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HUMAN FACTORS EXPERIMENTS FOR DATA LINK
Interim Report No. 6
An Evaluation of Data Link Input/Output Devices Using Airline Flight Simulators

James M. Diehl

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16. Abstract

An evaluation of candidate cockpit Data Link input/output (I/O) devices using airline flight simulators was conducted. The opinions of airline pilots regarding Air Traffic Control by Data Link were obtained. Three full complements of I/O devices were evaluated. The complements were differentiated by the presence of (1) a visual short message ATC (SMATC) display, (2) a voice synthesizer (Vosyn), and (3) a combination of SMATC and Vosyn. An experimental design was developed to evaluate these complements by means of three scenarios in both DC-9 and B-727 airline flight simulators. The experimental setup provided for the collection of quantitative data in the form of message response times and communications events. Qualitative data consisting of questionnaire responses and comments were obtained.

The visual SMATC display was more desirable than the Vosyn, the Vosyn/SMATC combination, or conventional voice during ground, low en route, and high en route flight. Conventional voice was favored during local control and was ranked equally with the SMATC during arrival and departure. The SMATC provided the fastest comprehension. No major differences in Data Link were found between two- and three-crew-member simulators. The loss of essential other-aircraft, weather-advisory, and terminal routing information caused by the presumed selective-address capability will necessitate a compensating ATC improvement or alternative before an ATC system based solely on Data Link will receive wide acceptance by airline pilots.

17. Key Words
Airline Flight Simulators, Air Traffic Control, Data Link, Display, Synthetic Speech

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PREFACE

This report presents an evaluation of Data Link input/output devices using airline flight simulators. Throughout its 13 months' duration, this project has been characterized by the complete and enthusiastic support of the U.S. air carrier industry for the Federal Aviation Administration, acting through the Transportation Systems Center, in its quest to develop a safer, more cost-effective air traffic control system through automation.

The evaluation of cockpit input/output devices is only a portion of the total Data Link project; investigations of the computer/controller interface requirements and link characteristics are being performed concurrently. This report is the sixth in a series of interim reports describing the continuing stages of development for Data Link cockpit input/output devices.

ARINC Research Corporation wishes to express its appreciation for the support of many individuals and organizations. Charles W. Schild of United Airlines and Steven C. Nardone of ARINC Research were particularly helpful in achieving the project objectives -- Mr. Schild in planning and conducting the flight simulator evaluations, and Mr. Nardone in developing data-collection and analysis programs.

Also greatly appreciated is the generous and valuable assistance of Dr. J. Kent Haspert and Mr. Herbert Dagen of ARINC Research; Captain Robert E. Cole and Mr. Arthur Ogilvie of Trans World Airlines; Mr. Kenneth Allbee of United Airlines; Mr. Frank C. White of the Air Transport Association; Captain J. J. Ruddy of the Airline Pilots Association; Mr. John F. Canniff, Mr. Edwin H. Hilborn, Mr. Jerrold Sabath, and Mr. Robert W. Wisleder of the Transportation Systems Center; Mr. Robert Grace of the Federal Aviation Administration; and the numerous airline pilots who traveled and participated at their own expense.

SUMMARY

S.1 INTRODUCTION

The evaluation reported on herein, which was performed for the Department of Transportation/Transportation Systems Center, concludes a three year effort involving laboratory and flight-simulator evaluation of cockpit digital Data Link input/output devices.

The evaluation was performed by the Telecommunications Systems Program of ARINC Research Corporation, a subsidiary of Aeronautical Radio, Inc. Trans World Airlines and United Airlines were selected from among five proposing airlines as subcontractors to ARINC Research Corporation. They provided the use of DC-9 and B-727 flight simulators, respectively, along with the support of their flight-training and flight-simulator staffs. Airline pilot participation, provided principally by Trans World and United Airlines, was substantially augmented by volunteer participation coordinated by the Airline Pilots Association,International (ALPA), the Air Transport Association (ATA) of America, and the Federal Aviation Administration (FAA).

S.2 OBJECTIVE

The primary objective of this work was to evaluate candidate cockpit I/O devices for possible use in an eventual Air Traffic Control air-ground-air Data Link communications system. A further objective was to expose a significant number of airline pilots to a postulated Data Link concept and to obtain their opinions on means of improving the concept. The evaluation of these devices and concepts was based on their relative desirability when compared with each other and with present day concepts rather than on some absolute measurement.

S.3 APPROACH

The I/O devices to be evaluated were combined into three distinctive complements, or complete suites, of equipment that provided full ground-air (uplink) and air-ground (downlink) communications -- even to the extent of incorporating airline company operational communications for the purpose of realism in the evaluation.

The first complement was distinguished by a visual short message ATC (SMATC) display mounted in both the captain's and first officer's instrument panels. The second complement was characterized by a voice synthesizer

(Vosyn); and the third complement consisted of both the SMATC and the Vosyn. A Control and Downlink Unit (CDU), which simulated downlink capability, and a cockpit page printer were included with all complements.

The simulators employed featured both motion and runway visual systems in order to simulate possible flight and out-the-window distracting effects. The DC-9 and B-727 represented a large portion of the two- and three-crew-member air carrier fleet.

An experiment was designed to evaluate the I/O device complements and Data Link concepts. This consisted of developing three simulated missions or scenarios designed to be representative of today's typical airline flights. The Data Link environment was evaluated against these scenarios.

S.4 CONCLUSIONS

This experimental evaluation collected both qualitative and quantitative data. The qualitative data are believed to be the more meaningful of the two categories because they provided an assessment of pilot reaction to a wide range of questions concerning airborne Data Link concepts and specific input/output (I/O) devices. The quantitative data were based on relatively narrow parameters such as device response time and device utilization. In general, they seemed to validate the qualitative data. Conclusions based on the data and recommendations for further evaluation are discussed in the following paragraphs.

S.4.1 Short Message ATC Display (SMATC)

The SMATC display was found to be easily readable and well located. With the exeception of a small number of commands, the abbreviations used on it were not confusing.

The SMATC did not distract pilots during most phases of flight. Their attention may have been distracted from the adjacent airspeed indicator during climbs and descents. A majority of pilots believed that the SMATC could potentially distract them during an instrument approach. Figure S-1 shows the SMATC message "CLR LAND RWY 14" being displayed as the aircraft approaches a simulated touchdown at O'Hare Airport.

The use of the SMATC display for emergency or time-critical messages such as minimum-safe-altitude warning or "go-around" is not considered effective. Even with the audio alert, it does not adequately command the crew's attention under high-workload situations.

The SMATC display was very popular when used as a recall instrument for currently assigned Heading, Altitude, and Airspeed information.

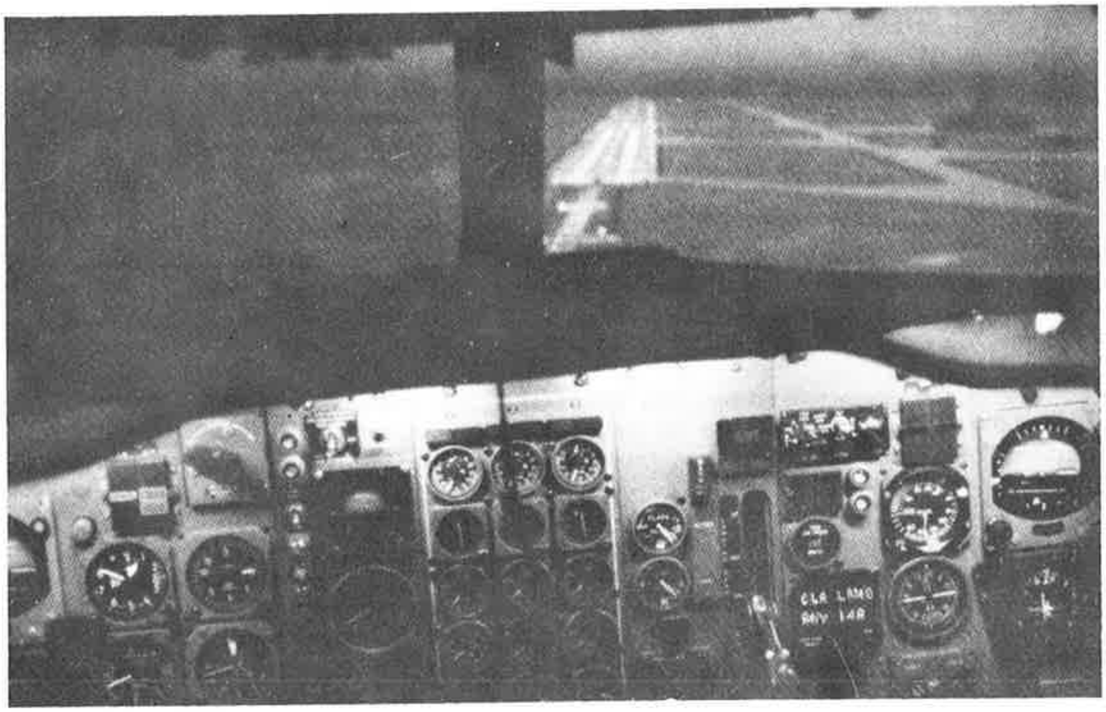


Figure S-1. Simulated Landing at O'Hare International

S.4.2 Printer

The use of a printer seemed to be quite desirable. Crews found it especially useful for the longer messages such as ATC clearances, ATIS information, and some company traffic. The use of the printer on shorter, more perishable information did not seem desirable. A page printer might be preferable to a line printer although the former was not evaluated here.

The paper-management problems arising from the printing and line-feeding of every message were severe. It would have been highly desirable for crews to be able to obtain "loose copies" of only the specific messages they required.

Restriction of printer access to the second officer (flight engineer) is satisfactory in a three-crew-member aircraft. In a two-crew-member aircraft, however, the printer must be accessible to both crewmen since the aircraft is routinely flown from either position.

The use of red print to distinquish company messages and the absence of some method to alert the crew to a company message were unacceptable.

S.4.3 Control and Downlink Unit (CDU)

Although the CDU was somewhat complex, the crews learned to be fully proficient in its use after about two one-hour flights that had been preceded by a 20-minute training session.

The left-center-right method of entering alpha characters on the modified "Touch Tone" type key pad was tedious but not wholly objectionable. This conclusion is based on short (three- to five-character) messages. The great majority of pilots participating were right-handed. They experienced no problem in operating the CDU with the left hand.

One pilot commented that the complexity of the CDU could be greatly reduced by eliminating alphas in favor of numbers and several special-function buttons. The observation was somewhat validated by the quantitative data on CDU utilization.

A tabulation of the most frequently used CDU features indicated that ATIS requests, HAS recall requests, and I/O Blank accounted for more than 60 percent of the CDU usage. The I/O Blank usage was caused by the undesirable bright red display of the SMATC figures, and this could be eliminated by a better design.

Geographic plots of destination ATIS requests showed that they occurred in the high en route phases of flight earlier than currently encountered with voice. A plot of HAS distribution shows the feature to be used primarily in the departure and arrival terminal areas, with the heaviest use during the arrival phases.

A WILCO acknowledge button on the CDU will be operated primarily by the non-flying officer. A WILCO button on the control yoke will be operated by both pilots.

The AUTOTUNE feature, in which the communications frequencies were automatically selected, was highly desirable. The idea of extending this automatic ground control to any other device, with the possible exception of the transponder, was equally undesirable.

Pilots did not show a strong relative preference for the use of Data Link to provide ATC navigational or non-navigational commands, preprinted departure clearances, ATIS, or automation of company reports.

S.4.4 Voice Synthesizer

The intelligibility of the Vosyn is believed to be unacceptable for routine communications. Pilots found that its mechanical sound and the lack of tonal inflection and volume variation made it difficult to understand in a simulated airborne noise environment as well as annoying. The effect apparently did not mitigate with practice.

The Vosyn should be limited to short messages; it seems to be well suited for emergency or time-critical messages. It was effective as an attention-getter during the busy phases of flight. The synthetic voice detracted from one of the prime advantages of Data Link, as commented upon by one pilot, in that it seemed to demand attention while, on the other hand, the SMATC allowed two people to communicate effectively without devoting full attention to each other.

No strong opinions were exhibited in the responses to questions on combined SMATC and Vosyn use. The predominant belief was that the duplication provided by the two devices was either undesirable or not clearly desirable. When pilots were asked to choose one for elimination, the SMATC emerged as the strong survivor.

S.4.5 Ranking of Devices

In the ranking of the relative desirability of air traffic control by conventional voice, SMATC display, or Vosyn for various phases of flight, the SMATC was found to be a slight favorite in the ground phase but a strong favorite in low and high altitude en route phases. Conventional voice was more desirable in local control (airport traffic areas), with the SMATC and conventional voice being ranked approximately equally in the arrival and departure phases. Figure S-2 shows this result.

An analysis of variance of response times showed that there were no significant differences among simulators, scenarios, crews, or order of missions flown. Differences among device complements and phases of flight were significant. The mean values for response times by complement and phase of flight, excluding miscellaneous values of 30 seconds or more, were:

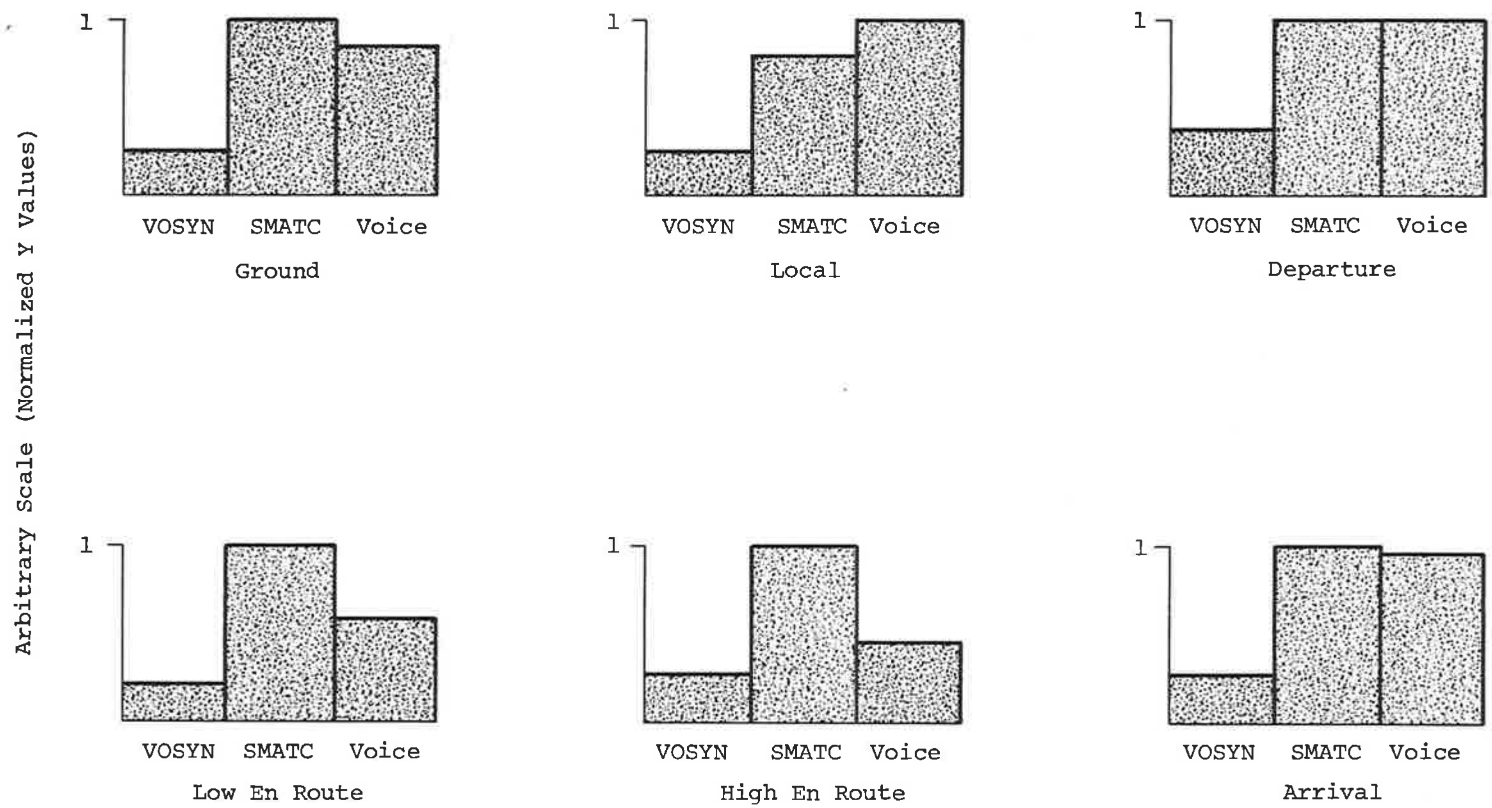
Device Complement		Flight Phase	
SMATC	- 6.30 seconds	Departure	- 7.66 seconds
Vosyn	- 8.69 seconds	En Route	- 7.52 seconds
SMATC/Vosyn	- 6.75 seconds	Arrival	- 6.89 seconds

Histograms of response times by complement showed that crews respond partly to Vosyn commands and partly to SMATC commands when all commands are displayed on both devices.

Histograms by phase of flight showed that this double peaking, or cross-reference effect, of response times is quite pronounced during the relatively low-workload en route phase of flight. During the higher-workload departure and arrival phases, the two peaks tend to merge as some responses are delayed by workload while others are speeded up.

S.4.6 General Data Link Concepts

With two exceptions, no significant differences were observed between the operation of Data Link in two- and three-crew-member aircraft. The exceptions were the relative levels of intelligibility of the voice syn-



Computation Method

$$Y = \{ 2 \times (\text{Number of times ranked first}) + 1 \times (\text{Number of times ranked second}) \}/\text{Total}$$

Figure S-2. Desirability of Data Link Options thesizer and the relative acceptability of abbreviations and symbols on the cockpit page printer. The first is explained by unintentional variations in audio quality in the two simulators. The second represents a difference of opinion between flight engineers and first officers. This difference of opinion, causing the flight engineers to be more receptive to the symbols and abbreviations used on the printer, is probably due to differences in in-flight workloads.

The selective-address capability of the Data Link, in which each aircraft received only transmissions intended for it, did cause a loss of information that pilots consider essential. It was stated that the information loss could affect both the safety of flight and the comfort and convenience of airline passengers. A majority of pilots believed that the loss of knowledge of the proximity of other aircraft in the same en route or terminal sector, which is normally acquired on a common-channel VHF system, could be detrimental to flight safety. Similarly, a majority of pilots believed that the loss of both terminal-area routing information (such as aircraft ahead, holding patterns in use, approaches in use, and anticipated descent instructions) and specific weather-anomally information (such as the extent, location, and altitude of encountered turbulence) is detrimental to passenger comfort and convenience. (The discretionary use of the seat-belt sign, the food and beverage service schedules, and the use of different altitudes which affect fuel burnout are often predicated on the knowledge of these circumstances.)

Although no objective test was made of this effect, airline pilots generally did not favor a system that would require them to wait in a queue for data-polled acquisition of an ATC voice channel. Comments repeatedly indicated that when they found it necessary to converse with ATC, usually because of a time critical situation, immediate access was desired. These comments apparently resulted from occassional misunderstandings or misstatements of test instructions concerning the procedure for talking with ATC: The assumption was in all cases, that ATC was constantly available.

The concept of Data Link control was somewhat disliked during ground-proximate flight phases, including local control, arrival, and departure. The requirement for pilots to use the Control and Downlink Unit (CDU) or receive Data Link instructions during a missed-approach execution caused considerable unfavorable comment.

These comments indicate an apparent operational requirement for the continuation of conventional style voice communications to some extent to supplement the Data Link environment. Voice is required for pilot/controller discussions. Voice is also needed to advise of encountered en route weather (turbulence, thunderstorm detour paths, icing, etc.) and for occasional air-to-air communications of this nature. Perhaps certain abbreviated voice procedures can supplement Data Link to overcome the feeling of isolation expressed by some pilots during a pure Data Link operation and to provide some of the clues on traffic flow and congestion available today.

S.4.7 Acceptability of a Data Link System

The concept of air traffic control by an air-ground-air Data Link appears to be a viable alternative to today's system. However, two problems must be solved before air traffic control can be exercised entirely through a digital Data Link system:

- Loss of common-channel information because of selective-address communications
- Dislike of Data Link and increased work load due to its use in ground-proximate flight phases

S.5 RECOMMENDATIONS

S.5.1 Development and Simulator Evaluation of Data Link Concept

It is recommended that the Data Link concept be further developed and then evaluated in a simulator environment. The concept development should attack the central issues that made this evaluation concept likely to be unacceptable in an operational system. Alternatives that enable flight crews to maintain their current overall "feel" for their environment should be examined. Data Link procedures during ground-proximate flight phases should be simplified. Finally, the use of conventional voice for certain communications in the Data Link environment should be expanded in future tests.

S.5.2 Evaluation of a Limited Data Link System

It is recommended that consideration be given to in-flight evaluation of a limited Data Link system. This could probably be a domestic "add-on" to the currently envisioned AEROSAT Test and Evaluation Program, in which it is planned to equip a small number of airliners with Data Link type equipment.

This evaluation could assess the operation of a simpler CDU device, a page printer, and possibly a SMATC and AUTOTUNE type device.

In addition to device refinement, primary consideration should be given to the potential dislike of Data Link due to information loss, data-polled company voice-channel acquisition, and unacceptability of Data Link commands during ground-proximate flight or flight in heavy traffic areas.

S.5.3 Interchange System

The ability of the NAS/ARTS/ARINC ground system effectively to interchange and deliver information under a Data Link concept such as that hypothesized in this project should be evaluated under actual conditions.

A limited interchange system should be established between two short-length, high-density terminals such as San Francisco and Los Angeles. A limited number of aircraft flying regularly scheduled turn-arounds on such a trip could yield a significant quantity of cost-effective test data.

The objective of this effort should be to measure the feasibility of delivering predeparture clearance, en route and destination weather, and ATIS information, and possibly to control information to aircraft through a system of ground communications switches and terminals. A parallel study should investigate the possible cost benefits of such a system to both the Federal Aviation Administration and the airline industry. These benefits would be examined in terms of potentially reduced staffs for FAA functions such as tower clearance delivery and airline functions such as en route communications.

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1. INTRODUCTION

1.1 PROJECT OVERVIEW

The Systems Research and Development Service of the Federal Aviation Administration (FAA) has sponsored a program to determine the suitability of air traffic control (ATC) communications that are composed digitally in the ground-controller environment, transmitted digitally by any of several conceivable "links," and displayed on digital-type devices in the cockpit. The composition, transmission, and display constitute the three phases of the program, and work has been undertaken in all three of these phases. This report addresses the message-display phase of the program.

The Department of Transportation/Transportation Systems Center (TSC), working for the FAA, has been using flight simulators to evaluate the use of digital Data Link concepts and prototype equipment in aircraft cockpits. This work is known as Phase I of the FAA's Data Link program. The other phases of this program have involved simulation of the ground environment and evaluation of link propagation characteristics.

Flight simulators used prior to this program have included the GAT-1 single-engine general-aviation simulator at the TSC Cambridge facility and the GAT-2 multi-engine general-aviation simulator at the FAA's National Aviation Facilities Experimental Center (NAFEC). The report describes Phase ID, in which commercial airline simulators representing both two- and three-crew-member aircraft have been used.

All of the Data Link input/output (I/O) devices evaluated in this airline simulator effort have been evaluated in previous tests -- most of them by a mixture of general-aviation pilots, NAFEC test pilots, and volunteer airline pilots. The devices tested include a visual display device, a printer, a voice synthesizer, a control and downlink device, and various company communications terminals.

ARINC Research Corporation conducted this airline simulation effort with two subcontractors, Trans World Airlines (TW) and United Airlines (UA). The work, which began 11 April 1974, was performed under Contract DOT-TSC-793 by the Telecommunications Systems Program of ARINC Research.

The following eight tasks comprise the contract effort:

1. Select the complements of I/O devices to be evaluated
2. Develop combined ATC and air-carrier message bases
3. Determine simulator-facility requirements
4. Define test instrumentation hardware and software requirements
5. Prepare a simulator test plan
6. Prepare test facilities
7. Conduct simulator flight testing
8. Analyze the data collected and report the results

Tasks 1 through 6 have been completed. Reports on these efforts have been submitted as required under Contract DOT-TSC-793. This report describes the results of Tasks 7 and 8.

The test plan describes a program of evaluation using professional aircrews in the United Airlines Boeing 727 simulator and the Trans World Airlines DC-9 simulator. Three different missions or scenarios of about 1 hour and 10 minutes each, representing typical airline flights, were conducted to evaluate the Data Link I/O devices. Three complements, or mixtures, of I/O devices were evaluated at each simulator site, yielding nine unique combinations of device complements and scenarios. Nine aircrews, consisting of two NAFEC crews, several volunteer airline crews, and other professional airline crews (from UA and TW), each participated in the three missions at each simulator site. A total of 54 data runs were conducted; company communications were included in each of the three scenarios to provide realistic message workloads.

Data collected on these 54 trial runs consisted of both qualitative and quantitative data. Qualitative data were developed from questionnaires and from comments made by crew observers. Quantitative data were collected by means of a minicomputer tape recording system, which kept an accurate time log of various data-link events.

The data collected were grouped and analyzed with respect to influencing or suspected influencing factors. Appropriate statistical tests were applied to the results of this analysis to identify real differences.

In concluding this evaluation, the device complements evaluated have been ranked qualitatively and quantitatively, and the impacts of various Data Link concepts have been discussed.

1.2 OBJECTIVES

The purpose of the effort described in this report is to further the efforts to determine how best to present air traffic control (ATC) information in an automated ATC system by evaluating candidate data-link cockpit I/O devices and postulated Data Link concepts in a simulated airline airborne environment. The work is complementary to current evaluations of the Data Link propagation characteristics of present aeronautical ATC transmission media.

The primary objective of this work is to evaluate candidate cockpit input/output (I/O) devices for air-ground-air Data Link applications in the more realistic and sophisticated environment of commercial aircraft flight simulators. A further objective is to expose a significant number of air-carrier pilots to the Data Link concept by participation in the airline simulator experiments and then obtain their opinions and suggestions regarding Data Link hardware and procedures in the cockpits of modern commercial aircraft.

The field of candidate I/O devices includes a short-message display device, a voice synthesizer with a programmed vocabulary, a hardcopy printer, a link control device that permits the pilot to send pre-text requests and responses of free-form digital messages to the ground, and a company communications terminal. This field has been progressively narrowed and refined in previous cockpit I/O evaluations. With air carrier operations comprising the large majority of the ATC communications that may be suited for eventual digital transmission, the knowledge acquired in this series of tests is believed to be extremely important. The conclusions drawn from the quantitative and qualitative data obtained can be used to modify, refine, add, or eliminate devices that may be considered for eventual Data Link flight testing. They can also be used to validate or refute certain postulated concepts.

Although airline pilots' opinion have been obtained previously on a volunteer basis, this is the first time a relatively large number of professional line-qualified crews have evaluated these devices in standard-configuration/air-carrier simulators. Their opinions and suggestions relating to operational procedures are considered invaluable.

1.3 PROJECT HISTORY

The increasing level of automation in the ATC ground system is dictated primarily by two factors. The first is the ever-increasing volume of Instrument Flight Rule (IFR) operations being conducted by faster airplanes, reducing the time allowed for critical separation decisions and transfer of necessary flight data. The second is the expense of controller personnel involved in separating this traffic.

The recommendations of the Air Traffic Control Advisory Committee (ATCAC) in 1969 included automation techniques to increase controller productivity. These have been initiated with the nationwide implementation of the Automated Radar Terminal System (ARTS) and National Airspace System (NAS) En Route Stage A. Whether these or similar ground-based computer systems now under consideration will ever be used to effect an automated control of, transfer of information to, or display of information within aircraft has not been determined.

It is hoped that through the effort described herein, as well as future efforts and related work being accomplished for the ground system, the practicality of a fully automated ATC system can be demonstrated. Although the need for automation is predominatly in the ground system, the eventual limitations to the automation of control as well as the relative desirability of various automation aspects may well be determined by the practicality of Data Link within the cockpit.

To establish a proper frame of reference, the reader should be aware of several on-going projects. This effort is the sixth in a series of interim investigative laboratory and simulator evaluations, all involving the human-factors considerations of airborne data-link. The preceding efforts have evaluated the automated airborne presentation of ATC information through a series of activities:

- Two experiments on the GAT-1 simulator
- Four experiments on the GAT-2 simulator
- Five laboratory tests of message formats and coding schemes for Short Message ATC (SMATC) commands and advisories
- Two experiments involving the preliminary evaluation of synthetic speech for providing ATC information ,

Further information on these efforts can be obtained from two reports entitled "Human Factors Experiments for Data Link". These are a summary of Interim Reports 1-4 (FAA-RD-74-82, February 1974) and Interim Report 5 (FAA-RD-75-14, February 1975).

A parallel effort (Phase II) is being conducted to determine the display techniques and operating procedures that best enable an air traffic controller to work in a mixed voice/digital communications environment. This effort involves a simulation of a simplified ARTS III Metering and Spacing system that was conducted at the National Facilities Experimental Center (NAFEC).

These efforts are complemented by a Phase III effort, which is evaluating link-propagation characteristics.

1.4 REPORT ORGANIZATION

This report is organized into six sections and four appendixes. Section 2 describes the experimental approach used in conducting the evaluation. Section 3 is a discussion of the experimental design and its conduct. Sections 4 and 5 present analyses, respectively, of the qualitative and quantitative data collected. Section 6 includes conclusions drawn as a result of the analysis and recommendations concerning areas suitable for further study.

Five appendixes are included in this report:

Appendix A - A Listing of Flight Scenarios Employed

Appendix B - Flight Crew Information

Appendix C - Flight Crew Questionnaires, with Responses and Comments

Appendix D - Supplemental Questionnaire, with Responses and Comments

Appendix E - Report of Inventions.

2. EXPERIMENTAL APPROACH

In this section the overall evaluation approach is discussed and the experimental apparatus illustrated. The major components of experimental equipment are also described, including the individual I/O devices evaluated, the airline simulator test facilities employed, and the experimental support equipment used.

2.1 OVERALL APPROACH

A key part of the Data Link development effort is the man-machine interface in the aircraft. It is important that eventual operational I/O devices that implement this interface between the Data Link and the crew be structured in a manner that provides good information throughout while consistently meeting the highest standards of safety.

The approach applied in this study has served to provide relative evaluation of competing prototype-hardware concepts while determining what hardware and operational concepts are consistent with the requirements stated above. ARINC Research was assisted in this evaluation not only by the simulator and flight training staffs of United Airlines and Trans World Airlines but also by numerous other airlines and user groups acting both individually and in response to requests by the Air Transport Association.

The general approach consisted of evaluating a series of device complements in the DC-9 simulator and B-727 simulator under identical conditions. These particular simulators represent a major portion of the two-crew-member and three-crew-member aircraft currently employed by the U.S. airlines. Because of the magnitude and potential expense of a relatively large-scale program, the major constraint on the design and conduct of the experiment was an economic one.

I/O devices were grouped into three test complements for evaluation. Three flight profiles were developed, along with their accompanying message scripts. Simulation facilities, including DC-9 and B-727 simulators, were used to test the complements in each of the scenarios.

Eight tasks were performed in the conduct of this evaluation:

Task 1 - Select I/O Complements to be Evaluated. In association with TSC, ARINC Research identified the I/O complements to be evaluated.

Task 2 - Develop Combined ATC and Air Carrier Communications Message Scripts. Test-flight profiles were established, and the accompanying message scenarios were developed for use in the test activity.

Task 3 - Determine Simulator-Facility Requirements. Installation details for placing the I/O devices and their supporting systems were developed.

Task 4 - Define Test-Instrumentation Hardware and Software. ARINC Research supported TSC in defining the test-instrumentation hardware and software needed to perform the prescribed test program.

Task 5 - Prepare Simulator Test Plan. A test plan, including a detailed experimental design, was developed to provide a plan for measuring desired test variables. This was published in August 1973 by ARINC Research Corporation (Publication 1304-01-1-1312).

Task 6 - Prepare Test Facilities. Simulator facilities were prepared to accomplish the test program.

Task 7 - Perform Simulator Flight Testing. The I/O devices and software were tested according to the test plan prepared in Task 5.

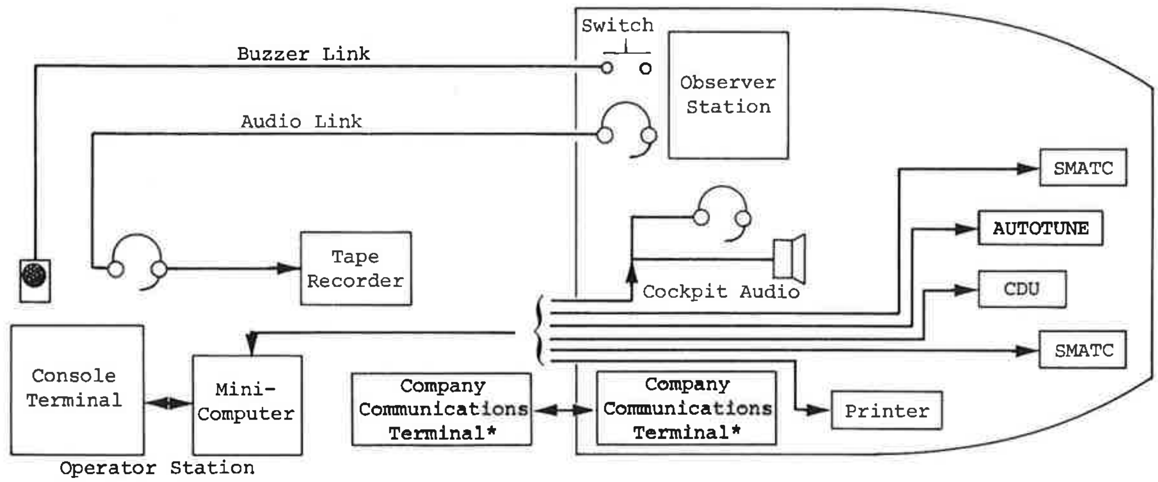
Task 8 - Analyze Data and Prepare Final Report. The test data were analyzed in detail. The results are published in this report.

Figure 2-1 is a block diagram of the generalized experimental set-up. It depicts the placement of the I/O devices, the simulator test facilities, and the test support equipment used to record experimental data. These will be described in the sections that follow.

The experimental crews were asked to fly "block-to-block" trips between major air terminals. These trips were described in three scenarios, which were pre-recorded on digital cassette tapes. The scenario messages were retrieved and dispatched to the appropriate I/O devices, and the desired data were recorded on cassette tapes. These data were later reduced and analyzed.

2.2 I/O DEVICE COMPLEMENTS

In an operational communications system, the true measure of relative merit has to be based on the performance of the system and not of its components. Therefore, complements of I/O devices were selected on the basis of proven and available prototype hardware and on the basis of certain assumptions made with regard to the operation of a Data Link.



*B-727 only.

Figure 2-1. Overall Simulator Layout

The following concept assumptions were used in selecting I/O device complements:

- All complements would provide a downlink (air-to-ground) message capability.
- All complements would be capable of receiving both short ATC and long or extended-length ATC messages in addition to airline operational messages.
- All complements would provide a simulated Automatic Tuning (AUTOTUNE) capability for communications transceivers.
- All complements would provide a control-yoke type WILCO capability.
- All complements would provide back-up voice capability.

The three complements selected are defined as follows:

- Complement I
  - 2 × 8 Character Display (also called Short Message ATC, or SMTAC, Display)
  - ANADEX Page Printer
  - AUTOTUNE Radio Head
  - Control and Downlink Unit (CDU), including control yoke WILCO buttons
  - Aural Alert
- Complement II
  - Voice Synthesizer (Vosyn)
  - ANADEX Page Printer

- - AUTOTUNE Radio Head
    - CDU, including control yoke WILCO buttons
    - Aural Alert
- Complement III
    - 2 × 8 Character Display (SMATC Display)
    - Voice Synthesizer (Vosyn)
    - ANADEX Page Printer
    - AUTOTUNE Radio Head
    - CDU, including control yoke WILCO buttons
    - Aural Alert

A separate data communications terminal was mounted at the second officer's (flight engineer's) station on the B-727. It was used for company communications in all complements.

Each of these devices is defined in the following subsections. Additional details on these devices can be found in Cockpit I/O System Specification by TSC, PGS-413-2.0, dated December 1973. All devices were furnished or constructed by the government unless otherwise noted. Figures 2-2 and 2-3 show the locations, in the DC-9 simulator, of the devices described in the following pages. With the exception of the page printer location, the B-727 installation was almost identical.

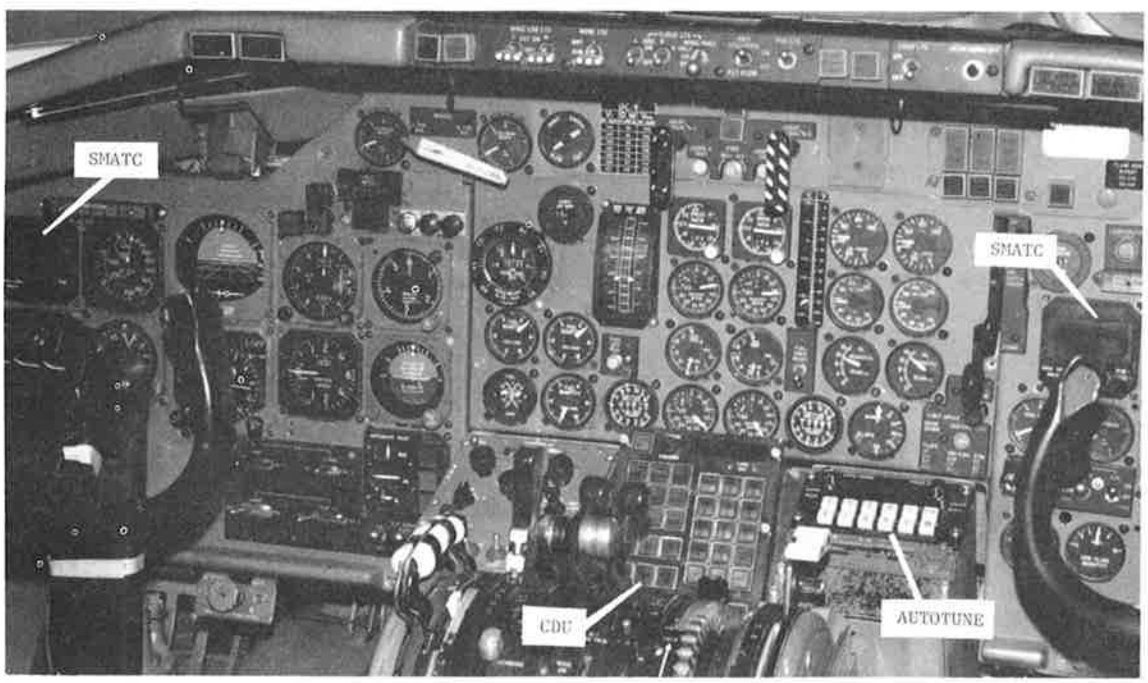


Figure 2-2. I/O Device Locations in the DC-9 Simulator

Figure 2-3. Printer Locations in the DC-9 Simulator

2.2.1 2 × 8 SMATC Display

The SMATC display shown in Figure 2-4 was constructed by TSC; it consists of two lines of eight alphanumeric characters per line. Five-by-seven dot matrix LED display elements are used to form red characters one-fourth inch high by one-fifth inch wide. Located above the two ends of the top line and below the center of the bottom line were the lighted labels HDG, ALT, and SPD. These abbreviations are lighted independently from the display characters under program control and indicate that the numbers within the main body of the display refer to the current heading, altitude, and speed commands. Requests for this information to be displayed are initiated by the pilot via buttons on the Control and Downlink Unit (CDU). For normal ATC messages, these labels are extinguished and not visible to the pilot. A dimming control is included on the front panel of the SMATC displays; it controls the brightness of both the 16 alphanumeric characters and the three labels.

One of these devices was mounted in front of each flight officer in the primary instrument panel. The devices were used only for perishable, short ATC messages such as radar vectors, altitude commands, transponder codes, and en route clearances.

Upon receipt of a new message, the display flashes on and off for a short period in order to attract the crew's attention.

The SMATC display interfaces with the driving computer. It is packaged in a standard ARINC 3ATI case approximately nine inches deep excluding a connector, which adds two and three-quarter inches.

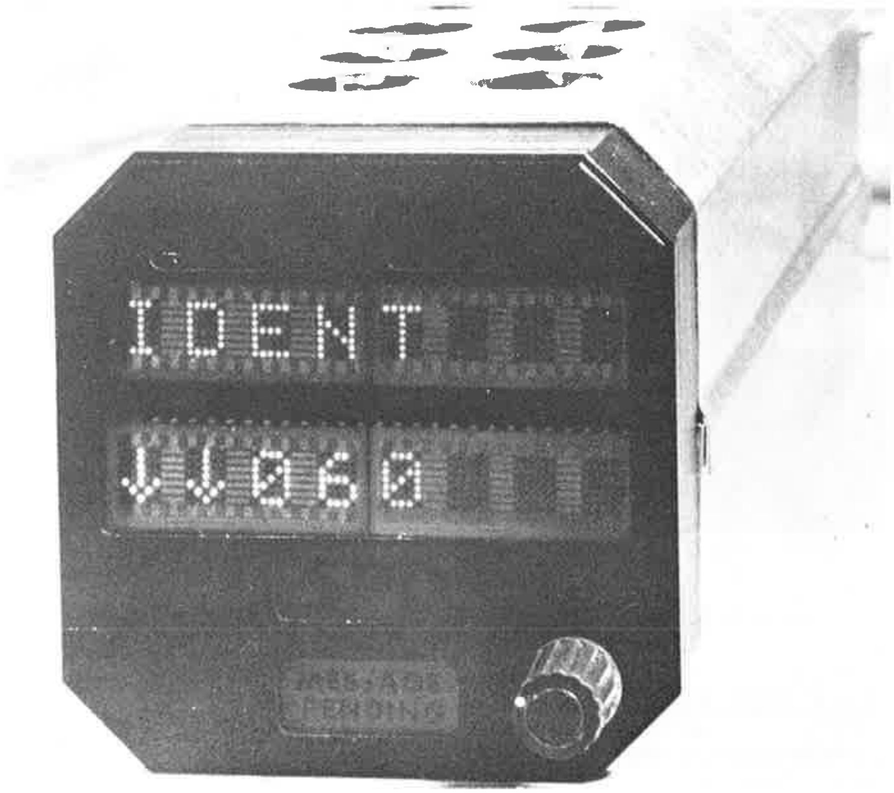


Figure 2-4. SMATC Display

2.2.2 Voice Synthesizer (Vosyn)

Figure 2-5 shows the Vocal Interface VOTRAX Model Six voice synthesizer equipment that was used for this evaluation. The Vosyn was mounted outside the simulator and interfaced with the cockpit audio system in the B-727. In the DC-9 it was channeled through its own amplifier. The unit outputted its messages directly into the simulator. A volume control and a message-repeat button contained on the CDU were used for in-cockpit control of the Vosyn. The Vosyn vocabulary of 256 words was stored in the supporting computer.

This device was used for both short- and long-message ATC commands. However, no company communications were allowed on it in keeping with the philosophy that ATC and airline company communications should not be confused with each other.

2.2.3 Printer

Figure 2-6 shows the ANADEX Model DP-751 printer selected as the cockpit hard-copy display. The unit prints 21 columns of characters on 3-1/2

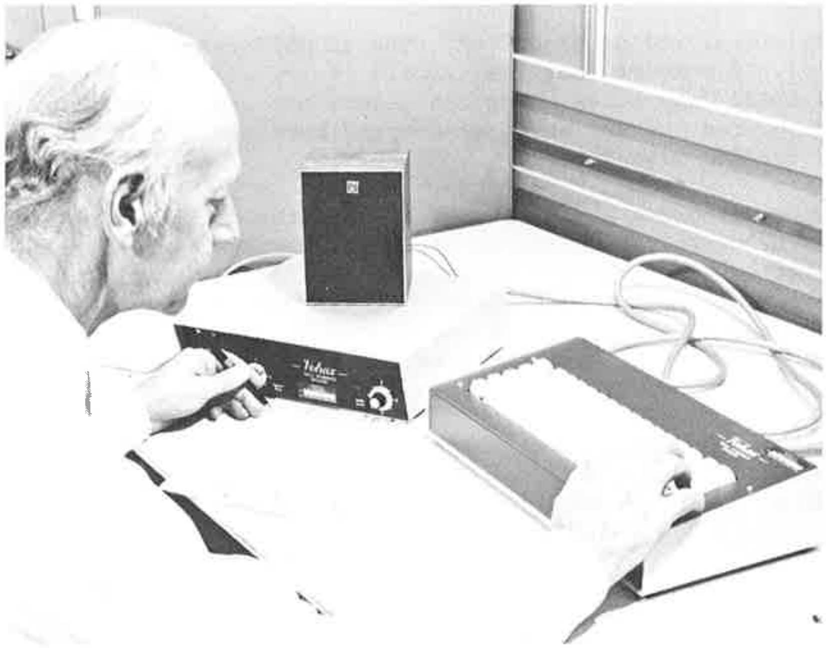


Figure 2-5. VOTRAX Voice Synthesizer with Programming Unit

Figure 2-6. ANADEX Model DP-751 Printer

inch paper in either red or black ink. The 42 different characters include the 26 letters, 10 numbers, and the symbols *$-./, which are selected by the standard ASCII data codes. The characters are one-tenth inch high. In this evaluation, red ink was used for company messages, while black ink was reserved for ATC messages.

The printer recorded every message sent to the cockpit, whether it was displayed on any other I/O device or not. The message "see Printer" on the SMATC called attention to an ATC message appearing only on the printer, such as ATIS or clearance. Typical company-business messages were outputted by the printer to add a realistic workload to the experiments. All messages were tagged on the printer with the time the message arrived. The printer interfaced with the computer.

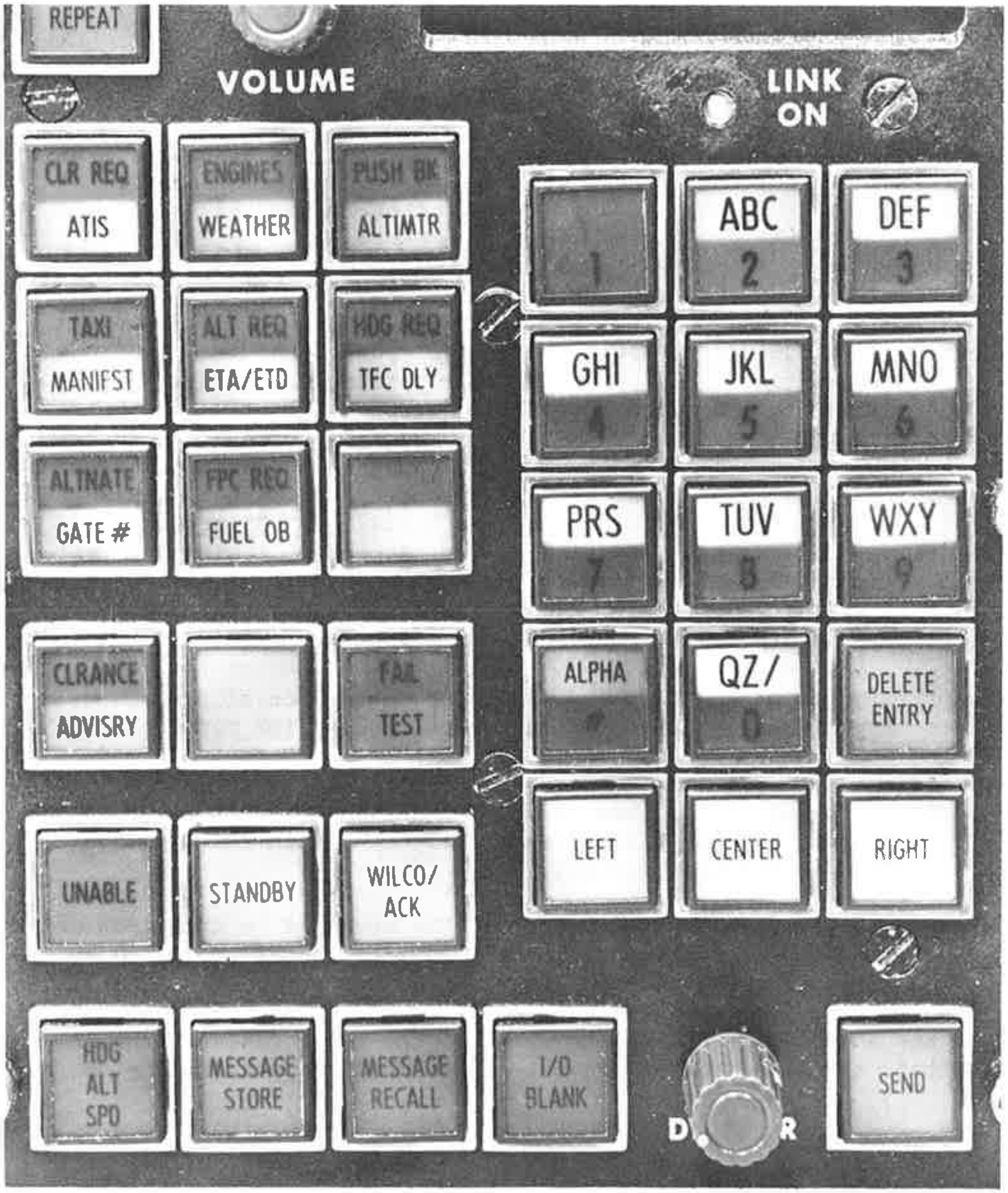
2.2.4 Control and Downlink Unit

The Control and Downlink Unit (CDU) shown in Figure 2-7 has three functions:

1. Generation of messages of up to 16 characters in length by the pilot for downlink transmission to the ground
2. Control and status indication of the cockpit I/O system
3. Provision of certain control and message-acknowledgment functions for some of the I/O devices (WILCO, UNABLE, STANDBY, Vosyn repeat, message recall, etc.)

The CDU was mounted in the forward pedestal. The unit was made up of 12 discrete function buttons and one clearance/advisory button for generating downlink messages; a 14-button keyboard for generating general alphanumeric messages and data; 12 buttons, knobs, and indicators for control of the I/O system and status indications; and an eight-window scratch pad display for message composition. The functions of each of these CDU elements are described in the following paragraphs. An additional alphanumeric terminal was provided at the second officer's station in the B-727 simulator since the CDU was mounted on the forward pedestal and was not within reach of the second officer. It had been hoped that the CDU could be mounted within reach of all three crew members in the B-727; however, installation problems necessitated mounting it in the forward panel.

2.2.4.1 Function Buttons - The function-button portion of the CDU has modes of operation, "clearance" and "advisory", the mode being selected by the correspondingly labeled alternate-action pushbutton. This is illustrated in Figure 2-7. In the "clearance" mode, only the top half of each function button is illuminated, and depressing a button initiates the top, clearance-type downlink message. Similarly, when the "advisory" mode is selected, only the bottom half of the buttons will be illuminated and the corresponding messages will be of the advisory type. The labeling on the switches is such that the unilluminated half will be invisible. The meanings of these function buttons are self-evident from the button descriptors shown in Figure 2-7.



Note: Function buttons shown above were modified somewhat for the airline tests. See Figure B-2 (Appendix B) for a diagram showing function buttons actually present.

Figure 2-7. Control and Downlink Unit (CDU)

Messages requiring a WILCO response cause the UNABLE, STANDBY, and WILCO buttons to light. The WILCO button will then flash. When WILCO is pushed, the UNABLE and STANDBY lights will go off and the WILCO light will become steady. After the simulated polling and transmission delays, the WILCO light will extinguish. If the UNABLE button is pushed, the WILCO and STANDBY lights will extinguish while the UNABLE light becomes steady and then extinguishes after simulated polling and transmission delays. No change will occur if the STANDBY button is pushed.

2.2.4.2 Alphanumeric Keyboard - The 14-button alphanumeric keyboard consists of 10 dual-function alpha/number pushbuttons (the alpha half of the "1" button is not used); left, center, and right letter-select buttons; and an alpha/# alternate-action pushbutton. When the keyboard is in the alpha mode, only the top half of the 10 alpha/number keys will be illuminated, as will be the "alpha half of the alpha/# select button. The numbers and the "#" legend on the alpha/# button will be invisible. By pressing the alpha/# button, the number mode will be selected, extinguishing the letters and "alpha" legend and illuminating the numbers on the lower half of each button as well as the "#" legend. Successive depressions of the alpha/# button will alternately select the alpha and # modes.

The primary use of the keyboard is in the generation of alphanumeric identifiers or parameter values to be appended to downlink messages, such as "BOS" for a Boston ATIS request or "160" for a 16,000-foot altitude request. In order to generate numbers, the pilot selects the # mode with the alpha/# select button and then presses the desired number key(s). The numbers selected in this way will automatically appear in the CDR eight-window display as each key is pressed.

Letters are generated by first placing the keyboard in the alpha mode and then pressing the button containing the desired letter, followed by the "left", "center", or "right" button depending on the position of the letter within its own key. Thus the letter J would be generated by pressing first the "JKL" key and then the "left" key. After the left, center, or right key is pushed, the selected letter will automatically appear in the CDU display.

2.2.4.3 CDU Display - The CDU includes an eight-window alphanumeric scratch pad display to assist the pilot in composing messages with the keyboard. It utilizes red-dot-matrix LED characters one-fourth inch high, the brightness of which is controlled by the CDU dimming control.

Characters appear on the display automatically, being added from left to right as they are generated with the function buttons. For those messages requiring more than eight characters, the entire message shifts from right to left by one character as each character after the eighth is generated. The leftmost character is simultaneously dropped from the display (but still remains in the message).

When the keyed-in message is transmitted downlink by depressing the SEND button, the scratch pad erases.

2.2.4.4 Control Buttons and Status Indicators - The CDU includes 12 buttons, knobs, and indicators for various I/O system-control and status-indication functions. They are continuously illuminated, and the brightness is controlled by the CDU dimming control. These special function buttons are as follows:

- Delete Entry - Used to delete entered characters.
- Send Button - Causes keyed-in messages to be transmitted downlink.
- I/O Blank Button - Blanks SMATC displays. Pushing it a second time will cause the return of the message to the screen.
- HAS Recall Button - Pushing this button will cause the current heading, altitude, and airspeed command information (if any is assigned) to be displayed.
- Message Store Button - May be used to store any SMATC or Vosyn message such as clearance.
- Message Recall Button - Pushing this will cause the last stored message to be recalled.
- Vosyn Repeat Button - Pushing this will cause the last Vosyn message to be repeated.
- Vosyn Volume Control - Self-explanatory.
- Dimming Control - Controls the brightness of all indicators.
- Poll Indicator - Indicates receipt of simulated data-poll from the ground station.
- Test/Fail Button - When this button is pushed, the I/O system will go into a self-test routine, during which the TEST half of the button will flash off and on. When the test is completed, the TEST legend will return to normal illumination. If the system passes the test, no other indications will be made. If it fails the test, the FAIL half of the button will be turned on and will remain on until the self-test operation is again initiated or defective circuitry is repaired.
- REQ Voice Button - Depressing this button will provide an ARINC or Company (simulated) voice channel.

2.2.5 AUTOTUNE Device (Automatic Frequency Selector and AUTOTUNE Indicator)

The AUTOTUNE device, illustrated in Figure 2-8, simulates the automatic tuning, via Data Link, of the voice and data transceivers. Two displays at the top of the unit display the current frequencies of the Data Link and voice radios, respectively, with a resolution of 25 kHz. The lower single element is a scratch pad for pilot entry. These display elements are visible in direct sunlight. Two selector knobs are provided. The outer portion of the left-hand knob provides manual or automatic frequency selection, and the

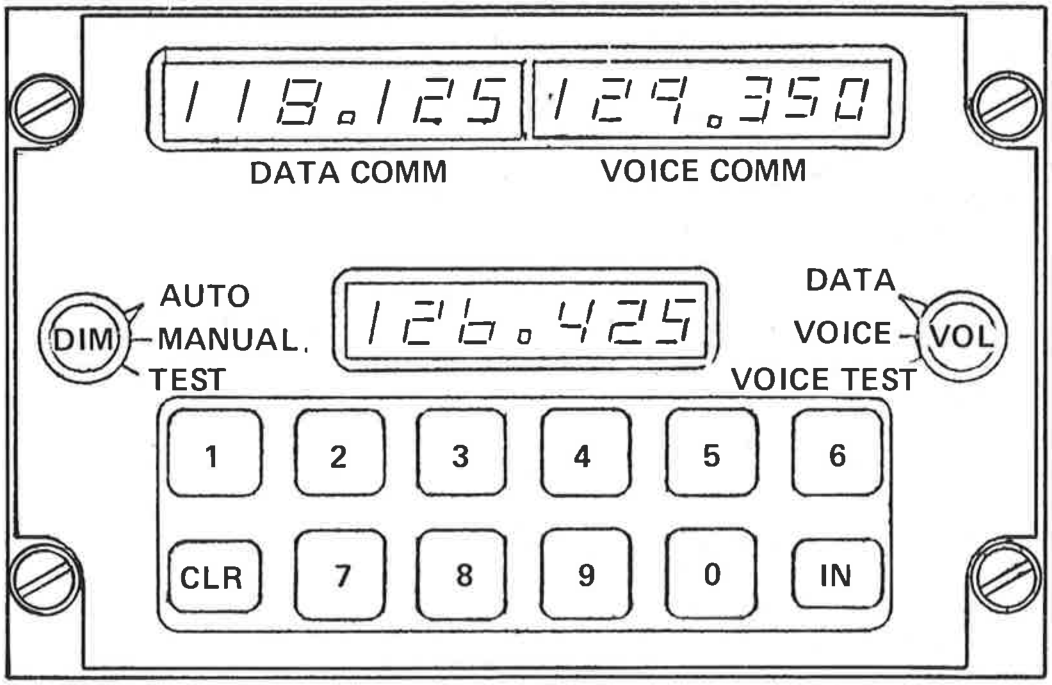


Figure 2-8. AUTOTUNE Indicator Panel

center portion provides a dimming control. The outer portion of the right-hand knob allows selection of data or voice radio tuning for manual entry, and the center portion provides the volume control for the voice radio. The Voice Test position is a springloaded position that has no operational function for this simulation. The test position on the left-hand knob illuminates all light-bar segments.

In the automatic mode, the frequencies were inserted by an uplink message from the computer after a WILCO response from a crew member. The manual entry mode was not used in these tests. The AUTOTUNE was mounted in the forward pedestal.

Voice and data AUTOTUNE messages were initially displayed on the SMATC (or Vosyn) display as conventional messages. Upon pilot acknowledgment by depression of the WILCO button, the appropriate display elements of the AUTOTUNE device (e.g., DATA COMM or VOICE COMM) displayed the frequency currently appearing on the SMATC (or Vosyn).

2.2.6 Company Communications Terminal on B-727

In order to handle Data Link company communications, the B-727 second officer needed access to an input device. This device was required for standard messages such as Departure and Arrival Reports, Off Reports, Revised ETA/ETO, Manifest, and Gate Requests, in addition to a free-form digital company message that the second officer might send.

Originally it was planned to mount the TSC-supplied CDU within reach of all three crew members in order to use the same device for both company and ATC downlink messages. However, installation difficulties made it necessary to mount the CDU on the forward pedestal, where only the captain and first officer could reach it. Consequently, a separate input unit was provided solely for the use of the second officer in the B-727.

Two different devices were obtained by ARINC Research, and each was used in approximately one-half of the B-727 evaluations. One device was the KUSTOM MCT-10 Mobile Communication Terminal built by KUSTOM Data Communications. The other was the Motorola MODAT, Mobile Data Terminal. Both were off-the-shelf equipments currently used in law-enforcement mobile units. Both had full alphanumeric keyboards and volatile-character scratch pads, which allowed the second officer to review a message prior to transmitting it.

2.3 SIMULATOR TEST FACILITIES

The two participating airlines, United Airlines (UA) and Trans World Airlines (TW), were selected from among five prospective participants as the most capable of assisting ARINC Research in achieving its project objectives.

The DC-9 and B-727 aircraft simulators supplied by TW and UA, respectively, represent two of the most common aircraft in the commercial fleet. Their choice, it was thought, would help to highlight any significant differences in Data Link communications between aircraft with two-member crews and those with three-member crews. The process of installing these devices provided significant insight into the location problems that will eventually be encountered in the installation of Data Link equipment in any aircraft.

2.3.1 DC-9 Simulator

The TW DC-9 simulator includes an authentic facsimile of the DC-9 aircraft flight compartment, containing exact replicas of the DC-9 crew stations and duplicating all portions of the external cockpit structure normally visible to the captain and first officer. There is an instructor's station located aft of the captain's station.

A visual-display closed-circuit television system is installed on the DC-9 simulator. Ceiling, visibility, and lighting conditions are variable. The motion system incorporated in the DC-9 simulator provides independent motion in three degrees of freedom.

The photograph presented in Figure 2-2 shows the installation of the two SMATC displays, the CDU, and the AUTOTUNE in the DC-9 simulator. The printer installation is also shown in Figure 2-3. It was mounted to the right of the first officer's seat on the simulator floor. It was placed in an upright (or end) position to make it easily readable by the first officer.

No installation difficulties were encountered, with the exception of mounting the captain's SMATC display. This device was nine inches long and would not flush-mount with the instrument panel because of the outer simulator shell. It protruded about one-fourth inch at the bottom. However, this did not detract from experimental realism.

2.3.2 B-727 Simulator Facility

The simulator cockpit shown in Figure 2-9 conforms to the UA B-727-222. Cockpit configuration and system operation are identical in all significant respects to the B-727-222 aircraft in the UA fleet. The fuselage contains an instructor's console from which environmental conditions can be set or varied. The simulator incorporates a hydraulically powered three-axis motion system.

The simulator incorporates a visual system with a color image projected on a large screen in front of the cockpit. The image is developed from a scaled 10 × 5 mile earth model surrounding an Instrument Landing System (ILS) runway.

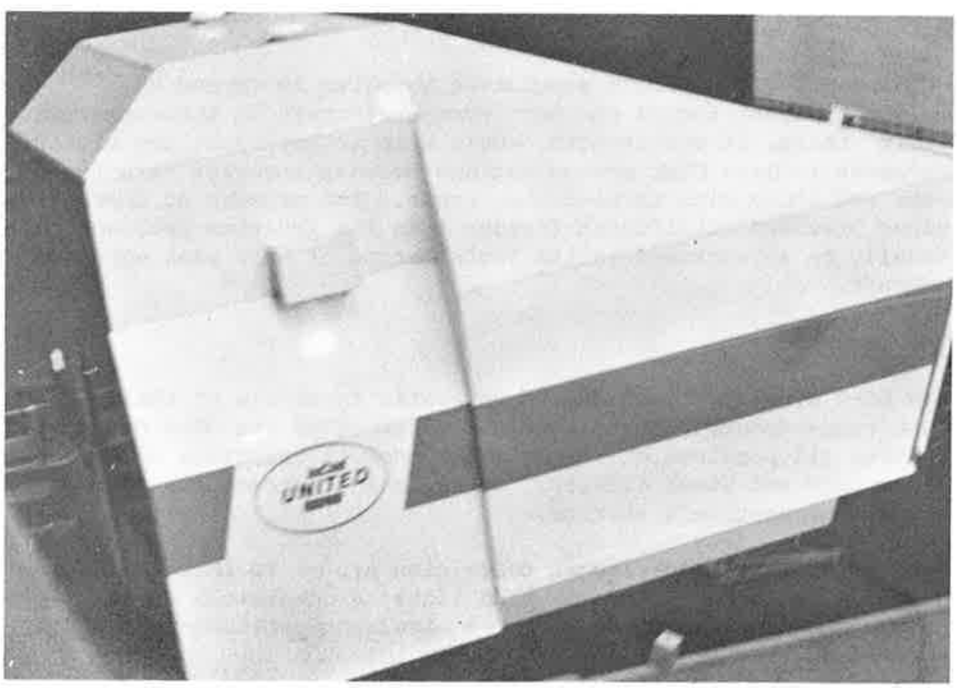


Figure 2-9. B-727 Simulator Cockpit

Environmental controls for the visual model include visibility variable from 0 to 9-3/4 miles, ceiling variable from 0 to 2,000 feet, time-of-day variation, and approach lighting control. The ability to vary surface and altitude winds was a major contributor to keeping the scenarios on schedule.

Figures 2-10 through 2-12 depict the B-727 installation of the two SMATC displays, the CDU, the AUTOTUNE, and the printer. The independent company communications data-terminal device was located near and behind the second officer's shelf. The cockpit printer was located on a shelf below this terminal. No installation problems were experienced in the mounting of these devices. The simulator was returned to its normal configuration immediately after Data Link test sessions. Because of the requirement for rapid configuration change, a primary consideration in installation was the quick changeability of these devices.

2.4 TEST EQUIPMENT

All of the experimental I/O devices installed in the simulators were driven by a government-provided Texas Instruments 960A minicomputer located outside the simulator. Each of the three scenarios consisted of approximately 60 messages. During the actual conduct of the experimental flights, these messages were stored in memory in the minicomputer. Each message was automatically displayed on an ASR 733 Printer-Keyboard Terminal associated with the minicomputer. At the proper time, the console operator would release these messages to the simulator. The Texas Instruments 960A minicomputer appears on the right side of Figure 2-13. The ASR 733 appears on the left side of the figure.

The ASR 733 console included a twin magnetic-tape cassette read/write unit. This can be seen immediately above the keyboard console in Figure 2-13. Each scenario was programmed onto one cassette, while the other cassette was used for data collection. The printer allowed the operator to observe the process of the scenarios as each message was printed out. The keyboard gave him control over the system operation, enabling him to dispatch each message in sequence, skip or go back one or more messages, add messages, and initialize various parameters prior to a given experimental run. The computer was mounted in an equipment rack along with the Vosyn and associated power supplies. The ASR 733 console was placed on a table adjacent to the computer rack.

Figure 2-14 shows the actual test equipment configuration used at the B-727 simulator location. In addition to the equipment shown, an audio link and one-way buzzer (depicted in Figure 2-1) was provided between the console operator's station outside the simulator and the test observer's station inside the simulator. These links were used for test coordination during the actual scenario delivery. This will be described further in Section 3.

The buzzer link and audio link as well as associated headsets were provided by the airlines at their respective sites.

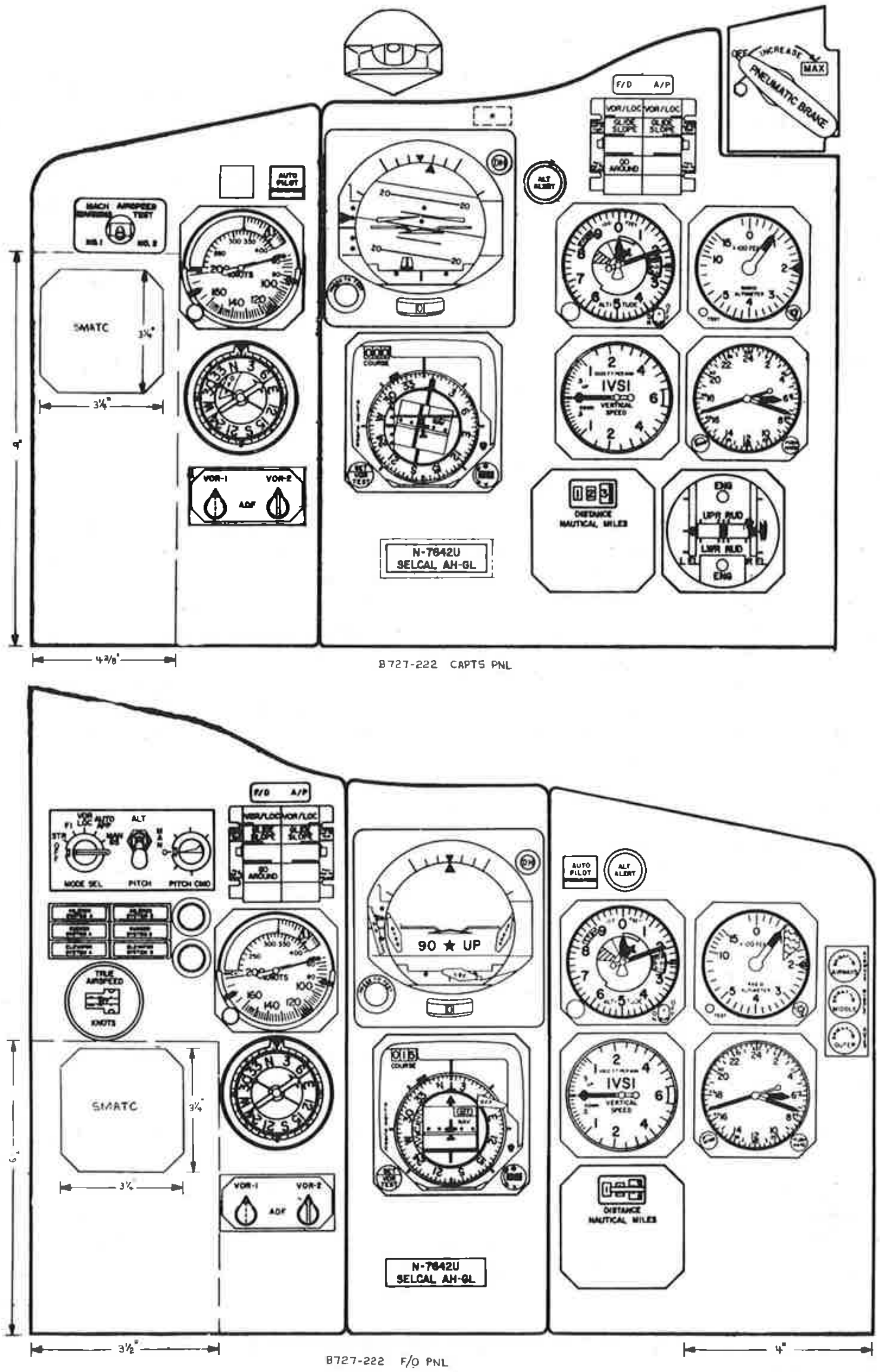


Figure 2-10. Captain and F/O Panels with Proposed SMATC Locations, B-727 Simulator

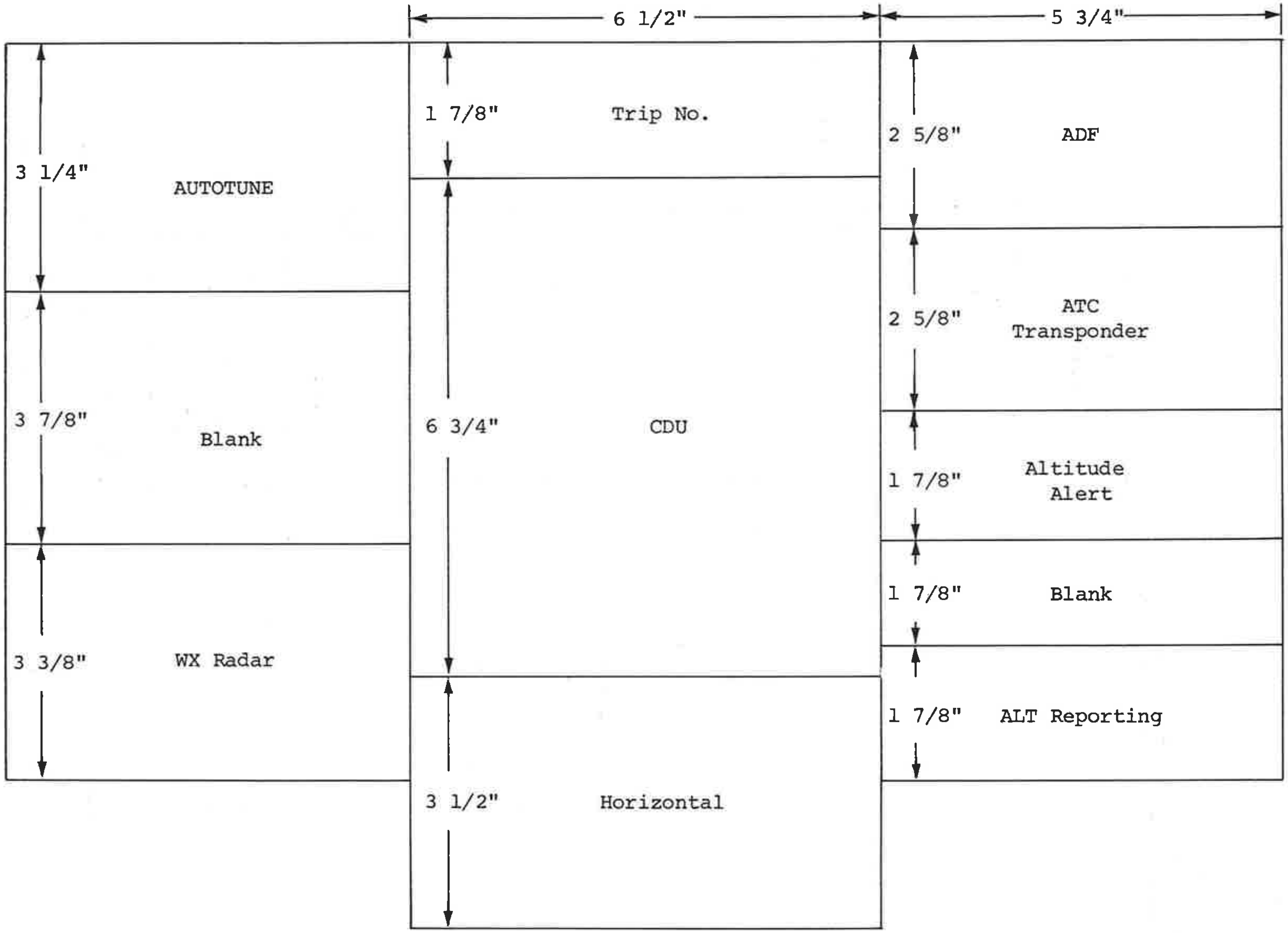


Figure 2-11. B-727 Forward Pedestal

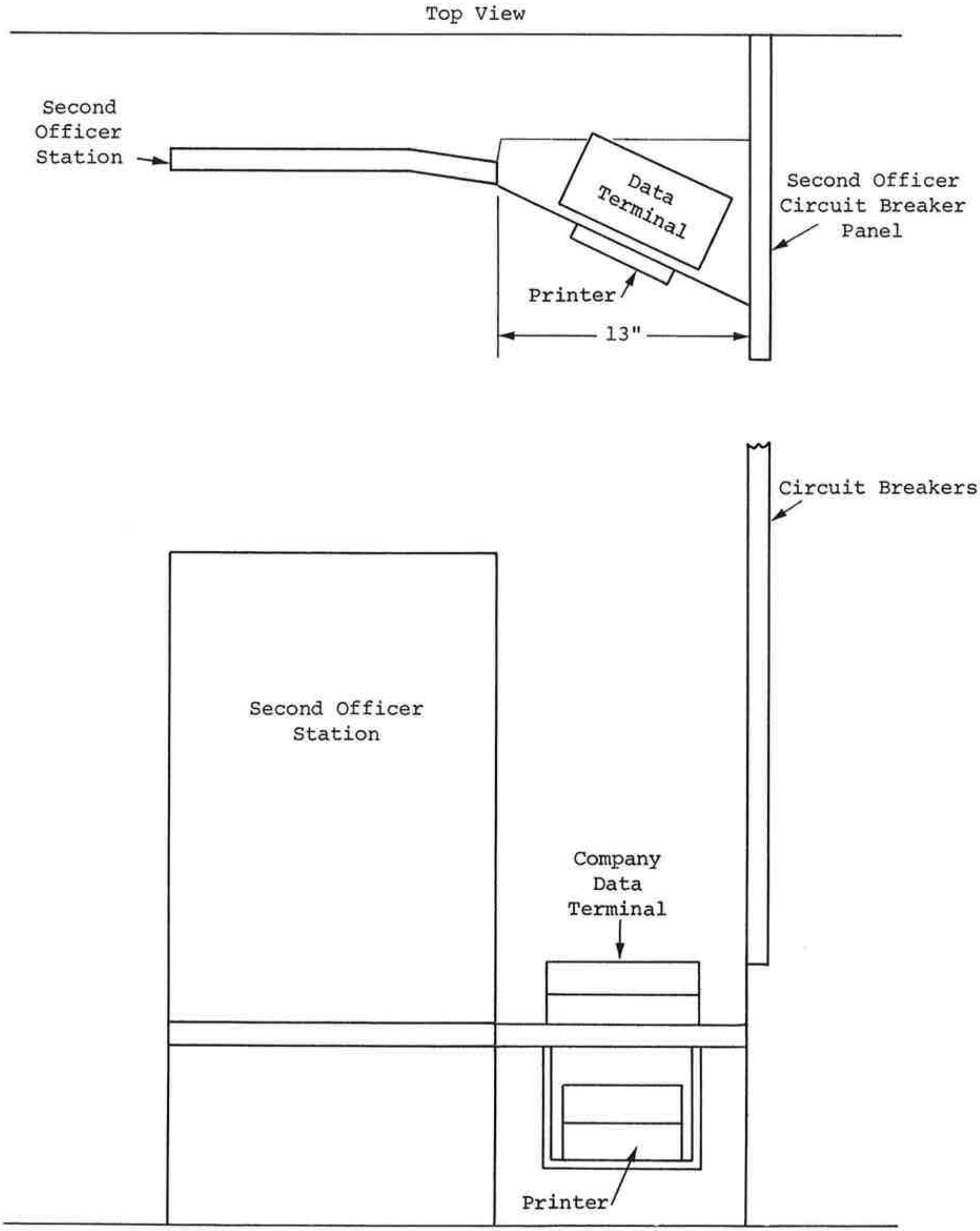


Figure 2-12. B-727 Printer and Company Communications Data Terminal Installation

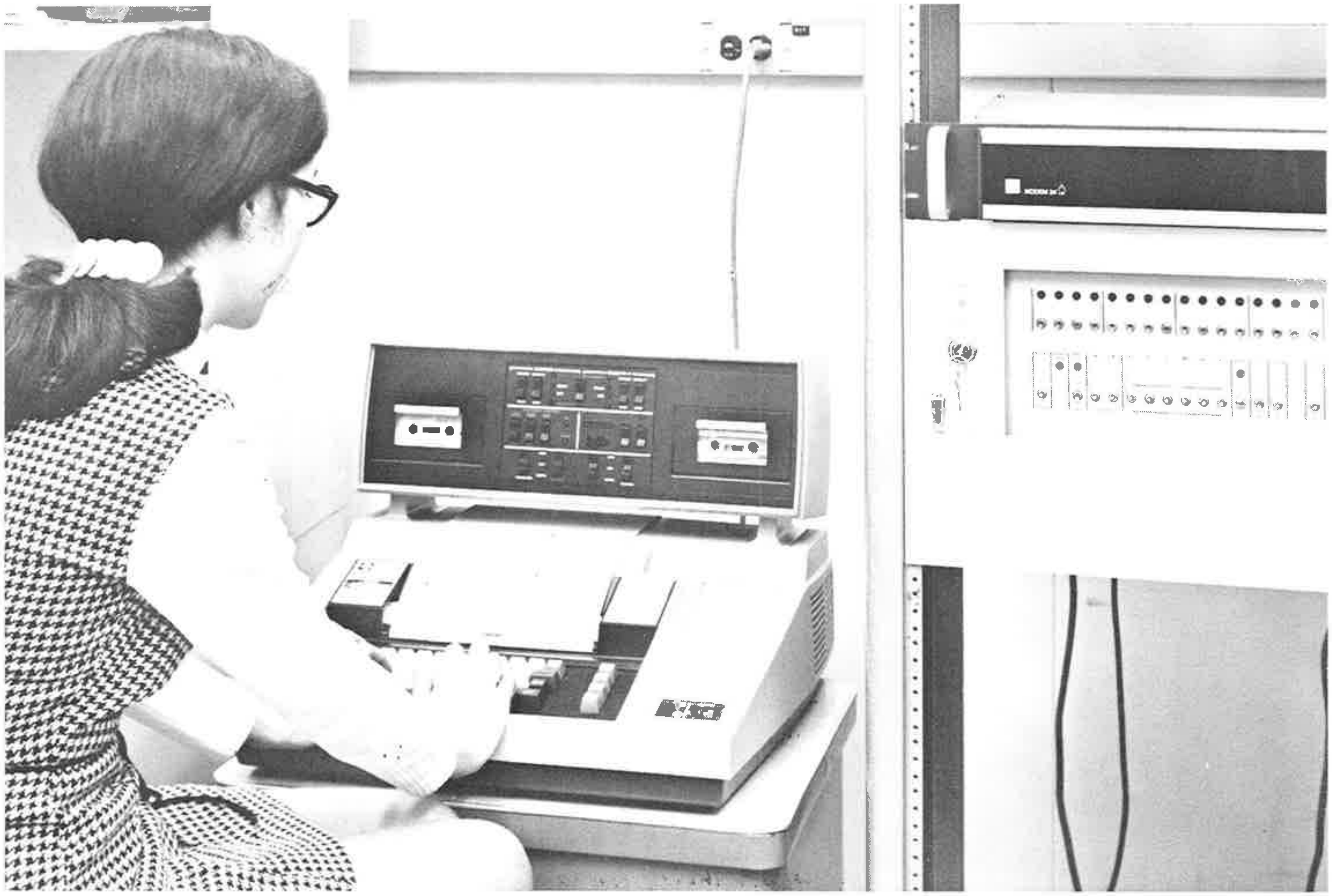


Figure 2-13. Texas Instruments 960A Minicomputer and ASR 733 Console

Figure 2-14. Test Equipment Configuration, B-727 Simulator

Redundancy was provided where possible. Only one of each I/O device was supplied (two SMATC displays) by TSC because of the time required to construct duplicates. A spare minicomputer and console terminal were available at the test site. In addition to backup, this computer was used for off-line "quick look" analysis of each day's data to verify that the system was operating properly. A spare wiring harness or cable was also provided at each site. This was used to test the devices when they were not installed in the simulator. Additional wire pairs were provided in each installed cable in case of failures within cables after installation.

In addition to the equipment provided by the government and ARINC Research, TW and UA both supplied facilities that allowed the test operator outside the simulator to be constantly aware of the simulated aircraft's geographic position and altitude. In essence, he had the same type of information that is available to air traffic controllers.

3. DESIGN AND CONDUCT OF EXPERIMENT

The overall evaluation objectives will be expanded into specific objectives in this section. The development of an experimental test was based on these specific objectives and required measurements of the effects of various factors on communications performance. The procedure used to acquire experimental pilots and the characteristics of these pilots are discussed, and the daily evaluation operating schedule and the method of scenario delivery are described.

3.1 SPECIFIC EVALUATION OBJECTIVES

The overall evaluation objectives stated in Section 1 have been further defined in terms of specific objectives:

- To determine pilot reactions concerning three complements of I/O devices based on a wide range of commercial airline pilots
- To measure and record crew communications performance using the Data Link I/O devices
- To investigate the possible effects of scenario, simulators, turbulence, lighting conditions, and crews on various I/O complements
- To evaluate which features afforded by a Data Link would be used by a crew
- To investigate the differences between Data Link in two- and three-crew-member aircraft
- To rank the three demonstrated complements of I/O devices on the basis of both quantitative and qualitative data

The factors that may influence data include the following:

- Simulators
- Scenarios
- Complements
- Crews

* Turbulence conditions
* Light conditions
* Practice effects

In order to meet the above-listed objectives, both quantitative and qualitative data were collected. The quantitative data were collected by the Data Collector subroutine of the TI 960A computer. Response time upon message comprehension was the quanitative variable. The qualitative data were collected from the debriefing questionnaires, from the observations of the cockpit observer, and from the supplemental questionnaires.

3.2 EXPERIMENTAL DESIGN

The cost of owning, operating, and maintaining a well equipped airline simulator often approaches several hundred dollars per hour. For this reason the major constraint in developing an adequate design was that of economics.

An Analysis of Variance of the anticipated experimental design indicated that, within the program constraints, two simulators, three scenarios, and three device complements could be adequately evaluated. Two main criteria were taken into consideration in designing this evaluation:

1. Interaction among and between causal factors
2. Variations in measures due to factors not controlled in the experiment, such as crew background

The first of the criteria was handled by obtaining responses while varying all the factors simultaneously rather than varying only one factor at a time. The second of the criteria was obtained by randomizing the factor combinations to the experimental units (i.e., individual crew sorties).

Nine aircrews were tested at each of two simulator sites and three scenarios were employed. Each scenario, describing a communications profile for a typical airline flight of approximately one hour ten minutes, started as shown in Figure 3-1. The three complements combined with the three scenarios yielded nine distinct combinations.

Each crew flew one four-hour test session consisting of three flights. This provided a total of 27 flights per simulator, or 54 overall. Each flight experimental run in Table 3-1 was smooth or turbulent and flown under day or night conditions. This yielded 36 possibilities. To accommodate this number with nine crews in two blocks (simulators), we used a fractional factorial design in which the occurrence of complement and scenario was completely balanced with the crews, the turbulence, and the daylight conditions.

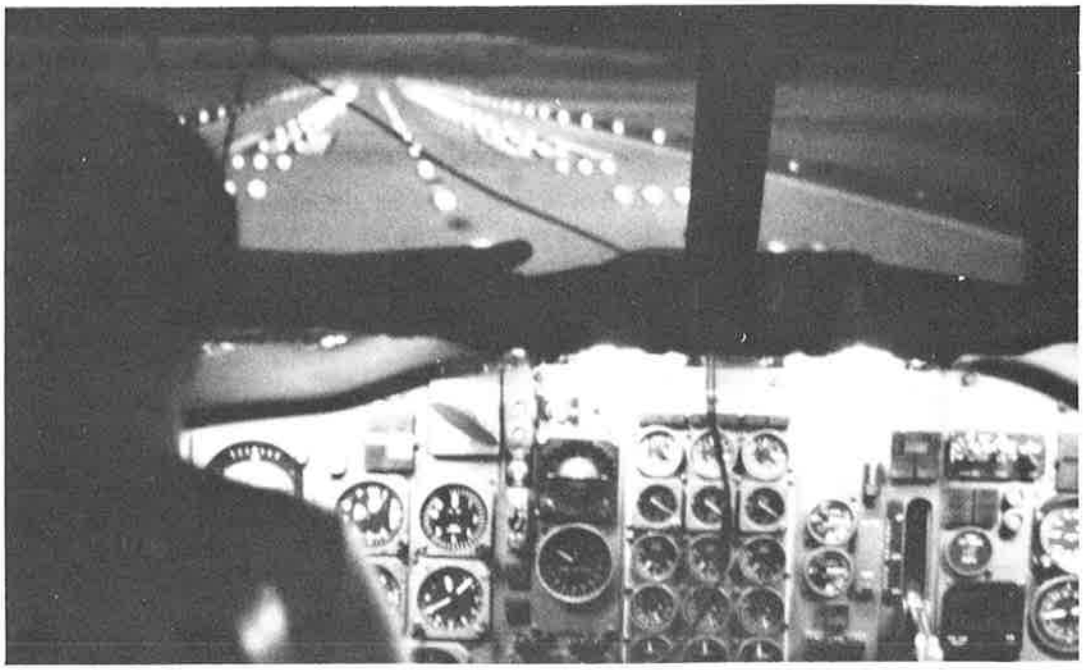


Figure 3-1. B-727 in Take-Off Position at Kansas City International

TABLE 3-1. CREWS BY TEST CONDITIONS

Scenario and Condition		SMATC		VOSYN		SMATC/VOSYN	
		Day	Night	Day	Night	Day	Night
I	Smooth	5		8	3	6	9
	Turbulent	7	1	4			2
II	Smooth	9	6	1	7	3	
	Turbulent	2			5	8	4
III	Smooth	4	8		2	7	1
	Turbulent		3	6	9	5	

Note: The terms SMATC, VOSYN, and SMATC/VOSYN indicate the distinctive characteristics of each complement. The full suite or complement of devices in each case may be reviewed from the listing on pages 9 and 10.

The basic experimental unit for this evaluation was a flight on a particular simulator using a particular complement, with a particular daylight and turbulence condition during a particular scenario. Although normally all the factor combinations used in the experiment were randomized on the experimental units, in this situation there was a restriction resulting from each crew's having to fly three flights in a row.

Table 3-1 shows for each of the simulators the combinations of conditions each of the crews experience. As the crews became available, they were assigned to one of the crew numbers in Table 3-2. The order of missions for each of the nine crews in Table 3-2 was randomly selected.

TABLE 3-2. ORDER OF MISSIONS FLOWN

	Scenario (S)								
Crew	SMATC			VOSYN			SMATC/VOSYN		
	S-I	S-II	S-III	S-I	S-II	S-III	S-I	S-II	S-III
1	2				3				1
2		2				1	2		
3			2	1				3	
4			3	2				1	
5	3				1				2
6		1				2	3		
7	2				1				3
8			1	3				2	
9		3				2	1		
S-I: SFO-LAX; S-II: MCI-ORD; S-III: LAX-SFO									

Table 3-1 was restructured into five two-factor tables as presented in Table 3-3. Only in Table 3-3(a) is there represented a full-factorial (i.e., all factor combinations tested) design with replications so that the differences among crews can be tested as well as all the interaction among crew, complements, and scenarios.

Appropriate transformations on the data were made in order to attain variance stabilization and normalization, which are the necessary assumptions in conducting the desired analysis of variance. This analysis is described in Section 5.

TABLE 3-3. CREWS BY FACTOR COMBINATIONS: TWO FACTORS CONSIDERED AT A TIME (NUMBERS LISTED ARE CREW NUMBERS)

	Scenario by Complement			
	Scenario	SMATC	VOSYN	SMATC/VOSYN
(a)	I	1, 5, 7	3, 4, 8	2, 6, 9
	II	2, 6, 9	1, 5, 7	3, 4, 8
	III	3, 4, 8	2, 6, 9	1, 5, 7
	Light Condition by Complement			
	Light Condition	SMATC	VOSYN	SMATC/VOSYN
(b)	Day	2, 4, 5, 7, 9	1, 4, 6, 8	3, 5, 6, 7, 8
	Night	1, 3, 6, 8	3, 5, 7, 9, 2	1, 2, 4, 9
	Turbulence by Complement			
	Turbulence	SMATC	VOSYN	SMATC/VOSYN
(c)	Smooth	4, 5, 6, 8, 9	1, 2, 3, 7, 8	1, 3, 6, 7, 9
	Turbulent	1, 2, 3, 7	4, 5, 6, 9	2, 4, 5, 8
	Light Condition by Scenario			
	Light Condition	Scenario I	Scenario II	Scenario III
(d)	Day	4, 5, 6, 7, 8	1, 3, 8, 9	4, 5, 6, 7
	Night	1, 2, 3, 9	2, 4, 5, 6, 7	1, 2, 3, 8, 9
	Turbulence by Scenario			
	Turbulence	Scenario I	Scenario II	Scenario III
(e)	Smooth	3, 5, 6, 9, 9	1, 6, 3, 7, 9	1, 2, 4, 8
	Turbulent	1, 2, 4, 7	2, 4, 5, 8	3, 5, 6, 7, 9
	Turbulence by Light Condition			
	Turbulance	Day	Night	
(f)	Smooth	1, 3, 4, 5, 6, 8, 9	1, 3, 6, 7, 8, 9	
	Turbulent	2, 4, 5, 6, 7, 8	1, 2, 3, 4, 5, 9	

3.3 EXPERIMENTAL CREWS AND SCENARIOS

In selecting experimental crews, it was desired to obtain the widest possible cross-section of qualified pilots from the air carrier industry.

The primary element of this participation was to be the professional pilots and flight instructors on the staffs of TW's and UA's training centers. They were chosen since scheduling conflicts with them could be minimized. Additionally, it was desired to obtain volunteer pilot participation from interested user groups in the industry and FAA test-pilot participation.

The number of volunteers surpassed all expectations, undoubtedly due to the written request made by the ATA to all member airlines. Pilots currently flying for or on the staffs of the following organizations participated in the evaluation:

- Airline Pilots Association
- American Airlines
- Boeing Company
- Braniff International
- Continental Airlines
- Federal Aviation Administration (NAFEC)
- Southern Airways (not used because of equipment malfunction)
- Northwest Airlines
- Ozark Airlines
- Pan American World Airways
- Society of Automotive Engineers (S-7 Committee)
- Trans World Airlines
- United Airlines
- Western Airlines .

The participating pilots could be classified as follows:

- Line Pilots
- Management Pilots (Flight Instructors and Flight Managers)
- Engineering and Test Pilots .

Table 3-4 shows a breakdown of certain pilot characteristics.

TABLE 3-4. EXPERIMENTAL CREW CHARACTERISTICS

Simulator	Average Hours	Average Hours in Aircraft	Airline Transport Rated (in Aircraft)	Line Pilots	Management Pilots	Test Pilots
DC-9	9600	1530	17 (11)	6	8	4
B-727	11600	1900	19 (14)	5	16	6

The three scenarios, which were used at both simulator sites, were as follows:

Scenario I - San Francisco to Los Angeles

Scenario II - Kansas City to Chicago

Scenario III - Los Angeles to San Francisco

Each of these scenarios described a typical flight of about one hour ten minutes between two high-density terminals. Approximately 60 messages were contained in each scenario: roughly 50 were ATC messages, and the remaining 10 were company messages. Situations that required the crew to use the CDU for downlink-message composition were provided. Each scenario was coded into three message scripts, one for each device complement. It had been desired to use at least one international scenario. However, the geographic detail stored in the simulator computer as well the lack of suitable navigation capabilities in the simulators prevented this.

Runway visual systems were used for all takeoffs and landings to simulate realism and note any distracting effects of the I/O devices.

Three varying degrees of company automation were employed in the three scenarios to obtain qualitative pilot opinion on the acceptability of the varying amounts of button-pushing required in composing these messages. The three scenarios are illustrated in the following subsections and are described in detail in Appendix A.

3.3.1 Scenario I - San Francisco to Los Angeles

Scenario I, illustrated in Figure 3-2, involved a non-stop flight from San Francisco International Airport to Los Angeles International Airport. The crew initially requested Automatic Terminal Information Services (ATIS) by using the CDU. Next they requested clearance. Prior to takeoff but after gate departure, the flight was advised of a ten-minute delay and asked to forward a delay report to the company. The flight took off, was vectored through its departure procedure, and was instructed to climb to altitude. (The altitudes were somewhat different for the two simulators, consistent with the altitudes for which the aircraft would actually file.)

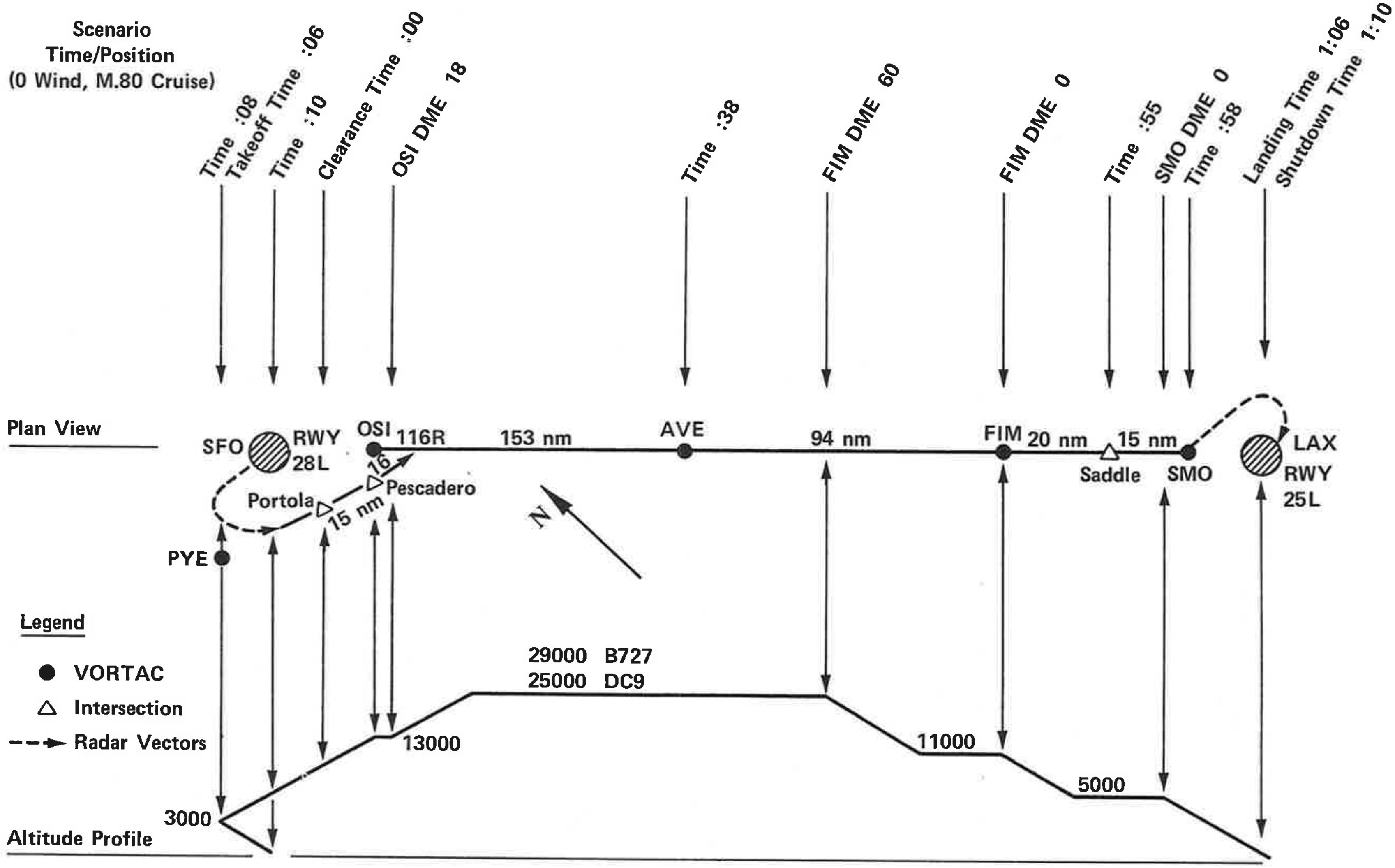


Figure 3-2. Scenario I, San Francisco to Los Angeles

An impossible altitude command was given to the crew in order to require the use of the UNABLE button on the CDU. Following the resolution of the difficulty on the voice channel, the flight was instructed to proceed to its proper altitude.

Clear Air Turbulence (CAT) was encountered en route, forcing the crew to request a change to a smoother altitude. The flight was cleared to a smoother altitude and eventually descended for its approach into Los Angeles. The flight was radar-vectored for an instrument approach at Los Angeles. The assigned approach differed from the one mentioned in the ATIS information. The aircraft landed and taxied to the gate. The flight concluded with the crew filing its arrival report with the company.

A certain degree of automation was assumed for company messages in this scenario. It was assumed, for the purpose of Gate Departure, Airborne, Landed, and Gate Arrival reports [respectively called OUT, OFF, ON, and IN ("OOOI")], that on-board flight devices automatically inserted the flight number and applicable station identifiers. The crew entered only the proper function (e.g., DEPARTED) and the applicable time and fuel-weight digits, and then depressed the SEND button.

3.3.2 Scenario II - Kansas City to Chicago

Scenario II, illustrated in Figure 3-3, involved a routine flight from Kansas City International Airport to O'Hare International Airport. As in Scenario I, the crew requested ATIS and ATC clearance via the CDU.

The aircraft took off, was radar-vectored to intercept the proper departure course, and climbed to its flight-planned altitude. An impossible transponder code was given to the flight in order to require the crew to use the UNABLE buttom on the CDU. Once this situation was resolved on the voice channel, the flight was given the correct transponder setting via the data link. The flight was instructed to circle and hold prior to entering the Chicago terminal area.

Full automation of company "OOOI" messages was assumed in this scenario. The crew pressed only the applicable function button, followed by the SEND button. On-board sensors and devices caused the flight number, station identifier, applicable time, and fuel-weight digits to be entered.

3.3.3 Scenario III - Los Angeles to San Francisco

Scenario III, illustrated in Figure 3-4, involved a flight from Los Angeles International Airport to San Francisco International Airport. As in Scenario II, the scenario began with the crew requesting ATIS and Clearance via the CDU. The flight was vectored through a departure procedure to its flight-planned route.

The flight proceeded normally through the departure, en route, and initial arrival stages. An unreadable heading command was given to the flight in order to force the use of the UNABLE button. After this

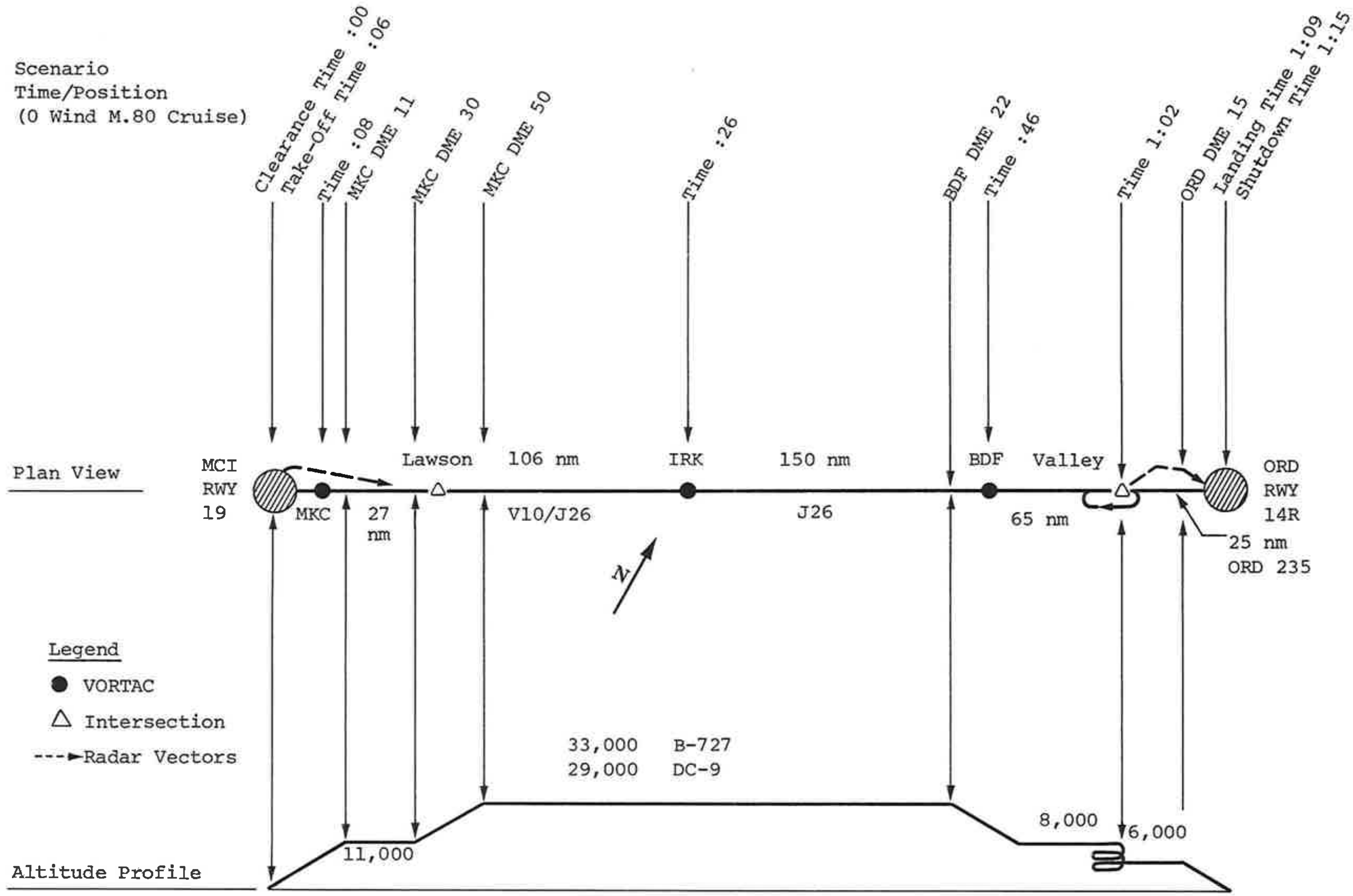


Figure 3-3. Scenario II, Kansas City to Chicago

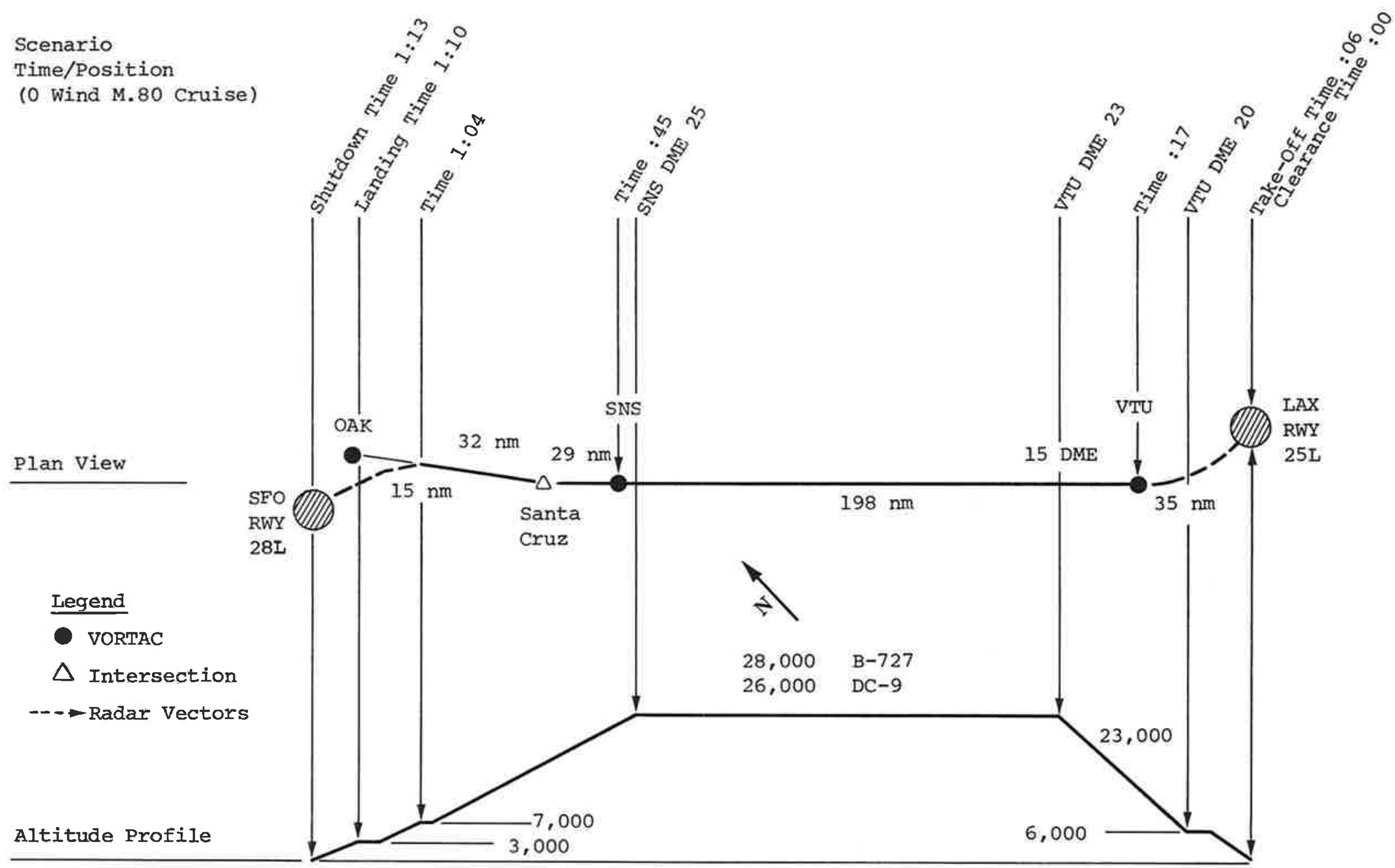


Figure 3-4. Scenario III, Los Angeles to San Francisco

situation was resolved on the voice channel, the correct heading was given. On final approach, the flight was told to go around because of a disabled aircraft on the runway. The flight was radar-vectored for another instrument approach and landed. This scenario was concluded with the crew filing its arrival report.

Only the flight numbers were automated in the company messages of this scenario. The crew entered station identifiers, times, and fuel-weight digits for the "OOOI" messages.

3.3.4 Downlink Request Messages

There were two conditions under which the crew was instructed to generate downlink request messages via the CDU. The first occurred when they wanted to obtain a clearance, taxi instructions, ATIS, weather, or altimeter setting, or to send company-type messages. The second condition for downlink messages occurred in some scenarios at predetermined points. At the proper time, the on-board observer informed the crew that a certain situation existed. The observer instructed the crew on the action to be taken in terms of a downlink request, which was predetermined. The downlink messages that fall into this category are "ALT Request," "HDG Request", and "Alternate Airport." A crew member would key in the required downlink request, for which the uplink response was the next sequential message of the scenario.

3.4 EXPERIMENTAL PROCEDURE

Test personnel included the Test Observer and the Test Operator. In the B-727 simulator, an additional person, the radio aids operator, was used.

The test observer, seated inside the simulator at the instructor's station, had three principal functions:

1. Act as advisor to the crew as necessary
2. Advise the console operator when to release certain messages
3. Observe and record crew action for purpose of data gathering .

He was also responsible for initializing the simulator at the beginning of every trial; this activity included setting light conditions and locating identifiers, environmental, and visual system parameters. He adjusted the wind component to keep the tests on schedule. In addition, he operated the visual system on takeoffs and landings. Figure 3-5 shows the test observer operating the B-727 simulator initialization and control panel.

The console operator, seated with the test equipment located outside the simulator (shown in Figure 2-1), effectively ran the experiment from his station. The operator loaded the script cassette and data-collection tapes into the ASR-733 cassette terminal. He set all required initial values into the minicomputer. When the observer advised him to release

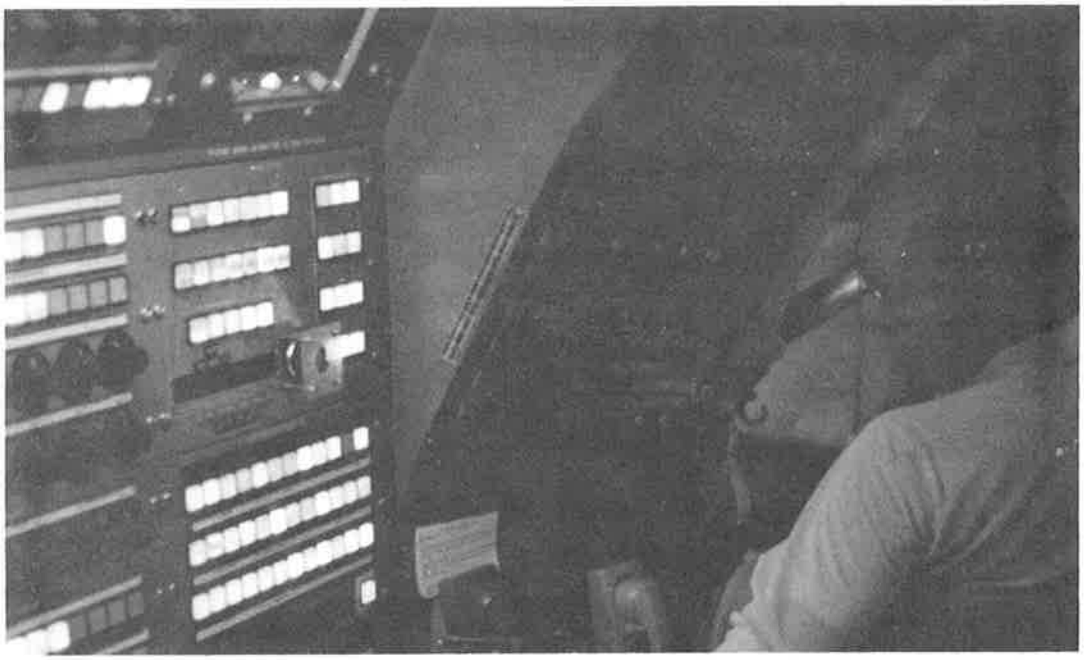


Figure 3-5. Test Observer Operating Simulator Control Panel

the first message, he did so. In addition to releasing messages, he also functioned as ground voice controller for both ATC and company purposes. There was at least one instance in every scenario in which it was necessary to use a voice channel for ATC or company purposes. Whenever the UNABLE button on the CDU was pushed, the observer responded on the voice channel as the appropriate ATC controller. Whenever the company voice button on the CDU was pushed, the operator responded as the Company Radio Operator. When the B-727 second officer sent a company message downlink on the independent terminal, it appeared on a separate printer at the operator's location. The operator entered the reply on the ASR-733 console. This reply appeared on the page printer in the cockpit.

Figure 3-6 shows the exact procedure used at TW with the DC-9. The procedure for the B-727 was somewhat more complicated in that the approach recorder was not accessible to the test console operator. He had to use an additional audio link to a UA Radio Aids Operator located in a distant section of the building.

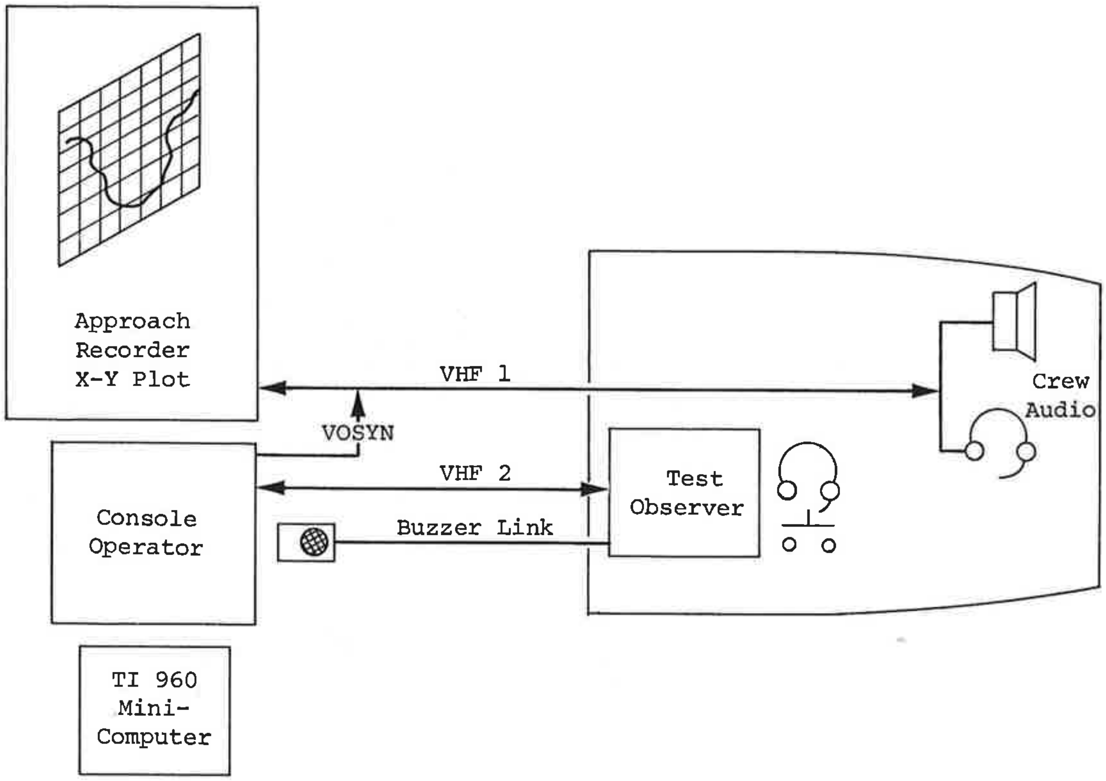


Figure 3-6. DC-9 Test Operating Procedure

An experimental session consisted of approximately one day's activity for the experimental flight crew and test operating personnel. It included four hours of simulator time during which three flights were conducted in accordance with the experimental design tables (3-1 and 3-2).

Each test session was planned to last not more than four hours, but the sessions sometimes ran 20 to 30 minutes long, at the convenience of the host airlines. Immediately prior to and following these sessions, the simulator was configured for standard training. All devices were removed from the simulator or stowed out of sight when not being used during the I/O trials.

A typical seven-hour day for the flight crew, with a one-hour lunch break, was broken down approximately as follows:

Time (0800 start is arbitrary)	Event
0800-0815	Flight crew reads or rereads Appendix B, Briefing Information.
0815-0855	Flight crew is briefed.

0900-1300	Four-hour simulator session.
0900-0910	Crew-familiarization run -- Appendix B.
0910-1020	First flight is conducted.
1020-1030	Break. Second trial run is made ready.
1030-1140	Second flight is conducted.
1140-1150	Break. Third trial run is made ready.
0150-1300	Third flight is conducted.
1300-1400	Lunch.
1400-1500	Flight crew completes questionnaire and is debriefed.

The simulator testing was begun at UA's facilities in Denver on 26 October 1974 and was completed at TW's facilities in Kansas City on 20 December 1974. With the exception of some minor technical problems with the Voice Synthesizer in early December, the tests proceeded without incident.

4. QUALITATIVE DATA ANALYSIS

When an automated information-transfer system, such as Data Link communications, is integrated into a system in which critical life-protecting decisions are dependent on the quality of the man-machine interface, the subjective evaluations of the operators may be as decisive as the technical measurements of the system. The use of simulators in this experiment is aimed directly at comparing the quality of the man-machine interface of various complements of Data Link communications equipments. The subjective, or qualitative, data were derived from three sources in this evaluation:

- Debriefing questionnaires
- Observer comments
- Supplemental questionnaires

The most useful data collected were those compiled from the 44 responses to the debriefing questionnaire. At the completion of the three trials, each crew was taken to a classroom and asked to complete the questionnaire, which is reproduced in Appendix C. The questions concerned the device complements, the individual devices, and many of the general assumptions or Data Link concepts tested during the evaluation. After the questionnaire was completed, a question-and-answer or free-comment session was held. Significant remarks were recorded by the observer, who was also the debriefer. The entire process took about one hour.

Another significant source of data was the compilation of the test observer's comments. Four persons acted as observers during the 54 trials. All four were instrument-rated pilots, and the one who observed about 83 percent of all trials had considerable heavy-jet experience. Their comments primarily concerned the effects of Data Link on crew performance and interaction and were usually recorded on an exception basis. In other words, if the observer noted something he considered unusual, he recorded it.

Another function of the observer was to enable the computer to record whether the left- or right-seat pilot responded on the CDU. It was intended that this be done by manually changing the switch provided as part of the test instrumentation. The observer's workload prevented him from actively using this switch. As a practical matter, however, it was noted by all observers that, almost invariably, the CDU was operated by the non-flying officer. For the flying officer to operate the CDU, he would have to lean forward across the engine controls, and this action was observed infrequently, if ever.

The supplemental questionnaire was distributed about four months after completion of the testing. Its purpose was to help provide additional insight into overall crew sentiment toward various device complements and Data Link concepts. One of its principal advantages is that it provided all responders a four-month period to re-examine their initial reactions to Data Link and to formulate considered opinions.

4.1 INITIAL QUESTIONNAIRE RESULTS

The questions deal with the attributes of Data Link I/O devices, device complements, and concepts. The 45 questions presented were distributed as follows:

• SMATC Display	11
• Vosyn	4
• SMATC with Vosyn	5
• Printer	6
• CDU	4
• General Concepts	15

In addition to answering the questions, crew members often provided amplifying and clarifying comments. Sometimes the question called for specific comments. In explaining the results, this report employs some of these comments. The initial questionnaire responses and all additional comments are tabulated in Appendix C. The B-727 crews generally provided more additional comments than the DC-9 crews. Because of a slight error in administering the questionnaire, the DC-9 crews were given a longer, unabridged version, which left them little time for additional comment. The abridged questionnaire used for the B-727 crews is a subset of questions in the longer, unabridged version. No data have been lost as a result of this error, however.

Since one of the major objectives of the evaluation was to determine the differences in Data Link communications between two- and three-crew-member aircraft, the questionnaire responses from the two-member DC-9 crews and the three-member B-727 crews were examined for significant differences. The test used to determine these differences was the Chi-Square test of independence in contingency tables at the 0.05 (5 percent) level of significance, which compares the expected values of responses against the observed values at a stated level of significance. These differences are discussed before the basic analyses of all responses because of the desirability of treating the remaining data -- in which no response differences could be attributed to simulators -- as data belonging to a single population.

A significant difference between the simulators was found in the responses to three questions. Two questions were related to Vosyn intelligibility, and a third was related to desirability of abbreviations used on the printer.

The Vosyn was found to be more acceptable in the DC-9 than in the B-727 simulator. The integration of Vosyn audio into the B-727 audio system provided a poor-quality sound because of stray noise and interference, mismatch of impedances, and the generally less than excellent quality of sound in the simulator audio system. The speakers used in the audio system were, however, identical to those used in the fleet aircraft.

In the test installation for the DC-9 the Vosyn audio output was fed into its own amplifier and then into a dedicated speaker directly behind the crew. A much improved audio quality was thus obtained. Since the total cost of the amplifier and speaker used in the DC-9 simulator was small, the improved acceptability of the Vosyn here cannot be attributed solely to the use of "high fidelity" equipment. The significant difference in the Vosyn audio-quality acceptability of the two simulators is a result of the improved installation technique employed in the DC-9. However, the feasibility of pursuing this improved technique in the aircraft, with its attendant high-noise environment, is not known.

In the examination of the significant difference in the desirability of abbreviations used on the printer, it appeared unusual that the DC-9 crews were much less receptive to the use of any abbreviations on the printer than were the B-727 crews. However, the respondents in the B-727 case were all flight engineers, or non-flying officers. In the DC-9 the respondent was always the right-seat pilot, who was sometimes the flying officer. It is readily understandable, in view of his relatively heavier workload, that the flying officer would be less receptive to abbreviations used on the printer than the non-flying officer in the B-727. Providing only the right-side crew member with access to a printer in the DC-9 was the unfortunate result of having to make the simulator easily convertible to the normal training configuration.

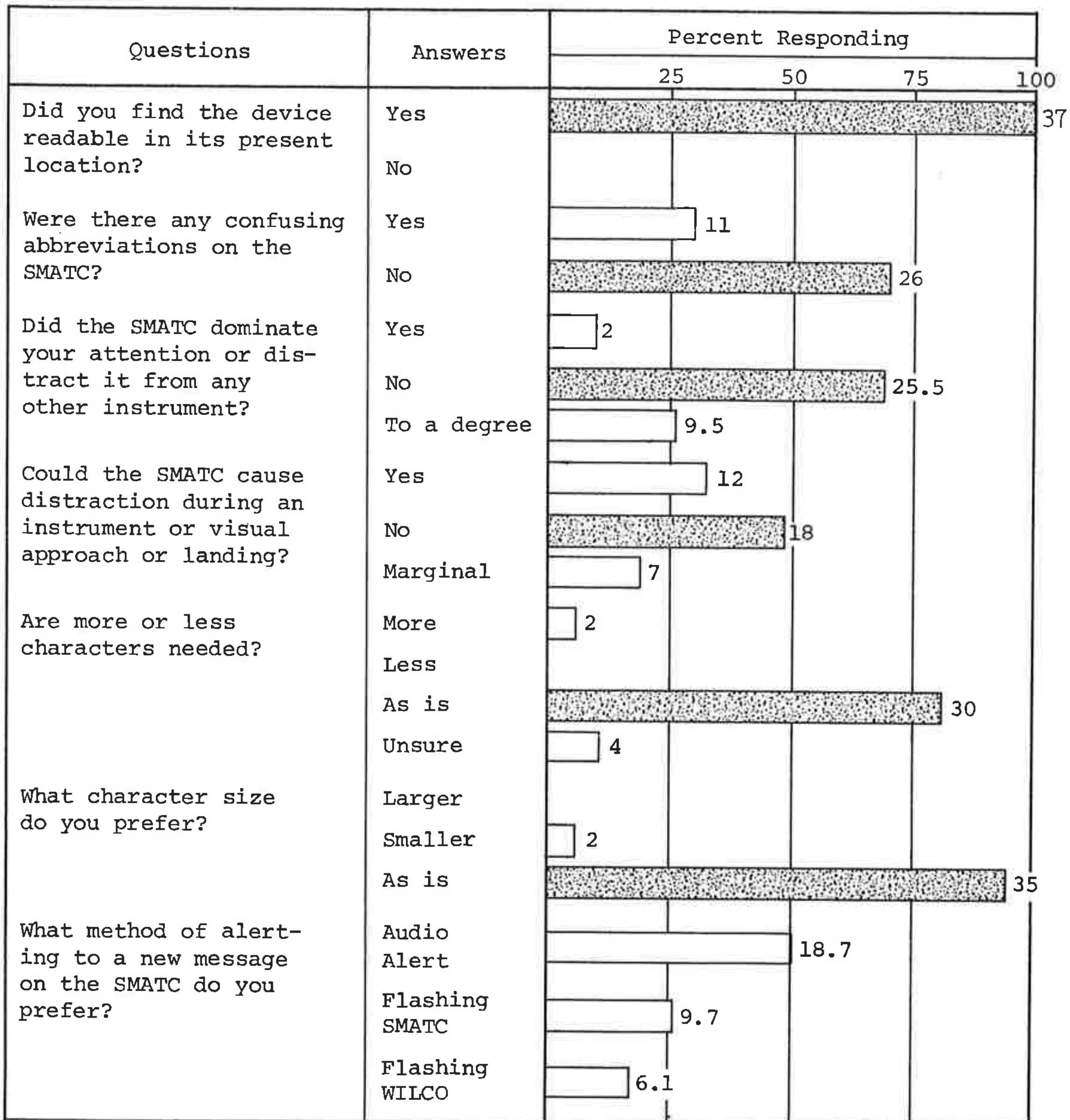
No other significant differences between simulators were found in any of the responses. Therefore, the remaining qualitative data will be treated as though they belong to a single population.

4.1.1 SMATC Display

The SMATC display was used by itself as a complement and in combination with the Vosyn. Eleven questions were asked concerning the SMATC. Four were of the Yes/No type, two concerned distracting effects, and five asked for opinions on device employment. These questions are discussed below, along with selected comments that support the majority or contrasting responses. Only the two flying officers were asked to respond; however, B-727 second-officer responses were not excluded. Responses to seven SMATC questions are illustrated in Figure 4-1.

Without exception, all pilots found the SMATC readable in its present location (see Figure 4-1). One pilot commented that in a small cockpit such as the DC-9's, one centrally located device would be sufficient.

The majority of pilots agreed that there were no confusing abbreviations on the SMATC display. A complete list of abbreviations on the SMATC



Note: The shaded bars represent those responses considered favorable to the device or concept being evaluated. Decimals represent multiple responses.

Figure 4-1. SMATC Display Responses

is given in the SMATC column of the scripts in Appendix A. The following abbreviations cited as confusing could have affected aircraft navigation:

- OSI (identifier for Woodside) was confused as the 051 radial.
- DEP 050R (meaning "depart 050 radial") was interpreted by one pilot as an altitude clearance of 5,000 feet.

The first comment was cited by two pilots. The second comment, along with six others not pertaining to navigation, was mentioned once. The majority of pilots felt that the SMATC display did not dominate their attention or distract it from any other flight or navigation instrument. Those who commented that the SMATC did distract, or could do so to a degree, cited the horizontal situation indicator, flight director, altitude, and airspeed instruments as those which could be neglected. Three pilots felt that distraction could be caused during climb and descent. Since the SMATC was positioned next to the airspeed indicator, which is a primary instrument during climbs and descents, this is understandable. Two pilots cited the red light of the SMATC LED characters as distracting since this color is usually reserved for high-priority fault annunciations. One pilot commented that the flashing of the SMATC upon displaying a new message could be distracting during critical flight phases.

In the approach and landing phase, the majority of pilots believed that the SMATC display could cause at least a marginal distraction. Again, the flashing was mentioned as being distracting, along with the audio alert.

The great majority of pilots thought that the 16-character field of the device was adequate. This is based on the assumption of printer availability in the cockpit with the SMATC being limited to short ATC messages. Similarly, a majority thought that the individual character size was adequate.

Most pilots showed preference for an audio alert of a new message on the SMATC as opposed to flashing the message on and off to gain attention. The choice of having the WILCO button flash was not attractive to the pilots.

During the approach into San Francisco a go-around was given at typically 250 feet while IFR conditions still prevailed. On three trials in each simulator the SMATC display alone was present. In most cases the flying officer, who was giving full attention to the flight director and one or two other instruments, did not notice the go-around message, which was preceded by the aural alert. In at least one case the flight engineer called the message to the crew's attention. Several pilots observed that the SMATC went unnoticed during the busier phases of flight, including the instrument approach. One pilot observed that a message on the SMATC during this phase of flight should be more attention-getting.

The SMATC display was found to be easily readable and well located. With the exception of a small number of commands, the abbreviations used on it were not confusing. The SMATC did not distract pilots during most phases of flight. Some distraction of the pilot's attention from the adjacent airspeed indicator may have been caused during climbs and descents.

A majority of pilots believed that the SMATC could potentially distract them during an instrument approach.

The use of the SMATC display for emergency or time-critical messages, such as minimum-safe-altitude warning or go-around, is not recommended. Even with the audio alert employed, it does not adequately gain the crew's attention under heavy-workload situations.

4.1.2 Voice Synthesizer (Vosyn)

The Vosyn was used in two device complements -- once by itself and once in combination with the SMATC display. The crew was asked four questions concerning the Vosyn's intelligibility, the improvement of intelligibility with practice, the effect of mechanical speech, and the application of the Vosyn in air-traffic control. The results of these questions are shown in Figure 4-2.

Overall, only 20 percent of the pilots rated the intelligibility of the Vosyn good, while 80 percent rated it marginal or unacceptable. However, in the DC-9 simulator, which did not use the simulator audio system for the Vosyn, the intelligibility rating was much higher. In the DC-9 alone, 47 percent rated the Vosyn good, 47 percent marginal, and 6 percent unacceptable. These latter percentages are thought to be more representative of the responses to this question. In either event, fewer than half the pilots thought that the Vosyn intelligibility was good.

No real differences between the simulators were cited in the responses to the remaining questions. In commenting on the applicability of the Vosyn, several pilots observed that it should not be used for routine communications but instead should be used only for emergency or semi-emergency type communications of the first priority, such as minimum-safe-altitude warning or missed approach.

Pilots found the long messages to be distracting and hard to follow. There was practically no tonal inflection or volume variation in the Vosyn words. The lack of space between words made the speech difficult to follow. One pilot commented that he found the Vosyn quite difficult to understand while others in the cockpit were speaking.

One engineering test pilot observed that the Vosyn detracts from one operational advantage of Data Link -- namely, that two persons can communicate without devoting full attention to each other at the same time. He felt that, in contrast to the SMATC, the Vosyn demanded the pilot's attention because it blocked out other conversation.

The intelligibility of the Vosyn is considered unacceptable for routine communications. Pilots found the mechanical sound and the lack of tonal inflection and volume variation to create difficulty in understanding in a high-noise environment as well as annoying. This effect apparently did not diminish with practice.

Questions	Answers	Percent Responding
How would you rate the intelligibility of the Vosyn?	Good	8.5
	Marginal	29.5
	Unacceptable	5
Did the intelligibility improve with practice?	Yes	19
	No	7
	Only Slightly	17
Apart from intelligibility, did you find the mechanical quality of speech to be annoying?	No	18
	Moderately	21
	Very	3
	Undecided	1
Should the Vosyn be limited to certain types of messages?	Short Only	24.5
	Long Only	1
	No	7
	Other	7.5

Note: The shaded bars represent those responses considered favorable to the device or concept being evaluated. Decimals represent multiple responses.

Figure 4-2. Voice Synthesizer Responses

On the basis of the foregoing, it is concluded that the Vosyn should be limited to short messages. It detracts from one of the prime advantages of Data Link, in that it seems to demand attention, while on the other hand the SMATC allows two people to communicate effectively without devoting full attention to each other at the same time. This characteristic, however, would be desirable for emergency or time-critical messages. The Vosyn is not recommended for routine ATC communications.

4.1.3 Vosyn With SMATC

There were five questions concerning the combined use of the SMATC and the Vosyn. Figure 4-3 shows the results of the questions.

Only 27 percent responding stated that synthetic speech should be restricted to takeoff and landing. A slightly higher percentage, 37, thought that this device complement provided too much redundant information. (See questions 1 and 2 on pages C-10 and C-11.) Two pilots independently found the combined use annoying on the heading, altitude, airspeed (HAS) messages. Apparently, the SMATC would first display the recalled HAS information; the Vosyn would then recite it with a slight delay as the SMATC was switched back to the original message by the crew member.

A large majority reported that it was not confusing to have the same ATC messages presented on both the SMATC and the Vosyn. (The response-time analysis, however, shows that this did significantly delay responses.) Several pilots commented that the duplication, although not confusing, was both irritating and unnecessary.

Only 26 percent considered the device duplication desirable. In the answers to the question there was a significant difference between the B-727 and DC-9 crews, and this is probably directly attributable to the higher Vosyn quality in the DC-9 simulator. Disregarding this unintended experimental variation, we would expect (on the basis of the DC-9 responses) 10 of 18 respondents, or 55 percent, to find the duplication desirable, as did the DC-9 crews.

It is noted that the comments in favor of the duplication frequently came from the crew that had been given the low-altitude go-around with only the SMATC device. In these and similar instances, the Vosyn served as an effective attention-getter.

A large majority, 84 percent, believed that the Vosyn could be most readily eliminated, with only 5 percent stating that the SMATC could be eliminated. The response did not vary significantly with the simulator used, indicating that the better audio quality of the Vosyn in the DC-9 did not affect the relative desirability of the SMATC and Vosyn.

No strong reactions were exhibited in the responses to questions on combined SMATC and Vosyn use. The predominant belief was that the duplication provided by the two devices was either undesirable or not clearly desirable. Given the choice of eliminating one of the two, the pilots strongly favored retaining the SMATC.

Questions	Answers	Percent Responding
Should synthetic speech be limited to when pilot's eyes are busiest (such as takeoff or landing) with a visual display otherwise?	Yes	10
	No	23
	No Opinion	4
Did some of the device complements provide too much redundant information?	Yes	14
	No	23
	No Opinion	1
Was it confusing to have the same ATC messages presented on both the SMATC and the Vosyn at the same time?	Yes	2
	No	31
	To Some Extent	5
Was the duplication in this complement desirable or unnecessary?	Desirable	10
	Unnecessary	14
	Neither	14
Which device could be most readily eliminated?	SMATC	2
	VOSYN	32
	Neither	4

Note: The shaded bars represent those responses considered favorable to the device or concept being evaluated. Decimals represent multiple responses.

Figure 4-3. SMATC and Vosyn Combined

The Vosyn was determined to be effective as an attention-getter during the busier phases of flight.

4.1.4 Printer

Questions were asked concerning the possible applications of the printer and the method of presenting and calling attention to information. Twelve percent believed that the printer should be restricted to long messages only, while 75 percent believed that it should not be so restricted. Comments on this question indicated the general desirability of printing all ATC clearances, ATIS information, company communications, and any other information requiring documentation. The printing of such perishable information as traffic advisories, HAS, etc., was not considered desirable.

When asked if abbreviations and/or symbols on the printer were desirable, flight engineers and pilots answered as follows:

Category	Flight Engineers	Pilots
Abbreviations	7	0
Symbols	1	0
Both	6	1
No Opinion	0	1
None	5	14

In the B-727, the respondents are primarily flight engineers, whereas they are pilots in the DC-9. The two groups responded quite differently. The pilots appeared to be almost unanimously opposed to abbreviations or symbols, while the flight engineers were agreeable to abbreviations, symbols, or both. As stated earlier, the printer operator in the DC-9, who was sometimes the flying officer, was generally much busier than the B-727 printer operator.

A time-tag was appended to all printer messages. A majority of respondents either believed that this time-tag had no value or had no opinion on it. Several pilots observed that the time-tag served no value during the flight although it might be needed later for record purposes.

Seventy percent of pilots stated that there should be a visual or aural alert to let the crew know of impending company messages. In this evaluation, no alert was provided other than the printer line-feed noise, which was relatively loud.

The majority of pilots believed that all messages, both company and ATC, should be displayed on the printer. The majority also felt that a distinction such as red and black ink for company and ATC messages, respectively, was sufficient, although several pointed out that red ink is invisible at night in a red-lighted cockpit, indicating that another color ink should be shown. However, the determination of night lighting acceptability was not among the evaluation objectives.

The printer location to the right side of the flight engineer's panel in the B-727 was considered satisfactory and convenient. The location on the DC-9, however, was considered generally unsatisfactory. It was observed that the printer should be accessible to both pilots in a two-man cockpit.

Because every communication was printed and then line-fed out of the printer, severe paper-management problems arose on all flights. One method of remedying this situation would be for the printer to print only a loose copy of requested messages, which could then be torn off and accumulated on the pilots' chart boards.

The use of a printer appeared to be quite desirable. Crews found it especially useful for the longer messages, such as ATC clearances, ATIS information, and some company traffic. The use of the printer on shorter, more perishable information did not seem desirable.

It should be noted that several airlines have conducted flight evaluations of printers that might be used for company communications. They have generally concluded that a page printer is preferable to a line printer because of the potential volume of material that might be printed.

Restriction of printer access to the second officer (flight engineer) is satisfactory in a three-crew-member aircraft. In a two-crew-member aircraft, however, the printer must be accessible to both crewmen since the aircraft is routinely flown from either position.

4.1.5 Control and Downlink Unit

Only one of 35 pilots reported that he was left-handed. The great majority (30 pilots) indicated, however, that left-handed keying from the copilot's side posed no difficulty.

One pilot observed that entering letters on the CDU by the left-center-right method was tedious. Downlink messages entered were typically three to five characters in length. Longer messages could be expected to generate more comments.

Another thought that dedicated function buttons and numbers could handle 95 percent of all messages that the crew would want to send to the ground. The remainder, he suggested, could be handled by voice.

4.1.6 General Considerations

General questions were asked concerning the various features that were or could be provided by a Data Link system and the overall impact of the Data Link concept on flight operations.

Questions about the features included the AUTOTUNE concept, in which certain on-board equipment was tuned upon ground command; the provision of heading, altitude, airspeed (HAS) data; acquisition of voice channels; and alerting to uplink information.

Figure 4-4 shows the pilot reaction to some of the features provided. Opinion was heavily in favor of having the AUTOTUNE device automatically set the voice and data communications transceivers. Somewhat surprisingly, opinion was almost as heavily against the use of AUTOTUNE to set or tune any other instrument or radio. Those who responded positively to this question indicated that transponder codes and company radio frequencies could be automatically set. Several pilots suggested that navigation frequencies should be set, but several others seemed strongly opposed to this.

There was mixed and indifferent reaction to the question of setting the altitude alert or heading and speed bugs. A large majority of pilots found that the audio alert prior to each message was helpful (see Appendix C).

Most pilots thought that the HAS recall capability was useful even though they may have set their heading bug and altitude alert. An HAS recall capability using the SMATC was strongly favored over a recall capability with the Vosyn or a SMATC display dedicated to HAS only. When questioned about the usefulness of the STANDBY button in responding to uplink messages, 38 percent reported that it was useful, while 45 percent had no opinion and presumably had not considered using it in any of their trials.

Sixty percent thought the message-store capability was desirable even though the HAS capability was provided. Others did not consider it necessary as long as the printer collected long messages such as clearances.

Several questions asked concerned the overall impact of Data Link on flight-crew operations. Figure 4-5 shows the responses to some of these. As can be observed from the response to the first question, only three percent of pilots thought that no valuable information was lost. Obviously, information is lost, but how valuable it is cannot be determined from the question. For this reason this question was expanded somewhat in the supplemental questionnaire, which will be described in Section 4.3.

The loss of data results from the assumed selective-address capability of Data Link, such that only one aircraft receives or transmits the ground-air or air-ground messages intended for it. Although this provides a large benefit in communications efficiency, it seems to pose one of the major liabilities of the Data Link concept.

Comments provided by pilots regarding the loss of common-channel voice communications may be reviewed in Appendix C. Simply stated, many pilots view their own mental air-traffic-situation analysis as a necessary part of safe and reliable air traffic control. For instance, many pilots can refer to instances in which they detected potentially dangerous ATC errors that might otherwise have gone undetected. A pilot's decision to accept an ATC clearance is often based on his knowledge of the proximity of other aircraft. This topic is explored further in the discussion of the supplemental questionnaire (Section 4.3).

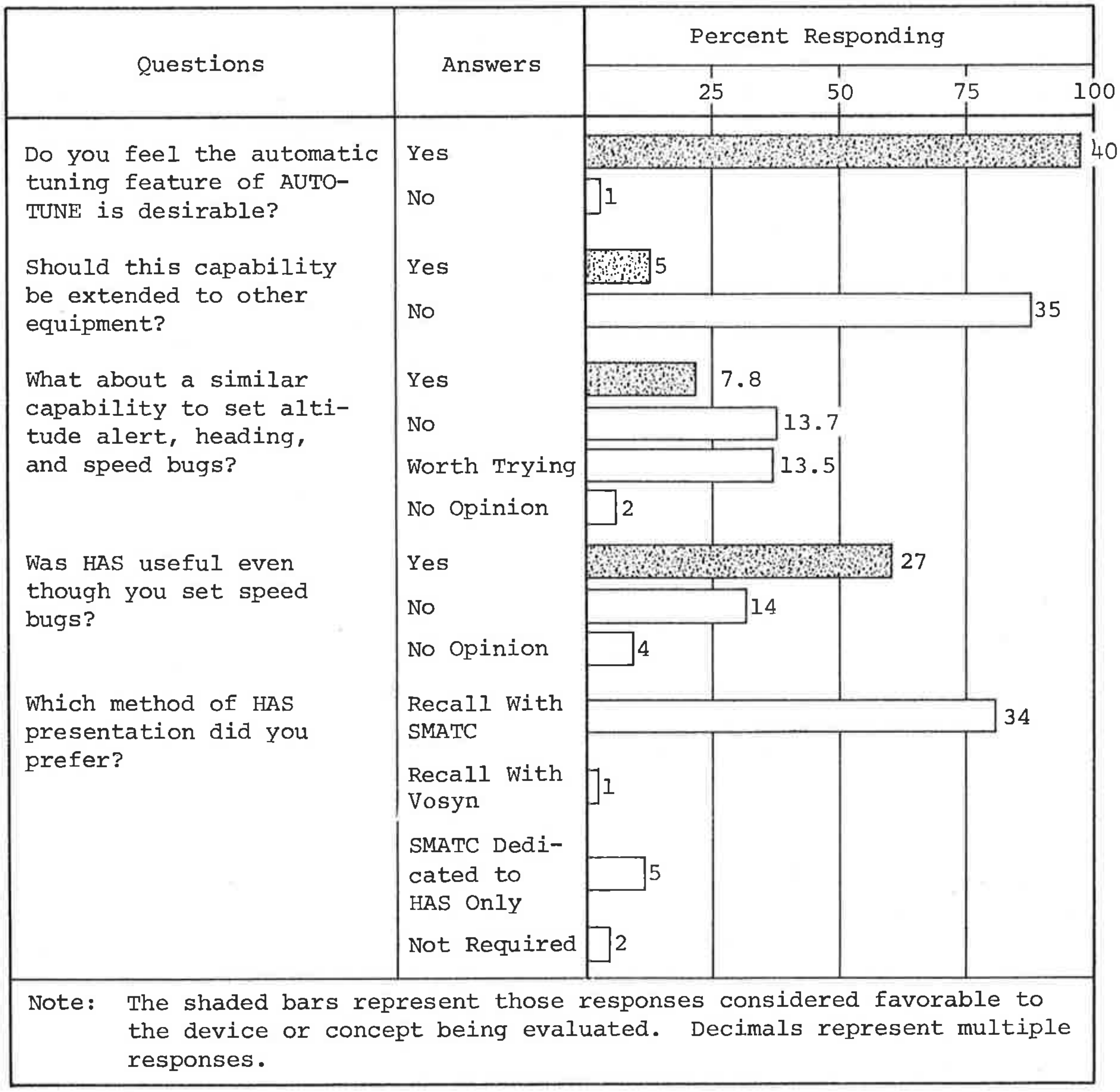
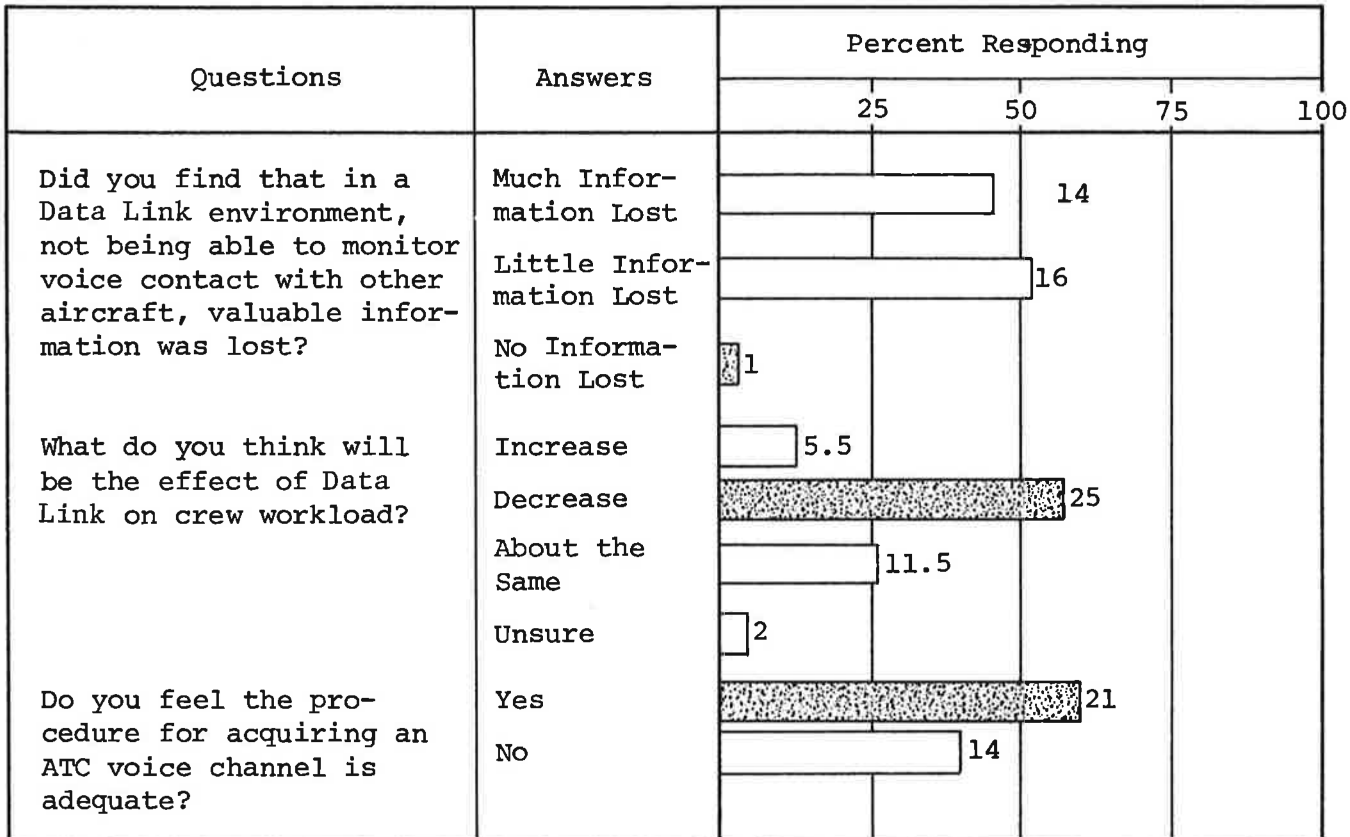


Figure 4-4. Desirability of Data Link Features



Note: The shaded bars represent those responses considered favorable to the device or concept being evaluated. Decimals represent multiple responses.

Figure 4-5. Impact of Data Link

The majority of pilots believed that Data Link would reduce crew workload. This view was taken not strictly with respect to air-ground-air communications but also with respect to other crew duties. As one pilot commented, "The lack of constant talk format over the radios allowed the crew to perform check lists and other command type duties."

Sixty percent of pilots viewed the procedure for obtaining a voice channel as adequate. The comments received on this question, however, indicated some confusion over the availability of voice ATC channels as well as the procedure to obtain one. The briefing instructions pointed out that an open channel, or "hot" mike, to ATC was always available. Further, if pilots responded UNABLE to a message, the ATC controller would always inquire over this channel. The Request Voice (REQ VOICE) button on the CDU, it was explained, was to be used only for acquiring a company voice channel.

Apparently these potentially confusing instructions were either misstated or misunderstood in several cases: numerous critical comments were received from crews about having to push a button in order to talk with their controller. These comments stress the importance pilots place on having instantaneous voice contact with the controller, independent of a Data Link system.

Invariably the pilots seemed displeased with the idea of data-polled voice-channel acquisition. This is viewed as a second potential liability in the implementation of a Data Link. Since this was not a variable designed into the experiment, no measure of its significance is attempted. Nevertheless, the strength of the comments offered indicated that this aspect should be given careful study in the design of an air-ground Data Link system.

A third potential liability in Data Link implementation arose, also through the comments received rather than through specific questions on the attributes of Data Link. Numerous comments indicated a high reluctance to accept or trust Data-Link during ground-proximate flight phases, including local control, approach, and departure. Not only did pilots feel that the visual presentation of messages while the aircraft is flying close to the ground could be distracting; they were wary of the Data Link in such circumstances. There seems to be a certain reassurance in talking to a human on the other end of the circuit, and not to a computer responding to buttons pushed by a human.

This subject is further explored in the supplemental questionnaire.

On the basis of the foregoing, it is concluded that the AUTOTUNE feature, in which the communications frequencies were automatically selected, was highly desirable. The idea of extending this automatic ground control to any other device with the possible exception of the transponder was equally undesirable. Also, the selective-address capability of the Data Link, in which each aircraft received only transmissions intended for it, caused a loss of information that pilots believe to be essential. Airline pilots generally were not in favor of a system that would require them to wait in a queue for data-polled acquisition of an ATC voice channel. Also, the concept of Data Link control was somewhat disliked during ground-proximate flight phases, including local control, arrival, and departure.

4.2 OBSERVER COMMENTS

A trained observer accompanied the crew on each of the 54 evaluation tests. The four different observers used had varying amounts of flight experience, but as a minimum all were instrument-rated pilots with considerable experience in large-jet in-flight crew observation.

4.2.1 Role of the Observer

The observer had three main functions to perform:

- Assist the crew in flying the scenario
- Coordinate test conduct with other test personnel
- Observe crew functioning in the Data Link environment

The observer was usually the crew briefer. His first 20 minutes in the cockpit would involve illustrating points discussed in the briefing. He would conduct the experimental familiarization run, assist the crew in assembling charts, explain simulator equipment or procedures to pilots unfamiliar with them, and be alert for areas of crew confusion in order to keep the test running smoothly.

As explained previously, conduct of the test was a precise coordination exercise that required the test minicomputer operator to know when to release messages. The test observer in the cockpit would perform this coordination. In addition, he would initialize the simulator at the beginning of every trial with the appropriate location, environment, and visual system parameters.

His third function in the cockpit was to observe crew performance under the Data Link concept. He noted crew errors and areas of crew confusion caused by the Data Link, and he recorded significant crew comments that otherwise might not be recorded. It was unfortunate, but necessary, that this be his lowest-priority function. Nevertheless, the compilation of observer comments has produced significant information on Data Link concepts and procedures.

4.2.2 Recorded Observations

Observer comments were collected primarily during the conduct of the three trials, but in several instances additional comments resulted from discussions during the debriefing. For presentation here, they have been subdivided into the following general classifications:

- General Observations
- Data-Link Concepts
- SMATC Display
- Vosyn Device
- Combined SMATC with Vosyn
- CDU
- Printer

4.2.2.1 General Observations - As a general observation, the crews were usually quite rushed. Under optimum conditions the three tests and familiarization runs could barely be accomplished in the four hours allotted. Any simulator or test equipment problem, any delay in obtaining use of the simulator, or even a long coffee break would cause the schedule to be delayed. The observer controlled the amount of simulated tailwind to keep scenarios on schedule. Usually 100 knots or more was used during en route phases of flight.

This rushing seemed to create crew frustration and annoyance in several instances. It is hoped that this did not bias them against the Data Link concept or specific equipments. As a positive benefit, this pressure provided an atmosphere more conducive to mistakes and, consequently, a more rigorous test.

Crew mistakes occurred fairly consistently. These were largely the result of planned irregularities in the scenario. For instance, one message instructed the crew to "squawk 8626." It was thought that this message would require the crew to respond UNABLE since the transponder head does not provide codes above 7777. The "dummy" head in both simulators, however, went as high as 9999. All crews set in the 8626 code, although some questioned it. The Los Angeles (LAX) ATIS told the crews to expect Runway 24L; yet they were cleared to Runway 25L for their approach. At least one crew commenced approach to the wrong runway.

A few ARINC Research script errors were pointed out by crews. For instance, we used an Expect Approach Clearance (EAC) instruction, where technically we should have used Expect Further Clearance (EFC) in assigning a holding pattern.

Along with the time constraints, some crews' lack of familiarity with the scenario geography caused confusion. This was compounded in several instances by a lack of familiarity on the part of some guest pilots with the exact instrument configuration of the aircraft simulated. Also, the ready-for-takeoff assumption and the lack of a TAKEOFF request button confused some crews since this procedure is not used at all air-carrier airports.

Overall, no adverse performance was observed that could be attributed to the Data Link.

4.2.2.2 Data Link Concept - The loss of information from the aircraft ahead regarding holding, approaches, descent instructions, and weather was frequently commented upon. One pilot commented that if "exception" type information from the aircraft ahead was available on a common voice channel, this loss might be tolerable.

Many pilots were critical of the use of Data Link below approximately 2,000 feet above ground level. One volunteer captain commented, "From clearance to takeoff until above 2000 and from clearance to land until turning off the runway I am too busy trying to keep from killing myself to push buttons."

4.2.2.3 SMATC Display - The SMATC seemed to distract pilots during low-altitude phases of flight and could be dangerous under certain circumstances.

The use of SMATC for emergency or critical communications appeared to be inadvisable since it did not command attention. This was the reaction of several pilots.

Pilots were quite pleased with the SMATC display of recalled HAS information.

4.2.2.4 Vosyn Device - Many printer verifications were required for Vosyn-only messages, especially long ones. In the case of ATIS, it had to be either repeated or confirmed by the printer with regularity.

One pilot, confusing a VOR radial intercept instruction going into Los Angeles, stated that he would not have misinterpreted the same instruction on the SMATC. (The reason for this comment is not known.)

Several informal remarks indicated that the Vosyn might be desirable for emergency or critical messages.

The imagined or simulated cockpit air noise at 300 knots in addition to the poor-quality audio in the B-727 simulator seemed to make the Vosyn undesirable for routine communications.

"Expedite through 190" was misinterpreted at least twice as "Expedite through 150."

4.2.2.5 Vosyn with SMATC - When the devices were used in combination, low-altitude critical messages such as "go around" were observed often by Vosyn and not by SMATC presentation. The SMATC was generally favored for routine communications.

Vosyn HAS recall was disregarded when SMATC HAS recall was available.

4.2.2.6 CDU - Several crews indicated a desire for a CDU capability that would "REQUEST 10 mile DME LEG" when a holding pattern was assigned.

The CDU seemed somewhat complex and confusing, and different pilots made suggestions for simplifying it, primarily by combining or eliminating buttons.

The crews experimented with the CDU at cruising altitude although they frequently complained of excessive button pushing at lower altitudes and described a feeling of being boxed in by its use on these occasions. The pilot report message suggested as a result of turbulence, "PI MODURB 250, SEND," required an average of 43 seconds to generate (based on speed-of-entry data described in Section 5).

The use of ambiguous codes such as LT for altitude seemed to annoy pilots, and one commented on his reluctance to use the control column switch instead of the CDU WILCO button while this button was flashing. Others indicated that on final approach, a control column WILCO capability was preferable.

4.2.2.7 Printer - The DC-9 printer location was poor in that only the right-seat pilot could access it. In general, the DC-9 pilots would not notice the company messages, which appeared only on the printer and without aural alert.

4.3 SUPPLEMENTAL QUESTIONNAIRE

A supplemental questionnaire was mailed to 44 test subjects on 31 March 1975. Its purpose was to obtain further clarification of several aspects that were somewhat ambiguous as a result of the first questionnaire and to achieve an overall ranking of Data Link type systems as compared with conventional voice. The response to the questionnaire was excellent, with 38 pilots (86 percent) responding. The three- and four-month lapse periods provided the DC-9 and B-727 crews, respectively, is considered beneficial. It allowed the crews to reflect on their simulated experience with Data Link and form more carefully considered opinions than they probably would have formed if the questions had been asked immediately following their evaluation flights.

The supplemental questionnaire and a compilation of responses and comments are presented in Appendix D.

4.3.1 Ranking of Options

The crews were asked to consider air traffic control by the following means:

- Conventional Voice
- SMATC Display
- Synthetic Voice

They were requested to rank them 1, 2, or 3 from most desirable to least desirable for the six different phases of flight:

- Ground Control - Ground movement on other than the active runway
- Local Control - Takeoff clearance through 2,000 feet and landing clearance through active runway turnoff
- Departure - Radar-controlled departure, typically through 5,000 feet but often as high as 15,000 feet
- Low En Route - Radar control from departure handoff through approximately 18,000 feet
- High En Route - Above 18,000 feet
- Arrival - Radar control from low en-route handoff until cleared for final approach and handoff to local control.

Figure 4-6 shows the results of a weighted tabulation of the answers. Arbitrarily the first choice was weighted 2; the second choice 1; and the third choice 0, since it was probably selected as a default option of the other two. A different weighting would have yielded similar rankings.

The SMATC is shown to be ranked first choice in the ground phase and conventional voice second. Conventional voice is a clear first choice in the local phase, followed by SMATC.

Conventional voice and SMATC are equally ranked for both the arrival and departure phases, with SMATC emerging as a clear first choice in both the low- and high-en-route phases of flight.

Examination of the individual responses for both simulators shows that the conventional voice was chosen in both arrival and departure phases in the DC-9, while the SMATC was chosen in both arrival and departure phases in the B-727. The differences in the rankings of these two phases between the simulators was not overwhelming, and no explanation will be offered in this report.

4.3.2 Effect of Better Vosyn

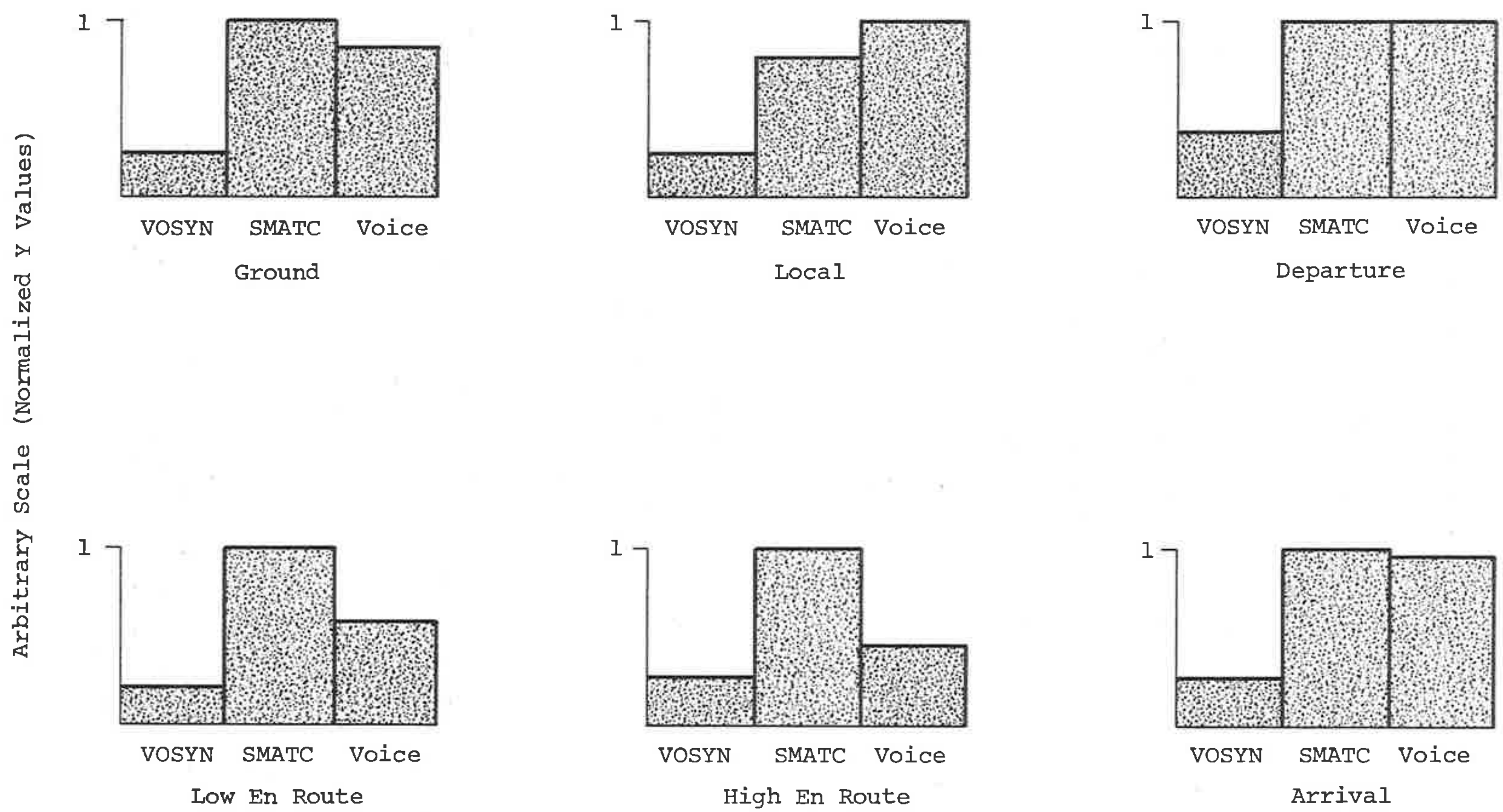
The opinion about the effect of a better quality of synthetic voice on the overall ranking was evenly split, with 48 percent stating that they would have answered differently and 52 percent stating that this would have no effect.

Those who answered "yes" could be placed in different categories. Several would have exchanged the Vosyn with the SMATC in the ground, local, arrival, and departure phases. Several who had chosen SMATC first in a given phase would have moved Vosyn up to second choice. It appears from their comments that the major effect, if any, of improved synthetic voice would be a redistribution of the second and third choices; it does not appear that the first choice would be altered. Nevertheless, as several pilots commented, the improved synthetic voice would have to be re-evaluated for an accurate answer.

4.3.3 Loss of Essential Information

The original questionnaire queried the crews as to whether information they considered valuable was lost by their not being able to monitor voice communications of ATC with other aircraft. Although the majority concluded that little information was lost, only three percent concluded that this lost information was not valuable. To clarify the result of that question, a supplemental question was asked. Figure 4-7 shows the supplemental question and a tabulation of its responses.

We chose the categories of flight safety and flight comfort or convenience in which to describe the effect of information loss. We thought that this information could consist basically of en route weather advisory or phenomena, the relative position of other aircraft, or terminal-area routing information.



Computation Method

$$Y = \{ 2 \times (\text{Number of times ranked first}) + 1 \times (\text{Number of times ranked second}) \} / \text{Total}$$

Figure 4-6. Desirability of Data Link Options

Question

Was the information lost by not being able to monitor voice communications with limited number of aircraft on the same frequency essential to flight safety or to comfort and convenience?

Type of Communication	Answers	Percent Responding
Flight Safety		
Weather Advisory	Yes	14
	No	18
Position of Other Aircraft	Yes	37
	No	7
Terminal Area Routing Information	Yes	22
	No	17
Comfort or Convenience		
Weather Advisory	Yes	25
	No	8
Position of Other Aircraft	Yes	13
	No	17
Terminal Area Routing Information	Yes	18
	No	12

Note: The shaded bars represent those responses considered favorable to the device or concept being evaluated. Decimals represent multiple responses.

Figure 4-7. Impact of No Common-Channel Voice Communications

In the consideration of flight safety, a clear majority of pilots are concerned about the position of other aircraft and the rare instances in which they feel that two aircraft might otherwise be cleared to the same airspace were it not for crew intervention. Weather advisory and terminal-area routing were each listed by about 50 percent of pilots as information loss affecting the safety of flight.

In the area of flight comfort or convenience, a clear majority of pilots considered the loss of weather advisory information significant. More than 60 percent related terminal-area routing information to flight comfort or convenience. Knowledge of position of other aircraft was not considered essential to flight comfort or convenience.

It might be unexpected that a majority of pilots considered weather advisory and terminal-area routing information essential to comfort and convenience. It should be kept in mind that the captain's decision on the use of the "Seat Belt" sign may often be influenced by a knowledge of "what's up ahead" and that the schedule for meal and beverage service is often influenced by the arrival schedule anticipated by the crew.

To summarize the results of this question, a majority of pilots believe that information essential to flight safety (relative position of other aircraft) and information essential to flight comfort or convenience (weather advisory and terminal-area routing information) is lost as a result of their inability to monitor VHF communications with other aircraft.

Pilots were asked to comment on what would be required to replace the lost information. The comments (see Appendix D) are well formulated, and it is recommend that the reader review them. Pilots suggested that a device which would let them know the locations of nearby aircraft would give them the information they might lose. In the case of weather information, an acceptable substitute for common-channel voice appears to be "by exception" reporting of weather anomalies on an open channel. The type of information desired is not synoptic, forecast, or station weather (they currently have these). It is specified (Pilot Report, or PIREP) information such as "Moderate Chop - 40 SW JOLIET, B727". This information is extremely perishable in the case of aircraft traveling at 480 knots with as little as five miles' separation.

These comments indicate an apparent operational requirement for the continuation of conventional style voice communications to some extent to supplement the Data Link environment. Voice is required for pilot-controller discussions. Voice is also needed to distribute weather advisories (on turbulence, thunderstorm detour paths, icing, etc.) and for occasional air-to-air communications of this nature. Perhaps certain abbreviated voice procedures can supplement Data Link to overcome the feeling of isolation expressed by some pilots during a pure Data Link operation and to provide some of the clues on traffic flow and congestion available today.

4.3.4 Effect of Computer Conflict Prediction on the Loss of Essential Information

The pilots were asked whether the presumption of computer conflict-prediction backup (i.e., a system free from human error) would have affected their answer on the loss of essential information. The majority answered "no." One "yes" answer was qualified by the statement that weather information would be needed.

4.3.5 Rank of Most Desirable Features

In the ranking of the most desirable features that could be provided by Data Link, a criterion for weighting was applied. Choice number 1 was weighted with a value of 5; choices 2 through 4 were weighted with decreasing values; and choice 5 was weighted with a value of 1. The result is shown in Figure 4-8.

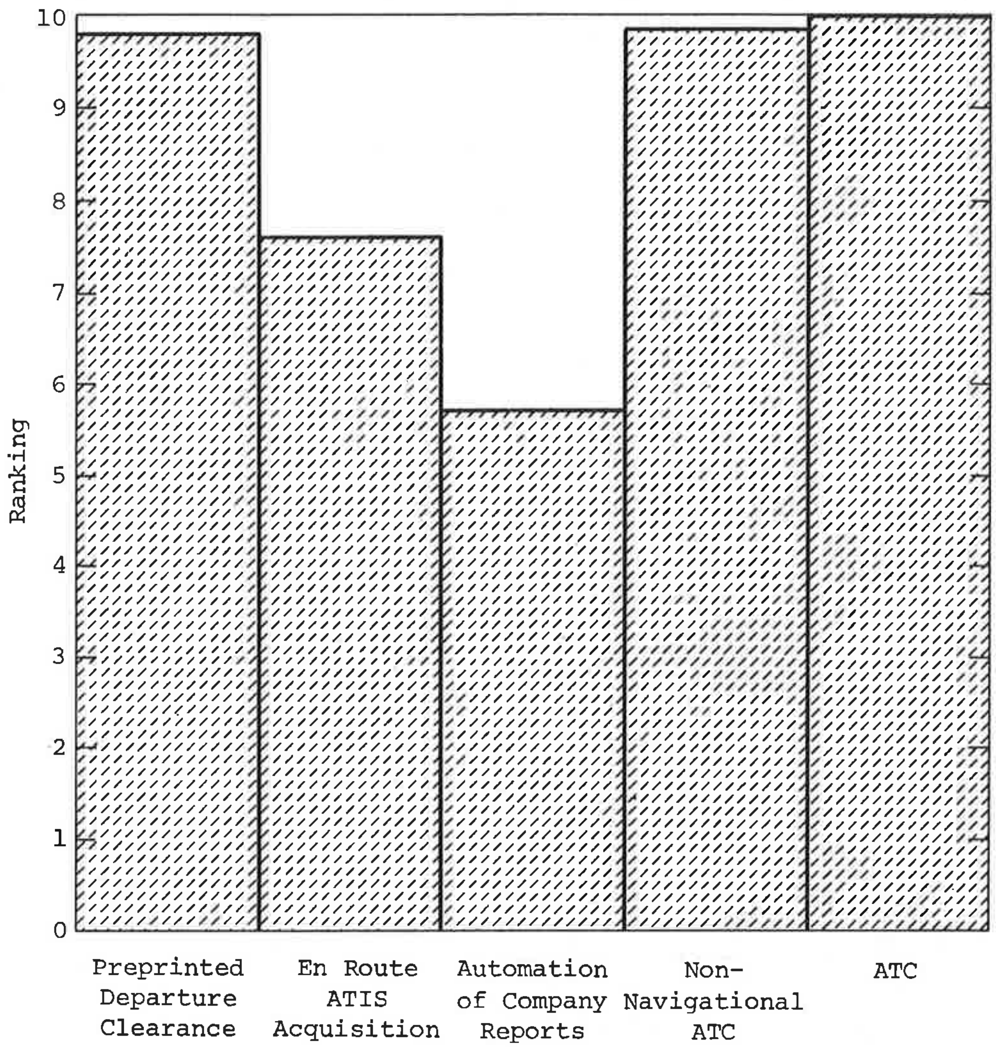


Figure 4-8. Relative Desirability of Data Link Features

On the weighted basis, the relative desirabilities of Data Link features were determined to be the following:

1. Data Link presentation of ATC commands
2. Data Link presentation of non-navigational ATC commands (e.g., a transponder code change)
3. Preprinted departure clearances
4. Acquisition of en route ATIS information
5. Automation of company reports

Other items mentioned as desirable included the elimination of voice congestion (mentioned frequently), maintenance-data transmission (telemetry), minimum-safe-altitude warning, and collision-avoidance system (CAS).

4.4 TREATMENT OF AIRLINE COMPANY COMMUNICATIONS

Although the evaluation was concerned primarily with ATC communications, company communications were included in the evaluations in order to make the flights more realistic and to ensure that any workload associated with company data communications would be included in the overall operations.

In the DC-9 simulator the pilots utilized the standard CDU for company communications. This was not feasible in the B-727, since the second officer (who is responsible for company communications in a three-man crew) could not reach the CDU, which was mounted where the radar indicator is normally mounted in the forward pedestal in front of the throttles.

4.4.1 Present-Day Messages

The routine company communications messages used in present-day operations were used in the scenarios for the simulations. Departure reports, weight manifest checks (B-727 only), off reports, arrival reports, revised estimated times, and gate assignments were sent via Data Link. Since these six message categories account for more than 75 percent of all company communications, pretext function buttons were provided for these functions. These messages were sent on every flight. The exact message varies from company to company. Normal United Airlines and Trans World Airlines procedures were used for the B-727 and DC-9, respectively.

With the present voice procedures, considerable time is wasted while the attention of the officer conducting company communications is directed toward voice communications. In addition to the initial callup, he must often wait while the ARINC operator completes communications with another aircraft. Sometimes the operator does not respond to the first call. Repeats are sometimes required to ensure that the message has been received properly. This is particularly true where free-text messages such as maintenance messages (airplane condition reports) are communicated, because the difficulty of the terminology often requires readbacks.

4.4.2 Variations in Assumed Level of Automation

There is a difference of opinion in airline circles as to the degree of automation that should be attempted in communicating with Data Link. This difference is due to varying assessments of what will be acceptable operationally to the pilots on the one hand and what can be cost/benefit-justified by management on the other. Some seek *complete* automation of OUT, OFF, ON, and IN (OOOI) reports, for instance, in order to reduce flight-crew workload. Others believe that the complexity and cost involved in achieving this degree of automation cannot be justified.

Similarly, the degree of automation that will be available on the ground is open to a good deal of conjecture. Data Link may ultimately provide direct access into airline flight planning, reservations, and operational control computers. It may be used to access trunked voice channels, providing dial-type access to many airline offices. Initially, Data Link will probably allow limited messages to be sent directly into the ARINC ESS (Electronic Switching System) message-delivery system for all airlines to utilize as they do today, depending on the individual airlines' degree of computerization.

4.4.3 Difficulties in Locating CDU Accessible for Company Communications

A completely separate additional data terminal was provided for the second officer to use for company communications on the B-727. This was necessary because the B-727 second officer could not reach the CDU located ahead of the throttles.

Several other approaches were rejected before this approach was selected. Relocating the CDU to a location where all three pilots could operate it was considered impractical without modifying the simulator to such an extent that it would be useless for regular flight training. The possibility of building and installing a second CDU was investigated, but this approach was rejected because of the expense and schedule constraints involved. Building a special-purpose panel for company communications was rejected for the same reason. Finally, it was decided that a completely isolated terminal operating independently with a similar terminal outside the simulator should be employed. Two manufacturers who build data communications terminals used in the land mobile radio service supplied hardware for the company communications portion of the tests. Each manufacturer's terminal was used during a portion of the tests.

4.4.4 Second Officer's Company Communications Terminal

The terminals used in the B-727 consisted of full alphanumeric keyboards with LED-type character displays. A terminal was mounted to the right side of the second officer's station at the same height as his table. Uplink messages could be sent to the terminal and the cockpit printer. The cockpit printer used was the same one supplied by TSC for ATC communications, although company messages appeared in red in order to distinguish them from ATC messages.

One type of terminal was connected to a minicomputer, which automatically supplied responses from a computer data file when function buttons on the cockpit terminal were depressed, querying the data file. The software for this feature was programmed for a land mobile radio application since there was insufficient time before the tests to change the software for the specialized airline company communications application. Nevertheless, this inquiry-response feature seemed to offer great potential and could be incorporated into the ground computer as requirements develop.

Some experimentation was performed on some flights to utilize these data terminals for other company communications needs. In some instances free-form Data Link messages were sent to maintenance and dispatch. The equipment was also used to simulate "CALSEL", the automatic assignment of a trunked voice channel and automatic connection to the proper ground office. This simulation functioned as follows: The pilot would enter "SFODD" or "ORDMM" (UA mnemonics for San Francisco Dispatch or Chicago Line Maintenance) as the function he desired to speak with. The ground computer would automatically make the telephone connection to that office and assign and connect an available voice channel. The frequency of this channel would be sent back to the flight-crew cockpit data terminal as "130.6 go ahead." The pilot would manually retune his regular company radio to that frequency and converse by voice, returning to the data channel when finished. Similarly, a "SELCAL" from the ground displayed the frequency to be used and identified the caller.

4.4.5 Conclusions on Airline Company Communications

On each of the three flights for every crew, a varying level of automation was assumed for the OOOI reports. At the one extreme, as many as 16 button depressions were required to enter the station identifier, out time, off time, and fuel weights (requiring an average of 46 seconds). At the other extreme, the pushing of one button automatically caused all these variables to be transmitted.

As could be expected, the crews preferred the most automated case, which required the least button-pushing. However, crew reaction did not seem to be strongly for or against any of the three assumed levels demonstrated.

The use of a data terminal by the second officer in the B-727 for company communications during this simulation appeared both feasible and practical. Although complete automation of OOOI is most desirable, some manual entry by the second officer appears acceptable. The second officer's workload, when he is using a data terminal, although somewhat changed in nature, appears comparable to present voice procedures. While the pilot must enter data, he can do so at his leisure. Once the entry has been made, he can forget about it and be assured that the data will be properly communicated.

5. QUANTATIVE DATA ANALYSIS

Quantitative data collected during this evaluation consisted of response times to uplink messages and time-logged records of events such as crew-initiated downlink messages.

In this evaluation, as in previous I/O device evaluations, the response times to messages have been used as a measure of the "goodness" of various displays or complements. If it can be assumed that the crews do not respond until they comprehend the message but do respond as rapidly as they comprehend it, then the response time does provide a measure of the communications efficiency of each display or complement. Since the crew was briefed to respond accordingly and since the previously described experimental design was rigorously adhered to, response times are thought to provide a good indicator of communications performance.

The records of events other than response times may be used to determine the relative usefulness of various features provided by Data Link. In addition, crew input errors and practice effects in the use of the CDU can be analyzed. This is, in effect, an evaluation of the Control and Display Unit (CDU) since all events other than response times must be initiated from the CDU.

5.1 EFFECTS OF INFLUENCING FACTORS

The effects of several factors on response times can be examined from the evaluation results. Interactions among these factors can also be examined. The following factors are of interest:

- Device complements
- Simulators
- Scenarios
- Phase of flight
- Practice effects
- Turbulence effects

- Lighting effects
- Crew effects

It was anticipated in our experimental design that Analysis of Variance (ANOVA) could be used to look for significant differences within and among these factors.

ANOVA is a statistical technique that permits the simultaneous study of the effects of several factors. In essence, a test is made of the null hypothesis that there is no difference in the expected values of several populations (e.g., the populations of all SMATC, Vosyn, and all SMATC with Vosyn response times). Observed differences in samples are tested to determine whether they are true differences or random variations due to noise in the data. The use of this technique presumes normally distributed data and similar variances for each population.

The mathematical treatment of an ANOVA of an eight-factor experiment is quite complex. It was decided, therefore, to conduct an ANOVA based initially on four factors -- Simulators, Scenarios, Complements, and Phase of Flight. These were thought to be probably the most significant factors. The results could be used to determine how best to treat the remaining four factors.

It was anticipated that response times would probably be either normally or log-normally distributed. It was decided to test both distribution assumptions in the ANOVA. Further, it was observed upon examination of response data that while the SMATC had a characteristically quick response time, there were several outlying values (some more than 200 seconds). These outlying values could generally be attributed to periods of known crew confusion (as determined by the observer's notes) or to inadequate crew briefing. The ANOVA, assuming log-normally distributed data, was conducted using only values of less than 30 seconds (96 percent of the data). This log-normal analysis was not conducted for all values, because of the distortion that could have been introduced by truncating the longer times.

The test was conducted at the 0.01 (1 percent) level of significance in order to avoid making overstatements from the data. The results of the ANOVA are shown in Table 5-1.

The last four significant effects observed in the log-normal analysis represent the interactions of the factors shown with either the Phase Factor or Complement Factor. Scenario by Phase, for example, indicates that different combinations of Scenarios and Phases probably have different means. Because of their complexity, no attempt was made to explain these effects. It should be noted, however, that even in the ANOVA of the log-normal distribution, Complements and Phases were by far the most significant in terms of sample differences.

TABLE 5-1. SIGNIFICANT EFFECTS DUE TO FACTORS AFFECTING RESPONSE

Distribution	Values Included	Observed (0.01 Level) Significant Differences
Normal	All	• Complements • Phase
Normal	Less than 30 seconds	• Complements
Log-Normal	Less than 30 seconds	• Complements • Phase • Scenarios by phase • Simulator by scenarios by complement • Simulator by scenario by phase • Simulator by complement by phase

It can be safely stated, on the basis of the analysis described above, that there are significant differences in the population response times of the three complements -- SMATC, Vosyn, and SMATC with Vosyn -- and in the three phases of flight considered -- departure, en route, and arrival.

No significant differences were observed in the sample means of the two simulators or in any of the three scenarios tested.

Table 5-2 is a tabulation of average response times and standard deviations by simulator, scenario, phase, and complement. It is based on all 2471 response-time values, and it repeats the tabulation based on the 2356 values that are less than 30 seconds. Table 5-3 classifies the 115 excluded values of 30 seconds or longer by phase of flight, simulator complement, and scenario. The values appear to be uniformly distributed among these factors.

Generally the first message of every trial had an abnormally long response time because of crew unfamiliarity (the crew usually had to be prompted to respond to the first message). One crew had abnormally large response time on almost all messages in one scenario, indicating an inadequate briefing. One crew completely alien to the geographic scenario had two long response times, 169.8 and 238 seconds, during their SMATC trial. The exclusion of these two times alone reduces the overall SMATC sample response average time by one-half second. For the reasons cited, the exclusion of outlying values of 30 seconds or greater does not seem unreasonable in an attempt to determine the true characteristics of each factor.

TABLE 5-2. MEAN VALUE AND STANDARD DEVIATIONS OF RESPONSE TIMES BY FACTOR

Factor			All Values (Seconds)		Values Less Than 30 (Seconds)	
			Mean	Standard Deviation	Mean	Standard Deviation
Simulator:	1.	B-727	8.49	8.51	7.21	5.00
	2.	DC-9	9.47	12.7	7.27	5.58
Scenario:	1.	SFO-LAX	9.27	9.64	7.49	5.53
	2.	MCI-ORD	8.58	9.40	6.97	5.03
	3.	LAX-SFO	9.04	12.7	7.25	5.27
Complement:	1.	SMATC	8.06	13.1	6.30	5.11
	2.	VOSYN	10.6	9.82	8.69	5.41
	3.	Both	8.26	8.76	6.75	5.03
Phase:	1.	Departure	10.3	14.2	7.66	5.66
	2.	En Route	9.13	9.17	7.52	5.89
	3.	Arrival	7.96	7.73	6.89	4.85

TABLE 5-3. DISTRIBUTION OF RESPONSE TIMES OF 30 SECONDS OR LONGER

Factor	Occurrences by Simulator	
	B-727	DC-9
Scenario		
1 SFO-LAX	15	28
2 MCI-ORD	14	20
3 LAX-SFO	17	21
Complement		
1 SMAT	8	23
2 VOSYN	19	28
3 Both	19	18
Phase		
1 Departure	21	38
2*En Route	5	9
3 Arrival	20	22

*Phase 2 has approximately one-quarter the messages of other phases.

A histogram of the total sample of 2,471 response times is presented in Figure 5-1. This histogram shows a distribution that builds rapidly and has a long trailing tail. The overall mean of this distribution is 8.97 seconds, with a standard deviation of 10.8 seconds. Approximately 96 percent of all values are less than 30 seconds.

A visual inspection of the distribution of response times indicates that it may be more of a log-normal than normal distribution. A plot of the Cumulative Probability Distribution drawn on logaritimic probability paper yielded a piecewise linear composite of three straight lines. This indicates that the plot of Figure 5-1 may be a composite of separate distributions.

Since the ANOVA showed Device Complement and Phase of Flight to be the significant factors, the distributions of response times among these factors were separately examined.

Figure 5-2 presents the histograms of response-time distributions for each of the three complements. The three distributions are distinct, with the SMATC having a smaller mean than the Vosyn. The combined complement of the SMATC and the Vosyn has bimodal distribution, which shows some characteristics of both individual distributions.

It can be inferred from Figure 5-2 that in the combined SMATC/Vosyn trials the responding crew members are responding to the SMATC in some instances and to the Vosyn in others. A certain amount of this effect can be expected since long messages such as pre-departure clearances, ATIS, or weather were never presented on the SMATC but were presented on the Vosyn. The number of such occurrences, however, is quite small (on the order of 3 out of 50 messages per flight). The delayed peak in the SMATC/ Vosyn distribution is higher than the first peak, indicating that pilots are responding more often upon message completion by the VOSYN than by the SMATC when both messages are presented.

The apparent effect displayed in the complement with both the SMATC and Vosyn is that the crews are attempting to verify or cross-check one source of information against the other when both are presented. Analogously, anyone who has tried to read a passage while the same passage is being read to him by someone else can appreciate the delay caused by trying to follow information presented simultaneously in the visual and aural modes.

Figure 5-3 shows the distribution of all response times as a function of flight phase. Phase 2, the en route phase, is a relatively low-workload period, which shows the pronounced effect of the visual and aural peaks. The crew is verifying the visual source with the aural source before replying. Phases 1 and 3 on the other hand are high-workload phases. The two distinct peaks tend to converge toward one. The increased crew workload tends to delay crew response to the visual display, while the need for quick action by the crew tends to make them respond before the aural presentation is completed.

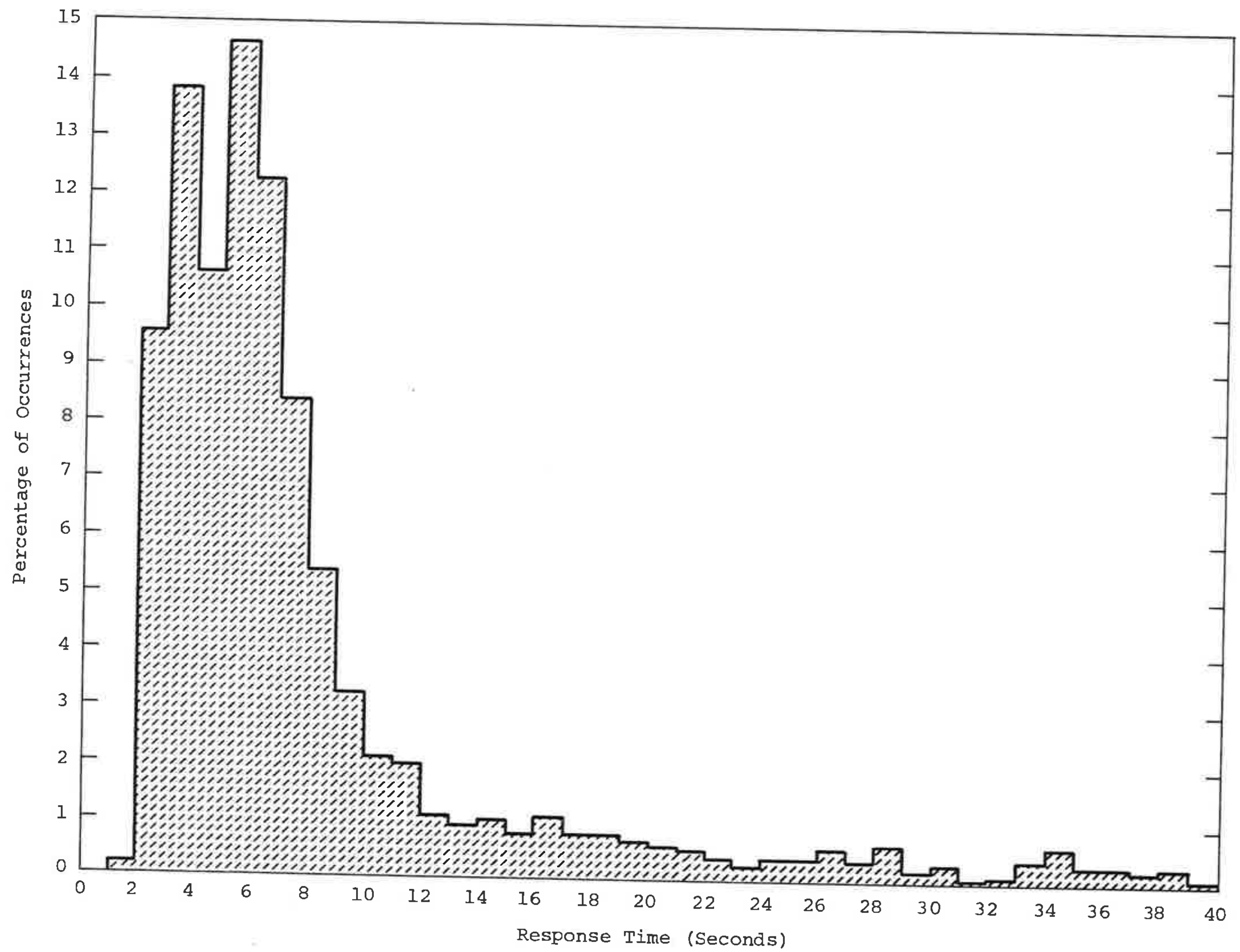


Figure 5-1. Distribution of Response Times (All Responses)

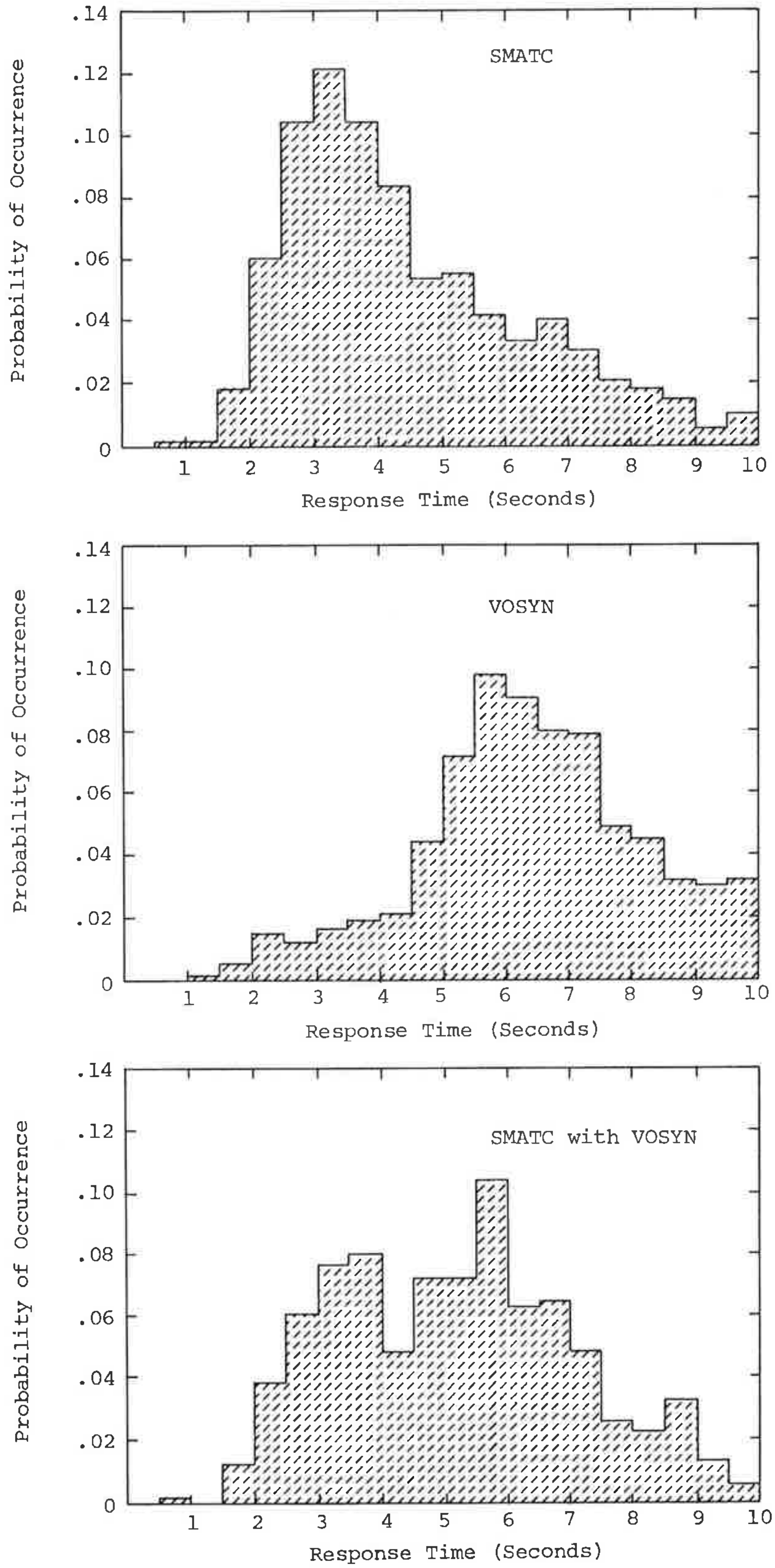


Figure 5-2. Response Time Distribution of Each Complement (Probability Density Function)

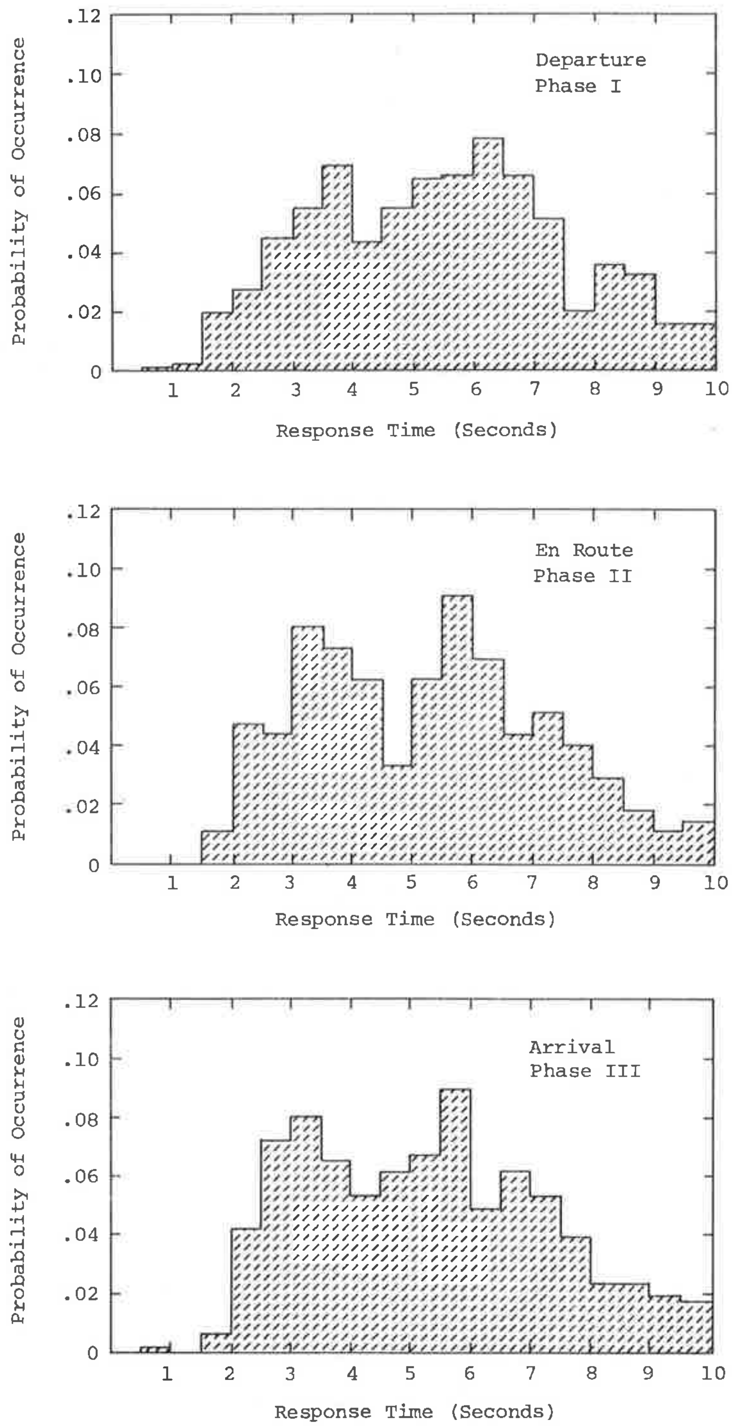


Figure 5-3. Response Time Distribution of Each Phase (Probability Density Function)

The effects of lighting conditions and turbulence on response times and CDU operation are not determinable from this evaluation. There was very little difference in interior cockpit illumination whether the day or night runway visual system was selected. No glare, direct sunlight, or brilliance effects could be simulated. In addition, the use of visual systems that were acquired on a shared-time basis with other simulators meant that acquisition was usually lost by 2,000 feet MSL and not regained until the final-approach phase of flight. In effect, all flights were then conducted under night-time conditions, but without fully darkening the cockpit.

The ability to measure turbulence effects was equally ineffective. The amount of turbulence that could be simulated was at best comparable to what is described as a light chop. It is doubtful that it provided any distraction or coordination difficulty to the non-flying officer, who was usually the one operating the I/O devices.

We are left then with consideration of practice effects and crew effects. "Practice effects" addresses whether communications performance significantly improves as the crew gains experience with the I/O devices. "Crew effects" addresses significant differences among the eighteen participating crews.

The value of the practice-effects measurement is somewhat questionable since one crew member generally communicated on his first and third trials, while the other crew member generally communicated on his second. While there may be some overall crew learning effect between the first and second trials, no individual effect can be judged.

A significance test of the interations among crews, complements, and learning effects or order (meaning the order in which complements were tested) was desirable. However, because the data were confounded (i.e., not all factor combinations were represented), the ANOVA was not directly applicable. The proper use of the ANOVA would have required complex modifications that were considered beyond the scope of this study. To simplify matters, a two-factor ANOVA of crews and orders was performed. A significance test at the 1% level performed on the ANOVA result showed both factors and their interaction to be significant.

To conclude however that differences among crews and orders are definitely significant would be a statistical overstatement. It must be remembered that in collapsing the three-factor ANOVA into a two-factor ANOVA, the device complement (previously determined to be significant) was confounded with other factors and in effect masked. The fact that crew differences were shown to be significant may simply indicate that the interaction of crew and complement is significant. Likewise, an inference that the order effect is significant may simply mean that the order and complement interaction is significant.

Table 5-4 shows the mean response times and standard deviations as a function of flight order and of crew.

TABLE 5-4. MEANS AND STANDARD DEVIATIONS OF RESPONSE TIMES GROUPED BY ORDER AND BY CREW

Factor	Group of Response Times Less Than 30.0 Seconds		Group of All Response Times	
	Mean (Seconds)	Standard Deviation (Seconds)	Mean (Seconds)	Standard Deviation (Seconds)
Order 1	7.88	5.56	9.41	9.10
Order 2	7.28	5.45	9.14	9.94
Order 3	6.54	4.72	8.33	13.00
Crew 1	7.88	5.11	8.56	7.25
Crew 2	8.28	5.40	9.46	8.30
Crew 3	6.47	4.44	6.86	5.47
Crew 4	7.55	5.50	8.92	9.87
Crew 5	8.38	5.16	11.30	11.40
Crew 6	7.86	4.26	9.47	8.93
Crew 7	8.11	5.43	9.47	9.13
Crew 8	5.71	4.19	7.29	7.99
Crew 9	4.94	3.94	4.94	3.94
Crew 10	5.55	5.72	6.40	7.50
Crew 11	7.55	5.53	8.13	6.76
Crew 12	6.91	5.59	7.08	5.92
Crew 13	7.70	5.28	15.00	27.50
Crew 14	6.27	4.56	7.40	7.27
Crew 15	5.87	4.66	6.87	8.80
Crew 16	9.53	6.51	13.20	11.50
Crew 17	7.56	5.26	9.04	8.43
Crew 18	9.08	5.71	12.50	12.60

An analysis of variance of response times showed that there were no significant differences among simulators or scenarios. Differences among device complements and phases of flight were significant. Differences among crews and order of flights were not determined but are believed to be insignificant. The mean values for response times by complement and phase of flight, excluding miscellaneous values of 30 seconds or more, are:

Complement Mean Response Time (Seconds)		Phase Mean Response Time (Seconds)	
SMATC	- 6.30	Departure	- 7.66
Vosyn	- 8.69	En Route	- 7.52
SMATC/Vosyn	- 6.75	Arrival	- 6.89

Histograms of response times by complement showed that crews respond partly to Vosyn commands and partly to SMATC commands when all commands are displayed on both devices. Histograms by phase of flight showed that this double peaking or cross-reference effect of response times is quite pronounced during the relatively low-workload en route phase of flight. During the higher-workload departure and arrival phases, the two peaks tend toward one as some responses are delayed because of workload while others are speeded up.

5.2 UTILIZATION OF DATA LINK FEATURES

The Control and Downlink Unit (CDU) served three purposes in this evaluation:

- Acknowledgment of ground-air ATC messages
- Generation of air-ground ATC and company messages
- Control of Data Link operation

Data have been collected on the extent of CDU utilization in these areas. Not all members of each use category are discussed. For example, the company functions Estimated Time of Arrival or Off Time (ETA/ETO), Departed, Manifest, Request Voice, Gate Number, Off, and Arrived were not evaluated. These functions were included primarily to provide realism in the experiment and were not treated in the experimental design.

Functions that were not used or were used only infrequently in recurring situations were not tabulated in this section. These functions include Engines (Start), Flight Plan Change, Alternate Request, Heading Report, Push Back, and Taxi. Table 5-5 tabulates the utilization of link control functions and message-generation functions by simulator, complements, and scenarios. The first five columns are Data Link control functions, and the last six represent air-ground message operation. The differentiation

TABLE 5-5. CONTROL AND DOWNLINK UNIT UTILIZATION (NUMBER OF OCCURRENCES)

Factor	I/O* Blank	Clearance Request	Altitude Request	Wind Check	HAS Recall	MSG Store	VOSYN** Repeat	Weather	Altimeter	ATIS	Message Recall	Total
Simulator												
B-727	99	44	33	18	171	27	58	16	11	75	32	585
DC-9	63	30	21	6	123	18	16	17	17	76	29	416
Complement												
SMATC	101	29	26	12	154	27	1	8	4	47	35	444
VOSYN	4	23	16	10	61	7	59	18	16	57	9	280
Both	57	22	12	2	79	11	14	7	8	47	17	276
Scenario												
SFO-LAX	51	23	35	5	102	19	12	8	4	47	26	332
MCI-ORD	71	28	11	12	99	11	19	13	13	55	16	348
LAX-SFO	40	23	8	7	93	15	43	12	11	49	19	320
Total	162	74	54	24	294	45	74	33	28	151	61	1000

*Applies to SMATC and SMATC/VOSYN only.

**Applies to VOSYN and SMATC/VOSYN only.

between the two is that the link control function uses information already resident within the assumed airborne digital control unit, while the air-ground message requires ground communication. Although this list is not complete, functions not shown here were used so infrequently as to make the value of any tabulation of them doubtful.

By coincidence, exactly 1000 CDU actions are tabulated here, yielding direct conversions to relative percentages of use. Fifty-eight percent of actions occurred in the B-727, leaving 42 for the DC-9. This difference is not thought to be of any significance. Two possible reasons for this difference are: (1) the three crew members of the B-727 generated, as a rule, more use of the Data Link features than did the two DC-9 crew members; and (2) the normal B-727 crew briefing was oriented more to airline pilot training than was the normal DC-9 briefing.

By complements, the SMATC complement accounts for 44 percent of the usage, leaving the remainder equally divided between the other two complements. The higher incidence of SMATC messages is primarily due to the frequent occurrence of I/O Blank Request, which cleared the SMATC display.

The data are equally divided, as would be expected, among the three scenarios.

The heading, altitude, airspeed (HAS) recall capability accounted for 29 percent of CDU usage. The popularity of this feature is somewhat surprising in view of the fact that today assigned altitude is already set in a device as required by regulation and heading is set on a rotatable reference as a general practice. This feature did not receive more than a proportionate share of briefing attention, and it was emphasized that HAS recall was a Data Link (on-board) control function, as differentiated from a ground-air message. Nevertheless, it was used frequently and approximately equally in all three scenarios. It appeared more frequently in the B-727, consistent with overall usage in the two simulators. The SMATC complement received more than twice the HAS recall requests than either other complement, indicating a strong SMATC preference for this feature.

Figure 5-4 shows a distribution of HAS recall requests as a function of flight progress. The number of requests is shown as a function both of distance from the departure and destination airports and of the climb/descent profile, which was approximately the same in all three scenarios.

The HAS data were requested most frequently in the departure phase from takeoff until final cruise-altitude clearance was given (10,000-15,000 feet about 30 miles from departure point). The HAS data were requested most frequently during the arrival phase after a descent through approximately 20,000 feet and within 75 miles of destination. Relatively heavy usage was observed during the flight portion below 10,000 feet. The unexpected missed approach at SFO and the arrival-delay holding pattern at ORD were both large sources of HAS data requests.

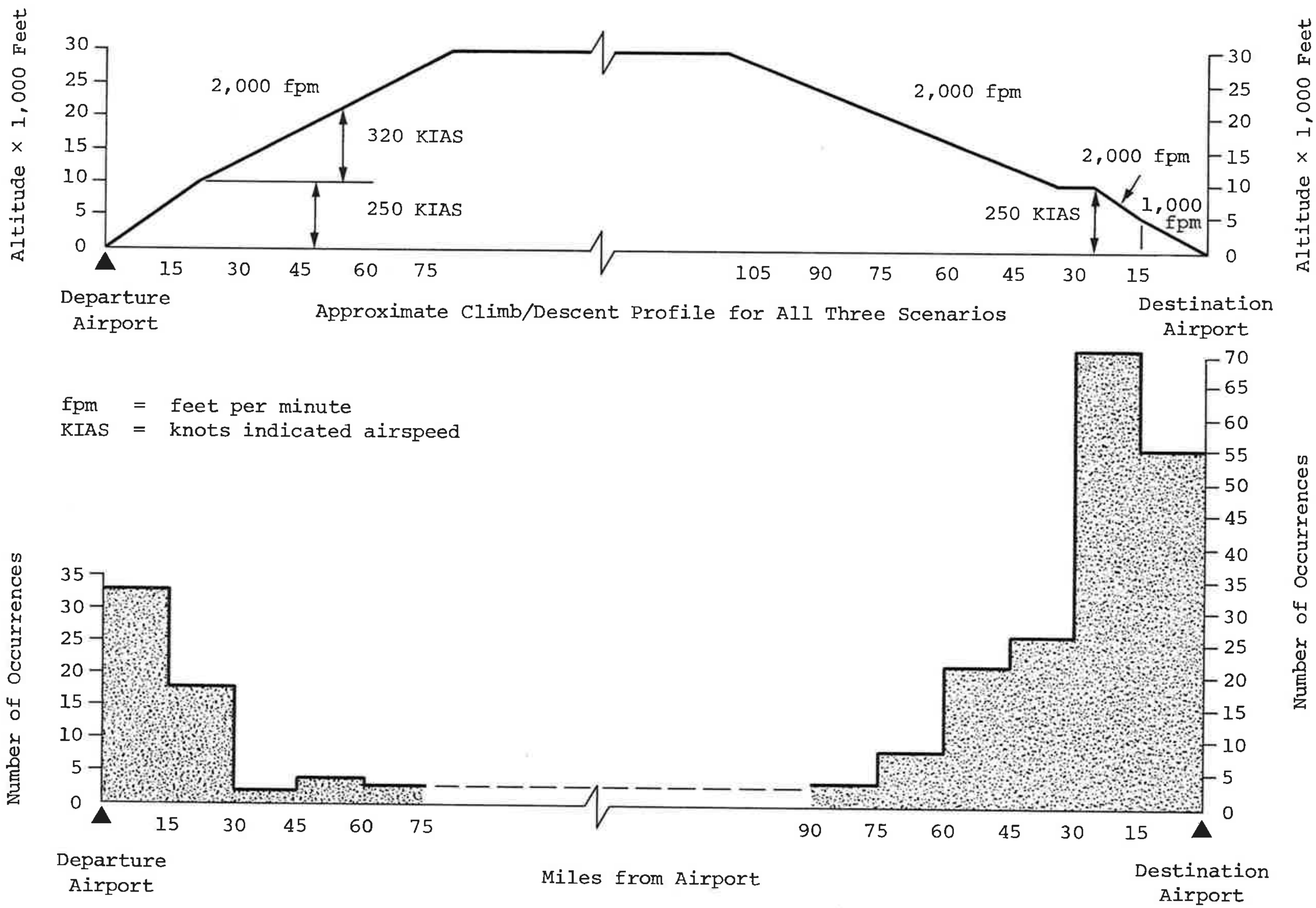


Figure 5-4. Distribution of Heading, Altitude, Airspeed Recall Requests for All Scenarios

I/O Blank, accounting for 16 percent of CDU usage, ranked second in use among the Data Link control features. The LED display characters were bright even when the dimming control was in the dim position. The SMATC device was located in the primary flight instrument scan area as shown in Figure 2-1 (Section 2); and the display characters were red, which suggested an emergency-type display to many subjects. The combination of these three factors explains the heavy use that this function received. The slightly heavier use on the lower-message-density MCI-ORD scenario tends to demonstrate that the longer pilots looked at the same message, the more inclined they were to erase it.

Vosyn Repeat, amounting to about seven percent of CDU utilization, was used almost four times more often in the B-727 than in the DC-9. This is probably due to the poor-quality audio system in the B-727, which has been described earlier. The one occurrence of Vosyn Repeat during a SMATC-only trial is obviously a mistake. The disproportionally high occurrence of Vosyn Repeat requests during Scenario 3 (LAX to SFO) occurred during the arrival phase and was probably due to an intentionally undecipherable heading command and to the fast tempo of action during the go-around.

Message Store and Message Recall accounted for five percent and six percent of CDU utilization, respectively. Both were used more frequently with the SMATC complement than with the other two complements.

The most frequently used ground-air request was ATIS, or Automated Terminal Information Service, accounting for 15 percent of CDU usage. It was normally acquired twice for each of the 54 flights, once at destination and once during arrival. The roughly 50-percent excess over the required usage indicates unprompted experimentation into this feature on the part of the pilots.

The occurrence for all destination ATIS requests was plotted for all three scenarios for both the DC-9 and B-727 crews. The mean distance from destination for this request and the scenario altitude were determined. The results are plotted in Figures 5-5, 5-6, and 5-7, and are summarized as follows:

Scenario	Mean Request Distance (nm)	Altitude
SFO-LAX	LAX - 155 nm	30000 +
MCI-ORD	ORD - 175 nm	30000 +
LAX-SFO	SFO - 92 nm	30000 +

In today's voice system a typical maximum-range ATIS acquisition can be made 100 miles out and at 30,000 feet. Generally, the crew may not be able to acquire ATIS until much closer in (50 miles, for instance). The most significant element of ATIS other than current weather information is the designation of arrival and approach procedures and notices to airmen (NOTAMs) concerning the destination airport.

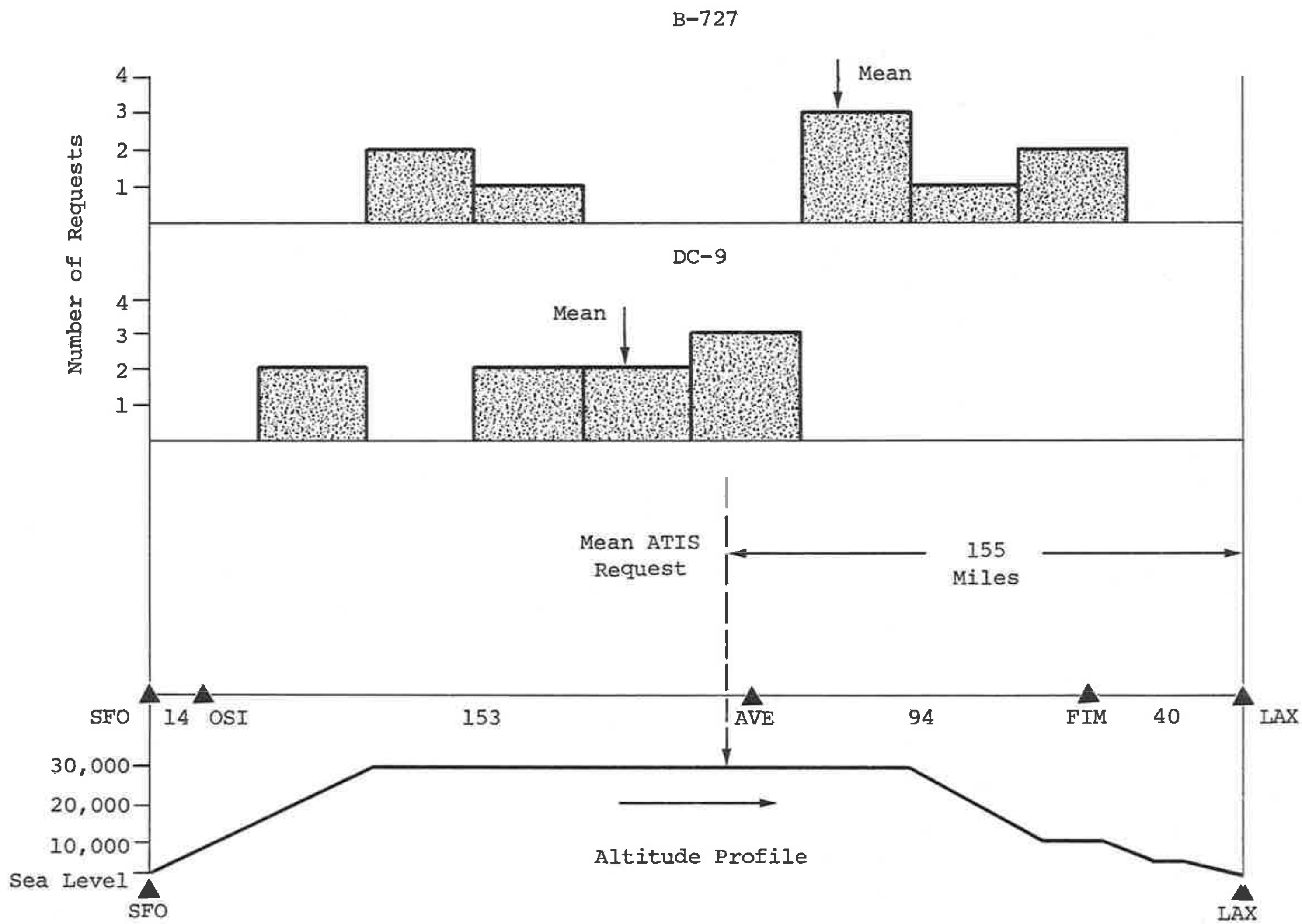


Figure 5-5. Destination ATIS Requests for Data Link Trials: Scenario I, San Francisco to Los Angeles

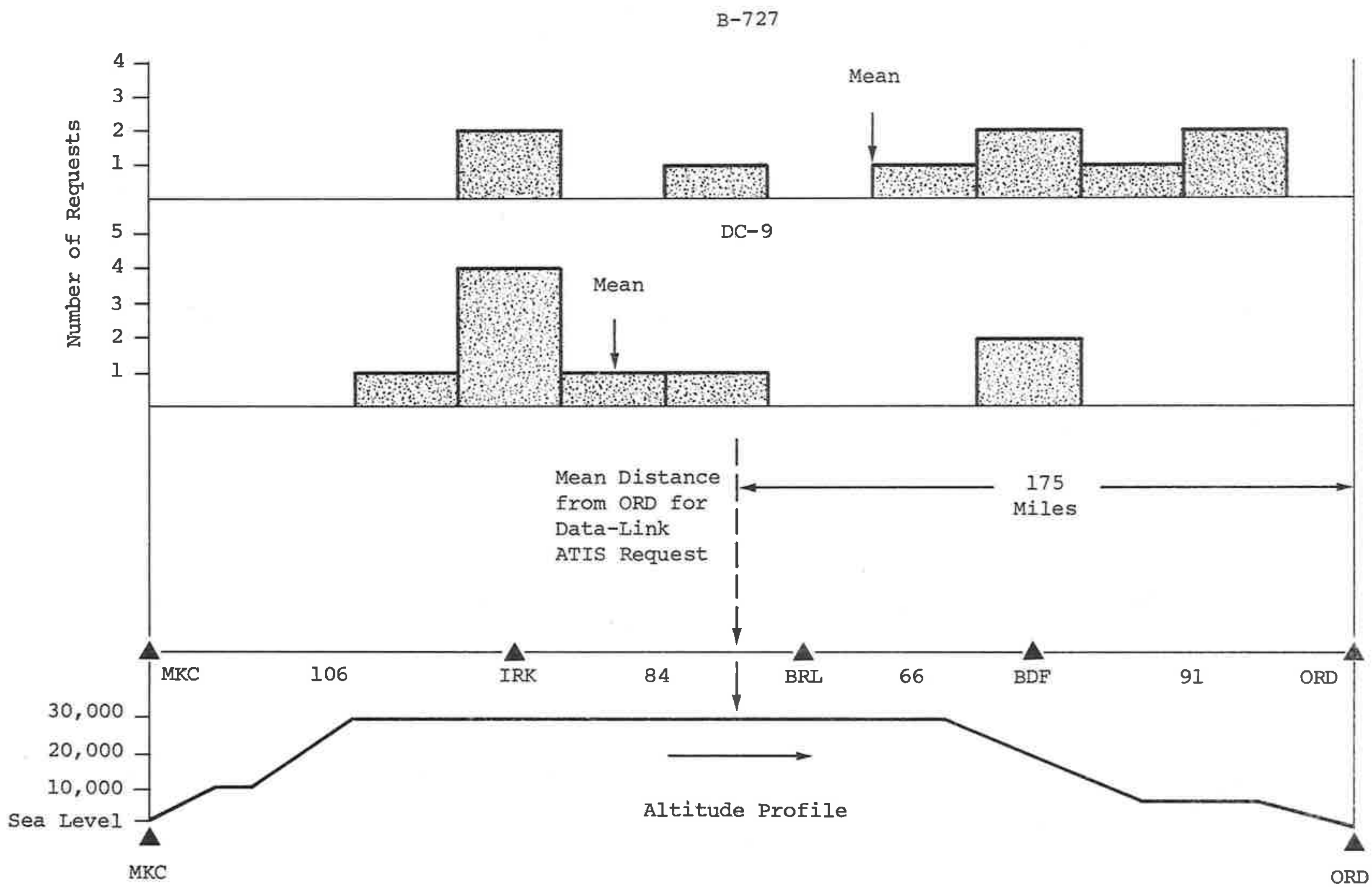


Figure 5-6. Destination ATIS Requests for Data Link Trials: Scenario II, Kansas City to Chicago

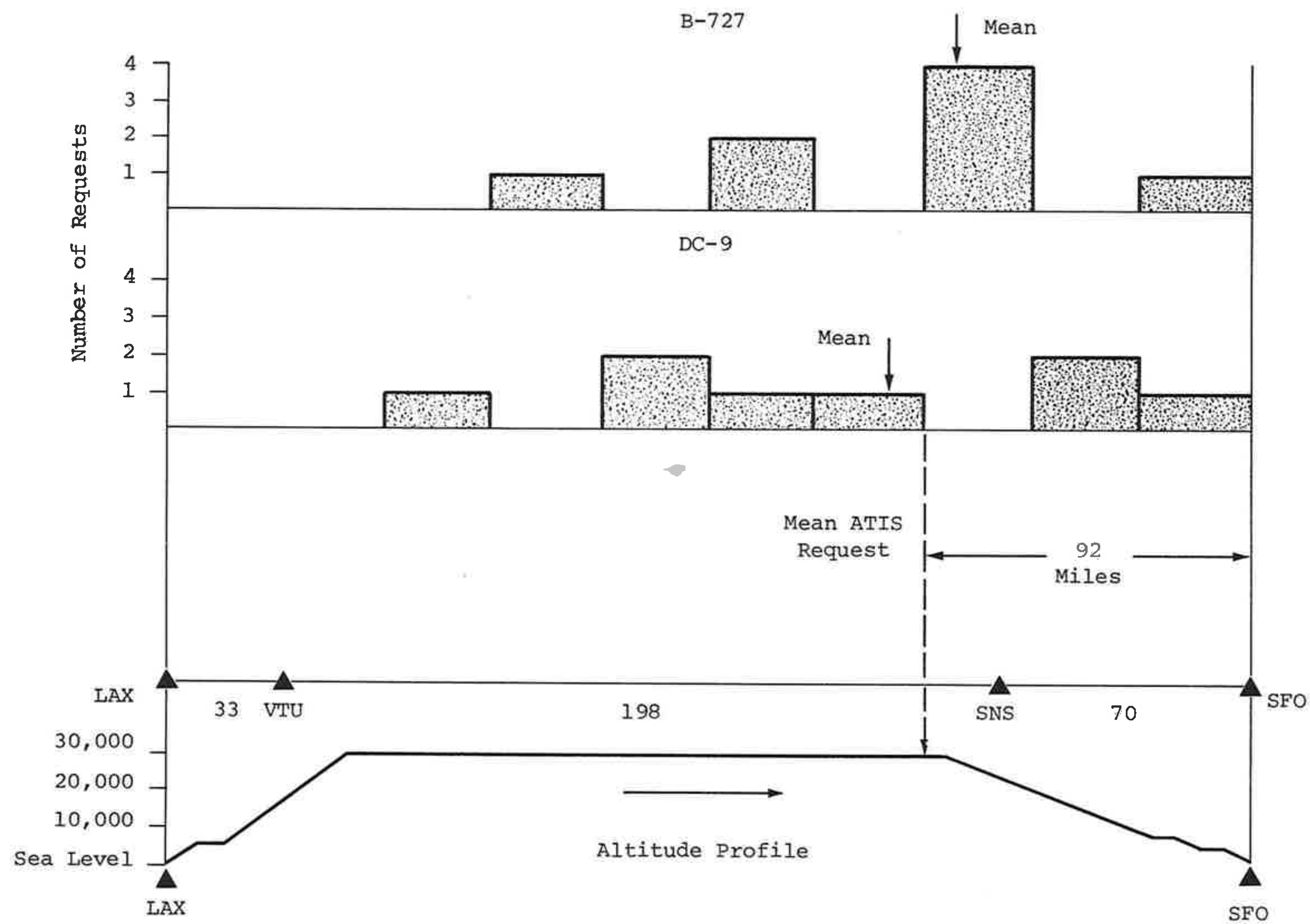


Figure 5-7. Destination ATIS Requests for Data Link Trials: Scenario III, Los Angeles to San Francisco

It can be safely assumed, and perhaps demonstrated from the plots of ATIS requests, that flight crews would like to have this information at an earlier stage of flight than they are currently able to acquire it.

At cruise altitude, for instance, the work pace is generally slow and all other traffic is under positive IFR control. Acquisition of ATIS here would provide the crew an opportunity to determine and examine applicable procedures at their convenience. Once the descent phase begins, however, the flight and communications workloads both increase, and below 18,000 all crew members must be vigilant for reported and unreported other air traffic.

With the exception of the third scenario (LAX to SFO), ATIS on the Data Link was requested primarily during the low-workload high en route flight phases. In every case, the mean request distance for the DC-9 crews was less than that for the B-727 crews, as shown in the figures.

Clearance Request accounted for seven percent of CDU utilization. Fifty four requests, or 18 per complement, were required during the course of the script in each scenario. The additional 20 requests were mostly in the B-727 and most often made when the SMATC device was present. These requests were balanced among scenarios.

Altitude requests, accounting for five percent of CDU usage, occurred predominantly in Scenario I (SFO to LAX). About 27 of the 35 shown for Scenario I resulted from programmed script variations. Except for these 27, the distribution of altitude requests is balanced among the scenarios, and the requests are made most often in the B-727 simulator and the SMATC complement.

Weather and altimeter setting requests are anomalies in that they appear more often during Vosyn complements than during SMATC. Consistent with this is the higher occurrence of these functions in the DC-9, which had a better-quality Vosyn audio system than the B-727.

Wind check was used most often in the B-727 simulator and during the second scenario (MCI-ORD). The simulator preference is probably due to a briefing variation. The reason for the complement variation is not known. This feature was generally not treated in detail during the briefing.

Ground-to-air (uplink) messages in a Data Link system require some form of technical and procedural-compliance acknowledgment. The one postulated in the tests is called a WILCO. All ATC messages in this evaluation except Radar Contract and Ident messages required a WILCO response. No company messages, however, required a WILCO response.

The pilot could respond in one of three fashions: (1) he could WILCO the message; (2) he could UNABLE the message, signaling his inability to comply or decision not to comply with the uplink message; or (3) he could depress STANDBY if he wanted more time to decide whether to WILCO or

UNABLE the message. The incidence of STANDBY responses was practically zero. UNABLE was used predictably in two instances in which the crews were given altitude or heading commands with which they could not comply. The most probable use of STANDBY in actual practice would be to indicate that the pilot had received a traffic advisory but had not yet located the traffic. This condition could not be simulated during this experiment.

The WILCO response was analyzed with respect to which crew member made the response and how he made it. Either flying officer could respond with WILCO through one of two methods: he could depress the WILCO button on the centrally located CDU, or he could use a switch provided in his own location. In the B-727, this individual switch was a pendant switch mounted on the side windshield. In the DC-9, this switch was placed on the outboard side of the control yoke so that the pilot could respond with the hand on the control yoke without releasing his grip of the yoke.

The variation in the distribution of response times between the control column and the centrally located CDU was not considered to be of interest here. Previous experiments conducted by TSC have shown no difference in the mean response times between pilot and copilot or between control-column switch and CDU. The tabulation of WILCO responses by flight officer and by complement is shown in Table 5-6. In general, all WILCO responses on the CDU were made by the non-flying officer. A response on the CDU required the responder to lean forward across the flight and engine controls, and the flying officer would usually not do this. Locating a CDU behind the throttle quadrant may have yielded a different result.

The flying officer in the B-727 WILCO'd a total of 37 messages, compared with 189 in the DC-9. The reason for this disparity is probably the convenience of the DC-9 control switch over the B-727's windshield-mounted WILCO switch. This same result is observed in a comparison of the non-flying officer WILCOs between the DC-9 and B-727. The majority of non-flying officer responses in the DC-9 are made on the column, whereas those in the B-727 are predominantly made on the CDU and not the windshield.

Practice effects in the use of the CDU are described in terms of messages attempted, messages completed, CDU error rate, use of CDU functions, and CDU character-entry speed as a function of the number of trials flown by the crew. Because one officer generally operated the Data Link devices on the first and third trials while the other officer operated the devices only on the second trial, the repetitive learning effects on each individual crew member cannot be judged. Only the overall crew effect can be examined.

Table 5-7 shows the practice effects on the extent of CDU usage. The simulators were comparable with regard to messages attempted, completed, and additional (other than those required) messages sent. The one exception is the message completion rate, which was generally higher in the B-727 than in the DC-9. More effective training in the use of the CDU in the B-727 is believed to be responsible for this effect.

TABLE 5-6. DISTRIBUTION OF WILCO RESPONSES

Factor	Flying Officer	Non-Flying Officer			Unnecessary WILCO	Total
		Total	Column	CDU		
B-727 Complement						
SMATC	0	408	120	288	10	418
VOSYN	11	415	94	321	14	440
Both	26	424	150	274	8	458
Total						1316
DC-9 Complement						
SMATC	67	383	362	21	6	456
VOSYN	88	344	338	6	22	454
Both	34	372	362	10	6	412
Total						1322
Averages						
B-727	1.3	46.1	13.4	32.7	1.1	
DC-9	7.0	40.7	39.3	1.3	1.2	

TABLE 5-7. PRACTICE EFFECTS ON CDU USAGE

Message Completion					
Trial	Messages Attempted	Messages Completed	Additional Messages Sent	Fractional Completion Rate	
				B-727	DC-9
1	238	208	122	0.91	0.83
2	229	207	120	0.92	0.88
3	214	180	93	0.85	0.82

Function Usage				
Trial	HAS Recall	MSG Store	MSG Recall	MSG Completions
1	75	10	14	208
2	127	21	28	207
3	90	14	19	180

Average Character Entry Speed (Seconds)				
Trial		B-727	DC-9	All Flights
1		2.7	3.2	Overall Average 2.87
2		3.1	2.7	Button Depressions per Trial 67
3		2.6	2.3	

Completion rate is the ratio of messages completed to messages attempted. Once a message was entered in the CDU, it could be terminated in one of three ways:

- It could be sent to the ground (SEND button) - i.e., a message completion.
- It could be deleted by use of the DELETE button.
- It could be erased if the crew member responded to a WILCO before he sent or deleted the message he was composing.

The occurrence of either of the latter two events caused the message to be aborted. The occurrence of the third event (an erasure caused by WILCOing an uplink message) was not designed to be a part of the experimental Data Link system; it was the result of a design fault. Although the crews were generally briefed on the system fault, it caused numerous message aborts and was a constant source of frustration to the crews.

The messages completed are about the same for the first two trials and then decrease markedly on the third trial. The same effect is observed with the optional HAS Recall, MSG Store, and MSG Recall functions. The decrease in the use of the CDU during the third trial is probably the result of two effects: (1) hurriedness -- the first two trials generally ran long, requiring a frantic pace on the third trial; and (2) crew fatigue -- by the beginning of the third trial, the crew were generally starting to show the effects of fatigue.

Character entry speed seemed to improve slightly during the tests, but not significantly. The overall average crew entry speed was 2.87 seconds per character. An ATIS request for Los Angeles, for example, required the following nine key strokes:

CLEARANCE

ATIS

JKL
RIGHT } L

ABC
LEFT } A

WXY
CENTER } X

SEND

On the average, this required 26 seconds to enter and send via the CDU.

A tabulation of the most frequently used CDU features indicated that the three features ATIS requests, HAS recall requests, and I/O Blank accounted for more than 60 percent of the CDU usage. A plot of HAS distribution shows the feature to be primarily used in the departure and arrival terminal areas, with the heaviest use during the arrival phases. Geographic plots showed that destination ATIS requests occurred in the high en route phases of flight earlier than currently encountered under voice.

The I/O Blank usage was caused by the undesirable bright red display of the SMATC figures, and this could be eliminated by a better device design.

The remaining CDU functions were used only infrequently, tending to support one comment that the CDU alphas could possibly be eliminated in favor of numbers only, with some special function keys. (ATIS requests, for example, could possibly be accomplished by assigning a three-digit number to each of the roughly 500 air-carrier airports.) This conclusion is generally supported by the functional CDU design developed by the Society of Automotive Engineers, Inc. (SAES7 Committee): It does not incorporate alphas.

6. CONCLUSIONS AND RECOMMENDATIONS

This section presents conclusions based on the data analysis discussed in Sections 4 and 5. In addition, it offers recommendations on Data Link areas that we consider worthy of further joint airline-industry/government study.

6.1 CONCLUSIONS

This experimental evaluation collected both qualitative and quantitative data. The qualitative data are believed to be the more meaningful of the two categories because they provided an assessment of pilot reaction to a wide range of questions concerning airborne Data Link concepts and specific Input/Output (I/O) devices. The quantitative data were based on relatively narrow parameters such as device response time and device utilization. In general, they seemed to validate the qualitative data.

6.1.1 Short Message ATC Display (SMATC)

The SMATC display was found to be easily readable and well located. With the exception of a small number of commands, the abbreviations used on it were not confusing.

The SMATC did not distract pilots during most phases of flight. Their attention may have been distracted from the adjacent airspeed indicator during climbs and descents. A majority of pilots believed that the SMATC could potentially distract them during an instrument approach. Figure 6-1 shows the SMATC message "CLR LAND RWY 14R" being displayed as the aircraft approaches a simulated touchdown at O'Hare Airport.

The use of the SMATC display for emergency or time-critical messages such as minimum-safe-altitude warning or "go-around" is not considered effective. Even with the audio alert, it does not adequately command the crew's attention under high-workload situations.

The SMATC display was very popular when used as a recall instrument for currently assigned Heading, Altitude, and Airspeed information.

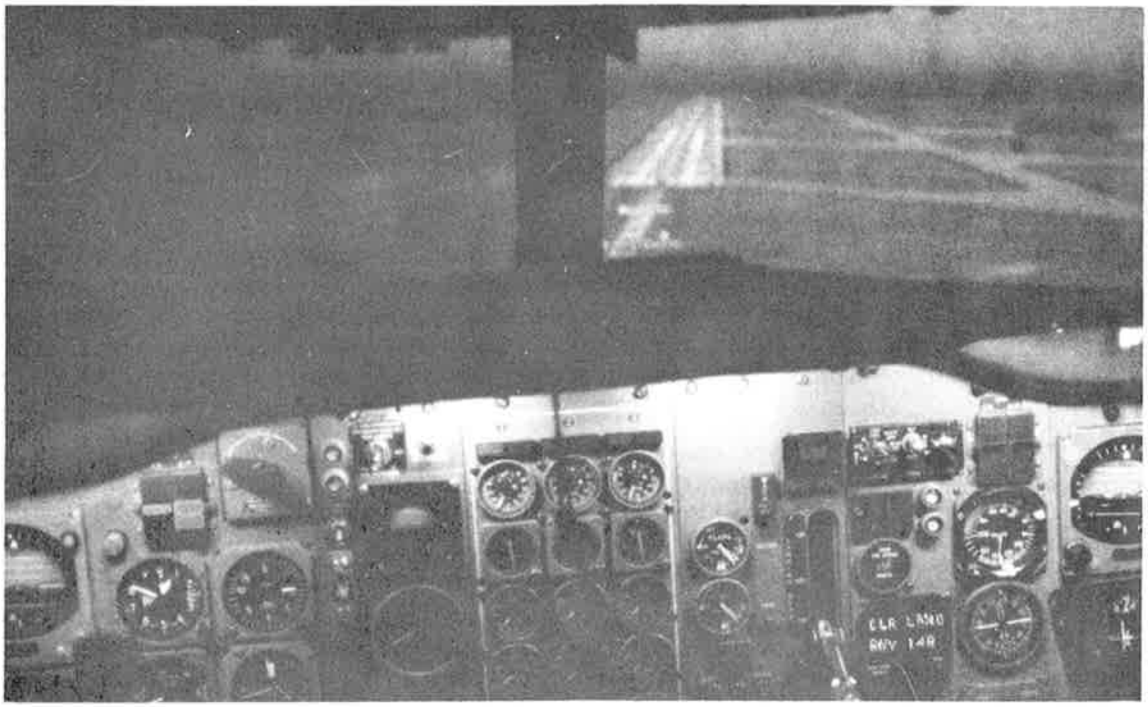


Figure 6-1. Simulated Landing at O'Hare International

6.1.2 Printer

The use of a printer seemed to be quite desirable. Crews found it especially useful for the longer messages such as ATC clearances, ATIS information, and some company traffic. The use of the printer on shorter, more perishable information did not seem desirable. A page printer might be preferable to a line printer although the former was not evaluated here.

The paper-management problems arising from the printing and line-feeding of every message were severe. It would have been highly desirable for crews to be able to obtain "loose copies" of only the specific messages they required.

Restriction of printer access to the second officer (flight engineer) is satisfactory in a three-crew-member aircraft. In a two-crew-member aircraft, however, the printer must be accessible to both crewmen since the aircraft is routinely flown from either position.

The use of red print to distinguish company messages and the absence of some method to alert the crew to a company message were unacceptable.

6.1.3 Control and Downlink Unit (CDU)

Although the CDU was somewhat complex, the crews learned to be fully proficient in its use after about two one-hour flights that had been preceded by a 20-minute training session.

The left-center-right method of entering alpha characters on the modified "Touch Tone" type key pad was tedious but not wholly objectionable. This conclusion is based on short (three- to five-character) messages. The great majority of pilots participating were right-handed. They experienced no problem in operating the CDU with the left hand.

One pilot commented that the complexity of the CDU could be greatly reduced by eliminating alphas in favor of numbers and several special-function buttons. The observation was somewhat validated by the quantitative data on CDU utilization.

A tabulation of the most frequently used CDU features indicated that ATIS requests, HAS recall requests, and I/O Blank accounted for more than 60 percent of the CDU usage. The I/O Blank usage was caused by the undesirable bright red display of the SMATC figures and could be eliminated by a better design.

Geographic plots of destination ATIS requests occurred mainly in the high en route phases of flight earlier than currently encountered with voice. A plot of HAS distribution shows the feature to be used primarily in the departure and arrival terminal areas, with the heaviest use during the arrival phases.

A WILCO acknowledge button on the CDU will be operated primarily by the non-flying officer. A WILCO button on the control yoke will be operated by both pilots.

The AUTOTUNE feature, in which the communications frequencies were automatically selected, was highly desirable. The idea of extending this automatic ground control to any other device, with the possible exception of the transponder, was equally undesirable.

Pilots did not show a strong relative preference for the use of Data Link to provide ATC navigational or non-navigational commands, preprinted departure clearances, ATIS, or automation of company reports.

6.1.4 Voice Synthesizer (Vosyn)

The intelligibility of the Vosyn is believed to be unacceptable for routine communications. Pilots found that its mechanical sound and the lack of tonal inflection and volume variation made it difficult to understand in a simulated airborne noise environmnet as well as annoying. The effect apparently did not mitigate with practice.

The Vosyn should be limited to short messages and seems to be well suited for emergency or time-critical messages. It was effective as an attention-getter during the busy phases of flight. The synthetic voice seemed to detract from one of the prime advantages of Data Link, as commented upon by one pilot, in that it seemed to demand attention while, on the other hand, the SMATC allowed two people to communicate effectively without devoting full attention to each other.

No strong opinions were exhibited in the responses to questions on combined SMATC and Vosyn use. The predominant belief was that the duplication provided by the two devices was either undesirable or not clearly desirable. When pilots were asked to choose one for elimination, the SMATC emerged as the strong survivor.

6.1.5 Ranking of Devices

In the ranking of the relative desirability of air traffic control by conventional voice, SMATC display, or Vosyn for various phases of flight, the SMATC was found to be a slight favorite in the ground phase but a strong favorite in low and high altitude en route phases. Conventional voice was more desirable in local control (airport traffic areas), with the SMATC and conventional voice being ranked approximately equal in the arrival and departure phases. Figure 6-2 displays this result.

An analysis of variance of response times showed that there were no significant differences among simulators,scenarios, crews, or order of missions flown. Differences among device complements and phases of flight were significant. The mean values for response times by complement and phase of flight, excluding miscellaneous values of 30 seconds or more, were:

Device Complement		Flight Phase	
SMATC	- 6.30 seconds	Departure	- 7.66 seconds
Vosyn	- 8.69 seconds	En Route	- 7.52 seconds
SMATC/Vosyn	- 6.75 seconds	Arrival	- 6.89 seconds.

Histograms of response times by complement showed that crews respond partly to Vosyn commands and partly to SMATC commands when all commands are present on both devices.

Histograms by phase of flight showed that this double peaking or cross reference effect of response times is quite pronounced during the relatively low-workload en route phase of flight. During the higher-workload departure and arrival phases, the two peaks tend to merge as some responses are delayed by workload while others are speeded up.

6.1.6 General Data Link Concepts

With two exceptions, no significant differences were observed between the operation of Data Link in two- and three-crew-member aircraft. The two exceptions were the relative levels of intelligibility of the voice synthesizer and the relative acceptability of abbreviations and symbols on the cockpit page printer. The first is explained by unintentional variations in audio quality within the two simulators. The second represents a difference of opinion between flight engineers (non-flying crew members) and first officers (flying crew members). This difference of opinion, causing the flight engineers to be more receptive to the use of symbols and abbreviations used on the printer, is probably due to in-flight workload differences.

Although a majority of pilots thought that little information was lost, the selective-address capability of the Data Link, in which each aircraft received only transmissions intended for it, did cause a loss of information pilots believe to be essential. It was stated that the importance of this lost information could affect both the safety of flight and the comfort and convenience of airline passengers. A majority of pilots believed that the loss of knowledge of the proximity of other aircraft in the same en route or terminal sector, which is normally acquired on a common-channel VHF system, could be detrimental to flight safety. Similarly, a majority of pilots believed that the loss of both terminal-area routing information (such as a knowledge of aircraft ahead, holding patterns in use, approaches in use, and anticipated descent instructions) and specific weather-anomaly information (such as the extent, location, and altitude of encountered turbulence) could be detrimental to passenger comfort and convenience. (The discretionary use of the seat-belt sign, the food and beverage service schedules, and the use of different altitudes which affect fuel burnout are often predicated on the knowledge of these circumstances.) The postulation of a ground-computer conflict-prediction system had little effect on these opinions, reflecting a skepticism as to whether a system could ever be totally free from human error.

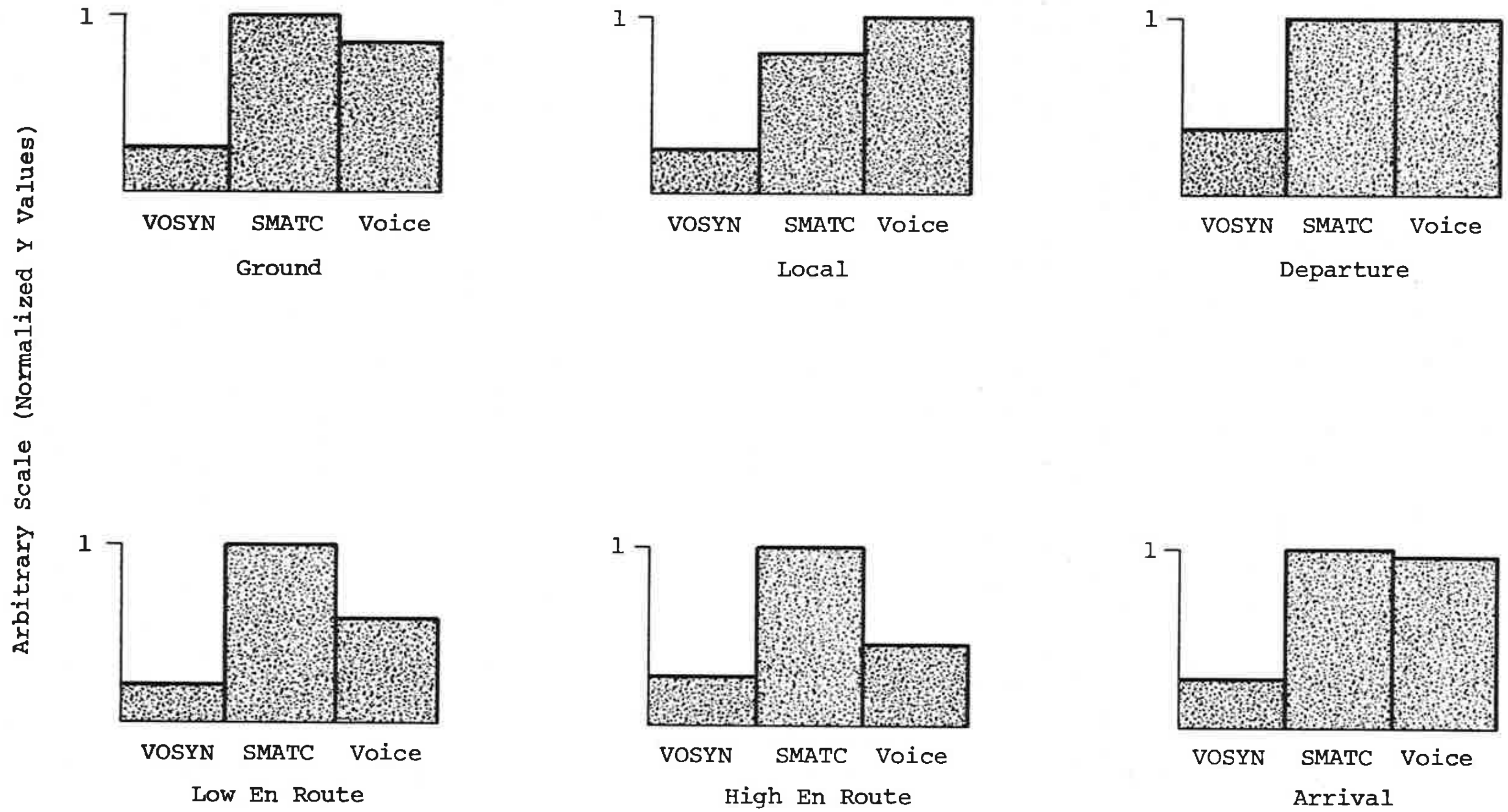
Although no objective test was made of this effect, airline pilots generally did not favor a system that would require them to wait in a queue for data-polled acquisition of an ATC voice channel. Comments repeatedly indicated that when they found it necessary to converse with ATC, usually because of a time critical situation immediate access was desired. These comments apparently resulted from occasional misunderstandings or misstatements of test instructions concerning the procedure for talking with ATC: The assumption was in all cases, that ATC was constantly available.

The concept of Data Link control was somewhat disliked during ground-proximate flight phases, including local control, arrival, and departure. The requirement for pilots to use the Control and Downlink Unit (CDU) or receive Data Link instructions during a missed-approach execution caused considerable unfavorable comment.

These comments indicate an apparent operational requirement for the continuation of conventional style voice communications to some extent to supplement the Data Link environment. Voice is required for pilot-controller discussions. Voice is also needed to advise of encountered en route weather (turbulence, thunderstorm detour paths, icing, etc.) and for occasional air-to-air communications of this nature. Perhaps certain abbreviated voice procedures can supplement Data Link to overcome the feeling of isolation expressed by some pilots during a pure Data Link operation and to provide some of the clues on traffic flow and congestion available today.

6.1.7 Acceptability of a Data Link System

The concept of air traffic control by an air-ground-air Data Link appears to be a viable alternative to today's system. However, three problems must be solved before air traffic control can be exercised entirely through a digital Data Link system:



Computation Method

$$Y = \{ 2 \times (\text{Number of times ranked first}) + 1 \times (\text{Number of times ranked second}) \} / \text{Total}$$

Figure 6-2. Desirability of Data Link Options

- Loss of common-channel information because of selective-address communications
- Inability to obtain an immediate voice channel in a polled system when needed
- Dislike of Data Link and increased workload due to its use in ground-proximate flight phases

6.2 RECOMMENDATIONS

6.2.1 Development and Simulator Evaluation of Data-Link Concept

It is recommended that the Data Link concept be further developed and then re-evaluated in a simulator environment. The concept development should attack the central issues that made this evaluation concept likely to be unacceptable in an operational system. Alternatives that enable flight crews to maintain their current overall "feel" for their environment should be examined. Data Link procedures during ground-proximate flight phases should be simplified. Finally, the use of conventional voice for certain communications in the Data Link environment should be expanded in future tests.

6.2.2 Flight Evaluation of a Limited Data Link System

It is recommended that consideration be given to in-flight evaluation of a limited Data Link system. This could probably be a domestic "add-on" to the currently envisioned AEROSAT Test and Evaluation Program, in which it is planned to equip a small number of airliners with Data Link type equipment.

This evaluation could assess the operation of a simpler CDU device, a page printer, a SMATC display, and an AUTOTUNE type device.

In addition to device refinement, primary consideration should be given to the potential dislike of Data Link due to information loss, data-polled voice-channel acquisition, and unacceptability of Data Link commands during ground-proximate flight or flight in heavy traffic areas.

6.2.3 Interchange System

The ability of the NAS/ARTS/ARINC ground system effectively to interchange and deliver information under a Data Link concept such as that hypothesized in this project should be evaluated under actual conditions. A limited interchange system should be established between two short-length, high-density terminals such as San Francisco and Los Angeles. A limited number of aircraft flying regularly scheduled turn-arounds on this type of trip could yield a significant quantity of cost-effective test data.

The objective of this effort should be to measure the feasibility of delivering predeparture clearance, en route and destination weather, and ATIS information, and possibly to control information to aircraft through a system of ground communications switches and terminals. A parallel study should investigate the possible cost benefits of such a system to both the Federal Aviation Administration and the airline industry. These benefits would be examined in terms of potentially reduced staffs for FAA functions, e.g., tower clearance delivery; and airline functions, e.g., en route communications.

APPENDIX A
FLIGHT SCENARIOS

This appendix contains the three flight scenarios that were employed in the Evaluation of Data Link I/O Devices using Airline Flight Simulators.

These message scenarios were not shown in advance to any crew member who participated in the evaluation. To do so might have produced undesired learning effects on the part of the crew, which could have distorted the data.

Each scenario contains the messages for all devices for a typical airline flight of one hour ten minutes. Each message script was separately coded for use with three device complements.

The scenarios included here consist of the following:

I San Francisco to Los Angeles

II Kansas City to Chicago

III Los Angeles to San Francisco

Supplemental ATIS and WEATHER Reports •

SCENARIO I

SAN FRANCISCO TO LOS ANGELES

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM HA)
-	ATC	San Francisco International Airport Information Lima Ceiling measured 300 overcast, visibility 1 mile in fog, Temperature 53, Dewpoint 53. Wind 270 at 12. Altimeter 30.04. ILS runway 28L approach in use. Landing runway 28L. Departures runways 28 left and 28 right	ATIS,SEND	X	SEE PTR ATIS	San Francisco International Airport Information Lima Ceiling measured three hundred overcast, visibility one mile in fog. Temperature five three, Dewpoint five three. Wind two seven zero at one two. Altimeter three zero zero four. ILS runway two eight left, approach in use. Departures runways two eight left and three two right.	H--- A--- S---	
1	ATC	UA 781 is cleared to the Los Angeles International Airport via Portola Seven Departure Avenal Transition, Avenal, Fillmore Five Arrival, Avenal Transition Los Angeles. Maintain flight level 290. Squawk 7401 on departure	CLRANCE, SEND	X	SEE PTR CLRANCE	United seven eight one is cleared to the Los Angeles International Airport via Portola Seven Departure, Avenal Transition, Avenal. Fillmore Five Arrival, Avenal Transition, Los Angeles. Maintain flight level two niner zero. Squawk seven four zero one on departure	H--- A--- S---	TW 781 is cleared to the Los Angeles, etc. (same as Message Text Printer except Maintain flight level two <u>five</u> zero) (VOSYN MESSAGE CORRESPOIDINGLY MODIFIED)
2	ATC	SFO Ground 121.65		X	SFO GND 121.65	San Francisco Ground one two one point six five	H--- A--- S---	
3	ATC	Cleared to Push Back	PUSH BK,SEND	X	CLR PUSH BACK	Cleared to push back	H--- A--- S---	
-	COMPANY	UA 781 B727 AC 7619 ZFW 127.1 ATOGW 146.0 MAC 22.4 PSGRS 18F 106Y	MANIFEST, SEND					(Delete this message)
-	COMPANY	UA 781 Departure Report Received (type 1)	DEPARTD ---- 199, SEND					(Delete this message)

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
		UA 781 Departed SFO at ____ Fuel 19.9 (Inserted message)						
4	ATC	Taxi to Runway 28L	TAXI,SEND	X	TAXI RWY28L	Taxi to runway two eight left	H--- A--- S---	
-	COMPANY	UA 781 ETO Report Received (Type 1)	ETA/ETO----, SEND					TW 781 ....
		UA 781 Estimated Time Off---- (Inserted Message)						
5	ATC	SFO Tower 120.5		X	SFO TWR 120.5	San Francisco Tower one two zero point five	H--- A--- S---	
6	ATC	Cleared for Takeoff runway 28L		X	CLR TKOF RWY 28L	Cleared for takeoff runway two eight left	H--- A--- S---	
-	ATC	Wind 270 at 13 (Type 1 message valid to Seq. No. 20)	WIND CK, SEND	X	WIND 270 at 13	Wind two seven zero at one three		
7	ATC	SFO Departure 124.4		X	SFO DEP 124.4	San Francisco Departure one two four point four	H--- A--- S---	
8	ATC	Squawk Ident			IDENT	Squawk Ident	H--- A--- S---	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
9	ATC	Radar Contact			RADAR CONTACT	Radar Contact	H--- A--- S---	
10	ATC	Maintain Heading 280 Climb to and maintain 13000		X	HDG 280 ↑↑ 130	Maintain heading two eight zero Climb to and maintain one three thousand	H280 A130 S---	
11	ATC	Turn left heading 180		X	←←180	Turn left heading one eight zero	H180 A130 S---	
12	ATC	Intercept PYE 135R		X	INTERCPT PYE 135R	Intercept the Point Reyes one three five degree radial	H--- A130 S---	
-	COMPANY	UA 781 Off Report Received (Type 1)	OFF----, SEND					TW 781 Off Report Received
		UA 781 Off SFO At____ (inserted message)						TW 781 off SFO out---- Off---Fuel 170 (CDU input message correspondingly modified)
13	ATC	Turn left heading 090		X	←←090	Turn left heading zero niner zero	H090 A130 S---	
14	ATC	Intercept OSI 116R		X	INTERCPT OSI 116R	Intercept the Woodside one one six degree radial	H--- A130 S---	
15	ATC	Squawk 2100			SQK 2100	Squawk two one zero zero	H--- A130 S---	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
16	ATC	OAK Center 132.65		X	OAK CNTR 132.65	Oakland Center one three two point six five	H--- A130 S---	
17	ATC	Squawk Ident			IDENT	Squawk Ident	H--- A130 S---	
18	ATC	Radar Contact			RADAR CONTACT	Radar contact	H--- A130 S---	
19	ATC	Climb to and maintain flight level 490		UNABLE	↑↑490	Climb to and maintain flight level four niner zero	H--- A490 S---	
20	ATC	Climb to and maintain flight level 290		X	↑↑290	Climb to and maintain flight level two niner zero	H--- A290 S---	Climb to and maintain flight level 250 A250
21	ATC	Proceed direct AVE flight plan route		X	DRCT AVE FPR	Proceed direct AVENAL flight plan route	H--- A290 S---	A250
22	COMPANY	UA 781 SFO WX ADVISRY. Clear air turbulence FL 250 thru FL 300 smooth above and below				Clear air turbulence FL 250 through FL 300 smooth above and below		TW 781.... A250
23	ATC		ALT REQ 330, SEND				H--- A290 S---	ALT REQ 230, SEND A250

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
24	ATC	OAK Center 128.7		X	OAK CNTR 128.7	Oakland Center one two eight point seven	H--- A290 S---	A250
25	ATC	Squawk Ident			IDENT	Squawk Ident	H--- A290 S---	A250
26	ATC	Radar Contact			RADAR CONTACT	Radar Contact	H--- A290 S---	A250
27	ATC	Climb to and maintain flight level 330		X	↑↑330	Climb to and maintain flight level three three zero	H--- A330 S---	Descend to and maintain flight level 230 (16 window and VOSYN correspondingly modified) A230
-	COMPANY	UA 781 Moderate Turbulence FL 290 B727	PIMODTURBFL290 SEND					TW781 Moderate Turbulence FL 250 DC9 A230 (CDU input also modified)
28	ATC	LAX Center 134.85		X	LAX CNTR 134.85	Los Angeles Center one three four point eight five	H--- A330 S---	A230
29	ATC	Squawk Ident			IDENT	Squawk Ident	H--- A330 S---	A230
30	ATC	Radar Contact			RADAR CONTACT	Radar Contact	H--- A330 S---	A230

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
31	ATC	Descend to and maintain 11000		X	↓↓110	Descend to and maintain eleven thousand feet	H--- A110 S---	
32	ATC	Squawk 2701			SQK 2701	Squawk two seven zero one	H--- A110 S---	
33	ATC	LAX Altimeter 30.00		X	LAX ALTM 30.00	Los Angeles Altimeter three zero zero zero	H--- A110 S---	
34	ATC	Speed 250		X	SPEED 250	Speed two five zero knots	H--- A110 S250	
-	COMPANY	UA 781 Plan Gate D6 Connections 471 D7 292 E6, 311 D3 (Type 1 message valid to message No. 52)	GATE, SEND				H--- A110 S250	TW 781....
35	ATC	Descend to and maintain 7000		X	↓↓070	Descend to and maintain seven thousand feet	H--- A070 S250	
36	ATC	Depart FILLMORE Heading 148		X	DEP FIM HDG 148	Depart Fillmore heading one four eight	H--- A070 S250	
37	ATC	LAX Approach 124.5		X	LAX APP 124.5	Los Angeles Approach one two four point five	H148 A070 S250	
38	ATC	Squawk Ident			IDENT	Squawk Ident	H148 A070 S250	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT (WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
39	ATC	Radar Contact		RADAR CONTACT	Radar Contact	H148 A070 S250	
40	ATC	Turn left heading 110	X	←←110	Turn left heading one one zero	H110 A070 S250	
41	ATC	Intercept SMO 261R	X	INTERCPT SMO 261R	Intercept Santa Monica 261 degree radial	H--- A070 S250	
42	ATC	Descend to and maintain 5000 Reduce speed to 200	X	↓↓050 SPD 200	Descend to and maintain five thousand Reduce speed to two hundred knots	H--- A050 S200	
43	ATC	Proceed direct SMO depart heading 078	X	DRCT SMO DEP 078	Proceed direct Santa Monica Depart heading zero seven eight	H--- A050 S200	
44	ATC	Radar vectors for ILS runway 25L approach	X	VCTR ILS RWY 25L	Radar vectors for ILS runway two five left	H--- A250 S200	
45	ATC	Turn right heading 140	X	→→140	Turn right heading one four zero	H140 A050 S200	
46	ATC	Turn right heading 220	X	→→220	Turn right heading two two zero	H220 A050 S200	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM LA)
-	ATC	Wind 280 at 15 (Type 1 valid after No. 48)	WIND CK, SEND	X	WIND 280 AT 15	Wind two eight zero at one five		
47	ATC	Intercept runway 25 left localizer		X	INTERCPT 25L LOC	Intercept runway two five left localizer	H--- A050 S200	
50	ATC	Cleared for ILS runway 25 left approach		X	CFAP ILS RWY 25L	Cleared for ILS runway two five left approach	H--- A--- S---	
49	ATC	Your position is 4 miles east of the outer marker		X	PSN 4 Ē LOM	Your position is four miles east of the outer marker	H--- A--- S---	
50	ATC	LAX Tower 118.9		X	LAX TWR 118.9	Los Angeles tower one one eight point niner	H--- A--- S---	
51	ATC	Wind 280 at 15		X	WIND 280 AT 15	Wind two eight zero at one five	H--- A--- S---	
52	ATC	Cleared to land runway 25 left		X	CLR LAND RWY 25L	Cleared to land runway two five left	H--- A--- S---	
53	ATC	LAX ground 121.8		X	LAX GND 121.8	Contact Los Angeles ground on one two one point eight	H--- A--- S---	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
54	ATC	Taxi to gate		X	CLR GATE	Taxi to gate	H--- A--- S---	
-	COMPANY	UA 781 Gate D6 (Type 1 valid after No. 55)	GATE,SEND					TW 781 Gate D6
-	COMPANY	UA 781 Arrived LAX on---- In---- Fuel 11.1 (inserted)	ARRIVED---- ---- 111, SEND					TW 781 Arrived LAX on---- in---- Fuel 101 (CDU input correspondingly modified)

* Type 1 messages are not numbered since they can occur anywhere within the scenario. They are shown only to establish their approximate position.

SCENARIO II

KANSAS CITY TO CHICAGO

NOTE: This Scenario requires cockpit clocks/pilot watches to be reset to 1800 (6PM) CDT prior to the start.

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
	ATC	Kansas City International information Foxtrot ceiling measured 900 broken 2000 overcast visibility 6 miles in very light drizzle, temperature 68 Dewpoint 62, wind 040 at 8 Altimeter 29.99 Instrument approaches in use runway 1, Departures runway 1	ATIS, SEND	X	SEE PTR ATIS	Kansas City International information Foxtrot ceiling measured nine hundred broken two thousand overcast visibility six miles in very light drizzle, temperature six eight Dewpoint six two, Wind zero four zero at eight Altimeter two niner niner niner, Instrument approaches in use runway one, Departures runway one		
1	ATC	UA 492 is cleared to the O'Hare International Airport via radar vectors to the Kansas City 052 radial Jet 26 Bradford Vortac O'Hare 235 Radial to O'Hare Maintain 11000, Expect flight level 330 10 minutes after departure Maintain runway heading after takeoff. Squawk 2631 on departure	CLRANCE, SEND	X	SEE PTR CLRANCE	United four ninety two is cleared to the O'Hare International Airport via radar vectors to The Kansas City zero five two radial Jet Twenty-six Bradford Vortac, O'Hare two three five radial to O'Hare, Maintain eleven thousand, Expect flight level three three zero ten minutes after departure. Maintain runway heading after takeoff Squawk two six three one on departure.	H--- A--- S---	TW492 is cleared to the O'Hare International Airport via etc. (same as Message Printer except expect flight level two niner zero) (VOSYN MESSAGE IS CORRESPONDINGLY MODIFIED)
2	ATC	MCI Ground 121.8		X	MCI GND 121.8	Kansas City Ground one two one point eight	H--- A--- S---	
-	COMPANY	UA 492 B727 AC 7619 ZFW 127.1 ATOGW 149.3 MAC 22.5 PSGRS 16F105Y	MANIFST, SEND					(Delete this message)
3	ATC	Cleared to Push Back	PUSH BK, SEND	X	CLR PUSH BACK		H--- A--- S---	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
4	ATC	Taxi to runway 1	TAXI,SEND	X	TAXI RWY 1	Taxi to runway one	H--- A--- S---	
-	COMPANY	UA 492 Departure report received (Type 1) UA 492 Departed MCI at ---- Fuel 21.1 (inserted message)	DEPARTD, SEND					(Delete this message)
5	ATC	MCI Tower 125.75		X	MCI TWR 125.75	Kansas City Tower one two five point seven-five	H--- A--- S---	
-	ATC	Wind 050 at 10 (Type 1 Valid to message no. 15)	WIND CK, SEND	X	WIND 050 AT 10	Wind zero five zero at one zero		
6	ATC	Wind 050 at 10		X	WIND 050 AT 10	Wind zero five zero zero at one zero	H--- A--- S---	
7	ATC	Cleared for takeoff runway 1		X	CLR TKOF RWY 1	Cleared for takeoff runway one	H010 A110 S---	
8	ATC	MCI Departure 123.95		x	MCI DEP 123.95	Kansas City Departure one two three point niner five	H010 A110 S---	
9	ATC	Squawk Ident			IDENT	Squawk Ident	H010 A110 S---	
10	ATC	Radar Contact			RADAR CONTACT	Radar Contact	H010 A110 S---	

MSG.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
11	ATC	MCI Altimeter 30.06		X	MCI ALTM 30.06	Kansas City Altimeter three zero zero six	H010 A110 S---	
12	ATC	Traffic 1 o'clock 5 miles Altitude 6000 westbound slow		UNABLE	TFC 1 5 060 W S	Traffic one o'clock five miles six thousand feet westbound slow	H010 A110 S---	
13	ATC	Turn right heading 080		X	→080	Turn right heading zero eight zero	H080 A110 S---	
14	ATC	Intercept Kansas City 052 radial		X	INTERCEPT MKC 052R	Intercept the Kansas City zero five two radial	H080 A110 S---	
-	COMPANY	UA 492 Off report received (Type 1)	OFF,SEND					TW 492 Off Report received
		UA 492 off MCI at ---- (inserted message)						TW 492 off MCI out---- off---- Fuel 185 (CDU input message correspondingly modified)
15	ATC	Clear of traffic		X	CLR TFC	Clear of traffic	H080 A110 S---	
16	ATC	MKC Center 125.25		X	MKC CNTR 125.25	Kansas City Center one two five point two five	H--- A110 S---	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT (WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
17	ATC	Squawk Ident		IDENT	Squawk Ident	H--- A110 S---	
18	ATC	Radar Contact		RADAR CONTACT	Radar Contact	H--- A110 S---	
19	ATC	Climb to and maintain flight level 330	X	↑↑330	Climb to and maintain flight level three three zero	H--- A330 S---	Climb and maintain level 290 (16 window and VOSYN message correspondingly modified) A290
-	COMPANY	UA 492 Contact ORD Maintenance on 131.4 (a free-form voice message follows)					TW 492....
20	ATC	MKC Center 132.6	X	MKC CNTR 132.6	Kansas City Center one three two point six	H--- A330 S---	A290
21	ATC	Squawk Ident		IDENT	Squawk Ident	H--- A330 S---	A290
22	ATC	Radar Contact		RADAR CONTACT	Radar Contact	H--- A330 S---	A290
-	COMPANY	UA 492 ORD Advisory, Expect 10-15 Minutes delay due to traffic vcty ORD					TW 492....

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT (WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
23	ATC	Chicago Center 135.6	X	CHI CNTR 135.6	Chicago center one three five point six	H--- A330 S---	A290
24	ATC	Squawk Ident		IDENT	Squawk Ident	H--- A330 S---	A290
25	ATC	Radar Contact		RADAR CONTACT	Radar Contact	H--- A338 S---	A290
26	ATC	Descend to and maintain 8000	X	↓↓080	Descend to and maintain eight thousand	H--- A080 S---	
27	ATC	Squawk 8626	UNABLE	SQK 8626	Squawk eight six two six	H--- A080 S---	
28	ATC	Squawk 2626	X	SQK 2626	Squawk two six two six	H--- A080 S---	
29	ATC	ORD Altimeter 30.10	X	ORD ALTM 30.10	Chicago Altimeter three zero one zero	H--- A080 S---	
30	ATC	ORD Approach 125.7	X	ORD APP 125.7	Chicago approach one two five point seven	H-- A080 S---	
31	ATC	Squawk Ident		IDENT	Squawk Ident	H--- A080 S---	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
32	ATC	Radar Contact			RADAR CONTACT	Radar Contact	H--- A080 S---	
33	ATC	UA 492 cleared to the valley intersection Hold southwest on the O'Hare 235 radial, expect approach clearance at 0012		X	SEE PTR CLRANCE	United four ninety two is cleared to the valley intersection Hold southwest on the O'Hare two three five degree radial, expect approach clearance at zero zero one two	H--- A080 S---	TW 492---
34	ATC	Speed 210		X	SPEED 210	Speed two one zero knots	H--- A080 S210	
-	COMPANY	UA 492 Revised ETA report received (Type 1) UA 492 Revised ETA ---- (Inserted message)	ETA/ETO----, SEND					TW 492---
35	ATC	Descend to and maintain 7000		X	↓↓070	Descend to and maintain seven thousand	H--- A070 S210	
-	COMPANY	UA 492 Plan Gate El (Type 1 Valid to message No. 49)	GATE, SEND					
36	ATC	Descend to and maintain 6000		X	↓↓060	Descend to and maintain six thousand	H--- A060 S210	
37	ATC	Radar vectors for ILS 14 Right approach		X	VCTR ILS RWY 14R	Radar vectors for ILS runway one four right approach	H--- A060 S210	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
38	ATC	Depart VALLEY heading 030		X	DEP VALY HDG 030	Depart valley intersection heading zero three zero	H030 A060 S210	
39	ATC	Traffic 12 o'clock 2 miles 4000 feet Westbound Slow		X	TFC 12 2 040 WB S	Traffic twelve o'clock two miles four thousand feet Westbound Slow	H030 A060 S210	
40	ATC	Descend to and maintain 4000		X	↓↓040	Descend to and maintain four thousand	H030 A040 S210	
41	ATC	Clear of traffic		X	CLR TFC	Clear of traffic	H030 A040 S210	
42	ATC	Speed 160		X	SPEED 160	Speed one six zero knots	H030 A040 S160	
43	ATC	Turn right heading 110		X	→→110	Turn right heading one one zero	H110 A040 S160	
44	ATC	Cleared for ILS runway 14 right approach		X	CFAP ILS RWY 14R	Cleared for ILS runway one four right approach	H--- A--- S---	
-	ATC	Wind 180 at 7	WIND CK, SEND	X	WIND 180 AT 7	Wind one eight zero at seven		

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
45	ATC	Your position is 3 miles northwest of Romeo		X	PSN 3 NW ROMEO	Your position is three miles north-west of Romeo	H--- A--- S---	
46	ATC	ORD tower 120.7		X	ORD TWR 120.7	O'Hare tower one two zero point seven	H--- A--- S---	
-	ATC	Wind 180 at 7 (Type 1 Valid after sequence No. 45)	WIND CK, SEND	X	WIND 180 AT 7	Wind one eight zero at seven		
47	ATC	Cleared to land runway 14 Right		X	CLR LAND RWY 14R	Cleared to land runway one four right	H--- A--- S---	
48	ATC	ORD ground 121.9		X	ORD GND 121.9	Chicago ground one two one point niner	H--- A--- S---	
49	ATC	Cleared to taxi to E Pavillion via the outer taxiway		X	TAXI E BY OUTER	Cleared to taxi to Echo Pavillion via the outer taxiway	H--- A--- S---	
-	COMPANY	UA 492 Gate E2 (Type 1 message valid after message no. 49)	GATE, SEND					TW 492 Gate E2
-	COMPANY	UA 492 Arrived ORD on---- in---- Fuel 10.1 (Inserted message)	ARRIVED, SEND					TW 492 Arrived ORD on---- in---- Fuel 110

* Only Type 2 messages have sequence numbers; Type 1 messages are not sequentially numbered.

SCENARIO III

LOS ANGELES TO SAN FRANCISCO

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
-	ATC	Los Angeles International Airport information Zulu Ceiling unlimited visibility 3 miles in haze and smoke Temperature 61 Dewpoint 54 Wind 270 at 14 Altimeter 30.10 ILS approaches runways 24 left and 24 right Departures runways 25 left and 25 right	ATIS,SEND	X	SEE PTR ATIS	Los Angeles International Airport information Zulu ceiling unlimited visibility three miles in haze and smoke, Temperature six one, Dewpoint five four, Wind two seven zero at one four, Altimeter three zero one zero ILS approaches runways two four left and two four right Departures runways two five left and two five right		
1	ATC	UA 246 is cleared to the San Francisco Airport via Ventura Two departure Salinas Transition Jet 88 Santa Cruz Intersection Woodside 141R, Woodside Victor 25 San Francisco Maintain Flight level 280, Squawk 4701 on departure	CLRANCE, SEND	X	SEE PTR CLRANCE	United two forty-six is cleared to the San Francisco Airport via Ventura Two Departure Salinas Transition Jet eighty-eight Santa Cruz Intersection Woodside one four one radial Woodside Victor twenty-five San Francisco Maintain flight level two eight zero, Squawk four seven zero one on departure	H--- A--- S---	TW 246 is cleared etc. except maintain flight level two six zero. (VOSYN message correspondingly modified)
2	ATC	LAX Ground 121.8		X	LAX GND 121.8	Los Angeles Ground one two one point eight	H--- A--- S---	
3	ATC	Cleared to push back	PUSH BK, SEND	X	CLR PUSH BACK	Cleared to push back	H--- A--- S---	
4	ATC	Taxi to runway 25 left	TAXI, SEND	X	TAXI RWY 25L	Taxi to runway two five left	H--- A--- S---	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
-	COMPANY	UA 246 B727 AC 7619 ZFW 127.1 ATOGW 146.1 MAC 22.4 PSGRS 18F 104Y	MANIFEST, SEND					(Delete this message)
-	COMPANY	UA 246 Departure report received (Type 1) UA 246 Departed LAX at ---- Fuel 20.0 (Inserted message)	DEPARTED LAX ---- 200, SEND					(Delete this message)
5	ATC	LAX Tower 118.9		X	LAX TWR 118.9	Los Angeles Tower one one eight point niner	H--- A--- S---	
6	ATC	Cleared for takeoff runway 25 left		X	CLR TKOF RWY 25L	Cleared for takeoff runway two five left	H--- A--- S---	
-	ATC	Wind 275 at 16 (Type 1 valid until message no. 12)	WIND CK, SEND	X	WIND 275 AT 16	Wind two seven five at one six		
7	ATC	LAX Departure 125.2		X	LAX DEP 125.2	Los Angeles Departure one two five point two	H--- A--- S---	
8	ATC	Squawk Ident			IDENT	Squawk Ident	H--- A--- S---	
9	ATC	Radar Contact			RADAR CONTACT	Radar Contact	H--- A--- S---	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT (WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
10	ATC	Maintain heading 250 Radar Vectors for VTU	X	HDG 250 VCTR VTU	Maintain heading two five zero vectors for ventura	H250 A--- S---	
11	ATC	Climb to and maintain 6000	X	↑↑060	Climb to and maintain six thousand	H250 A060 S---	
12	ATC	Traffic 11 o'clock 3 miles 4000 feet Southeast bound slow	X	TFC 11 3 020 SE S	Traffic eleven o'clock three miles Altitude two thousand feet Southeast bound Slow	H250 A060 S---	
13	ATC	Proceed direct VTU	X	DRCT VTU	Proceed direct Ventura	H--- A060 S---	
14	ATC	Traffic 3 o'clock 4 miles 6000 feet Southbound Fast	UNABLE	TFC 3 1 030 S F	Traffic three o'clock four miles Altitude six thousand feet South-bound Fast	H--- A060 S---	
15	ATC	Clear of traffic	X	CLR TFC	Clear of traffic	H--- A060 S---	
16	ATC	LAX Center 125.0	X	LAX CNTR 125.0	Los Angeles Center one two five point zero	H--- A060 S---	
17	ATC	Squawk Ident		IDENT	Squawk Ident	H--- A060 S---	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
18	ATC	Radar contact climb to and main-tain flight level 280		X	RDR CNCT ↑↑280	Radar Contact Climb to and maintain flight level two eight zero	H--- A280 S---	Radar Contact Climb to Flight level 260. (VOSYN and 16 window messages correspondingly modified) A260
-	COMPANY	UA 246 Off Report received (Type 1)	OFF LAX ----,SEND					TW 246 OFF LAX OUT---- Off----Fuel 175 (CDU input also modified) A260
	•	UA 246 off LAX at ---- (Inserted message)						
19	ATC	Expedite through flight level 190		X	EXPEDITE THRU 190	Expedite through flight level one niner zero	H--- A280 S---	A260
20	ATC	OAK CNTR 128.7		X	OAK CNTR 128.7	Oakland Center one two eight point seven	H--- A280 S---	A260
21	ATC	Squawk Ident			IDENT	Squawk Ident	H--- A280 S---	A260
22	ATC	Radar Contact			RADAR CONTACT	Radar contact	H--- A280 S---	A260
-	COMPANY	UA 246 SFO Advisory, UA/TW flights tow-in if unable to park with idle thrust due to pavillion construction						TW 246....

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
-	COMPANY	(Free-form voice) Airplane Condition report, Lower rotating beacon has one bulb out.	VOICE, SEND					
23	ATC	Descend to and maintain 7000		X	↓↓070	Descend to and maintain seven thousand feet	H--- A070 S---	
24	ATC	OAK Center 126.8		X	OAK CNTR 126.8	Oakland Center one two six point eight	H--- A070 S---	
25	ATC	Squawk Ident			IDENT	Squawk Ident	H--- A070 S---	
26	ATC	Radar Contact			RADAR CONTACT	Radar Contact	H--- A070 S---	
27	ATC	SFO Altimeter 30.15		X	SFO ALTM 30.15	San Francisco Altimeter three zero one five	H--- A070 S---	
28	ATC	Proceed direct OAK direct SFO		X	DRCT OAK DRCT SFO	Proceed direct Oakland direct San Francisco	H--- A070 S---	
29	ATC	SFO Approach 123.85		X	SFO APP 123.85	San Francisco Approach one two three point eight five	H--- A070 S---	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
30	ATC	Squawk Ident			IDENT	Squawk Ident	H--- A070 S---	
31	ATC	Radar Contact			RADAR CONTACT	Radar Contact	H--- A070 S---	
32	ATC	Speed 230		X	SPEED 230	Speed two three zero knots	H--- A070 S230	
33	ATC	Radar vectors for ILS runway 28 left approach		X	VCTR ILS RWY 28L	Radar vectors for ILS runway two eight left approach	H--- A070 S230	
34	ATC	Turn right heading 3*5		UNABLE	→→3*5	Turn right heading three (long pause) five	H3-5 A070 S230	
35	ATC	Turn right heading 345		X	→→345	Turn right heading three four five	H345 A070 S230	
-	COMPANY	UA 246 Plan gate C6 (Type 1 valid to message no. 53)	GATE,SEND					TW 246....
36	ATC	Descend to and maintain 3000		X	↓↓030	Descend to and maintain three thousand feet	H345 A030 S230	
37	ATC	Turn left heading 310			←←310	Turn left heading three one zero	H310 A030 S230	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
38	ATC	Intercept localizer for runway 28 Left		X	INTERCPT LOC 28L	Intercept localizer for runway two eight left	H310 A030 S230	
39	ATC	Cleared for ILS runway 28 Left approach		X	CFAP ILS RWY 28L	Cleared for ILS runway two eight left approach	H--- A--- S---	
40	ATC	Your position is 3 Southeast of Foster		X	PSN 3 SE FOSTER	Your position is three southeast of Foster	H--- A--- S---	
-	ATC	Wind 265 at 12 (Type 1 valid after message no. 41)	WIND CK, SEND	X	WIND 265 AT 12	Wind two six five at one two		
41	ATC	SFO Tower 120.5		X	SFO TWR 120.5	San Francisco Tower one two zero point five	H---	
42	ATC	Go Around		X	GO AROUND	Go Around	H--- A--- S---	
43	ATC	Disabled Aircraft on runway		X	DISAB AC ON RWY	Disabled Aircraft on runway	H--- A--- S---	
44	ATC	SFO approach 123.85		X	SFO APP 123.85	San Francisco Approach one two three point eight five	H--- A--- S---	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
45	ATC	Turn left heading 180 Climb to and maintain 4000		X	←←180 ↑↑040	Turn left heading one eight zero, Climb to and maintain four thousand feet	H180 A040 S---	
46	ATC	Turn left heading 100		X	←←100	Turn left heading one zero zero	H100 A040 S---	
47	ATC	Turn left heading 010		X	←←010	Turn left heading zero one zero	H010 A040 S---	
48	ATC	Turn left heading 310 Reduce speed to 150		X	←←310 SPD 150	Turn left heading three one zero Reduce speed to one five zero knots	H310 A040 S150	
49	ATC	Cleared for ILS Runway 28 Left approach		X	CFAP ILS RWY 28L	Cleared for ILS runway two eight left approach	H--- A--- S---	
50	ATC	Your position is 1 southeast of Foster		X	PSN 1 SE FOSTER	Your position is one southeast of Foster	H--- A--- S---	
51	ATC	SFO Tower 120.5		X	SFO TWR 120.5	San Francisco Tower one two zero point five	H---	
52	ATC	Cleared to land runway 28 Left		X	CLR LAND RWY 28L	Cleared to land runway two eight left	H--- A--- S---	

SEQ.* NO.	ATC OR COMPANY	MESSAGE TEXT (PRINTER)	CDU INPUT	(WILCO)	(SMATC)	VOSYN	HAS RECALL	TW MESSAGE (IF DIFFERENT FROM UA)
53	ATC	SFO Ground 121.8		X	SFO GND 121.8	San Francisco ground one two one point eight	H--- A--- S---	
54	ATC	Taxi to Concourse C		X	TAXI CNCRSE C	Taxi to concourse C	H--- A--- S---	
-	COMPANY	UA 246 Gate C6 (Type 1 valid after message no. 53)	GATE,SEND					TW 246 Gate C6
-	COMPANY	UA 246 Arrived SFO on ---- In ---- Fuel 11.1 (Inserted)	ARRIVED SFO ---- ---- 111, SEND					TW 246 Arrived SFO on ---- In---- Fuel 105 (CDU input also modified)

* Type 1 messages are not numbered. Only sequential Type 2 messages are numbered.

SUPPLEMENTAL ATIS AND WEATHER REPORTS

SUPPLEMENTAL ATIS

	MESSAGE TEXT (PRINTER)	(SMATC)	VOSYN
Chicago ATIS	O'Hare International Airport. Information Kilo. Ceiling 1100 broken, visibility 4 miles in haze and smoke. Temperature 65, Dewpoint 60. Wind 180 at 15. Altimeter 30.05. Approach in use ILS runway 14 right. Departures runway 14 left.	SEE PTR ATIS	O'Hare International Airport. Information Kilo. Ceiling eleven hundred broken, visibility four miles in haze and smoke. Temperature six five, Dewpoint six zero. Wind one eight zero at one five. Altimeter three zero zero five. Approach in use ILS runway one four right. Departures runway one four left.
San Jose ATIS	San Jose Municipal Airport information Alpha 2500 scattered ceiling measured 5000 overcast visibility 8. Temperature 63 Dewpoint 57. Wind 210 at 12. Altimeter 29.98. Approach in use ILS runway 30L. Departures 30L.	SEE PTR ATIS	San Jose Municipal Airport information Alpha two thousand five hundred scattered ceiling measured five thousand overcast visibility eight. Temperature six three Dewpoint five seven. Wind two one zero at one two. Altimeter two niner niner eight. Approach in use ILS runway three zero left. Departures runway three zero left.
Ontario ATIS	Ontario International Airport information Whiskey 25000 thin broken visibility 10. Temperature 68 Dewpoint 60. Wind 270 at 10. Altimeter 30.11. ILS approaches for runway 25 in use. Departures runway 25.	SEE PTR ATIS	Ontario International Airport information Whiskey two five thousand thin broken visibility one zero. Temperature six eight Dewpoint six zero. Wind two seven zero at one zero. Altimeter three zero one one. ILS approaches for runway two five in use. Departures runway two five.
Milwaukee ATIS	Milwaukee General Mitchell Field information Sierra Ceiling measured 2500 broken 4500 overcast visibility 7. Temperature 63 Dewpoint 56. Wind 110 at 10. Altimeter 30.08 ILS approaches in use runway 7R Departures on runway 7R.	SEE PTR ATIS	Milwaukee General Mitchell Field information Sierra Ceiling measured two thousand five hundred broken four thousand five hundred overcast visibility seven. Temperature six three Dewpoint five six. Wind one one zero at one zero. Altimeter three zero zero eight. ILS approaches in use runway seven right. Departures on runway seven right.

WEATHER REPORTS

	MESSAGE TEXT (PRINTER)	(SMATC)	VOSYN
SFO Weather	San Francisco. Weather: Ceiling measured 300 overcast, visibility 1 mile in fog, Temperature 53, Dewpoint 53. Wind 270 at 12, Altimeter 30.04.	SEE PTR WEATHER	San Francisco Weather. Ceiling measured three hundred overcast, visibility one mile in fog. Temperature five three, Dewpoint five three, Wind two seven zero at one two, Altimeter three zero zero four.
LAX Weather	Los Angeles. Weather: Clear, Visibility 3 miles in haze and smoke, Temperature 61, Dewpoint 54. Wind 270 at 14. Altimeter 30.10.	SEE PTR WEATHER	Los Angeles Weather. Clear. Visibility three miles in haze and smoke. Temperature six one, Dewpoint five four. Wind two seven zero at one four. Altimeter three zero one zero.
MCI Weather	Kansas City Weather: Ceiling measured 900 broken, 2000 overcast, visibility 6 miles in very light drizzle. Temperature 68 Dewpoint 62. Wind 040 at 8. Altimeter 29.99	SEE PTR WEATHER	Kansas City Weather. Ceiling measured nine hundred broken two thousand overcast. Visibility six miles in very light drizzle. Temperature six eight. Dewpoint six two. Wind zero four zero at eight. Altimeter two niner niner niner.
ORD Weather	Chicago O'Hare Weather: Ceiling 1100 broken visibility 4 miles in haze and smoke. Temperature 63. Dewpoint 60. Wind 180 at 15. Altimeter 30.05.	SEE PTR WEATHER	Chicago O'Hare Weather. Ceiling one thousand one hundred broken. Visibility four miles in haze and smoke. Temperature six five. Dewpoint six zero. Wind one eight zero at one five. Altimeter three zero zero five.
SJC Weather	San Jose Weather: 2500 scattered. Ceiling measured 5000 overcast visibility 8. Temperature 63 Dewpoint 57. Wind 210 at 12. Altimeter 29.98.	SEE PTR WEATHER	San Jose Weather. Two thousand five hundred scattered. Ceiling measured five thousand overcast. Visibility eight. Temperature six three Dewpoint five seven. Wind two one zero at one two. Altimeter two niner niner eight.

WEATHER REPORTS Contd.

	MESSAGE TEXT (PRINTER)	(SMATC)	VOSYN
ONT Weather	Ontario Weather: 25000 thin broken. Visibility 10. Temperature 68 Dewpoint 60 Wind 270 at 10. Altimeter 30.11.	SEE PTR WEATHER	Ontario Weather. Two five thousand thin broken. Visibility one zero. Temperature six eight Dewpoint six zero. Wind two seven zero at one zero. Altimeter three zero one one.
MKE Weather	Milwaukee Weather: Ceiling measured 2500 broken. 4500 overcast visibility 7. Temperature 63 Dewpoint 56. Wind 110 at 10. Altimeter 30.08.	SEE PTR WEATHER	Milwaukee Weather. Ceiling measured two thousand five hundred broken. Four thousand five hundred overcast. Visibility seven. Temperature six three Dewpoint five six. Wind one one zero at one zero. Altimeter three zero zero eight.

APPENDIX B

FLIGHT CREW INFORMATION

EVALUATION OF DATA LINK
INPUT/OUTPUT DEVICES USING
AIRLINE FLIGHT SIMULATORS

FLIGHT TESTING PHASE NOVEMBER 1974 - JNAUARY 1975

B.1 GENERAL INFORMATION

B.1.1 Nature of the Effort

You have been selected to participate in an evaluation program for various data-link Input/Output devices. What devices are we talking about? Digitally driven instruments for displaying present-day Air Traffic Control and company-oriented communications. Devices similar to these could eventually be used in the cockpit of the aircraft you fly.

The objectives of this series of tests are:

(1) To evaluate candidate Input/Output (I/O) devices for air-ground-air data-link application in the more sophisticated and realistic environment of commercial airline flight simulators.

(2) To expose a significant number of air-carrier pilots to the data-link concept by participation in the airline simulator experiments and to obtain their opinions and suggestions regarding data-link hardware, location, and procedures within the cockpit.

We plan to accomplish the first objective by collecting a large quantity of data from our computer equipment and from the answers to questionnaires you will be asked to fill out at the completion of the tests. For the results of the second objective, we rely heavily on your subjective opinions--Do you like it or do you not? If not, what can be done to improve it? If you think we are on the wrong track, what is the right one?

B.1.2 Brief History of the Program

This evaluation program, which has been going on for several years now, is sponsored by the Systems Research and Development Service of the Federal Aviation Administration. In turn, they have funded the DOT/Transportation System Center (TSC) to carry on the cockpit environment, ground environment, and radio-link development efforts. TSC has contracted with ARINC Research, along with its subcontractors, United Air Lines and Trans World Airlines, to plan, organize, conduct, and evaluate the experiments involving airline simulators.

This effort is the culmination of the simulator tests. Previous tests with these same devices have been conducted at the FAA's National Aviation Facilities Experimental Center (NAFEC) using the GAT-II simulator flown by general aviation, NAFEC, and volunteer airline pilots. Previous efforts involving some devices that have now been eliminated in favor of the current devices have been flown also in the GAT-II and in TSC's GAT-I test laboratory in Cambridge, Massachusetts.

B.1.3 Experimental Devices

Digitally driven instruments supplied by the Transportation Systems Center will be used in these trials. With the increasing level of automation and computer assistance now being employed in the enroute centers, the approach control facilities, and company dispatch centers, there are many instances in which digitally transmitted and displayed information could benefit both the system and the pilot.

These devices can be broken into various classes:

Visual versus Aural: We will expose you to devices using digital voice synthesis as well as those using visual digital display.

Hardcopy versus Softcopy: We will use devices with perishable displays as well as permanent-copy devices.

Uplink versus Downlink: We will provide devices capable of transmitting a wide variety of responses/requests to the ground in addition to devices that receive only.

These devices include the following:

- 16-character short-message ATC display (SMATC)
- Voice Synthesizer (VOSYN)
- Printer
- Control and Downlink Unit (CDU)

In addition, data-link equipment will include control yoke or pendant-mounted WILCO switches for message acknowledgement and an aural alert to advise you of an impending message.

These devices will be driven by a small computer that we have located immediately outside the simulator area. This computer will also be used to collect the data (mainly times) on your responses and use of the equipment.

B.2 TEST PROCEDURE

You will be asked to complete three flights, each lasting about one hour and ten minutes. On each of these three flights you will use a different complement or mixture of I/O devices. At the conclusion of this briefing, you will be given a sheet describing the filed clearance route of the three flights in the order you will fly them. The devices available on each of these flights will be listed.

Some of these will be daytime, some will be nighttime. Some flights may be completely smooth, while turbulence may be introduced for portions of others.

There are no in-flight emergencies (unless you create one)--only normal occurrences such as inclement weather, traffic delays, etc.

Please visualize this as a normal flight and not a data-gathering exercise. We have tried to make the flights realistic and hope that you will inject yourself into the scenario. The Observer will offer comment if you have questions about a particular aspect of operation. If you have a question, do not hesitate to ask the Observer. He may ask you to transmit certain messages during the course of the flight. These might be company messages or ATC-type messages.

Prior to the beginning of the first flight, you will be given an opportunity to familiarize yourself with the operation of the devices. The crew-familiarization run will be conducted under the direction of the Observer. There will be approximately a 10-minute break in each flight while the tapes for the next flight are loaded. During this period you will be asked to answer questions relating to the devices you just flew with.

B.3 TEST DEBRIEFING

At the completion of the three tests, you will be asked to complete a questionnaire. This will relate to the devices and the procedures used during the test. You will also be asked to discuss some of your more significant impressions with the Observer during a brief interview.

Thank you for your participation.

B.4 DEVICE DESCRIPTIONS

B.4.1 SMATC Display

The Short Message ATC (SMATC) display is shown in Figure B-1. The SMATC (Short Message ATC) display consists of sixteen alphanumeric characters arranged in two lines of eight characters each. The characters are red-dot-matrix LEDs, and a dimming control is provided. Each new message sent to the SMATC will be accompanied by an audible alert (three separate tones in sequence). As explained under the "Full CDU" section, the latest heading, altitude, and speed messages may be recalled onto the SMATC, with appropriate labels, at the pilot's discretion.

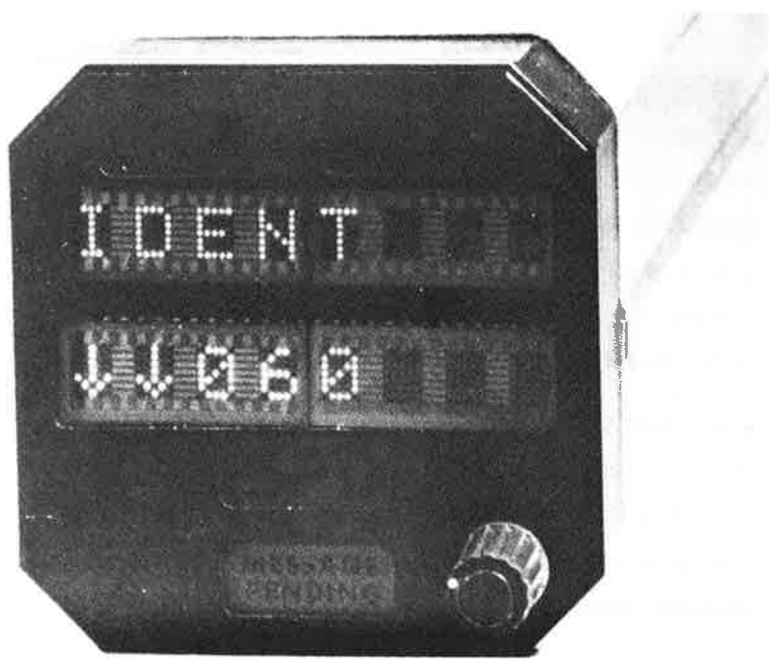


Figure B-1. SMATC Display

The following abbreviations will be used with the SMATC display:

ALT = MAINTAIN ALTITUDE
ALTM = ALTIMETER
APP = APPROACH
CFAP = CLEARED FOR APPROACH
CLR = CLEAR OR CLEARED
CTR = CENTER
DEP = DEPART(URE)(ED)
FPR = FLIGHT PLAN ROUTE
DRCT = DIRECT
GND = GROUND
HDG = HEADING
LND = LAND
LOC = LOCALIZER
NAV = NAVIGATION
← = TURN LEFT
→ = TURN RIGHT
NORM = NORMAL
LOM = OUTER MARKER
PSN = POSITION
PTR = PRINTER
RWY = RUNWAY
SHRT = SHORT
SQK = SQUAWK
TFC = TRAFFIC
TKOF = TAKEOFF
TWR = TOWER
VCTR = VECTORS
↑↑ = CLIMB TO AND MAINTAIN
↓↓ = DESCEND TO AND MAINTAIN

The meaning of messages containing these abbreviations should be self-explanatory, with the possible exception of traffic advisories. Here, a standard format will be used for all such advisories as follows:

Clock Position   Distance (in miles)

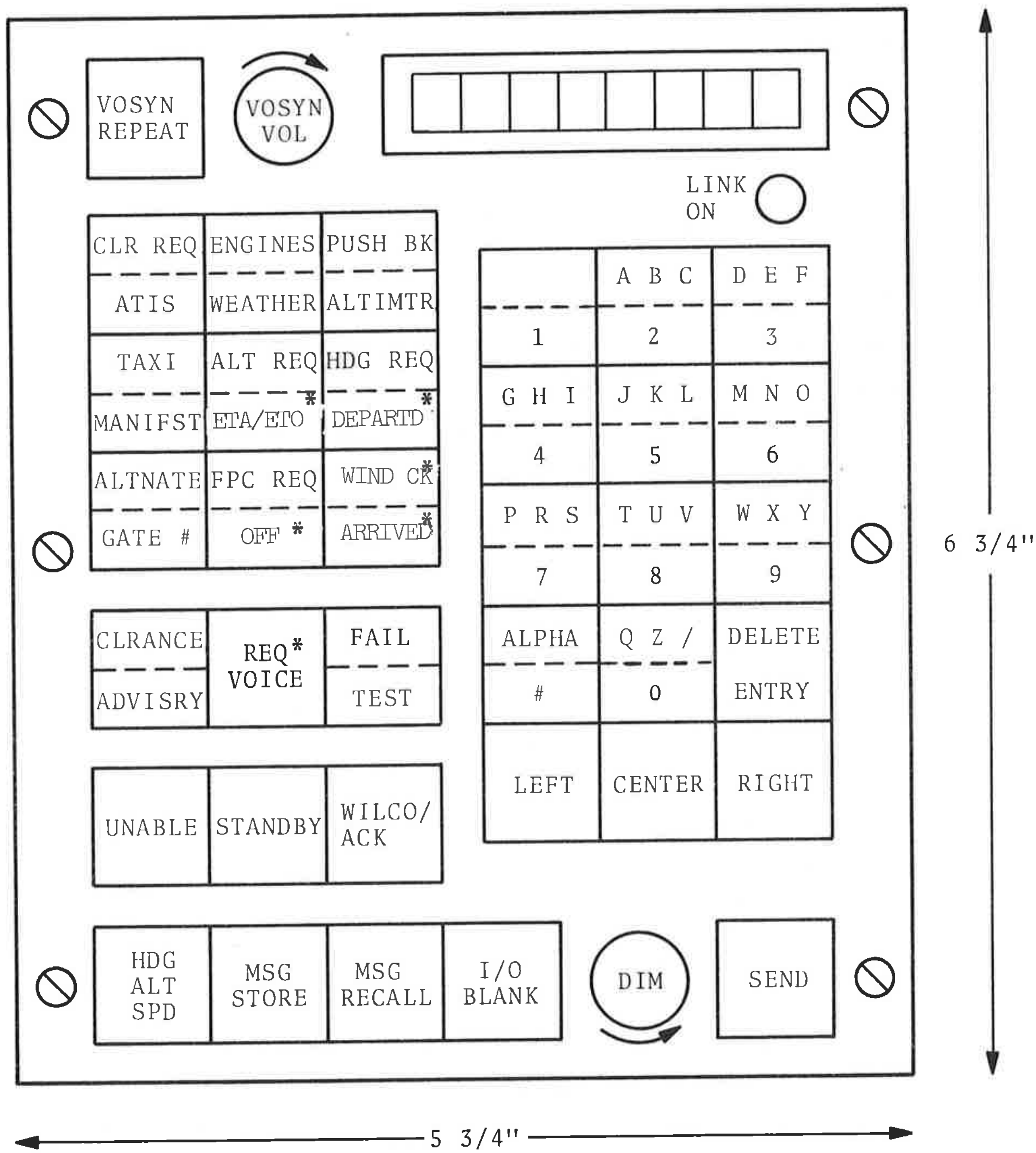
TFC 02 3
050 NE F

Alt.   Hdg.   Speed (F = Fast, S = Slow)

B.4.2 Control and Downlink Unit (CDU)

Figure 2 is a picture of the CDU keyboard. No attempt will be made to explain every button or function since many of them are self-evident from the name. Rather, we will attempt to acquaint you with the capabilities of the CDU and urge you to use it as much as possible during your three flights.

Every uplink ATC message transmitted from the ground must be responded to. Exceptions to this are replies to IDENT or RADAR CONTACT messages. This response may consist of WILCO, UNABLE, or STANDBY. If STANDBY is pushed, it must be followed with either WILCO or UNABLE before another message can be displayed. If UNABLE is depressed for



*MODIFICATIONS BEING ACCOMPLISHED

Figure B-2. CDU Keyboard Modified for Airline Tests anything other than a traffic advisory, the air traffic controller (simulated) will contact the crew on voice to determine the reason for the UNABLE. The WILCO buttons on the control yoke (DC-9) or the WILCO pendant switches (B-727) may be pushed in place of the WILCO or the CDU.

The pre-text function buttons in the upper left of the CDU are self-explanatory. Depressing the CLRANCE/ADVISRY button causes the top and bottom halves of these function buttons to be alternately lighted.

For example, if you want to receive your clearance, you would just make sure the CLR REQ button was lighted. If it was not, you would first depress CLRANCE/ADVISRY and then depress CLR REQ. If next you wanted to request weather, you would depress CLRANCE/ADVISRY again so as to light the lower halves of the function buttons. You would then depress WEATHER. Whenever one of the function buttons is depressed, it must be followed by the SEND button on the lower right. Certain buttons may be followed by either numbers or letters prior to depressing SEND in order to complete the request. These are:

ATIS - Followed by 3-letter station identifier

WEATHER - Followed by 3-letter station identifier

ALT REQ - May be followed by 3 numbers (e.g., 060 for 6000)

HDQ REQ - May be followed by 3 numbers (e.g., 345 degrees)

ETA/ETO - Followed by 4-digit Zulu time

DEPARTD
OFF
ARRIVED
} - These are company functions that may be followed by times, stations, and full weights depending on Observer instructions for the particular flight.

The alphanumeric buttons on the right-hand side are also alternate action depending on whether ALPHA or # is selected. If the numbers are lighted, then the letters can be selected by depressing ALPHA/#; conversely, if the letter keys are lighted, the depressing of ALPHA/# will cause the numbers to become lighted. Because there are three letters on each key, any push of the letter key must be followed by depressing Left, Center, or Right.

Some examples may be helpful. For instance, the current Philadelphia weather would be requested by the following sequence of keystrokes:

<u>CDU ACTION</u>

CLRANCE/ADVISRY - Only if the Advisory portions of these keys are not lighted.

WEATHER - **NOTE: The two-letter code WE will appear on the scratch pad. All function buttons have associated two-letter codes.**

ALPHA/# - Only if the letter halves of these keys are not lighted.

PRS }
Left } - P

GHI }
Center } - H

JKL }
Right } - L .

The request entered in the 8-window scratchpad display would then read WEPHL. Depressing the SEND button would cause this information to be transmitted downlink. The last letter, number, or function button depressed could be erased by depressing "DELETE ENTRY". Multiple errors could be erased anytime before the SEND button is depressed by successive depressions of the "DELETE ENTRY" key.

One further example is a request for altitude change to flight level 290:

<u>CDU ACTION</u>

CLRANCE/ADVISRY - Only if the top halves of the function buttons are not lighted.

ALT REQ

ALPHA/# - Only if the lower halves of the letter/number keys are not lighted.

2

9

Ø .

The 8-window scratchpad entry would read "LT29Ø" if the message was correctly entered. The SEND button would be pushed to transmit the entry downlink.

The functions of the remaining buttons on the CDU are as follows:

VOSYN REPEAT - Repeats the last VOSYN (Voice Synthesizer) message.

VOSYN VOLUME - Adjusts the VOSYN volume.

HDG ALT SPD - Recalls the latest heading, altitude, and speed on the VOSYN or SMATC.

MSG STORE - Causes the currently displayed message to be stored.

MSG RECALL - Recalls the stored message.

I/O BLANK - Successive depressions of this button clear the SMATC display and return the message to view.

TEST/FAIL - Causes internal tests on the CDU to be made. Test light will return if the unit is operating properly. Also causes following test message on all devices: "SQUAWK Ø123 ROMEO".

REQ VOICE - Depressing this button will cause the company radio operator to make voice contact with the crew.

B.4.3 The Vosyn

The voice synthesizer being used during this series of simulated flights represents some compromise between cost and voice quality using present-day technology. While machines with better diction are available at much higher cost, we believe that with only a slight amount of practice you will be able to understand the output of the present machine readily. We will be interested in your assessment of this.

Within the cockpit, you will have control of VOSYN volume on the CDU. At the VOSYN itself, there is an additional control that adjusts the rate of speech.

All VOSYN messages delivered to your aircraft will start with an audio alert and be followed by your call sign.

B.4.4 The Printer

This is a standard item, and no instructions as to its use should be required. Figure 3 is a picture of the printer which will be used.

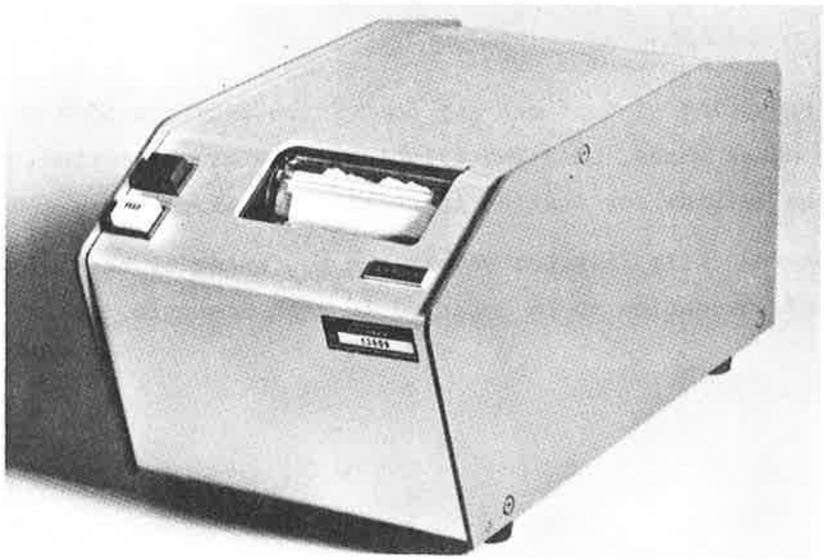


Figure B-3. ANADEX Model DP-751 Printer

You may tear off individual messages or accumulate a group of messages, as you prefer. Each message will be preceded by the time of day, and plain text will be used (i.e., no symbols or unusual abbreviations will occur). Where a message appears on the printer as well as the VOSYN and/or SMATC, the printer message will not contain any additional information.

Company messages will appear on the printer only and will be printed in red ink. ATC messages will be printed in black ink.

B.4.5 Alphanumeric Terminal for Company Communications

The B-727 simulator will contain an additional downlink device. This is an alphanumeric terminal with a full keyboard. It also contains a scratchpad display that can be used to verify downlink messages before they are transmitted downlink. This terminal will be used to send company communications downlink. These messages will include standard flight time (OOOI) reports in addition to other company messages. Varying degrees of data-link automation will be assumed for each of your three flights. In some cases the company reports are almost completely automated, requiring at most one key depression plus the SEND or TRANSMIT button. In other cases, only the flight numbers are automated, requiring keystroke entries for station identifiers, fuel weights, and times.

The observer will instruct you at the beginning of the flight as to the degree of automation to be employed in each scenario.

NOTE: The training scenario presented on the following pages was conducted by the cockpit observer and lasted about 20 minutes. It is included here for information only; it was not furnished to the crew.

AIRCREW FAMILIARIZATION RUN

The following brief scenario is designed to demonstrate some of the features of the data-link equipment with which the crews will be working. It presents some command and advisory type ATC messages and some company messages. It provides the crew with some opportunity to enter downlink messages also. The observer will talk the crew through this familiarization run.

ATC message will be displayed on all displays unless otherwise indicated. Company messages will be displayed on the printer only in red ink (ATC printer messages will be displayed in black ink.)

MESSAGE (PRINTER TEXT)	CREW ACTION	OPERATOR ACTION	OBSERVER ACTION	RESULT
1. Proceed direct OAK	Press VOSYN Repeat on CDU Press VOSYN Repeat on CDU Press Message STORE on CDU	Send Message No. 1 - Normal pitch rate --High Pitch --Low Pitch, return to normal	Explain variable pitch and demonstrate. Advise crew that volume may be adjusted by controlling the cockpit audio volume.	
--No message--	Press TEST button on CDU	None	Explain test sequence	TEST button will flash on and off. When test is completed, the TEST button will return to normal illumination; otherwise FAIL appears on the top half of the button and will remain on until the self test operation is again initiated. During the test, all display element indicators and buttons on the CDU will be illuminated. Each display will present a test message.
2. UA 246 is cleared to the San Francisco Airport	If CLRANCE/ADVISRY button is not in CLRANCE mode, press it. Then press CLR REQ and SEND. Acknowledge with WILCO	Send Message No. 2	Call crew's attention to various displays.	Clearance appears on all displays.
-- Los Angeles International Airport information Zulu Ceiling unlimited visibility 3 miles in haze and smoke	Press CLRANCE/ADVISRY button to place CDU in ADVISRY mode. Then press ATIS		Point out that LAX identifier is not required since aircraft was at LAX	ATIS is spoken on the VOSYN and is printed
3. Taxi to runway 25 left	Press CLRANCE/ADVISRY button to place CDU in CLRANCE mode, then press TAXI button. Acknowledge with WILCO	Send message No. 3	None	Taxi clearance appears on all displays.

MESSAGE (PRINTER TEXT)	CREW ACTION	OPERATOR ACTION	OBSERVER ACTION	RESULT
4. LAX Tower 118.9	Acknowledge with WILCO	Send message No. 4	Point out the appearance of the new frequency in the AUTOTUNE windows.	Message appears on all displays. The new frequency appears in the AUTOTUNE windows after WILCO is pressed.
5. Cleared for takeoff runway 25 left	Acknowledge with WILCO	Send message No. 5	None	The displays indicate take off clearance.
6. Climb to and maintain 6000	Acknowledge with WILCO	Send message No. 6	None	Command is displayed on all displays
			Instruct the crew in sending an OFF report in the least automated format.	
	Press CLRANCE/ADVISRY button to put CDU into ADVISRY mode. Press OFF button followed by keyboard inputs of JKL, RIGHT } L ABC, LEFT } A WXY, CENTER } X		Point out to the crew that the procedure would be similar for entry of ATIS or WEATHER requests.	OF LAX1012 will appear in the scratchpad display.
-- UA246 OFF LAX AT 1012	Enter 1012 Then press SEND	Type in reply message using insert feature	Point out that no WILCO is required for company messages.	OFF report appears only on the printer in red ink.
7. Proceed direct VTU	Acknowledge with WILCO (Don't set transponder)	Send message No. 7	None	Transponder code will appear on all displays
	Depress HAS recall button		Point out that Heading, Altitude, and Speed can be recalled.	VOSYN and SMATC displays will redisplay heading and speed command given on departure.
	Acknolwedge with WILCO			

MESSAGE (PRINTER TEXT)	CREW ACTION	OPERATOR ACTION	OBSERVER ACTION	RESULTS
	Depress message RECALL button	None	Point out that the message stored at the beginning will be redisplayed	Initial clearance message will be displayed
8. Traffic 3 o'clock 4 miles 6000 feet Southbound Fast	Acknowledge with UNABLE	Send message No. 8	None	All displays will present this traffic advisory
9. LAX Center 138.950	Acknowledge with UNABLE	Send message No. 9 Contact the crew on voice channel as ATC controller	Point out that an UNABLE response to anything other than a traffic advisory will bring the ATC controller up on the voice channel. Company radio operator may be similarly requested by pressing the VOICE button.	The ATC controller will contact the crew to determine the nature of their difficulties.
-- SFO Altimeter 30.15	Press CLRANCE/ACVISRY button to put CDU in ADVISRY mode if it is not there. Press ALTIMTR and then SEND Acknowledge with WILCO	None	None	Stored JFK altimeter setting of 30.10 will be displayed on all devices.
	Press I/O blank	None	Direct crew's attention to the SMATC display	SMATC display will blank
	Press I/O blank again	None		Last SMATC message will reappear

This concludes the familiarization run. Any additional questions will be answered at this time while the cassette tape for the first scenario is being loaded. The observer will now furnish the crew with a copy of their flight mission designation showing both clearances for which filed and device complements for each flight. At this time he will explain the company automation procedures to be used for each flight.

APPENDIX C

FLIGHT CREW QUESTIONNAIRES

A questionnaire was distributed to each pilot after he completed his three data-link trials. The questions were divided into six groups:

- SMATC
- VOSYN
- SMATC and VOSYN
- Printer
- CDU
- General considerations

In this appendix the questions are repeated exactly as they appeared on the original questionnaires. Although the DC-9 pilots were mistakenly given a longer, unabridged version of the questionnaire, only the questions that coincided with the abridged B-727 version are included here so that we can effectively compare the responses.

The answers and comments are displayed separately (i.e., with paragraph spacing between) for each pilot. Multiple responses to a question by the same pilot are grouped into one paragraph. Infrequently, minor editorial changes have been made to improve readability.

SMATC DISPLAY QUESTIONS

1. *Did you find the display readable in its present location?*

   All "Yes" answers

   18 DC-9 Pilots

   19 B-727 Pilots

   37 (100%)

2. *If not, where do you recommend it be located?*

Answers

In a small cockpit such as the DC-9, one centrally located display would suffice.

Readable in present location, but I would prefer having it further from the basic flight instruments, possibly inside console.

Current location O.K.

3. *Do you feel that a larger or smaller number of characters is needed on the SMATC?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Larger	1	1	2	5
Smaller	0	0	0	0
As is	15	15	30	81
Unsure	2	3	5	14

Comment

It should remain the same if the SMATC continues to do only the job it is currently doing.

4. *If so, how many?*

Answers

Possibly three lines; smaller characters would be O.K.

Unsure; however, present arrangement did not seem to present any difficulties.

Enough for any planned texts.

Enough to display a complete ATC clearance (using appropriate symbols and abbreviations).

The number of characters was sufficient so long as printer is available.

5. *What character size do you prefer?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Larger	0	0	0	0
Smaller	0	2	2	5
As is	18	17	35	95

6. *What method of alerting to a new message on the SMATC do you prefer?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Audio alert	8-1/6*	10-1/2	18-2/3	56
Flashing SMATC	6-1/6	3-1/2	9-2/3	29
Flashing WILCO	1-2/3	4-1/2	6-1/6	15

*Fractional numbers result from pilots' circling more than one response.

7. *Were there any confusing abbreviations used on the SMATC?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	5	6	11	30
No	13	13	26	70

Comments

No particular objections. I just need to let the learning sink in.

Schooling on abbreviations required.

Not on the limited number of displays that I observed.

OSI (VOR) was illuminated, and I confused it with 051 (as in radial).

I misinterpreted OSI as 051, although on steady examination the characters were readable.

CFAP, but it will probably be O.K. with familiarity; PTR should be PRNTR; PSN should be POS; use phrases such as ATIS and CLNC on Printer.

W should be WB; CFAP should be CLRD APCH; PTR should be PRNTR; TFC should be TRFC; TKOF should be TKOFF.

Airborne traffic advisory was confusing but it would be O.K. after seeing it displayed a few times; no suggestion for improvement.

CFAP ILS RYW14R should be CLAP ILS 14R.

PSN should be POS.

DRCT SMO DEP 050R was confusing and 050 could be interpreted as an altitude command. The message should say "DRCT SMO then DEP 050R."

CFAP should be CLAP.

DRCT should be DIR.

8. *Do you feel the SMATC display dominated or distracted your attention from any of the other flight or navigation instruments?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	2	0	2	5
No	12	13-1/2	25-1/2	69
To a degree	4	5-1/2	9-1/2	26

Comments

Familiarity tended to limit distraction.

Only as a new instrument on panel, but not when accustomed to it.

9. *If so, from what instrument and during what phase of the flight?*

Answers

If the SMATC display flashed to gain attention, it would be distracting during critical flight phases.

From the course-deviation indicator and gyro-horizon.

Only caused a momentary interruption on instrument cross-check.

During all phases lost some normally applied scan time because often returns to SMATC when not really necessary.

When the message changes or appears, I am momentarily distracted. I could get used to this.

From the general scan.

From any instrument and during any phase of the flight because of the reaction to red light. Lighting for immediate-action items.

From the altimeter and airspeed indicator during climb and descent.

From the horizontal direction indicator during approach.

Distracts during climb and descent.

Initial and secondary climb and final approach.

From any instrument at any time due to instinctive reaction generated at any time by the appearance of a red light.

10. *Do you feel the SMATC display could cause distraction problems during an instrument or visual approach including the landing transition?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	9	3	12	32
No	7	11	18	49
Marginally	2	5	7	19

Comment

No, because it would of necessity be ignored at this time.

11. *If so, under what conditions?*

Answers

During final phase of approach and landing (i.e., 500 feet to landing).

If there is a need for a clarification.

Again the same answer I gave for Question 9.("From any instrument and during any phase of the flight because of the reaction to red light. Lighting for immediate-action items.")

At certain times such as flare the audio going off could cause distraction.

All hand-flown instrument maneuvering in terminal area.

During low approaches with high crosswinds when high-level concentration is necessary.

During approach. I think that after you were familiar with the SMATC it would not bother you. You would put it in your scan with everything else.

From approximately 500 feet down to minimum could distract, especially under CAT II conditions. Should leave go-around decision to pilot. On one occasion crew received go-around at 200 feet (minimum). Too late, in my opinion.

I would rather not have additional lights on the panel during final phases of approach.

It could be greatly distracting during takeoff and landing when weather is less than VFR.

When transitioning to visual on an instrument approach.

May cause pilot to momentarily lose his concentration during final phase of approach.

If it is already on, no distraction; but if it comes on with aural signal, it could be a marginal distration.

I would prefer the instruments remain blank from landing clearance to touchdown.

If flashing on final.

Best display yet.

A built-in delay of several seconds after the WILCO or UNABLE switches were activated in the cockpit might be useful. This would allow the crew to respond to a message should an error have been made (wrong button pushed) and the SMATC been cleared. This would preclude lengthy and time-consuming actions in order to correct mistakes.

I think that only direct voice contact should be used between pilot and controller during critical phases of flight operations. SMATC, VOSYN, and Printer should never be used for takeoff and landing clearances or instructions to abandon an approach. SMATC should never be used inside the OM on a landing approach regardless of WX conditions and SMATC should never be used when parallel approaches are in progress once an aircraft has reached the initial approach altitude or positioned on an intercept heading and been cleared for approach....SMATC is handy to display wind information on final approach but must achieve the capability to display gust information.

Rather than being a distraction the display was more or less lost during certain phases of flight, particularly the go-around message at minimum altitude. At this point, the pilot's attention is centered on the flight instruments; and the SMATC display seemed to be out of the scan pattern.

Aural signal was a pleasant surprise. I am generally opposed to any more aural warnings in cockpit, but this was distinctive without being annoying or distracting.

SMATC presentation should auto-erase ten seconds following WILCO, but should have recall ability. Distracted me when I was the first officer.

Alert should be more attention-getting, especially in an emergency situation.

By accident and not obvious to pilots, a go-around was transmitted on the SMATC. There was no aural on the VOSYN. The first officer's comment was "I just happened to see it." I feel consideration should be given to identify an emergency transmission and to attract the pilot's eyes especially during CAT II/III approaches.

Would like to see three rows of eight characters on SMATC since longer messages (i.e., clearances with abbreviations) could be shown there with less dependence on the Printer. At least first half or a significant portion of long messages would be more easily handled.

During instrument approach, I would not look at SMATC and depend on my first officer for advisories; therefore, SMATC would not distract me.

The SMATC display is the most acceptable component of the data-link system. However, green color characters should be less distracting while removing the sense of urgency psychologically associated with the red characters.

VOSYN QUESTIONS

1. *How would you rate the intelligibility of the VOSYN?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Good	8-1/2	0	8-1/2	20
Marginal	8-1/2	21	29-1/2	69
Unacceptable	1	4	4	11

Comment

Good, but marginal under some conditions.

2. *Did you find that intelligibility improved with practice?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	9	10	19	44
No	5	2	7	16
Only slightly	4	13	17	40

3. *Apart from intelligibility, did you find the mechanical quality of the speech to be annoying?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
No	9	9	18	42
Moder- ately	7	14	21	49
Very	1	2	3	7
Undecided	1	0	1	2

4. *Would you like the use of the VOSYN to be limited to certain types of messages?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes, short messages	9-1/2	15	24-1/2	61
Yes, long messages	0	1	1	2
No, all messages	4	3	7	18
Other	4-1/2	3	7-1/2	19

Comments

...cockpit on-off switch so it was available but could be turned off.

To alert items, traffic, etc.

Yes, at pilot's decision.

ATC only.

No messages at all!

For long messages, such as clearances, I had to refer to printout.

Don't believe this to be a factor so long as voice is intelligible.

None at all; reserve this type of signal for isolated emergencies of the first priority like ground proximity warning.

(1) Suggest VOSYN only for semi-emergency type (i.e., radar targets, missed approach). (2) Suggest a longer pause after each sentence on the VOSYN.

Long messages should be punctuated. Oral punctuation such as pauses between logical phrases would be helpful in understanding long messages, such as clearances, ATIS, etc.

SMATC should be used for short messages and the VOSYN-Printer combination used for long messages.

VOSYN can be distracting but probably not any more than current voice procedures. Short messages O.K., but should include ATIS and initial airways clearance.

Do not use VOSYN for longer messages such as clearance when the message is also printed out.

When receiving a clearance, the tendency was to fall behind in receiving the message while trying to understand a word.

Long messages are distracting. Should be limited to short messages such as clearance.

The words are very difficult to understand. It sounds foreign There is no spacebetweenthe words which makes it difficult to follow. It is difficult to determine when the sentence ends. Some very short messages may be acceptable. The fact that there is no way to shut the VOSYN off, and we are forced to listen to this irritating sound when we know what it is saying is annoying. (Guess I just plain don't like it.)

Possibly a pause between words would make them more distinctive. Since there are no tonal inflections, each word needs to be separated to prevent a running-together sound.

Numbers hard to understand on occasions.

I do not particularly like VOSYN because of its mechanical tone and its susceptibility for misinterpretation of what was said. Continued reference to the Printer had to be made. Some messages, maybe emergency types, would alert the pilot especially if the cockpit communications (oral) are at a minimum. I found it quite difficult to understand what was said when other persons in cockpit were speaking. Also, what have I gained by replacing one voice with another?

For some reason, if anyone else was speaking in the cockpit during VOSYN transmissions, it became almost completely unreadable to me. Also, it seemed that the first few words were unreadable on all transmissions.

The VOSYN detracts from some of the operational advantages of the data-link; namely, that two people can communicate without devoting full attention to each other at the same time. The VOSYN tends to demand attention because it blocks other conversations and to understand VOSYN requires full attention.

It was impossible to understand the clearance the first time it was given when you had no idea what it might be.

The VOSYN is unnecessary and is distracting and annoying during an approach and a landing maneuver. Frankly it adds nothing to safe execution of the flight and is contrary to the concept of data link.

With improved intellibility, the mechanical quality of the speech will be less annoying upon increased familiarity. However, in-cockpit control of pitch and rate of speech would deter familiarization if not preclude it.

VOSYN AND SMATC QUESTIONS

1. *Would you like the use of synthetic speech limited to periods when the pilot's eyes are busiest, such as takeoff and landing, with a visual display the remainder of the time?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	4	6	10	27
No	11	12	23	62
No opinion	3	1	4	11

Comments

Don't need it.

VOSYN and SMATC should never...be used from time aircraft is "number one" awaiting takeoff on the runway until cleared to departure frequency, or next to be cleared for a landing approach until cleared to GND control frequency.

Short messages presented on VOSYN at all times.

I think all communications except emergency should be eliminated between cleared-to-takeoff and 1500 AGL, and between cleared-to-land and turnoff from runway.

Limited during takeoff and landing.

2. *Did some of the device complements provide too much redundant information?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	4	10	14	37
No	14	9	23	60
No opinion	0	1	1	3

Comments

Perhaps a switch could be provided so that the pilot could turn the synthetic voice on or off.

Yes, VOSYN.

Yes, during heading, altitude, and speed requests.

Yes, company readback and acknowledgment of messages.

Yes, VOSYN and most Printer messages.

Yes, I prefer no audio.

Yes, VOSYN.

VOSYN not necessary on short messages.

Use of VOSYN when using CDU to call up HDG/ALT/SPD information is distracting.

Message recall could be displayed on only SMATC; voice display was not a necessity.

HAS would appear on SMATC; VOSYN would then repeat HAS while SMATC was returning to original message.

VOSYN when the information was available on the SMATC.

VOSYN on many occasions. (IDENT-Radar for most short clearances.)

3. *Was it confusing to you to have the same ATC messages presented on both the SMATC and VOSYN at the same time?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	2	0	2	5
No	15	16	31	82
To some extent	1	4	5	13

Comments

Not confusing, irritating.

It was unnecessary. SMATC was sufficient.

Not confusing, but unnecessary.

4. *Was the duplication in this complement (SMATC and VOSYN) desirable or unnecessary?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Desirable	10	0	10	26
Unnecessary	5	9	14	37
Neither	3	11	14	37

Comments

For a command such as go-around, VOSYN would be mighty desirable because the pilot is certainly not watching the SMATC, and all his attention is on the F/D.

The VOSYN may have some value in the duplication of a few high-priority messages (i.e., go-around, cleared for landing).

5. *Which device (SMATC or VOSYN) could be most readily eliminated?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
SMATC	2	0	2	5
VOSYN	14	18	32	84
Neither	2	2	4	11

Comments

I found myself responding to the SMATC directions before the VOSYN was complete.

VOSYN messages should be limited to only those displayed on the SMATC with the exception of on-the-ground pre-taxi ATC clearance and advisory.

VOSYN is hard to understand and the tempo is too fast. VOSYN could be reduced to about 20% of calls.

SMATC seemed adequate for short messages, including departures.

VOSYN was desirable during initial use of SMATC; however, with familiarity the VOSYN could be mostly eliminated.

The duplication seems generally desirable. In my opinion, this is the best arrangement. If necessary to sacrifice one, I would prefer to eliminate the VOSYN.

VOSYN (pure voice would be better) is absolutely essential during final-approach and initial-takeoff.

Prefer use of both SMATC and VOSYN but with improved VOSYN.

PRINTER QUESTIONS

1. *Should the use of the Printer be restricted to long messages?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes, long messages only	3	1-1/2	4-1/2	12
No, all messages	12	15	27	75
No opinion	0	0	0	0
Other	1	3-1/2	4-1/2	13

Comments

Initial ATC clearances and company messages.

Why not? Paper is cheap.

All clearances should be printed but some information could be deleted (traffic information, clear of traffic, etc.).

Essential on all messages but ALT, HDG, and airspeed.

Initial ATC clearances (perhaps all ATC clearances), ATIS, and company messages should be recorded.

Messages that require documentation, later reference, etc.

2. *Would you like to see some abbreviations and/or symbols used on the Printer so as to shorten the messages?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Abbreviations	0	7	7	20
Symbols	0	1	1	3
Both	1	6	7	20
No opinion	1	0	1	3
None	14	5	19	54

Comments

The communications should be as short as possible; logical abbreviations and symbols should be used. But, it is impossible to say that I will agree with some symbols and abbreviations that you may use.

Only if done very carefully so that a smudge, for instance, would not mislead the crew.

Present abbreviations satisfactory; however, this doesn't preclude eliminating the Printer entirely.

Not necessarily.

3. *Was the time tag on messages of any value?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	6	5	11	31
No	7	7	14	40
No opinion	3	7	10	29

Comments

For this test, the time tag was not utilized. The only value would be legal in the event of mishap.

Yes, but only for a later record, not on flight.

4. *Do you think there is a need for a visual or audible alert for company messages on the Printer?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Audible	2	9	11	34
Visual	8	3	11	34
Both	3	2	5	16
Neither	2	2	4	13
Either	1	0	1	3

Comments

A small light on the Captain's or first officer's instrument panel.

At least one.

Company messages could be disregarded under high-density departure and arrival workloads.

No, we have enough aural already.

INOP on flights.

Not as far as PIC and SIC are concerned.

Yes, I was not aware a message had been received.

5. *Do you feel that all communications, company and ATC, should be recorded on the Printer?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	12	19	31	74
No	3	6	9	21
Undecided	1	1	2	5

Comments

Only long messages and clearances - heading, altitude, speed, frequency.

Printer is distracting for second officer; interrupts his crew duties. He should be able to get WT manifest and gate information with his equipment. Suitable location for second officer's station equipment. Printer hard to read in minimal light conditions; some numbers not very clear in good light.

6. *Do you feel that red ink versus black ink provides a sufficient distinction for company versus ATC messages?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	13	9	22	71
No	3	6	9	29

Comments

Some color other than red would be easier to read under night-lighting conditions.

Red ink is invisible at night in any red-lighted cockpit.

Some distinction, but not necessarily red and black.

Poor. Red print is unacceptable.

It's a good idea, but not altogether necessary.

Did not notice difference.

Pre-taxi ATC clearances, ATIS, and enroute weather were torn off individually, and other messages were accumulated....Visual alert of impending company message could be accomplished by SMATC instruction to see the Printer for company message....Automatic line feed was used as indication that message was completed, and possibly this could be combined with a soft bell-chime sequenced with the multiple line feed....Printer should be accessible to either crew member on two-pilot crew complement aircraft.

CDU QUESTIONS

1. *Was the requirement for left-handed keying on the co-pilot side a source of difficulty?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
No	15	15	30	88
Marginal	2	2	4	12
Yes	0	0	0	0

Comments

I used my right hand anyway.

The location in this case made it difficult for both sides. Pedestal location would be better.

No, but cockpit controls interfere in present location.

2. *Are you left-handed?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	0	1	1	3
No	17	16	33	97

3. *Do you feel the procedure for acquiring an ATC voice channel is adequate?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	12	9	21	60
No	6	8	14	40

Comments

REQ voice button on CDU is redundant.

When unable to comply with message. [This was taken verbatim from the questionnaire.]

I would like to see voice backup automatically available at all times, so pilot could talk to controller at all times.

At this time, no. It seemed to take too long to get a response. It could be acceptable if I was sure that he was going to answer me.

Did not have enough exposure to its use to make a reasonable judgment.

Should be able to key controller at any time in emergency. [This comment is repeated almost verbatim in the additional comments section of this appendix.]

4. *If not, what procedure would you suggest?*

Answers

I would like to use the mike without having to depress any other request button. This is particularly important on tower frequency and approach control frequency.

Voice should always be available without having to ask for a frequency. The pilot should have voice communication available by merely picking up the mike.

Constant and immediate voice contact should be available (hot mike and receiving speaker).

Separate buttons.

Ability to communicate with ground facility via conventional method at any time by simply keying microphone.

UNABLE is useful because it transmits a reply that requires controller action. STANDBY could be changed to ATC VOICE so that you can have a channel to converse with controller about traffic, weather, turbulence, etc.

Re-label the button. If you push UNABLE you want to talk to ATC so why not label the button REQ ATC VOICE.

If you are being vectored for an approach and you are vectored through the LOC course, as an example, it is time-consuming to have to use the CDU prior to being able to use voice communications.

UNABLE, STANDBY, and WILCO should be completely independent of SEND and other functions. On occasion a partially prepared message for sending on the CDU was interrupted by an uplink message on the SMATC. Acknowledgment of the uplink message through WILCO erased the partially prepared downlink message. The system should have the capability for acknowledging SMATC messages while retaining partially prepared CDU messages.

Entering letters on the CDU by the left-center-right method is tedious.

If the CDU is lined up with two INS CDUs, confusion could exist. I wonder about the possibility of combining this CDU with an INS/CDU.

There should be a button for takeoff request.

With numbers and dedicated function buttons, 95 percent of all messages can be handled. Use voice direct for those that would require alpha keys.

GENERAL CONSIDERATIONS

1. *Do you feel the automatic tuning feature of the AUTOTUNE is desirable?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	17	23	40	98
No	0	1	1	2

Comment

Yes, if it works. Changing frequencies constitute a large percentage of cockpit workload.

2. *Should this automatic tuning capability of data link be extended to any other ratio or navigation equipment?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	2	3	5	13
No	15	20	35	87
Other	0	0	0	0

Comments

Transponder.

NAV receiver as is now done in R-NAV systems.

No, like authority as to what I like to tune in.

Transponder.

Company guard frequencies.

Not to navigation equipment as pilot should have full control over NAVAID selected, and he may not want to change over at time AUTOTUNE indicated.

I would like to see VOR navigation set or waypoints set in the case of RNAV, but I think we must step softly in this direction.

Yes, NAV radios when area navigation is used.

3. *What about a similar capability to automatically set the altitude alert, and heading and speed bugs?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	5	2-5/6	7-5/6	22
No	4	9-2/3	13-2/3	37
Worth trying	9	4-1/2	13-1/2	36
No opinion	0	2	2	5

Comments

It should be selectable by pilot.

No ground-based device should ever be used to physically reposition any switch or control in an airborne cockpit. To do so removes the pilot from the command circuit and invites disaster.

Should have capability to monitor altitude alert, heading and speed bug settings so that controller could use system to check that clearance was understood correctly.

Does not appear feasible. These must be retained as cockpit functions.

4. *Was the audio alert prior to each message helpful, unnecessary, distracting, and/or confusing?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Helpful	13-1/2	25	38-1/2	90
Unnecessary	0	0	0	0
Distracting	3-1/2	0	3-1/2	8
Confusing	1/2	0	1/2	1

Comments

Could be confusing during approach phase.

Too loud.

For SMATC, audio alert is needed, but this was awful.

Lasted too long.

Necessary.

5. *Did you feel the HDG, ALT, and SPD information was useful even though you may have set heading and speed bugs?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	17	23	40	93
No	1	0	1	2
No opinion	0	2	2	5

Comment

You would only set the airspeed bug for V2 (takeoff) and Vref (landing).

6. *As long as HDG, ALT, and SPD can be retained in some manner, is it really necessary to be able to store other messages?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	12	15	27	60
No	6	8	14	31
No opinion	0	4	4	9

Comments

Probably not, at least not if clearances are printed.

Via Printer only.

Yes, the last en route clearance received should be stored.

Yes, people forget this information when they are tired.

Last message prior to HDG, ALT, and SPD would be nice to have.

Some clearances.

7. *Do you feel that the STANDBY button serves a useful purpose?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	8	7	15	38
No	4	3	7	17
No opinion	5	13	18	45

Comments

Not in this particular test.

Never used nor did I seem to require it.

Did not use in these tests.

8. *Which method of retaining heading, altitude, and speed (HAS) information did you prefer?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Recall with SMATC	13	21	34	81
Recall with VOSYN	0	1	1	2
Small display dedicated only to HAS	4	1	5	12
This capability not required	1	1	2	5

9. *Did you find that in a data-link environment, the lack of capability to monitor communications with other aircraft over the voice link resulted in your losing information which you consider valuable (e.g., traffic flow, weather deviations, etc.)?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Much information lost	6	8	14	45
Little information lost	12	4	16	52
No information lost	0	1	1	3

Comments

With total data-link communications one gets the feeling of being encapsulated in space, isolated by ATC from contact with others in the same environment. The importance of such contact cannot be underestimated as a factor in the equation that results in an airman's command abilities to achieve safe flight.

Much more was gained by not being distracted than was lost.

No, I felt we could obtain such information from ground station.

Yes, essential information was lost, but anticipated necessary information could be provided in uplink messages.

10. *Were any of the scenarios unfair to any of the device complements tested? In other words, were any of the scenarios difficult with the device complement available, but might have been usable on a different scenario?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Yes	3	0	3	7
No	13	14	27	61
No opinion	2	12	14	32

11. *Which ones?*

Answers

Lack of familiarity with routes involved and simulator instrumentation.

SFO-LAX due to lack of procedures, experience, and familiarity with TWA instrumentation in simulator and route of flight.

12. *What do you think will be the effect of data link on crew workload?*

Response	DC-9 Pilots	B-727 Pilots	Total	Percent
Increase	1-1/2	4	5-1/2	12
Decrease	9-1/2	15-1/2	25	57
About the same	7	4-1/2	11-1/2	26
Unsure	0	2	2	5

Comments

Based on what we're doing today, there is an increase. Eventually we may be able to refine to the point where there is less workload.

After some use and experience with equipment.

With familiarity.

Increase at first but will probably be about the same as efficiency improved.

ADDITIONAL COMMENTS

(1) During test, delays and problems were encountered regarding altitude changes, speed changes, and weather detours on all three flight segments, (2) any mechanical difficulties affecting remainder of flight should be handled on a direct pilot-controlled basis (conventional voice method), (3) after outer marker passage, all clearances issued by controller and acknowledge by flight crew should be by direct voice contact. This includes (a) clearance to land, (b) execute missed approach. Some reasons for this feeling: (a) inadvertant action by controller for "clearance to land" could be sent as "execute missed approach" or vice versa, the reason being heavy traffic and habit of continuous repetition, (b) same inadvertant action on part of crew. Note: Button-pushing can become automatic, and an error during this phase of flight might go undetected on the part of crew or controller. But seldom might one say into a mike something contradictory to what he meant to say.

The data-link system undoubtedly has great potential and a vast range of possibilities. Component location will be important. I found the equipment tended to distract me from primary second officer's duties until I became more familiar with its use and purpose.

Would prefer regular voice communications from 5000 feet to touchdown. Traffic watch could be impaired with too many messages close to ground - more on approach than departure. VOSYN and SMATC is very desirable combination except as mentioned above.

Would like to see availability to call controller in any emergency conditions and for traffic if necessary.

The use of the Printer is mandatory with the devices tested. Without it, the VOSYN would have been disastrous. The SMATC is not a complete system in itself. It requires the Printer for data recovery. Handling these messages is awkward and a method must be developed for good cockpit management.

The lack of constant "talk" format over communications radios allowed crew to perform checklists and other command-type duties.

Too much automation could breed complacency.

In this experiment, it is worthwhile to operate as a pilot as well as a copilot because one's tasks and concentration are different, and ones awareness of messages is different; at least for me the SMATC was much easier to absorb while performing a demanding task.

Momentary contact switch for a light-on Printer readout. Backup with hard printout appears to be a necessity. If Printer is muted (as I think it should be), suggest audible signal for company messages. If your canned message format was covered with acetate then second officer could enter times in grease pencil as a reminder aid.

During the approach phase, I would like to hear messages to other aircraft to have a feel for the terminal conditions. Also data link is too slow for updated advisory requests and traffic requests during the approach phase. I feel that at least the last ten miles before touchdown should be controlled by voice with data link as a backup only. Requested information on the CDU diverts at least one pilot's attention from traffic watch and other cockpit duties.

Main complaint: Inadequate warning that system is malfunctioning. Captain should WILCO clearance items for proper follow-through (even if the first officer is communicating on that flight leg). Printer location unsatisfactory.

Not yet having any knowledge of the type of equipment and operation on and from the ground station, I am not sure that I can be confident of the accuracy of the sending of each message to its destination.

I thought VOSYN readability was quite good. When hand flying in high workload area, I disregarded SMATC and took messages by VOSYN. This was an automatic reaction and not intentional. Where only SMATC was used, I found I missed information when copilot WILCOs a message. VOSYN appears preferable to SMATC although the latter may be acceptable. Visual display is better than VOSYN for HAS scratchpad. Audible warning for VOSYN terrible (and unnecessary). All eight segments on numbers for communications panel missing. Buttons on CDU should be lighted; no problem with VOSYN.

(1) Buzzer stays on too long when requesting clearance; (2) need Printer where both can reach it; and (3) would be desirable to receive ATIS far out.

Give ATIS on weather button. Have some way of giving notice of message from Company other than just on Printer. Need Printer where both can get to it.

Continuous tone during uplink and downlink messages was extremely annoying, particularly during approach and landing.

Ground contacts should be made as at present due to various taxiways and other circumstances. Clearances should be taped, but voice contacts used on ground. Sometimes the presentation detracts from one's looking out windshield. There is room for error in computer information, and no way to verify proper insertion of information. On the whole, data link can be helpful, but only after tested during all conditions. Interesting!

Since the system was presented strictly from the viewpoint of its operation without formal training in both airborne and ground-based component systems, a crew member would be buying a pig in a poke to express any degree of confidence at this time. Theoretically accepting the system as infallible and without limitations, I am apprehensive of human error on the part of the ground controller. Possibly this is largely due to lack of knowledge of procedures to be followed in operating ground-based equipment. The present voice communications permit the pilot to visualize his aircraft's relation to the ATC environment in his sector. This ability has enabled me to correct an ATC error on three occasions. The decision to accept an ATC clearance on many occasions is affected by knowledge of the proximity of other aircraft. I therefore consider the lack of capability to monitor communications with other aircraft as a major liability inherent in the isolated environment of data link.

APPENDIX D

SUPPLEMENTAL QUESTIONNAIRE

An additional questionnaire was distributed on 31 March 1975 to the same pilots who completed the three data-link trials. The questions and answers are treated the same as in Appendix C.

1. *In considering the three scenarios which you flew, which method of ground-to-air ATC message delivery would you prefer? Please rank them for each phase of flight from most desirable (1) to least desirable (3).*

DC-9 Pilots

Phase of Flight	VOSYN			SMATC			Voice		
	Rank			Rank			Rank		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Ground control	1	6	7	8	4	2	5	4	5
Local control		8	6	4	6	4	10		4
Departure	3	5	6	3	7	4	8	2	4
Low en route	1	7	6	7	4	3	6	3	5
High en route	2	7	5	8	4	2	4	3	7
Arrival	1	7	6	4	5	5	9	2	3

B-727 Pilots

Phase of Flight	VOSYN			SMATC			Voice		
	Rank			Rank			Rank		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Ground control	1	2	17	9	11		10	7	3
Local control		3	17	9	9	2	11	8	1
Departure		5	15	13	5	2	7	10	3
Low en route		4	16	18	2		2	14	4
High en route		4	16	19	1		1	15	4
Arrival		3	17	12	7	1	8	10	2

2. *If the quality of the synthetic voice (VOSYN) had been comparable to that of conventional voice, would you have answered the above question differently?*

Response	DC-9 Pilots	B-727 Pilots
Yes	6	10
No	8	10
Unanswered	2	2

Comments to "Yes" Responses

VOSYN would have been on a par or possibly ranked above SMATC for ground control, local control, and arrival and departure. (Those operational phases where it is extremely important to scan outside the cockpit.)

Could accept good VOSYN for ground-control and pre-clearance information.

Replace the number 2 into VOSYN column in each instance.

Voice quality should be the best available. I would prefer both visual and voice.

Would have selected VOSYN as first choice for both low- and high-en route instead of number 2.

With better quality thus less chance for misunderstanding, VOSYN would be acceptable for en route messages.

Same as conventional voice.

Ratings for VOSYN would then become same as conventional voice.

Familiarity with a program message would enable one to understand a message that was not clearly received.

Main problem with VOSYN was understanding what it was saying because of the poor quality. I also am assuming that VOSYN has the capability of delivering any message that is normally received during each of the phases of flight.

Optimum VOSYN would be an improvement over voice, i.e., absolute clarity, invariable metre, elimination of accents.

I would have ranked VOSYN second during ground control, local control, and arrival phases.

Low altitude en route and high altitude en route would be O.K. on VOSYN if quality of voice were improved.

I would have rated them equal.

This would be O.K. for clearance delivery but not for ground control on approach.

VOSYN would then be acceptable in most situations as a substitute for conventional voice.

Comments to "No" Responses

It is my feeling that VOSYN has no place in the system. I would rather have a printout or visual display.

The quality could be improved; however, I found that I "learned" to understand all but long clearances.

It is not possible for me to guess at what is comparable. I would have to experience the improved synthetic voice.

In any call, I would like to have a SMATC backup for any garbled voice message, conventional or VOSYN.

Comments to "Maybe" Responses

I would have to evaluate again.

Maybe. I would have to hear it first to give a reasonable answer.

3a. *One of our previous questions related to the amount of information lost in a data-link environment due to one's inability to monitor voice communications with the limited number of aircraft on the same frequency. Please indicate below whether you feel that the information lost was essential either to flight safety or to flight comfort or convenience.*

DC-9 Pilots

Type of Information	Flight Safety		Flight Comfort or Convenience	
	Yes	No	Yes	No
Weather Advisory	6	8	8	6
Relative Position of Other Aircraft on Same Frequency	11	4	5	8
Terminal Area Routing Information	8	6	8	6

B-727 Pilots

Type of Information	Flight Safety		Flight Comfort or Convenience	
	Yes	No	Yes	No
Weather Advisory	8	11	16	4
Relative Position of Other Aircraft on Same Frequency	15	5	8	10
Terminal Area Routing Information	10	11	10	7

3b. *What would be required to replace the lost information (i.e., improvements in the ATC system)?*

Answers

One would need an input, which could be conventional voice, during departure and arrival (particularly arrival) which would allow pilot to plan his arrival and departure speeds and ascent/descent rates to maximize safety, comfort, and fuel economy. The only way this can be accomplished smoothly is for pilot to have advance knowledge of weather and turbulence, arrival/departure routing, altitude and speed restrictions, and operational latitudes in relation to aircraft preceding and following.

An interrogation system allowing crew to request information and receive information in reasonable period of time.

A current and accurate display of weather in the sectors you are approaching (i.e., ice, turbulence, etc.). Traffic situation display in cockpit to monitor any ATC separation error.

Weather information would be more beneficial if: (a) Aircraft encountering turbulence could downlink position and 'G' loads derived from INS (or equivalent navigational system). This could be recorded on board. This information could then be retransmitted to all aircraft on the routes. (b) All weather-related problems such as traffic routing changes or other slowdowns should be transmitted in near-real time.

SMATC could offer greatest improvement. Some items such as aircraft proximity may require voice.

Aircraft properly briefed on weather, would not normally require advisory. If indeed a change occurred, then normal voice would still be available. Hopefully, better computer talk through data link will be available and will thus standardize STARS and SIDS for all airports. Rarely does the other aircraft's position mean too much; maybe CAS is the answer.

Designate certain classes of messages as priority and send them by voice.

It is essential to be able to talk to other pilots about the weather they have encountered, avoidance routes, and altitudes. What I feel would be affected is curtailment of the pilots ability to anticipate flight conditions concerning weather, traffic, and routing. This affects both safety and passengers' comfort.

I found that I "missed" such information; however, it is probably habitual rather than essential.

A means of identifying aircraft in immediate area as to their relative position. I believe it technically feasible to portray an aircraft's transponder blip on a pictorial progress screen in the cockpit. To identify another aircraft in your immediate vicinity and within 1000 to 2000 feet above or below is most desirable.

Traffic advisories other than collision avoidance (i.e., you're third in line for approach, following a 727 at your 2 o'clock position).

Knowledge of other aircraft at my altitude or assigned altitude. In particular, knowledge of the progress of preceding aircraft approaches. Some immediate alert and contact frequency in the case of equipment failure.

Use SMATC in addition to present-day listening watch.

Be able to option relative traffic information and/or routing.

I can think of no replacement in terminal areas, especially during heavy thunderstorm activity, etc.

Weather advisory could be given to a flight when it is switched to a new frequency. This message could cover any significant weather along route of flight within this sector of control, and severe weather in the next sector.

The main concern here is with conflicting traffic, weather advisory playing a secondary role. A moving map display which would show other traffic would be one answer.

More up-to-date ATIS: Runway in use, type of approach, vector delays, etc. Including traffic in area. En route, possibly a periodic route report on turbulence, clouds, etc.

SAE S-7 committee has stated other aircraft need not be heard if weather, traffic, and routing anticipatory messages are provided in the data-link transmissions (see S-7 Scenario).

I feel that right now we need direct voice contact during approach and landing portions of flight.

More weather information should be given by controllers as to upcoming turbulence or other unforeseen conditions.

Need alternate voice communication for necessary requested pilot clarification.

I cannot conceive of any improvements for ATC that would be as versatile as or preferable to human voice communications.

There is no way that I know, as yet, to replace this lost information.

Terminal routing should always be handled with conventional voice communications. An excellent backup source of this information would be SMATC.

Nothing more required.

Cannot remember any lost information.

I can't imagine what might replace this "feel" for your environment.

Traffic, weather, and ATIS information on SMATC surface; with wind condition on final on SMATC.

Pilot reports (PIREPS) or other weather information should be relayed immediately to all aircraft in affected area. I would prefer to hear all communications between controllers and aircraft in my area, particularly in holding, arrival, and departure areas.

We have ATIS and can ask for any other information. I'm not aware of all this "other information" supposedly being heard today.

4. *Presuming that Computer-Conflict-Prediction Backup for the controllers existed (i.e., an ATC system free from human error), would your answer to the above questions be different? If so, how?*

Response	DC-9 Pilots	B-727 Pilots	Total
Yes	2	5	7
No	11	14	25

Comments to "Yes" Responses

Yes, would accept proven error-free separation system that could properly cope with deviation (WX) requests. Most still have current level of environmental information.

Possibly, It is pretty difficult to accept that any system will be free of human error; however, confidence could be gained in time. The human voice is still very comforting at times.

Yes, put 3a in the convenience category (i.e., routing information not essential to flight safety).

I would feel much more comfortable to know about another aircraft in my close proximity.

Yes. Again there is today a need to be aware of other traffic locations in case of human error on the part of the controller. If we can assume there will be no mistakes on their part, the need for this information would not exist.

If computer was also free of error, we would not need voice contact most of the time.

Yes. I believe a small amount of safety information is lost without voice communications with all aircraft. But, being free from human error would help some.

Only in the category of other aircraft position would that information not be essential to the safety of flight.

Comments to "No" Responses

Not materially different because safe separation from traffic is only one consideration in the safe, comfortable, and efficient operation of air carrier airplanes. ATC's record for keeping us operating comfortably and efficiently is not good (i.e., fuel economy). They will, in fact, exclaim "That's not our function."

I find it very difficult to visualize a system free from human error (such as human entry into computer). But, my answer to above question would have been "no" in all cases.

My response was predicated on an ATC system free of human error. With human element, I'm afraid a loss of flight safety may occur as a result of losing the present awareness that occurs by listening to the other aircraft separations.

Probably not, because my understanding of the present plan is that the controller will be giving each aircraft the same attention it presently gets, and will advise verbally if a conflict appears.

I don't exactly understand your term, but I think it has been proven that Murphy's Law is immutable. Men and machines are not error-free.

No, because at this time computers must have human input.

Not entirely; pilots like to know who's around and where they fit into the picture.

No. Computer makes errors. Also, someone has to "feed" the computer all of its information and I cannot see such a system.

I don't know; even knowing you were controlled by a foolproof system, you would have to fly in that environment for some time before you could be reasonably comfortable.

5. *Please rank the following prospective features of data-link from most desirable (1) to least desirable (5).*

Feature	Rank					Pilot Category
	(1)	(2)	(3)	(4)	(5)	
Printed pre-departure clearances	8	2	3	5	0	B-727
	4	3	2	3	2	DC-9
Ability to acquire destination ATIS and weather while en route at high altitude	0	1	5	7	5	B-727
	1	4	5	3	1	DC-9
Automation of company arrival and departure reports	0	1	4	4	9	B-727
	3	1	0	3	7	DC-9
Data-link presentation of non-navigational ATC commands (e.g., communications frequency changes, transponder code changes, etc.)	1	10	5	1	1	B-727
	3	2	5	3	1	DC-9
Data-link presentation of all other ATC commands (i.e., vectors, traffic, en route clearances)	9	4	1	1	3	B-727
	3	4	2	2	3	DC-9

Other Features Named as Desirable

Pilot report from aircraft to ground.

The AUTOTUNE was a desirable feature.

Engine start, push back.

Clarity of communications through elimination of interference from weather, ionosphere, distance; and solution of language and accent problems.

Ability to contact ATC at any time without waiting for someone else to stop talking.

Automatic recording and transmission of aircraft maintenance reliability data and other company required reports (such as position, in range, etc.) utilized primarily as a telemetric system and secondly as an advisory communication system.

Eliminate excessive, irritating, contradictory and, at times, inane voice communications.

Takeoff and landing clearances as well.

GENERAL COMMENTS

Automatic switching of NAVAID radios, heading bugs, or any tie-in with autopilot. (This is an area where data-link has no business at all.)

When a system is developed, a Collision Avoidance System presentation should fit into data-link to avoid cockpit panel congestion. As I see it, if data-link is prime link, then pilots will use it with the same priority as they do a flight director, and I feel strongly that data-link should include CAS.

I feel that data-link certainly has a place in the ATC picture, especially in frequency congested areas such as ORD, LGA, and ATL. A hard-copy departure clearance would eliminate a lot of radio traffic. I fail to see why something such as this could not be picked up by the pilot in his company flight operations when he gets his weather. The variations from stored flight plans are rare, and if one is desired, it could be arranged by conventional voice. Where on feels the need most for data-link is when you are turned over to arrival in ORD and then spend the next five minutes trying to get your "hat in the ring." Blocked transmissions, lack of acknowledgments, and missed clearances are reasons enough for a modified system.

It is difficult to evaluate the data-link without considering the environment (i.e., data-link on ground control at a busy field [ORD] would probably be hazardous, whereas at cruise, the congestion does not appear). A big plus is the definite reduction in cockpit workload, noise, etc., and the hard-copy backup. It seems like a look at the future.

It is difficult to provide meaningful answers to the questions at this late date. Too many other programs are more currently in my mind. I would suggest that this type of questionnaire be made available immediately after the flight.

In view of the fact it has been over 4 months since participating in the program, the answers to this questionnaire may not be valid.

I'm very impressed with data-link and it could improve safety and efficiency of operation. However, it must be developed with the ground controller's workload, and equipment requirements must be taken into full consideration. Also would like your people to look at the S-7 data-link CDU.

APPENDIX E

REPORT OF INVENTIONS

It has been determined by a diligent review of the work performed under this contract that no innovation, discovery, improvement, or invention was made.

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