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Abstract

Previous studies have shown that air traffic control (ATC) message exchange with a data link offers the potential benefits of increased airspace system safety and efficiency. To accomplish these benefits, data link can be used to reduce communication errors and relieve overloaded ATC voice radio frequencies, which hamper efficient message exchange during peak traffic periods. Flight tests with commercial airline pilots as test subjects were conducted in the NASA Transport Systems Research Vehicle Boeing 737 airplane to contrast flight operations that used current voice communications with flight operations that used a data link to transmit both strategic and tactical ATC clearances during a typical commercial airline flight from takeoff to landing. The results of these tests that used data link as the primary communication source with ATC have shown flight crew acceptance, a perceived reduction in crew work load, and a reduction in crew communication errors.

Introduction

Air traffic control (ATC) message exchange with a data link can increase system safety and efficiency by reducing communication errors and enabling more information to be exchanged between the aircraft and ground facilities. Digital communication between the air and ground may also relieve the overloading of ATC radio frequencies, which impedes efficient message exchange during peak traffic periods in many busy terminal areas.

A piloted simulation study (ref. 1) was conducted to evaluate the pilot interface with various levels of data link capability in general aviation, single-pilot, instrument flight rule (IFR) operations. The results of that study showed that the data link and its flight deck interface reduced demands on the pilot's short-term memory, reduced the number of communication transmissions, and permitted the pilot to more easily allocate time to critical tasks while receiving ATC messages. The pilots who participated in this study unanimously indicated a preference for data link communications over voice-only communications.

A second ground-based simulation study (ref. 2) was conducted to compare the benefits of using data link for tactical and strategic ATC messages and automatic terminal information service (ATIS) reports with conventional voice communications in a two-crew-member transport airplane. The results of this study were similar to those attained in the single-pilot IFR tests (ref. 1). The flight crews preferred message exchange with the data link for routine tactical and strategic communications with ATC facilities.

The data link communication process used during this second simulation test entailed time delays that were related to the physical characteristics of the data link system and its interface. As a result of these delays, the crews preferred to use voice radio when exchanging urgent messages. The crews expressed concern over losing pilot out-the-window vigilance when they looked down to read the alphanumeric display of ATC messages. They also expressed concern that information could no longer be received by monitoring voice communications with other aircraft on the common radio frequency (i.e., the missing party-line effect).

Flight tests were then conducted in the NASA Transport Systems Research Vehicle (TSRV) Boeing 737 airplane to determine the pilot acceptance of the data link as the primary communications source. Specifically, these flight tests contrasted current voice communications with a data link used to transmit both strategic and tactical ATC messages during a typical commercial airline flight from pretaxi to takeoff to landing. This report describes the results of these flight tests.

Abbreviations

ACARS	Arinc (Aeronautical Radio, Incorporated) communications addressing and reporting system
AIRMET	airmen's meteorological information
ALT	altitude
ATC	air traffic control

ATIS	automatic terminal information service
bps	bits per second
CDU	control display unit
CLR	clear
CRT	cathode ray tube
DLP	data link processor
DP	dew point
EFIS	electronic flight instrumentation system
FL	flight level
FMS	flight management system
FP	flying pilot
FREQ	frequency
GEOG	geographical data
HDG	heading
IFR	instrument flight rules
MCP	mode control panel
MF	metering fix
MLS	microwave landing system
ND	navigation display
NFP	nonflying pilot
NOTAM	notice to airmen
OBS	observations
OSI	Open Systems Interconnection
PFD	primary flight display
PIREP	pilot report
R	roger
RE	roger/enter
RFD	research flight deck
RTE MOD REQ	route modification request
SIGMET	significant meteorological information
TEMP	temperature (used as TMP in fig. A9)
TSRV	Transport Systems Research Vehicle
TWEB	transcribed weather broadcast

VHF	very high frequency
VOR	very high frequency omni-directional range radio
WAL	Wallops airport
WAL APR	Wallops approach control
WALFT	terminal forecast for Wallops airport
WCP	weather communications processor

Description of Test Systems

Airplane

The airplane used in these flight tests was the NASA TSRV, which is a modified Boeing 737 airplane (fig. 1). The TSRV airplane is equipped with highly flexible experimental systems that consist of an electronic flight display system, a digital fly-by-wire flight control and flight guidance system with a side-stick controller, and an advanced area navigation system. These experimental systems were overlaid on the conventional airplane navigation and flight control systems.

A research flight deck (RFD) is located in the cabin behind the conventional flight deck as shown in the cutaway model of the airplane in figure 2. Flight operations from takeoff to landing may be performed from the RFD.

The interior of the RFD is a full-size flight deck that contains eight 8- by 8-in. flight-quality, color CRT displays (fig. 3). Each pilot has a primary flight display (PFD) and a navigation display (ND). The four CRT displays located on the center panel of the flight deck are used for engine instruments, check lists, and flight test purposes. During these tests, the CRT located in the lower right-hand center panel was used for the data link interface with the flight crew.

The display formats on each PFD are integrated in design to correspond to the selected flight control system mode and the selected flight guidance system. To select the flight guidance and control system modes, pilots used the mode control panel (MCP) that is located in the center of the glare shield. Reference 3 contains a detailed description of the PFD formats and the operation of the flight guidance and control system.

Each pilot has a control display unit (CDU) to interface with the flight management system (FMS).

Data Link System

The data link system in these tests was designed to evaluate the use of a data link as the primary

communications system between the air and the ground. The following types of information were communicated: ATC strategic clearances (predeparture, en route, and approach clearances); ATC tactical clearances (vectors, intermediate speed, and altitude restrictions); weather information; ATIS; and company messages. For test purposes, the data link messages were assigned two levels of importance: time-critical and non-time-critical messages. Time-critical messages were defined as the tactical and airborne strategic clearance messages that were received from ATC. All other messages were considered to be non-time-critical messages, which included the predeparture route clearance from ATC, weather information, and company messages.

In these tests, the data link system consisted of a ground system, a data link system radio source between the ground and the airplane, and an interface between the airborne data link, the flight systems, and the crew. A block diagram of this system is shown in figure 4.

Ground system. The ground system used in these tests was designed to support the airborne aspects of the data link operations. No effort was made to evaluate how the data link system affects the air traffic controller. A single person served as the pseudo air traffic controller for each ATC sector that the airplane passed through. Voice communications were also provided between the pseudo air traffic controller and other pseudo aircraft traffic to investigate the effects on situational awareness when ATC communications with other traffic are not heard.

The ground system consisted of a data link processor (DLP), a telephone modem to access a real-time, digital weather data base, a ground-based radar to track the position of the airplane, two different data link radio sources to the airplane, and multiple VHF frequencies for voice radio communications.

The DLP was a personal computer with multiple interrupt-driven, serial communications ports for communicating with the airplane and the real-time weather data base. Ground personnel used the DLP to store ATIS messages, compose and send ATC and company messages to the airplane, receive downlinked messages, communicate with the weather data base, and log all messages. The ATIS information was stored in a buffer in the DLP and automatically sent to the airplane on a request-reply basis.

Weather information used during these flight tests was obtained from a Federal Aviation Administration weather data base in McLean, Virginia. This data

base was developed and is supported by the MITRE Corporation. The DLP acted as a gateway between the airplane and the weather data base by automatically relaying weather information requests from the airplane through a land-based telephone line to the weather data base. These requests and the response from the weather data base were automatically sent without any action by the ground personnel.

The tracking radar was used to determine the position of the research airplane. This position was shown on a CRT display and used by the pseudo air traffic controller.

Data link radio sources. Two different radio sources for the data link system were used during these tests. The first data link source, called "Packet," was implemented by using a 1200-bps radio modem over a frequency of 168.35 MHz (VHF). An AX.25 protocol (ref. 4) operating in a connection mode was used to implement the bottom three layers of the Open Systems Interconnection (OSI) architecture.

The second data link source was the commercially available Aeronautical Radio, Inc. (ARINC) communications addressing and reporting system (ACARS) data link. This system was used to report on a commercially shared VHF frequency.

Airborne data link system. The airborne data link system and displays were designed for ease of use and for reduction of flight crew work load. To achieve ease of use, the data link display was designed with menu-selectable information in overlapping windows. A touch panel mounted on the CRT display of the data link was designed to minimize crew-typing activities and reduce crew work load. However, the flight crew could, at their option, use the CDU keyboard to type free-text information into the data link system. A digitized voice was used to provide auditory output of time-critical ATC data-linked messages and the initial data-linked route clearance.

Another system design that reduced crew work load was the capability of the crew to readily transfer data-linked information into the airplane flight guidance system and/or the FMS. Information, however, could not be transferred into the airplane flight guidance system or FMS directly from the ground. Thus, the flight crews were *required* to make the decision to transfer the information, and they could do so with a single-button activation.

Display windows. The data link display formats are contained in small, medium, and large windows that can overlay each other (fig. 5). The large

window is used to display the main menu page or weather menu page. The medium window is used to display all information composed by the flight crew to be data linked to the ground and to view stored messages and current ATC clearances. The small window is used to display information sent from the ground to the airplane.

The data link windows are drawn on three layers. The small window is always displayed on the top layer. When it is viewed, the small window always has visual priority over the medium and large windows. The medium window is always displayed on the middle layer. When it is viewed, the medium window overlays the large window. The large window is always displayed on the bottom layer and does not overlay any other window. The uppermost layer displayed is the active window. Windows shown below the uppermost layer are inactive.

Each window contains touch-sensitive areas that are drawn as buttons. These buttons contain labels for annunciating various actions to be performed or format selections to be shown on the data link display. At the bottom of the large window, an area is used for message-annunciation buttons to alert the crew when non-time-critical messages arrive. (Non-time-critical messages included weather information, ATIS, company messages, general announcement messages from ATC, and strategic or en route clearances when the airplane was on the ground.) When these buttons are activated, the appropriate message is shown.

Except for scroll buttons (buttons containing an arrow), the data link system interprets a button to have been activated when the pilot's finger (or other touch device, such as a pencil) is lifted from the button on the touch panel. If the pilot keeps touching the display but slides his or her finger off the button, no action is taken by the data link system.

Scroll buttons contain arrows that point up or down. When messages cannot be entirely seen on one window, the pilots can touch a scroll button to move the message up or down so that they can read different parts of the message. Scroll buttons also increase or decrease numerical values that are generated by the flight crew. As long as the pilot keeps touching the button, the scrolling action will continue.

Different colors are used in the displays to indicate the active and inactive windows, the currently touched button, and the perpendicular touch target lines (fig. 6). The blue windows and buttons are inactive. Touching blue buttons does not cause any action to occur. The white windows and buttons are

active. White buttons may be touched to cause an action to be taken by the data link system. In figure 6, the small window indicates a time-critical message has been received. The medium window, which is drawn in white, overlays the main menu window, which is drawn in blue. (Time-critical messages were the tactical messages, such as vectors, altitude and speed clearances, and route modifications, transmitted by ATC.)

The magenta touch-target lines and the green button provide two indications of where the pilot is touching the panel. The touch-target lines cross the position on the touch panel that the airborne data link system interprets is being touched. If more than one area is being touched, the average position between those areas is computed as the touched location and would be appropriately indicated by the touch-target lines.

When the touch-sensitive area inside a white (active) button is being touched, the color of that button changes to green. When the pilot's finger is lifted from a green button, it flashes twice to indicate that the command has been accepted by the data link system and that the appropriate action is being taken.

Ground-to-air messages. In figure 7, non-time-critical messages from the weather communications processor (WCP), general information from ATC, and company communications from the airline (NASA in this example) are annunciated by the buttons on the lower part of the main menu page. One or more of these buttons is only displayed when a corresponding non-time-critical message has been received. The crew may touch the appropriate button to respond to these message annunciations in any order and at their convenience. Their response results in that message being shown on a small window that overlays any previous large or medium windows shown. Once the crew responds to that message, the small window will disappear, and the crew may select another non-time-critical message.

Figure 8 is an example of a time-critical message from ATC. When a time-critical ATC message is linked to the airplane, the message is displayed automatically in the small window. An electronic digitized voice then repeats the message to the flight crew. The flight crew must respond to that message before any other message can be viewed or composed for down-linking to the ground.

With the example shown in figure 8, the crew may respond by activating the ROGER, ROGER/ENTER, or UNABLE button. When the ROGER button is activated, a "roger" message is sent back

to ATC, the small window is removed, the message is stored for later inspection on the view message page, and the appropriate message information is shown on the view clearance page. (See appendix.)

If the ROGER/ENTER button is activated, the same actions occur when the ROGER button is activated; in addition, appropriate commands are inserted into the airplane flight control system and/or the flight management system. In this example, the 350° heading and the 27 000-ft altitude clearances are inserted into the flight control and guidance system.

If the UNABLE button is activated, an "unable" message is sent to ATC, the small window is removed, and the message is stored with an unable response for later inspection on the view message page. The test crews were told to immediately contact ATC by voice radio or data link if they sent an unable response back to ATC.

In figure 9, more than one time-critical message and numerous non-time-critical messages are waiting for a crew response. All time-critical messages must be responded to before the non-time-critical messages (buttons now shown in blue) may be observed. The crew may examine all time-critical messages by activating the TIME CRITICAL MESSAGE WAITING button on the top of the large window. When this button is activated, the time-critical message displayed is removed, and the next time-critical message is displayed. The crew may respond to the time-critical messages in any order. Once all the time-critical messages have been responded to, the non-time-critical buttons are changed from inactive to active (blue to white), so the crew can respond to these messages at their convenience.

Main menu options. The main menu page is shown in figure 10. From this page, the crew may select six display page options:

1. The ATC page is used for constructing ATC related requests from the flight crew to ATC.

2. The weather menu page is used for constructing requests for weather information from a weather data base located on the ground.

3. The ATIS page is used for requesting ATIS information.

4. The NASA ground page is used for typing any free-text messages to be sent to the crew's company.

5. The view clearance page is used to view the strategic (route) clearance, the current tactical (vectors, altitude assignments, airspeed

restrictions) clearances, and the current ATC voice communications frequency that should be monitored.

6. The view message page allows the crew to recall all ground-to-air and air-to-ground data-linked messages that have occurred on their flight. The message list identifies the source of each message and the time the message was sent through the data link. For a message transmitted from the ground to the airplane, the list shows when the message was received in the airplane, when the crew answered or responded, and the type of response ROGER, ROGER/ENTER, or UNABLE to the message.

Page format. Figure 11 is a tree diagram of the pages that may be selected on the data link display. The display formats of each page are designed to lead the crew through the tree so that crew requests may be readily constructed and sent to the ground. Further details on the operation of this data link system and page formats may be found in the appendix and in reference 5.

Test Design

Purpose of Flight Tests

The objective of these flight tests was to compare flight operations for which all air-to-ground communications were voice radio with flight operations for which the air-to-ground communications were primarily data link. Voice radio was always used as a backup communications source during the data link portion of the flight tests. Communications included ATC clearances and messages, ATIS, weather information, and company messages. The flight operations were typical of commercial airline flights in an airplane with an electronic flight instrumentation system. During this test, the following specific issues were addressed:

1. The flight crew acceptance of data link communications for strategic and tactical ATC messages

2. Perceived work load of flight crew

3. Evaluation of the design of the interface between the NASA data link and the flight crew

4. The flight crew acceptance of the ability to transfer ATC commands directly from the data link system into the aircraft FMS and flight guidance and control system at their discretion

Test Conditions

For this evaluation, six test crews flew three different flight paths from takeoff to landing. Each path was flown on a different route to reduce the flight crew's anticipation of similar operational scenarios during the flight test. The airborne communications capabilities and/or procedures were also different for each path. However, specific scenarios were developed for each path so that the types of transmitted messages were the same. Thus, comparisons could be made between the different communications capabilities and procedures.

The flight path shown in figure 12 was used to establish a data baseline for which all communications were made with normal voice radio. The data established during this flight were used for comparison with the data obtained from the data link flights. Flights on the other two paths, shown in figures 13 and 14, were made by using the data link system as the primary communications source, with voice radio as a backup.

For flights on the path shown in figure 12, the flight crew was instructed to use the voice radio to make an initial "sign-on" call whenever there was a radio frequency change with ATC. The initial sign-on call was done to assure that voice radio contact with ATC had been established. Flights on this path were denoted as data link/contact ATC flights.

For flights on the path shown in figure 14, the flight crew was instructed to tune and only monitor the radio after each frequency change, that is, not make the initial sign-on call. These flights were denoted as data link/monitor ATC flights.

The order that the paths were flown was changed for each crew. The purpose of this change was to reduce learning-curve effects upon the crew's comments and evaluations of the data link system. These learning-curve effects are caused by operating a new airplane with new communications procedures.

Flight crew tasks. The flying pilot's (FP) tasks were to control the airplane by manually steering it with the side-stick controller or by engaging and monitoring the autopilot. The FP was responsible for the overall control of the airplane and would instruct the nonflying pilot (NFP) to make inputs to the data link system, the flight control and guidance system, and the flight management system when necessary. The main task of the NFP was to support the FP, which included operating the airplane landing gear and flaps, making inputs to the FMS and the flight control and guidance system, and maintaining communications with ATC.

Communications tasks. The communications tasks for both the data link flights and the baseline voice communications flights were the same as those that would normally be accomplished during a typical airline flight. These tasks included obtaining the following: ATIS information prior to engine start; ATC predeparture clearance (strategic clearance); taxi and takeoff clearances; numerous vectors, intermediate altitudes, and airspeed restrictions (tactical clearances); route modifications due to weather or traffic restrictions; last minute modifications to the final instrument approach procedure; clearance to land; requests for weather information; and company information, such as gate number inquiries or wheelchair requests for a passenger.

The same types of ATC and ATIS related messages were transmitted to the airplane on each of the flight paths based on the location of the airplane along the path. Similar message types ensured that each crew had approximately the same work load on each of the flight paths and that crew comments would be based on the same communications tasks. Requests for weather information and company messages were made at the discretion of the flight crew.

The clearances for taxi, takeoff, and landing were always made with voice communications. The test crews were also instructed to use the voice radio when they felt that it was most appropriate, such as during unusual requests or negotiations with ATC. The crews were told that urgent or traffic advisory calls would be made by voice radio from ATC.

Flight profiles. All test flights began and ended at Wallops Flight Facility. Each of the three test flights were flown on different routes, and each route was approximately 250 miles long. Each of the flights consisted of a takeoff and climb phase, an abbreviated cruise phase, and a descent and approach-to-landing phase. Cruise altitudes were maintained between 15 500 and 17 500 ft.

During these tests, it was desirable to operate the airplane according to visual flight regulations. This choice allowed greater flexibility for vectors, altitude and speed restrictions, and route modifications from the pseudo air traffic controllers on the ground.

Test Subjects

Seven two-man test crews were selected as subjects for these flights. Since training time for each crew was limited to only 1 day prior to their flight, several criteria were used to select them. Each test crew was selected from the same airline so that normal crew procedures would be the same. To reduce the learning-curve effect from transitioning into a

new electronic flight deck, each subject was required to have some operational experience flying airplanes with EFIS displays. To reduce the training time required for CDU operations, the nonflying test crew members were also required to be somewhat proficient with FMS CDU operations.

The crew members selected for these tests were employed by major United States air carriers or freight airlines. Crew members, who represented both management and line pilots, varied in experience levels from many hours of flight time to very little airline operational experience.

Test Crew Training Procedures

Prior to arrival for the flight tests, each crew member was mailed operational instructions for the primary flight display and the flight guidance and control system. No instructions were given on the operation of the data link system.

The first day after the test crew members arrived was used for training. The test crews were given a briefing that lasted approximately 90 minutes on the operation of the flight guidance and control system, a review of the primary flight display, and a 15-minute presentation on the data link format and system operation that they would be evaluating.

After the briefing, the crew spent approximately 5 hours in the TSRV simulator. During this time, $\frac{1}{2}$ hour was devoted solely to the operation of the data link system, and approximately $\frac{1}{2}$ hour was devoted to the operation of the FMS CDU. The remaining time was used to familiarize the crew with both systems and operational procedures. Paths were flown that were similar to those flown during the actual flight test runs. After the training in the simulator was completed, the test crew was taken to the research airplane for briefings on the differences between the displays and flight control systems of the simulator and the airplane.

Recorded Data

The data recorded during these flights included digital recordings of the airplane state (i.e., airspeed, altitude, headings, bank angle, etc.) and flight guidance and control mode selections and commands. Video recordings were made of the primary flight display, the map display, and the test crew operations in the RFD. Audio recordings were made of all radio communications and interphone communications that were conducted in the airplane. All data-linked messages were time stamped and recorded both at the ground station and in the airplane. Research observation notes were also recorded during the test operations. After the flight test was completed, each

test crew member participated in an extensive debriefing period, which lasted from 2 to 4 hours.

Results and Discussion

The following results and discussion are based upon debriefing notes from seven test crews and recorded flight data from six of those crews. The flight with the seventh test crew had to be canceled because of adverse weather conditions. However, because that crew had received the simulation training, they were debriefed as if they had completed the flight test. Comments obtained from the seventh crew were very similar to those obtained from the other test crew members.

Communication Confusion, Errors, and Repeats

Crew-ATC communication confusion, errors, and verbal repeats were recorded during each of the flights. During these tests, confusion was defined to have occurred when information was transmitted but the receiving party either did not understand the intent of the message or they forgot it. Some pilot errors and message repeats resulted from confusion.

Pilot errors were defined to have occurred when an incorrect action or event took place as a result of communications. An error could be as simple as mistuning an assigned radio frequency or as significant as flying to an incorrect waypoint.

Communication repeats were defined to have occurred when part or all of the message had to be repeated. Repeats could occur when simultaneous radio transmissions blocked each other or simply when the receiving party did not hear or understand the message.

The number of times that message confusion, errors, and repeats occurred on the baseline test flights that used voice radio as the primary communication with ATC was compared with that for the flights that used data link as the primary communication with ATC. The data link flights were divided into those in which the pilots were required to establish radio contact with ATC at each voice radio frequency change (data link/contact ATC) and those in which the pilots would just tune the voice radio and monitor the ATC (data link/monitor ATC). The results of this comparison are summarized in table 1 and are referred to in the remainder of this section.

Table 1. Communication Confusion, Errors, and Repeats

	Baseline voice only	Data link contact ATC	Data link monitor ATC
Confusion	5	0	0
Errors	7	4	3
Repeats	46	9	3

Confusion. During the test flights, five events were judged to be pilot confusion all occurred during baseline, voice communications flights. In one of the events, the airplane was on the final approach and had been cleared to land, but the crew had forgotten that they were cleared to land. In two other events, the crew had forgotten their assigned altitude or heading during vectors from ATC. These events caused additional communications to occur but did not cause any significant operational problems.

The fourth confusion event occurred shortly after takeoff during a vector from ATC. The airplane was established on a vector directly towards the first waypoint of the departure route. At that time, ATC gave a new and unusual vector that required a left turn of more than 130° (i.e., away from the first en route waypoint). As the airplane was turning, ATC asked the present heading of the airplane, and the pilot responded with 360°. The air traffic controller then said: "That'll be okay." Then, the pilot questioned whether to maintain the heading of 360° or continue the turn. Several voice transmissions were needed to clarify that the turn was to be continued. This event occurred during actual IFR operations that included interacting with an actual ATC facility. Depending upon the traffic situation, this type of error could have caused significant problems.

The fifth confusion event occurred when the crew had been cleared to conduct a VOR 17 approach to a landing at Wallops Flight Facility. In this approach, the final waypoint was the airport at Wallops. Just prior to starting the VOR 17 approach, the pilot requested an MLS 22 approach. Approach control then gave the following clearance: "Cleared direct to WALAP, then cleared for the MLS 22 approach." (WALAP is an intersection located 16 miles northeast of the Wallops airport.) The pilot gave the correct clearance readback to ATC but interpreted the clearance to mean that he was cleared direct towards Wallops airport, then cleared for the MLS 22 approach. This resulted in the pilot committing an error by actually flying to the airport and a repeat by asking ATC to clarify the clearance. Depending upon the traffic situation, this type of error could have caused significant problems. This event also

occurred during actual IFR operations during interactions with an actual ATC facility.

Errors. During the test flights that used baseline, voice-only communications, seven errors occurred. Twice as many test flights used data link; these flights also resulted in seven errors. Of these errors, four occurred during the data link/contact ATC flights, and three occurred during the data link/monitor ATC flights. However, all errors that occurred during the data link flights were the result of the crew improperly tuning or selecting the voice communications radio and not contacting ATC with the voice radio when necessary. This failure to contact ATC could be a very significant problem during time-critical messages.

During the voice-only communication flights, the errors included flying to the wrong waypoint, mistuning the radio, missing an assigned waypoint crossing altitude, and giving an improper clearance readback.

It was concluded that the use of data link could substantially reduce the number of communication errors. The reduction of errors was attributed to the fact that the crew had an accurate, written text of instructions that they could refer to at any time.

Repeats. Fifty-eight repeats were encountered during this study. All repeats occurred with the use of the voice radio. During the baseline, voice communication flights, 46 communication repeats occurred. Of these repeats, 12 were caused by errors and/or confusion, and 34 were caused by the crew missing all or part of a voice transmission. During the data link/contact ATC flights, nine repeats occurred because the pilot missed part of an ATC message. Three repeats occurred on the data link/monitor ATC flights during voice transmissions when the pilot inquired about adverse weather conditions that he had overheard from communications between other traffic and ATC.

It was concluded that data link could reduce the number of communication repeats. The repeats could be reduced because data link prevents signal interference or voice interruptions from other transmissions and allows the crew to defer reading the message until time-critical tasks are completed.

Pilot Utilization of ROGER and ROGER/ENTER

All flight test crews indicated that the ROGER/ENTER button was beneficial. A comparison of pilot utilization of the ROGER/ENTER button versus the ROGER button is illustrated in figure 15. For tactical messages, the ROGER/ENTER button was

used 86 percent of the time, while the ROGER button was used 14 percent of the time.

Message Timing of ATC Communications

ATC messages that were linked to the airplane were divided into three basic types: clearance, information, and tactical. Clearance messages included predeparture, reroute, and approach clearances. Information messages were non-time-critical messages, such as ATC initiated ATIS, congestion reports, and local weather alerts. Tactical communications included time-critical messages, such as heading, speed, and altitude assignments; altimeter settings; transfer of ATC communications; and free text that the ground controller wished to immediately communicate to the flight crew.

During these flight tests, the ACARS data link system was used on two of the test runs and the Packet data link system was used on the remaining test runs. Although the ACARS data link system worked well, it was felt that the uniformity of delivery times offered by Packet would yield more consistent times for comparison of the test results. Thus, the timing results reported in this section include only the data runs that use the Packet data link system.

The message delivery time of the Packet data link system required an average time of 1.5 sec. This tune included transmission and protocol handling. Thus, the total message transaction time and total task time of the following sections include a round-trip time of about 3 sec for message transmission and protocol handling.

Timing results use the following definitions:

1. Total message transaction time: the time from when a message is sent from the ground until the ground receives the pilot's roger or unable response

2. Response time: the time from when the pilot is alerted to or begins hearing a message until the pilot makes a roger or unable reply

3. Total task time: the time from when the message is sent from the ground until the pilot makes a roger or unable reply and enters the data into the appropriate flight system

As mentioned previously, the total transaction times for the data link are simply the response times plus the 3-sec round-trip delay time of the Packet system.

Tactical transaction times. As illustrated in figure 16, the average total tactical message transaction time of the data link was 12.5 sec with a standard deviation of 5.7 sec. Subtracting the 3-sec transmission time of the Packet System yields an average pilot response time of 9.8 sec. This response time is comparable to the grand mean of 9.3 sec for those research efforts that are summarized in reference 6.

The largest total message transaction time recorded was 36 sec. The corresponding 33-sec maximum pilot response time was within the 40-sec time limit described in reference 7 as a proposed "failed message" limit.

Strategic clearance transaction times. Strategic clearances are subdivided into airborne clearances and predeparture clearances. Airborne clearances were considered to be time critical, but predeparture clearances were not.

Figure 17 illustrates the airborne strategic total message transaction times. The mean transaction time was 20.9 sec with a standard deviation of 8.8 sec. Although these messages were treated as time critical, the reroute clearances in each test run were longer and more complex than most of the tactical messages. This difference resulted in a larger mean total message transaction time for the airborne strategic clearances than for the tactical messages, which was 12.5 sec.

Predeparture clearances were not considered to be time critical; thus, only a message-annunciation button appeared on the data link display when such clearances arrived. Figure 18 illustrates the distribution of total message transaction times with a mean of 43.3 sec and a standard deviation of 15.4 sec.

Total task time for certain tactical messages. In an attempt to compare the speed of compliance with the ATC instructions that used voice instead of data link, the concept of total task time for certain tactical messages was considered. Since video recordings of the test crew and flight deck panel were made, the time the crew took to enter data into the mode control panel could be measured. Thus, if the desired action is to enter data into the mode control panel and send a roger to the ground, then a comparison could be made between voice and data link. Consequently, the concept of total task time was defined, and a comparison was made for those tactical messages that contained one or more speed, altitude, or heading assignments.

As shown in table 2, the mean total task time for all tactical messages with one or more altitude, heading, or speed commands was 10.7 sec for data link versus 15.6 sec for voice. Data link was faster because the pilot entry consisted of activating the

ROGER/ENTER button on the data link display instead of manually dialing the information into the flight control system MCP as required for voice communications. When only one of either altitude, speed, or heading was assigned, no appreciable difference occurred between the data link and the voice test runs, with mean times of 10.8 sec for voice versus 10.2 sec for data link. Each of the data link times included the 3-sec transmission time delay for the Packet data link system.

Table 2. Mean Total Task Time for Tactical Messages With Altitude, Speed, or Heading Command

	One or more commands		Only one command	
	Voice	Data link	Voice	Data link
Average	15.6 sec	10.7 sec	10.8 sec	10.2 sec
Standard deviation	10.1 sec	4.5 sec	4.5 sec	4.8 sec
Samples	39	106	18	85

Pilot Acceptance of Data Link for ATC Messages

Six of the test crews found the use of data link for ATC tactical and strategic clearances to be acceptable if there was a voice radio capability for backup communications. These crew members felt that when pilots operate in the terminal area, voice radio should be used as the primary communication device to reduce their "heads-down" time (time when they should be visually monitoring for other aircraft traffic). However, the point where the pilots felt that the transition from data link to voice radio should occur varied between entering the terminal area and the final approach to the runway.

One test crew was more conservative in their opinion on the use of data link as a communication device with ATC. They felt that data link could be used as a backup to normal voice radio communications. In addition, they felt that data link should only be used for ATC purposes during periods of low work load, such as when flying at cruise altitudes. However, they wanted to use data link while waiting to receive their predeparture en route clearance.

Overall, the test crews expressed a high degree of enthusiasm for the use of data link to receive ATC strategic and tactical messages. Their primary reasons for favoring the data link were the reduction of message errors, the capability to retrieve past messages, and the reduction of frequency congestion. They also favored the capability of accessing the

weather data base. The crews felt that voice radio should be available for certain time-critical messages and for messages that would require lengthy composition (typing).

The primary concerns expressed by the test crews, particularly the more conservative crew, were the loss of the subtleties from the tone of the controller's voice, the loss of the controller's comments, and the "heads down" time required when flying in the terminal area. One crewman was concerned about the training time requirements that would be involved when crews that transfer from one type of airplane to another are required to learn the various types of airborne data link interfaces (i.e., negative transfer of learning effects).

The crews were also concerned about the loss of the party-line effect, whereby listening to ATC communications with other aircraft gives pilots an advance indication of information that could affect their flight (i.e., traffic congestion, delays, weather, etc.). One crew member indicated that they would miss the party-line effect but could operate without it as long as the frequency congestion was reduced.

In an effort to provide some of the general information that results from the party-line effect, general information messages were sent through the data link system to all airplanes. These messages included traffic delays and severe weather reports for a particular geographic area and significant changes to information contained in the ATIS when the airplane was in the terminal area. The flight crews indicated that this type of general information sent through the data link was helpful.

Perceived Work Load

The majority of the test crews felt that data link, in general, would reduce the nonflying pilot's work load and mistakes. They felt that the single-button entry of route modifications and barometric altimeter settings into the FMS, and airspeed, heading, and altitude commands into the flight guidance and control system significantly contributed to the reduction of work load and number of mistakes.

One crew member expressed his concern that the need to read the data link display and verify the entry of information into the flight guidance and control panel required too much heads-down time. However, another crew member indicated that writing the information on a piece of paper and then entering it into the flight guidance and control panel required much more heads-down time than entering the information on the data link system.

A third crew member indicated that the data link system let him distribute his work load more evenly. He could look away from the written message to perform other tasks and then look back to finish reading the message.

ATC Radio Frequency Changes

In an effort to further reduce voice-radio frequency congestion with the use of data link, some crew members have suggested that no verbal sign-ons be required by the flight crews whenever an ATC frequency change occurs. However, without an initial sign-on, the crew members would not know if they were in actual contact with ATC.

Pilot comments indicated that a voice sign-on would be necessary for each ATC frequency change during the initial implementation of data link in the operational environment. After the transition period, pilots would only need to tune and monitor the radio. However, when the initial voice sign-on is removed, some indication must be given to the flight crew and ATC that the radios are tuned correctly in case time-critical voice communications are necessary.

Data Link Display Location

Much discussion took place with the test subjects on the implementation and location of the data link system in the flight deck. All subjects agreed that, while space in the flight deck is at a premium, the data link display, when used for ATC tactical messages, must be located on the instrument panel or the center console in front of the throttles in the pilot's forward field of view.

Because of the shortage of flight deck space, the data link display may have to be divided into two areas. The time-critical messages, or some type of visual alert of them, could appear in the pilot's forward field of view. The remainder of the data link system (display, keyboard, etc.) could then be inserted on the center throttle console. Also, a data link message alerting mechanism and the ROGER, ROGER/ENTER, and UNABLE buttons could be located on the glare shield.

The majority of the crew members indicated that they do not want the data link display and the FMS CDU combined, particularly when they use the data link for ATC tactical messages. Crew members also felt that the CDU contained too much information that the pilot needed, and the CDU would not be able to time-share the information with the data link messages.

Several of the pilots felt that if the airplane contained three CDUs, incorporating the data link display into the third CDU would be acceptable. However, they could not decide, location wise, which CDU should be dedicated to the data link and which CDU should be dedicated to the FMS.

The majority of the pilots indicated that they wanted to make alphanumeric inputs to any of the systems in the airplane through the same keyboard. This ability would keep the keyboard layout consistent (better pilot familiarity) and would tend to reduce confusion. The pilots indicated that they would like to use the CDU keyboard to make inputs to the data link system. This appears to contradict their desire to keep the data link and CDU separate.

Flight Deck Printer

Although a flight deck printer was not used during these tests, crew members were asked if they needed a printer for the test scenarios. The test crews concluded that a flight deck printer is not necessary for certain data link system interfaces, such as the CRT display formats used in these tests.

Data Link Display Formatting Concept

In an overall evaluation, the test crews judged that the data link window–menu-formatting concept with the touch-panel capability was very easy to use. The window–menu-formatting concept required little training time even when used to its maximum capability.

The test crews also found that transferring route clearances and route modifications directly into the FMS CDU and transferring airspeed, heading, and altitudes directly into the flight guidance and control system were very acceptable. The single-button activation, which causes the transfer of commands at the pilot's discretion, was viewed as a significant work saver and error reducer.

During the design of the data link touch-panel display formats, there was some concern about parallax problems that could occur. However, since the magenta touch-target lines and the touched button changed from white to green, the crews decided that parallax was not a problem.

The color coding of the display format was judged to be acceptable. The white active display shown over blue inactive windows was easy to view.

Most test crew members liked the electronic digitized voice that delivered all time-critical messages and the predeparture route clearance where they were received. They did not, however, feel that the electronic digitized voice was a necessity for the operation of the data link system. The crew felt that, compared with the normal radio voice, the digitized

voice was a distinctive feature and a good message-alerting device. One crew member indicated that he could remember the clearance better with both voice and written text and that he could distinguish between the electronic voice and the voice radio.

The test crew members suggested several items and changes to the design format. Several crew members wanted a STAND-BY button next to the ROGER, ROGER/ENTER, and UNABLE buttons. The STAND-BY button would send the message to ATC that they received the clearance information but have not yet accepted it. During these tests, the crews indicated that they would have used a STAND-BY button to transfer route modifications into the FMS as a provisional route for inspection purposes before accepting the route modification clearance with a roger message.

All test crew members liked the name of the ATC facility displayed adjacent to its radio frequency (the last assigned frequency) on the view clearance page. They also said that they would like to have the name of the last ATIS information received shown on the view clearance page.

Several of the test crew members indicated that they did not like the scroll keys that were used on the ATC heading, airspeed, and altitude request pages. Touching these keys scrolled the number, starting at the present state of the airplane, up or down. These crew members indicated that they would rather use a digital keyboard to type the desired value directly into the display.

Conclusions

A flight test was conducted to evaluate the use of data link as the primary communication source for air traffic control strategic and tactical clearances, weather information, and company messages. Seven crews were trained for the flight tests; however, flight evaluation by one of the crews was not possible because of adverse weather conditions. Six test crews flew three different flight paths of approximately 250 miles. One path provided the baseline condition for which normal voice communications were used.

The other two paths were flown with data link as the primary communication source and voice radio as a secondary or backup communication source.

Based on these flight tests, six of the test crews found that data link with voice backup for ATC tactical clearances was acceptable to use from takeoff until operating within the terminal area for landing. A seventh test crew concluded that data link should only be used during periods of low flight deck work load.

Based on the type and total events of confusion, errors, and communication repeats, it was concluded that the use of data link would result in substantial reductions in significant operational errors and radio frequency confusion. This reduction of errors and confusion should increase operational safety and efficiency.

Pilot comments have led to the following conclusions:

1. The majority of the crews believed that data link reduced the nonflying pilot's work load and mistakes. They all indicated that the capability of transferring ATC tactical and strategic information into the flight management system and into the flight guidance and control system with a single-button activation at the pilot's discretion significantly reduced crew work load.

2. The test crew members indicated that ATC tactical messages and all other time-critical messages should be displayed in the pilot's forward field of view.

3. The test crew members indicated that the data link window–menu-formatting concept with the touch panel was very easy to use and required very little training time.

Appendix

Data Link Display System

Introduction

A study was conducted to determine pilot acceptance of data link as the primary communications system between the air and ground for purposes of air traffic control (ATC), weather, and company message exchanges. To support the research, a data link system was designed for the NASA Transport Systems Research Vehicle (TSRV) Boeing 737 airplane and simulator. This appendix describes the airborne operational functions of the display formats of the data link system that was flight tested in the TSRV airplane.

The NASA TSRV data link system and displays were designed to be easy to use and to reduce flight crew work load. The display formats were designed with menu-selectable information in overlapping windows to achieve ease of use. A touch panel mounted on the data link CRT display was designed to minimize keyboard activities and reduce crew work load.

Display Formats

Main Menu Page

The crew may select the following six display page options from the main menu page shown in figure A1:

1. The ATC page is used for constructing ATC related requests from the flight crew to ATC.

2. The weather menu page is used for constructing requests for weather information from a weather data base located on the ground.

3. The automatic terminal information source (ATIS) page is used for requesting ATIS information.

4. The NASA ground page is used for typing any free-text messages to be sent to the crew's company.

5. The view-clearance page is used to view the current strategic (route) clearance, the current tactical (vectors, altitude, speed) clearances, and the current ATC voice communications frequencies that should be monitored.

6. The view-messages page is used to observe all ground-to-air and air-to-ground data-linked messages that have occurred on a particular flight.

Any of these pages may be selected from the main menu by activating the appropriate button.

ATC Request Menu Page

The ATC request menu page, shown in figure A2, allows the crew to construct requests to be sent to ATC. From this page the crew may select the following buttons: CANCEL, CLEAR, SEND, CLEARANCE, COMPOSE, PROFILE, RTE MOD REQ, SPEED, HDG, and ALT.

Activating the CANCEL button removes all information constructed on this page and transfers the display back to the main menu page.

Activating the CLEAR button clears the last information constructed on this page but keeps any previously constructed information. The ATC request menu page remains displayed.

Activating the SEND button causes the constructed request to be sent to the ground and a copy of the message to be stored on the view-messages page.

Activating the COMPOSE button causes the crew's alphanumeric inputs on the FMS CDU keyboard to be displayed on the data link display. The crew can then compose any free-text message to be sent to the ground. After the crew is satisfied with the message, they activate the OK button, and the CDU keyboard is returned to the FMS.

Activating the CLEARANCE button causes the request for a strategic (route) clearance to be constructed on the data link display. Then, activating the SEND button causes the clearance request to be sent to ATC. This clearance is normally requested before starting the flight. When ATC transmits a reply to the airplane a non-time-critical ATC message announciation key is displayed at the bottom of the data link display. When this key is activated by the crew, the clearance is displayed on the small window. The crew may then automatically enter the entire route into the flight management system by activating the ROGER/ENTER button.

Activating the PROFILE button causes the location of the top of the descent point and the speed profile used during the descent to be copied from the flight management system. The crew may then send that information to ATC.

Activating the route modification request (RTE MOD REQ) button causes a modified route in the flight management system, if one exists, to be copied to the data link system (fig. A3). This route modification is then displayed on the medium window in the format necessary for transmission to ATC (fig. A4). The crew may then activate the SEND button to send that request for a new route. If a modified route does

not exist in the FMS, the current active route will be copied to the data link system.

When the ATC request menu page is initially brought to the display, the current altitude, heading, and airspeed of the airplane is shown in the respective buttons (fig. A5). These buttons may be activated one at a time to construct a request for a new heading, altitude, and/or airspeed. For example, the crew activates one of the buttons (airspeed as shown in fig. A5). Another medium page is displayed (fig. A6) with the current airspeed of the airplane. The crew may adjust that airspeed figure by touching either of the scroll keys (up or down arrow buttons). If the scroll key is continuously touched, the airspeed will continue to be incrementally changed. In this example, the crew adjusted the speed to 250 knots. The crew would then activate the OK button, and the display window would be changed back to the ATC request menu page. Also, the airspeed button would be changed to blue (inactive key).

In figure A7, the crew has constructed a request for an altitude of FL270, a heading of 200°, and an airspeed of 250 knots. When the crew is satisfied with the construction of their request, the SEND button is pushed and the request is sent to ATC.

ATIS Request Page

Activating the ATIS button on the main menu page causes the ATIS request page to be displayed on a medium window (fig. A8). The airport name that is automatically shown on the ATIS request page is the origin airport programmed in the FMS when the airplane is on the ground. If the airplane is in the air, the destination airport name will be shown.

If the ATIS from another airport is desired, the crew activates the CLEAR/CDU button. As a result, the pilot inputs from the keyboard of the FMS CDU are sent to the data link system so that the crew can type the airport identifier name. If the SEND or CANCEL button on the data link window is activated, pilot inputs through the CDU keyboard are sent to the FMS.

When the SEND button is activated, the ATIS request for the airport identifier shown in the middle of the ATIS window is sent to ATC. If the CANCEL button is activated, the ATIS request page is removed from the display and replaced with the main menu page.

View-Messages Page

Activating the VIEW MESSAGES button on the main menu page causes the view-messages page to be displayed on a medium window (fig. A9). The message list that is shown includes the sender of each message and the time the message was sent on the data link. If a message was transmitted from the ground to the airplane, the view-messages page also contains the time the message was received by the airplane, the time the crew answered or responded, and the type of response—ROGER, ROGER/ENTER, or UNABLE—to the message.

The messages are listed in the order of the time that they are transmitted to the air or the ground. The message list may be scrolled up or down by touching the scroll buttons.

If the airplane is on the ground, the crew may erase the message list by activating the CLEAR button. This causes a message to be shown that inquires whether the list is really to be erased. If it is to be erased, the crew touches the CLEAR button again. If it is not to be erased, the crew touches any other button, and the view-messages page is shown again. The messages may only be erased when the airplane is on the ground.

Activating the MAIN MENU button removes the view-messages page and shows the main menu page.

View-Clearance Page

Activating the VIEW CLEARANCE button on the main menu causes the view-clearance page to be displayed on a medium window (fig. A10). The top of that page shows the current ATC strategic (route) clearance. Below that clearance is a list of the current tactical clearances (heading, altitude, speed, metering fix time for 4D operations), the voice communications frequency, and the ATC facility name that the crew has been assigned to monitor. Activating the MAIN MENU button causes a return to the main menu page.

Weather Menu Page

From the weather menu page, shown in figure A11, the crew may select from eight weather display page options or return to the main menu. The weather page is used for constructing weather-related requests from an aviation weather data base that is located on the ground. When activating the TWEB (transcribed weather broadcast) button on the weather menu, a request for a route code is automatically displayed. The crew then has to type the TWEB route code on the data link display through the CDU keyboard to obtain weather information along specific routes.

When the SIGMET/AIRMET button is activated on the weather menu, a request for the name of the state in which the information is desired

is automatically displayed. The crew then has to type the name of the state on the data link display through the CDU keyboard to obtain the SIGMET/AIRMET information. Activating the MAIN MENU button causes the data link display to be changed back to the main menu page.

Activating any other button on the weather menu page (except TWEB, MAIN MENU, or SIGMET/AIRMET) results in a location request for the weather information. While on the ground, location is the origin airport programmed in the FMS; while in the air, location is the destination airport. If neither of these airports is the desired location for the weather request, the crew activates the CLEAR/CDU button and types the airport identifier on the CDU keyboard (fig. A12).

Activating the SEND button sends the request to the ground, removes the terminal forecast request window, and shows the weather menu window.

Figures A13 to A16 show an example of the pages necessary to request winds and temperatures aloft.

When the WINDS TEMP button is activated on the weather menu, the destination airport is displayed (fig. A13). If the crew wishes to change that airport name, they may do so through the CDU keyboard by activating the CLEAR/CDU button and then typing the identifier. When the location is satisfactory to the crew, the OK button is activated, and the desired altitude is requested next.

Figure A14 shows that the present altitude of the airplane is inserted in the winds-aloft forecast request page. Any other altitude may be inserted by touching either of the scroll buttons. When the desired altitude is shown on the window, the crew activates the OK button. Next, the time for the winds-aloft forecast information is requested on the display format shown in figure A15. The crew may adjust the requested forecast time, in hourly increments, from the present time by touching the scroll buttons. When the time is selected, the crew activates the OK button and the scroll buttons are replaced with the SEND button as shown in figure A16. The crew may then send the request by activating the SEND button.
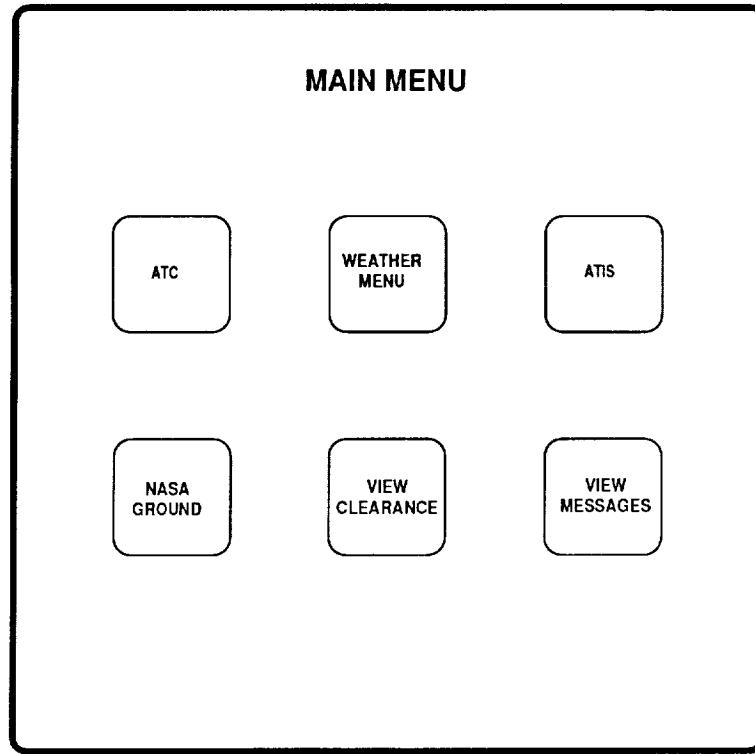
Figure A1. Main menu page.
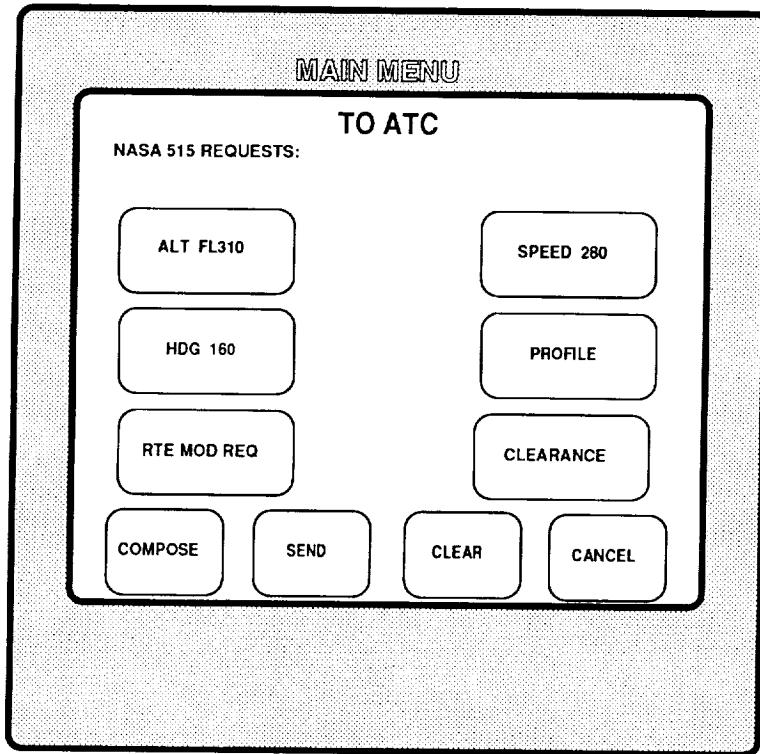
Figure A2. ATC request menu page.
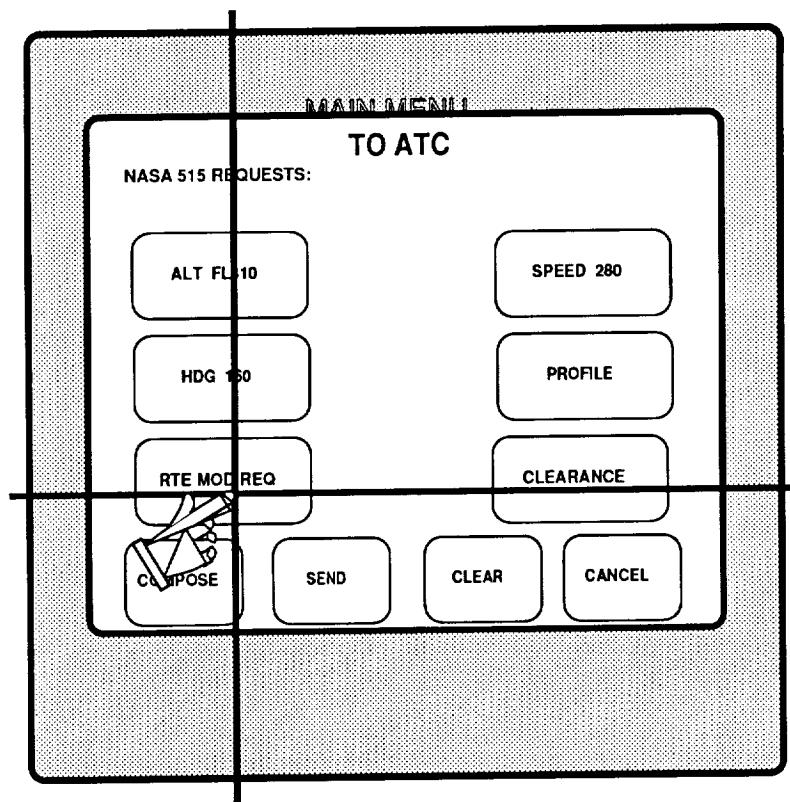
Figure A3. Route modification request on the ATC request menu page.
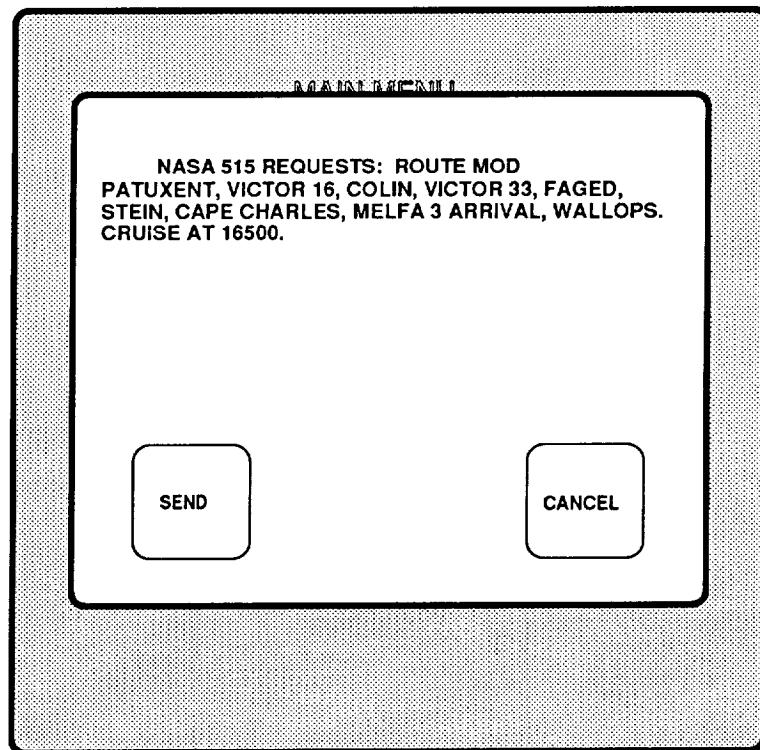
Figure A4. ATC route modification request page.
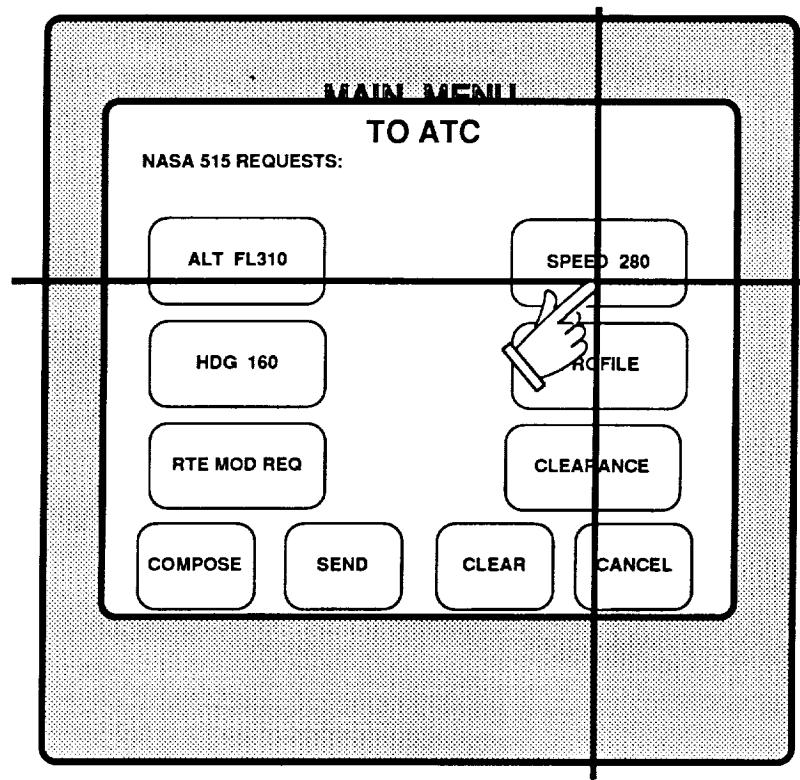
Figure A5. Airspeed request on ATC request menu page.
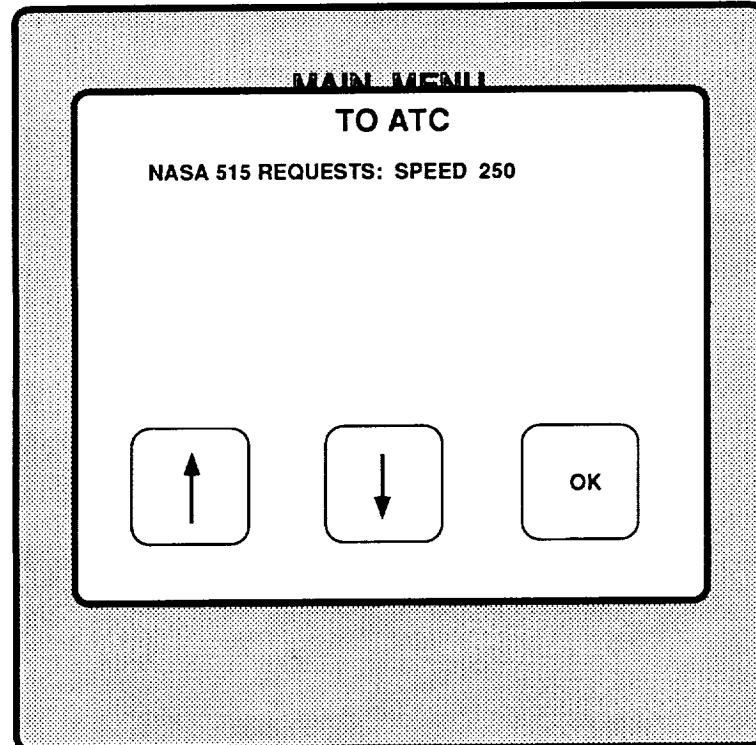
Figure A6. ATC airspeed request page.

**TO ATC**

NASA 515 REQUESTS
SPD 250: ALT FL270: HDG 200:

ALT FL270
HDG 200
RTE MOD REQ

SPEED 250
PROFILE
CLEARANCE

COMPOSE SEND CLEAR CANCEL
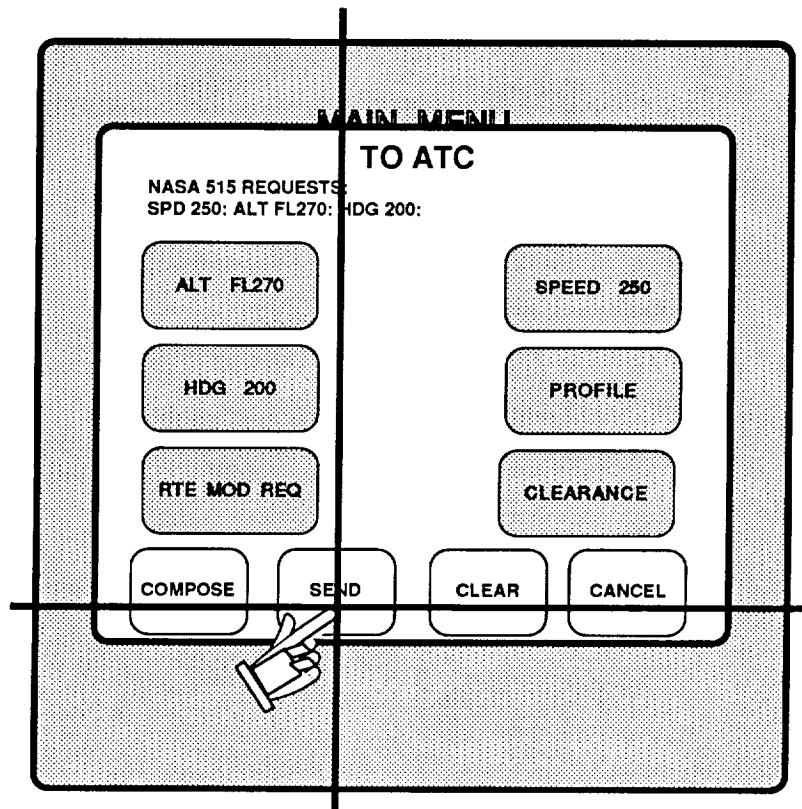
Figure A7. Requests sent to ATC from the ATC request menu page.

ATIS REQUEST

ENTER THE THREE LETTER IDENTIFIER:

WAL

SEND CLEAR CDU CANCEL
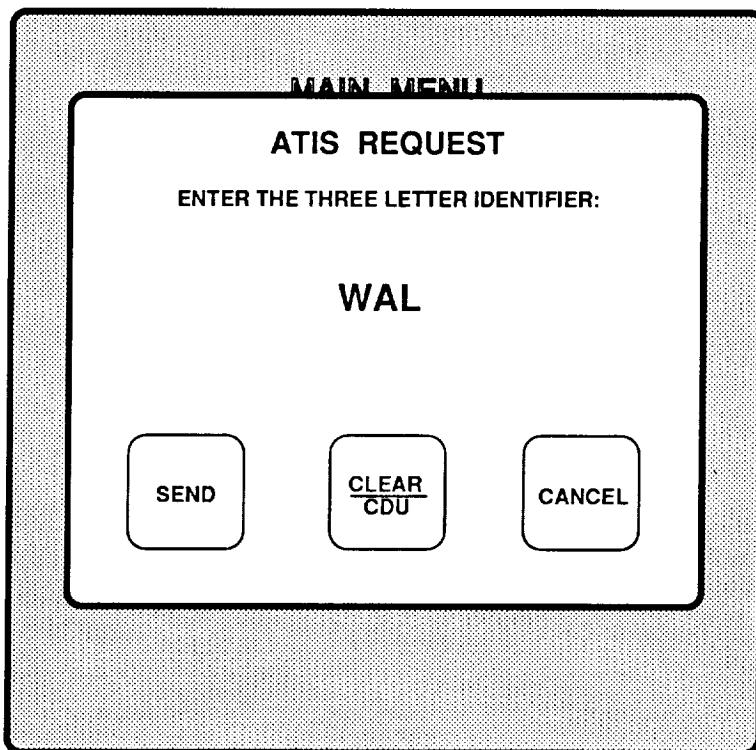
Figure A8. ATIS request page.

TO ATC 155510: NASA 515 REQUESTS ALT FL350.

ATC 155530,155535,155550RE: CLIMB AND MAINTAIN 35 THOUSAND.

ATC 160513,160519,160539R: RESUME OWN NAVIGATION

TO WCP 161716: WAL

WCP 161716,161723,161839R: WAL   1551 CLR
VISIBILITY 20 TMP/DP 68/ 48
WIND 310/11G17 ALTIMETER 29.89

TO WCP 161850: WALFT

| ↑ | ↓ | CLEAR | MAIN |
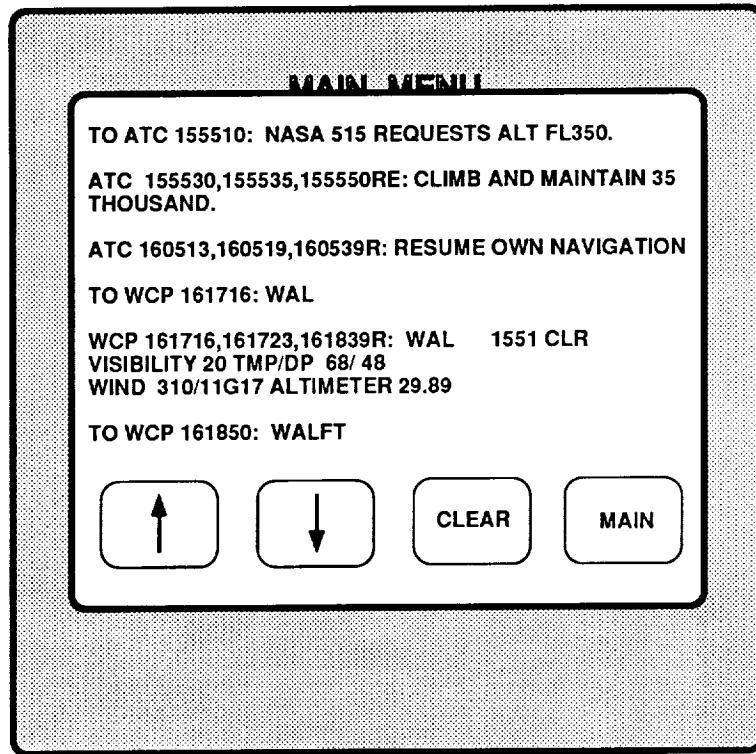
Figure A9. View-messages page.

CURRENT CLEARANCE:
KWAL.D-W2MFV.JAMIE.STEIN.FAGED.COLIN.V213.ENO.
ATR.S-IL2ATR.KWAL:EA165:SQ4545:DF23450:

CURRENT ASSIGNMENTS:

ALTITUDE:	08500	
HEADING:	2500	
SPEED:	210	
MF TIME:	----------	
VOICE FREQ:	123.550	WAL APR

MAIN
MENU
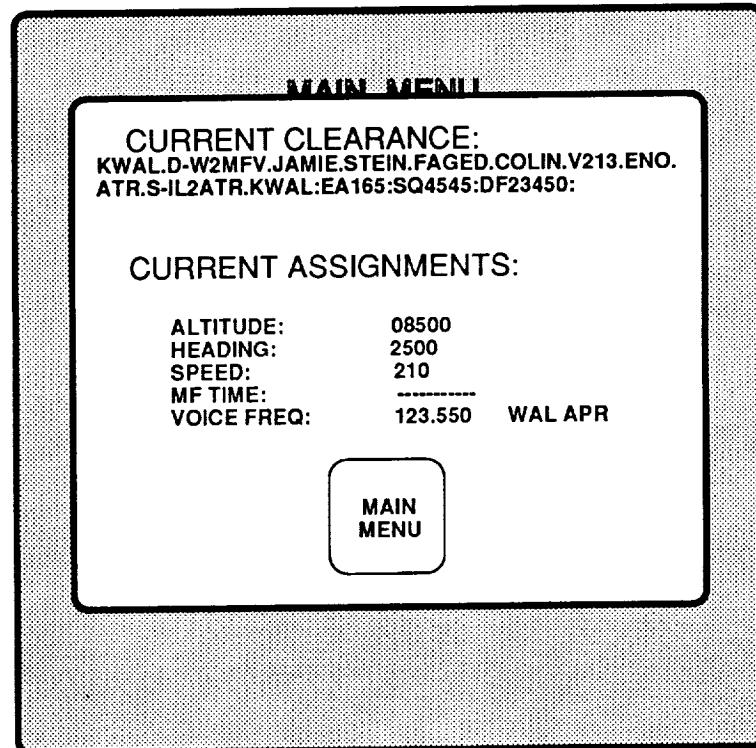
Figure A10. View-clearance page.
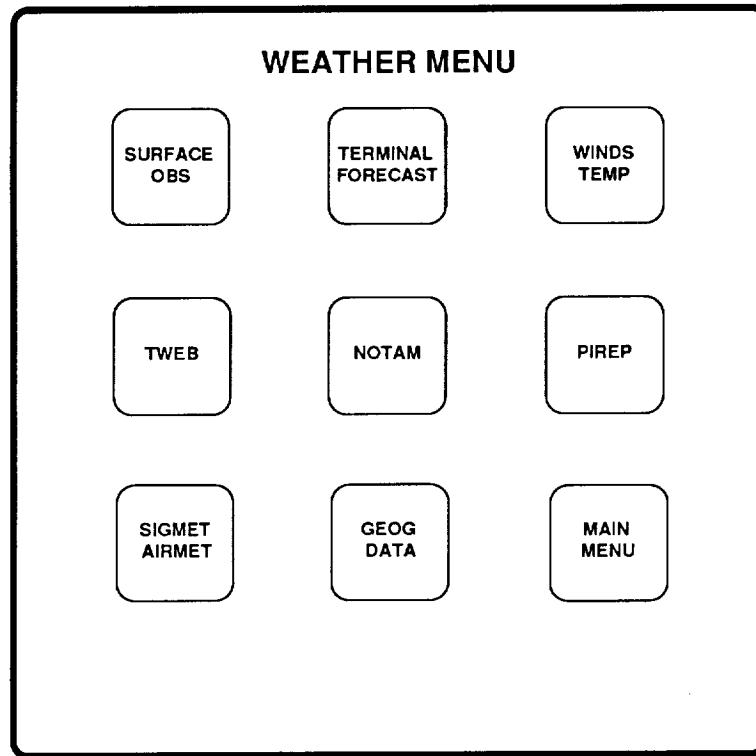
Figure A11. Weather menu page.
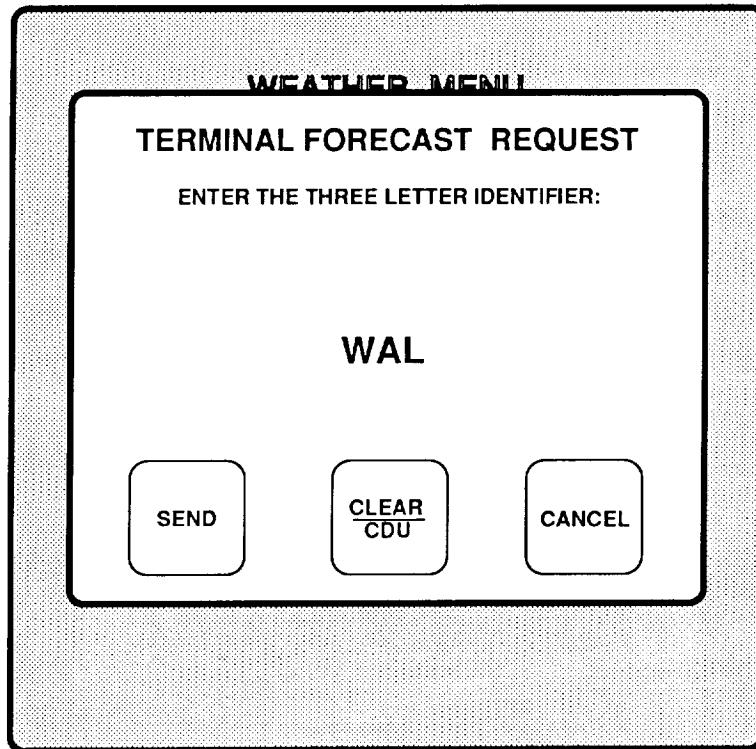
Figure A12. Weather forecast request page.
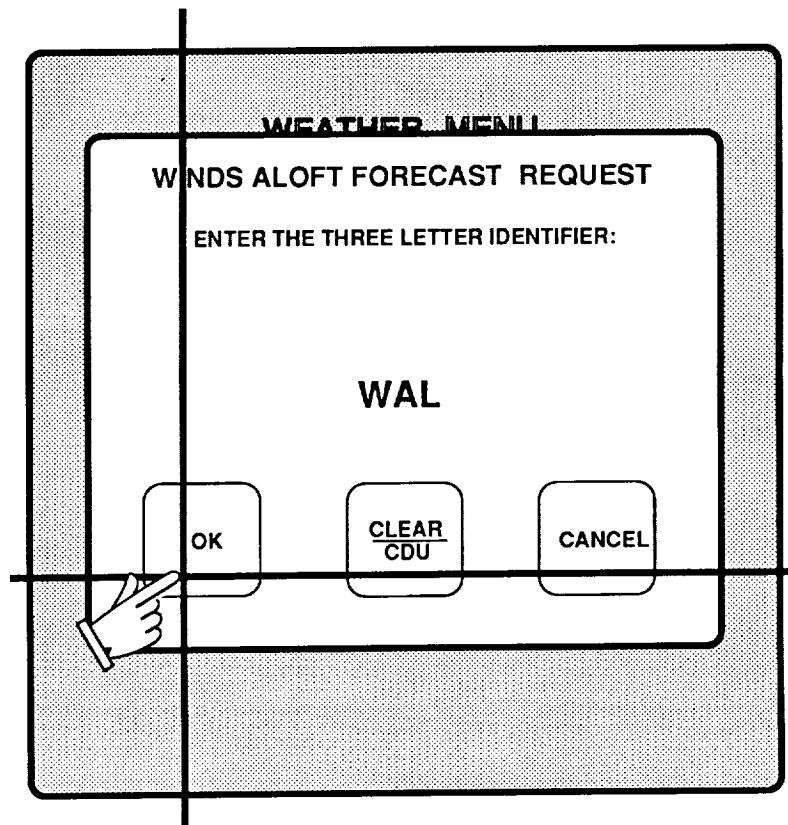
Figure A13. Winds-aloft request page 1.
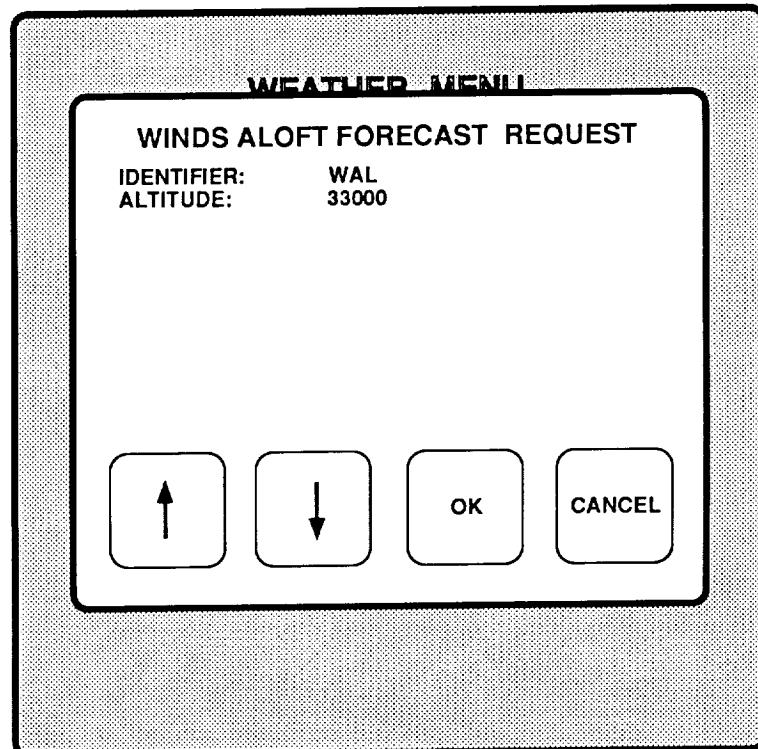
Figure A14. Winds-aloft request page 2.

WINDS ALOFT FORECAST REQUEST

IDENTIFIER:	WAL
ALTITUDE:	33000
HOURS FROM NOW:	00

↑ ↓ OK CANCEL
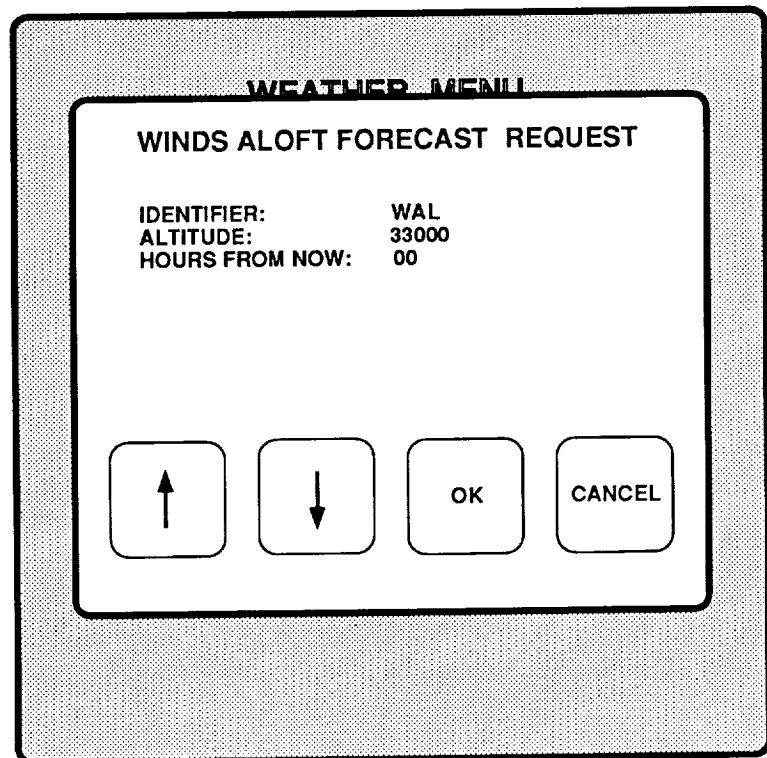
Figure A15. Winds-aloft request page 3.

WINDS ALOFT FORECAST REQUEST

IDENTIFIER:	WAL
ALTITUDE:	33000
HOURS FROM NOW:	00

SEND CLEAR CANCEL
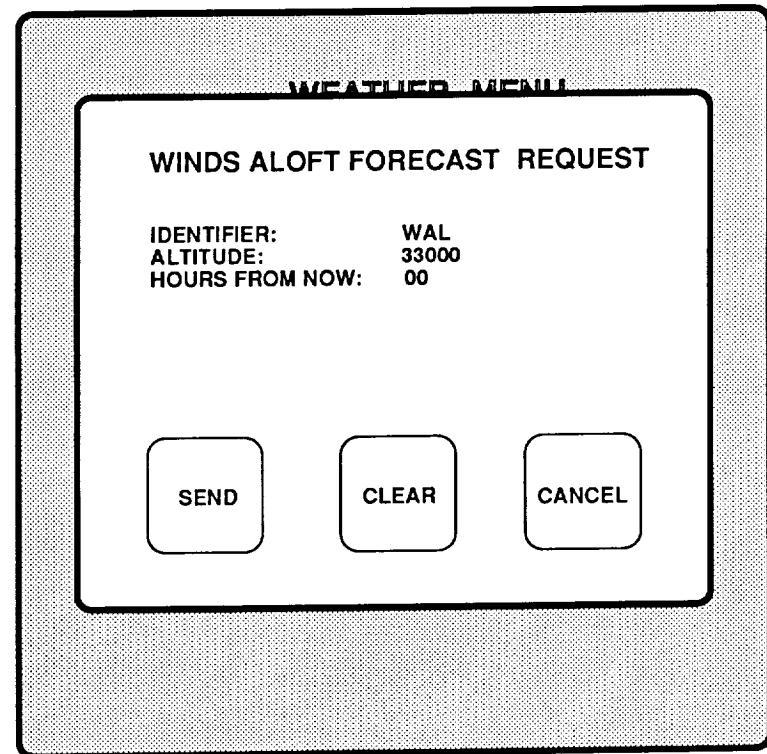
Figure A16. Winds-aloft request page 4.

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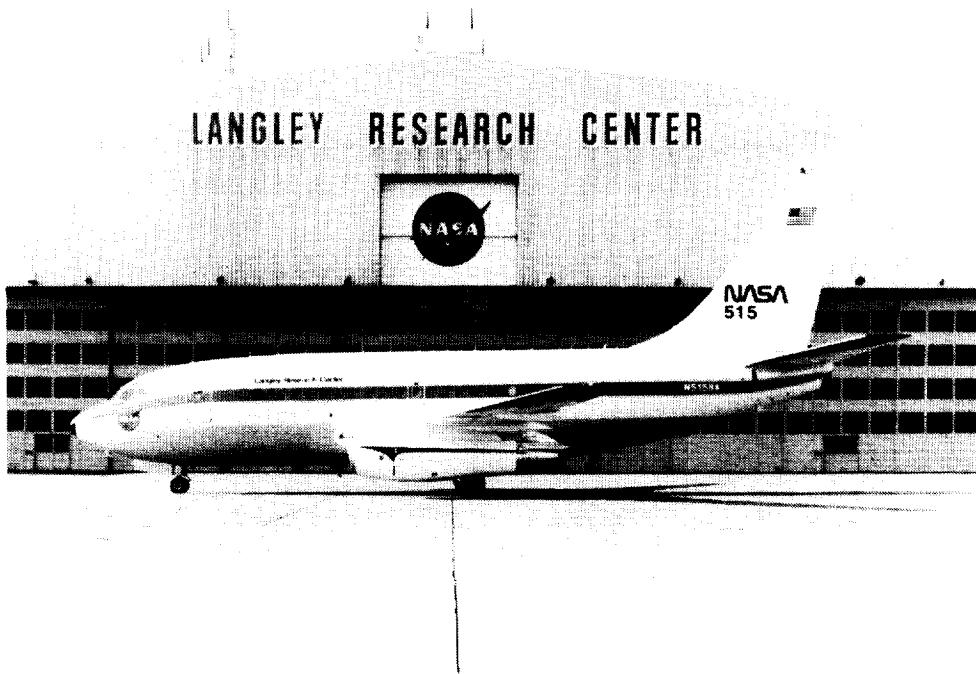
L-89-12405

Figure 1. NASA Transport Systems Research Vehicle Boeing 737 airplane.
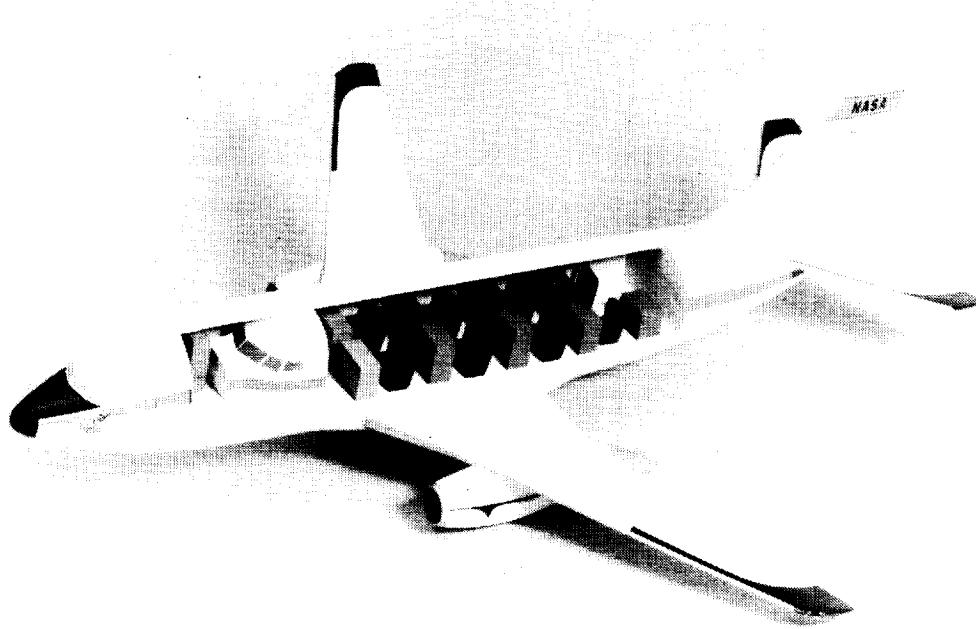
L-80-2580

Figure 2. Cutaway model of NASA Transport Systems Research Vehicle Boeing 737 airplane.

L-90-8321
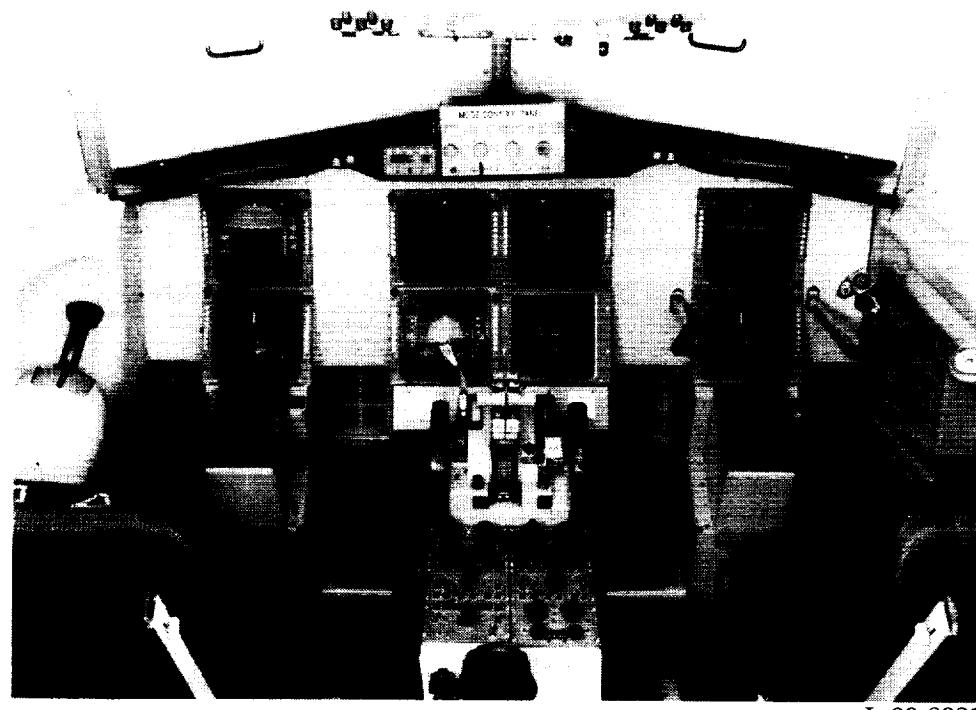
Figure 3. Research cockpit of NASA Transport Systems Research Vehicle Boeing 737 airplane.
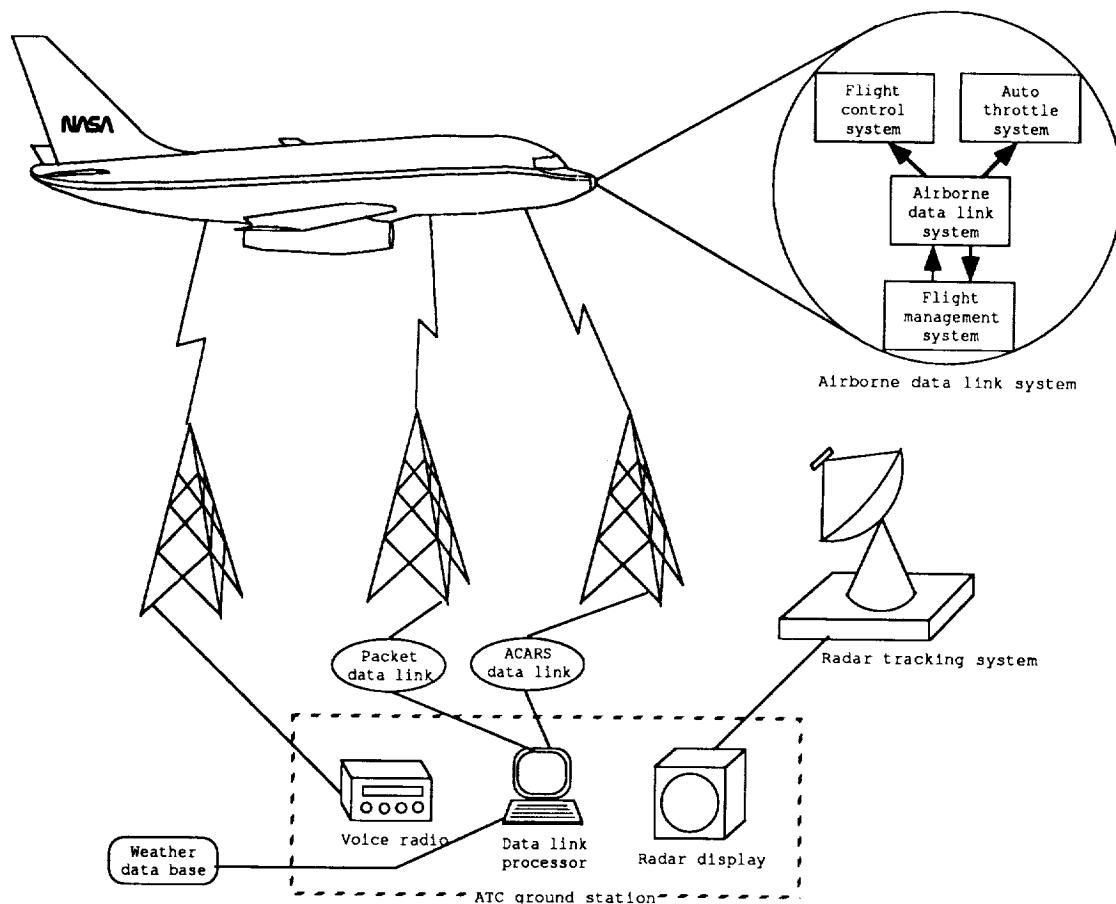
Figure 4. Block diagram of data link system for flight tests.
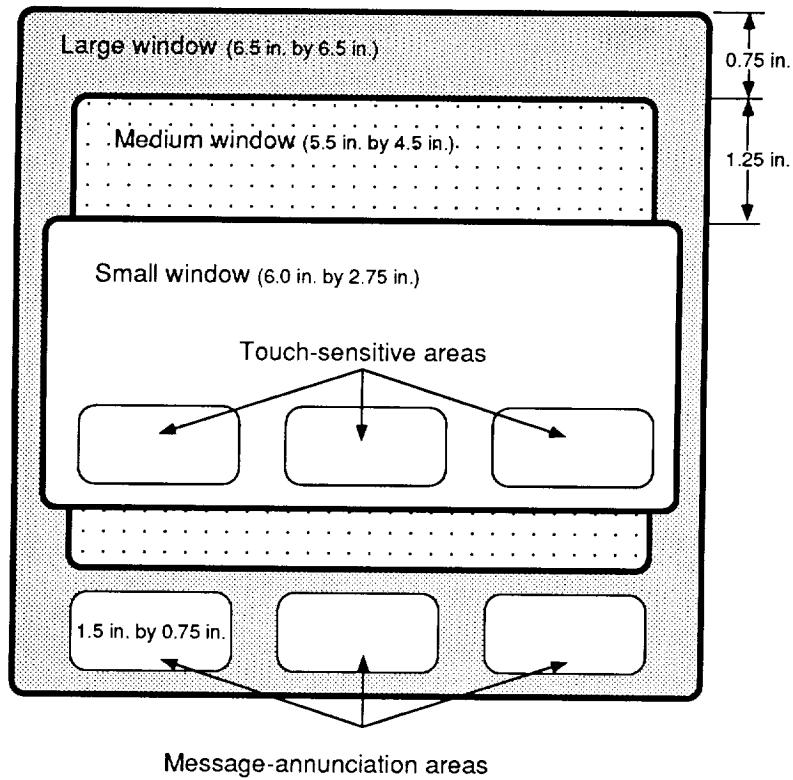
Figure 5. Window format sizes of data link display.
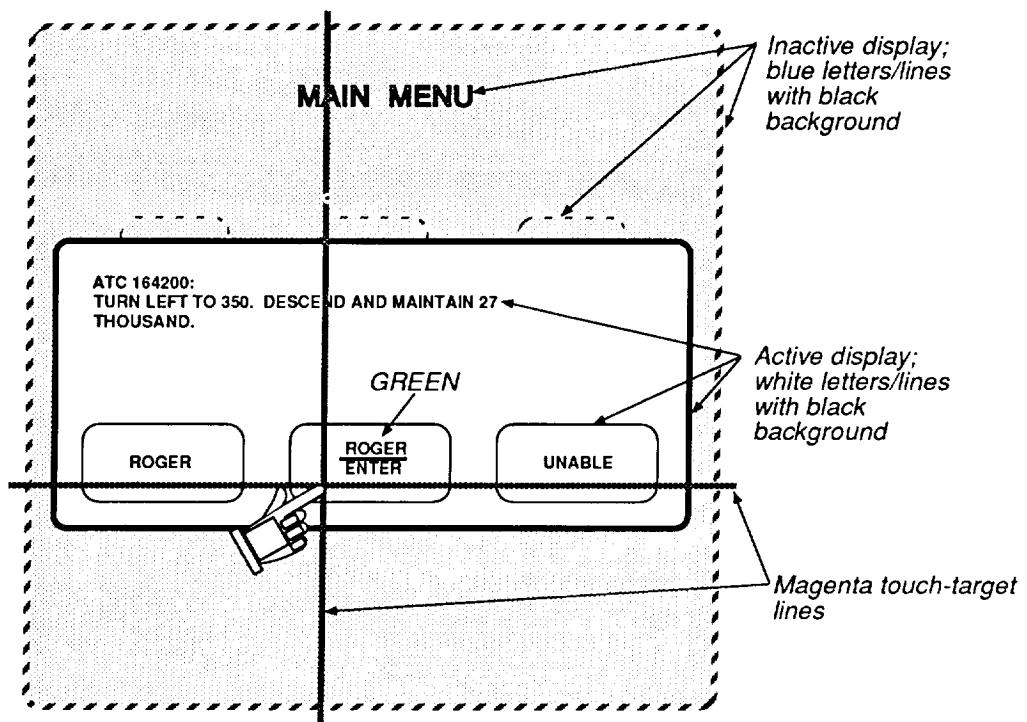

Figure 6. Colors of data link display.
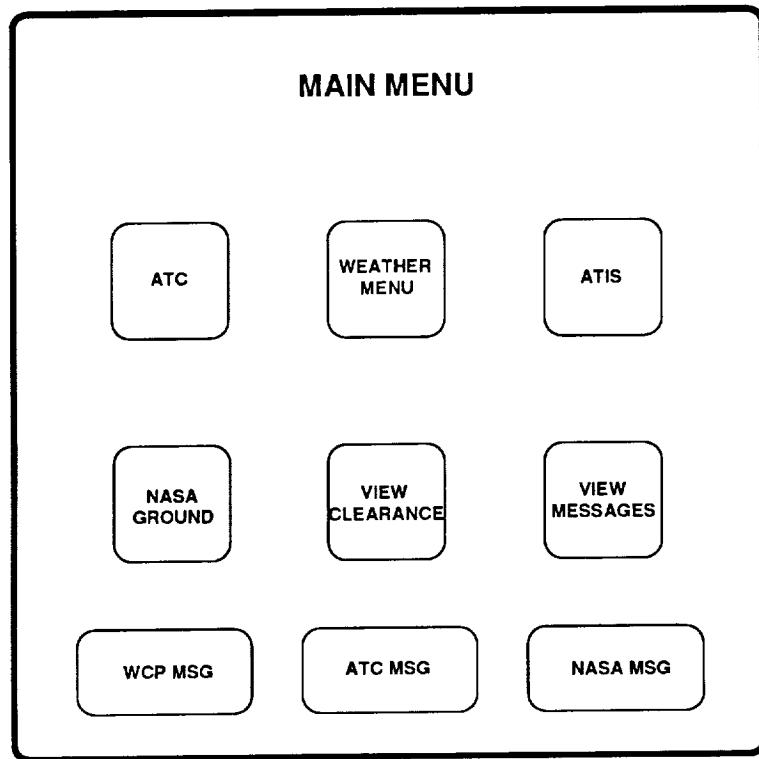
Figure 7. Non-time-critical message overlay.
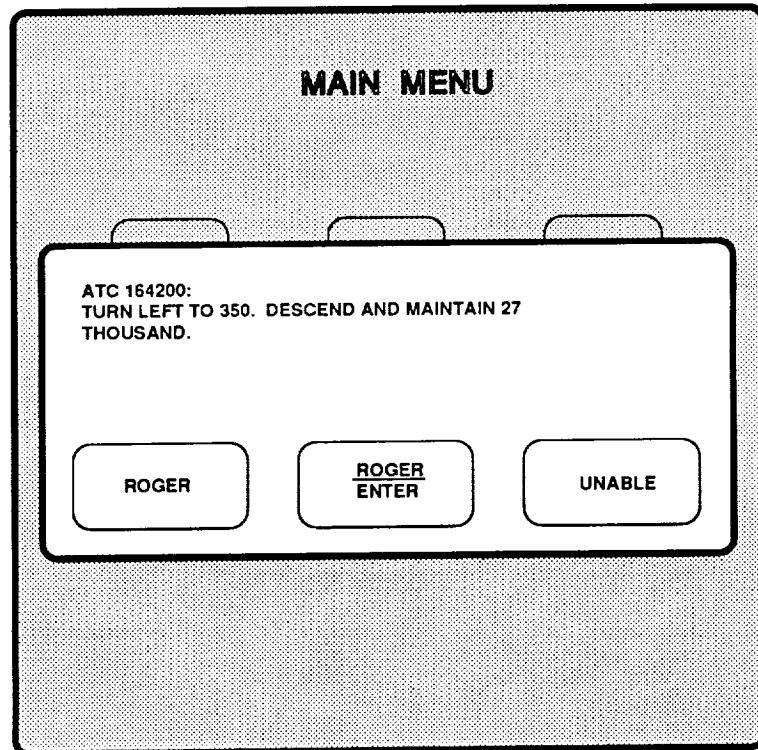
Figure 8. Time-critical message overlay.
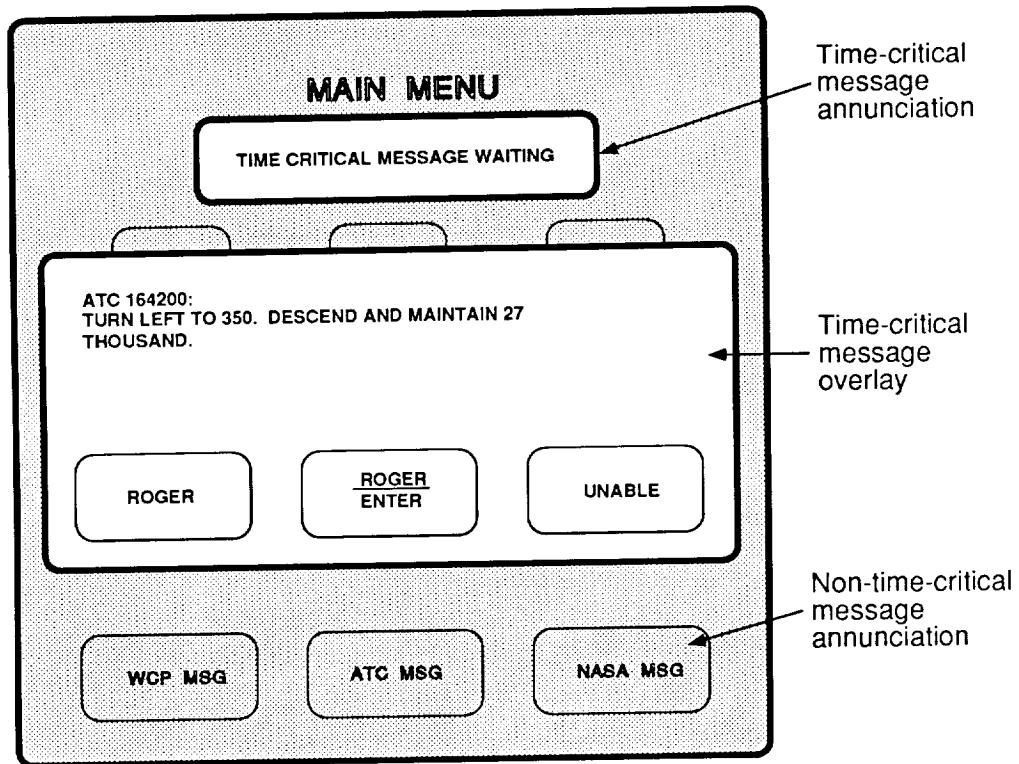
Figure 9. Multiple time-critical and non-time-critical message overlay.


Figure 10. Main menu page.

MAIN
MENU

ATC   ATIS   NASA   VIEW   VIEW   WEATHER
                GROUND CLEARANCE MESSAGES   MENU

SURFACE OBS

ALTITUDE   TERMINAL FORECAST

SPEED   TIME — ALTITUDE — LOCATION — WINDS TEMP

HEADING   TWEB

PROFILE   NOTAM

ROUTE MODIFICATION   PIREP

CLEARANCE   SIGMET/AIRMET

COMPOSE   GEOGRAPHICAL DATA
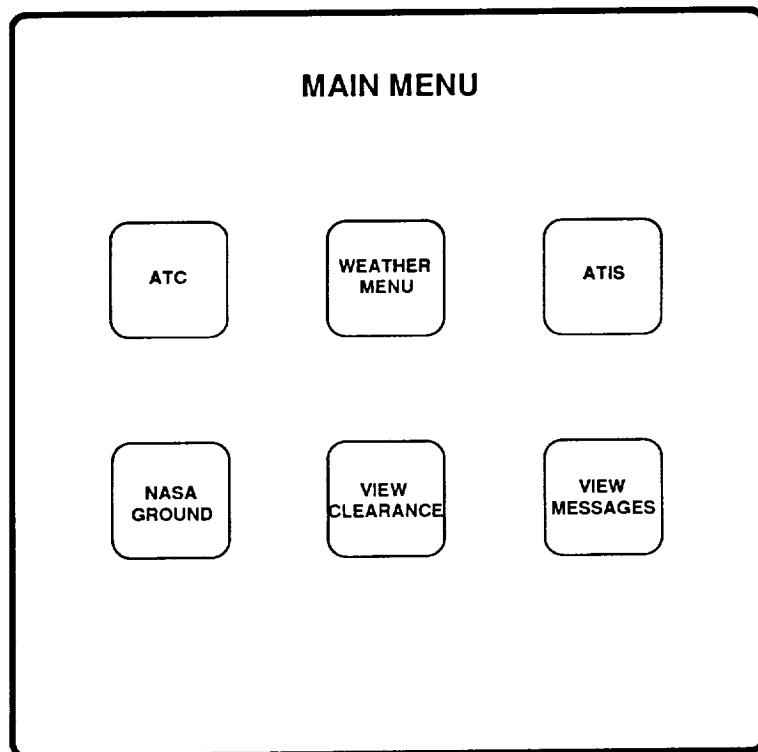
                                            MAIN MENU
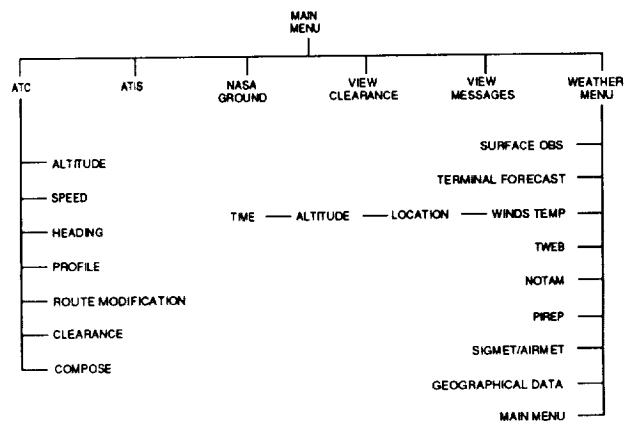
Figure 11. Page format tree for data link display.
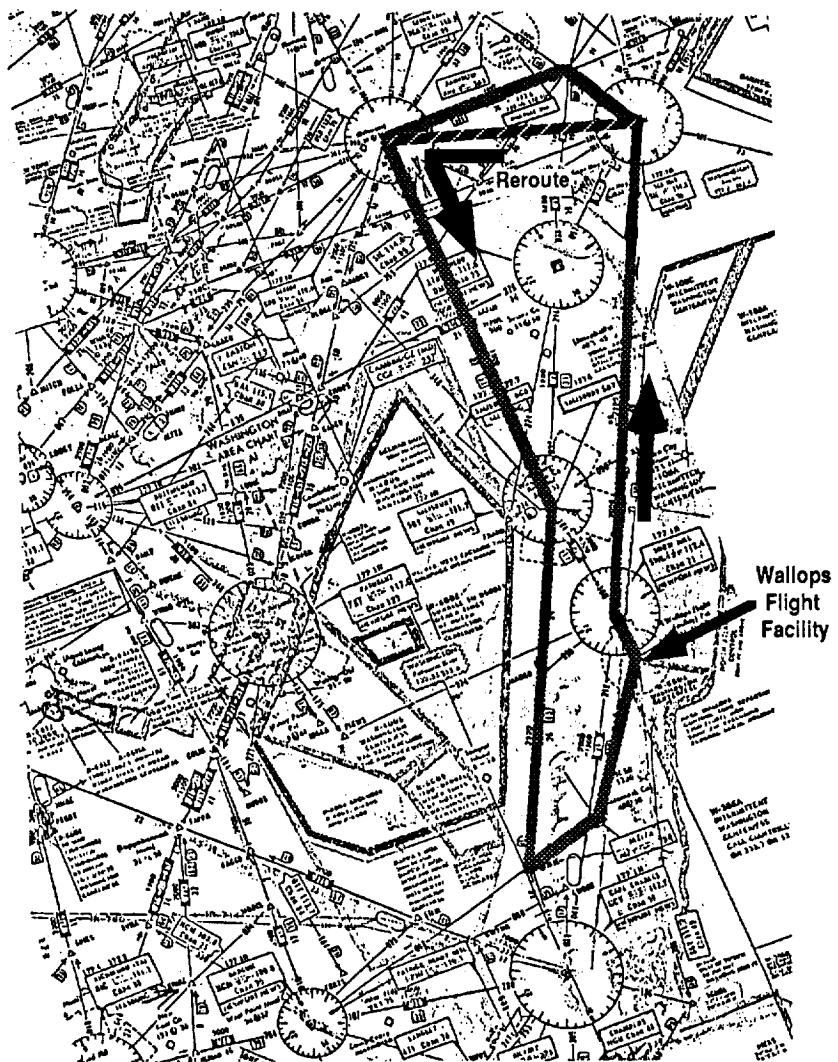
Figure 12. Flight path for baseline voice-radio communication flights.
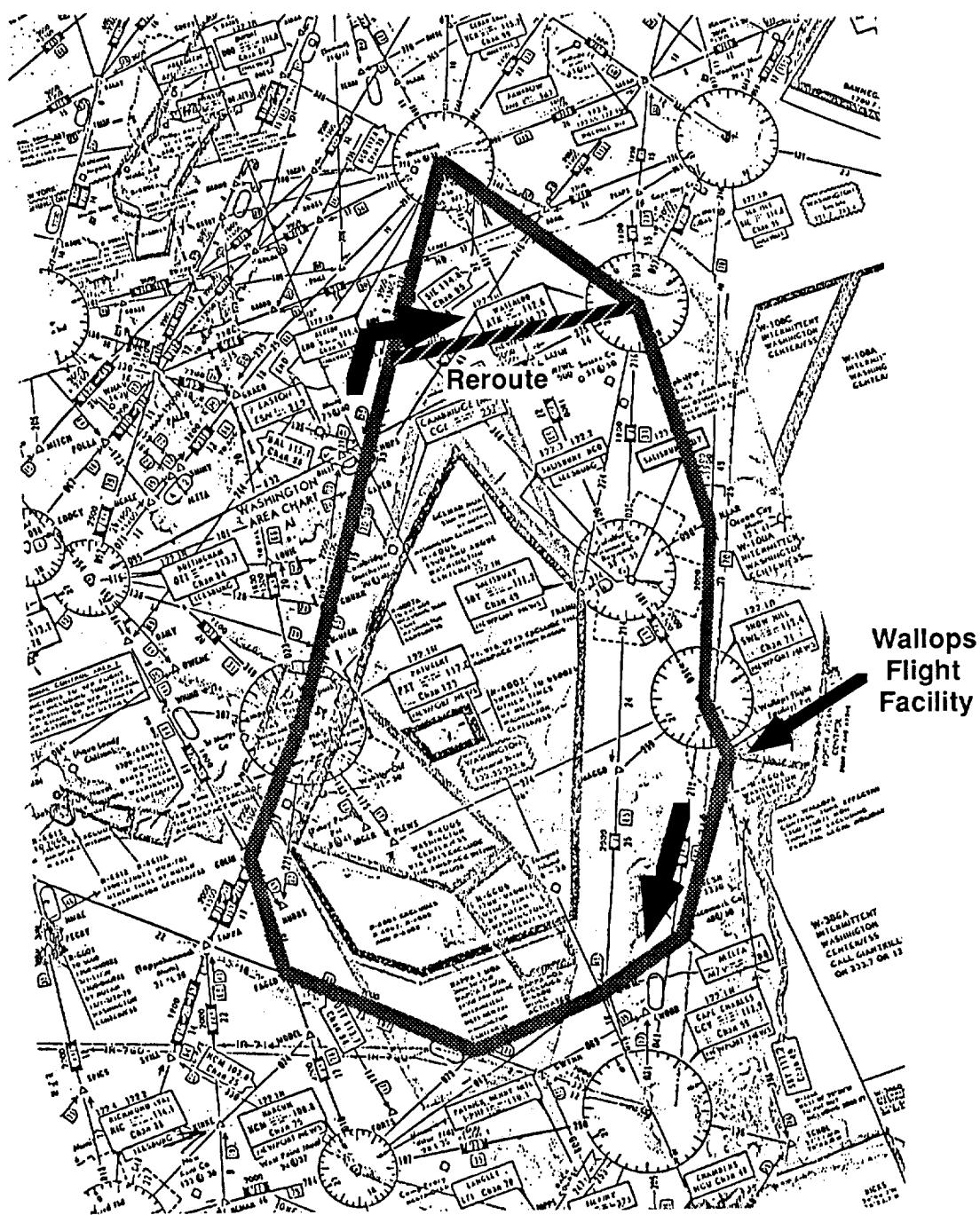
Figure 13. Flight path for data link/contact ATC flights.
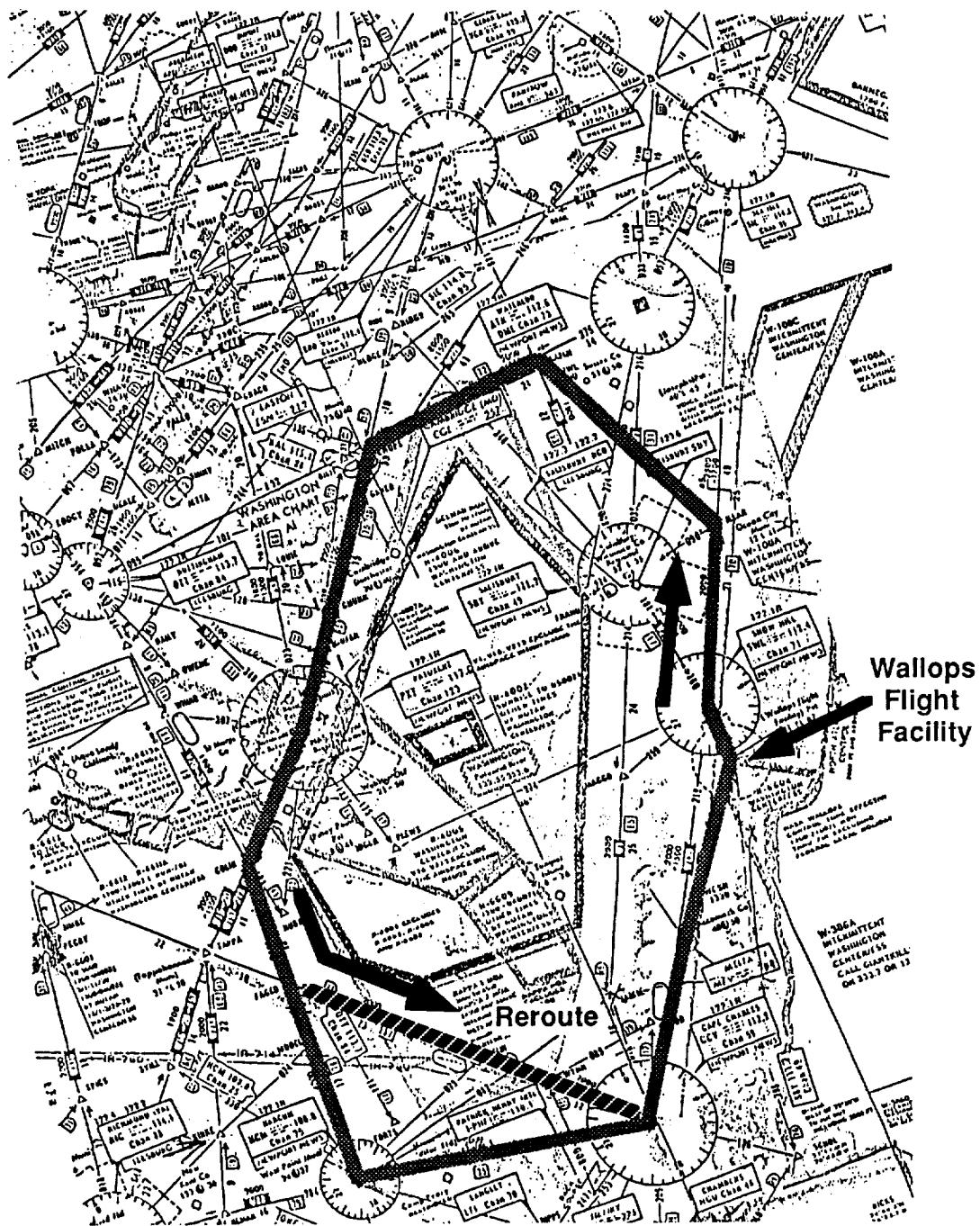
Figure 14. Flight path for data link/monitor ATC flights.
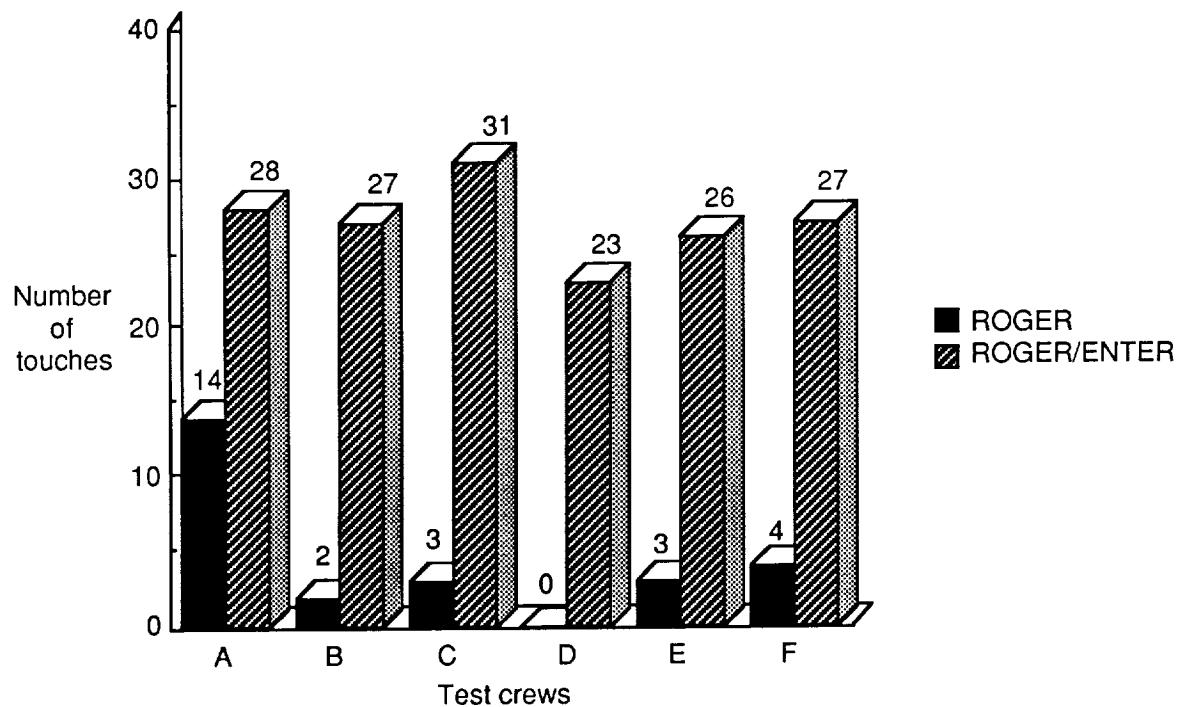
Figure 15. Responses to data-linked tactical ATC messages.
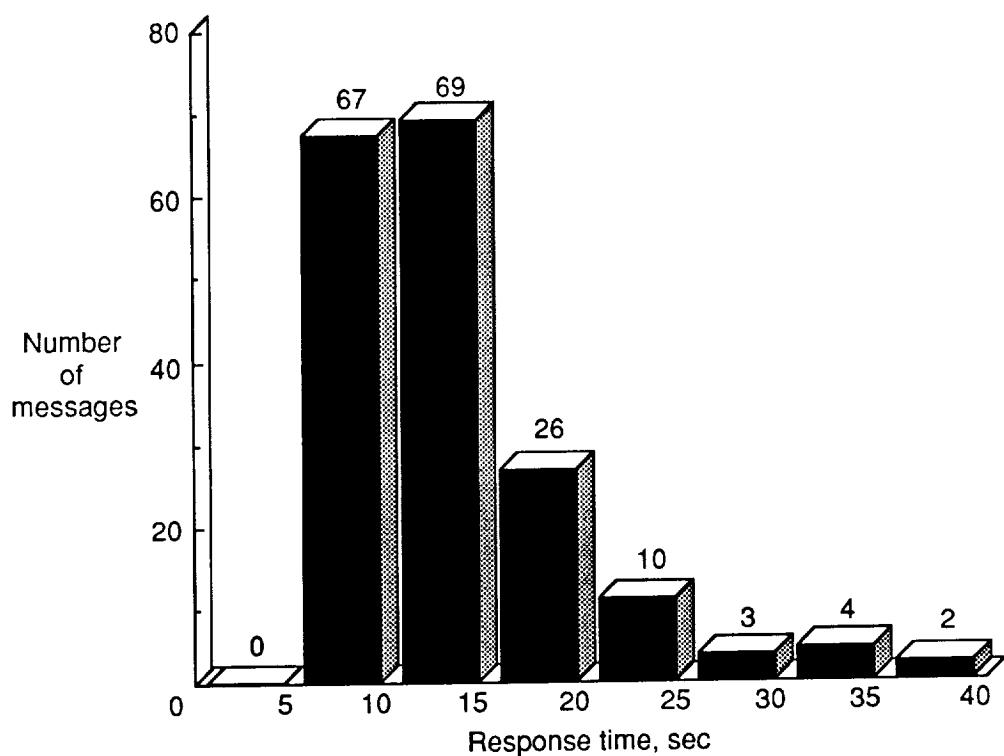
Figure 16. Total tactical message transaction time. Average time = 12.5 sec; Standard deviation = 5.7 sec; Count = 181.
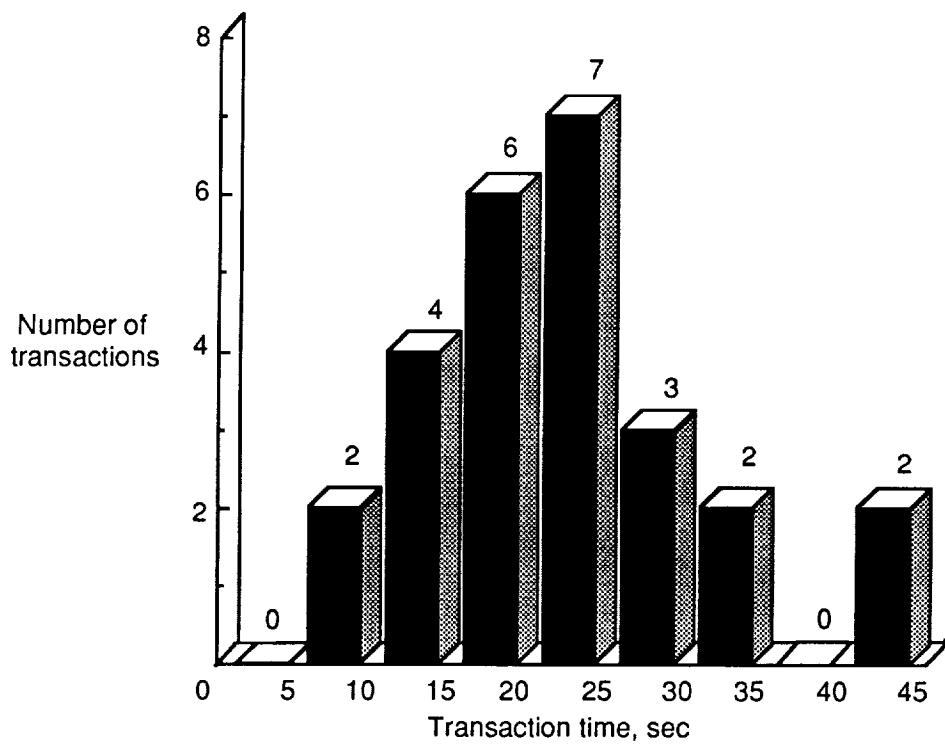
Figure 17. Total airborne strategic message transaction times through data link. Average time = 20.9 sec; Standard deviation = 8.8 sec; Count = 26.
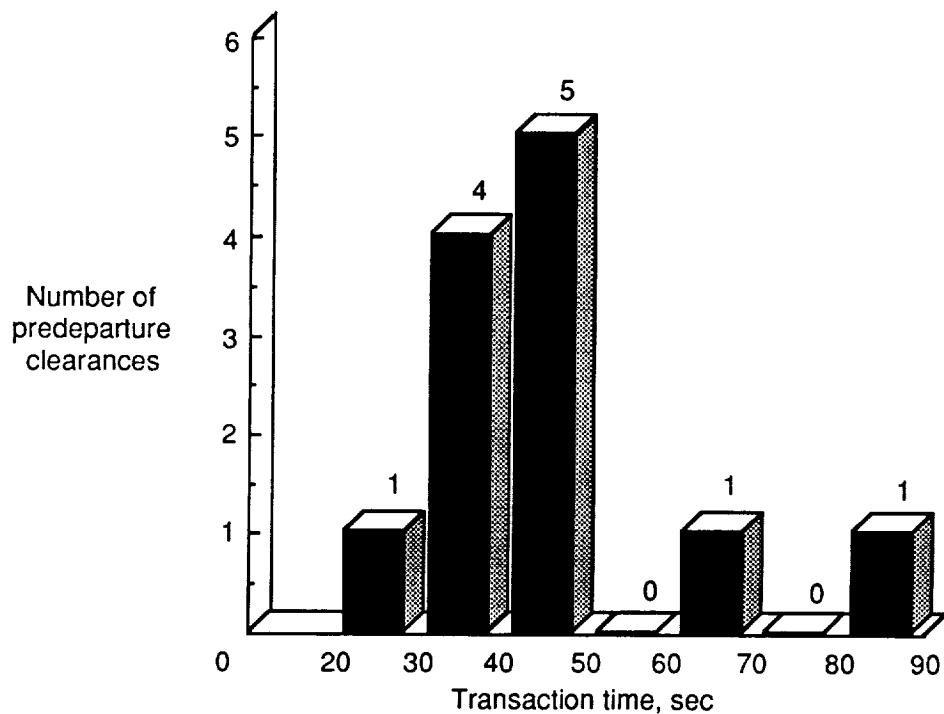

Figure 18. Total predeparture clearance message transaction times through data link. Average time = 43.3 sec; Standard deviation = 15.4 sec; Median = 40 sec; Count = 12.

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15. Supplementary Notes

16. Abstract

Previous studies have shown that air traffic control (ATC) message exchange with a data link offers the potential benefits of increased airspace system safety and efficiency. To accomplish these benefits, data link can be used to reduce communication errors and relieve overloaded ATC voice radio frequencies, which hamper efficient message exchange during peak traffic periods. Flight tests with commercial airline pilots as test subjects were conducted in the NASA Transport Systems Research Vehicle Boeing 737 airplane to contrast flight operations that used current voice communications with flight operations that used a data link to transmit both strategic and tactical ATC clearances during a typical commercial airline flight from takeoff to landing. The results of these tests that used data link as the primary communication source with ATC have shown flight crew acceptance, a perceived reduction in crew work load, and a reduction in crew communication errors.

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