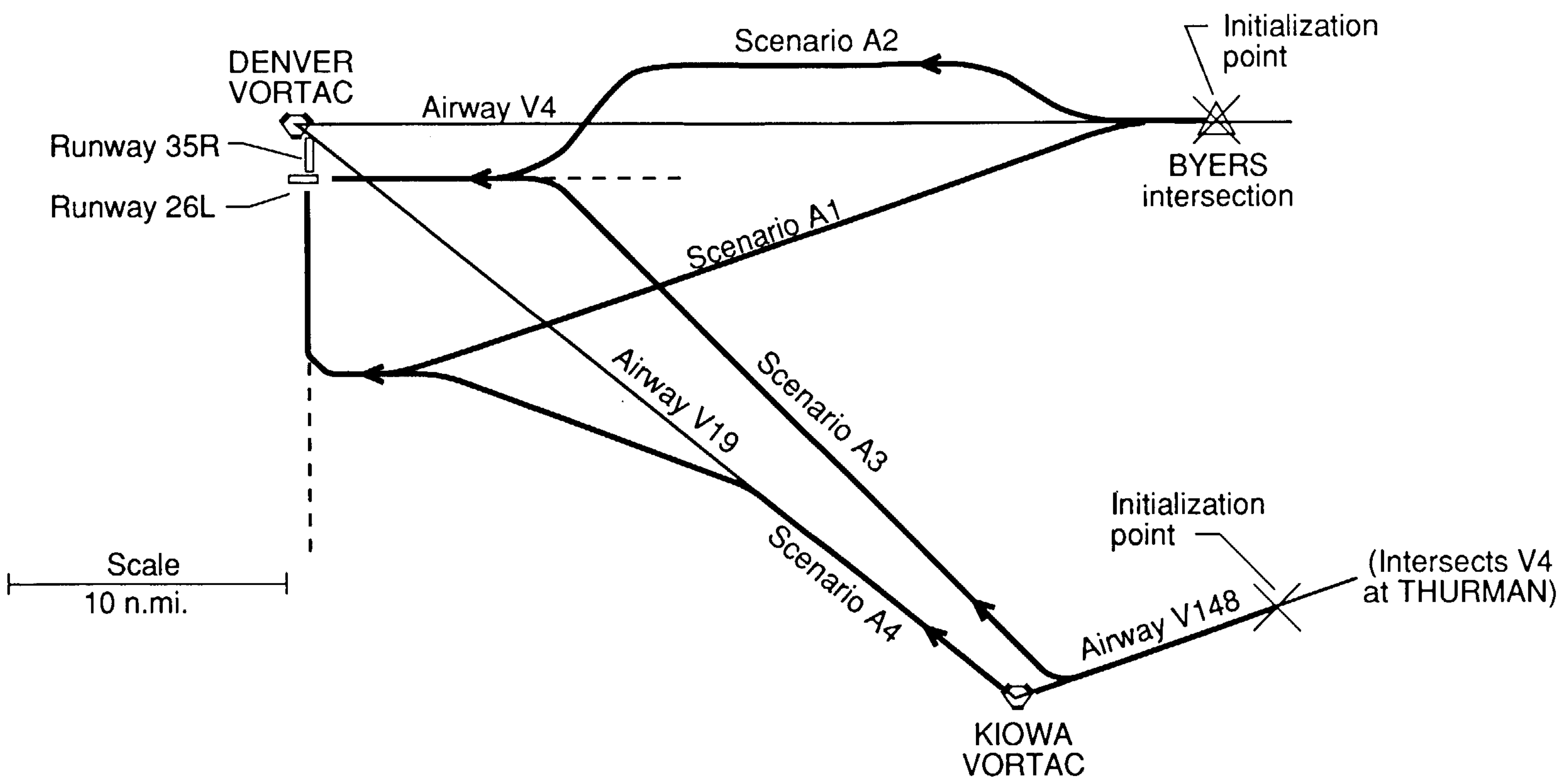
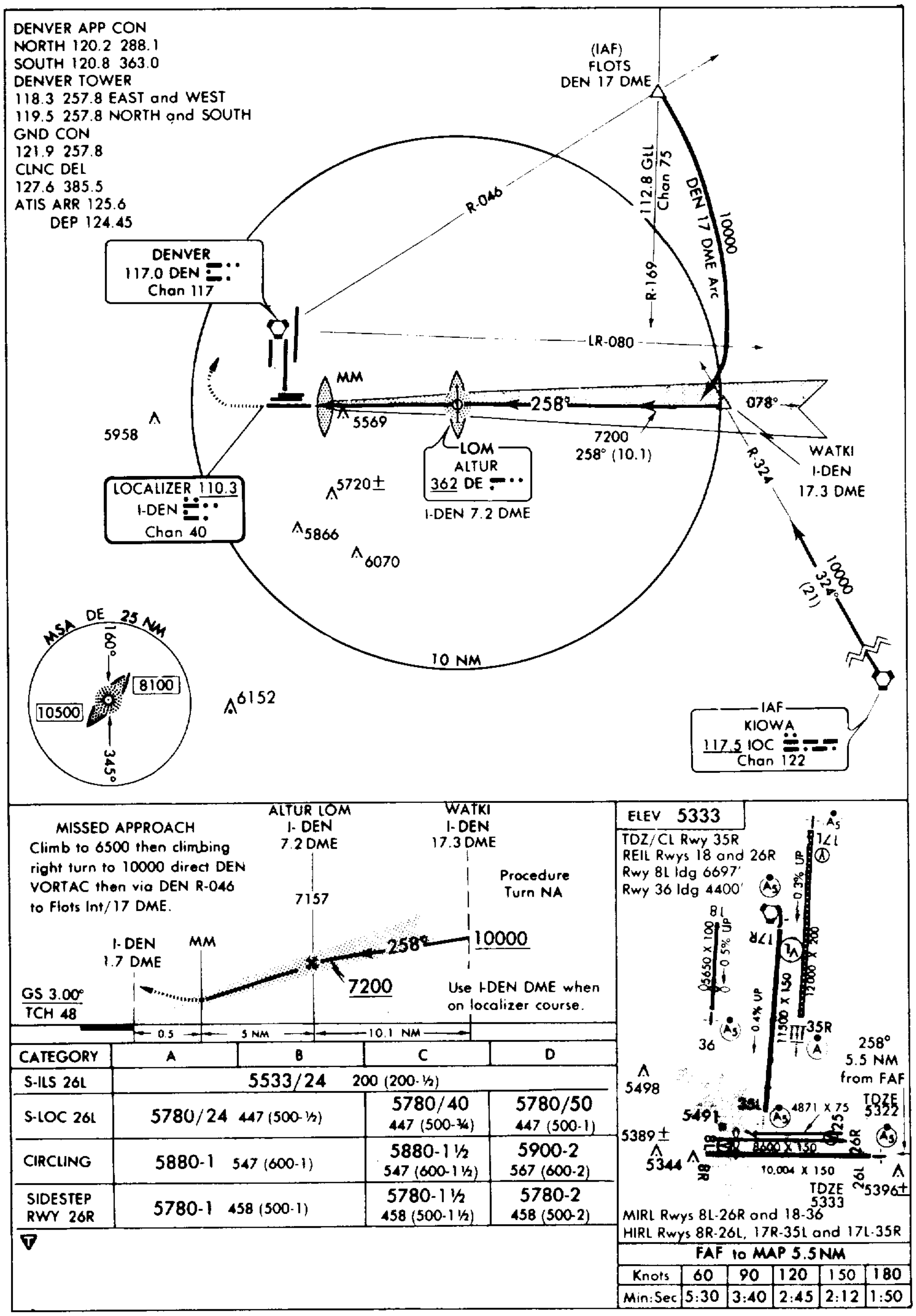


Figure 4. Routes used in arrival scenarios.



CATEGORY	A	B	C	D
S-ILS 26L	5533/24 200 (200-½)			
S-LOC 26L	5780/24 447 (500-½)		5780/40 447 (500-¾)	5780/50 447 (500-1)
CIRCLING	5880-1 547 (600-1)		5880-1½ 547 (600-1½)	5900-2 567 (600-2)
SIDESTEP RWY 26R	5780-1 458 (500-1)		5780-1½ 458 (500-1½)	5780-2 458 (500-2)

FAF to MAP 5.5 NM

Knots	60	90	120	150	180
Min:Sec	5:30	3:40	2:45	2:12	1:50

Figure 5. Instrument landing system approach to runway 26L.

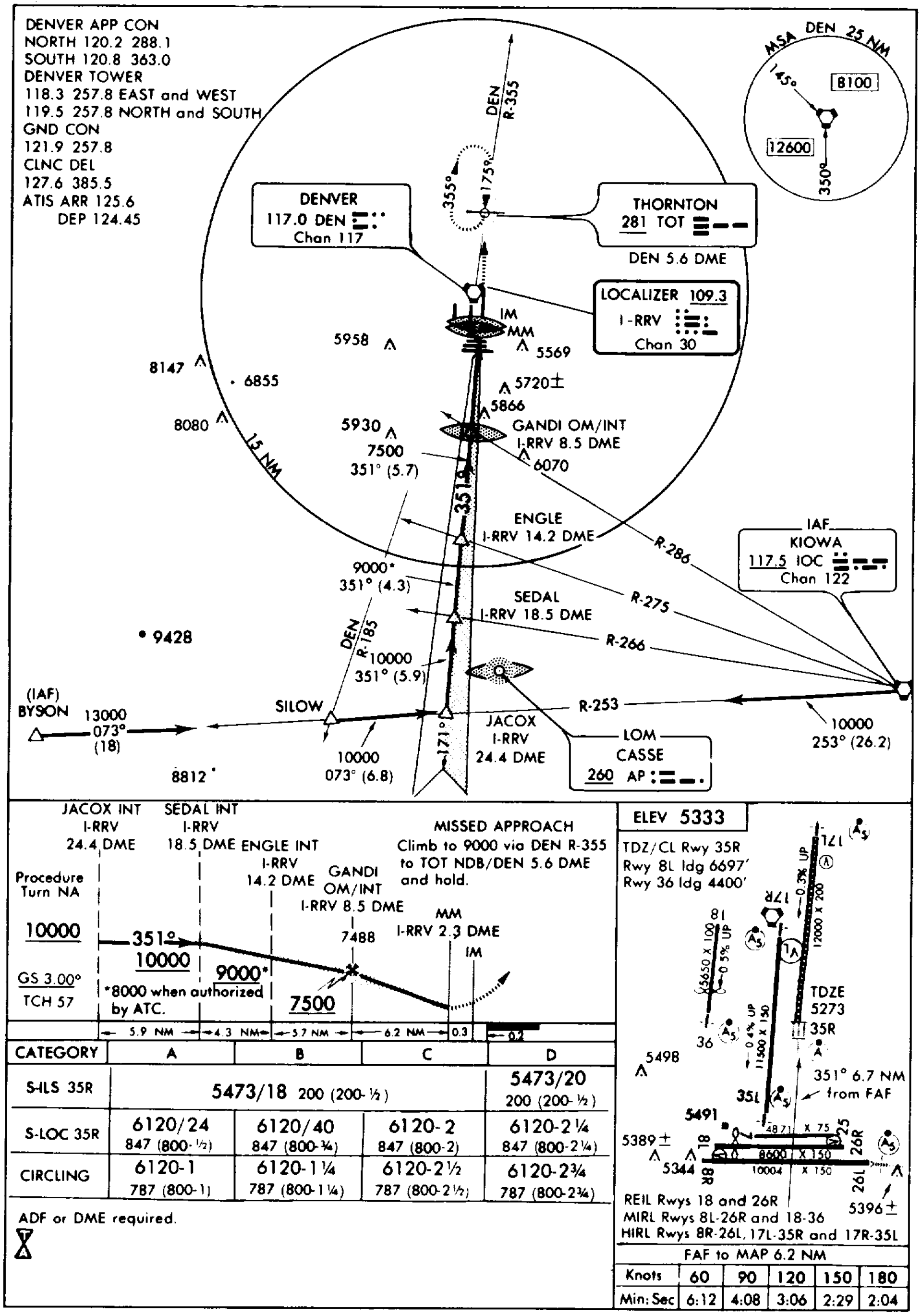
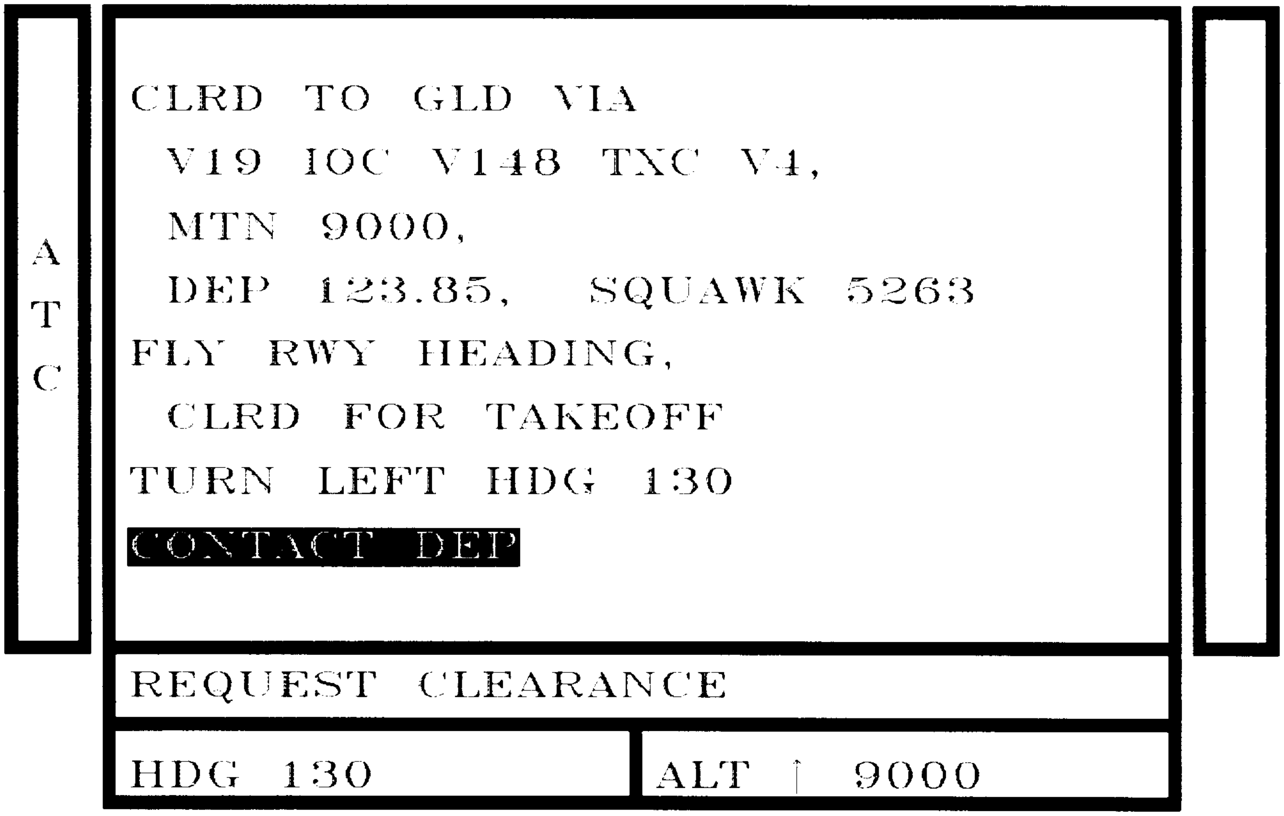


Figure 6. Instrument landing system approach to runway 35R.

3YERS
ntersection

(Intersects V4
at THURMAN)



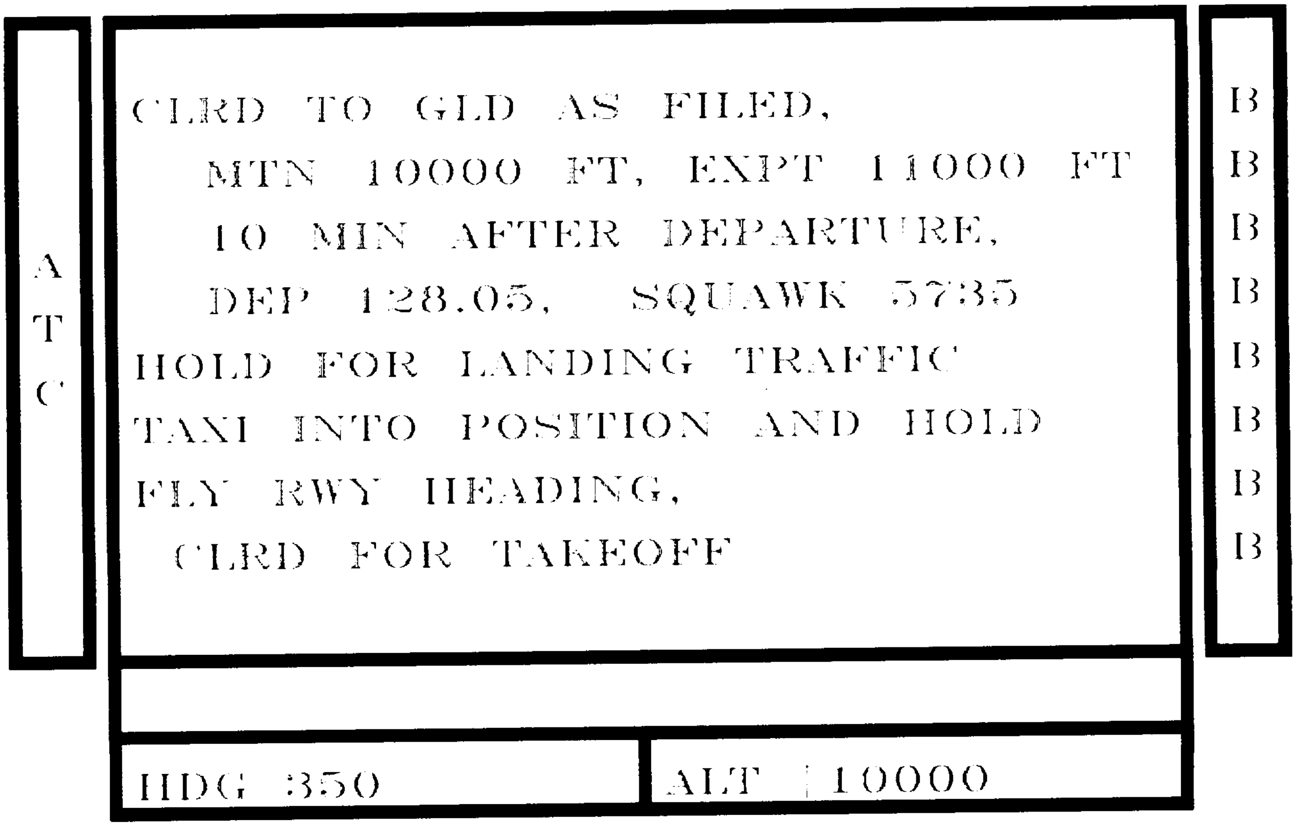
A
T
C

CLRD TO GLD VIA
V19 IOC V148 TXC V4,
MTN 9000,
DEP 123.85, SQUAWK 5263
FLY RWY HEADING,
CLRD FOR TAKEOFF
TURN LEFT HDG 130
CONTACT DEP

REQUEST CLEARANCE

HDG 130
ALT ↑ 9000

Figure 9. Data-link level-4 display.



```
CLRD TO GLD AS FILED,
   MTN 10000 FT, EXPT 11000 FT
   10 MIN AFTER DEPARTURE,
   DEP 128.05,  SQUAWK 5735
HOLD FOR LANDING TRAFFIC
TAXI INTO POSITION AND HOLD
FLY RWY HEADING,
 CLRD FOR TAKEOFF

HDG 350                 ALT 10000
```

Figure 10. Data-link buffer information display.

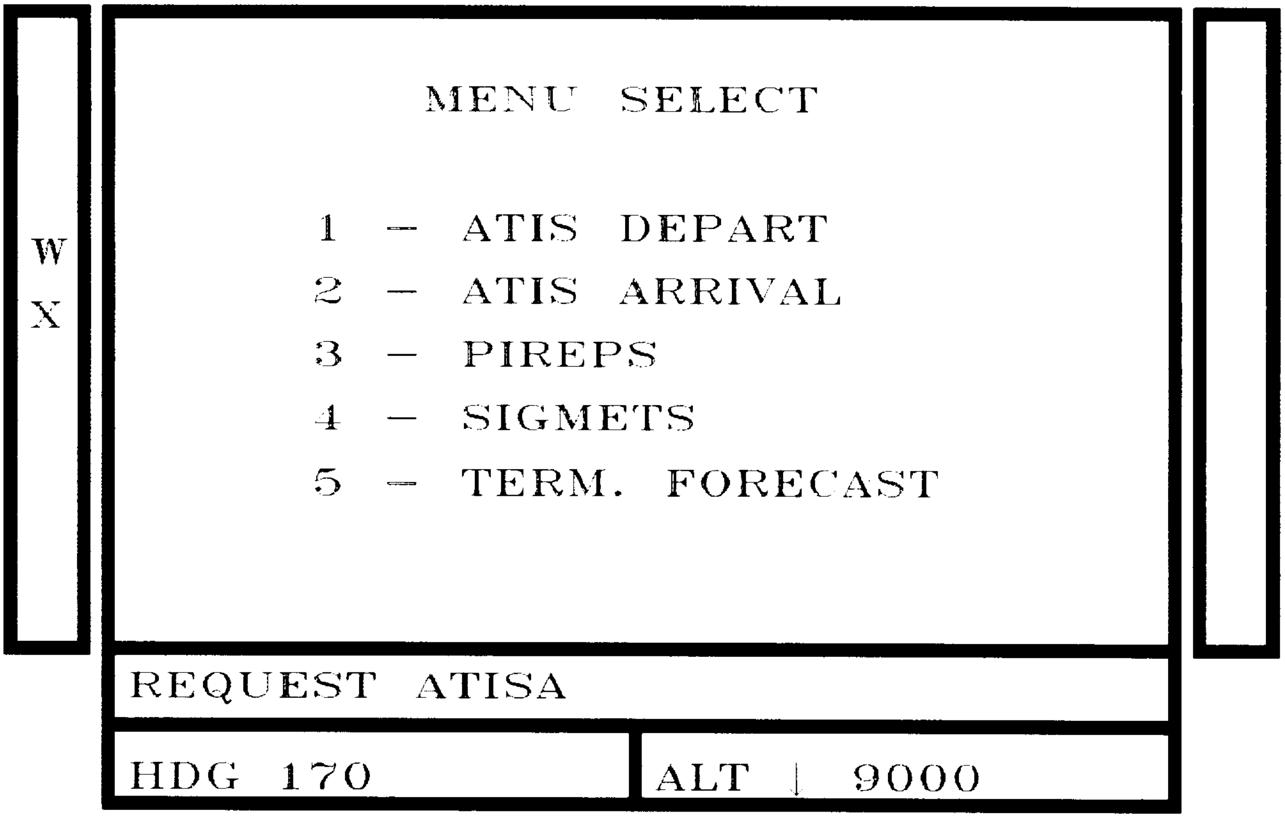


Figure 11. Data-link weather menu display.

National Aeronautics and Space Administration

Report Documentation Page

1. Report No. NASA TP-2837	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Simulator Investigation of Digital Data-Link ATC Communications in a Single-Pilot Operation	5. Report Date December 1988
	6. Performing Organization Code
7. Author(s) David A. Hinton and Gary W. Lohr	8. Performing Organization Report No. L-16457
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665-5225	10. Work Unit No. 505-66-41-02
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546-0001	13. Type of Report and Period Covered Technical Paper
	14. Sponsoring Agency Code

15. Supplementary Notes

David A. Hinton: Langley Research Center, Hampton, Virginia.
Gary W. Lohr: Embry-Riddle Aeronautical University, Daytona Beach, Florida.
Appendix by Patricia B. Naftel, Research Triangle Institute, Research Triangle Park, North Carolina; on-site contractor at Langley Research Center, Hampton, Virginia.

16. Abstract

Previous studies have shown that radio communications between pilots and air traffic control contribute to high pilot work load and are subject to various errors. These errors are caused by congestion on the voice radio channel and result in missed and misunderstood messages. The use of digital data link has been proposed as a means of reducing the work load and error rate. A critical factor, however, in determining the potential benefit of data link will be the interface between future data-link systems and the operators of those systems, both in the air and on the ground. The purpose of this study was to evaluate the pilot interface with various levels of data-link capability in simulated, general-aviation, single-pilot, instrument-flight-rule operations. Results show that the data link reduced demands on the pilots' short-term memory, reduced the number of communication transmissions, and permitted the pilots to more easily allocate time to critical cockpit tasks while receiving air-traffic-control messages. The pilots who participated in the study unanimously indicated a preference for data-link communications over voice-only communications. There were, however, situations in which the pilots preferred the use of voice communications, and the ability of pilots to delay processing the data-link messages during high-work-load events caused delays in the acknowledgment of messages to air traffic control.

17. Key Words (Suggested by Authors(s)) General aviation Single-pilot IFR Data link ATC Avionics	18. Distribution Statement Unclassified–Unlimited Subject Category 04

19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 39	22. Price A03

NASA FORM 1626 OCT 86

NASA-Langley, 1988

For sale by the National Technical Information Service, Springfield, Virginia 22161-2171