Report No. FAA-RD-75-133,II

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THE CONTROLLER/COMPUTER INTERFACE WITH AN AIR-GROUND DATA LINK

VOLUME II

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Prepared for

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D. C. 20

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-75-133, II		

4. Title and Subtitle	5. Report Date
THE CONTROLLER/COMPUTER INTERFACE WITH AN AIR-GROUND DATA LINK (VOLUME II)	September 1975
	6. Performing Organization Code
7. Author(s) S. Rossiter (NAFEC), R. Wiseman (TSC), M. Connelly (ESL/MIT, and T. Morgan (CSC)	8. Performing Organization Report No. FAA-NA-74-21
9. Performing Organization Name and Address Federal Aviation Administration National Aviation Facilities Experimental Center Atlantic City, New Jersey 08405	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. 062-222-040
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590	13. Type of Report and Period Covered Final May 1974 to August 1974
	14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

A dynamic simulation study was 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. The study focused on the benefits that might accrue to ground-based automatic control through further automation of the controller's communication tasks. The simulation was performed at the National Aviation Facilities Experimental Center as a joint effort with the Department of Transportation, Transportation Systems Center. A simplified version of the ARTS III Metering and Spacing system was used to assess the controller's communication task when automatically generated control commands were transmitted to voice link or to data link-equipped aircraft in terminal approach traffic. Subject to follow-on testing of a more operational nature, it was concluded that a data link channel efficiently augments the voice channel, the value increasing as the percentage of data link aircraft increases. System test measures and questionnaire results show that further efficiencies can be obtained through the use of computer-generated speech, one-at-a-time display of commands moving with the aircraft target symbol, and by the automatic transmission of commands on both the voice and data link channels. The automatic command transmission eliminates the controller's tasks of approving commands, placing more emphasis on traffic situation monitoring. With a careful optimization of display formats and operating procedures, the controllers' acceptance of automation features will improve while they are still provided with safe traffic management and recovery techniques during system failures. Volume I of this study is a Summary Report.

17. Key Words	18. Distribution Statement
Air Traffic Control Simulation Data Link Terminal ATC	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	250	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

Volume I is the Summary report of this effort, and this, Volume II, contains the detailed analytical material. They represent the preliminary simulation phase of a subprogram that deals with the air traffic controller's role in a digital data link communications environment. The subprogram is one of three parts of an overall program that had the following objectives:

1. To develop and evaluate cockpit display and input devices that take advantage of the automatic capability of a data link channel.

2. To determine the controller's reaction to a new channel that addresses aircraft with these devices.

3. To measure the characteristics of a very high frequency (vhf) data link between these air and ground stations.

The cockpit activity is currently well underway and has been reported in FAA-RD-74-82 under the title "Human Factors Experiments for Data Link." The results of the activity indicate that (1) air traffic control (ATC) messages and advisories can be efficiently presented in data link-equipped aircraft, and (2) the data link supplements and may eventually replace a good portion of the present voice communications channel, especially as more aircraft become data link-equipped. The activity also provided measurements of pilot response time in full simulations of his workload in the terminal area. These measurements and the known characteristics of the link were used in the formulation of realtime simulation experiments that were centered on the controller. This report deals with the first of two sets of these experiments, both under the title of Controller/Computer Interface Subprogram.

The authors wish to express appreciation to the numerous people who were instrumental in the development and conduct of this simulation study:

1. Program Sponsorship: William Hyland and Thomas Williamson, FAA, SRDS.

2. Software Design: Linda Hartz and John Vanderveer, NAFEC.

3. Software Development: John DiNofrio and Stanley Pszczolkowski, NAFEC.

4. Data Reduction: Dr. John Royal, Kentron of Hawaii, Ltd.

5. Data Summaries: Iva Callio, NAFEC.

6. Traffic Sample Preparation: Christine Law and Jesse Bellino, NAFEC.

7. Data Analysis: Donald Eldredge, NAFEC, and Edward Stevens, CSC.

8. Hardware and Test Rescue: Louis Bona, NAFEC.

9. Guidance and Public Relations: Felix Hierbaum, NAFEC.

10. Controller Operations: Stephen Karovic, John Badzo and William Mullen, NAFEC.

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LIST OF ABBREVIATIONS

ACID - Aircraft Identification
AEEC - Airlines Electronic Engineering Committee
AGACS - Automatic Ground-Air-Ground Communications System
ARINC - Aeronautical Radio, Inc.
ARTS - Automated Radar Terminal System
ATC - Air Traffic Control
ATD - Assigned Time of Departure
ATIS - Automatic Terminal Information Service

BMDIIV - Biomedical Computer Program

CALCOMP - California Computer Products, Inc.
CBA - Control By Approval
CBE - Control By Exception
CID - Command Initiation Delay
CONUS - Continental United States
CPTT - Controller Push to Talk
CSC - Computer Sciences Corporation

DABS - Discrete Address Beacon System
DEDS - Data Entry and Display System
DICE - Direct Course Error
DR&A - Data Reduction and Analysis
DSF - Digital Simulation Facility
DSF Sigma 5 - Xerox Computer System

EQD - Equipment Delay (Up/Down Link)

F - Data Link Failure
FDB - Full Data Block

HAS - Heading, Altitude, Speed

IAS - Indicated Airspeed
ICAO - International Civil Aviation Organization
IDICE - Initial Direct Course Error
IFR - Instrument Flight Rules
ILS - Instrument Landing System
I/O - Input/Output
ISO - International standards Organization

KHz - Kilohertz

LSR - Least Squares Regression

LIST OF ABBREVIATIONS (continued)

M&S - Metering and Spacing
MDT - Message Delivery Time
MIP - Message in Process
MSL - Mean Sea Level
MTT - Message Transaction Time

NAFEC - National Aviation Facilities Experimental Center
NAK - Data Link Message Received Incorrectly by Airborne/Ground System
NAS - National Airspace System

OM - Outer Marker

PPTT - Pilot Push to Talk
PRT - Pilot Response Time

SRDS - Systems Research and Development Service
ST - Service Time

TAB - Tabular List
TAS - True Airspeed
TATF - Terminal Automation Test Facility
TSC - Transportation Systems Center

U - Data Link Unable

vhf - Very High Frequency
Vosyn - Voice Synthesizer
VPTT - Vosyn Push to Talk

W - Data Link "Will Comply"
WILCO - Will Comply
WMSC - Weather Message Switching Center

4LN - Longmont Feeder Fix
4RG - Roggen Feeder Fix

INTRODUCTION

PURPOSE.

The purpose of this activity was to determine the display techniques and operational procedures that best enable a terminal area air traffic controller to work in a mixed voice/digital communications environment. More explicitly, a simulation study was conducted to obtain the following:

1. The controller's reaction to increasing percentages of data link-equipped aircraft in traffic situations that involved (a) a high volume of control messages, and (b) a reasonably realistic model of an air traffic control (ATC) system currently under development.

2. The most practicable of various candidate modes of data link operations for use in an ATC facility. The selection of these modes was to be obtained from measures of the controller's acceptance and his traffic-handling capacity while maintaining his ability to evaluate the commands.

BACKGROUND.

The idea of a digital data link for ATC is probably more than 30 years old. Early efforts by the Federal Aviation Administration (FAA) go as far back as 1958 when an experimental Automatic Ground-Air-Ground Communication System (AGACS) was developed. The system performed well in later testing at the National Aviation Facilities Experimental Center (NAFEC), but was felt to be too far ahead of its time. This conclusion was made in 1961 by the Task Force on Air Traffic Control (reference 1), more popularly known as PROJECT BEACON. The task force effectively postponed further data link work until a number of related technologies could catch up. Among these were improvements in air traffic surveillance systems and the automation of the control functions on the ground. The task force did, however, lay the ground work for the development of techniques and system standards for future automatic digital communications. This led to specifications of message formats and codes (reference 2), and follow-on activity that covered transmission speeds and modulation characteristics. In March 1968, a final report (reference 3) was issued to establish these standards on a national level.

Since 1968, there has been a strong upswing in data link activity within the FAA. The prime factor in this renewed interest was the need to keep pace with the projected increases in air traffic. It was obvious that such increases could not be accommodated without coordinated programs utilizing recent technological advances in the areas of radar surveillance, communications, cockpit displays, and the automation of ground-based air traffic control. At the same time, computer speeds and memories were improving to the point where it was possible to process the information that could maintain a national airspace system. Low-cost minicomputers were becoming available to perform a variety

of message formatting and routing tasks within remote ground and airborne systems. Airborne equipment manufacturers were considering low-cost applications for new display elements (such as light-emitting diodes, liquid crystals, etc.) that could fit in smaller spaces on the cockpit panels.

In the automation area, the FAA has been developing two major systems, National Airspace Systems (NAS) Stage A and Automated Radar Terminal System (ARTS), for ATC in the enroute and terminal airspaces. One version, namely ARTS III, is being designed to automate ATC functions in high-density terminal areas. The first of these functions now provides the controller with a two-line alphanumeric data block that is placed near the radar symbol that is displayed for each of his aircraft. The block indicates the aircraft's identity on the first line and its altitude and ground speed on the second. This basic feature is now operational at most large airports and has led to an FAA ARTS III enhancement program for other automatic functions. One function, dealing with high-density terminal approaches is now being developed in the ARTS III Metering and Spacing (M&S) program. This program envisions the use of automatically generated aircraft heading, altitude, and speed (HAS) commands in place of those normally issued by the controller. That is, the commands would be displayed for controller approval and voicing after the decisions for routine aircraft spacing and sequencing had been made by a computer. The idea here is to relieve the controller of his continuous computation of HAS values so that he can focus on the more difficult situations in his overall traffic picture. Since the HAS commands occur at a high rate with a simple format, there was a strong reason to consider their application to a data link.

FAA programs in other areas were also promoting data link activity. Channel availabilities on the very high frequency (vhf) voice frequency had reached the point where the bandwidths had to be decreased from 50 kilohertz (kHz) to 25 kHz. It was possible to further relieve voice-channel congestion with rapid transmissions of ATC commands on a separate digital link. This led to the inclusion of a data link capability as a part of the surveillance function in the newly developing Discrete Address Beacon System (DABS) program. DABS was established to eliminate garble in the current radar returns via a selective addressing of aircraft equipped with DABS transponders. The transponders could be used for the transmission and reception of data link commands simultaneously with each radar interrogation.

In July 1968, the Airlines Electronic Engineering Committee (AEEC) of Aeronautical Radio, Inc. (ARINC) reestablished its long-dormant Data Link Subcommittee in order to prepare a data link airborne equipment specification (reference 4). One of the major concerns of the committee was to determine the types of data link cockpit input/output (I/O) devices and communications techniques that could be used with the current vhf transceiver equipment. The committee has been working, in cooperation with the FAA, to investigate a vhf data link as an alternative to that in the DABS program. This effort was a part of an FAA staff study to continue vhf data link programs in parallel with DABS until the technical risks in the newer program could be more accurately assessed.

Among these risks were the high costs of outfitting the entire airline fleet with new transponders while considering the possibility that the vhf link itself might provide an adequate capacity for any future ATC operations.

By 1972, the data link setting had crystalized to the point where specific FAA programs were underway. DABS development had started and a number of oceanic and Continental United States (CONUS) satellite systems were being defined. As a part of this overall effort, a 3-year data link operational experimental program was outlined for development at the Transportation Systems Center (TSC) by the Communications Division (ARD-200) of Systems Research and Development System (SRDS). In the planning stages, the FAA requested TSC to satisfy two objectives: first, to develop and evaluate cockpit I/O devices that could be used with any data link (DABS, vhf, etc.) and secondly, to define operational interfaces between the airborne equipment and the ground ATC systems. One of the first issues in the design of the cockpit devices was to determine the types of ATC messages best suited to a data link. Since the ultimate aim was to provide an operational demonstration, a timetable was set up to obtain these messages from the various ATC systems currently under development. This led to the specification of a ground minicomputer system with communication links to ARTS III, NAS Stage A, Weather Message Switching Center (WMSC), and an ARINC system that would be used for airline company operational messages. The ground system was to act as a message-switching center, passing the messages back and forth on the existing vhf radio channel. The messages would then continue through the airborne transceivers and an airborne system to the cockpits.

In late 1972, the TSC data link program had progressed to the stage where detailed plans were developed for live testing at Denver Stapleton International Airport. The plans called for a ground system operating with up to 20 data link airborne systems that were to be installed in commercial aircraft. The participating airlines would have cockpit displays and keyboards for a two-way communication of ATC messages and advisories in the terminal area.

The keyboards and single function keys would allow the pilot to request and send weather information and to indicate compliance (WILCO) to ground commands from the ARTS III M&S system. These latter commands were to be shown on short-message displays along with cockpit printouts of the longer flight plan information Automatic Terminal Information Service (ATIS) reports, etc. The decision to select M&S commands as the first source of automatic control messages was based on three factors: (1) An initial version of the M&S system was being evaluated at NAFEC with plans for follow-on preoperational tests at Denver; (2) the HAS command types were identical to the controller's current procedures for manual vectoring on the voice link; and (3) the high frequency and standard formats of the commands were ideal for measurements of pilot workload with a data link.

In early 1973, a reduction in funds for the TSC data link program virtually postponed the construction of all but two of the airborne systems. This caused a restructuring of the program in favor of a more expanded use of simulation in three separate subprogram areas: the cockpit I/O; the vhf link characteristics; and the controller interface with a data link. It was reasoned that occasional trips to Denver by only two data link-equipped aircraft would not provide enough data to support an operational demonstration. Fortunately, earlier simulations with breadboard versions of the cockpit devices suggested that a careful scenario design would permit an independent evaluation in each area. That is, the major data link effect of the pilot on the controller (and vice versa) could be expressed as a set of communication time delays. With the obvious exception of the vhf link subprogram, these delays could be selected to suit any type of data link (DABS, vhf, or whatever) in separate simulations of the ground and airborne environments.

By late 1973, development plans were finalized to conduct the ground side of the data link experiments as a simulation study under the title "Controller-Computer Interface Subprogram." The idea was to use the existing Digital Simulation Facility (DSF) and Terminal Automation Test Facility (TATF) simulation facilities at NAFEC in two stages of a joint TSC/NAFEC effort. The first stage of this effort is the subject of this report and was performed at the DSF using a simplified model of the M&S traffic pattern. The plan then called for selection of a few of the candidate modes of operation for follow-on tests on the real ARTS III M&S system in the TATF. This approach was taken for a number of reasons, the main one being that there were at least 10 different ways that M&S commands could be displayed and dispatched in a combined voice/data link environment. Each of these test modes had good and bad points that brought out diverging opinions from the controllers during the initial stages of the design. Since the second stage of TATF testing was envisioned as a larger and more expensive operation, it was decided to conduct a preliminary evaluation on the DSF (a detailed description of the DSF is contained in appendix A). This would provide sufficient quantitative and qualitative information under test conditions that would also be more easily controlled. However, there remained the problem of establishing a low cost, but reasonable, facsimile of the M&S environment while that FAA program was still undergoing development.

TEST METHODS

From a global point of view, the FAA operational requirement for a data link was at least 5 to 10 years in the future and had to have some automated system that could benefit from further automation of the communications channel.

However, even if these benefits were accepted, it would be a long time before all of the aircraft were equipped for data link. Moreover, the voice channel would still be used for backup, especially during emergencies. So the experimental situation had to be one where the controller was operating with

two separate channels with the data link initially in the minority role. As more and more aircraft became data-link equipped, this process would reverse, but the voice link would still be used for those aircraft that were not so equipped. This setting made it necessary to adopt a test approach that would permit a comparison of the controller's performance on both links. This would be done in such a way that his proportional activity on each link was determined by the mixture of voice and data link aircraft in his airspace.

The next issue was to select a system that had a sufficiently high volume of automatically generated ATC messages. Obviously, such a system would have to assure that the controller's communication task was a large part of his total workload. This implied that the messages had to occur frequently and, therefore, have a format that was easily recognized in a high-density ATC situation. These conditions were ideally matched by the proposed ARTS III M&S system (for simplicity, the proposed ARTS III M&S system will be called the "real M&S").

FUNCTIONAL MODEL OF THE ATC SYSTEM.

The development of a laboratory model of M&S involved decisions weighing realism against cost and the desire to have test data that was both manageable and meaningful. At the outset, it was assumed that comparative measures of controller performance on the two links were relatively independent of the terminal area geometry. Moreover, as long as the essence of the control mechanism was maintained, the controller's communications task would be largely unaffected by the elimination of peripheral M&S functions. These conclusions will be justified starting with a simplified portrayal of M&S shown in figure 1. The figure uses solid lines to symbolize the paths of aircraft as they might proceed into runway 8R at Denver Airport. The main features of these paths are as follows:

1. Enroute aircraft proceed inward to the two feeder fixes, Longmont (4LN) and Roggen (4RG), and are then ready for handoff to the approach controller.

2. In current operation, the approach controller would form a string of aircraft between the feeder fixes and the outer marker (OM) by manual vectoring of each aircraft. The vectoring would consist of heading, altitude, and speed commands issued in such a way that a safe spacing is maintained at all points in the airspace. This procedure is altered by M&S which employs a structure where the aircraft, at both feeder fixes, converge into an inner fix.

3. At the inner fix, the aircraft would be given a heading command for a turn onto a final approach path proceeding through the approach gate, and onto the runway.

The ARTS III M&S system was designed to replace the controller's manually calculated vectors with commands that are automatically generated by a computer algorithm. The premise was that since the radar position and aircraft type

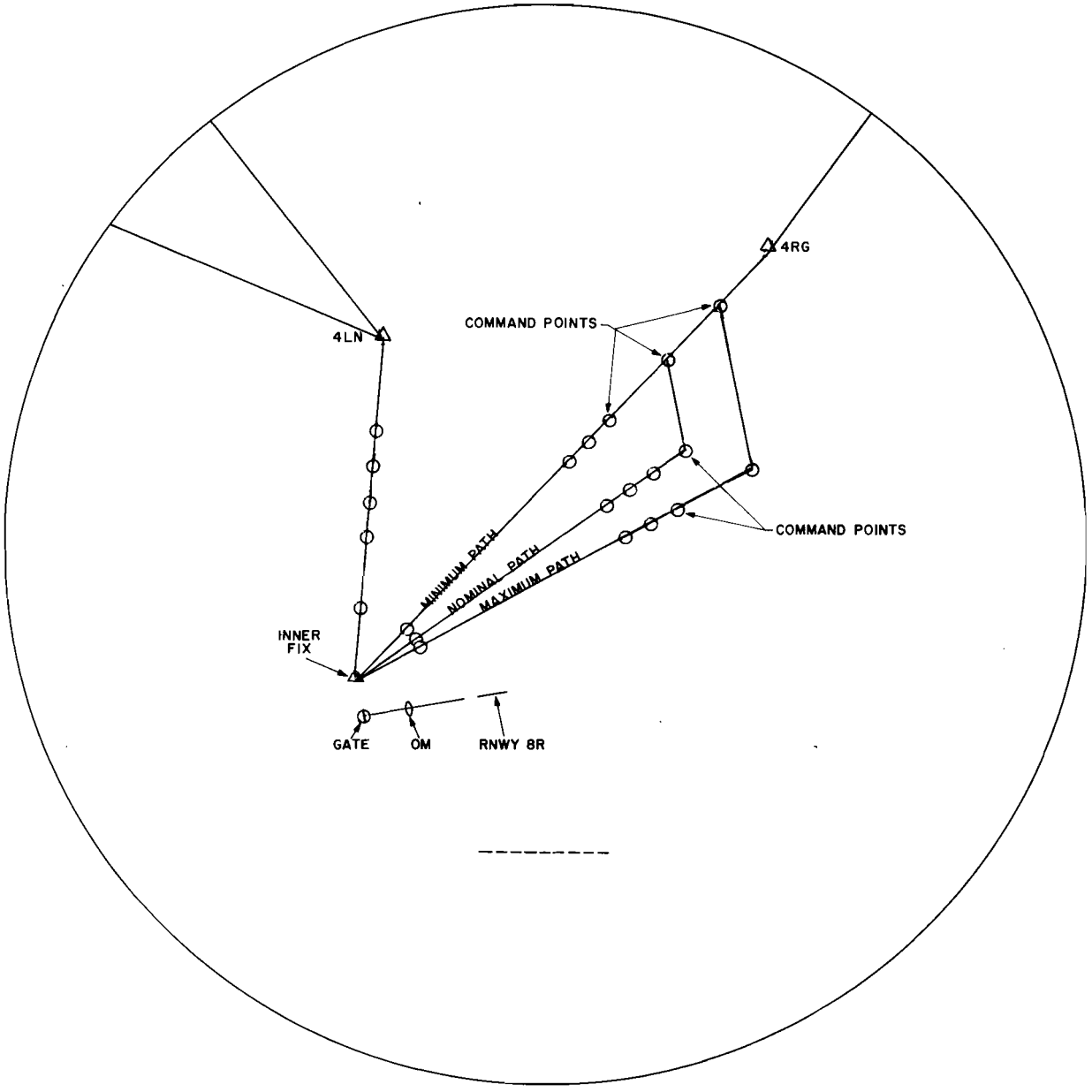

FIGURE 1. SIMPLIFIED M&S GEOMETRY

were known, the algorithm could provide a better regulation of the traffic flow in the entire approach area, thereby decreasing controller stress and (possibly) increasing traffic density. This regulation was to be obtained through an automatic sequencing of aircraft through each of the fixes and thereafter by path stretching and speed control. This situation is symbolized by the three paths forming the triangles from the Roggen feeder fix. The algorithm would schedule the aircraft to proceed through the feeder fix within 1 minute of an ideal time. The ideal time was precalculated from the aircraft's performance characteristics to assure that the aircraft would mesh smoothly with the other traffic between the inner fix and the runway. If the aircraft had passed through the feeder fix at its ideal time, the algorithm would issue two heading commands (the two initial blue circles) to have the aircraft take the nominal triangular path to the inner fix. If the aircraft was a minute early, the heading commands would increase the route to the maximum path. If a minute late, the aircraft would shoot straight into the inner fix. Once these path-stretching maneuvers were completed, speed commands were issued along the inbound radials to achieve the final small adjustments in the aircraft's assigned time of arrival at the inner fix. This entire derandomizing process assures that the minimum spacing between aircraft was never violated - especially between the inner fix and the runway. The real M&S included other features such as multiple altitude slots at the fixes, a "trombone" effect for final turns to the runway, and departures arranged from the known spacing of inbounds (reference 5).

The next step in the development of the functional model was to place it in the test setting and examine the interface between the computer algorithm and the controller. This is best accomplished with the aid of the block diagram shown in figure 2. The diagram represents an adaptation of existing capabilities in the NAFEC DSF. Although these capabilities are explained in detail in appendix A, a brief description is in order.

The label "DSF ARTS III Data Entry and Display System (DEDS)" represents a controller display and keyboard capability much like that found in an operational facility. Software in the DSF Sigma 5 computer establishes an ATC situation on the display from standard target generation and display format programs. The display programs include vector generation for video maps of the situation geometry and alphanumerics that can be grouped in the same way as the real ARTS III formats. A dynamic simulation of aircraft maneuvers is initiated by programs that form a prescripted traffic scenario for selected performance types in 12 categories ranging from single props to heavy jets. These types, along with the aircraft identity (ACID) and its time of initial appearance on the display, are set up in a traffic sample program before an experimental run begins. During the run, the controller may alter the course of any aircraft by a voice command to simulator "pilots" located at a remote set of displays and keyboards. These pilots then voice back a compliance (WILCO) message after they have keyed in the ACID and the command value. The entries would cause the target generator to realistically maneuver the aircraft on the display.

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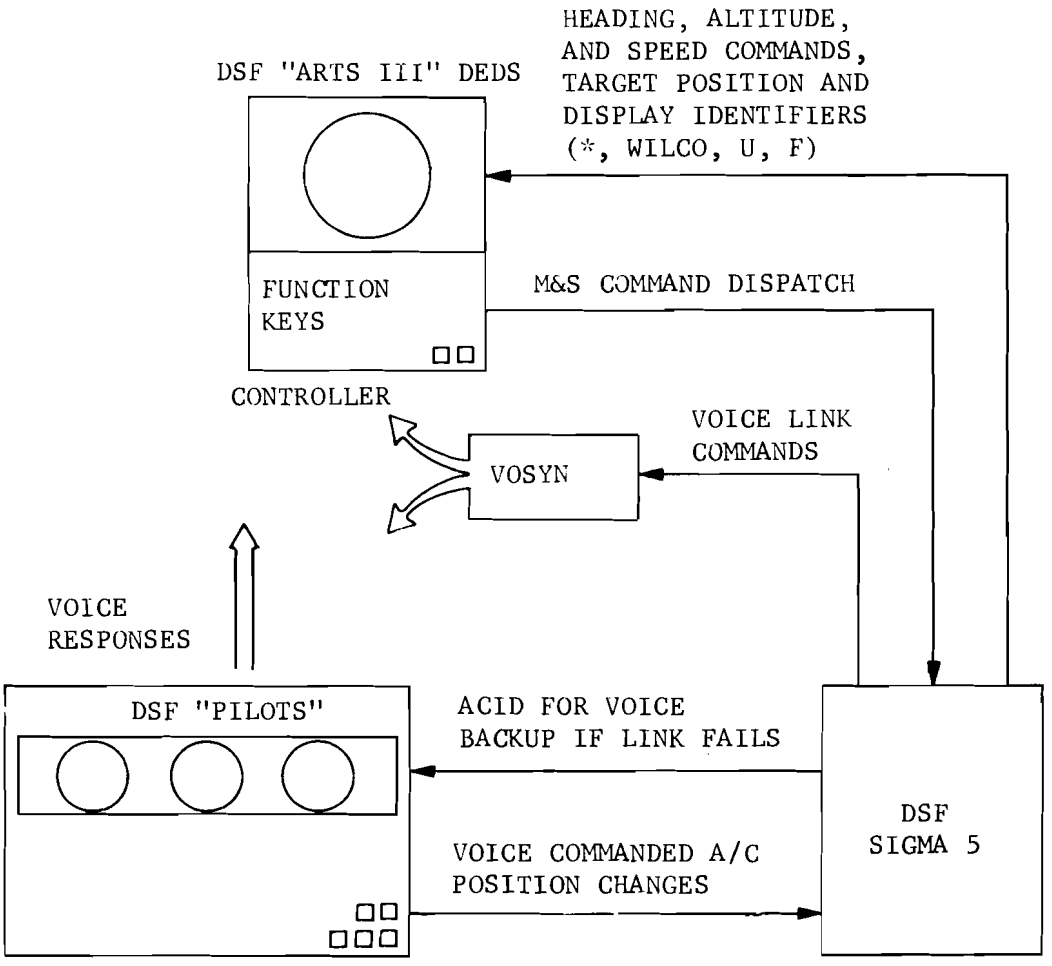

FIGURE 2. BLOCK DIAGRAM OF TEST SETTING IN DSF

The DSF has a large library of software programs that are easily adaptable for data reduction and analysis (DR&A) on a rapid turn-around basis. There is also a capability to develop special software for particular project needs. Four such software routines were written for data link: (1) A module simulating the equipment and pilot WILCO delays in the data link ground and airborne systems; (2) a vocabulary routine that would translate digital data to voice commands via a voice synthesizer, Vosyn (a detailed description of the Vosyn is contained in appendix B); (3) a program for data extraction and summary printouts at the end of each test run; and (4) a dynamic scenario that served as the main part of the functional model of the ARTS III M&S system. This latter program was the result of an experimental design in two major areas: (1) simplification of the M&S traffic situation and control mechanisms; and (2) development of display techniques and special function key procedures for each candidate mode of operation. These areas are discussed in detail, respectively, in appendices C and D.

Given the setting and some understanding of M&S, it is now important to address the major issues in the simulation modeling. The first of these was the decision to use only one approach controller as the test subject in each experiment. Studies (reference 6) had shown that it was difficult enough to characterize a controller's interaction with a computer without involving him in communications with other sectors, assistants, enroute, etc. Besides, these communications cover a wide range of extemporaneous messages that are not easily digitized and therefore do not lend themselves to a comparison of voice versus data link operation. The decision resulted in a number of simplifications that provided some standardization in the scenario and data base. It also led to the elimination of holding at the feeder fixes and the display of departing aircraft. However, some realism was still maintained in that the controller could still refuse a handoff and manually vector aircraft in any area up to the runway.

The second major issue was to simplify the M&S traffic pattern to the point where the entire set of control algorithms would not have to be reconstructed as a software package in the DSF Sigma 5 computer. For this reason, two major simplifications were made: (1) Elimination of the "trombone" adjustment of final turns from the inner fix to the runway; and (2) segregation of low- and high-performance aircraft to separate feeder fixes. The elimination of the "tromboning" made sense for other reasons, the main one being controller difficulty with the sets of turn commands that were generated by the real M&S system. Besides, if M&S were to assure a safe spacing for all inbounds, a single standard turn to the runway would be adequate for any aircraft that passed the inner fix near its ideal time. If not, the controller would have one path as a reference when he decided to make his own (manual) adjustment of the path length. This seemed to be a more sensible procedure in the small, high-density region around the inner fix. Moreover, since the "tromboning" was a part of the real M&S control scheme, a controller's extemporaneous adjustment of the final turn would force the algorithm to change the spacing

of all other aircraft clear back to the feeder fixes. This was a very complex task that could be eliminated without a drastic effect on the controller's communication environment. Therefore, it was decided to restrict the simulation of M&S control to the area between the feeder fixes and the inner fix. Within this area, a further simplification was made to assign all high-performance aircraft to the Roggen entry path and to have all low-performance go through Longmont. The assignment was necessary because a high-traffic density was needed in order to get a high-message rate. The resulting minimum separation requirement was virtually impossible to satisfy when light prop aircraft were mixed with jet traffic.

The above simplifications of the M&S traffic pattern may now be summarized with the aid of figure 1 and a scenario discussion involving four other basic features, namely:

1. The generation of prescripted (canned) traffic entry times from a single master traffic sample that was calculated to have all aircraft reach the feeder fix at their ideal times. These times were then altered at random, in a ± 1 minute range, to produce variations in traffic for each test run.

2. The selection of only two aircraft performance types for each feeder fix: light, single, and twin props for Longmont; and medium and heavy commercial jets for Roggen. These four types covered an adequate range for the tests.

3. The elimination of path stretching in the Longmont approach in favor of speed commands that were, by themselves, sufficient for the time adjustments of light aircraft.

4. A 1-hour test run with no winds and a ramp increase in traffic density from zero to 11 aircraft. The density was defined to be the approach controller's instantaneous aircraft count in the region between his handoff acceptances at the feeder fixes and the gate.

The above features address the third major issue in the simulation modeling; that is, simplification while still maintaining the appearance of differences in the traffic situations. Fortunately, the real M&S system assigned the task of scheduling aircraft through the fixes to the enroute controller. The procedure employed a list of feeder fix departure times that were automatically displayed for his approval. Stack departure or fix entry commands were then issued to each aircraft to insure that they would pass through the fix within 1 minute of their ideal time. The same list was also displayed to the approach controller to provide him with some advance information prior to his accepting a handoff. However, his main impression of incoming traffic was one where the aircraft would appear at regularly spaced intervals and then have their paths adjusted by the M&S system. This type of situation was easily duplicated by simulation software that operated, first of all, on a perfectly constructed traffic-entry schedule. The schedule (or traffic sample) was prepared, in a backwards fashion from the runway, to insure that safe aircraft separations

were maintained through the entire flight (this procedure is discussed in detail in appendix C). The sample initiated a traffic pattern in which all of the aircraft would be commanded to fly along the nominal path to the inner fix. Once this had been done, the ideal feeder fix times were changed to produce a random variation of flight paths through the triangular path-stretching region. This process established seven different traffic samples for use in the series of tests. The differences were further accented in many other ways. These included variations in the aircraft identities and the random insertion of conflict situations and exception conditions. Collectively, these variations were sufficient to insure that the controller would not be able to recognize a current pattern from his impressions of previous ones.

Given a simple mechanism for the preparation of traffic samples, it was still necessary to establish the duration of each test run and a pattern of aircraft densities. Considerations weighing available computer time and the structure of the series of tests set the test duration at approximately 1 hour. This time seemed long enough to get results that were representative of an operational situation provided the subject controller was familiar with the procedures. With this in mind, a traffic sample with a completely different sequence of aircraft types was prepared for use in separate training runs that were scheduled before each test run. These assured an immediate familiarity with the many operational modes that were being evaluated.

Another issue relating to test duration was to select a pattern of aircraft densities that was realistic while still providing sufficient test data. This raised the enigma of the wide range of differences in the ATC controllers' ability to handle heavy traffic. Obviously, a maximum density had to be picked beforehand. But what was a suitable value that would not prove to be too light or too heavy when the results were in? This question could be answered for all controllers if the density was increased in a linear fashion to a maximum value that was thought to be virtually impossible to service. The idea was that each controller would eventually reach a point where his heavy workload would cause his communication delays to increase. In fact, his attention to his traffic might be so absorbing that he might not have time to complete his communications.

This led to the choice of a ramp load leading to 11 aircraft at the end of each test run. The choice placed a major emphasis on the continuous measurement of the controller's average communication delays. That is, it was reasoned that these delays would slowly increase until the controller had reached his individual workload limit; at which time the increase would be quite rapid. This type of measurement was used as a substitute for other controller stress indicators (such as psychophysiological effects in reference 5 previously cited). It was decided that it was not important to measure the amount of controller stress but, rather, to simply identify its onset. Besides, a wealth of related information could still be obtained through an expanded use of controller questionnaires and observer interviews.

The choice of 11 aircraft as the maximum density necessitated a reduction in the minimum allowable separation from 3 to 2 nautical miles (nmi). This lower separation was to be considered allowable for all intrail spacings except those behind heavy jets. In the latter case, a 5 nmi, 120° fan-tail was prescribed as the separation limit to avoid wake vortex problems. These two limits were used in DSF conflict detection programs that would report any spacing violation that might have occurred during each test run (see appendix A for a detailed description of the conflict detection programs). The programs would list the position, time, and identity of pairs of aircraft that violated the 1000 foot altitude or horizontal spacing minimums.

In order to eliminate learning effect on the part of the controllers, a different conflict situation was deliberately inserted in the traffic pattern of each test run. The situation was one where an erroneous set of M&S commands would be displayed to the controller. If he transmitted these commands, they would ultimately cause the aircraft to violate another's airspace. The controllers were told that when these potential conflicts developed, they were to press a key to eliminate the display of any further M&S commands to the intruding aircraft. After this disengage action was completed, the controller would voice his own manual vectors to the aircraft. A record of these actions was kept and later combined with the conflict reports as a check on the controller's awareness of his traffic situation. The check also provided some assurance that the controller was evaluating each command. As a further step in this direction, a set of "exception" conditions were assigned at random times in each traffic sample. These conditions involved temporary failures in the communications channel and pilot delays in command compliance. A communications failure was identified by a pilot repeat request (R) on the voice link and a 10 to 15 second outage (F) on the data link. One R and one F occurred on the respective links during each test run; the number being consistent with the failure rates obtained from studies (reference 7) of actual operations. (Data link failure rates were based on a conservative bit error rate of 10^{-4}. A rate of better than 10^{-5} had been observed on a vhf 2400-bit/second minimum shift key channel.) Similarly, one delayed compliance ("Standby approach") was used for the voice link and one indication of can't-comply (unable, U) was used for the data link. The whole set of these unusual conditions were combined with other workload items so that the controller would have a more realistic message environment. Among these were his acceptance of the enroute handoff and tower frequency and outer marker distances messages to aircraft as they passed the gate.

At this point, the main features of the functional model are briefly summarized as follows:

1. Realistic traffic profile with "M&S-like" geometry and control functions.

2. Single approach controller operating with inbounds from two feeder fixes to one runway.

3. Separate voice and data link communications channels.

4. One-hour simulation runs with a ramp density up to 11 aircraft.

5. Controller involvement with unusual conditions (conflicts, failures, etc.) and other workload items.

6. Aircraft segregation by performance type and with multiple altitude slots at the fixes.

SYSTEM DISPLAY AND CONTROL PROCEDURES.

Having established the traffic patterns and their control algorithms, it was necessary to address the related techniques for display presentations and function key operation. These techniques were defined as three sequential tasks: (1) Develop a basic display environment similar to that used with the ARTS III system; (2) examine the additional ARTS III enhancement features required for M&S operation with a voice link; and (3) combine the ARTS III and M&S techniques into a candidate set of operational modes that would work with a data link.

The "ARTS III like" display environment was obtained through a study of available display functions on the DSF and a consideration of the needs expressed by ATC controllers who had participated in the structuring of the model. The results of these efforts may be summarized (see appendix D for more detailed information) with the aid of figure 3 as follows:

1. The standard block of system data (altimeter setting, emergencies, radio failures, etc.) was not required.

2. The primary radar with its map video, weather identification, and range rings, etc., was not available on the DSF. This led to the formation of another video map using digital vector display and special symbols.

3. A 30-mile display range with an offcenter radar was used to provide maximum viewing of the approach controller's airspace. The runway is shown as the straight line below the three-line tag for the aircraft AA237.

4. Aircraft position was indicated by the controller's symbol, not the beacon slashes. As shown near the blinking tag for N4957, the symbol would appear as a "C" prior to handoff. Upon handoff acceptance, the symbol would change to an "A" with a nonblinking tag. When the aircraft reached the gate, the tag would be dropped and the symbol would change to a "T", indicating transfer to the tower.

5. A fixed-length leader line was used to associate aircraft tags with their corresponding symbols. To minimize tag overlaps, the tags were deliberately placed in a prearranged orientation with respect to the symbol. For example, the light-aircraft tags would change from the upper right quadrant to the left side after the aircraft had passed the feeder fix. However, the controller still had an ARTS III capability to manually relocate the tags.

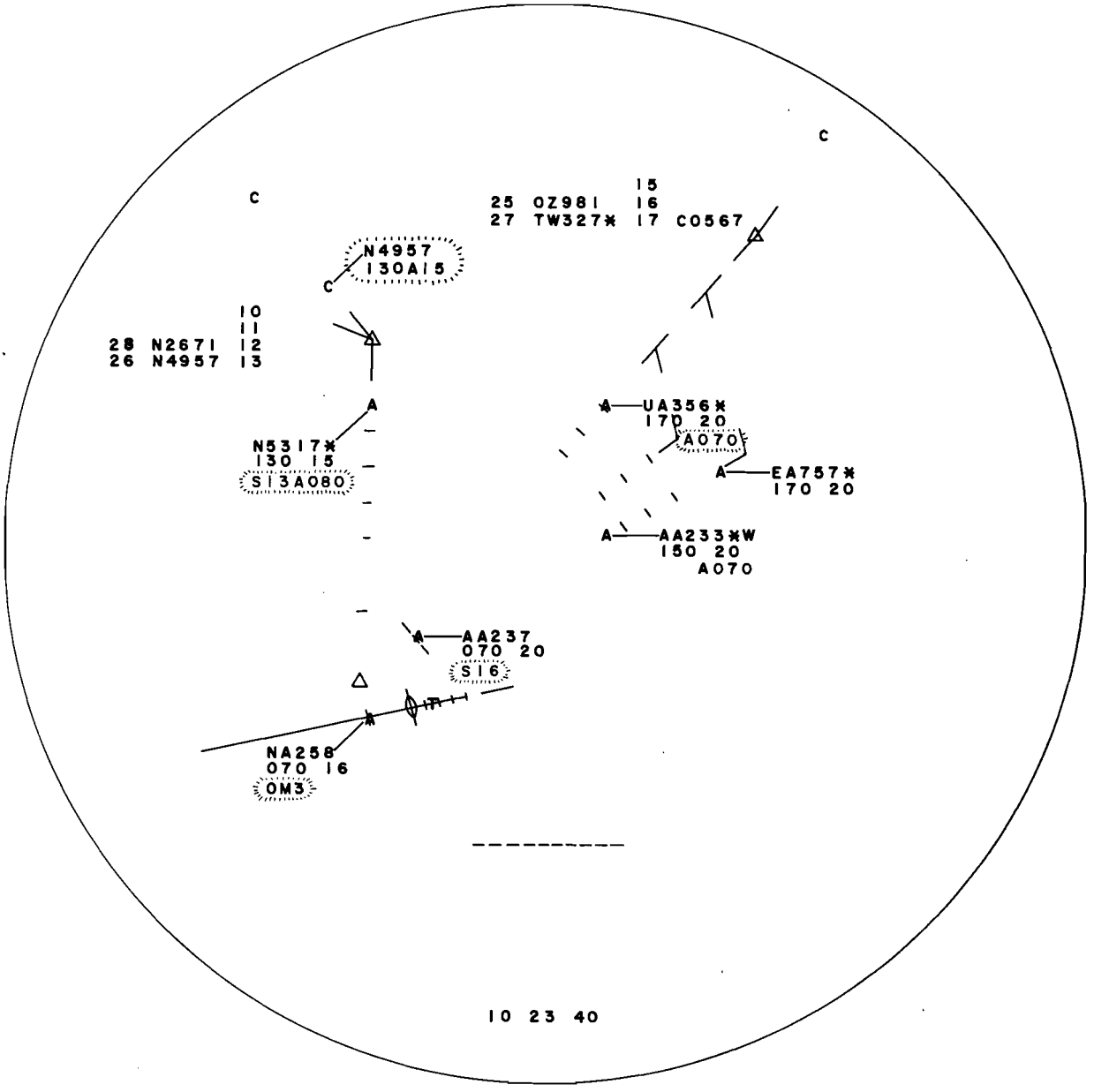

FIGURE 3. MULTIPLE COMMAND DISPLAY IN THE FULL DATA BLOCK

6. The ARTS III tag would consist of a five-character aircraft identity with the standard use of the second line for altitude and groundspeed. As shown in the tag for N4957, the approach controller's symbol (A) would appear in the second line during the handoff.

7. All aircraft would have instrument flight rule (IFR) flight plans and would be equipped with Mode C transponders.

In a number of cases, the above features were considered as reasonable alternatives to an exact duplication of ARTS III display functions. For example, the elimination of the primary radar and beacon slashes resulted in less display clutter and associated target identification problems that were, at best, infrequent workload items. Similar reasoning applied to the creation of a vector-generated video map instead of the usual analog map that indicated route structure, weather, etc. The construction of the replacement map was based on three assumptions: (1) A representative situation with IFR aircraft would not involve weather indications; (2) the controller's familiarity with his terrain would, generally, only require the display of high-altitude obstructions; and (3) the controller would need some visual cues of M&S control boundaries and route structure. The idea here was that since the M&S system was regulating the path structure, it could automatically select the available routes, and thereby provide some indication of the path boundaries with, at least, specialized sets of alphanumeric symbols. These would help the controller in his understanding of the general location of the commands and the amount of path stretching that was needed. With this in mind, a video map was designed as shown in figure 4. This map had three main features: (1) Identification of the maximum, minimum, and nominal paths in the Roggen triangular boundary; (2) short dotted lines to indicate the nominal points for altitude and speed commands; and (3) special symbols for the gate, outer marker, and 1-mile range marks near the runway.

The M&S capability to structure the traffic geometry led to another alternative to the standard ARTS III method for automatic repositioning of the data block (tags). Although the current method relocates a tag whenever it touches another one, the tag motion sometimes causes a temporary loss in the controller's identification of the aircraft. Since the DSF did not have an automatic tag repositioning capability, it was decided to select three sets of advantageous tag positions that were prearranged for traffic from both feeder fixes. These positions are shown in figure 5 and resulted in a low number of tag repositionings during the test runs. The idea here was that the controller's attention to the tag orientation was difficult to measure. Besides, this spurious workload item could be minimized if the tags only changed position at the feeder fixes and the gate. Of course, another set of tag positions could have been automatically or manually selected for any operational M&S route structure.

The second major item in the development of the candidate operational modes was to examine the display presentations and function key operation that were proposed for use in the <u>original</u> M&S program. At the outset, two different

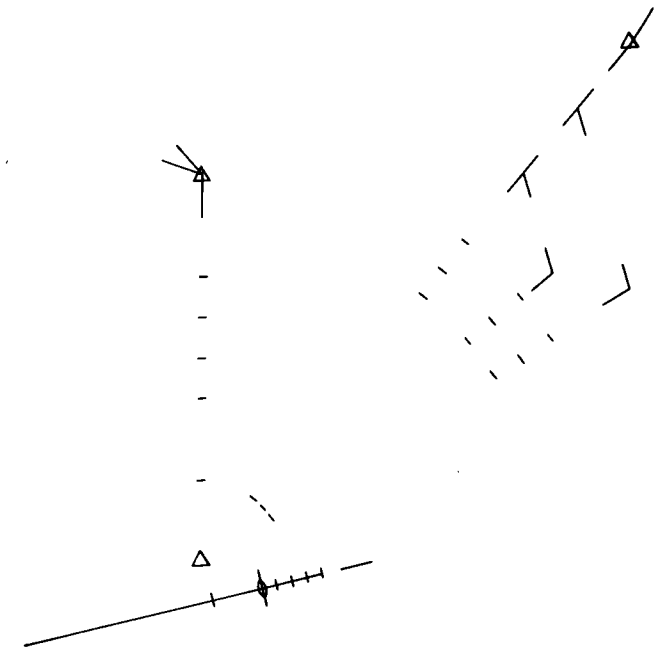

FIGURE 4. VIDEO MAP

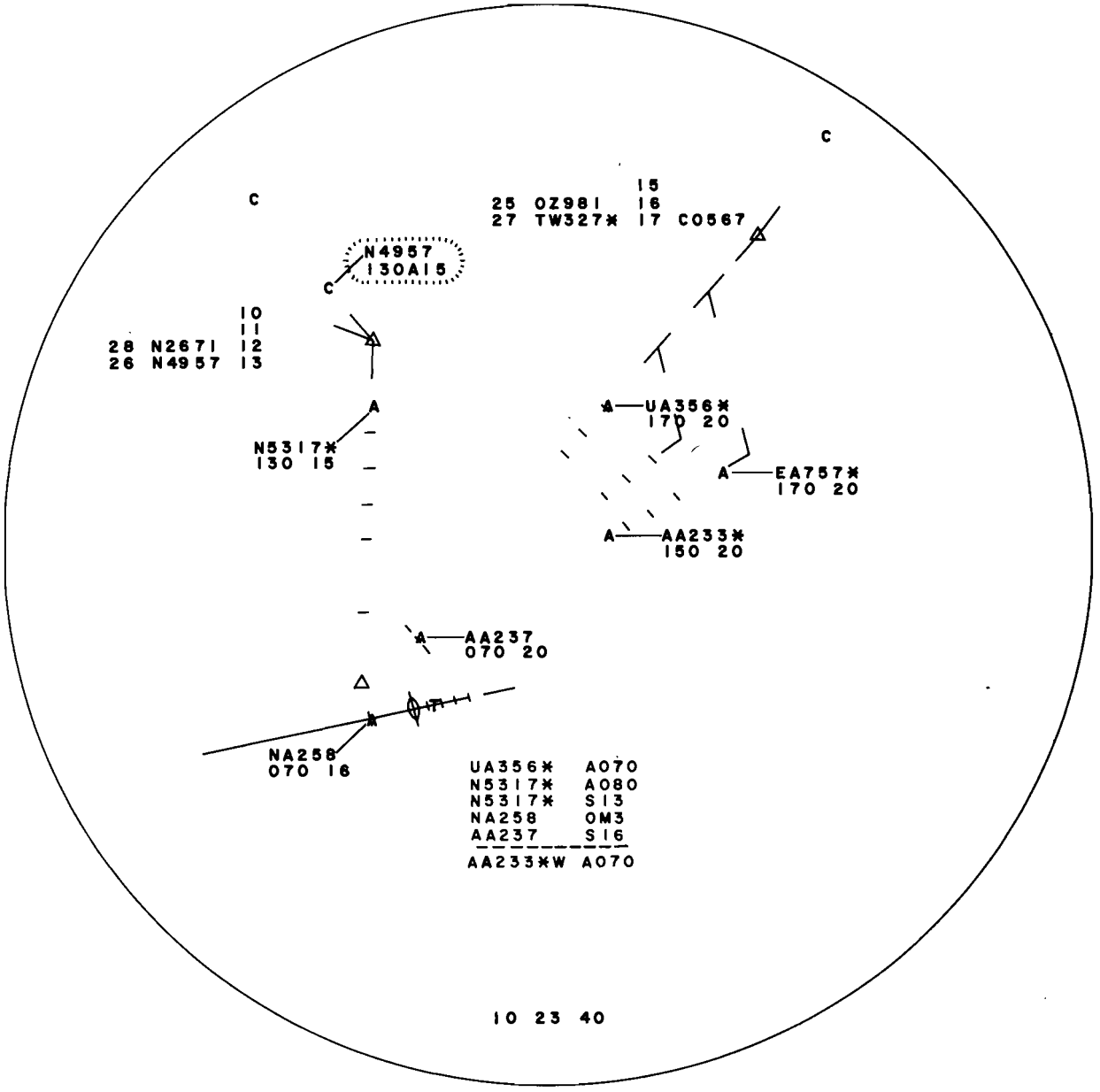

FIGURE 5. TABULAR LIST MULTIPLE COMMAND DISPLAY

methods for the display of these M&S commands were being investigated: (1) The Full Data Block (FDB); and (2) the tabular list (TAB). These methods are respectively summarized (see appendix D for a more detailed explanation) with the aid of figures 3 and 5 as follows:

1. FDB - Combinations of M&S heading, altitude, and airspeed commands were displayed blinking in a newly created third line of the ARTS III data block. These commands are shown in red in the tags for the aircraft N5317, UA356, and AA237. In practice, the commands had the same white color as all of the other characters and appeared blinking about 12 seconds ahead of the desired time for execution by the aircraft. The commands then became solid for a fixed time interval of about 6 seconds before they were automatically erased. On occasion, the controller would use the trackball with a special function key to erase the command after he had voiced it to the pilot. This would help him distinguish between commands that were already dispatched and those that were pending.

2. TAB - Heading, altitude, or speed commands were displayed, one at a time, in a separate tabular list much like that shown in red in figure 5. The command timing and voice link dispatch action were similar to that used with the FDB except that the controller could only cause a premature erasure of the top line. When an older command on the top of the list was erased, all lower commands would "page-up" one line.

The last major step in the simulation design was to "iron-out" the issues that would enable the addition of a data link capability to the controller's M&S communications environment. The first, and relatively minor one of these issues, was to identify a data link-equipped aircraft. Obviously, it was desirable to place a special character in the first-line after the ARTS III aircraft identity (as shown by the asterisk in figures 3 and 5). However, this choice presented a problem with seven-character aircraft identity limitations in the top line of the ARTS III data block. In the interest of simplicity, it was decided to restrict aircraft identities to five characters and to place the data link asterisk in the sixth character position. This decision left the seventh character position for the mutually exclusive data link indications of pilot compliance (W), noncompliance (U), or link failures (F). These indications appeared as follows:

1. A solid W would appear about 5 seconds (the delay was actually normally distributed between 2 and 8 seconds, σ=1 second in accordance with measurements taken in reference 8) after the controller had dispatched a command to a data link aircraft. This delay was automatically generated within the Sigma 5 computer in order to simulate the pilot's recognition of the command on his display and his subsequent depression of a WILCO button. The W would remain on the display for 3 seconds in order to give the controller a positive indication of the aircraft's compliance.

2. A blinking U or F would occasionally appear after command dispatch and would remain until the controller had resolved the problem on the voice link. The idea here was that the voice link would provide the backup for the infrequent data link failures or noncompliances.

At this point, it is important to focus on the controller's operation with M&S commands in a data link communications environment. At the outset, this operation may be characterized in the context of the following basic assumptions:

1. Since the data link channel is automatic, it could transmit the computer-generated commands and receive the pilot responses without a single controller action.

2. If the controller is to have prior approval of all commands, his dispatch action can be as simple as the depression of a single function key after the computer knows the associated aircraft's identity.

3. The same dispatch action could be used for voice link commands if a voice synthesizer (Vosyn) were used to convert the digital information into an audible message. In fact, if prior approval were not required, these messages could also be transmitted automatically.

In the early stages of the design, the above assumptions were presented to ATC controllers as a part of a detailed description of the entire simulation. The description contained a number of candidate operational techniques and a discussion of their relative merits. The discussion raised issues in four major areas. These are briefly summarized as follows:

1. <u>FORMAT</u> - FULL DATA BLOCK VERSUS TABULAR LIST

   a. Command/response correlation with the target aircraft.
   b. Display clutter and awareness of the number (queue) of messages pending.

2. <u>ACCESS</u> - SINGLE VERSUS MULTIPLE COMMAND DISPLAY

   a. Speed of command association and recall ability.
   b. Elimination of trackball action versus priority selectability.

3. <u>CONTROL</u> - BY APPROVAL VERSUS BY EXCEPTION

   a. Controller attention to traffic situation versus command display monitoring.
   b. Continuous verification of command content versus occasional error correction.
   c. Resolving potential conflicts and system failures.

4. <u>COMMUNICATION MEDIUM</u> - VOICE VERSUS VOSYN

   a. Intelligibility, adaptability, and speed.
   b. Common procedures with the data link.
   c. Negotiation during unusual conditions and channel discipline.
   d. Possibility for automatic command transmission.

A better picture of the types of problems encountered in each of the four areas can be obtained from a view of the controller's operational procedures (the detailed design of these procedures is contained in appendix D). These procedures begin with the presentation of an M&S command on the display. Obviously, if the command appeared in a newly created third line of the ARTS III data block, there would be an easy correlation with the aircraft identity and its target symbol. However, if a number of commands were rapidly generated for different aircraft, the controller might find it difficult to identify the sequence of all of the commands that should be serviced. This sequence is clearly indicated when the commands are placed in the separate tabular list. The list has the advantage of reducing the display clutter and permits the insertion of other commands in a priority line position for fast servicing. It also minimizes the motion of a trackball that might be needed to identify the aircraft before the command could be transmitted. However, the list has the disadvantage of forcing the controller to move his eyes between the commands and his targets. This process is difficult enough even in a small field of vision without the further annoyance of commands jumping to a new position in the list whenever a prior command was erased.

The next operation, after the controller has seen the commands, is covered under the title of "access." In this area, the main issue is that of recognition and transmission of multiple commands to more than one aircraft when rapid adjustments in traffic control are required. One approach to this issue would be to display all commands as they are generated and let the controller select each one for successive transmission with his trackball. That is, in their simplest form, these commands could be sent to data link aircraft by the repeated action of slewing to each aircraft symbol and then depressing a DISPATCH function key. If many commands were generated simultaneously for voice link aircraft, the controller would need a similar action to indicate completion of his service for a particular command. For this reason, a second ADVANCE function key would be needed to change the command from a blinking to a solid state immediately after the controller had voiced it to the pilot. This also allowed a more rapid display of subsequent commands and avoided cases where (1) a busy controller might mistakenly voice the same command twice; or (2) become confused with voice versus data link transmissions.

An alternate approach in the "access" issue was to allow each command to be dispatched one at a time. Only one command would become active after the service to a previous command had been recognized from the depressions of the DISPATCH or ADVANCE keys. This approach eliminated the time-consuming trackball operation and rapidly focused the controller's attention to one point on his display. However, it did not permit him to transmit one command from an active group on a priority basis. For example, when a number of commands were blinking, it might be more important to first service those aircraft that were nearer to the highly congested inner fix area. Since this would not occur too often, another solution was proposed to present each command singly in the full-data block while a separate tabular list of all active commands was also displayed. This "composite" mode would allow the controller to select a list command out of order with a special function key and slew action. It could also provide the controller with information on the number of commands in the queue while he was servicing one command at a time.

A completely separate issue in the command processing deals with the type of command "control" that is to be exercised over each aircraft. Traditionally, the controller has had the responsibility to generate his own vector commands in such a way that the aircraft were safely spaced. With the advent of M&S, his role changes to that of a manager who approves each command before it is forwarded to the aircraft. If most of the commands are operationally acceptable, it would be more efficient to transmit them automatically after the controller had had some time to preview their content. This procedure would be good for a data link since the controller would not have to use a dispatch action for commands that were acceptable and would only occasionally halt commands that were not. However, he would still have to enunciate each command to voice link aircraft unless the Vosyn was used to perform this task for him. For this reason, the Vosyn was included in a "control-by-exception" (CBE) operational mode in which all commands were automatically transmitted regardless of their content. The idea here was to allow the controller more time to countermand an unacceptable command by extending his review past the time of transmission. For example, with the voice link, the controller did not have to pay strict attention to the displayed commands because he could always listen when the Vosyn subsequently enunciated the message. In this way, he could focus more on his traffic situation and rely on his DISENGAGE function key to stop any further command flow to any aircraft.

Although the CBE mode is more efficient than "control-by-approval" (CBA) modes, it does have a few drawbacks. The most important of these is that it is difficult for a controller to continually concentrate on his traffic when he is removed from his command conversation with each aircraft. Although this conversation may be an unnecessary workload item, it does provide him with more contact with the vector magnitudes. Without this contact, an operational situation might develop where M&S fails and the controller cannot quickly readjust to his older manual vectoring. Of course, this situation could be rectified with periodic training or standard traffic recovery procedures when failures occur. Alternatively, it might be better to have him operate in a CBA mode and then switch to CBE when the traffic density was high.

Another minor problem with CBE exception occurs when the Vosyn has to enunciate a stream of M&S commands that were generated close together. Since the commands are automatically transmitted, the controller may not be able to interrupt the Vosyn when he has a more important message that he needs to voice up himself. For this reason, a HALT function key was provided to stop the current Vosyn speech and all subsequent M&S voice commands. These commands were held in storage until the controller depressed a RESUME function key permitting the entire command queue to be enunciated.

The use of the Vosyn, in any mode, raised other questions relating to the voice communication medium. To begin with, the Vosyn was slower than the controller's speech and had some minor problems with intelligibility. On the other hand, the Vosyn did allow the same DISPATCH key to be used for voice and data link messages.

This eliminated the need for an ADVANCE key depression with the net result that the voice and Vosyn modes would have about equal message delivery times. The intelligibility issue did not prove bothersome when it was recognized that the controller's familiarization with the Vosyn "accent" was quite rapid and the simulator pilots were not having trouble with its speech. Besides, the Vosyn was enunciating commands that the controller had already seen on the display.

The last issue relating to the voice versus Vosyn question was that of channel discipline. In this area, it was decided to provide a 3-second pause between successive Vosyn messages to allow the pilot to voice back compliance to a command. This same pause would be needed so that the pilot could have an extemporaneous communication with the controller without being interrupted by the Vosyn; that is, since there is no ground sensing of pilot push-to-talk key depressions, the HALT key was used to inform the computer of Vosyn interruptions. A similar discipline was necessary whenever the pilot might answer "standby approach" to a controller command. In this case, since the controller was aware of the M&S command load, it was better for him to recontact the pilot than vice versa. This procedure was called "delayed compliance" and avoided interruptions of the Vosyn that could not be automatically monitored in operational situations. For the same reason, it was considered simpler to have the controller repeat a Vosyn message when a repeat request was received.

At this point, the operational techniques may be briefly summarized in terms of the specific function keys, options, and the test modes selected as candidates for the simulation evaluation.

The special <u>function keys</u> and their uses were:

1. DISPATCH: Uplink data link and Vosyn commands.

2. ADVANCE: Stop blinking of voice link command and (in TAB modes) send it to a nonblinking storage list in case of pilot repeat request.

3. DISENGAGE: Halt flow of commands to a specified aircraft for the remainder of its approach.

4. HALT: Stop Vosyn speech for controller intervention.

5. RESUME: Restart Vosyn at beginning of interrupted message.

The <u>options</u> to be considered were:

1. Full Data Block (FDB) versus Tabular List (TAB)

2. Single Command versus Multiple Commands

3. Voice versus Voice Synthesizer (Vosyn)

4. Control-by-Approval (CBA) versus Control-by-Exception (CBE)

The seven test modes selected for evaluation were:

1. FDB - Multiple Commands - Voice

2. FDB - Multiple Commands - Vosyn

3. TAB - Multiple Commands - Voice

4. TAB - Multiple Commands - Vosyn

5. TAB - Single Command - Voice

6. TAB - Single Command - Vosyn

7. Control-By-Exception (FDB - Vosyn)

Although there were 16 possible combinations of the options, 9 modes were eliminated for the following reasons:

a. Voice (rather than Vosyn) transmission is not applicable to CBE, since if the controller speaks the command, he is, in effect, approving it.

b. Control-by-exception with TAB involves automatic changes in the command state and position that would be difficult to follow.

c. The single display of active commands and its elimination of the trackball operation is not applicable to the automatic transmission of commands in a CBE mode.

d. Two other modes (FDB - single - voice and Vosyn) were discarded because of the presumed expense in providing a single command FDB capability to the real M&S program. The argument here was that the candidate modes should apply to the existing system and should not require modification of the system. A similar argument also caused the elimination of the "composite" mode previously discussed (combined use of the FDB and TAB).

A brief summary of the operations in each of the seven candidate modes is provided as follows (a more detailed description, including event time lines, is contained in appendix D):

Mode 1. FDB-Multiple-Voice: As shown in figure 3, commands would appear blinking 12 seconds before the desired time of execution by the pilot. This "lead time" would allow for an average 7-second delay by the controller and 5 seconds for the pilot to indicate compliance. Data link commands were transmitted by a DISPATCH operation that involved the following steps: (1) Press DISPATCH; (2) slew trackball to target symbol; and then (3) press the ENTER key. (This three-step operation was required because the DSF would only identify a slewed target from the ENTER key.) When this operation was completed, the command would become nonblinking and then be erased 3 seconds

after the aircraft's simulated WILCO, W, response was received (the W would appear in the first line as shown for the aircraft AA233). Voice link commands were changed to a nonblinking state after the controller had completed a similar three-step ADVANCE key operation indicating that he had voiced the command to an aircraft. The command would then be displayed, nonblinking, for 20 seconds in case the pilot requested a repeat or delayed compliance. The HAS command values for a given aircraft were displayed singly or in pairs. For example, 225 (heading only); 225S16 (heading and 160 knot speed); and S16A070 (speed and 7,000-foot altitude). Two special messages, OM3 and a heading command of 077, were respectively used to (1) identify the tower frequency when the aircraft was 3 nmi from the outer marker, and (2) imply an instrument landing system (ILS) clearance.

Mode 2. FDB-Multiple-Vosyn: Operation here was identical to Mode 1 except that the three-step DISPATCH key sequence was used for both voice and data link commands. In this case, the 20-second nonblinking holdover interval for voice commands began as the Vosyn started enunciating the message.

Mode 3. TAB-Multiple-Voice: As shown previously in figure 5, commands would be displayed nonblinking in a new command list located above the fixed dotted line. Each new command would appear along with its associated aircraft identity in a higher line than a previous command. The controller would use the aircraft's symbol to select a data link command by slewing his trackball to any location on the line. The three-step DISPATCH action was again used to transmit the message and would cause it to be moved to a storage list below the dotted line. The command would remain in this list until 3 seconds after a W was received or whenever an UNABLE, U, or link failure, F, was received. In these latter cases, the command and the condition would reappear in the high-priority second line of the new command list. A similar three-step ADVANCE action was used to transfer voice link commands to the storage list after the controller voiced the command to an aircraft. As before, voice commands would be held over in the nonblinking state for 20 seconds before being erased. The HAS command values were displayed in the same formats as those in the FDB, except that pairs of values were shown on separate lines. For example, a single trackball action and two successive DISPATCH and ENTER key depressions would be required to send the altitude and speed commands for the aircraft N5317*.

Mode 4. TAB-Multiple-Vosyn: Operation was the same as Mode 3, except that the three-step DISPATCH key sequence was used for both voice and data-link commands.

Mode 5. TAB-Single-Voice: As shown in figure 6, only one command at a time would be displayed blinking in the bottom line of the new command list. All other commands would appear nonblinking in successive lines above this active command on a priority basis. Highest priority was given to commands that had U or F responses or for turns to the ILS. Otherwise, the priority was assigned to commands for aircraft that were near the inner fix. In any case, whenever a

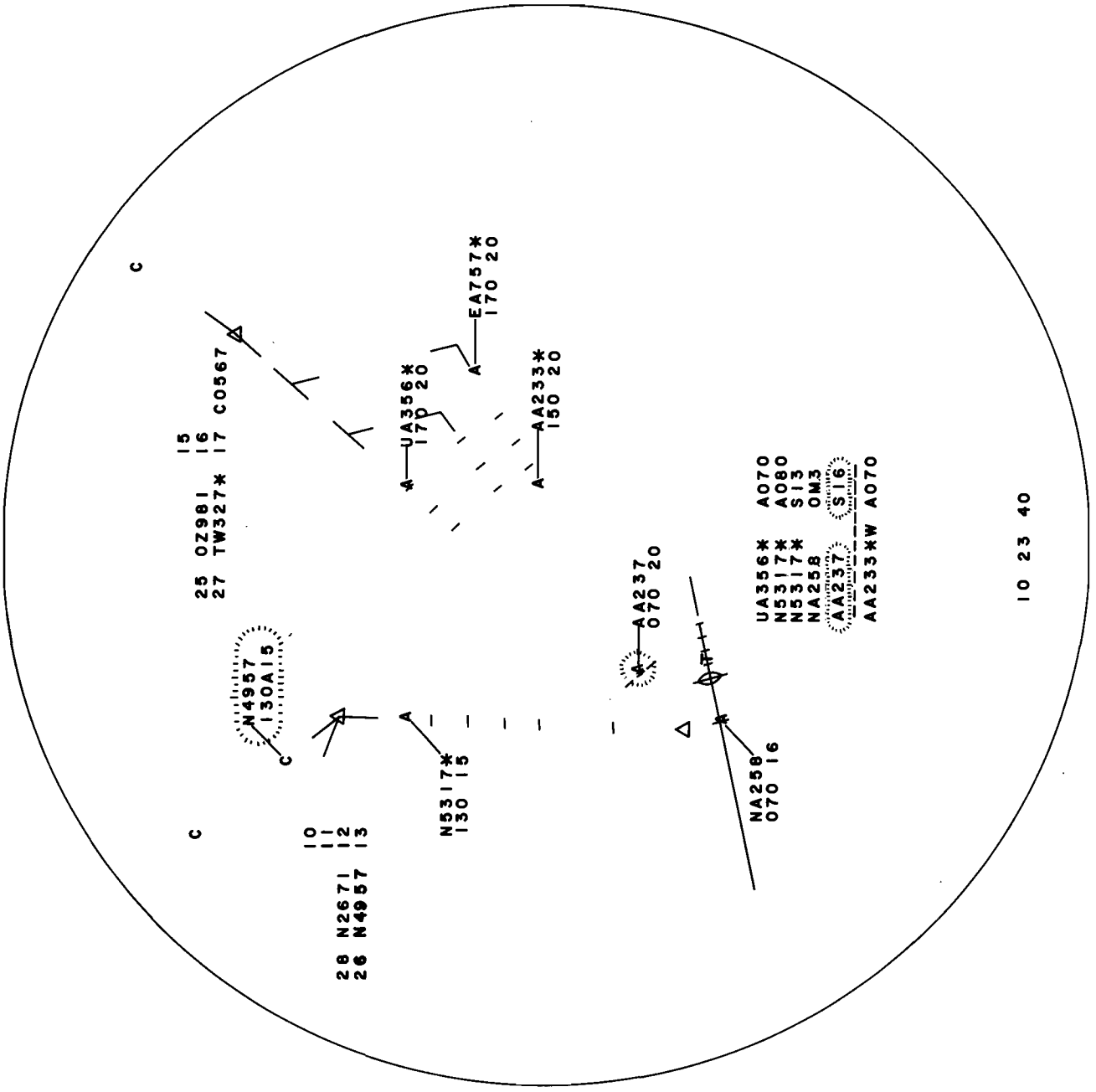

FIGURE 6. TABULAR LIST SINGLE COMMAND DISPLAY

command became active, its associated aircraft's target symbol would also blink for a more rapid command/target association. All other aspects of this mode were the same as mode 3, except that data link and voice link commands were respectively serviced by a single DISPATCH or ADVANCE key depression. The trackball operation and the ENTER key were not required.

Mode 6. TAB-Single-Vosyn: This mode was the same as mode 5, except that the DISPATCH key depression was used for both voice and data link aircraft.

Mode 7. Control-By-Exception: In this mode, all commands would appear nonblinking in the full data block 5 seconds before their desired execution time. The commands were automatically transmitted at this time either via the data link or by Vosyn enunciation. As before, data-link commands would be erased 3 seconds after the WILCO was received. However, if a blinking U or nonblinking F occurred, these symbols would remain until either (1) the controller had indicated his own voicing of the U command by a depression of the ADVANCE key, or (2) the Vosyn had enunciated the F message. At this time, the U or F would be erased and the command would be held over for 20 seconds. This same interval was used to hold over Vosyn commands.

TEST CONDUCT.

This section addresses the steps involved in conducting each 1-hour evaluation run in the simulation study. The steps are described in the following four areas:

1. The instruction, training, and test schedule that was established for each subject controller.

2. The activities of other controllers acting as test observers.

3. The simulation techniques and "pilot" procedures that were used in real-time to support each test run.

4. The subjective and objective data that were obtained throughout the experiment.

Prior to the start of a series of tests, a detailed set of procedures were distributed to the subject controllers. The procedures explained the traffic situation and contained step-by-step instructions of the operation in each of the seven candidate modes. In addition to this written material, the controllers were orally briefed on all aspects of the study. Whenever possible, the subjects were also permitted to observe the operation of the display in an over-the-shoulder manner shortly before the start of their test series. For each of the modes of operation in which a subject was tested, he received a 1-hour training run immediately before his evaluation run. The schedule for each subject's assignment to these pairs of runs was kept in strict accordance with a test matrix document that is described in the next section of this report.

Figure 7 pictures the subjects's display situation and shows the five special function keys that were conveniently located in a separate area on the upper right side of the keyboard. During each training and evaluation run, the

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FIGURE 7. TEST SUBJECT DISPLAY SITUATION

subject was observed by another controller who was very familiar with the simulation design and operation. These observers would sit to the left of each subject as pictured in figure 8 in order to (1) provide assistance during practice runs, and (2) verify an acceptable level of operation of all aspects in an evaluation run. A checklist of these aspects was specified in an observer questionnaire that was completed at the end of each test run pair. At this time, the observer would determine whether a run should be repeated because of equipment malfunctions or other peculiar problems with the test operation. For example, a few tests were rerun when a subject's confusion with a sequence of operations led to a breakdown in the online data collection. When these rare cases were observed, a confirmation was obtained through a review of the end-of-run summary printout shown in figure 9. The observer controller would examine the printout with data analysis personnel in order to verify problems like excessive delays, disengagements, or conflicts. (The exact nature of these problems will be discussed shortly under the heading of "data validation.") Each questionnaire also listed the identity of those aircraft that were pre-scheduled to have a potential conflict or one of the four command exception conditions (U, F, repeat request, and delayed compliance). This list gave the observer some advance notice of the occurrence of these conditions in the traffic sample for each operational mode.

The next issue in the test conduct was to define the operations performed by the simulator pilots during each test run. A full complement of these "pilots" and their display and keyboard consoles is pictured in figure 10. As mentioned previously, the "pilots" alter the course of the aircraft on the controller's display through entries on their keyboard after they have recognized the commands. At an early stage in the design, it was decided to limit the pilot entries to the voice link commands and to rely on the automatic processing of data link messages through specialized simulation software. The main reason for this decision was that it was both costly and unrealistic to have the simulation pilots interact with replicas of the data link cockpit I/O devices. Besides, the data link effect on the controller could be easily characterized as a set of delays that occurred between the dispatching of a message and the receipt of its associated WILCO. These delays fell into two areas: (1) The pilot's reaction time between the appearance of a command on his cockpit device and his subsequent depression of a WILCO button; and (2) additional delays in the transmission of the messages through the data link ground and airborne systems. The pilot's reaction, or WILCO delay, was easily simulated by a Gaussian distribution of time delays that were activated at random by each data link message. The activation would cause WILCO delay to vary ± 3 seconds about a 5-second mean with a standard deviation of 1 second. (These parameters were considered the best approximation to the pilot WILCO delay measurements reported in reference 8.) Although the transmission delays (see appendix D for a more detailed description of these delays) were usually smaller than the WILCO delays, these additional delays were considered necessary for a realistic test of data link message processing that involved:

1. Equipment delays in the ground and airborne transceivers.

FIGURE 8. TEST OBSERVER/SUBJECT ENVIRONMENT FOR TWO INDEPENDENT TESTS

74-21-8

DATA REDUCTION:SUMMARY PRINTOUT

```
DATE     5/24/74
TIME EXPERIMENT STARTED  9:56 AM
FORMAT  2   50 PER CENT DATA LINK AIRCRAFT

SUBJECT CONTROLLER NO.  6
FORMAT NO.  3 FOR THIS CONTROLLER
OBSERVER NO.  2
TRAINING TEST SERIES  1


TOTAL NO. OF:
   NORMAL VOICE LINK COMMANDS          70
   NORMAL DATA LINK COMMANDS           75
   COMMANDS WITH UNABLE REPLY           1
   COMMANDS WITH LINK FAIL              1
   DELAYED COMPLIANCES                  0
   REPEAT REQUESTS                      0
   COMMANDS LEADING TO CONFLICT         0
   CONTROLLER-GENERATED COMMANDS        6

TOTAL NO. OF EXTEMPORANEOUS COMMUNICATIONS
 CONTROLLER    0  PILOT    0  VOSYN    0

TOTAL NO. OF HANDOFFS          29

TOTAL NO. OF QUEUE CHANGES    305
MAX. QUEUE SIZE                 3
AVE. QUEUE SIZE                   .19658

TOTAL NO. OF:
   AIRCRAFT LOAD CHANGES        47
   DISENGAGEMENTS                1
   TAG REPOSITIONINGS            2
```

```
TOTAL NO. OF AIRCRAFT ARRIVING AT INNER FIX                  18
AVE. ERROR IN ARRIVAL TIME AT INNER FIX (SEC)                3.4
STD. DEV. OF ARRIVAL TIME ERRORS AT INNER FIX (SEC)          .8

TOTAL NO. OF AIRCRAFT ARRIVING AT THRESHOLD                  16
AVE. ERROR IN ARRIVAL TIME AT THRESHOLD (SEC)               10.2
STD. DEV. OF ARRIVAL TIME ERRORS AT THRESHOLD (SEC)         26.1

TOTAL NO. OF VOSYN HALT-RESUME SEQUENCES                     1
TOTAL TIME HALTED (SEC)                                     4.0

TOTAL TIME FOR MESSAGE TRANSACTIONS (SEC)
VOICE LINK    942.6   DATA LINK    709.2
   AVE. MESSAGE TRANSACTION TIME (SEC)
VOICE LINK     13.5   DATA LINK      9.5
   MAX. MESSAGE TRANSACTION TIME (SEC)
VOICE LINK     21.2   DATA LINK     14.9

 TOTAL EXTEMPORANEOUS COMMUNICATION TIME (SEC)
CONTROLLER       .0  PILOT       .0  VOSYN       .0

   AVE. COMMAND INITIATION DELAY (SEC)
VOICE LINK      4.1   DATA LINK      3.8
    AVE. MESSAGE DELIVERY TIME (SEC)
VOICE LINK      6.9   DATA LINK       .6
     AVE. PILOT RESPONSE TIME (SEC)
VOICE LINK      2.5   DATA LINK      5.1
        AVE. SERVICE TIME (SEC)
VOICE LINK     12.6   DATA LINK      3.3

TOTAL NO. OF TIME CONFLICTS AT INNER FIX          0
TOTAL NO. OF TIME CONFLICTS AT RUNWAY THRESHOLD   1
```

IT'S A GOOD JOB

FIGURE 9. END OF RUN SUMMARY PRINTOUT

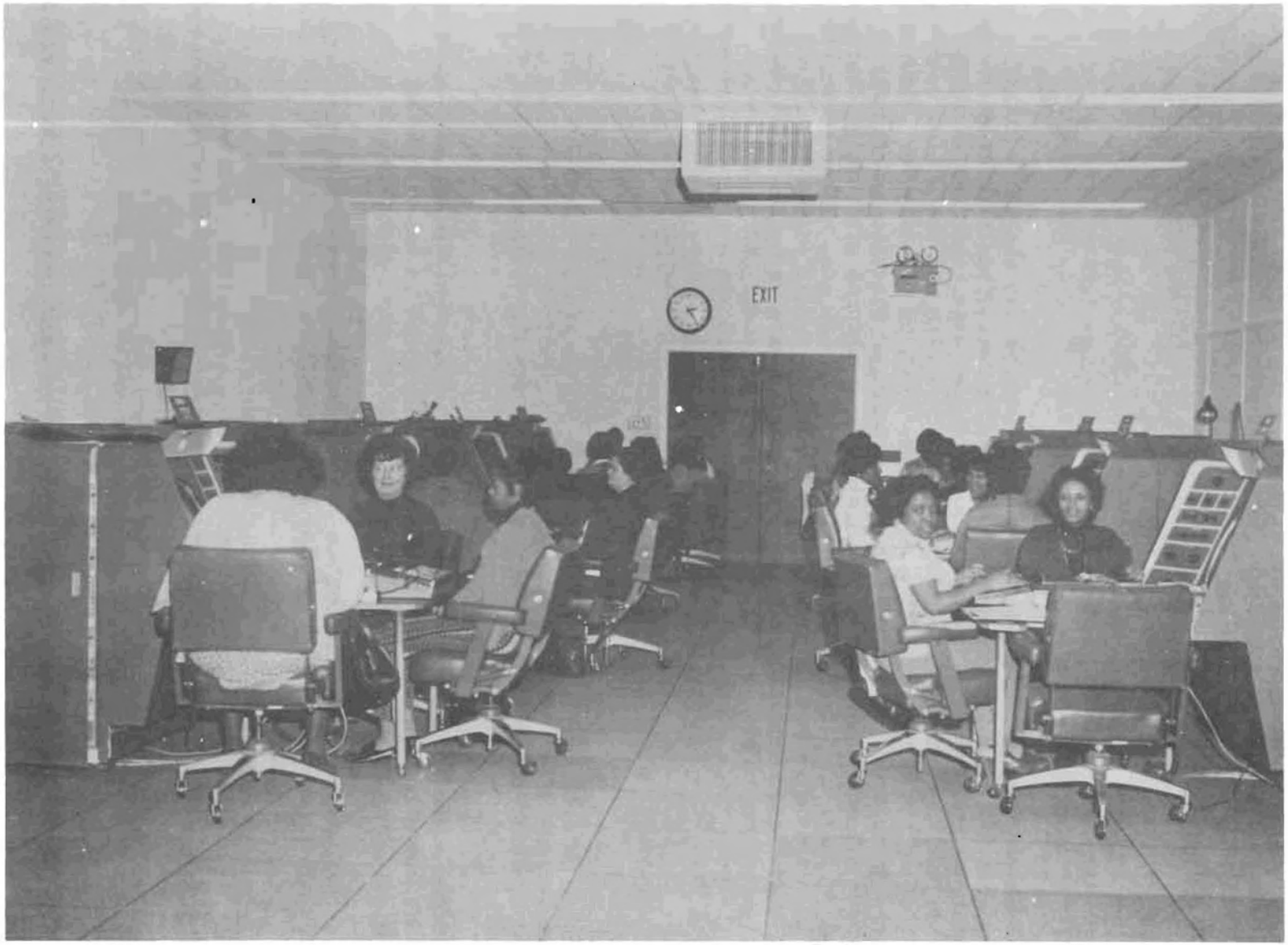


FIGURE 10. SIMULATOR OPERATORS (PILOTS) DISPLAY ENVIRONMENT

2. Delays due to uplinking of other "fictitious" messages (ATIS, weather advisories, etc.) when a high-priority M&S command was received by the data link ground system.

3. Sampling delays during the repeated ground system interrogation of an aircraft for its WILCO response.

With the above features, data link aircraft maneuvers and the WILCO display were automatically handled without pilot intervention. This eliminated the possibility of uncontrolled pilot errors during the experiment and suggested a similar partial automation of the pilot operations with the voice link commands; that is, since the command values were already known by the computer (alternate procedures for extemporaneous commands and disengaged aircraft are discussed in appendix D), the pilot only had to enter the associated aircraft's identity. Also, since there were less than 100 aircraft in a test run, unique identities were selected so that the entries could be further limited to the last three numeric characters. These characters were quickly entered by the pilot so that the controller would hear a rapid aircraft identity and WILCO answer to his command. These rapid answers were considered important to a fair comparison of voice and data link message transaction times; that is, in an operational situation, it was reasonable to expect the pilots to abbreviate or hurry their WILCO responses when the voice channel was busy.

The last issue in the test conduct was to specify and organize the test data that was to be obtained from the experiments. As mentioned previously, this data was derived from two sources: (1) Subject controller questionnaires; and (2) a continuous computer record of the operational events that occurred in each test run.

The questionnaires, or subjective data, were organized into three areas as follows (a composite set of questionnaires is contained in the Subjective Data Analysis Section):

1. A preexperiment questionnaire and a preexperiment opinionnaire that were completed by the subject before he started each pair of practice and evaluation runs.

2. A comprehensive postexperiment questionnaire was answered immediately after the subject's evaluation run and, in some instances, after specific groups of modes had been tested.

3. A short summary questionnaire that was filled in after each subject completed his last evaluation run.

The preexperiment questionnaire was intended to quickly determine whether the subject considered his briefing adequate for the particular operational mode that he was about to use. For this reason, he was asked to place a check mark alongside any of the nine operational aspects in which he was not confident. The aspects were selected from those areas of the tests that were thought to create the most problems. Among these were performance at maximum load,

exception cases, maintaining safe separation, and disengaging conflicting aircraft. The preexperiment opinionnaire continued this line of questionning to ascertain the subject's degree of understanding of the experiments. Once this was established, the controller was asked to check off three questions that graded his feelings on the eventual operational acceptance of automation with a data link relative to present-day ARTS procedures.

The postexperiment questionnaire was composed of three parts. The first part repeated the same preexperiment questions at a more detailed level. Finer gradations were used with specific supplementary questions to determine the controller's opinion of the mode he had just completed. Included among these were additional questions on function key operation, realism, and display formats and timing. This part was followed by a second set of questions that were only applicable to particular test modes. These were answered after the subject had completed one or more of the pertinent modes and included questions on Vosyn intelligibility and operation with the tabular list, full data block, multiple commands, etc. The third set of questions were comparative in nature and asked the subject to weigh each of the four major options in the experiments (i.e., FDB versus TAB, single versus multiple, voice versus Vosyn, etc.). These were distributed immediately after the subject finished a pair of modes that involved only one change in an option; for example, a single versus multiple comparison was made after the TAB-Multiple-Vosyn and TAB-Single-Vosyn runs were completed.

The summary questionnaire was designed to let the subject controller register his last opinion on all of the operational modes he had worked with. The questionnaire asked him to rank each mode in terms of his overall preference and other aspects that included stress levels, susceptibility to blunders and workload. He was also asked to grade each mode on the workload effect produced by the addition of a data link capability.

The second major source of test data was from data extraction programs that were run immediately after each test run. These programs measured the following three types of objective data:

1. Time intervals between successive communications actions.

2. Counts of significant events.

3. Aircraft positions.

The first two types of measurements were considered the most important part of the data collected during the experiment and involved considerable effort long before the tests were started. The first step in this effort was to define the most essential parameters that were to be analyzed. This definition began with the construction of event time-lines for every sequence of communications actions that occurred in each of the seven test modes. These time-lines are shown in appendix D and involved the command display times, push-to-talk actions and pilot entries that were associated with the two-way transaction

of each message. The time lines were prepared for both the voice link and the data link and resulted in the selection of five time intervals. These are listed in the summary printout in figure 9 and are explained as follows:

1. Message Transaction Time (MTT) - the total time between the creation of an M&S command within the computer to the completion of the pilot's WILCO response. This time interval involves the display of the command, the controller's dispatch or voice action and the pilot's reply.

2. Command Initiation Delay (CID) - the time between command creation and the initiation of controller action. Initiation was defined to occur when the controller pressed his push-to-talk button or when he completed his dispatch action.

3. Message Delivery Time (MDT) - the time between message initiation and final delivery to the pilot. This involved either the time for the controller to voice the command or the simulated delays in uplinking a data link message.

4. Pilot Response Time (PRT) - the time between the end of cockpit receipt of the command (either audible or simulated) and the controller's receipt of the pilot's WILCO response.

5. Service Time (ST) - the time required to service any active command that was being displayed. This time usually involved changing the command from a blinking to a nonblinking state or removing it from the new command list.

A close examination of the time lines will show that the message transaction time is always the sum of the command initiation delay, the message delivery time, and the pilot response time; that is:

$$MTT=CID+MDT+PRT \quad \ldots \quad \text{for all modes.}$$

This equation emphasized the importance of the message transaction times in the comparative analysis used to determine the best test modes. This time and its component command initiation delay were considered to be the prime factors in the controller's communications workload; that is, the MTT indicated the entire time span in which the controller would be concerned with a given command. The earliest part of this attention involved the CID in the sense that the controller had to service a queue of commands. For these reasons, an expanded list of message transaction and command queue measurements were included in the summary printout. The most important of these were the total times for all voice and data link message transactions and the average queue size.

In addition to the MTT and CID, two other time records were considered as indicators of the contribution to runway dispersion times that were caused by communication delays. The first of these was a measurement of the time of arrival of each aircraft at a small straight-line segment very close to the inner fix. A second set of time measurements was also made to indicate aircraft arrival at the runway threshold. However, these measurements were

somewhat coarse since they included disengaged aircraft and an inconsistent position detection mechanism. (The standard DSF program for threshold detection used a fixed time after the aircraft speed was below 30 knots. This led to different position points for the various aircraft types.)

The second type of objective data obtained during each test run consisted of counts of significant events, such as, normal voice and data link commands, exception cases, extemporaneous communications, handoffs, etc. The total number of these events was also listed in each summary printout as an aid in the test observer's determination of a valid test run. As mentioned previously, the observer could review these counts for unreasonably high numbers of such actions as disengagements, extemporaneous messages, Vosyn halt-resume sequences, etc. A total count of the number of tag repositionings was also provided as a measure of the controller's activity in this area. As with all of the counts of unusual events, these repositionings gave an indication of the controller's distraction from his normal communications task.

The last type of objective data was simply a once-per-second record of the x, y, and z position of all aircraft in the traffic situation. This trajectory information was used for the offline conflict detection programs that were exercised after the test runs were completed.

At this point, the major features of the data collection can be summarized through a discussion of the processing procedures that were used after each evaluation run. This processing consisted of two parts: (1) A manual tabulation of the votes on all questionnaires to obtain a Controller Consensus Report; and (2) a step-by-step "data validation" of the time intervals and trajectory information of each test run.

The results for data validation were processed in the manner shown in figure 11. The figure indicates the recording of two different evaluation runs being simultaneously formed on a time line history tape and a trajectory history tape. The time line history tape was used to produce two summary printouts (see figure 9) that were immediately examined to answer several questions. (Where numeric values are indicated, they are to be considered only as guidelines. Violation of these guidelines was considered reason for further investigation by the test observer and was not considered cause for scrapping the run.): These questions were:

1. Were the number of commands in the proper range (approximately 150 to 160) and were they distributed properly according to the percentage of data link-equipped aircraft?

2. Was there a single exception command of each type?

3. Were there approximately 27 to 30 handoffs?

4. Were disengagements kept to a reasonable level; i.e., less than five?

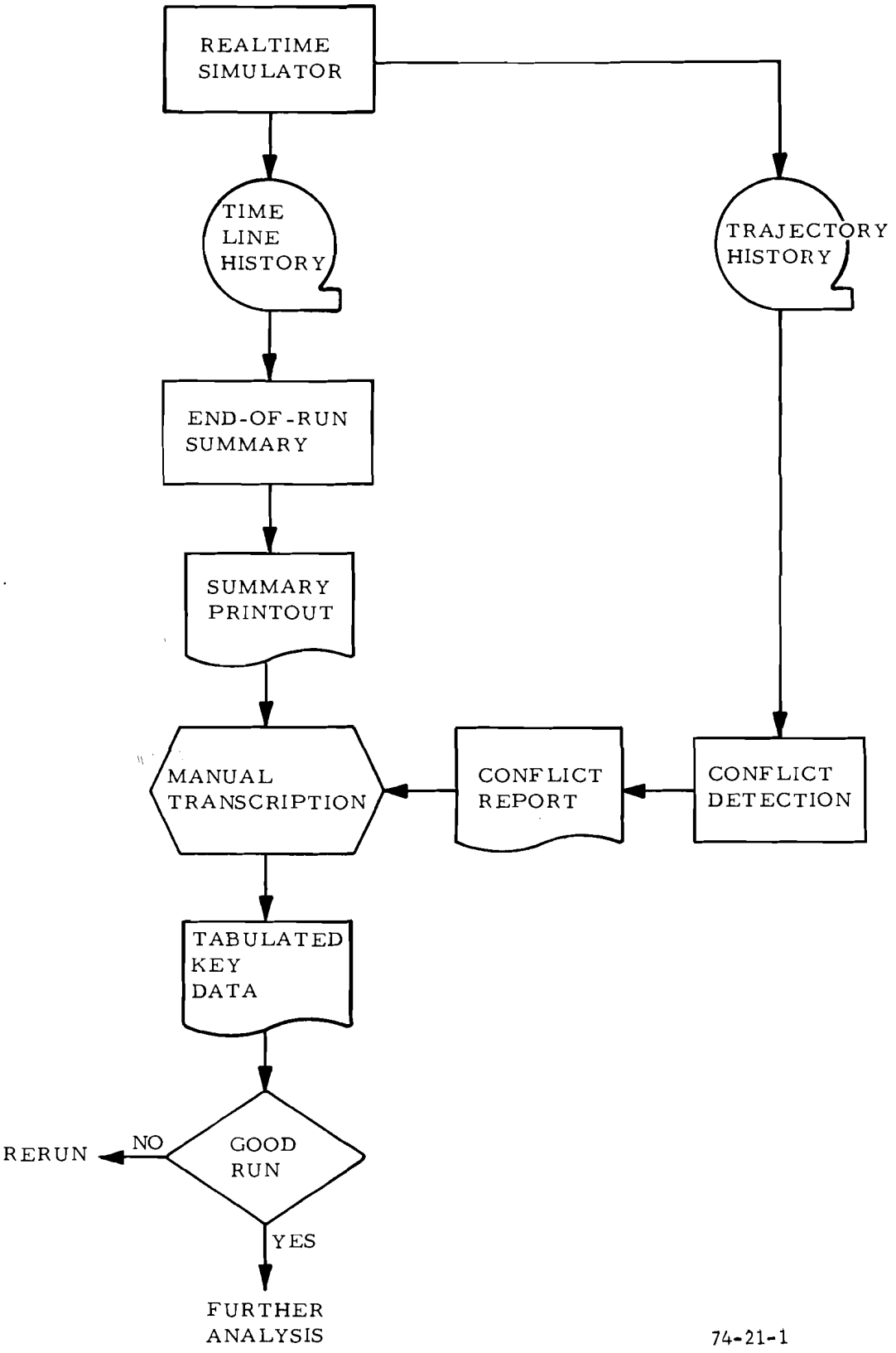


FIGURE 11. DATA VALIDATION PROCESS

5. Were there between 17 and 19 aircraft arriving at the inner fix and 15 to 17 aircraft at the threshold? (At the termination of the problem, there were typically 1 to 2 aircraft between the inner fix and the threshold.)

6. Were there less than three time conflicts at the inner fix and less than four at the runway threshold? (A time conflict was defined as a ±20-second error in arrival time at the inner fix (excluding disengaged aircraft) and a ±30-second error at the runway threshold (including disengaged aircraft).

7. Were the various arrival errors and message times reasonable for the mode being tested and do the times compare appropriately according to the time lines for that mode?

Initially, the checks for reasonableness of the data measurements were very weak since they were based only on intuitive rationale. As each run was made, selected data from the summary printouts were transcribed in a form to facilitate comparisons between controller performance for each format. An example of this form is shown in figure 12. With the help of this tabulation aberrant runs could be readily detected.

If an unusual situation which appeared to require rerunning was detected, the events of the day's run were discussed with the observer controllers to see if some obvious explanation, such as, a sticking key, momentary diversion during peak traffic loads, illness, software problems, or other reasons might explain the anomalous performance.

Shortly after the examination of the summary printouts, the trajectory history tape was processed through the conflict detection program in an offline time available mode. These results were added to the tabulated data and an eighth consideration was added to the list.

8. Were there less than four conflicts?

If any of the factors were sufficiently bad and there was some rationale for an external problem affecting the results of the run, then the current day's results were scrapped, and the test case was scheduled for rerunning.

Of the 91 data runs made, seven were rerun for a variety of reasons. In two cases, the ENTER button operated only intermittently, requiring excessive time to enter messages, and seriously degrading controller performance, particularly during peak traffic periods. In two other cases, the subject controller was distracted or inattentive due to some external events. The other three cases were attributable to a variety of hardware or software problems; i.e., failure to obtain a summary printout, machine failure after 32 minutes into the run, and failure of aircraft to accept its initial turns in a timely fashion.

FORMAT	SUBJECT:	HANDOFFS	AVE. QUENE SIZE	NUMBER DISEN-GAGEMENT	TAG REPO-SITIONINGS	STD DEVIATION ARRIVAL INNER FIX	....	AVERAGE MESSAGE TRANSACTION TIME VL	DL	....	COMM. INITIATION DELAY VL	DL	MESSAGE DELIVERY TIME VL	DL	PILOT RESPONSE TIME VL	DL	....
	A	29	.73304	1	4	2.0		19.1	16.1		9.3	10.6	4.2	.5	5.6	5.0	
1	B	29	.66237	3	1	3.8		18.2	16.0		9.7	10.3	3.7	.5	4.7	5.2	
	C	29	.54241	1	2	1.8		14.4	14.7		6.3	9.1	3.4	.5	4.7	5.0	
FDB-M-VOI	D	29	.45555	1	2	1.8		12.6	12.4		6.1	6.7	3.2	.5	3.3	5.2	
	E	29	.46331	1	8	1.4		12.8	12.6		5.4	7.1	3.8	.5	3.6	5.1	
	F	29	.50544	1	6	1.1		14.9	13.3		6.3	7.9	3.9	.5	4.6	4.9	
	G	29	.68156	1	7	2.9		16.1	17.3		7.2	11.7	4.5	.5	4.4	5.1	
	A	29	.29004	1	0	.8		15.0	11.0		6.1	6.0	6.4	.5	2.4	5.0	
2	B	29	.28889	1	0	1.0		14.2	12.0		5.5	6.4	6.4	.5	2.2	5.1	
	C	29	.35294	3	0	.8		17.1	11.9		8.0	6.4	6.7	.5	2.4	5.0	
FDB-M-VOS	D	29	.35828	1	0	1.3		15.7	12.6		7.0	7.2	6.2	.5	2.5	5.0	
	E	29	.23833	1	9	.6		14.2	10.4		5.2	4.9	6.5	.5	2.6	5.1	
	F	29	.36553	1	3	1.2		17.6	12.7		7.9	7.3	7.0	.5	2.7	5.0	
	G	29	.35841	1	9	.8		16.1	13.3		7.2	7.9	6.0	.5	2.8	4.9	
	A	29	.54977	1	3	1.1		15.4	14.2		7.2	8.8	4.3	.5	3.8	5.0	
3	B	22	.38087	1	0	.7		13.2	11.7		5.1	6.2	4.2	.5	3.8	5.1	
	C	29	.44853	6	0	2.1		12.3	12.9		5.2	7.4	3.2	.5	4.0	5.0	
TAB-M-VOI	D	29	.46683	1	1	1.3		13.5	12.9		5.6	7.3	3.5	.5	4.5	5.2	
	E	22	.44880	2	3	2.3		14.6	12.5		7.1	7.1	3.6	.5	3.8	4.9	
	F	29	.64906	1	2	1.5		17.0	15.8		7.9	10.3	4.3	.5	4.8	5.1	
	G	29	.50604	2	0	1.3		15.6	11.9		7.4	7.2	4.1	.5	4.0	5.2	
	.	.	.	.	.	.		.	.		.	.	.	.	.	.	
	.	.	.	.	.	.		.	.		.	.	.	.	.	.	
	.	.	.	.	.	.		.	.		.	.	.	.	.	.	

FIGURE 12. SAMPLE OF THE SUMMARY PRINTOUT DATA TABULATION

TEST MATRIX.

This section discusses the sequence and number of controllers and test runs that were to be scheduled during the entire simulation study. This scheduling was contained in a test matrix that addressed the evaluation of three major sets of parameters. These were:

1. Rankings of the seven candidate modes.

2. Individual comparisons of four pairs of mode options (e.g., FDB versus TAB, single versus multiple, voice versus Vosyn, etc.).

3. Performance as a function of the percentage (or mix) level of data link versus voice link-equipped aircraft.

The primary considerations in the development of the test matrix were influenced by the following factors:

1. At the outset, the controller's performance as a function of traffic density was not known. Moreover, it was important to keep the density profile the same throughout the tests. This requirement could be met in one of three ways: (1) Select one density value that was constant during each test; (2) select "n" different densities that were constant during each of "n" series of tests; and (3) select a density variation that changed with time during each test run, but was the same in any other test run. Of these choices, the single density was considered inadequate because it might prove easy for some controllers and too difficult for others. Similarly, the n-density choice was discarded because too much test time would be needed to perform a balanced experiment. This led to the choice of a density variation that always increased linearly with the test time to a maximum value of 11 aircraft. This value was thought to be sufficiently high to identify the onset of each controller's density limit without losing data before the limit occurred.

2. The allocation of Digital Simulation Facility time is quite often subject to change. In addition, the uncertainties of software development, hardware availability, and other scheduling problems may reduce the portion of that allocation that can be spent in actual experimentation. To insure that a meaningful body of data would be available should any of those contingencies arise, the experiment should be divided into several discrete phases (or series of tests). The most practical manner to partition the runs is by mix level. The 50 percent mix level was selected as the most significant, and all the runs for that level would be made first. All the runs for the 80 percent level would be made next, followed finally by the 20 percent mix level runs.

3. Direct comparisons of two test modes by a single controller should be incorporated in the test matrix in such a way that the modes differed with respect to only one test option. For example, the FDB-Multiple-Voice mode differs from the TAB-Multiple-Voice mode only with regard to the FDB and TAB presentations. Consequently, at least one controller should be assigned to both modes so that he can compare their respective merits directly.

Also, in order to have the controller's questionnaires answered with minimum confusion, he should be presented with those modes in sequence.

4. Each test mode should be handled by as many subject controllers as possible to prevent the relative evaluation of modes from being distorted by differences in the skills of individual controllers.

5. The order in which the modes are tested by the subject controllers will contaminate the results unless the test matrix is set up to balance out such effects. For example, if each controller tests three modes, it must be assumed that his performance on the third test will be better than his performance on the first because of his prior experience on tests one and two. To compensate for this, the sequence of the tests was assigned so that each mode was tested by one controller for whom the mode was his first, by one controller for whom the mode was his second, and by one controller for whom the mode was his third, etc. In statistical terminology, this technique is called BLOCKING in the sense that the run sequence is treated as a block effect.

6. Sequencing the data link mix levels at 50 percent first, 80 percent second, and 20 percent last would be contrary to the principle of blocking the run sequence. To eliminate any bias introduced by the run sequence and to increase the number of test controllers completing the subjective questionnaire, different groups of test controllers should be employed at each mix level. Using different controllers unfortunately causes somewhat less sensitive indication in the statistical methods used to test for the significance of the mix effects.

7. Separate scenarios should be introduced to prevent the subject controllers from memorizing a specific sequence of events and using this prior knowledge to improve their performance in subsequent tests. A separate scenario specifying target characteristics, target movement, metering and spacing scheduling and the off-normal events (mentioned previously) had to be prepared for each run on which the subject is tested. These scenarios should be functionally equivalent. To simplify analysis of the data, this factor should be blocked in the same manner as run sequence. For instance, if a controller is being tested on his fourth test mode, scenario number 4 should be used.

8. While the traffic situation simulated represents a fairly standard ATC situation, the manipulation of the function keys and slewball varied from mode to mode. To insure that each controller was operating at an acceptable level of proficiency and to familiarize him with the specific procedures for the mode being tested, each data hour was preceded by a 1-hour training run.

EXPERIMENTAL PLAN.

The considerations just discussed dictate the use of a standard randomized block design (reference 9) . Statistical computations are greatly simplified when the design is balanced. A balanced design can only be achieved when the number of subject controllers is restricted to certain choices. For this

case, with seven modes, either three, six, or any multiple of seven subject controllers will provide a balanced design. Three seven-mode/seven-controller blocks requiring 168 DSF hours were originally selected. Based on these blocks, the sequence under which each controller experienced each mode, was selected at random. This sequence is given in table 1 for the 50 percent mix level. As somewhat anticipated, just before the 50 percent level was completed, the DSF allocation was reduced. The remaining time allowed running either a complete 80 percent block, or two seven-mode/three controller blocks for both the 20 percent and 80 percent levels. Since dropping the 20 percent block would imply loss of any information concerning the effects of mix level, the 7X3 block approach was selected. The test matrices for those blocks are given in tables 2 and 3.

OBJECTIVE DATA ANALYSIS

This section describes results of the analysis of the objective (computer-generated) measures in terms of the statistical relationships identified. No attempt is made to infer the operational significance of these findings except as necessary to determine the course of further analysis. Throughout this section, key findings are underlined. As previously discussed, one of the major data sources of this experiment was the measurement of time intervals of each message and the arrival time error for each aircraft. From a statistical standpoint, using all of these measurements increases the sample size and thereby the statistical power of the analysis. As discussed in the test matrix section, this objective was somewhat complicated by the incorporation of aircraft load as a dynamic factor within each hour's run. Therefore, each measurement must be considered as being functionally related to the actual aircraft load at the time the measurement was made. Prior to the beginning of experimentation, no one was sure how the output measures would change as the number of aircraft under control increased. Conjectures advanced included: (1) No change, (2) linear increase, and (3) exponential or quadratic increase. Before the analysis of the experimental results could begin, an appropriate form for this functional relationship had to be determined.

The system shown in figure 13 was used to make this determination. The end-of-run summary program was modified to incorporate a polynomial regression analysis program, least squares regression (LSR) (from the Xerox Statistical Subroutine Library), to fit models of the following types:

(1) $y = a+bt$
(2) $y = a+bt+ct^2$
(3) $y = a+bt+ct^2+dt^2$

where

y = an output measure
t = the time of the measurement (a proxy for load)
a,b,c,d = the fitted regression coefficients

TABLE 1. FORMAT RUN SEQUENCE BY CONTROLLER SUBJECT FOR 50-PERCENT DATA LINK

Controller	Run Sequence 1	2	3	4	5	6	7
A1	1	3	5	6	4	2	7
B1	5	6	4	3	1	7	2
C1	2	1	3	4	7	6	5
D1	6	4	2	7	5	3	1
E1	4	2	7	1	3	5	6
F1	3	7	6	5	2	1	4
G1	7	5	1	2	6	4	3

TABLE 2. FORMAT RUN SEQUENCE BY CONTROLLER SUBJECT FOR 80-PERCENT DATA LINK

Controller	Run Sequence 1	2	3
A2	1	2	4
B2	2	5	3
C2	6	4	3
D2	5	4	7
E2	6	5	1
F2	6	7	2
G2	3	1	7

TABLE 3. FORMAT RUN SEQUENCE BY CONTROLLER SUBJECT FOR 20-PERCENT DATA LINK

Controller	Run Sequence 1	2	3
A3	4	2	1
B3	3	5	2
C3	3	4	6
D3	4	5	7
E3	1	6	5
F3	7	6	2
G3	1	3	7

LEGEND

1. Full Data Block - Multiple Command - Voice
2. Full Data Block - Multiple Command - Vosyn
3. Tabular List - Multiple Command - Voice
4. Tabular List - Multiple Command - Vosyn
5. Tabular List - Single Command - Voice
6. Tabular List - Single Command - Vosyn
7. Control-By-Exception

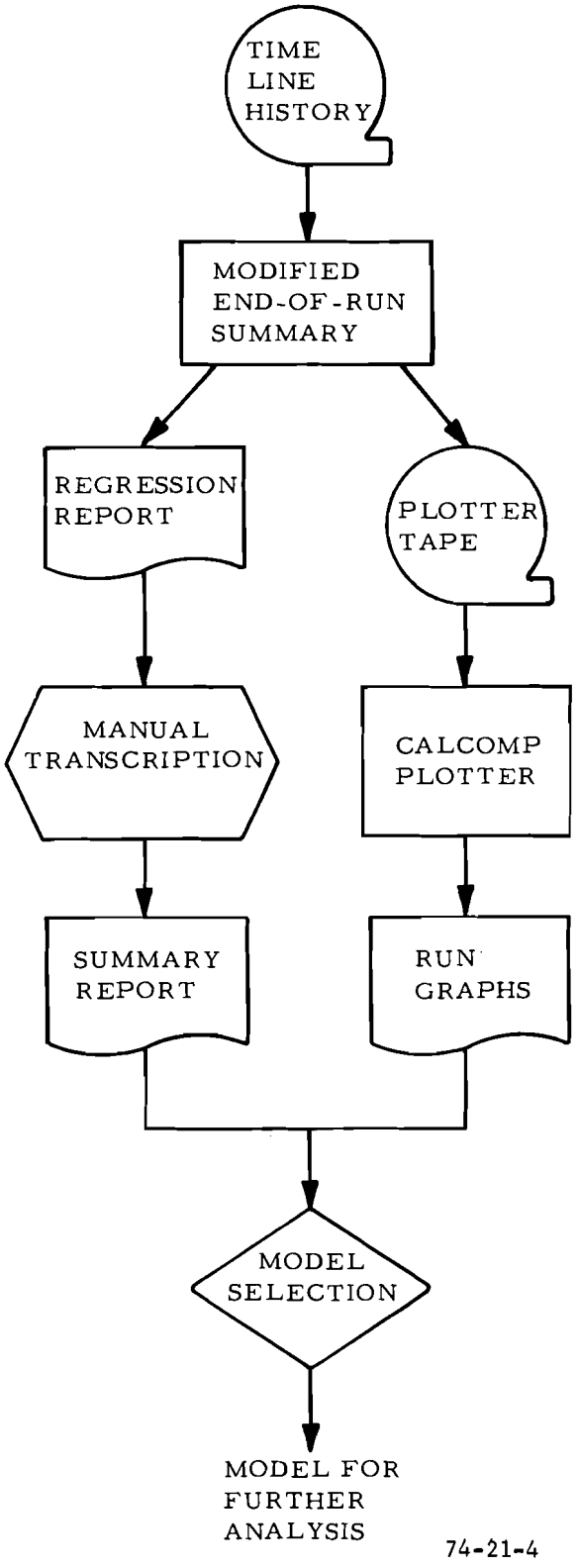


FIGURE 13. DATA PROCESSING DIAGRAM FOR REGRESSION ANALYSIS

While the actual aircraft rate of arrival increased in a stepwise fashion (see appendix B), the additional traffic was introduced at the feeder fix (area of least concern) and gradually moved toward the inner fix (area of most concern). The controllers' perception of the traffic load was that it linearly increased as the experiment progressed.

A sample of the output of the LSR program is shown in figure 14. The response to increasing load varied considerably from run to run. The predominant message transaction time variation with load was either a linear increase or a constant (i.e., a type 1 model). However, in some cases, the message transaction time actually decreased as the load increased. The type 2 (quadratic) and type 3 (cubic) models were eliminated since they showed no meaningful pattern. (A further analysis of these results is given in appendix E).

To supplement the results of the regression analysis and to visually depict the relationship between the output measures and the simulation time or controller load, the data points were plotted on the CalComp plotter as illustrated in figure 15.

The remaining analyses use the variance ratio or F statistic in tests of significance. In this test, the variance among the average level values of the effect being tested is compared to the error variance. If there is a true effect, that variance will be much larger than the sample error variance. To make the test as sensitive as possible, the variance due to all effects in the experiment should be accounted for and eliminated from the error variance. For the remaining analysis, the major consideration in selecting a model form was to account for a major portion of the variance caused by the relationship between the measures and the increasing load. As can be seen in the hypothetical situation shown in figure 16, the contribution of this relationship to the overall variance can be considerable. As shown in that figure, the variance introduced by the relationship between the variables (x and y) is eliminated from the data and the residual variance is substantially reduced. In the top graph, the data points are quite scattered along the MTT axis, resulting in the large variance of 357 sec^2. When the general linear trend has been eliminated from the data as shown in the middle graph, the spread (or variance) on the MTT axis is greatly reduced to a value of 8.2 sec^2. When the quadratic or curved effect is eliminated, the variance may be reduced still further to a value of 1.5 sec^2 as shown in the lower graph. For the purposes of subsequent analysis it was concluded that the linear (type 1) model is sufficient to account for the majority of the variance (appendix E).

Two additional preliminary analyses were performed in order to properly prepare for the remaining effort. The first of these was a correlation analysis to determine the interrelationships among the communications time measures. The results of this study can be seen in table 4. These data indicate that the message transaction time and command initiation delay are virtually identical statistically (correlation coefficient greater than 0.7) and that the remaining time line measures are independent. Based on these results, separate univariate analyses can be employed for each measure except command initiation delay, which can be dropped.

```
LEAST SQUARES REGRESSION (LSR)
LINEAR REGRESSION  N=    74

 A=        -10.252881
 B=          .001333
SOURCE        DF     SUM OF SQUARES          MEAN SQUARE            F
DUE TO REG     1      6339.570313          6339.570313          6.05045
ERROR         72     81890.500000          1130.423584
TOTAL         73     88230.125000

VAR OF B=          .000000       STD ERROR OF B=          .000542

QUADRATIC REGRESSION  N=    74

 A=         13.830333
 B=         -.001601
 C=          .000000
SOURCE        DF     SUM OF SQUARES          MEAN SQUARE            F
DUE TO REG     2      7827.219750          3913.609375          3.45592
ERROR         71     80402.875000          1132.434814
TOTAL         73     88230.125000

CUBIC REGRESSION  N=    74

 A=          7.348333
 B=          -.000288
 C=          -.000000
 D=          .000000
SOURCE        DF     SUM OF SQUARES          MEAN SQUARE            F
DUE TO REG     3      7841.816406          2613.938721          2.27615
ERROR         70     80388.250000          1148.403564
TOTAL         73     88230.125000

EST OF INDIVIDUAL TERMS
SOURCE        DF     SUM OF SQUARES          MEAN SQUARE            F
LINEAR         1      6839.570313          6839.570313          6.03970
QUADRATIC      1       987.648437           987.648437           .872146
ERROR         71     80402.875000          1132.434814
TOTAL         73     88230.125000

EST OF INDIVIDUAL TERMS
SOURCE        DF     SUM OF SQUARES          MEAN SQUARE            F
LINEAR         1      6839.570313          6839.570313          5.95572
QUADRATIC      1       987.648437           987.648437           .860019
CUBIC          1        14.597656            14.597656           .127113E-01
ERROR         70     80388.250000          1148.403564
TOTAL         73     88230.125000
```

FIGURE 14. SAMPLE OF LSR OUTPUT

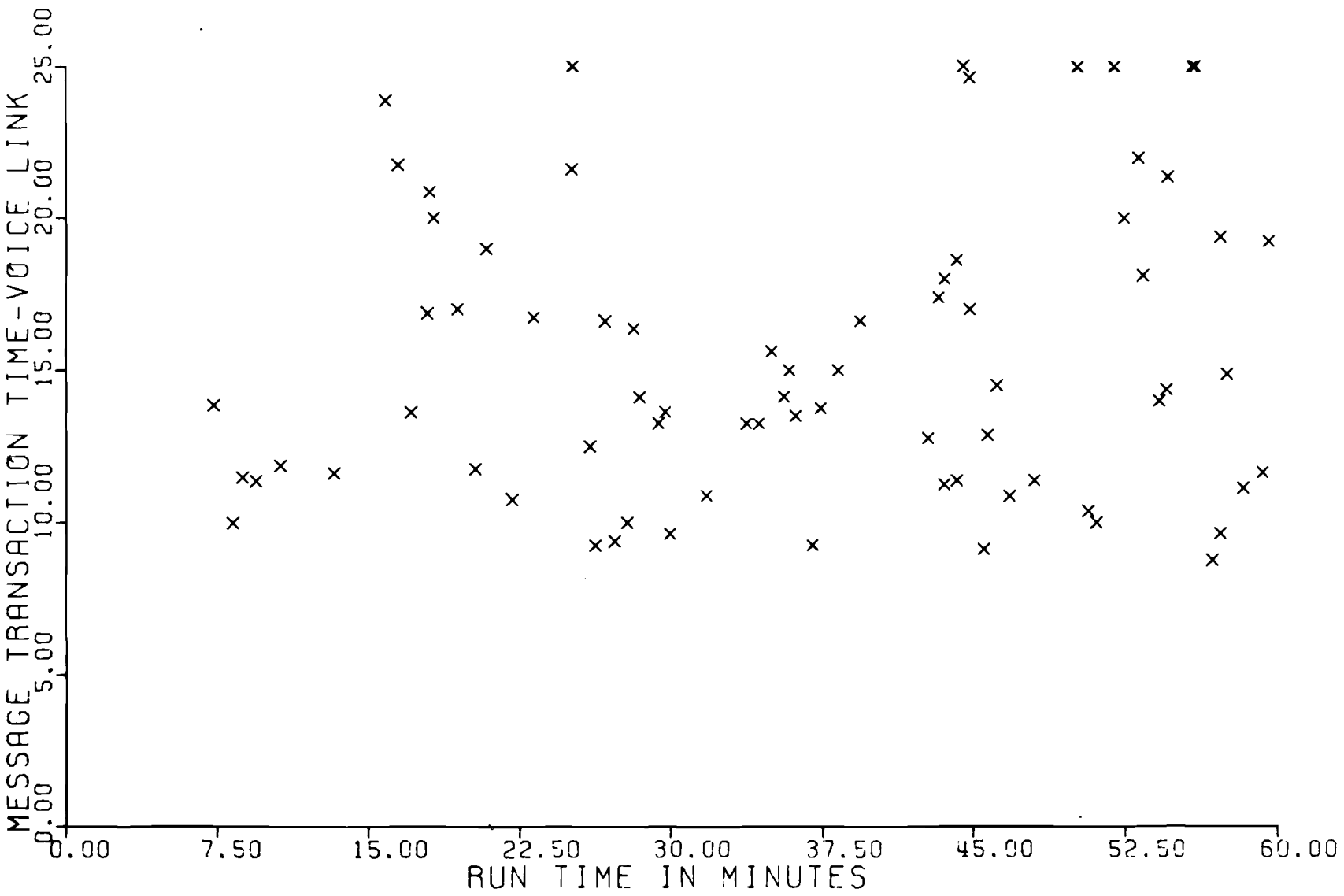


FIGURE 15. SAMPLE OF CALCOMP PLOTS

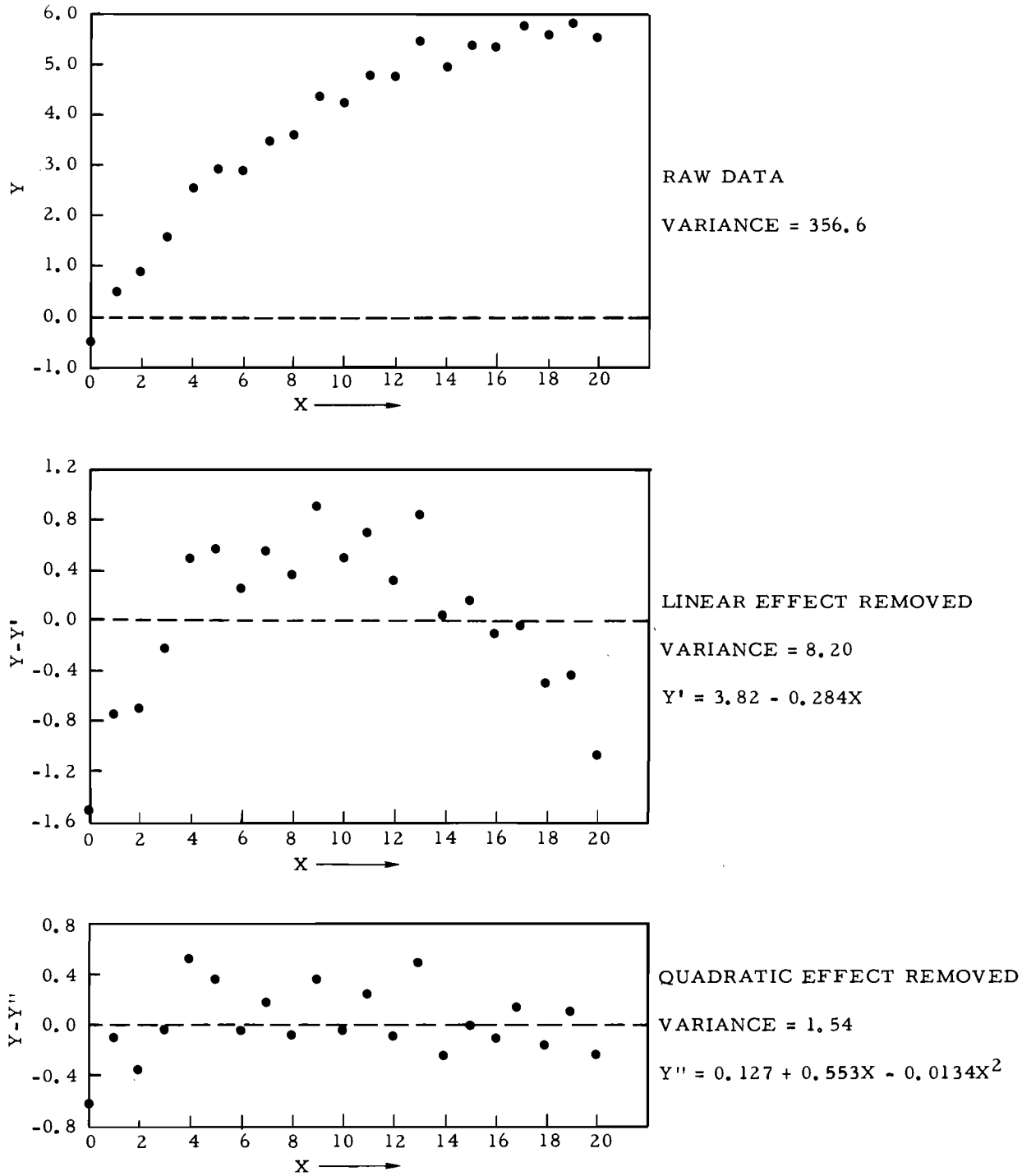


FIGURE 16. ILLUSTRATION OF EFFECTS OF MODEL ASSUMPTIONS ON RESIDUAL VARIANCE

TABLE 4. CORRELATIONS BETWEEN TIME LINE MEASURES

Data Link Employment Level			VOICE LINK Measure Type 1	2	3	4	5	6		DATA LINK* Measure Type 1	2	3	4	5	6
20%	Measure Type	1	1.00	.29	.26	-.01	.02	-.08	1	1.00	-.20	.01	----	-.05	.19
		2		1.00	.05	-.00	.25	.96	2		1.00	.04	----	.21	.99
		3			1.00	.17	.66	.31	3			1.00	----	-.13	.07
		4				1.00	.02	.08	4				----	----	----
		5					1.00	.42	5					1.00	.21
		6						1.00	6						1.00
	Measure Type	1	1.00	.22	-.03	-.01	-.01	.14	1	1.00	.12	-.06	----	-.05	.13
		2		1.00	-.10	.12	.09	.73	2		1.00	.01	----	.21	.99
		3			1.00	-.24	.67	.16	3			1.00	----	.19	.04
		4				1.00	.20	.18	4				----	----	----
		5					1.00	.27	5					1.00	.21
		6						1.00	6						1.00
80%	Measure Type	1	1.00	.13	-.03	-.07	.01	.08	1	1.00	.23	.09	----	.17	.23
		2		1.00	-.12	.15	.27	.91	2		1.00	.02	----	.17	.99
		3			1.00	-.26	.23	.07	3			1.00	----	.08	.00
		4				1.00	.55	.46	4				----	----	----
		5					1.00	.52	5					1.00	.17
		6						1.00							1.00

Measure Type
1. Queue Delay
2. Command Initiation Delay
3. Message Delivery Time
4. Pilot Response Time
5. Service Time
6. Message Transaction Time

*NOTE: The pilot response time for data link aircraft was independently sampled from a normal distribution during the simulation and therefore is not a measure being analyzed.

The second preliminary analysis was a test for homogeneity of variance, a basic assumption underlying analysis of variance and the F test. In this analysis, the residual or error variance from each of the preliminary linear model regression analyses was compared in two ways using the Bartlett and Cochran Tests (reference 10).

The Bartlett procedure tests whether all the sample variance can be considered equal (homogeneous). The Cochran procedure tests whether the largest sample variance is different than the remainder, a common occurrence which can significantly affect the results of the analyses of variance. These tests were performed for the voice and data link message transaction time measures and for the arrival time error at the inner fix. In all cases, the tests indicated a high degree of heterogeneity. The effect of heterogeneity is to overstate the significance of effects in the analysis of variance. Therefore, in all the subsequent analyses, a very conservative significance level (>.99) will be used in all tests of time line measures or arrival time measures.

Before the analysis of the test modes was started, the results of the experiments that were stored on approximately 50 individual tapes were condensed onto one master file to minimize the tape handling and potential errors in future steps. The program used to accomplish this consolidation was a modification of the post-run summary program which stored the individual data points for each run.

During this process the following transformation was made to all data to remove the time effect:

$$y_t' = \hat{y}_{30} + (y_t - \hat{y}_t)$$

where y_t' = new value of the data measure
y_t = original value of data measure
$\hat{y}_t$ = value of linear regression with slope β fitted to original data evaluated at time t minutes

This transformation converted the variations around the best linear fit of that data to variations around the value at the 30-minute point in the run. The computed slopes, β, were saved for subsequent analysis.

In order to exercise the statistical analysis programs, a second program was required to select appropriate subsets of data from the master file. The extraction program selected data based on the percentage of data link employment and the type of measure, i.e., voice message measure, data link message measure, or arrival time error measure.

The first step in the primary analysis of the modes consisted of running individual analyses of variance for each percentage level for three measures; message transaction time for voice link-equipped aircraft, message transaction time for data link aircraft, and arrival time error at the inner fix. These analyses were performed using the Biomedical Computer Program, BMD11V, Multivariate General Linear Hypothesis (reference 11).

As was mentioned previously in the test matrix section, the experimental design for the 50 percent level is a complete 7X7 block design while the design for the 80-percent and 20-percent data link levels are 3X7 balanced incomplete blocks. For this problem the model can be expressed as:

$$y(i,j) = \mu + M_i + B_j + e \qquad (4)$$

where μ = Grand average effect
M_i = The effect of mode
B_j = The effect of block
e = Normally distributed error

The block effect includes the effects of subjects, the effects of being the nth run in sequence and the effects of different traffic samples.

The model given in (4) was fitted to the data for each measure and percentage level using BMD11V. Two hypotheses were tested for each run. They were:

1. Mode Effect is Significant

   H_0: $M_1 = M_2 = M_3 = M_4 = M_5 = M_6 = M_7 = 0$

   H_1: At least one mode is different than the others.

2. Block Effect is Significant

   H_0: $B_1 = B_2 = B_3 = B_4 = B_5 = B_6 = B_7 = 0$

   H_1: At least one block effect is not equal to the others.

NOTE: A statistical hypothesis consists of two statements: First, a statement of the assumptions about the frequency function of a set of random variables called the null hypothesis (H_0) and second, about an alternative state of nature to be tested against the null hypothesis called the alternate hypothesis (H_1) (reference 10).

The results of these tests for each run are given in table 5. As can be seen in that table, the mode and block effects are highly significant for message transaction time. In the case of the inner fix arrival time errors, the results are somewhat mixed. The results of this analysis for the absolute value of arrival time errors yielded average errors of between 1.8 and 4.5 seconds. A detailed study of the end-of-run summary data showed that this error was caused by two different factors - a bias or regular difference between scheduled and actual arrival time and a dispersion around that bias. To understand the significance of each of these factors, additional analyses of variance were run for each of these factors independently. The results of these analyses are shown in tables 6 and 7. These results give the estimated values for all the parameters in the model and the significance level for the hypothesis that the effects are different from zero. As shown in the example

TABLE 5. SIGNIFICANCE OF EFFECTS BY DATA LINK EMPLOYMENT LEVEL AND MEASURE

	Data Link Employment Level	Significance Level[1] Hypothesis 1 Mode Effect	Significance Level[1] Hypothesis 2 Block Effect
Message Transaction Time Voice Link Aircraft	20%	.999+	.999+
	50%	.999+	.999+
	80%	.999+	.999+
Message Transaction Time Data Link Aircraft	20%	.999+	.990
	50%	.999+	.999+
	80%	.999+	.999+
Arrival Error at the Inner Fix	20%	.944	-
	50%	.999+	.975
	80%	.999+	.950

[1] The tabulated numbers give the probability at which the hypothesis is significant. Missing entries indicate that the significance level was less than .900.

TABLE 6. RESULTS OF ANALYSIS FOR AVERAGE ARRIVAL TIME BIAS

Model: $E(i,j) = \mu + M_i + P_j + I_{ij} + e$

where $E(i,j)$ = **estimated average error for mode i and percentage j**
μ = **average effect**
M_i = **effect of mode i**
P_i = **effect of percentage j**
I_{ij} = **interaction effect between mode i and percentage j**
e = **error**

Estimated Parameters:

μ = **2.72 seconds**

M_1 = 1.40 **seconds**
M_2 = .35 **seconds**
M_3 = -.60 **seconds**
M_4 = .38 **seconds**
M_5 = -.58 **seconds**
M_6 = .88 **seconds**
M_7 = .97 **seconds**

} **Significant at .999+**

P_{20} = .07 **seconds**
P_{50} = .09 **seconds**
P_{80} = -.16 **seconds**

} **Not significant** (all values assumed equal to zero)

I_{ij} **in Seconds**

j \ i	1	2	3	4	5	6	7
1	1.08	-.24	.64	-.46	-.27	-.34	-.41
2	.04	.08	-.31	.13	-.02	.04	.04
3	-1.12	.16	-.33	.33	.29	.30	.37

} **Significant at .995**

Example: $E(3,1) = 2.72 - .60 + .00 + .64 + e$
$= 2.76 + e$ **seconds**

Mode	Description
1	FDB-Multiple-Voice
2	FDB-Multiple-Vosyn
3	TAB-Multiple-Voice
4	TAB-Multiple-Vosyn
5	TAB-Single-Voice
6	TAB-Single-Vosyn
7	CBE

TABLE 7. ANALYSIS RESULTS FOR ARRIVAL ERROR DISPERSION

Model: $B(i,j) = \mu + M_i + P_j + I_{ij} + e$

where $B(i,j)$ = estimated dispersion for mode i and percentage j
μ = average effect
M_i = effect for mode i
P_j = effect for percentage j
I_{ij} = interaction effect between mode i and percentage j
e = error

Estimated Parameters:

μ = 1.73 seconds

M_1 = 1.19 seconds
M_2 = -.24 seconds
M_3 = .80 seconds
M_4 = -.36 seconds
M_5 = -.19 seconds
M_6 = -.78 seconds
M_7 = -.42 seconds

} Significant at .999+

P_{20} = .57 seconds
P_{50} = -.39 seconds
P_{80} = -.18 seconds

} Significant at .995

I_{ij} in Seconds

j \ i	1	2	3	4	5	6	7
1	1.05	-.02	.88	-.41	-.57	-.38	-.55
2	-.42	-.17	-.67	.10	.32	.34	.50
3	-.63	.19	-.21	.31	.25	.04	.05

} **Not significant** (all values assumed equal to zero)

Example: $B(5,3) = 1.73 - .19 - .18 + .00 + e$
$= 1.36 + e$ seconds

in each table, the results for a particular mode/percentage combination can be estimated by adding the values for the estimated parameters. If an effect is not significantly different from zero, the best estimate for each of those effect parameters is zero.

Using the results of the first analysis for message transaction times and arrival time dispersion, the modes were ranked for each percentage level/measure run according to their performance. The BMD11V program was rerun testing the significance of the contrasts (a contrast in an algebraic combination of the different effects) between successively ranked modes; i.e.,

H_0: $M(n) - M(n + 1) = 0$
H_1: $M(n) - M(n + 1) \neq 0$
where $M(n)$ = The effect of the mode ranked in the nth position.

For example, if the results of the preceding analyses indicated that the modes should be ranked in the following order: 1, 6, 7, 4, 3, 2, 5 then this step would consider the following contrasts: $M_1 - M_6$, $M_6 - M_7$, $M_7 - M_4$, $M_4 - M_3$, $M_3 - M_2$, $M_2 - M_5$. Using the contrast value and the variance estimate computed by the program, the multiple comparison procedure of Scheffe (reference 12) was manually applied to determine the significance of difference between modes. The standard F test was not appropriate since the comparison was based on observation of the results (posteriori rationale). The significant differences in the ranked modes are given in table 8. These results show which modes can be considered significantly better than lower ranked modes. For example, at the 50-percent level for Message Transaction Time for Voice Link Aircraft, mode 5 can be considered better than mode 3 at the .95 level. This also implies that all modes better than mode 6 are significantly better than mode 3. As can be seen in that table, the results for the message transaction time are fairly consistent. In particular, the control-by-exception mode (7) is almost universally ranked best by a significant amount.

In an attempt to obtain a consistent ranking across all the percentage levels, the BMD11V program was used to fit a model of the form:

$$y(i,j) = \mu + M_i + P_j + I_{ij} + e$$

where μ = the overall average
M_i = the effect of format i
P_j = the effect of percentage j
I_{ij} = the interaction between percentage level j and format i
e = normally distributed error

Since the controllers and the test matrix designs varied between the percentage levels, the block effect could not be isolated. Instead, all these effects were considered as random noise and were incorporated in the error term. The use of this model results in somewhat lower power due to the inflating of the error. However, the results given in tables 9 and 10 show that all the effects including the interaction effect are significantly different from zero for

TABLE 8. SIGNIFICANCE OF RANKED CONTRAST

DATA LINK

Measure	Mode	20-Percent Average	α	Mode	50-Percent Average	α	Mode	80-Percent Average	α
Message Transaction Time for Voice Link Aircraft (seconds)	7	10.470		7	9.854	.99	7	8.892	.95
	5	11.112		5	12.249		5	11.723	
	3	12.881		6	12.627	.95	6	12.345	
	6	13.371		3	14.410		4	14.473	
	1	13.974	.95	4	15.225		1	15.256	
	4	15.884	.95	7	15.363		2	15.362	
	2	17.725		1	15.689		3	16.368	
Message Transaction Time for Data Link Aircraft (seconds)	7	5.154	.999	7	4.455	.999	7	5.250	.99
	5	9.177		6	8.991	.999	6	8.419	
	6	9.296		5	10.517	.95	5	9.893	
	3	11.200		4	11.658		4	10.478	
	4	12.646		2	11.693		2	11.319	
	1	13.201		3	12.234		3	12.350	.999
	2	14.082		1	13.150		1	17.239	
Dispersion of Arrival Error at Inner Fix (seconds) (This measure was computed for the entire run only)				6	.94				
				7	1.32				
				4	1.37				
				2	1.49				
				5	1.53				
				3	2.52				
				1	2.92				

TABLE 9. RESULTS OF FULL MODEL ANALYSIS FOR VOICE LINK AIRCRAFT

Model: $T_V'(i,j) = \mu + M_i + P_j + I_{ij} + e$

where T_V' = message transaction time for voice link aircraft
μ = overall average
M_i = effect of mode i
P_j = effect of percent j
I_{ij} = interaction effect for mode i and percentage j
e = normally distributed error

Estimated from experimental data:

$\mu = 13.79$

M_1 = 1.34 seconds
M_2 = 2.52 seconds
M_3 = .92 seconds
M_4 = 1.56 seconds
M_5 = -1.94 seconds
M_6 = - .85 seconds
M_7 = -3.55 seconds

Significant at .999+

P_{20} = -.27 seconds
P_{50} = -.16 seconds
P_{80} = .43 seconds

Significant at .999+

I ij in seconds

j \ i	1	2	3	4	5	6	7
1	1.00	1.58	-1.67	.69	-.58	.59	.40
2	.72	-.79	-.14	.03	.56	-.15	-.22
3	.28	-.79	1.81	-.72	.02	-.44	-.18

Significant at .999+

For example: $T_V'(4,3) = 13.79 + 1.56 + .43 - .72 + e = 15.06 + e$ seconds

TABLE 10. RESULTS OF FULL MODEL ANALYSIS FOR DATA LINK AIRCRAFT

Model: $T_d^t(i,j) = \mu + M_i + P_j + I_{ij} + e$

where T_d^t = message transaction time for data link aircraft
μ = overall average
M_i = effect of mode i
P_j = effect of percentage j
I_{ij} = interaction effect for mode i and percentage j
e = normally distributed error

Estimated from Experimental Data:

μ = 10.37 seconds

M_1 = 3.91 seconds
M_2 = 1.92 seconds
M_3 = 1.46 seconds
M_4 = .97 seconds
M_5 = -.87 seconds
M_6 = -1.72 seconds
M_7 = -5.67 seconds

Significant at .999+

P_{20} = .11 seconds
P_{50} = -.47 seconds
P_{80} = .36 seconds

Significant at .999+

I_{ij}, in Seconds

j \ i	1	2	3	4	5	6	7
1	-1.33	1.54	-.88	1.05	-.57	.39	.20
2	-1.38	- .31	.61	.06	.43	.09	-.50
3	2.71	-1.23	.27	-1.11	.14	-.48	.30

Significant at .999+

For example: $T_d^t(2,1) = 11.09 + 1.92 + .11 + 1.54 + e = 14.66 + e$ seconds

voice and data link aircraft, respectively. The presence of the interaction effect means that the relationship between the modes changed by percentage level. This fact implies that the relative performance of the modes will change from percentage level to percentage level. For example, from table 9, T_V' (3,1)= 12.77 seconds and T_V' (2,1)=17.62 seconds implying that mode 3 is significantly better than mode 2 at the 20 percent level. However at the 80 percent level, T_V' (3,3)=16.95 seconds and T_V' (2,3)=15.95 seconds implying that mode 2 is slightly better than mode 3.

To understand the interrelationships between the different modes and the percentage factor, the data for each mode were run separately through the BMD11V to fit a model of the following form:

$$y(i) = M_i + \alpha P + e \qquad (5)$$

where y_i = the measured response
M_i = the average effect of the format
α = the regression coefficient for percentage
P = the percentage of the run
e = normally distributed error

The results of these analyses are given in table 11.

To complete the model of the time line data, the slopes or time relationships previously removed from the data were analyzed to estimate the parameters of a model of the form:

$$S(i) = m_i + \beta_i P + e \qquad (6)$$

where S_i = slope of time relationship
m_i = effect of mode i on the slope
β_i = change in the slope value with increasing percentage for mode i
e = error

The results of this analysis are given in tables 12 and 13 for both data link and voice link aircraft, respectively.

Combining the models of (1) and (2) gives a general expression for the message transaction time as a function of mode, percentage, and time:

$$y\ (i,j,t) = \mu + M_i + \alpha P + (m_i + \beta_i P)\ (t - 30) + e$$

where μ = overall average
M_i = effect of mode i
α = slope of percentage relationship
m_i = effect of mode i on slope of time relationship
β_i = slope of time slope/percentage relationship
P = percentage of data link aircraft
t = experiment time

TABLE 11. RESULTS OF REGRESSION ANALYSIS

Data Link Aircraft			Voice Link Aircraft		
Mode	Regression Equation	Significance	Mode	Regression Relationship	Significance
1	$T_D'(1) = 8.738 + .1081P$	(.99+)	1	$T_V'(1) = 13.144 + .0459P$	(.90)
2	$T_D'(2) = 13.922 - .0260P$	(.99)	2	$T_V'(2) = 18.221 - .0476P$	(.99+)
3	$T_D'(3) = 11.607 - .0202P$	------	3	$T_V'(3) = 11.317 + .0654P$	(.99+)
4	$T_D'(4) = 13.021 - .0234P$	(.98)	4	$T_V'(4) = 16.002 - .0142P$	------
5	$T_D'(5) = 9.360 + .0167P$	(.96)	5	$T_V'(5) = 10.598 + .0284P$	(.99+)
6	$T_D'(6) = 9.301 - .0026P$	------	6	$T_V'(6) = 13.377 - .0118P$	------
7	$T_D'(7) = 5.345 + .0018P$	------	7	$T_V'(7) = 10.312 - .0051P$	------

where $T_D'(i)$ = transformed message transaction time for data link aircraft for mode i

$T_V'(j)$ = transformed message transaction time for voice link aircraft for mode j

P = data link percentage level

TABLE 12. TIME SLOPES FOR DATA LINK AIRCRAFT

Model: $S_D(i) = m_i + \beta_i P + e$

where S_D = slope of line for time relationship for mode i
m_i = effect of mode i
P = data link employment percentage
β_i = slope of line for relationship of S with P for mode i
e = error

Estimated from Experimental Data:

$$\left.\begin{array}{ll} m_1 = & .1403 \text{ seconds/minute} \\ m_2 = & -.1330 \text{ seconds/minute} \\ m_3 = & .0471 \text{ seconds/minute} \\ m_4 = & -.0789 \text{ seconds/minute} \\ m_5 = & .2542 \text{ seconds/minute} \\ m_6 = & -.0057 \text{ seconds/minute} \\ m_7 = & -.0186 \text{ seconds/minute} \end{array}\right\} \quad \text{Significant at .999+}$$

$$\left.\begin{array}{ll} \beta_1 = & -.00064 \text{ seconds/minute/percent} \\ \beta_2 = & .00280 \text{ seconds/minute/percent} \\ \beta_3 = & .00019 \text{ seconds/minute/percent} \\ \beta_4 = & .00093 \text{ seconds/minute/percent} \\ \beta_5 = & -.00334 \text{ seconds/minute/percent} \\ \beta_6 = & .00012 \text{ seconds/minute/percent} \\ \beta_7 = & -.00006 \text{ seconds/minute/percent} \end{array}\right\} \quad \text{Significant at .999+}$$

TABLE 13. TIME SLOPES FOR VOICE LINK AIRCRAFT

Model: $S_V(i) = M_i + \beta_i P + e$

where S_V = slope of line for time relationship for mode i
M_i = effect of mode i
β_i = slope of line for relationship of S with P for mode i
e = error

Estimated from Experimental Data:

m_1 = .1970 seconds/minute
m_2 = .1198 seconds/minute
m_3 = .0776 seconds/minute
m_4 = .1014 seconds/minute
m_5 = .1071 seconds/minute
m_6 = .1101 seconds/minute
m_7 = .1090 seconds/minute

Insignificantly different than .1174 seconds/minute

β_1 = -.00241 seconds/minute/percent
β_2 = -.00112 seconds/minute/percent
β_3 = -.00154 seconds/minute/percent
β_4 = -.00196 seconds/minute/percent
β_5 = -.00158 seconds/minute/percent
β_6 = -.00165 seconds/minute/percent
β_7 = -.00171 seconds/minute/percent

Insignificantly different than -.00171 seconds/minute/percent

These results are shown graphically in figures 17 and 18 for full load (t=60 min) and for half load (t=40 min). In both cases, a significance level for the regression coefficients of .99 was used, as discussed previously. As can be seen in these figures, the regression relationship varies from mode to mode. In most cases, the message transaction time either decreases or remains constant with increasing employment level. However, for mode 4, the message transaction time increases as the employment level increases.

To investigate the impact of the various comparative parameters (Voice versus Vosyn, FDB versus TAB, multiple versus single, and control-by-exception versus the six control-by-approval modes) - BMD11V was rerun to fit the model shown in (4) and to test the following hypotheses:

1. Voice is different than Vosyn

   H_0: $(M_1 + M_3 + M_5) - (M_2 + M_4 + M_6) = 0$
   H_1: $(M_1 + M_3 + M_5) - (M_2 + M_4 + M_6) \neq 0$

2. Full data block is different than tabular list

   H_0: $(M_1 + M_2) - (M_3 + M_4) = 0$
   H_1: $(M_1 + M_2) - (M_3 + M_4) \neq 0$

3. Single Command is different than multiple command

   H_0: $(M_3 + M_4) - (M_5 + M_6) = 0$
   H_1: $(M_3 + M_4) - (M_5 + M_6) \neq 0$

4. CBE is different than CBA

   H_0: $6^* M_7 - (M_1 + M_2 + M_3 + M_4 + M_5 + M_6) = 0$
   H_1: $6^* M_7 - (M_1 + M_2 + M_3 + M_4 + M_5 + M_6) \neq 0$

where

M_1 = Full Data Block-Multiple Command-Voice
M_2 = Full Data Block-Multiple Command-Vosyn
M_3 = Tabular List-Multiple Command-Voice
M_4 = Tabular List-Multiple Command-Vosyn
M_5 = Tabular List-Single Command-Voice
M_6 = Tabular List-Single Command-Vosyn
M_7 = CBE

These runs were made for all contrasts for message transaction time and message delivery time for both voice and data link-equipped aircraft. The service time measured is defined for the voice versus Vosyn contrast only. The results of this analysis are shown in table 14 for voice and data link-equipped aircraft, respectively. For example, the results indicate that for voice-link message transaction times at 20 percent, the voice modes are significantly better than the Vosyn modes at the .999+ level, while for the other percentages, there is no difference between voice and Vosyn.

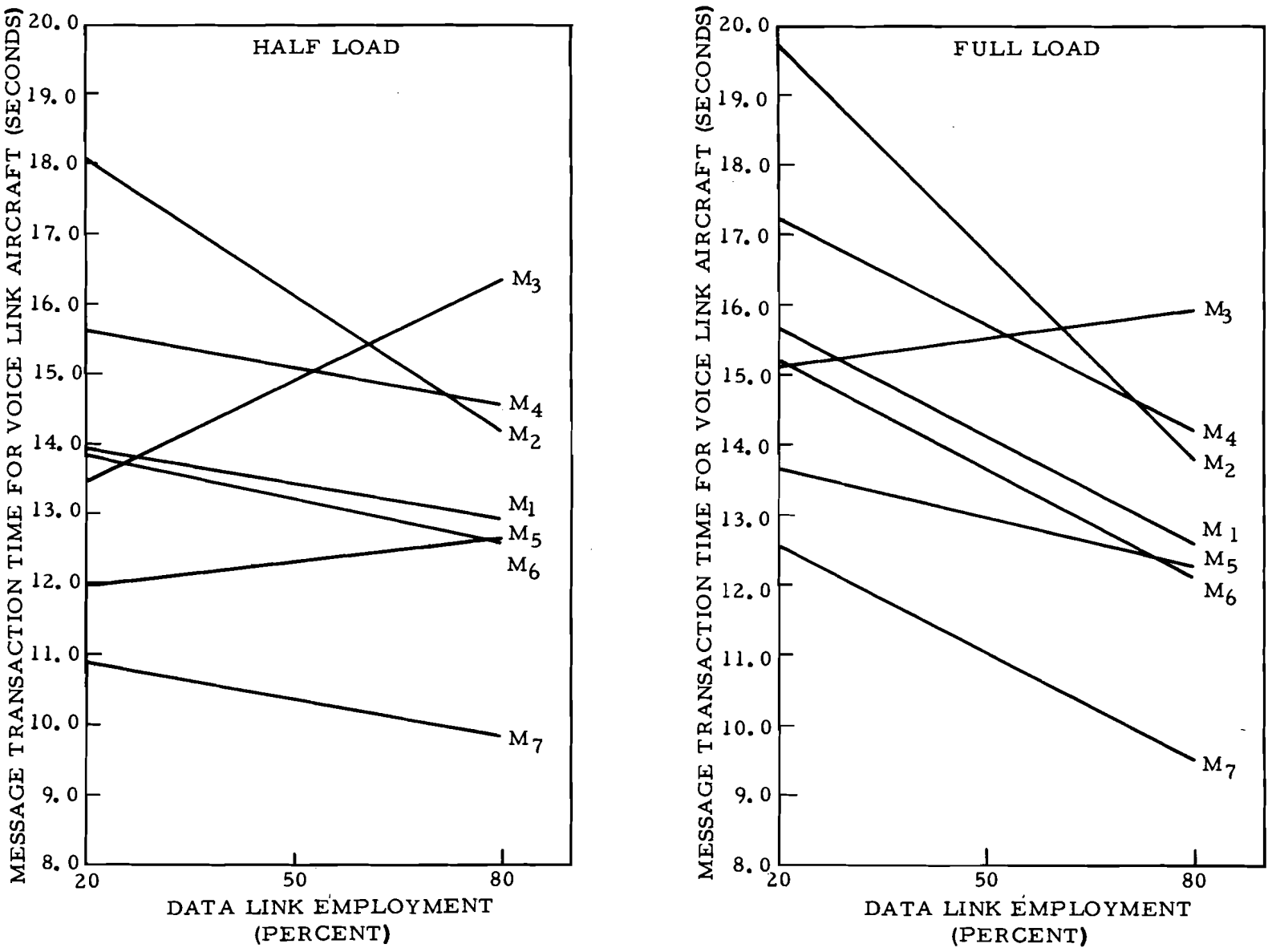


FIGURE 17. SAMPLE REGRESSION ANALYSIS PLOTS FOR VOICE LINK AIRCRAFT

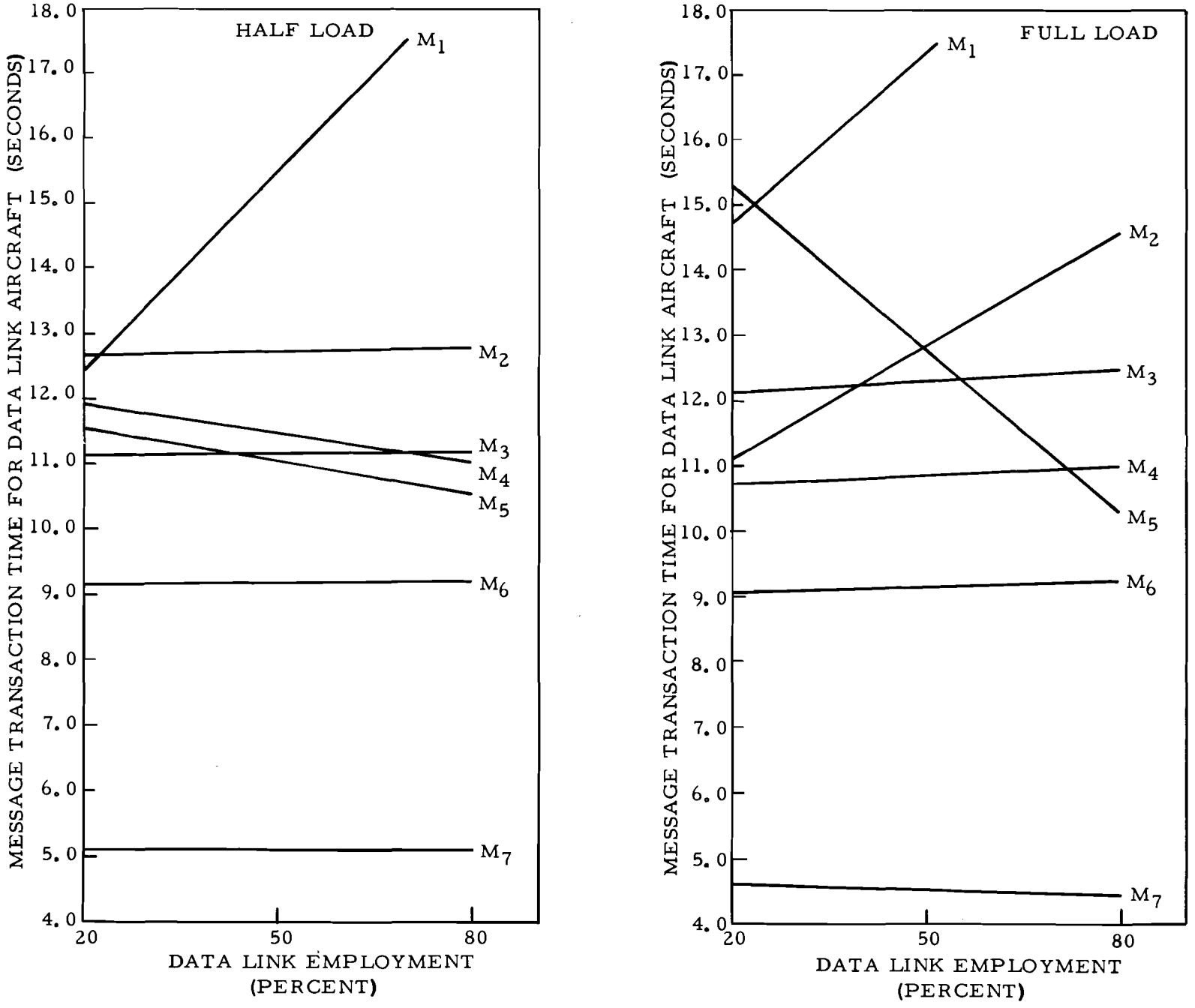


FIGURE 18. SAMPLE REGRESSION ANALYSIS PLOTS FOR DATA LINK AIRCRAFT

TABLE 14. SIGNIFICANCE OF HYPOTHESIS TEST FOR DESIGN PARAMETER CONTRAST

	Data Link Percent	Hypothesis #1		Hypothesis #2		Hypothesis #3		Hypothesis #4	
VOICE LINK		Voice is Better	Vosyn is Better	FDB is Better	Tab is Better	Single is Better	Multiple is Better	CBE is Better	CBA is Better
Message	20%	.999+			.999+	.999+		.999+	
Transaction	50%	----------			.999+	.999+		.999+	
Time	80%	----------		----------		.990		.999+	
Service	20%	.999+							
Time	50%	.999+							
	80%	.996							
Message	20%	.999+			.996	----------			.999
Delivery	50%	.999+		----------		----------		.999+	
Time	80%	.999+			.900	.997			.996
DATA LINK									
Message	20%		.997	----------		----------		.999+	
Transaction	50%		.999+		.999+	.999+		.999+	
Time	80%		.999+		.999+	.999+		.999+	
Service	20%	.999+							
Time	50%	.904							
	80%		.999+						
Message	20%	----------		----------			.999+	----------	
Delivery	50%	----------		----------			.999+		.999+
Time	80%	----------		----------			.999+	.999+	

----------Not Significant

A number of measures were collected on a run-by-run basis instead of by message or aircraft. These measures include the number of disengagements, the number of tag repositionings, and the average queue size. A fourth measure is proportional to the total test time the subject controller spent communicating. This important measure, called total message transaction time, was defined as the sum of the individual message transaction times for both data and voice link aircraft.

These four measures were analyzed to determine if there was any pattern to the run values. To this end, the BMD11V program was fitted to a model of the form:

$$y(i,j) = \mu + M_i + P_j + I_{ij} + e$$

where y = the value of the measurement
μ = the average response
M_i = the effect of mode i
P_j = the effect of percentage j
I_{ij} = the interaction effect between percentage j and format i
e = normally distributed error

In each analysis, the format effects, the percentage effects, and the interaction effects were tested for being equal to zero. The results of these analyses are given in tables 15 through 18.

As discussed previously, in each experiment run, a conflict was deliberately scheduled between two aircraft. These aircraft were scheduled to arrive at the inner fix at nearly the same time and altitude. In most of the cases, this planned conflict was detected and resolved without any actual confliction. However, in 13 cases, some degree of violation was detected. Each of these cases is analyzed in table 19. Most of these conflicts fall into two classes. Either the planned conflict was detected and resolved somewhat late or, in resequencing the disengaged aircraft, a violation occurred, usually near the inner fix. No attempt has been made to judge the operational severity of these conflicts. That discussion will be conducted under the combined analysis section.

With only 13 conflicts in the 91 runs, there is too little data to perform an analysis of variance, so a goodness-of-fit test was used to determine if the average number of conflicts differed significantly from mode to mode or from percentage to percentage. The mode effect is significant at the .995 level while the percentage effect is significant at the 91 percent level.

SUBJECTIVE DATA ANALYSIS

Analysis of the subjective (questionnaire) data of the Data Link Phase IIA experiment consisted of a tabulation of the responses to each question by mode and data-link percentage mix. These tabulations were analyzed to determine if there were any statistically significant differences between the modes or the mixes. In addition, where similar questions were given before and after

TABLE 15. RESULTS OF ANALYSIS FOR TOTAL MESSAGE TRANSACTION TIME, T_T

Model: $T_T(i,j) = \mu_T + M_i + P_j + I_{ij} + e$

where $T_T(i,j)$ = estimated total message transaction time
μ_T = average effect
M_i = effect of mode i
P_j = effect of percentage j
I_{ij} = interaction effect between mode i and percentage j
e = error

Estimated parameters:

μ_T = 1800 seconds/run

M_1 = 338 seconds/run
M_2 = 438 seconds/run
M_3 = -32 seconds/run
M_4 = 222 seconds/run
M_5 = -207 seconds/run
M_6 = -151 seconds/run
M_7 = -608 seconds/run

} Significant at .999+

P_{20} = 138 seconds/run
P_{50} = -42 seconds/run
P_{80} = -96 seconds/run

} Significant at .976

I_{ij} in seconds/run

j \ i	1	2	3	4	5	6	7
1	-260	285	-377	183	-182	194	157
2	38	-130	88	-44	28	10	10
3	222	-155	289	-139	154	-204	-167

} Significant at .978

Example: $T_T(7,3) = 1800 - 608 - 96 - 167 + e = 929 + e$ seconds/run

TABLE 16. RESULTS OF ANALYSIS FOR NUMBER OF DISENGAGEMENTS, D

Model:

$$D(i,j) = \mu_D + M_i + P_j + I_{ij} + e$$

where $D(i,j)$ = estimated excess number of disengagements[1]

μ_D = average effect
M_i = effect of mode i
P_j = effect of percentage j
I_{ij} = interaction effect between mode i and percentage j
e = error

Estimated parameters:

μ_D = 0.53 disengagements/run

M_1 = .565 disengagements/run
M_2 = .120 disengagements/run
M_3 = .136 disengagements/run
M_4 = -.420 disengagements/run
M_5 = .184 disengagements/run
M_6 = -.372 disengagements/run
M_7 = -.213 disengagements/run

} Not significant (All values may be assumed equal to zero.)

P_{20} = .469 disengagements/run
P_{50} = -.224 disengagements/run
P_{80} = -.245 disengagements/run

} Significant at .993

I_{ij} in disengagements/run

j \ i	1	2	3	4	5	6	7
1	1.44	-.45	-.14	-.58	.48	-.63	-.12
2	-.58	-.14	.56	.11	-.35	.21	.19
3	-.86	.59	-.42	.47	-.13	-.42	-.07

} Significant at .982

Example: $D(3,1) = 0.53 + 0.0 + 0.47 - .14 + e$
$= 0.86 + e$ excess disengagements/run

TABLE 17. RESULTS OF ANALYSIS OF NUMBER OF TAG REPOSITIONINGS, R

Model: $R(i,j) = \mu_R + M_i + P_j + I_{ij} + e$

where $R(i,j)$ = estimated number of tag repositionings
μ_R = average effect
M_i = effect of mode i
P_j = effect of percentage j
I_{ij} = interaction effect between mode i and percentage j
e = error

Estimated parameters:

μ_R = 1.719 repositionings/run

M_1 =	3.265 repositionings/run	Significant at .999+
M_2 =	.170 repositionings/run	
M_3 =	-.957 repositionings/run	
M_4 =	-1.243 repositionings/run	
M_5 =	-.814 repositionings/run	
M_6 =	-1.005 repositionings/run	
M_7 =	.584 repositionings/run	

P_{20} =	-.243 repositionings/run	Not significant (All values may be assumed equal to zero)
P_{50} =	.485 repositionings/run	
P_{80} =	-.242 repositionings/run	

I_{ij} = in repositionings/run

j \ i	1	2	3	4	5	6	7
1	1.59	-.98	-.19	-.23	.67	.20	-1.06
2	-1.18	.63	.04	.47	-.68	-.06	.78
3	- .41	.35	.15	-.24	.01	.14	.28
					0.0	0.0	

Not significant (All values may be assumed equal to zero)

Example: $R(5,2) = 1.719 - .814 + 0.0 - 0.0 + e$
$= .905 + e$ repositionings/run

TABLE 18. RESULTS OF ANALYSIS FOR AVERAGE QUEUE SIZE, Q

Model: $Q(i,j) = \mu_Q + M_i + P_j + I_{ij} + e$

where $Q(i,j)$ = estimated average queue size for format i and percentage j

μ_Q = average effect
M_i = effect of mode i
P_j = effect of percentage j
I_{ij} = interaction effect between mode i and percentage j
e = error

Estimated parameters:

μ_Q = .345 messages

M_1 = .255 messages
M_2 = .046 messages
M_3 = .139 messages
M_4 = -.036 messages
M_5 = .066 messages
M_6 = -.136 messages
M_7 = -.332 messages

Significant at .999+

P_1 = .061 messages
P_2 = -.024 messages
P_3 = -.038 messages

Significant at .999+

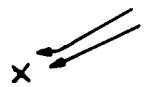
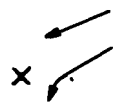
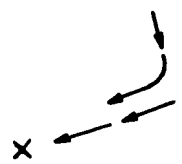
I_{ij} in messages

j \ i	1	2	3	4	5	6	7
1	.00	.02	-.01	.00	.03	.00	-.04
2	.00	-.05	.03	-.01	.02	-.01	.02
3	.00	.03	-.02	.01	-.05	.01	.02

Not significant (All values may be assumed equal to zero)

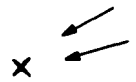
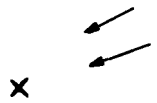
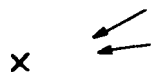
Example: $Q(6,2) = .345 - .136 - .024 - 0.0 + e$
$= .176$ messages in queue

TABLE 19. TABULATION OF CONFLICT DATA

Case	Subj	Data Link Percent	Mode	Closest Approach Horiz (nmi)	Closest Approach Vert (ft)	Duration (sec)	Conflict Geometry[1]	Remarks
1	D	20	7	1.45	4	22		Planned conflict was resolved, but in attempting to resequence the disengaged aircraft, the controller brought it back into conflict.
2	C	20	4	(a)1.71 (b)3.51	40 40	28 67		Planned conflict was a violation when detected and then disengaged aircraft was turned toward other aircraft. When the disengaged aircraft was turned back toward the inner fix, it still violated the 60° fan.
3	D	20	4	0.51	4	206		The planned conflict was not detected until very late.
4	G	20	7	1.56	4	38		The planned conflict was detected and resolved, but in resequencing, the disengaged aircraft was turned in too close at the inner fix.
5	G	50	1	1.10	0	10		The disengaged aircraft conflicts when being resequenced.
6	D	50	6	(a)3.16 (b)4.23	99 26	4 60		In resolving the planned conflict, the 5 nmi zone was violated two separate times.
7	C	50	3	(a)2.23 (b)0.88	0 433	26 76		Both aircraft disengaged, heavy was turned in front of a standard jet.

1 X = Inner Fix

TABLE 19. TABULATION OF CONFLICT DATA (Continued)

Case	Subj	Data Link Percent	Mode	Closest Approach Horiz (nmi)	Closest Approach Vert (ft)	Duration (sec)	Conflict Geometry[1]	Remarks
8	A	50	6	2.01	898	1		Very minor encroachment into 60° fan.
9	B	80	2	1.41	66	59		Planned conflict, controller did not provide solution until aircraft were within 1.41 nmi.
10	B	80	5	4.33	4	9		Minor encroachment into 60° fan.
11	D	80	5	(a)0.22 (b)4.23	840 4	123 3		Planned conflict. Controller waited too long and then turned one aircraft toward the other. Then reestablished aircraft on heading while still in 5 nmi zone.
12	E	80	5	1.80	120	4		Planned conflict resolved just as the aircraft came into violation.
13	D	80	7	1.60	40	26		Planned conflict not resolved until aircraft were within 1.60 nmi.

1 X = Inner Fix

the experiment, those data were analyzed to determine if the before and after responses differed significantly. Certain selected questions were investigated to see if the responses changed with increased exposure to the simulation.

The results of this analysis are reported question by question. Each question is related exactly as given in the questionnaire. Following each question is a discussion of the findings. Only significant effects are reported. If the mode or mix differences are not significant, no comment is made, and generally the results are aggregated across the nonsignificant effect(s). Where conclusions are drawn from patterns in the data which are not statistically significant, the basic data are shown and the conclusions are specifically labelled as inferences. All important findings are underlined.

As described previously, the questionnaires consisted of three parts: (1) The preexperiment questionnaire and opinionnaire given prior to each run, but after a review of documentation and an oral briefing on the mode; (2) the postexperiment questionnaire given following each data run; and (3) the summary questionnaire given after each subject completed an entire test series.

PREEXPERIMENT QUESTIONNAIRE.

THE PREEXPERIMENT QUESTIONS WERE CONCERNED WITH DETERMINING THE CONTROLLERS' ATTITUDES TOWARD THE PREPARATION FOR THE DATA RUNS AND IDENTIFYING THOSE AREAS OF THE SIMULATION ABOUT WHICH THE SUBJECT CONTROLLERS FELT LEAST CONFIDENT.

1. *Were the principal features of the mode explained clearly in the briefing and were all your questions resolved satisfactorily?*

Yes *100%* *No* _____

All the controllers in every mode and at every employment level responded yes.

2. *Check those aspects of the upcoming test which you feel least confident about.*

   a. *Performance at maximum traffic loads* ____
   b. *The mix of data link and voice link aircraft* _____
   c. *Exception cases (link fails, unables, repeat requests, etc.)* __
   d. *The skeleton metering and spacing algorithm* _____
   e. *The display format and controller I/O procedures* _____
   f. *Preventing tag overlaps* ___
   g. *Maintaining safe separations* _____
   h. *Disengagement of conflicting aircraft* _____
   i. *Trackball operations* _____

The response to this question is tabulated in table 20 where the number of times each aspect was checked are recorded by mode and percent. As can be seen in that table, the primary concern of the controllers prior to the experiment

TABLE 20. SUMMARY OF RESULTS FOR PREEXPERIMENT QUESTION 2

ASPECT	DATA LINK	MODE 1	2	3	4	5	6	7	TOTAL
Performance at Maximum Traffic Load	20	1	1	2	2	2	2	1	11
	50	4	4	3	3	4	3	3	24
	80	1	2	2	1	2	1	1	10
	Total	6	7	7	6	8	6	5	45
Mix of Data Link And Voice Link A/C	20	0	0	1	1	0	0	1	3
	50	1	2	1	0	2	1	2	9
	80	2	1	1	1	1	0	1	7
	Total	3	3	3	2	3	1	4	19
Exception Cases	20	2	3	2	2	1	1	1	12
	50	1	2	3	2	2	2	4	16
	80	1	2	2	2	2	1	3	13
	Total	4	7	7	6	5	4	8	41
Skeleton M&S Algorithm	20	-	-	-	-	-	-	-	-
	50	2	1	0	1	0	0	0	4
	80	-	-	-	-	-	-	-	-
	Total	2	1	0	1	0	0	0	4
Display Format and Controller I/O Procedures	20	1	1	0	1	0	0	0	3
	50	1	0	1	1	0	2	1	6
	80	1	1	1	1	2	2	1	9
	Total	3	2	2	3	2	4	2	18
Preventing Tag Overlaps	20	0	0	0	1	0	0	0	1
	50	0	1	1	2	0	0	0	4
	80	0	0	0	1	0	0	0	1
	Total	0	1	1	4	0	0	0	6
Maintaining Safe Separation	20	0	0	0	1	0	0	1	2
	50	1	0	1	0	1	0	0	3
	80	0	1	1	0	0	0	0	2
	Total	1	1	2	1	1	0	1	7
Disengagement of Conflicting Aircraft	20	0	0	1	1	2	0	2	6
	50	1	1	0	0	0	0	2	4
	80	2	1	2	1	1	2	0	9
	Total	3	2	3	2	3	2	4	19
Trackball Operations	20	0	1	0	1	0	1	0	3
	50	1	1	0	0	2	1	0	5
	80	0	0	0	1	1	1	0	3
	Total	1	2	0	2	3	3	0	11

was their ability to handle the traffic at maximum load. Nearly as important was the concern toward the exception cases. The mix of data and voice link aircraft, disengagement of conflicting aircraft and the display format and I/O procedures were checked less than half as frequently.

The responses to this question were also tabulated with respect to the run sequence at the 50 percent level to investigate the effect of prior test time (number of previous runs) on the selection of problem areas. (The 20 percent and 80 percent levels were not considered due to the very small (n=3) number of runs each controller made.) No time effect was evident from a visual comparison of the tabulated data.

The response to this data was also compared with the previous day's response to question B-2 on the postexperiment questionnaire. No strong correlation between these responses was evident. That is, surprisingly, the controllers' problem areas on the previous run were not selected as possible problems for the upcoming run.

OPINIONNAIRE.

THE FIRST TWO QUESTIONS ON THE OPINIONNAIRE WERE DIRECTED TOWARD DETERMINING THE CONTROLLERS' UNDERSTANDING OF THE SIMULATION.

1. *Do you understand the general objectives of the data link display experiments?* *Yes* *100%* *No* _____

The controllers unanimously answered that they understood the objectives of the experiment.

2. *Choose a statement describing the degree of understanding of the data link study which you achieved by reading the documentation provided.*

   a. *(3) - Complete and comprehensive* *12%*
   b. *(2) - Workable, with minor questions* *85%*
   c. *(1) - Marginal, with major questions* *2%*
   d. *(0) - Vague and confused* *1%*

Giving each response the value indicated in parentheses, the following average scores were received:

DATA LINK	MODE							
Percent	1	2	3	4	5	6	7	Average
20	2.3	2.3	1.7	2.3	2.3	2.0	2.0	2.2
50	2.0	2.0	2.1	2.0	2.1	2.1	2.0	2.1
80	1.7	2.3	2.0	2.0	2.0	1.7	2.3	2.0
Average	2.0	2.2	2.0	2.2	2.2	2.0	2.1	2.1

All of the responses are clustered around 2.0 indicating that the controllers generally considered their prior understanding as workable with minor questions.

THE NEXT THREE OPINIONNAIRE QUESTIONS WERE DESIGNED TO OBTAIN THE CONTROLLERS' ATTITUDE TOWARD DATA LINK PRIOR TO SIMULATION.

3. *In general, do you feel that the semi-automation of terminal ATC (computer-generated metering and spacing commands transmitted via data link) will eventually be accepted in actual operations?*

Yes *(71%)* *No* *(1%)* *Undecided* *(28%)*

Based on 91 responses, the percentages indicated in parentheses above were obtained showing a very favorable response toward the eventual acceptance of data link.

To determine if the attitude of the subject controllers changed with exposure to data link, the responses of each test subject at the 50-percent data link level were plotted. Of the seven controllers, three provided positive answers for all tests. Three others answered "undecided" initially and at some point shifted to a positive response. The other subject answered "undecided" until the last run when he checked "No." This indicates that the controllers felt slightly more positive toward data link as their exposure increased.

4. *Relative to present-day ARTS procedures, how do you anticipate that this mode of displaying and transmitting commands would perform:*

a. *(+2) - Much more favorable* _____
b. *(+1) - More favorable* _____
c. *(0) - About the same* _____
d. *(-1) - Less favorable* _____
e. *(-2) - Much less favorable* _____

Using the scores indicated in parentheses, the following average results were obtained:

DATA LINK	MODE							
Percent	1	2	3	4	5	6	7	Average
20	.67	.00	.67	.67	1.33	1.00	1.00	.76
50	.57	.57	.43	.71	.86	.29	.57	.57
80	.33	.33	.33	1.00	1.00	.67	.67	.62
Average	.54	.38	.46	.77	1.00	.54	.69	.63

These results show a mildly favorable controller response toward data link versus current ARTS which is fairly consistent for all modes. For this overall ranking, mode 5 (TAB-Single-Voice) is consistently ranked the best prior to the test.

5. *Compared with the present-day ARTS procedures scenario, how do you anticipate that this mode of displaying and transmitting commands will perform with respect to the following characteristics:*

Aspect	*Greatly Decrease*	*Decrease*	*Will Not Change*	*Increase*	*Greatly Increase*
Workload	*(+2)*	*(+1)*	*(0)*	*(-1)*	*(-2)*
Traffic-Handling Capacity	*(-2)*	*(-1)*	*(0)*	*(+1)*	*(+2)*
Susceptibility to Blunders	*(+2)*	*(+1)*	*(0)*	*(-1)*	*(-2)*
Stressfulness	*(+2)*	*(+1)*	*(0)*	*(-1)*	*(-2)*

Averaging the individual responses using the scores in parentheses gives the results shown in table 21. As can be seen in the summary lines, prior to the test the subject controllers generally felt that the use of a data link would improve operation in terms of workload, traffic-handling capacity, susceptibility to blunders, and stressfulness.

The response to the overall rating of question 3 and the control aspects of question 4 were studied using multivariance techniques using BMD11V. Based on these data, the percentage effect was significant at the .900 level, while the mode effect was not significant; however, from the grand total it can be inferred that the prior response favored CBE, TAB-Single-Voice, FDB-Multiple-Voice, and TAB-Single-Vosyn, in that order.

The row totals infer that the controllers differ in their definitions of the control aspects. This fact was substantiated when the controllers were asked to provide their interpretation of the terms used. Their definitions differed quite widely.

POSTEXPERIMENT QUESTIONNAIRE.

THE FIRST FOUR QUESTIONS ON THE POSTEXPERIMENT QUESTIONNAIRE WERE DESIGNED TO PROVIDE AN OVERALL EVALUATION OF THE MODE THAT WAS JUST TESTED. THE FIRST TWO QUESTIONS ARE ALMOST IDENTICAL TO QUESTIONS 3 AND 4 OF THE OPINIONNAIRE WHILE THE THIRD AND FOURTH QUESTIONS ASK THE SUBJECT TO EXTRAPOLATE HIS OPINION OF THE RUN TO A SITUATION IN WHICH ALL AIRCRAFT ARE DATA LINK-EQUIPPED.

A-1. *A.* *How would you rate the displaying and dispatching of commands in this mode with the present-day ARTS procedure applied to the same scenario:*

a. *(+2) - Much more favorable* _____
b. *(+1) - More favorable* _____

TABLE 21. OPINIONNAIRE AVERAGE CONTROL ASPECTS RATING[1]

	TEST MODE						
20-Percent Data Link	1	2	3	4	5	6	7
Workload	1.00	-.33	.67	.67	.33	.67	1.00
Traffic-Handling Capability	0.33	0.33	0.33	0.33	0.67	1.00	0.67
Susceptibility to Blunders	0.00	0.00	0.00	0.33	0.33	0.67	1.00
Stressfulness	0.67	0.00	0.33	0.33	0.67	0.67	1.00
AVERAGE	0.50	0.00	0.42	0.42	0.50	0.75	0.92
50-Percent Data Link							
Workload	0.57	-0.14	0.28	0.42	0.57	0.42	0.71
Traffic-Handling Capability	0.28	0.00	-0.14	0.00	0.28	0.14	0.28
Susceptibility to Blunders	-0.28	-0.14	-0.14	0.00	-0.28	-0.28	0.28
Stressfulness	0.00	-0.28	0.14	-0.14	-0.28	-0.28	0.14
AVERAGE	0.14	-0.14	0.03	0.10	0.07	0.00	0.36
80-Percent Data Link							
Workload	0.33	0.67	1.00	1.00	1.00	0.33	1.33
Traffic-Handling Capability	0.33	0.33	0.00	0.33	0.33	0.00	0.67
Susceptibility to Blunders	-0.33	-1.00	-0.67	-0.33	-0.33	-0.33	0.00
Stressfulness	0.67	0.33	0.00	0.33	1.00	0.33	0.33
AVERAGE	0.50	0.08	0.08	0.33	0.50	0.08	0.42
GRAND AVERAGE	0.30	-0.02	0.07	0.04	0.36	0.28	0.56

1 + = favorable, - = unfavorable, Scale = 2,1,0,-1,-2

LEGEND: 1 = FDB-Multiple-Voice
2 = FDB-Multiple-Vosyn
3 = TAB-Mulitple-Voice
4 = TAB-Multiple-Vosyn
5 = TAB-Single-Voice
6 = TAB-Single,Vosyn
7 = CBE-FDB-Vosyn

c. (0) - About the same _____
d. (-1) - Less favorable _____
e. (-2) - Much less favorable _____

Using the scores indicated in parentheses, the following average results were obtained:

DATA LINK	MODE							
Percent	1	2	3	4	5	6	7	Average
20	.67	.00	.00	1.00	1.33	1.33	.67	.62
50	.28	.71	-.57	.57	.57	1.14	.28	.43
80	-.33	1.00	.33	1.00	1.00	1.00	1.33	.76
Average	.21	.57	-.08	.77	.85	1.15	.62	.57

After the run experience, the results still show a mildly favorable response toward data link, which agrees with the responses to opinionnaire question 4. However, in contrast to the opinionnaire, mode 6 (TAB-Single-Vosyn) was preferred. More importantly, it is inferred that there was a definite improvement in controller attitudes toward the Vosyn modes (2, 4, 6) and a corresponding lowering of opinion toward the voice modes (1,3,5).

A-1. B. For the above, what ratings would you give for the following aspects:

Aspect	*Greatly Decrease*	*Decrease*	*Will Not Change*	*Increase*	*Greatly Increase*
Workload	*(+2)*	*(+1)*	*(0)*	*(-1)*	*(-2)*
Traffic-Handling Capacity	*(-2)*	*(-1)*	*(0)*	*(+1)*	*(+2)*
Susceptibility to Blunders	*(+2)*	*(+1)*	*(0)*	*(-1)*	*(-2)*
Stressfulness	*(+2)*	*(+1)*	*(0)*	*(-1)*	*(-2)*

Averaging the individual responses, using the scores in parentheses, gives the results shown in table 22. These responses give a somewhat confused picture. The statistical analysis of the responses to this question indicated that both the percentage and mode effects were significant at the .999 and .975 levels, respectively. The differences in the format responses can be explained by the strong preference for the TAB-Single-Vosyn mode 6; the mildly favorable response for the CBE, mode 7; FDB-Multiple-Vosyn, mode 2; and TAB-Multiple-Vosyn mode 4; and the unfavorable response toward the FDB-Multiple-Voice mode 1 and TAB-Multiple-Voice mode 3. The significance of the percentage effect can be attributed to the generally lower grades at 50 percent that are caused by the operational difficulties when handling equal numbers of voice and data link aircraft.

TABLE 22. AVERAGE CONTROL ASPECTS, POSTEXPERIMENT QUESTION A-1.B

	TEST MODE						
20-Percent Data Link	1	2	3	4	5	6	7
Workload	1.00	0.33	-0.33	1.00	0.33	1.67	1.00
Traffic-Handling Capability	0.33	0.33	0.33	0.67	0.67	1.67	0.67
Susceptibility to Blunders	0.33	-0.33	0.33	0.33	0.67	1.00	1.00
Stressfulness	0.33	0.00	0.33	0.33	0.67	1.00	1.33
AVERAGE	0.50	0.08	0.17	0.58	0.58	1.33	1.00
50-Percent Data Link							
Workload	-0.14	0.28	-0.42	0.57	0.28	1.00	0.57
Traffic-Handling Capability	-0.28	0.28	0.00	0.00	0.28	0.28	-0.28
Susceptibility to Blunders	-0.42	0.28	-0.42	-0.42	-0.57	0.28	-0.42
Stressfulness	-0.28	0.28	-0.57	0.28	0.14	0.28	-0.42
AVERAGE	-0.28	0.28	-0.35	0.10	-0.03	0.46	-0.03
80-Percent Data Link							
Workload	-0.33	1.00	0.33	1.00	1.00	1.33	1.33
Traffic-Handling Capability	0.00	0.67	0.33	0.33	1.00	0.33	0.67
Susceptibility to Blunders	-0.67	-0.33	-0.67	-0.33	0.00	-0.67	0.00
Stressfulness	0.33	1.00	0.00	0.33	1.00	0.33	1.00
AVERAGE	-0.17	0.58	0.00	0.83	0.75	0.33	0.75
GRAND AVERAGE	-0.03	0.10	-0.05	0.09	0.10	0.21	0.13

+ = favorable - = unfavorable

When the responses to this question were combined with the responses to question 5 of the opinionnaire, the same significance was obtained for the percentage and mode effects, however, the differences between the pre- and post-testing responses were not significantly different. This means that while the opinionnaire responses did not show the same strong trend and/or preferences as the postexperiment responses, these differences between the two sets of responses are not statistically meaningful.

A-2. A. Relative to the question you have just answered, if ALL of the aircraft in the scenario had been equipped with a digital data link, how would this mode compare to present-day ARTS procedures:

a. (+2) - Much more favorably _____
b. (+1) - More favorably _____
c. (0) - About the same _____
d. (-1) - Less favorably _____
e. (-2) - Much less favorably _____

Based on scores indicated in parentheses, the following results were obtained:

DATA LINK				MODE				
Percent	1	2	3	4	5	6	7	Average
20	1.67	.67	.67	1.00	1.33	1.67	1.33	1.19
50	.71	1.00	.43	1.00	1.00	1.29	.57	.85
80	.33	1.33	.33	1.00	1.33	.67	1.33	.90
Average	.85	1.00	.46	1.00	1.15	1.23	1.08	.95

These results show a strong favorable response toward a total data link communications environment that is consistent for all modes. For this overall ranking, no single mode seems to dominate for all percentage levels. When compared to question A-1A., the total scores show an improvement in every mode, indicating that the controllers feel even more favorably toward data link when it would be the sole means of transmitting routine commands.

A-2. B. For the above, what ratings would you give for the following aspects:

Aspect	*Greatly Decrease*	*Decrease*	*Will Not Change*	*Increase*	*Greatly Increase*
Workload	*(+2)*	*(+1)*	*(0)*	*(-1)*	*(-2)*
Traffic-Handling Capacity	*(-2)*	*(-1)*	*(0)*	*(+1)*	*(+2)*
Susceptibility to Blunders	*(+2)*	*(+1)*	*(0)*	*(-1)*	*(-2)*
Stressfulness	*(+2)*	*(+1)*	*(0)*	*(-1)*	*(-2)*

Averaging the individual responses weighted by the scores in parentheses gives the results shown in table 23. Except for the four items circled, the subject controllers graded the 100-percent data link environment at least as favorably as the test environment, substantiating that the controllers are more favorably inclined toward data link when it would be the sole communications medium.

THE NEXT THREE QUESTIONS (B-1 THROUGH B-3) WERE CONCERNED WITH THE CONTROLLER'S ATTITUDE TOWARD HIS PREPARATION FOR AND PERFORMANCE DURING THE TEST RUN.

B-1. Now that you have been tested in this mode, do you feel that additional training and familiarization would have:

a. Improved your performance greatly (2%)
b. Improved your performance somewhat (16%)
c. Not affected your performance (82%)

This question was only given for the 50-percent data link runs and the results are indicated in parentheses next to the responses. For the 20-percent and 80-percent data link test series, this question was rephrased to provide additional information.

B-1. Now that you have been tested in this mode, how much more training time do you think you would need to feel comfortable with the procedures:

1. One hour (54%)
2. Three hours (28%)
3. Five hours (15%)
4. Ten hours (3%)

When these results are combined with those for 50-percent data link level, it can be inferred that no more than 1 to 3 hours of additional training would have been required to make the controllers completely comfortable with the test procedures.

B-2. Rank those aspects of the test run that gave you the most trouble (where the aspect giving the most trouble is numbered 1):

a. The traffic load _____
b. The mix of data and voice link aircraft _____
c. Exception cases (link fails, unables, repeat requests, etc.)__
d. M&S algorithm _____ (deleted from 20 and 80 percent series)
e. The display format and controller I/O procedures _____
f. Tag overlaps _____
g. Maintaining safe separations _____
h. Disengagement of conflicting aircraft _____
i. Trackball operations _____

TABLE 23. AVERAGE CONTROL ASPECTS-POSTEXPERIMENT QUESTION A-2.B

	TEST MODE						
20-Percent Data Link	1	2	3	4	5	6	7
Workload	1.67	1.00	1.00	1.00	1.33	1.67	1.67
Traffic Handling Capacity	1.00	0.33	0.33	0.67	0.67	1.67	1.00
Susceptibility to Blunders	0.33	0.33	0.33	0.33	1.00	1.00	1.33
Stressfulness	1.00	0.33	0.33	0.33	0.67	1.00	1.33
AVERAGE	1.00	0.50	0.50	0.58	0.67	1.33	1.33
50-Percent Data Link							
Workload	-0.14	-0.27	-0.42	0.57	0.28	1.00	0.57
Traffic-Handling Capacity	-0.28	0.28	0.00	0.00	0.28	0.28	0.28
Susceptibility to Blunders	-0.42	0.28	-0.42	-0.42	-0.57	0.28	0.42
Stressfulness	-0.28	0.28	-0.57	0.28	-0.14	0.28	0.00
AVERAGE	-0.28	0.14	-0.35	0.10	-0.03	0.46	0.32
80-Percent Data Link							
Workload	0.33	0.00	0.33	1.00	1.00	1.00	1.67
Traffic-Handling Capacity	0.33	0.67	0.33	0.33	1.00	0.33	1.00
Susceptibility to Blunders	-0.67	-0.33	-1.00	-0.33	0.00	-0.33	0.00
Stressfulness	0.33	1.00	0.00	0.33	1.00	0.67	1.33
AVERAGE	0.08	0.33	-0.08	0.33	0.75	0.42	1.00
GRAND AVERAGE	0.03	0.09	-0.03	0.09	0.10	0.22	0.24

+ = favorable
- = unfavorable

The results of this question are shown in table 24 where the actual ranks for each aspect were normalized for number of controllers voting and weighed as follows:

Rank	Weight
1	4
2	3
3	2
4	1
5 or Greater	

Clearly, the exception cases were the most troublesome, especially in the Vosyn modes where these cases were the only voiced commands and, therefore, more obvious. This was particularly true for the TAB-Multiple-Vosyn (mode 4) where the controller had the additional difficulty of identifying the aircraft due to the lack of an aircraft correlation symbol. Four other aspects were somewhat troublesome in the following circumstances. Parenthetical remarks are inferences drawn from the data:

1. The mixed communications environment with both voice and data link channels was more troublesome in the voice modes (because a single DISPATCH key could not be used).

2. Disengagements of conflicting aircraft were troublesome in the TAB modes (due to concentration on the disengaged aircraft, distracting attention from the TAB list) and CBE (due to the need to HALT the Vosyn for every subsequent command to the disengaged aircraft).

3. The display formats and I/O procedures were more troublesome in Voice and CBE, especially in the MULTIPLE Voice modes.

4. Trackball operations were troublesome in the MULTIPLE modes, especially when the FDB was used (since required trackball motion was greater).

Of the other aspects, the traffic load was only slightly troublesome, and maintaining safe separation and tag overlap were not considered bothersome.

When the above responses were compared to those in the preexperiment questionnaire, the results are almost identical except that the controllers felt much less concerned about traffic load after they had completed their test run.

B-3. At the end of the test run just concluded, did you feel that:

a. The aircraft load was relatively easy to handle (52%)
b. You could only control a small number of additional aircraft safely (11%)

TABLE 24. REDUCTION OF TROUBLESOME ASPECT DATA

ASPECT	PERCENT DATA LINK LEVEL	MODES 1	2	3	4	5	6	7	Total	COMMENT
Traffic Load	20	1.33	0.00	0.00	0.00	1.33	1.33	0.00	4.00	FDB somewhat worse.
	50	1.44	0.87	0.42	0.57	0.57	0.57	1.00	5.44	CBE somewhat better.
	80	0.00	1.33	1.00	1.00	0.00	0.00	0.00	3.33	
Total		2.75	2.20	1.42	1.57	1.90	1.90	1.00	12.77	
Mixed Communica-	20	1.00	0.33	1.33	0.00	1.00	0.00	0.67	4.33	Voice worse.
tions Environment	50	1.42	0.00	0.87	0.28	1.00	0.00	0.42	4.00	
	80	2.67	2.33	1.67	0.00	3.67	1.00	1.00	12.34	
Total		5.90	2.67	3.87	0.28	5.67	1.00	2.09	20.67	
Exception	20	0.67	3.33	1.00	3.67	1.00	1.00	2.67	13.34	Vosyn worse.
	50	1.14	0.87	0.51	1.72	1.00	1.00	1.28	8.98	TAB-Multiple-Vosyn
	80	1.00	2.00	2.00	4.00	1.33	4.00	2.00	16.33	Worst.
Total		2.81	6.20	3.57	9.39	3.33	6.00	5.95	38.64	
M&S Algorithm	20	dropped								
	50	0.28	0.28	0.42	0.57	0.42	0.42	0.00	2.39	
	80	dropped								
Display Format	20	1.33	1.00	2.67	0.67	0.67	0.00	0.67	7.01	Voice worse.
And I.O Procedures	50	.042	-	1.72	0.42	0.57	0.00	1.14	4.27	Multiple worse.
	80	2.33	1.67	1.67	0.00	0.00	0.00	1.33	7.00	CBE bad.
Total		4.08	2.67	6.06	1.09	1.24	0.00	3.14	18.28	
Tag Overlaps	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	50	0.00	0.57	0.00	0.00	0.00	0.00	0.00	0.57	FDB only.
	80	1.00	0.67	0.00	0.00	0.00	0.00	0.00	1.67	
Total		1.00	1.24	0.00	0.00	0.00	0.00	0.00	2.24	
Maintaining Safe	20	0.00	0.00	0.00	0.00	0.33	0.33	0.00	0.67	No notable
Separation	50	0.28	0.42	0.87	0.00	0.00	0.57	0.57	2.71	difference.
	80	0.00	0.33	0.00	1.00	1.67	0.00	0.00	3.00	
Total		0.28	0.75	0.87	1.00	2.00	0.90	0.57	6.38	
Disengagements	20	0.67	0.00	2.67	1.33	2.67	2.00	2.33	11.67	TAB worse.
	50	0.00	0.57	0.42	0.42	0.87	1.00	0.00	3.28	CBE worse
	80	0.00	1.00	1.00	1.00	0.00	1.00	1.33	5.33	
Total		0.67	1.57	4.09	2.57	3.54	4.00	3.67	20.28	
Trackball	20	1.33	3.33	1.00	0.00	0.00	0.00	1.00	6.67	Multiple worse.
Operations	50	2.28	2.14	1.00	2.00	0.00	0.42	0.00	6.84	FDB worse.
	80	1.33	0.00	1.67	0.00	0.33	0.00	0.00	3.33	
Total		4.94	5.47	3.67	2.00	0.33	0.42	1.00	16.84	

c. You were operating at your maximum capacity *(22%)*
d. You were somewhat overloaded *14%)*
e. You were badly overloaded *(2%)*

Slightly over half (52%) of the controllers found the traffic relatively easily handled, 33% were operating at or near their maximum capacity, while only 16% felt that they were somewhat overloaded.

THE REMAINING B QUESTIONS WERE DESIGNED TO ASCERTAIN THE CONTROLLERS OPINION OF CERTAIN ENGINEERING OR OPERATIONAL CHARACTERISTICS OF THE EXPERIMENT.

B-4. Considering that link failures and unables are exception cases and, as such, generally are more time-consuming, do you feel that an excessive amount of time or effort is required to resolve these exception cases?

Yes *(6.5%)* *No* *(93.5%)*

Overall, only 6.5% of the controllers felt that the exception cases required an excessive amount of time to resolve. However, for FDB-Multiple-Voice, 30.7% of the controllers were bothered by the time to resolve exception cases. The particular concern about the FDB-Multiple-Voice mode disagrees with the responses to Question B-2 where that mode is identified as troublesome least often.

B-5. The WILCO acknowledgement (W) symbol was displayed nonblinking for 3 seconds after the receipt of the WILCO. Do you feel that time should be:

a. Lengthened *(8.8%)*
b. Remain the same *(82.4%)*
c. Shortened *(8.8%)*

A large majority (82.4%) of the controllers felt that the 3-second WILCO display was adequate; 8.8% felt it should be increased, and 8.8% felt it should be decreased.

B-6. Was the display of the WILCO (W) acknowledgment symbol necessary or would the erasure of the command be an adequate indicator of successful dispatch. (Please check one.)

a. The WILCO symbol was required *(38.5%)*
b. Erasure would be adequate *(61.5%)*

The response to B-6 was somewhat mixed. Over one-third (38.5%) of the controllers indicated that the WILCO symbol was required while 61.5% indicated that an erasure of the command was sufficient to indicate acknowledgment.

B-7. *Commands to all voice link aircraft remain displayed for 20 seconds after acknowledgment of successful dispatch (ADVANCE). Should that time be:*

a. *Lengthened* *(0%)*
b. *Remain the same* *(81.4%)*
c. *Shortened* *18.6%)*

The majority of the controllers (81.4 percent) felt the 20-second display of voice link commands was adequate, and 18.6 percent felt it should be shortened. No controllers felt it should be lengthened.

B-8. *Envision the following situation: Computer-aided metering and spacing with data link suddenly becomes inoperative during the peak load of this test. However, you still have the current ARTS III display and procedures. In your opinion:*

a. *Could you continue operations indefinitely at the same traffic level?* *Yes* *(40%)* *No* *(60%)*

b. *Could you land all the aircraft under your control safely if no further handoffs were accepted?* *Yes* *(89%)* *No* *(11%)*

c. *If no further handoffs were accepted, could you clear the terminal areas of traffic safely?* *Yes* *(91%)* *No* *(9%)*

d. *A hazardous and unpredictable situation would exist.* *Yes* *(16%)* *No* *(84%)*

Two-fifths of the controllers felt they could continue operating indefinitely; a large majority (approximately 90 percent) felt that they could either land or safely clear the aircraft in the system if no further handoffs were accepted. Only 16 percent felt a hazardous situation would exist.

B-9. *Envision the following situation: Computer-aided metering and spacing with data link AND the ARTS III data block suddenly becomes inoperative during the peak load of this test. You would be left with only the primary radar targets. If you had the current capability to see a list of your targets and to request squawk ID:*

a. *Could you continue operations indefinitely at the same traffic level?* *Yes* *(2%)* *No* *(98%)*

b. *Could you land all the aircraft under your control safely if no further handoffs were accepted?* *Yes* *(46%)* *No* *(54%)*

c. *If no further handoffs were accepted, could you clear the terminal area of traffic safely?* *Yes* *(52%)* *No* *(48%)*

d. *A hazardous and unpredictable situation would exist.* *Yes* *(82%)* *No* *(18%)*

This situation represents a worse degradation than pictured in B-8. The results are consistent with that relationship. The percentage of controllers that feel they could operate indefinitely drops from 40 percent to 2 percent. The percentage of controllers that feel they could clear their area safely if no further handoffs were accepted either by landing the aircraft or clearing them back to the enroute feeder fix drops from approximately 90 percent to approximately 50 percent. The percentage of controllers that feel a hazardous situation would exist climbs from 16 percent to 82 percent.

B-10. Did the fact that the handoff procedure was different from the procedure for dispatching commands cause difficulties:
Yes (8%) No (92%)

Over 90 percent of the subjects indicated that the handoff procedures did not cause difficulties.

B-11. Were any of the characters, symbols, or actions employed in this mode particularly difficult to interpret:
Yes (14%) No (86%)

A large majority (86.8 percent) of the controllers had no difficulty with any of the characters, symbols or function key actions. Of the 13 responses indicating problems, most (7 cases) had some difficulty with the (*) symbol chosen to indicate that the aircraft was data link-equipped. These problems included not being noticeable or obvious, being confused with symbol (X), and not changing when the aircraft was disengaged. The second most frequent problem (2 cases) was inability to detect the F or U symbols for the exception cases. The other responses included a request for some visual indication (e.g., a lighted button) of the status of the Vosyn HALT button and finally a comment on the difficulty in distinguishing a "6" from an "8".

B-12. Did you find that the priorities given to exception cases and commands near the inner fix agreed with your picture of the situation? Yes (98%) No (2%)

This question was only given to the 50-percent data link series subjects and they experienced considerable difficulty in interpreting it. Of the 45 responses received (4 did not answer), a large majority of 43, or 98 percnet agreed with the priority system.

B-13. Were you able to evaluate each command carefully before you dispatched it via the data link?

a. Almost always (35%)
b. In a majority of cases (42%)
c. About half the time (17%)
d. In a minority of cases (5%)
e. Rarely (1%)

The results of this question are shown in parentheses next to the responses. As can be seen, a high percentage (77 percent) of the controllers stated that they evaluated each command in at least the majority of cases.

B-14. Were you able to maintain cognizance of the overall traffic situation and monitor it for potential conflicts even while transmitting commands at the maximum rate? Yes (80%) No (20%)

This question was administered only during the 50-percent series. For that series, 80 percent of the controllers felt they were maintaining cognizance of the traffic situation. For the 20-percent and 80-percent data link series to obtain a wider range of responses a new question was submitted.

The responses to this question were investigated to see if the individual controllers exhibited any pattern to their answers as the number of runs they had made were increased. Based on visual inspection, no trend was evident.

B-14. Were you able to maintain the "picture" of the overall traffic situation and monitor it for potential conflicts even while transmitting commands at the maximum rate?

a. Almost always (38%)
b. In a majority of cases (47%)
c. About half the time (9%)
d. In a minority of cases (5%)
e. Rarely (2%)

For this version of the question, 86 percent of the subjects responded that they could maintain the picture in at least a majority of the cases. The actual percentages are listed in parentheses next to the responses.

B-15. In connection with the merging operation at the inner fix, how often were you in doubt about whether approaching aircraft were safely spaced?

a. Frequently (5%)
b. Occasionally (52%)
c. Rarely (32%)
d. Never (11%)

The percentage of controllers checking each response is listed next to the response. Over half (57 percent) of the controllers had occasional difficulty with inner fix operations.

B-16. Do you consider the use of three altitude slots at the Roggen feeder fix and the possibility of near-simultaneous arrivals?

a. Unacceptable: a potential source of serious difficulties (0%)
b. Marginal: a source of frequent confusion in correlating commands with specific aircraft (2%)
c. Acceptable, but increases workload somewhat (20%)
d. No problem (78%)

The percentage of controllers checking each response is listed in parentheses next to the response. 98 percent of the controllers found the use of three altitude slots at Roggen acceptable.

B-17. How do you rate your confidence in being able to detect and resolve any conflicts that might occur while using this mode?

a. Extremely high (18%)
b. High (45%)
c. Moderate (26%)
d. Low (11%)
e. Very pessimistic (0%)

Over 60 percent of the subjects rated their ability to detect and resolve conflicts as either high or very high. Only 11 percent felt that their ability was below average. There were no significant mode differences for this question. The responses to this question were also checked for a time or experience effect. Based on visual examination, no pattern trend was observed.

B-18. Was the scenario and simulation realistic enough for the purposes of the skeleton test series? Yes (100%) No (0%)

In the above form, this question was used only in the 50-percent series where 100 percent of the controllers felt the simulation and scenario were sufficiently realistic. To obtain a wider spectrum of responses, this question was reworded for the 20-percent and 80-percent data link series.

B-18. How would you rate the realism of the scenario and simulation?

a. Acceptable as is (43%)
b. Adequate, with minor problems (57%)
c. Poor, with major problems (0%)
d. Totally inadequate (0%)

In this form, 100 percent of the controllers felt that the realism was acceptable (43 percent) or adequate with minor problems (57 percent).

QUESTION C-1 THROUGH C-3 PERTAIN TO THE USE OF VOSYN AND WERE GIVEN IN VOSYN MODES ONLY.

C-1. Did you find any of the following aspects of the voice synthesizer bothersome?

a. Intelligibility (12%)
b. Voice quality (15%)
c. Talking rate (8%)
d. Inability to repeat commands (33%)
e. Interference with your own extemporaneous messages (8%)

The percentage of times controllers checked each response is given in parentheses next to the response. The inablility to repeat commands was by far the most bothersome aspect of the Vosyn for one-third of the responses. Intelligibility, voice quality, talking rate and interference were generally not considered bothersome (less than 25% = not bothersome).

C-2. Do you find the dispatching and monitoring of Vosyn commands less tiring than voicing the commands yourself? Yes (81%) No (19%)

A large majority (81 percent) of the controllers felt that the Vosyn was less tiring.

C-3. Did you listen to the Vosyn deliver its message and to the pilot's reply before shifting your attention to the next command?

a. Almost always _____
b. In a majority of cases _____
c. About half the time _____
d. In a minority of cases _____
e. Rarely _____

The responses to question C-3 are given in table 25. The percentage and mode effects were tested using BMD11V. The percentage effect was not significant while the mode effect was significant at the .90 level. The differences between the modes can be seen by examining the averages across the three percentages. Those totals indicate certain operational differences between the CBE, TAB, and FDB modes. Assuming that a response of "almost always" means approximately 95 percent of the time, "in a majority of cases" means 75 percent, "about half the time" means 50 percent, "in a minority of cases" means 25 percent, and "rarely" means 5 percent, then an average percentage can be computed. Using these assumptions, for the CBE mode, the controllers listened to the Vosyn deliver its message and to the pilots reply before going on to the next command approximately 89 percent of the time; for the TAB modes, 73 percent, and for the FDB mode, 60 percent.

TABLE 25. DATA LINK PERCENTAGE RESPONSES TO QUESTION C-3

RESPONSE	PERCENTAGE	Mode 2	Mode 4	Mode 6	Mode 7	Average
Almost always	20	.33	.33	.67	1.00	.58
	50	.28	.43	.43	.43	.41
	80	.67	.00	.00	.33	.25
	Average	.38	.31	.42	.59	.41
In a majority of cases	20	.33	.33	.33	.00	.25
	50	.14	.43	.23	.57	.37
	80	.33	.67	1.00	.28	.67
	Average	.23	.46	.50	.46	.41
About half the time	20	.00	.33	.00	.00	.08
	50	.00	.00	.00	.00	.00
	80	.00	.33	.00	.00	.08
	Average	.00	.15	.00	.00	.04
In a minority of cases	20	.33	.00	.00	.00	.08
	50	.67	.14	.14	.00	.15
	80	.00	.00	.00	.00	.00
	Average	.23	.08	.08	.00	.10
Rarely	20	.00	.00	.00	.00	.00
	50	.28	.00	.00	.00	.07
	80	.00	.00	.00	.00	.00
	Average	.15	.00	.00	.00	.04

QUESTIONS C-4 THROUGH C-7 WERE DESIGNED TO CHECK ON ASPECTS OF THE FDB MODES.

C-4. Did the command line in the full data block increase display clutter to the point that your ability to control traffic was impaired? *Yes* *(5%)* *No* *(95%)*

Almost all (95 percent) of the controllers felt that the command line did not impair their ability to control traffic.

C-5. Did the command line in the full data block increase display clutter so as to require an excessive number of tag repositionings? *Yes* *(8%)* *No* *(92%)*

A large majority (92 percent) of the controllers felt that the command line did not cause an excessive number of tag repositionings.

C-6. Was the presentation and coding of the commands in the full data block easily interpreted? *Yes* *(97%)* *No* *(3%)*

Over 97 percent of the responses indicated that the M&S command in the third line was easily interpreted.

C-7. Did you have any difficulty in recognizing an unable (U) or a link fail (F) command to act on it in a sufficiently timely fashion? *Yes* *(10%)* *No* *(90%)*

90 percent of the subjects felt they were able to recognize these commands in a timely fashion.

QUESTIONS C-8 AND C-9 PERTAIN TO ASPECTS OF THE TAB MODES AND WERE GIVEN ONLY AFTER THOSE MODES WERE TESTED.

C-8. In the tabular list modes, the active commands are reordered as commands are dispatched or higher priority commands are generated. Did the use of the tabular list distract you from monitoring the flow of traffic for potentially conflicting or hazardous traffic? *Yes* *(43%)* *No* *(57%)*

This question was used only in the 50-percent data link series and it confuses the position and reordering of the list. For this question, 43 percent of the controllers felt the list was distracting. For the 20-percent and 80-percent data link series, this question was simplified to focus on the position of the list.

C-8. Did the position of the tabular list distract you from monitoring the flow of traffic for potentially conflicting or hazardous traffic? *Yes* *(17%)* *No* *(83%)*

For this version of the question, 17 percent of the controllers felt that they were distracted.

C-9. In the tabular list modes, the active commands in the list are reordered as commands are dispatched or higher priority commands are generated. Did the positioning of the lines in the tabular list annoy you?

a. Greatly (0%)
b. Somewhat (19%)
c. Very little (42%)
d. Not at all (39%)

As can be seen, more than 4 out of 5 (81 percent) controllers were minimally bothered by the repositioning of the lines in the tabular list.

QUESTION C-10 WAS SPECIFICALLY DESIGNED TO CHECK ON THE CORRELATION FEATURE OF THE TAB-SINGLE MODES.

C-10. Was it helpful to have the aircraft's position symbol blink in order to show the correlation of the active tabular list command with appropriate aircraft?

Yes (81%) *No (19%)*

Eighty-one percent of the controllers felt that the correlation feature was helpful.

QUESTIONS C-11 AND C-12 ARE APPLICABLE ONLY TO THE TAB-MULTIPLE MODES

C-11. Did you have any problem relating the command in the tabular list with the appropriate aircraft?

Yes (31%) *No (69%)*

Sixty-nine percent of the controllers had no difficulties relating the command in the TAB list to the aircraft.

C-12. Did you ever find it necessary to dispatch any command other than the bottom command of the list?

Yes (62%) *No (38%)*

Sixty-two percent of the controllers never found it necessary to dispatch a command other than the bottom one.

QUESTION C-13 PERTAINS ONLY TO THE MULTPLE COMMAND MODES.

C-13. When the number of commands waiting to be transmitted builds up, do you feel that it would be acceptable to dispatch several commands in rapid succession without evaluating each command?

Yes (59%) *No (41%)*

Fifty-nine percent of the subjects felt that transmitting commands without evaluation would be an acceptable technique in high-load situations.

QUESTIONS C-14 THROUGH C-21 PERTAIN ONLY TO THE CONTROL-BY-EXCEPTION MODE AND WERE INCLUDED IN THE QUESTIONNAIRE ONLY AFTER A RUN OF THAT MODE.

C-14. Were the provisions for halting and starting the voice synthesizer adequate for maintaining discipline on the voice channel?

Yes (100%) *No (0%)*

All the subjects felt the procedures were adequate.

C-15. Did you find it disconcerting not to have pre-transmission approval of issued commands?

Yes (57%) *No (43%)*

Fifty-seven percent of the controllers were bothered by the lack of pre-transmission approval.

C-16. Was the 3-second gap between Vosyn transmissions

a. Too long? (0%)
b. About right? (85%)
c. Too short? (15%)

Most of the controllers (85 percent) felt that the 3-second gap was just about right. The remaining 15 percent felt the time was too short.

C-17. Did you find it necessary to interrupt the Vosyn in the middle of a message?

a. Frequently (0%)
b. Occasionally (16%)
c. Rarely (38%)
d. Never (46%)

The percentage of controllers checking each response is given in parentheses next to the response. The majority of the controllers (84 percent) had to interrupt the Vosyn only rarely.

C-18. Do you feel that the low workload under control-by-exception might cause a controller to lose his concentration and, therefore, be less likely to detect a blunder or malfunction when it does occur?

Yes (43%) *No (57%)*

This question was used only for the 50 percent series where 43 percent of subjects felt that loss of concentration could effect performance. This question was dropped from the 20- and 80-percent data link series and four additional questions were added.

C-18. Envision the following situation: In an operational system, you would have the opportunity to review the command (it would be blinking) before it was automatically sent to the aircraft; you would also have a button to allow you to disapprove that command in the unusual circumstance that you felt the command was not operationally acceptable and you wanted to send your own. Compared to the operation you have just seen in CBE would this be:

a. Much more favorable (50%)
b. More favorable (50%)
c. About the same (0%)
d. Less favorable (0%)
e. Much less favorable (0%)

All of the six subjects responding felt that a disapproval option would be desirable as indicated by the results in parentheses next to the responses.

C-19. The control-by-exception mode is an attempt to relieve you of a communication task so that you can have more time to watch your traffic. Do you feel that the elimination of the task of pressing the dispatch button is:

a. A large improvement (67%)
b. A mild improvement (16%)
c. Insignificant (16%)
d. A mild detriment (0%)
e. A severe detriment (0%)

Five of the six controllers felt that the elimination of the dispatch button would be an improvement.

C-20. If you were provided with a disapprove option as discussed above as an addition to the CBE Mode, do you feel that would be:

a. A large improvement (67%)
b. A mild improvement (33%)
c. Insignificant (0%)
d. A mild detriment (0%)
e. A severe detriment (0%)

All of the controllers feel that the disapprove option would be an improvement to the CBE mode. These results substantiate the results of question C-18.

C-21. Given that you had a high traffic density for a prolonged period (more than 1 hour) would the automatic dispatch of commands provided you with be:

a. Very helpful (83%)
b. Somewhat helpful (0%)
c. About the same (0%)
d. Somewhat boring (17%)
e. Very boring (0%)

Five of the six subjects feel that automatic dispatch would be very helpful while only one felt it would be somewhat boring as shown above. However, since this characteristic could be both helpful and boring, these responses are somewhat meaningless.

THE D SERIES QUESTIONS WERE DESIGNED TO ASCERTAIN THE RELATIVE DESIRABILITY OF THE VARIOUS MODE OPTIONS (TAB VERSUS MULTIPLE, VOICE VERSUS VOSYN, AND CONTROL-BY-EXCEPTION VERSUS CONTROL-BY-APPROVAL). THESE QUESTIONS WERE INCLUDED IN THE QUESTIONNAIRE WHEN TWO SUCCESSIVE TESTS BY A SINGLE SUBJECT DIFFERED BY ONLY ONE OF THE CONTROL PARAMETERS. QUESTION D-1 AND D-2 PERTAIN TO THE TAB VERSUS FDB MODES.

D-1. The last two experiments in which you participated involved the use of the tabular list and the full data block modes. Based on your operational experience with those modes in the last two runs, how would you rate the tabular list mode with respect to the full data block mode for the following aspects:

		(+2)	(+1)	(0)	(-1)	(-2)	
	TABULAR LIST IS	Much More Desirable	More Desirable	About Equal to	Less Desirable	Much Less Desirable	
ASPECTS	Workload						THAN FDB
	Traffic-Handling Capacity						
	Susceptibility to Blunders						
	Stressfulness						

By using the scoring system shown in parentheses above each column the results can be tabulated as shown in table 26. The values presented in that table are the average scores for each data link percentage level. As can be seen in that table, FDB is preferred at the 20- and 50-percent, while TAB is preferred at the 80-percent data link mix. The sample size is too small to make a meaningful statement about the significance of this difference. However, in the overall total, there is a mild preference for FDB.

TABLE 26. REDUCED RESULTS OF QUESTION D-1

ASPECT	DATA LINK PERCENTAGE LEVEL			
	20	50	80	Average
Workload	.00	-.62	.00	-.42
Traffic-Handling Capability	.00	-.25	.00	-.17
Susceptibility to Blunders	-.50	-.37	1.00	-.17
Stressfulness	-.50	-.50	.00	-.42
Average	-.25	-.44	.25	-.24

+ = TAB List is more desirable
- = FDB is more desirable

D-2. Which of the two aspects of the full data block and tabular list caused most difficulty in monitoring the flow of traffic?

a. The additional clutter caused by having the commands in the third line of the full data block (27%), or
b. The distraction from the target position caused by using the tabular list (73%).

Seventy-three percent of the subjects felt that the distraction of the tabular list caused the most difficulty.

QUESTIONS D-3 AND D-4 PERTAIN TO THE SINGLE VERSUS MULTIPLE COMMAND MODES.

D-3. The last two experiments in which you participated involved the use of single and multiple generation of commands. Based on your operational experience with those two methods, how would you rate single command generation with respect to multiple command generation for the following aspects:

SINGLE COMMANDS ARE	(+2) Much More Desirable	(+1) More Desirable	(0) About Equal to	(-1) Less Desirable	(-2) Much Less Desirable
Workload					
Traffic-Handling Capacity					
Susceptibility to Blunders					
Stressfulness					

THAN MULTIPLE

Using the same scoring system shown in parentheses above each column, the results have been reduced, averaged, and are presented in table 27. As can be seen, the controllers prefer single commands at all percentage levels.

TABLE 27. REDUCED RESULTS OF QUESTION D-3

ASPECT	DATA LINK PERCENTAGE LEVEL			
	20	50	80	Average
Workload	1.50	.43	1.00	.73
Traffic-Handling Capability	.50	.00	.50	.18
Susceptibility to Blunders	.00	.42	-.50	.27
Stressfulness	.00	.28	.00	.18
Average	.50	.28	.25	.32

+ = Single Commands are preferable
- = Multiple Commands are preferable

D-4. In the multiple command modes, you had the ability to select any command from those available. However, at times there was more than one command to evaluate, and a trackball action may have been required. Was the additional time required to evaluate and indicate the multiple command worth the flexibility to choose the command you wish?

Yes (18%) *No (82%)*

Only 18 percent of the subjects felt that the ability to select the command was worth the bother of the trackball action.

QUESTIONS D-5 AND D-6 PERTAIN ONLY TO THE COMPARISON OF VOICE AND VOSYN MODES.

D-5. The last two experiments in which you participated involved the use of voice and the voice synthesizer (Vosyn) for transmitting commands over the voice channel. Based on your operational experience with those two methods, how would you rate voice transmission with respect to voice synthesizer transmission for the following aspects:

VOICE IS	(+2) Much More Desirable	(+1) More Desirable	(0) About Equal to	(-1) Less Desirable	(-2) Much Less Desirable	
Workload						THAN VOSYN
Traffic-Handling Capacity						
Susceptibility to Blunders						
Stressfulness						

Using the scoring system shown in parentheses, the results were reduced and averaged. The summary of that data is presented in table 28. Those results show a definite trend, with the controllers preferring Vosyn at the 20-percent (the mix at which voice link traffic is heaviest), indifferent at the 50-percent, and mildly preferring voice at the 80-percent data link level.

TABLE 28. REDUCED RESULTS OF QUESTION D-5

ASPECT	DATA LINK PERCENTAGE LEVEL			
	20	50	80	Average
Workload	-.33	-.18	.00	-.18
Traffic-Handling Capability	-.33	-.18	.33	-.12
Susceptibility to Blunders	-.67	.18	.67	.12
Stressfulness	-1.00	.00	.33	-.12
Average	- .58	-.04	.33	-.08

+ = Voice is preferable
- = Vosyn is preferable

QUESTION D-6 WAS ADDED FOR THE 20- AND 80-PERCENT TEST SERIES.

D-6. The voice synthesizer, although slower than most controller speech, may permit him to think about other parts of his job while it is speaking. Does this capability allow you to evaluate the next command while the voice synthesizer is speaking the previous one?

a. *Almost always (17%)*
b. *In a majority of cases (67%)*
c. *About half the time (0%)*
d. *In a minority of cases (17%)*
e. *Rarely (0%)*

The percentage of controllers selecting each response is given next to the response. All of the controllers felt that the Vosyn permits concurrent monitoring of the command being transmitted and evaluation of the next command. Eighty-four percent of the controllers felt that this technique could be employed most of the time.

The responses to this question somewhat contradict the responses to C-3. Over 80 percent of controllers stated that, in the majority of cases, they both listened to the Vosyn enunciate the command and evaluated the next command while the Vosyn was speaking.

QUESTION D-7 PERTAINS ONLY TO THE COMPARISON OF CONTROL-BY-EXCEPTION TO THE SIX CONTROL-BY-APPROVAL MODES.

D-7. *The last two experiments in which you participated involved your direct (conventional) control of traffic and control-by-exception (CBE). Based on your operational experience with those two methods, how would you rate conventional control with respect to control-by-exception for the following aspects:*

	(+2)	(+1)	(0)	(-1)	(-2)	
CONVENTIONAL CONTROL IS	Much More Desirable	More Desirable	About Equal to	Less Desirable	Much Less Desirable	
Workload						
Traffic-Handling Capacity						THAN CBE
Susceptibility to Blunders						
Stressfulness						

Table 29 gives the results of this question reduced by using the scoring system in parentheses and averaging by the number of subjects. That table shows that opinion on this issue is somewhat mixed. For the 20-percent mix, CBE is mildly preferred; at the 50-percent mix, it's almost equal, while at 80-percent data link mix there is a strong preference for CBE. The overall average response slightly favors CBE.

TABLE 29. REDUCED RESULTS OF QUESTION D-7

ASPECT	DATA LINK PERCENTAGE LEVEL			
	20	50	80	Average
Workload	-.33	-.09	-1.00	-.58
Traffic-Handling Capability	-.33	.00	- .75	-.21
Susceptibility to Blunders	-.33	.27	- .25	.05
Stressfulness	.00	.18	-.75	-.05
Average	-.25	.09	-.69	-.13

+ = Conventional Control is preferable
- = Control-By-Exception is preferable

SUMMARY QUESTIONNAIRE

THE SUMMARY QUESTIONNAIRE WAS GIVEN TO EACH SUBJECT AFTER HE HAD COMPLETED ALL TEST MODES. THE QUESTIONS WERE DESIGNED TO OBTAIN HIS IMPRESSIONS OF ALL MODES.

1. *Please rank (1 indicates the most preferred, 2 the next most preferred, etc.) every one of the 7 modes you worked for each characteristic:*

	Overall	Workload	Capacity	Susceptibility to Blunders	Stress-fulness
1. Full-Data Block-Multiple Command-VOICE					
2. Full Data Block-Multiple Command-VOSYN					
3. Tabular List-Multiple Command-VOICE					
4. Tabular List-Multiple Command-VOSYN					
5. Tabular List-Single Command-VOICE					
6. Tabular List-Single Command-VOSYN					
7. Control-by-Exception					

The source data were analyzed using standard analysis of variance and non-parametric (Friedman) techniques to test that the overall rankings were different. The results were mildly significant (i.e., in the 85- to 90-percent region) indicating that the conclusions drawn are statistically meaningful. In weighing responses, modes rated as equal by a subject are all assigned the average rank of the position they occupy collectively. For example, if three modes are rated equal and they collectively occupy rank positions 4, 5, and 6, they are all assigned the average rank index of 5.

In both the 20- and 80-percent data link tests, seven controllers ranked three modes each; hence, every mode received only three rankings. The best score a given mode could get was three 1's; the worst score was three 3's. Therefore, to convert the 20- and 80-percent data link rankings to an equivalent rank index on a scale of seven, the following transformation is used:

Rank Index = Sum of three rankings minus 2

The rank index for the 50-percent mix tests is simply the sum of the seven rankings for a given mode divided by seven.

In the tests having 50 percent of the aircraft equipped with data link, seven controllers ranked all seven modes; hence, a total of (6+5+ ... +1)7=147 separate decisions are incorporated in the 50-percent data link mix rankings. In the tests having 20 percent of the aircraft equipped with data link, seven controllers ranked only three modes each, so a total of (2+1)7=21 separate decisions were made. The same number of decisions (21) were involved in the ranking process for the 80-percent mix. In effect, there is seven times more information (147÷21) incorporated in the 50-percent mix rankings than there is in the 20- and 80-percent mix rankings. For this reason, in computing the overall rank index for each mode in the table, the 50-percent mix index is multiplied by a weighting factor of seven:

Overall Rank Index=(20% Rank Index)+7(50% Rank Index)+(80% Rank Index) ÷9

The overall rank index for every mode is a measure of relative merit, and these indices are given in table 30 in order for each criterion (workload, capacity, susceptibility to blunders, stress, and overall performance).

2. **Please** *check any of the modes you worked which you feel provides either TOO MUCH or TOO LITTLE information to adequately and rapidly communicate in the intended aircraft.*

		TOO MUCH	*TOO LITTLE*
A.	*Full Data Block - Multiple Command - Voice*	_____	*(1)*
B.	*Full Data Block - Multiple Command - Vosyn*	_____	*(2)*
C.	*Tabular List - Multiple Command - Voice*	_____	*(5)*
D.	*Tabular List - Multiple Command - Vosyn*	_____	*(2)*
E.	*Tabular List - Single Command - Voice*	_____	*(2)*
F.	*Tabular List - Single Command - Vosyn*	_____	*(2)*
G.	*Control-By-Exception*	_____	*(2)*

TABLE 30. RESULTS OF SUMMARY RANKING QUESTION

Summary Questionnaire Ranking

Criteria	Mode	20% Subjects A	B	C	D	E	F	G	20% Rank Index	50% Subjects A	B	C	D	E	F	G	50% Rank Index	80% Subjects A	B	C	D	E	F	G	80% Rank Index	Overall Rank Index	Rank
	1.	1	3		3				5	1.5	6.5	3	3	4	7	7	4.57	3		3		3			7	4.89	6
	2.	3				1		3	5	1.5	1.5	1.5	2	1	4	6	2.50	2	3					2	5	3.06	2
Workload	3.				2	2	3		5	7	6.5	5.5	6	5	6	5	5.86		2	2	3				5	5.67	7
	4.	2		2			2		4	6	3.5	5.5	4	6	3	3	4.43	1			2		3		4	4.33	4
	5.		2	3		3			6	5	5	5.5	7	3	5	2	4.64		1			1	2		2	4.50	5
	6.		1				1	1	1	4	3.5	5.5	5	2	2	1	3.29				1	2		3	4	3.11	3
	7.			1	1			2	2	3	1.5	1.5	1	7	1	4	2.71			1			1	1	1	2.44	1
	1.	1	3		2				4	1.5	6.5	3	4	4	4	6	4.14	2		1.5		3			4.5	4.17	5
	2.	3				2		3	6	1.5	1.5	1.5	4	3	4	4	2.79	2	3					1	4	3.28	2
Capacity	3.				2	2	3		5	7	6.5	5.5	4	5	4	5	5.29		2	1.5	3				4.5	5.17	7
	4.	2		2			2		4	6	4	5.5	4	6	4	3	4.64	2			2		3		5	4.61	6
	5.		2	3		2			5	5	5	5.5	4	2	4	2	3.93		1			1	2		2	3.83	3
	6.		1				1	1	1	4	3	5.5	4	1	4	1	3.21				1	2		3	4	3.06	1
	7.			1	2			2	3	3	1.5	1.5	4	7	4	7	4.00			3			1	2	4	3.89	4
	1.	1	1		2				2	7	1.5	5	5	4	6	4	4.64	2		3		3			6	4.50	7
	2.	3				2		3	6	2	1.5	6	1	4	5	4	3.36	3	3					1.5	5.5	3.89	2
Blunders	3.				3	2	3		6	6	5.5	2	2	4	4	4	3.93		2	2	1				3	4.06	4
	4.	2		2			2		4	4.5	5.5	4	6	4	3	4	4.43	1			2		3		4	4.33	6
	5.		2	3		2			5	2	5.5	1	3	4	2	4	3.07		1			1	2		2	3.17	1
	6.		3				1	1	3	4.5	5.5	3	4	4	1	4	3.71				3	2		3	6	3.89	3
	7.			1	1			2	2	2	3	7	7	4	7	4	4.86			1			1	1.5	1.5	4.17	5
	1.	1	1		2				2	1.5	7	3	5	5	4	7	4.64	2		2.5		3			5.5	4.44	5
	2.	3				2		3	6	1.5	1.5	1.5	6	1	4	4	2.79	2	3					1	4	3.28	1
Stress	3.				3	2	3		6	7	6	5.5	2	2	4	6	4.64		2	2.5	1				3.5	4.67	7
	4.	2		2			2		4	6	4	5.5	4	6	4	3	4.64	2			2		3		5	4.61	6
	5.		2	3		2			5	5	5	5.5	1	3	4	2	3.64		1			1	2		2	3.61	2
	6.		3				1	1	3	4	3	5.5	3	4	4	1	3.50				3	2		3	6	3.72	4
	7.			1	1			2	2	3	1.5	1.5	7	7	4	5	4.14			1			1	2	2	3.67	3
	1.	1	3		1				3	1.5	7	3	3	4	7	6	4.50	3		2		3			6	4.50	6
	2.	3				3		3	7	1.5	2	1	2	1	4	5	2.36	1	3					2	4	3.06	1
Overall	3.				3	2	3		6	7	6	5.5	6	5	6	4	5.64		2	1	3				4	5.50	7
	4.	2		2			2		4	6	3	5.5	4	6	3	3	4.36	2			2		3		5	4.39	5
	5.		2	3		1			4	5	5	5.5	7	3	5	2	4.64		1			1	2		2	4.28	4
	6.		1				1	1	1	4	4	5.5	5	2	1	1	4.64				1	2		3	4	4.17	3
	7.			1	2			2	3	3	1	2	1	7	2	7	3.29			3			1	1	3	3.22	2

Criteria	Mode	Overall Rank Index 20% Mix	20% Rank	Overall Rank Index 50% Mix	50% Rank	Overall Rank Index 80% Mix	80% Rank
Normalized	1	3.25	3	4.50	5	5.75	7
Summation	2	5.75	7	2.86	1	4.63	5
of Rank	3	5.50	6	4.93	7	4.00	3
Indices for	4	4.00	4	4.54	6	4.50	4
Workload,	5	5.25	5	3.82	3	2.00	1
Capacity,	6	2.00	1	3.43	2	5.00	6
Blunders and	7	2.25	2	3.93	4	2.13	2
stress							

3. *Please check any of the modes you worked which you feel was particularly bothersome to work with.*

A.	*Full Data Block - Multiple Command - Voice*	*(3)*
B.	*Full Data Block - Multiple Command - Vosyn*	*(5)*
C.	*Tabular List - Multiple Command - Voice*	*(9)*
D.	*Tabular List - Multiple Command - Vosyn*	*(3)*
E.	*Tabular List - Single Command - Voice*	*(3)*
F.	*Tabular List - Single Command - Vosyn*	*(2)*
G.	*Control-By-Exception*	*(2)*

There was considerable confusion about the above two questions and several controllers elected not to complete them. Of the responses obtained, the number of times each mode was checked out of the 13 possible times is given next to the mode. However, due to the poor phraseology of the questions, very little importance can be placed on the results.

4. *Assuming that some form of a metering and spacing already exists in all of the major airports, how do you feel that the addition of a data link will affect controller workload?*

CHECK ONE	(-2) Strongly Increase	(-1) Mildly Increase	(0) No Effect	(+1) Mildly Decrease	(+2) Strongly Decrease
A. Full-Data Block-Multiple Command-VOICE					
B. Full Data Block-Multiple Command-VOSYN					
C. Tabular List-Multiple Command-VOICE					
D. Tabular List-Multiple Command-VOSYN					
E. Tabular List-Single Command-VOICE					
F. Tabular List-Single Command-VOSYN					
G. Control-by-Exception					

The results of this question are shown in Table 31. The individual categories are combined using a weighting scheme to produce the total weight measure. Based on that measure, the TAB-Single-Vosyn mode (6) is obviously preferred, The CBE mode (7) is second and the TAB-Multiple-Vosyn (4) third. In the total or overall evaluation, the controllers had a mildly favorable opinion of data link across all modes.

COMBINED ANALYSIS OF TEST DATA AND QUESTIONNAIRES

Having discussed the experimental procedures employed in the test series, the experimental data collected, and the results of the statistical analysis, the next question concerns the implications of the accumulated evidence with respect to the main objectives of the program. It is worthwhile to restate these objectives in terms of the various alternatives that were to be compared against each other:

a. Comparison of Seven Modes

1. Full Data Block - Multiple Command - Voice
2. Full Data Block - Multiple Command - Vosyn
3. Tabular List - Multiple Command - Voice
4. Tabular List - Multiple Command - Vosyn
5. Tabular List - Single Command - Voice
6. Tabular List - Single Command - Vosyn
7. Control-By-Exception - Full Data Block - Vosyn

b. Comparison of Individual Mode Options

1. Full Data Block versus Tabular List
2. Single Commands versus Multiple Commands
3. Voice versus Voice Synthesizer (Vosyn)
4. Control-By-Approval versus Control-By-Exception

c. Comparison of Data Link and Voice Link

These comparative evaluations were to be carried out with traffic samples having 20, 50, and 80 percent of the aircraft equipped with data link. In addition, the instantaneous controller load varied with time, building up to a peak of about 11 aircraft during each run.

As discussed previously, the five principal experimental measures to be used in the evaluation of alternatives are:

1. Controller Opinion Questionnaires.

2. Time to execute equivalent functions. Five basic intervals are defined for each format on the time lines presented in appendix D. These are the Command Initiation Delay (CID), the Message Delivery Time (MDT), the

TABLE 31. RESULTS OF SUMMARY QUESTION 4

AVERAGE RESPONSES

MODE	DATA LINK PERCENTAGE	STRONGLY INCREASE WORKLOAD	MILDLY INCREASE WORKLOAD	NO EFFECT ON WORKLOAD	MILDLY DECREASE WORKLOAD	STRONGLY DECREASE WORKLOAD	TOTAL WEIGHT[1]
1. FDB,	20	0.00	0.00	0.00	0.67	0.33	1.33
Multiple,	50	0.14	0.14	0.00	0.57	0.14	0.43
Voice	80	0.00	0.33	0.33	0.33	0.00	1.33
Average		0.08	0.15	0.08	0.54	0.15	0.59
2. FDB,	20	0.33	0.33	0.00	0.33	0.00	-0.67
Multiple,	50	0.00	0.14	0.14	0.57	0.14	0.38
Vosyn	80	0.00	0.33	0.00	0.67	0.00	0.33
Average		0.08	0.23	0.08	0.54	0.08	0.23
3. TAB,	20	0.00	0.33	0.33	0.33	0.00	0.00
Multiple,	50	0.14	0.14	0.28	0.43	0.00	0.00
Voice	80	0.00	0.33	0.33	0.33	0.00	0.00
Average		0.08	0.23	0.33	0.28	0.00	0.00
4. TAB,	20	0.00	0.00	0.00	1.00	0.00	1.00
Multiple,	50	0.00	0.28	0.14	0.57	0.00	0.28
Vosyn	80	0.00	0.00	0.00	0.67	0.33	1.33
Average		0.00	0.15	0.08	0.69	0.08	0.62
5. TAB,	20	0.00	0.00	0.33	0.33	0.33	1.00
Single,	50	0.14	0.14	0.14	0.57	0.00	0.14
Voice	80	0.00	0.00	0.00	1.00	0.00	1.00
Average		0.08	0.08	0.15	0.62	0.08	0.46
6. TAB,	20	0.00	0.00	0.00	0.00	1.00	2.00
Single,	50	0.00	0.14	0.28	0.43	0.14	0.57
Vosyn	80	0.00	0.00	0.00	0.67	0,33	1.33
Average		0.00	0.08	0.15	0.38	0.38	1.08
7. CBE	20	0.00	0.00	0.00	0.67	0.33	1.33
	50	0.14	0.14	0.00	0.72	0.00	0.28
	80	0.00	0.00	0.00	0.33	0.67	1.67
Average		0.08	0.08	0.00	0.62	0.23	0.85

1 Total weight is the sum over the row of the average value in each cell times the column weight where: strongly increase = -2, mildly increase = -1, no effect = 0, mildly decrease = +1, and strongly decrease = +2. A positive total weight is therefore favorable and a negative unfavorable.

Pilot Response Time (PRT), the Message Transaction Time (MTT), and the Service Time (ST). The MTT will be the principal measure employed in the operational evaluation.

3. Queue behavior (messages waiting for data link or voice link service).

4. The dispersion of the errors in aircraft arrival times at the inner fix.

5. Counts of events such as conflicts, disengagements, tag repositionings, etc.

The approach in this section will be to individually discuss each of the comparative evaluations in turn: (1) the seven modes; (2) the mode options; and (3) data link versus voice link communications. In a given evaluation, all the evidence bearing on the particular question at hand will be introduced, drawing from the combined data base of questionnaire answers, experimental data, and the results of the statistical analyses.

COMPARISON OF THE SEVEN MODES.

There are a number of questionnaire items that provide evidence of controller preferences regarding the seven candidate modes. For example, question A.1.A on the postexperiment questionnaire asks, "How would you rate the displaying and dispatching of commands in this mode with the present-day ARTS procedures applied to the same scenario?"

The choice of replies is

a.	(+2)	Much more favorable
b.	(+1)	More favorable
c.	(0)	About the same
d.	(-1)	Less favorable
e.	(-2)	Much less favorable

By assigning the weights shown (+2, +1, ... -2) to every answer and summing results algebraically for all subjects who tested a given mode, an index of merit can be computed for each mode. The index is normalized by dividing it by the number of subjects who responded. These normalized or average indices can then be ranked to yield a quantitative measure of how the various modes compared on the basis of responses to this particular question. In assigning weights to various responses, a positive score is interpreted as favorable to the mode being evaluated and a negative score as unfavorable. The procedure can be generalized to encompass responses to any number of questions for matching sets of test parameters and subjects simply by adding every index pertaining to a given mode for all questions, and then dividing the sum by the total number of responses to obtain an overall normalized index. A similar index can be generated for each of the other candidate modes and these indices can be ranked as a measure of relative merit.

The main problem in evaluations of this type is in selecting the most meaningful components of the data base to use in the comparison. Questions A.1.A. and A.1.B. in the postexperiment questionnaire exhibited significant mode effects; hence, they will be used to generate an index of merit for each mode.

These questions and the subjects' choice of responses are given in the Subjective Data Analysis Section. Table 32 lists the components of the overall index of merit for each mode based on the weighted answers to the two questions selected. No significant effects between the three levels of data link-equipped traffic were detected on question A.1.A, so the 20-, 50-, and 80-percent data link mix data has been combined to produce one overall set of indices. The replies to question A.1.B. did exhibit a significant mix effect, so a separate set of indices were computed for each percentage mix. The workload, capacity, blunders, and stress components of the responses were combined, however, for this question. Modes having the same overall normalized index are all assigned the average rank of the position they occupy collectively. For example, if two modes have the same index, and they collectively occupy rank positions 4 and 5, they are both assigned the average rank of 4.5.

This subjective evaluation of the comparative merits of the various modes can be cross-checked by a more direct set of opinions. After completing all their runs, controllers were asked on the Summary Questionnaire to rank all the modes they had tested with respect to workload, capacity, susceptibility to blunders, stressfulness, and overall performance. The calculation of an overall rank index rank for each mode under these five criteria is summarized in table 28.

To get a measure of how the rankings change with the percentage mix, the rank indices for each mode in the workload, capacity, blunder, and stress categories are summed and normalized to yield separate rankings applicable to the 20-, 50-, and 80-percent mixes.

All ranking data presented thus far will now be examined in detail to extract information on

(a) Overall ratings,
(b) Ratings in each of the categories (workload, capacity, blunders, stress), and
(c) Variation of ratings with percentage mix.

First, the rankings obtained from question A.1.A. (comparison of modes with ARTS) and the overall rankings just obtained from the Summary Questionnaire are restated in order in table 33. In this table, a box is drawn around two modes having the same index, i.e., two modes that are of equal rank. The same convention will be used in subsequent tables. Since the summary question 1 represents a direct evaluation of the modes relative to each other and these responses were obtained after each subject had been exposed to all seven candidates, <u>this ranking will be regarded as the final consensus on the overall order of merit</u>.

TABLE 32. GENERATION OF AN INDEX OF MERIT AND RANK FOR EACH MODE BASED ON POSTEXPERIMENT QUESTIONS A.1.A. AND A.1.B.

Mode	MIX	Number of Subjects	Sum of Weighted Replies: A.1.A Mode vs. ARTS	Overall Normalized Index (Sums ÷ 13)	A.1.A Rank	Sum of Weighted Replies: A.1.B Mode vs. ARTS: Workload	Capacity	Blunders	Stress	Overall Normalized Index (Sums ÷ 12 or 28)	A.1.B. Rank: 20%	50%	80%
1. FDB-M-Voice	20%	3	2			3	1	1	1	.50	5		
	50%	7	2	.23	6	-1	-2	-4	-2	-.32		6	
	80%	3	-1			-1	0	-2	1	-.17			7
2. FDB-M-Vosyn	20%	3	0			1	1	-1	0	.08	7		
	50%	7	5	.62	4.5	2	2	1	1	.21		2	
	80%	3	3			3	2	-1	3	.58			3
3. TAB-M-Voice	20%	3	0			-1	1	1	1	.17	6		
	50%	7	-4	-.23	7	-3	0	-3	-4	-.36		7	
	80%	3	1			1	1	-2	0	.00			6
4. TAB-M-Vosyn	20%	3	3			3	2	1	1	.58	3.5		
	50%	7	4	.77	3	4	0	-3	2	.11		3	
	80%	3	3			3	1	-1	1	.33			4
5. TAB-S-Voice	20%	3	4			1	2	2	2	.58	3.5		
	50%	7	4	.85	2	2	2	-4	-1	-.04		5	
	80%	3	3			3	3	0	3	.75			1.5
6. TAB-S-Vosyn	20%	3	4			5	5	3	3	1.33	1		
	50%	7	8	1.15	1	7	3	3	3	.57		1	
	80%	3	3			4	-1	-2	1	.17			5
7. CBE	20%	3	2			3	2	3	4	1.00	2		
	50%	7	2	.62	4.5	4	-2	-2	1	.04		4	
	80%	3	4			4	2	0	3	.75			1.5

TABLE 33. SUMMARY TABLE OF OVERALL MODE RANKINGS

Rank	Question A.1.A Ranking	Summary Question 1	
		Overall Ranking	Mode Description
1	6	2	FDB-Multiple-Vosyn
2	5	7	Control-by-Exception
3	4	6	TAB-Single-Vosyn
4	2	5	TAB-Single-Voice
5	7	4	TAB--Multiple-Vosyn
6	1	1	FDB-Multiple-Voice
7	3	3	TAB-Multiple-Voice

The questionnaire responses analyzed in the previous section of the report indicate that the subject controllers favor full-data block over tabular list, single command over multiple command, and the Vosyn over voice. Unfortunately, the mode which combines all three preferred options (FDB-Single-Vosyn) was eliminated from the test program and cannot be ranked. Mode 2 (FDB-Multiple-Vosyn) and mode 6 (TAB-Single-Vosyn), however, both have two of the three preferred options and, along with control-by-exception, they rate as the top modes. Conversely, mode 3 (TAB-Multiple-Voice) has all three of the nonpreferred options, and it ranks at the bottom.

Prior to testing, controller reaction to the use of the voice synthesizer in an ATC environment was unknown. The results indicate not only acceptance of the Vosyn, but even a distinct preference for it when voice link traffic is heavy. Although the controller listens to the Vosyn deliver commands and to the pilot responses, he can look ahead to the next command while doing so. When he voices messages himself, the task occupies him fully and the net workload is greater. In the Vosyn modes, the controller employs the same key action to transmit both data link and voice link messages. In the voice modes, however, he must first ascertain whether a command is addressed to a data link or voice link aircraft, since the former requires DISPATCH (5) or DISPATCH-slew-ENTER (1,3), and the latter requires ADVANCE (5) or ADVANCE-slew-ENTER (1,3). This choice between two key actions also increases the relative workload of the voice modes (1,3,5) and, no doubt, contributed to their lower rankings.

The top ranking of mode 2 (FDB-Multiple-Vosyn) indicates a strong preference for full data block over tabular list. It achieved this rank despite the fact that the FDB format was combined with the multiple command option which

requires a trackball slew for each message dispatched or enunciated. The major advantage of FDB is that commands are displayed in each alphanumeric tag, close to the aircraft addressed. Correlation of the command and the aircraft's current situation is direct and quick. The tabular list format, on the other hand, splits the controller's attention between the list (where the commands appear) and the display of traffic movement itself. Mode 6 (TAB-Single-Vosyn) and mode 5 (TAB-Single-Voice) minimize the task of correlating commands in the list with the corresponding aircraft position by having the controller symbol, for a given aircraft, blink when a command addressed to that aircraft blinks. This feature is probably the principal reason that modes 6 and 5 rank higher than mode 4 (TAB-Multiple-Vosyn) and mode 3 (TAB-Multiple-Voice). Commands in the FDB format, of course, can be momentarily obscured by tag overlaps, although this problem was not a significant factor in the test series because tags were automatically oriented in prescribed locations in each stage of an approach to minimize overlaps.

All other factors being equal, the subjects would tend to favor customary procedures. In NAS and ARTS, the information utilized to control traffic is derived mostly from alphanumeric tags moving with the aircraft, and familiarity with this technique might bias controller judgements in favor of the FDB option. The subjects had no prior experience in using the Vosyn, however, so their affirmative attitudes toward it must be given additional weight.

Another interesting aspect of the ranking is the generally favorable controller reaction to control-by-exception. This mode ranked first with respect to workload and second overall, although several subjects expressed concern about its potential for blunders. Errors in judgement and execution would be more likely to occur, they felt, under conditions of sporadic activity, i.e., with the controller removed from the control loop for individual aircraft and acting solely as a monitor to detect and resolve occasional off-normal situations. The test observers believed that maintaining a "picture" would be difficult without the constant reinforcement provided by generating and enunciating commands. If the metering and spacing system failed and the controller had to assume manual control of traffic, an accurate "picture" at the time of the failure would be imperative. However, if manual control were not the sole backup for failures, the observers felt that the picture-maintaining workload associated with control-by-exception would be very much reduced.

To facilitate examination of the mode rankings under the four criteria (workload, capacity, blunders, stress), the rankings obtained from the summary questionnaire are restated in order in table 34.

These component rankings generally correspond to the overall ranking, with modes 2, 6, 5, and 7 rated above modes 3, 1, and 4. The concern over blunders using mode 7 (CBE) shows up as a low ranking item under this criteria. Mode 5 (TAB-Single-Voice), on the other hand, is rated highly except with respect to workload.

TABLE 34. SUMMARY QUESTIONNAIRE COMPONENT MODE RANKINGS

Rank	Modes			
	Workload	Capacity	Blunders	Stress
1	7	6	5	2
2	2	2	2	5
3	6	5	6	7
4	4	7	3	6
5	5	1	7	1
6	1	4	4	4
7	3	3	1	3

Changes in ranking with percentage mix can be seen by restating the results obtained from questions A.1.B. and summary question 1 as a function of mix. The results are given in table 35. Mode 2 (FDB-Multiple-Vosyn) is ranked lower at a 20-percent mix than at other mixes, whereas mode 6 (TAB-Single-Vosyn) is ranked lower at an 80-percent mix. Mode 7 (CBE) is well ranked at all mixes, but it is especially strong at 80 percent, as is mode 5 (TAB-Single-Voice). These variations in preference generally correspond to the changes in message transaction time with percentage mix as will be seen shortly.

The quantitative measurements made during the test series help to clarify the underlying reasons for the subjective opinions just discussed. The MTT represents the total time required for the system to process a given command; hence, it is probably the most meaningful measure of mode performance. The regression analysis results presented in tables 11, 12, and 13 yield the following linear approximations of MTT as a function of test time in minutes.

20% Mix		Data Link	Voice Link
Mode 1	(FDB-M-Voice)	MTT = 10.90 + .128 (t-30)	MTT = 14.06 + .149 (t-30)
Mode 2	(FDB-M-Vosyn)	MTT = 13.40 - .077 (t-30)	MTT = 17.27 + .097 (t-30)
Mode 3	(TAB-M-Voice)	MTT = 11.20 + .051 (t-30)	MTT = 12.63 + .047 (t-30)
Mode 4	(TAB-M-Vosyn)	MTT = 12.55 - .060 (t-30)	MTT = 15.72 + .062 (t-30)
Mode 5	(TAB-S-Voice)	MTT = 9.69 + .187 (t-30)	MTT = 11.17 + .076 (t-30)
Mode 6	(TAB-S-Vosyn)	MTT = 9.25 - .003 (t-30)	MTT = 13.14 + .077 (t-30)
Mode 7	(Control-by Exception)	MTT = 5.38 - .020 (t-30)	MTT = 10.21 + .075 (t-30)

These relations are plotted figures 19a and 19b.

50% Mix		Data Link	Voice Link
Mode 1	(FDB-M-Voice)	MTT = 14.14 + .108 (t-30)	MTT = 15.44 + .077 (t-30)
Mode 2	(FDB-M-Vosyn)	MTT = 12.62 + .007 (t-30)	MTT = 15.84 + .064 (t-30)
Mode 3	(TAB-M-Voice)	MTT = 10.60 - .057 (t-30)	MTT = 14.59 + .0006 (t-30)
Mode 4	(TAB-M-Vosyn)	MTT = 11.85 - .032 (t-30)	MTT = 15.29 + .003 (t-30)
Mode 5	(TAB-S-Voice)	MTT = 10.20 + .087 (t-30)	MTT = 12.02 + .028 (t-30)
Mode 6	(TAB-S-Vosyn)	MTT = 9.17 + .0003 (t-30)	MTT = 12.79 + .028 (t-30)
Mode 7	(Control-by Exception)	MTT = 5.435 - .022 (t-30)	MTT = 10.06 + .024 (t-30)

These relations are plotted figures 20a and 20b.

80% Mix		Data Link	Voice Link
Mode 1	(FDB-M-Vosyn)	MTT = 17.39 + .089 (t-30)	MTT = 16.82 + .004 (t-30)
Mode 2	(FDB-M-Vosyn)	MTT = 11.84 + .091 (t-30)	MTT = 14.41 + .030 (t-30)
Mode 3	(TAB-M-Voice)	MTT = 9.99 + .062 (t-30)	MTT = 16.55 - .046 (t-30)
Mode 4	(TAB-M-Vosyn)	MTT = 11.15 - .005 (t-30)	MTT = 14.87 - .055 (t-30)
Mode 5	(TAB-S-Voice)	MTT = 10.70 - .013 (t-30)	MTT = 12.87 - .019 (t-30)
Mode 6	(TAB-S-Vosyn)	MTT = 9.09 + .004 (t-30)	MTT = 12.43 - .022 (t-30)
Mode 7	(Control-by Exception)	MTT = 5.49 - .023 (t-30)	MTT = 9.90 - .028 (t-30)

These relations are plotted in figures 21a and 21b.

TABLE 35. VARIATION OF MODE RANKINGS WITH MIX

Rank	Modes (20% Mix)			Modes (50% Mix)		
		Summary Question 1			Summary Question 1	
	A.1.B.	Overall	Components	A.1.B.	Overall	Components
1	6	6	6	6	2	2
2	7	7	7	2	7	6
3	5	1	1	4	4	5
4	4	5	4	7	1	7
5	1	4	5	5	6	1
6	3	3	3	1	5	4
7	2	2	2	3	1	3

Rank	Modes (80% Mix)		
		Summary Question 1	
	A.1.B	Overall	Components
1	7	5	5
2	5	7	7
3	2	2	3
4	4	6	4
5	6	3	2
6	3	4	6
7	1	1	1

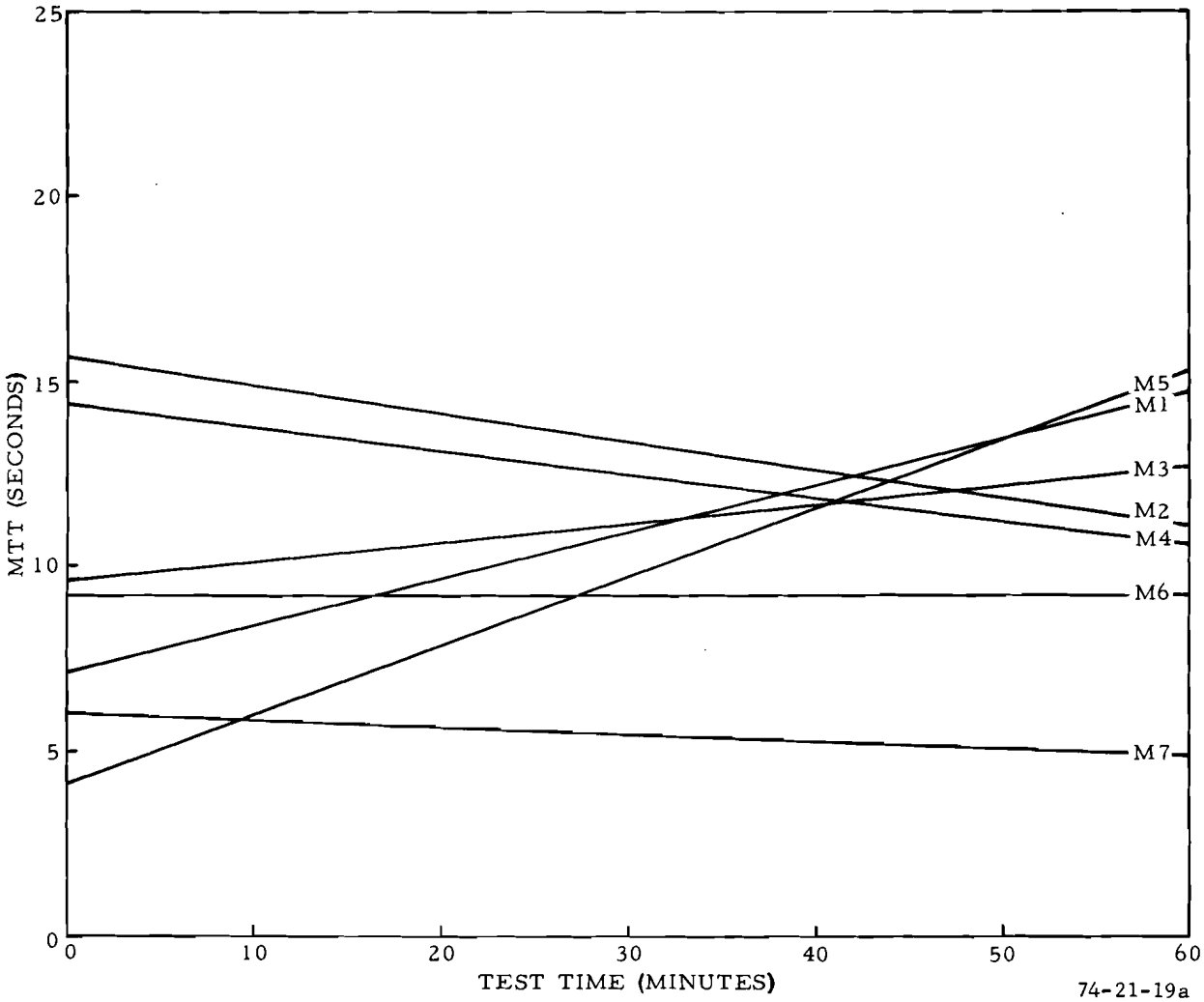


FIGURE 19a. MESSAGE TRANSACTION TIME VERSUS TEST TIME, 20-PERCENT MIX-DATA LINK COMMANDS

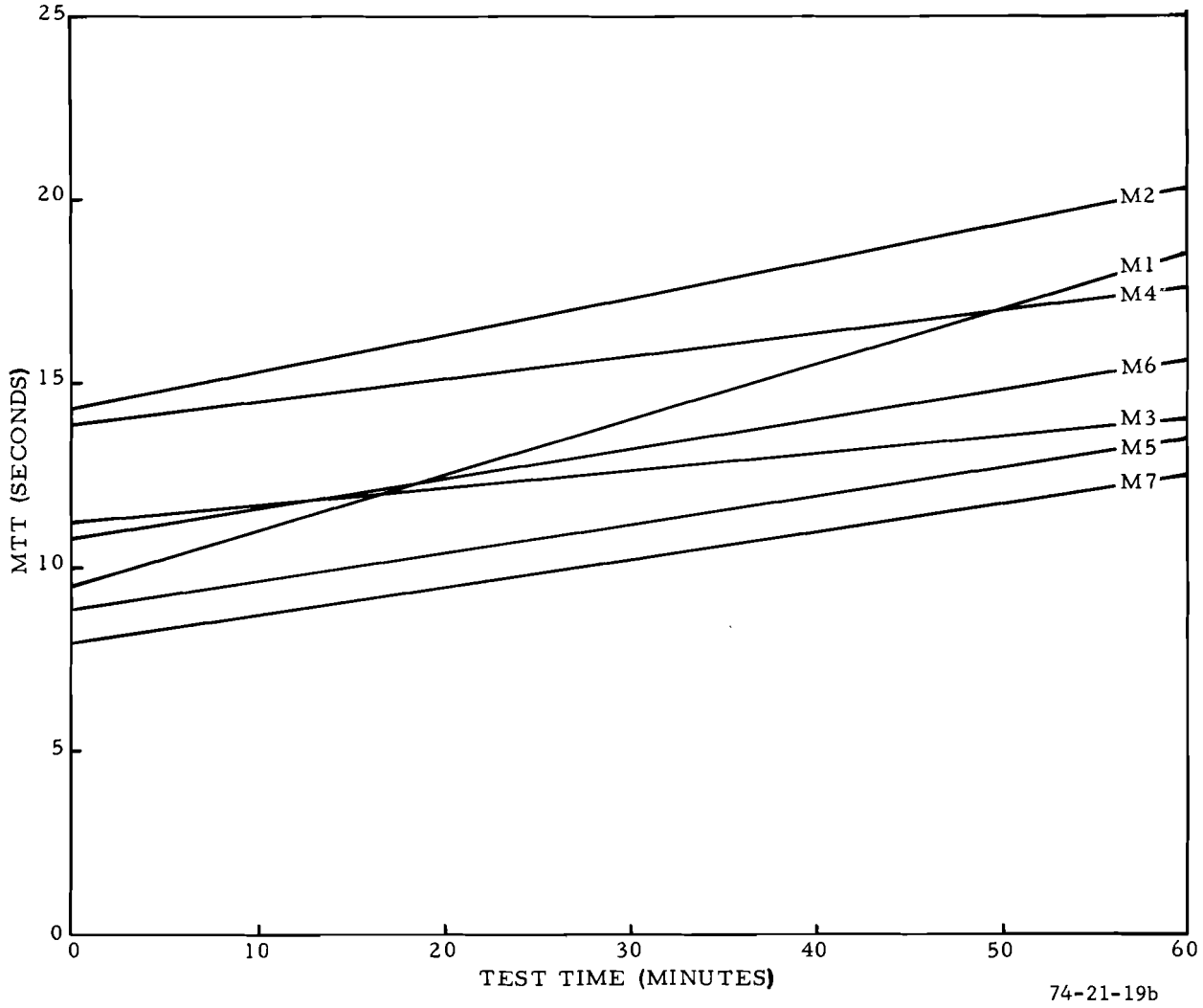


FIGURE 19b. MESSAGE TRANSACTION TIME VERSUS TEST TIME, 20-PERCENT MIX-VOICE LINK COMMANDS

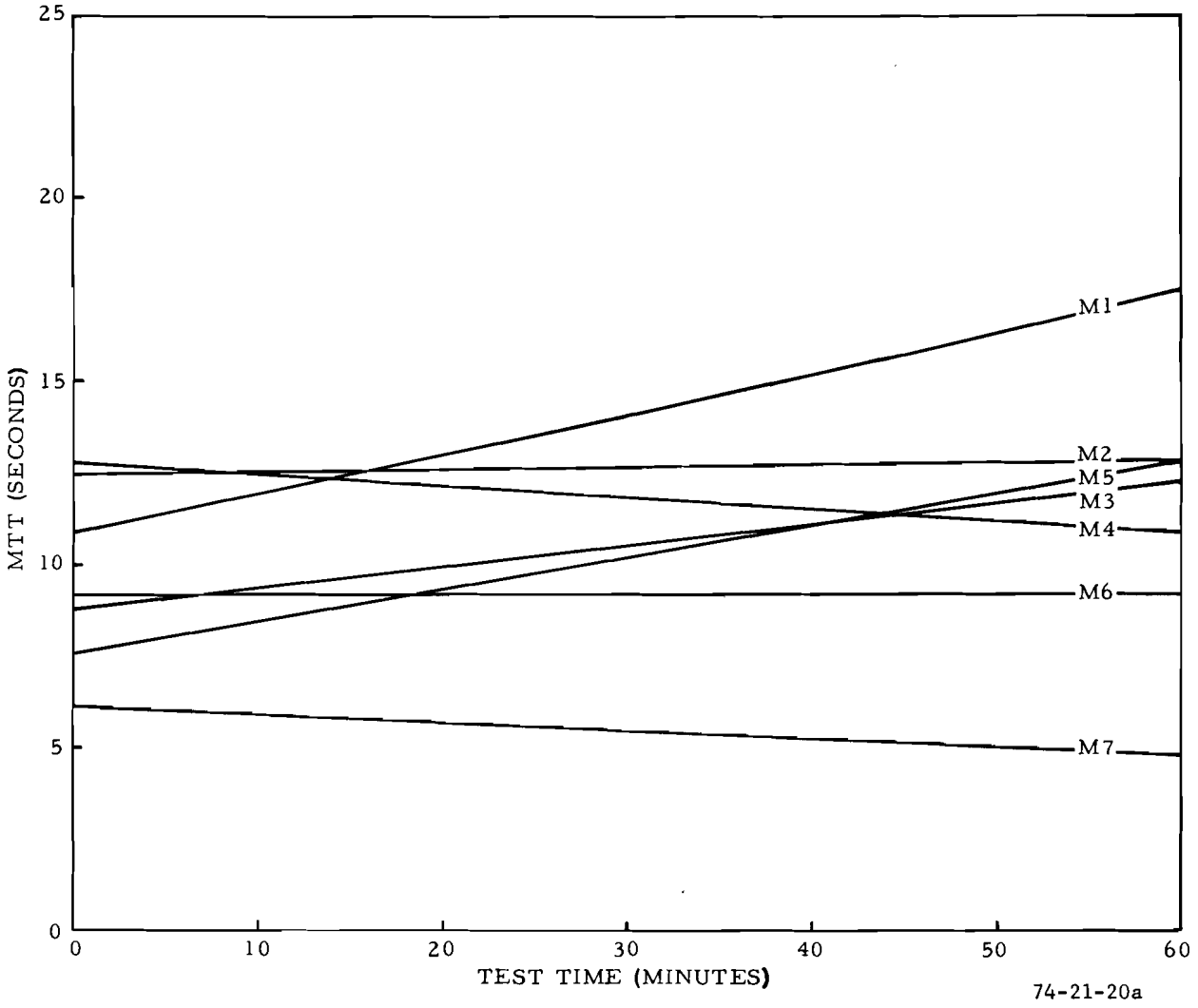


FIGURE 20a. MESSAGE TRANSACTION TIME VERSUS TEST TIME, 50-PERCENT MIX-DATA LINK COMMANDS

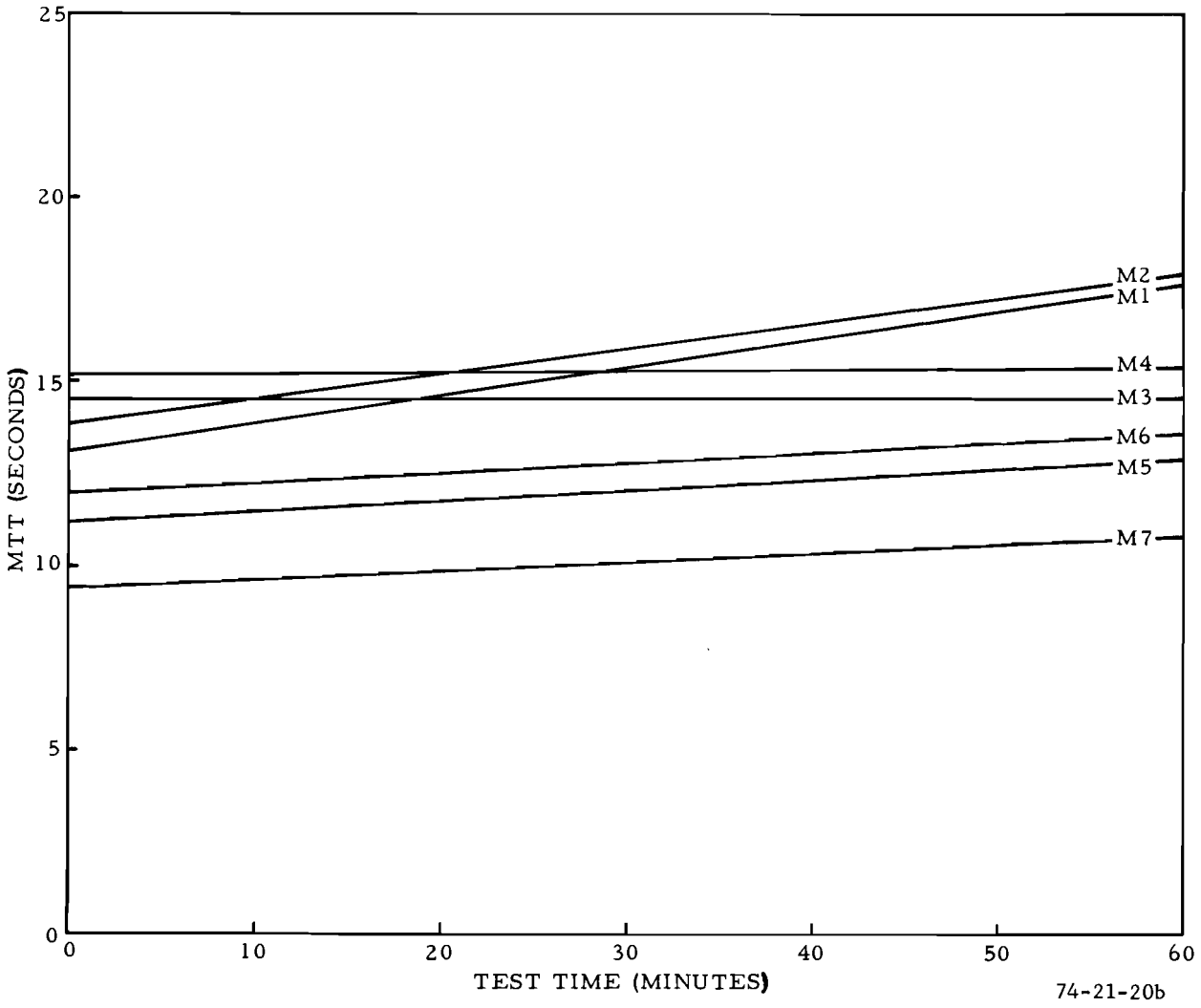


FIGURE 20b. MESSAGE TRANSACTION TIME VERSUS TEST TIME, 50-PERCENT MIX-VOICE LINK COMMANDS

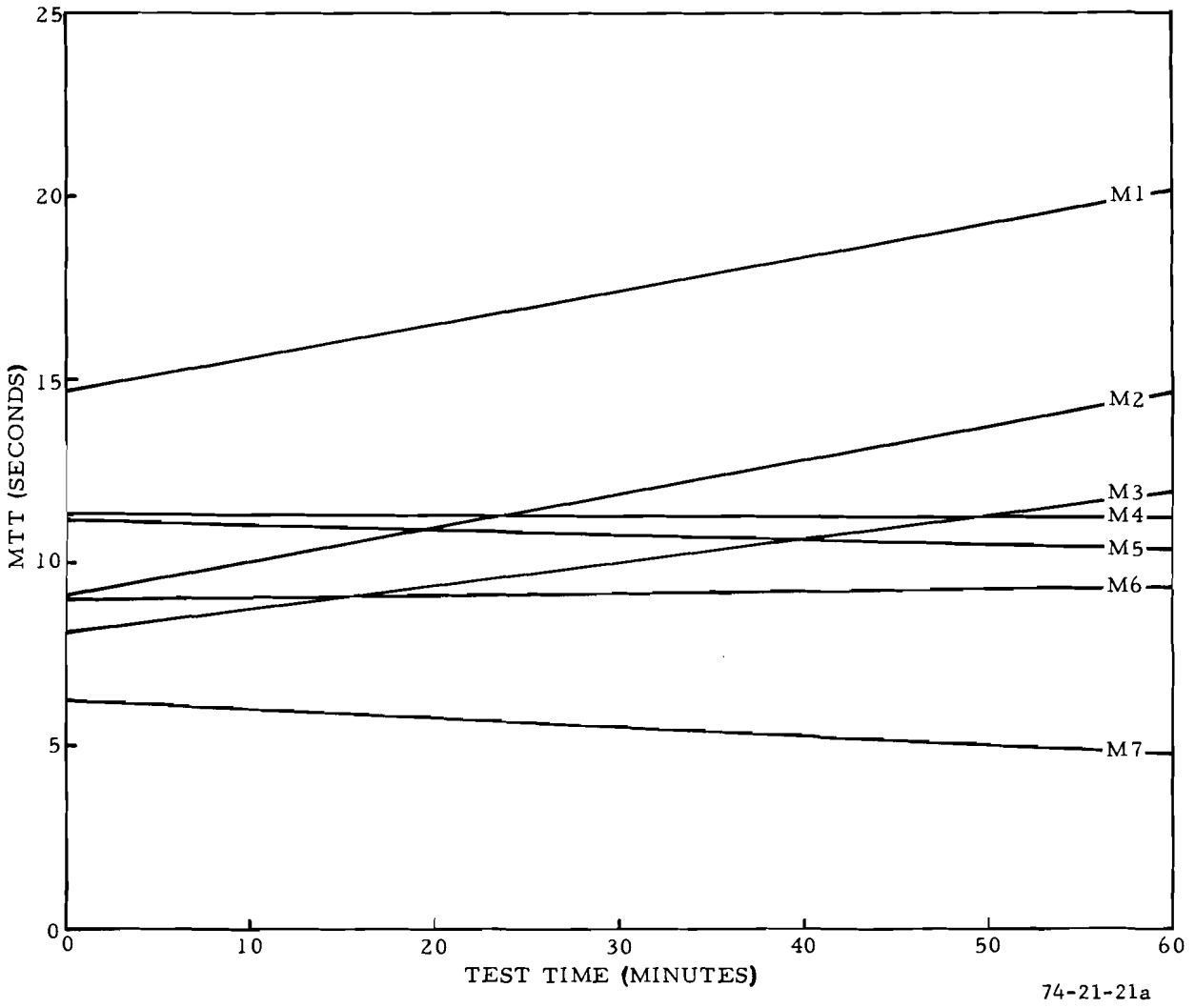


FIGURE 21a. MESSAGE TRANSACTION TIME VERSUS TEST TIME, 80-PERCENT MIX-DATA LINK COMMANDS

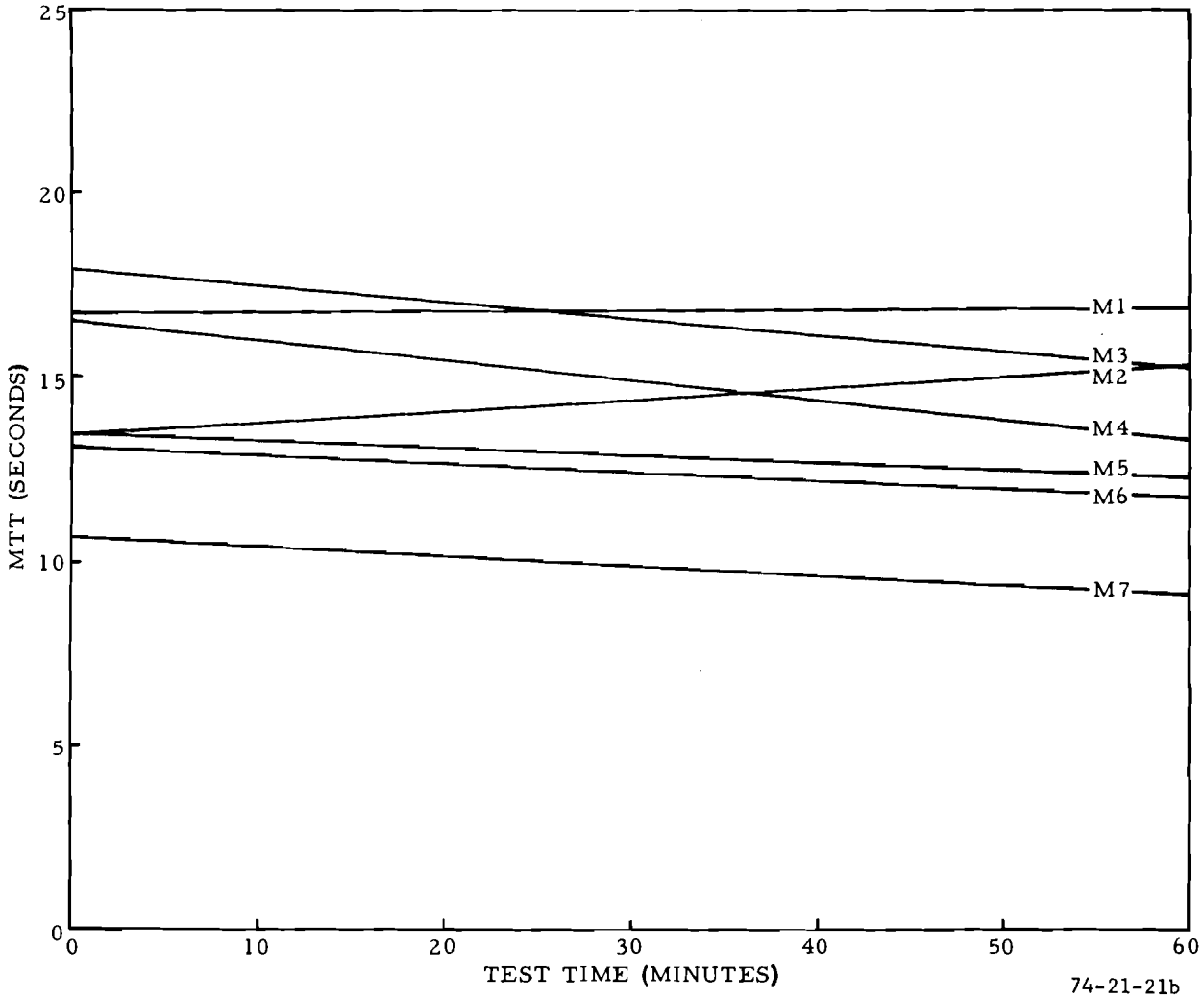


FIGURE 21b. MESSAGE TRANSACTION TIME VERSUS TEST TIME, 80-PERCENT MIX-VOICE LINK COMMANDS

Performance at maximum load is of primary interest, so the modes have been ranked in table 36 in order of increasing MTT, using the MTT values computed from the linear regression formulas for the end of the test run (t=60 minutes).

TABLE 36. MODES RANKED BY MTT AT FULL LOAD

Rank	Modes According to Data Link MTT			Modes According to Voice Link MTT		
	20% Mix	50% Mix	80% Mix	20% Mix	50% Mix	80% Mix
1	7	7	7	7	7	7
2	6	6	6	5	5	6
3	4	4	5	3	6	5
4	2	3	4	6	3	4
5	3	5	3	4	4	3
6	1	2	2	1	1	2
7	5	1	1	2	2	1

The ranking by MTT values at full load generally follows the previous ranking based on controller opinion (table 33) with two notable exceptions. First, mode 7 (Control-By-Exception) clearly outperforms all other candidate modes with respect to MTT, but it is only ranked second according to the questionnaire results. The lower subjective ranking is probably due to reluctance on the part of the controllers to give up their traditional function as part of the control loop of each individual aircraft to act solely as monitors of the overall situation. Some subjects believed that this control mode would be more susceptible to blunders, especially if the metering and spacing system fails and backup must be provided by manual control. Boredom and inability to maintain an accurate "picture" were cited as potential problems with the CBE mode.

The second discrepancy between the objective and subjective rankings is the fact that mode 2 (FDB-Multiple-Vosyn) ranks first according to the questionnaire results and is near the bottom with respect to MTT measurements. The high MTT values for mode 2 are the consequence of executing the following sequence of steps in processing each command:

1. The controller detects a blinking command.

2. The controller pushes the DISPATCH key and slews the trackball to the aircraft position symbol.

3. The controller evaluates the suitability of the command. If he approves, he pushes the ENTER key.

4. In the case of a voice link aircraft, the Vosyn enunciates the command. The "pilot" types in the aircraft identity as it is being enunciated and pushes the ENTER key after the Vosyn's message is completed, acknowledging receipt with a verbal "roger."

5. In the case of a data link aircraft, a computer-generated delay is inserted corresponding to the data link holdups and the time required for a real pilot to recognize and evaluate a command before transmitting a WILCO reply.

Obviously, the extra time required to service commands in mode 2 is largely due to the trackball slewing from aircraft symbol to aircraft symbol. In all the TAB modes, by contrast, the trackball can remain in one position throughout the test except for occasional slews to execute a handoff or disengagement. In spite of the added inconvenience of a trackball slew for each command, mode 2 was ranked first by the subjects. This choice indirectly indicates a strong preference for having commands displayed in the full data block, close to the position symbol of the aircraft addressed. This desirable feature could be retained and the trackball slewing eliminated in a FDB-Single-Vosyn mode. It is apparent that this mode, had it been tested, would have been ranked first in the subjective evaluations and would have probably out-performed all other modes, except CBE, in the MTT measurements. In the present ARTS III display format, of course, controllers work almost entirely with moving tag data.

A more detailed analysis of the differences in performance among the candidate modes will be presented in the next section of the report where the choice between TAB and FDB, Single and Multiple Commands, and Voice and Vosyn is discussed.

Another major factor in evaluating the candidate modes is the variation in performance with the percentage of data link-equipped aircraft.

Reformulating the regression analysis results presented in tables 11, 12, and 13 to get MTT at full load as a function of data link percentage (P), we obtain the following linear approximations with t set to 60 minutes:

Data Link

Mode 1	MTT = 12.947 + .0889 P
Mode 2	MTT = 9.932 + .058 P
Mode 3	MTT = 13.02 - .0145 P
Mode 4	MTT = 10.654 + .0045 P
Mode 5	MTT = 16.986 - .0835 P
Mode 6	MTT = 9.13 + .001 P
Mode 6	MTT = 4.787

Voice Link

Mode 1	MTT = 19.054 - .0264 P
Mode 2	MTT = 21.815 - .0812 P
Mode 3	MTT = 13.645 + .0192 P
Mode 4	MTT = 19.044 - .073 P
Mode 5	MTT = 13.811 - .019 P
Mode 6	MTT = 16.680 - .0613 P
Mode 7	MTT = 13.582 - .0564 P

These relationships are plotted in figures 22 and 23.

By computing data link and voice link MTT values at specific percentage mixes and averaging them together in the proportions indicated by the mix, it is possible to obtain the variation of the overall MTT (data link and voice link) with percentage mix for each mode. This has been done and the results are plotted in figure 24.

The higher MTT values shown explain why mode 2 was ranked lowest by the 20-percent mix subjects and why mode 1 was ranked lowest by the 80-percent mix subjects in table 32. Mode 7 was understandably well regarded at all mix levels. However, the relatively low ranking given to mode 6 by the 80-percent mix subjects stands in contrast to the low MTT values measured for this mode at that mix.

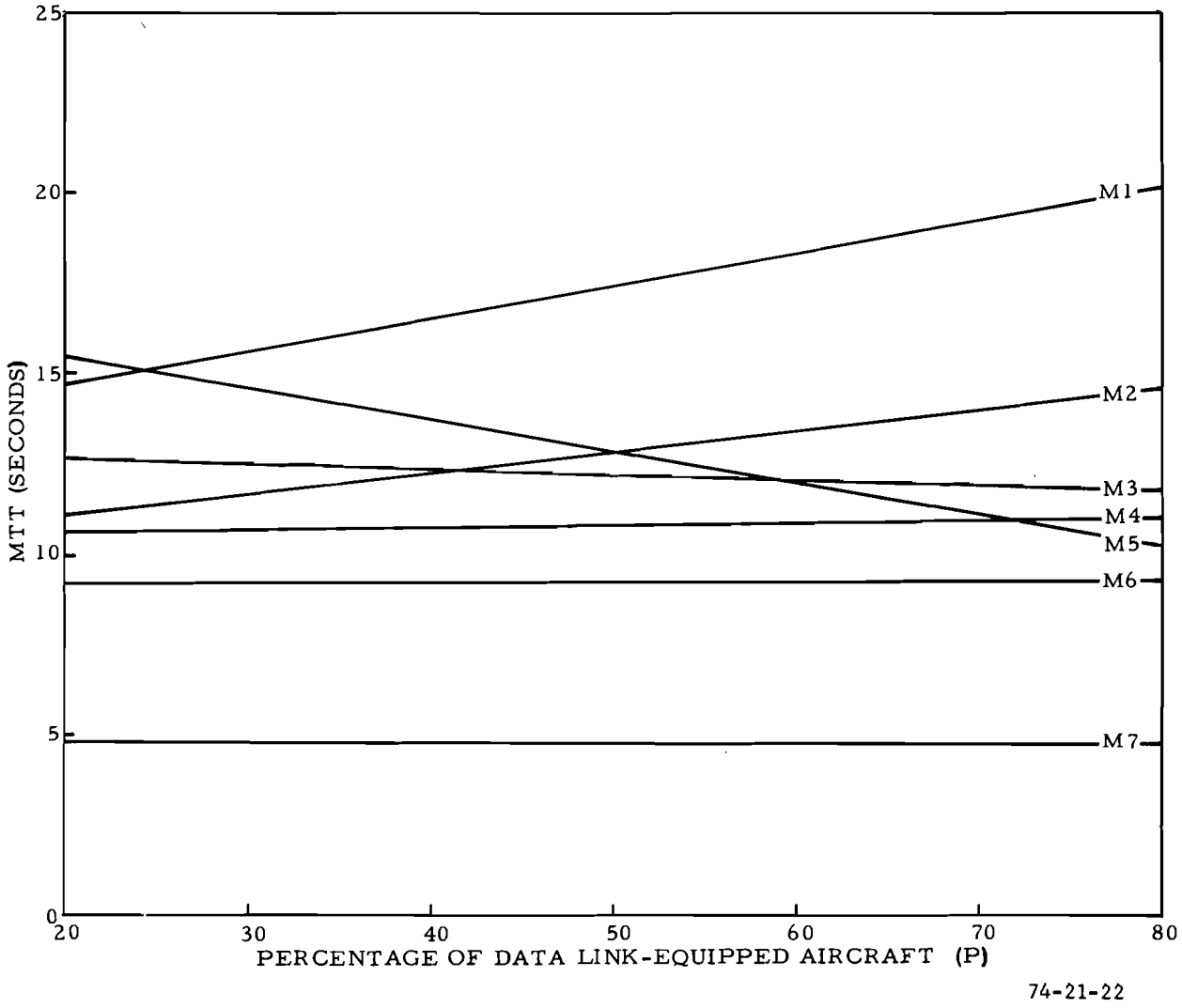


FIGURE 22. DATA LINK MESSAGE TRANSACTION TIME VERSUS PERCENT OF DATA LINK AIRCRAFT

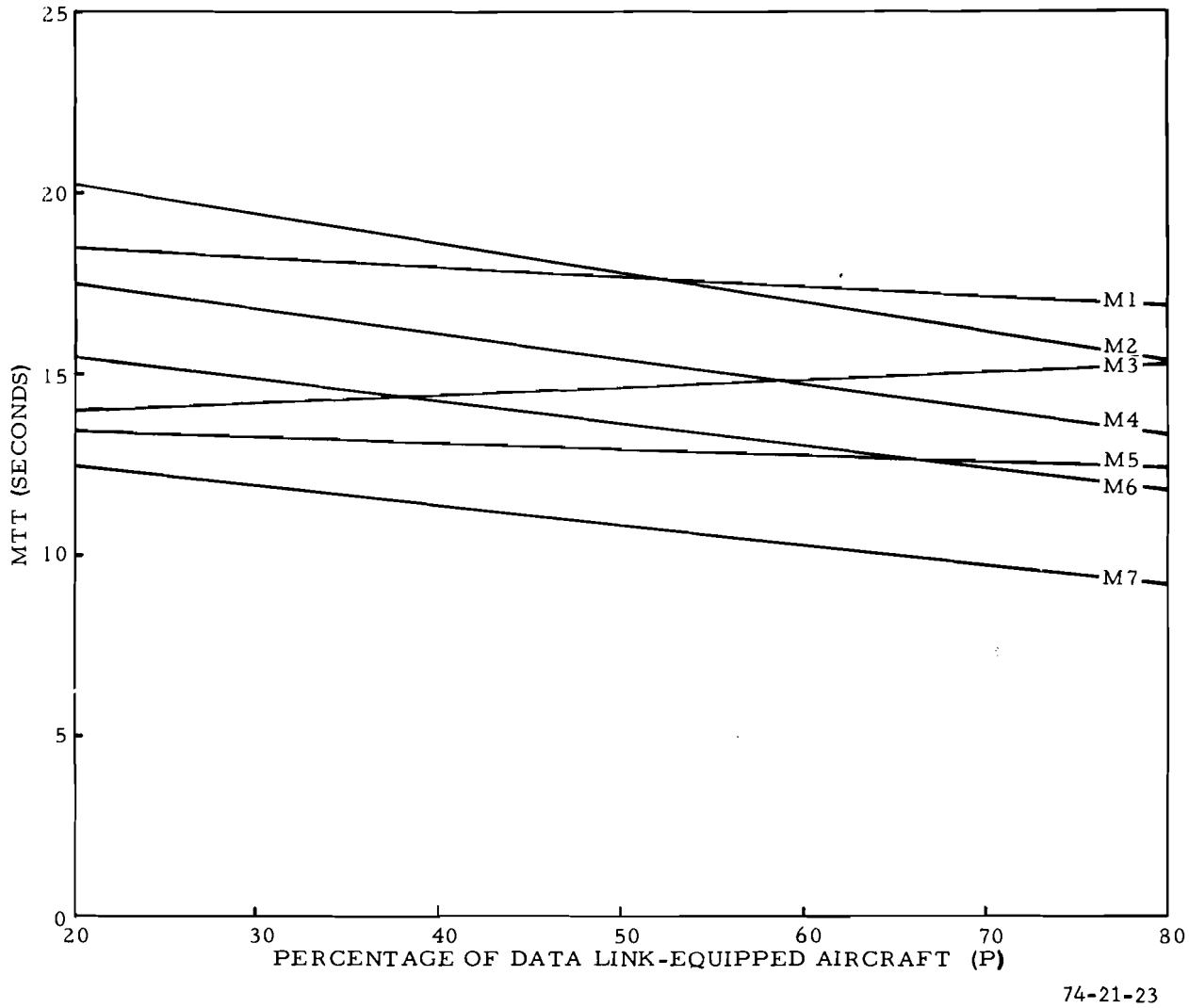


FIGURE 23. VOICE LINK MESSAGE TRANSACTION TIME VERSUS PERCENT OF DATA LINK AIRCRAFT

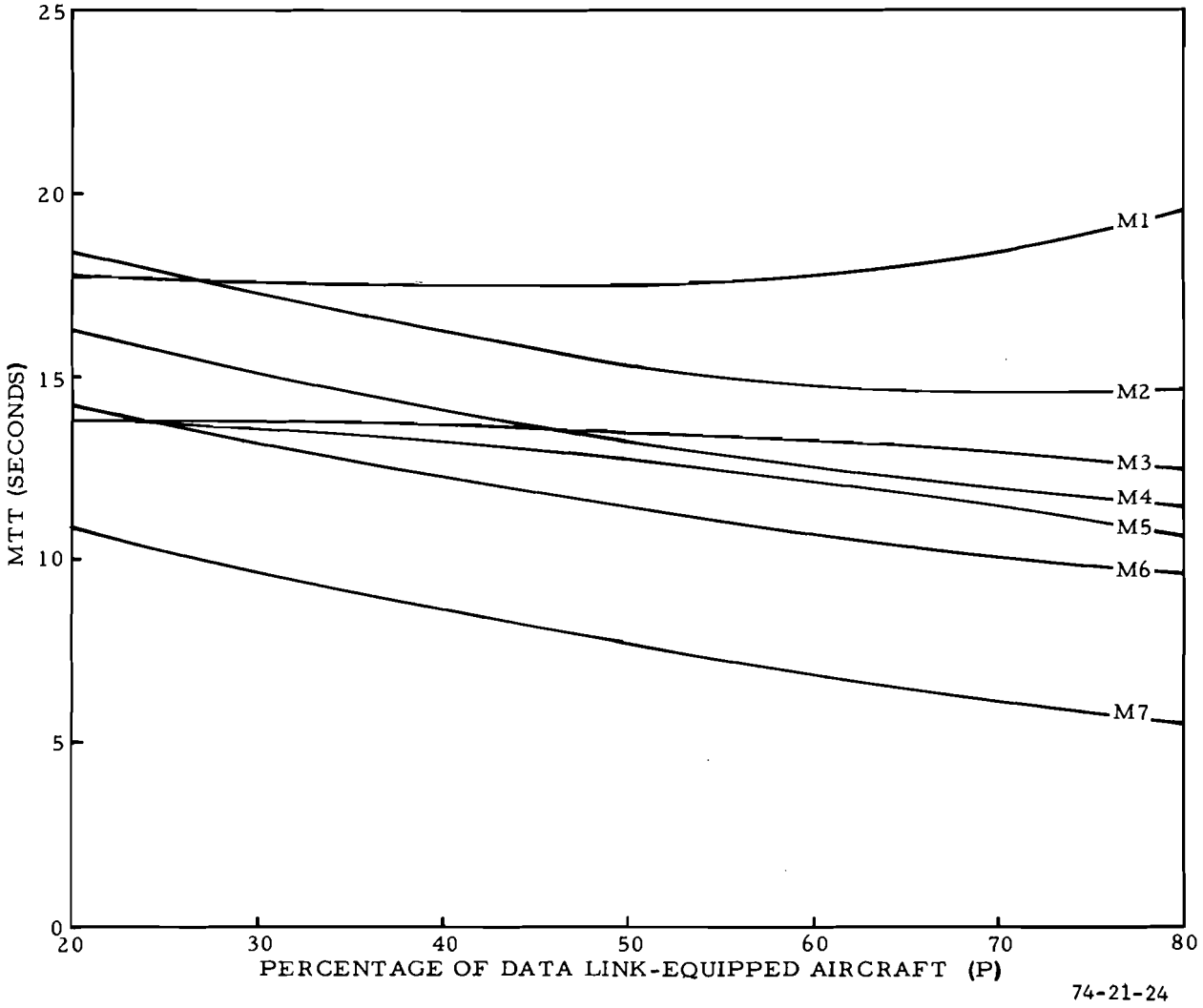


FIGURE 24. COMBINED DATA LINK AND VOICE LINK MTT VERSUS PERCENT OF DATA LINK AIRCRAFT

Before discussing the remaining measures of mode performance (queue behavior, arrival time errors at the inner fix, disengagements, conflicts, and tag repositionings), it is necessary to present the pertinent experimental data. This basic information, along with a set of average MTT, CID, MDT, PRT, and ST values for the 20-, 50-, and 80-percent tests, is listed in tables 37, 38, and 39, respectively.

In examining this data, a very definite correlation between average queue lengths, maximum queue lengths, and average MTT is revealed. This is to be expected since the longer it takes a controller to process each command, on the average, the greater the probability of a queue buildup. The mode rankings, in order of increasing average queue size, are presented in table 40, with separate columns showing maximum queue sizes and average overall MTT calculated from the following relationships:

20% Mix: Avg. MTT (overall) = [Avg. MTT (D/L) + 4 Avg. MTT (V/L)] ÷ 5

50% Mix: Avg. MTT (overall) = [Avg. MTT (D/L) + Avg. MTT (V/L)] ÷ 2

80% Mix: Avg. MTT (overall) = [4 Avg. MTT (D/L) + Avg. MTT (V/L)] ÷ 5

With the exception of mode 2 (FDB-M-Vosyn), which is rated at the top according to subjective measures, the rankings in table 40 correspond closely to the rankings previously discussed. Moreover, they do not change appreciably as function of mix. One interesting aspect of the data shown is that the Vosyn modes rank above the voice modes and that Vosyn modes 6, 4, and 2 exhibit lower average queue sizes than their relatively high average overall MTT values would lead us to expect. The explanation for this is that controllers, to a degree, commence processing the next command while the Vosyn is still enunciating the current command. The result is an effective MTT substantially shorter than the measured MTT value and a correspondingly reduced queue size. Look-ahead is not feasible in the voice modes (1, 3, and 5) since the controller enunciates the commands himself, and then must push his ADVANCE (5) or ENTER (1,3) key after the pilot's "roger" is received. This advantage of the Vosyn modes, however, decreases as the percentage of voice link commands decreases because there are fewer opportunities to save time by looking ahead. This can be seen by the fact that the average queue sizes for the Vosyn modes (2,4) are higher at 80 percent than at 50 percent; whereas, the average queue sizes for the voice modes (1,3,5) decrease uniformly as the percentage of data link aircraft increases.

Another set of measures based on system performance is the error in arrival time at the inner fix and the dispersion of arrival time errors about their mean. First, the mode ranking in order of decreasing average arrival time error is presented in table 41.

TABLE 37. SUMMARY OF TEST DATA FOR 20-PERCENT MIX

Mode	Subj.	Queue	Dis-engage	Tag Re-Position	Inner Fix Arrival Time Error		Avg. MTT		Avg. CID		Avg. MDT		Avg. PRT		Service Time		Max. Queue
					Bias	Std. Dev.	VL	DL	VL	DL	VL	DL	VL	DL	VL	DL	
1	A	.53210	4	13	2.0	3.0	12.8	13.9	6.7	8.3	3.4	.5	2.8	5.1	6.1	.9	4
FDB-M-	E	.62835	5	5	4.4	8.8	15.8	13.9	8.4	8.7	4.0	.5	3.5	4.7	7.4	1.0	4
Voice	G	.83151	3	1	1.0	1.8	20.1	16.6	11.7	11.3	4.1	.5	4.3	4.8	8.4	1.0	4
		.6640	4	6.3	2.48	5.69	16.2	14.8	8.9	9.4	3.8	.5	3.5	4.9	7.3	1.0	4
2	B	.39231	1	0	2.8	1.3	17.6	12.4	8.7	6.8	6.3	.5	2.6	5.1	11.3	2.2	4
FDB-M	F	.46810	2	0	2.8	1.8	18.7	15.1	9.8	9.7	6.9	.5	2.0	5.0	11.7	3.3	4
Vosyn	A	.56898	2	2	3.1	3.0	21.8	12.9	12.0	7.3	7.3	.5	2.5	5.2	11.4	1.5	6
		.4768	1.7	.7	2.90	2.14	19.4	13.5	10.2	7.9	6.8	.5	2.4	5.1	11.5	2.3	4.7
3	C	.45982	1	0	2.4	1.2	10.8	10.6	5.1	5.2	2.9	.5	2.9	4.9	5.8	1.0	4
TAB-M-	B	.50172	3	0	4.8	8.6	11.7	12.6	5.4	7.3	3.6	.4	2.6	4.9	6.2	1.3	5
Voice	G	.65217	2	1	1.3	2.1	16.4	13.6	8.5	8.0	4.1	.4	3.8	5.1	7.9	1.3	4
		.5379	2	.3	2.80	5.27	13.0	12.3	6.3	6.8	3.5	.4	3.1	5.0	6.6	1.2	4.3
4	A	.49094	1	0	2.2	2.0	18.7	16.2	9.8	10.7	6.4	.5	2.5	5.0	11.0	2.5	4
TAB-M-	C	.24371	1	0	3.2	1.1	14.7	9.7	5.4	4.0	7.0	.6	2.3	5.1	11.0	1.2	3
Vosyn	D	.39044	1	0	2.7	1.5	17.3	10.0	8.9	4.7	5.9	.5	2.5	4.9	9.8	1.2	3
		.3750	1	0	2.68	1.65	16.9	12.0	8.0	6.5	6.4	.5	2.4	5.0	10.6	1.6	3.3
5	D	.55053	3	1	1.5	1.8	13.0	13.5	6.2	7.7	4.1	.6	2.8	5.3	9.8	3.3	4
TAB-S-	E	.54288	4	3	2.0	1.2	13.8	15.6	7.3	9.8	4.0	.6	2.6	5.1	10.5	3.8	4
Voice	B	.41869	1	0	2.3	1.6	10.0	10.9	3.9	5.4	3.5	.5	2.6	4.9	8.2	1.8	4
		.5040	2.7	1.3	1.93	1.6	12.3	13.3	5.8	7.6	3.9	.6	2.7	5.1	9.5	3.0	4
6	F	.32392	1	0	2.8	1.5	15.6	9.9	7.2	4.5	5.8	.6	2.5	4.8	14.0	4.2	3
TAB-S	E	.30477	1	2	3.5	1.1	14.7	9.8	6.8	4.1	6.0	.6	1.9	5.1	12.9	3.6	4
Vosyn	C	.18368	1	0	3.7	.8	12.7	9.6	3.8	4.0	6.5	.6	2.4	5.0	12.2	3.0	3
		.2708	1	.7	3.33	1.23	14.3	9.8	5.9	4.2	6.1	.6	2.3	5.0	13.0	3.6	3.3
7	F	.03147	3	0	4.6	1.4	11.6	5.7	2.9	0	5.7	.5	3.0	5.2	8.7	.5	3
CBE	D	.00814	1	3	4.4	1.3	12.0	5.4	3.7	0	5.3	.5	3.0	5.0	8.3	.5	4
	G	.01610	1	0	4.8	1.3	10.3	5.6	1.6	0	5.7	.5	3.0	5.1	8.7	.5	2
		.0186	1.7	1	4.60	1.34	11.3	5.6	2.7	0	5.6	.5	3.0	5.1	8.6	.5	3

TABLE 38. SUMMARY OF TEST DATA FOR 50-PERCENT MIX

Mode	Subj.	Avg. Queue	Dis-engage	Tag Re-position	Inner Fix Arrival Time Error		Avg. MTT		Avg. CID		Avg. MDT		Avg. PRT		Service Time		Max. Queue
					Bias	Std. Dev.	VL	DL	VL	DL	VL	DL	VL	DL	VL	DL	
1 FDB-M-Voice	A	.73304	1	4	1.2	2.0	19.1	16.1	9.3	10.6	4.2	.5	5.6	5.0	9.7	2.7	4
	B	.66237	3	1	.8	3.8	18.2	16.0	9.7	10.3	3.7	.5	4.7	5.2	8.5	1.0	5
	C	.54241	1	2	1.8	1.8	14.4	14.7	6.3	9.1	3.4	.5	4.7	5.0	8.1	1.0	5
	D	.45555	1	2	1.8	1.8	12.6	12.4	6.1	6.7	3.2	.5	3.3	5.2	6.5	1.0	5
	E	.46331	1	8	1.8	1.4	12.8	12.6	5.4	7.1	3.8	.5	3.6	5.1	7.4	.8	3
	F	.50544	1	6	2.1	1.1	14.9	13.3	6.3	7.9	3.9	.5	4.6	4.9	8.6	1.0	4
	G	.68156	1	7	.6	2.9	16.1	17.3	7.2	11.7	4.5	.5	4.4	5.1	8.9	1.2	4
		.5777	1.3	4.3	1.44	2.35	15.4	14.6	7.2	9.1	3.8	.5	4.4	5.1	8.2	1.2	4.3
2 FDB-M-Vosyn	A	.29004	1	0	3.3	.8	15.0	11.0	6.1	6.0	6.4	.5	2.4	5.0	11.2	2.5	4
	B	.28889	1	0	3.5	1.0	14.2	12.0	5.5	6.4	6.4	.5	2.2	5.1	9.5	.8	3
	C	.35294	3	0	3.4	.8	17.1	11.9	8.0	6.4	6.7	.5	2.4	5.0	10.4	1.1	3
	D	.35828	1	0	3.1	1.3	15.7	12.6	7.0	7.2	6.2	.5	2.5	5.0	9.9	1.0	4
	E	.23833	1	9	3.6	.6	14.2	10.4	5.2	4.9	6.5	.5	2.6	5.1	9.7	.6	3
	F	.36553	1	3	2.8	1.2	17.6	12.7	7.9	7.3	7.0	.5	2.7	5.0	10.6	1.1	4
	G	.35841	1	9	2.9	.8	16.1	13.3	7.2	7.9	6.0	.5	2.8	4.9	10.0	1.1	4
		.3218	1.3	3.0	3.23	.99	15.7	12.0	6.7	6.6	6.5	.5	2.5	5.0	10.2	1.2	3.6
3 TAB-M-Voice	A	.54977	1	3	1.8	1.1	15.4	14.2	7.2	8.8	4.3	.5	3.8	5.0	8.2	1.4	6
	B	.38087	1	0	3.5	.7	13.2	11.7	5.1	6.2	4.2	.5	3.8	5.1	8.1	1.0	4
	C	.44853	6	0	1.4	2.1	12.3	12.9	5.2	7.4	3.2	.5	4.0	5.0	7.2	1.1	4
	D	.46683	1	1	2.2	1.3	13.5	12.9	5.6	7.3	3.5	.5	4.5	5.2	8.0	1.2	4
	E	.44880	2	3	1.5	2.3	14.6	12.5	7.1	7.1	3.6	.5	3.8	4.9	7.5	1.0	3
	F	.64906	1	2	1.5	1.5	17.0	15.8	7.9	10.3	4.3	.5	4.8	5.1	9.1	1.1	4
	G	.50604	2	0	1.4	1.3	15.6	11.9	7.4	7.2	4.1	.5	4.0	5.2	8.1	1.3	4
		.4928	2	1.3	1.87	1.65	14.5	13.1	6.5	7.8	3.9	.5	4.1	5.1	8.0	1.2	4.1
4 TAB-M-Vosyn	A	.25629	1	1	3.2	.9	15.0	10.4	5.5	4.9	7.0	.5	2.5	4.9	11.0	1.4	4
	B	.27454	1	0	3.4	.8	15.2	11.0	5.7	5.3	6.8	.5	2.8	5.2	10.5	1.0	3
	C	.22854	1	0	3.7	1.0	13.3	10.4	4.3	5.1	6.3	.5	2.8	4.8	10.3	1.2	4
	D	.30334	1	0	3.5	1.0	15.5	11.1	6.6	5.8	6.2	.5	2.8	4.8	10.2	1.2	3
	E	.28664	1	0	2.9	1.2	15.9	10.4	6.5	4.9	6.2	.5	3.2	5.0	10.2	.8	2
	F	.31134	1	6	2.8	2.1	15.3	12.2	6.1	6.7	6.7	.5	2.5	5.1	10.5	1.2	3
	G	.24123	1	3	3.7	.6	13.4	10.6	4.8	4.9	5.9	.4	2.6	5.2	9.9	1.2	3
		.2717	1	1.4	3.31	1.23	14.8	10.9	5.6	5.4	6.4	.5	2.7	5.0	10.4	1.1	3.1

TABLE 38. SUMMARY OF TEST DATA FOR 50-PERCENT MIX (continued)

Mode	Subj.	Avg. Queue	Dis-engage	Tag Re-position	Inner Fix Arrival Time Error		Avg. MTT		Avg. CID		Avg. MDT		Avg. PRT		Service Time		Max. Queue
					Bias	Std. Dev.	VL	DL	VL	DL	VL	DL	VL	DL	VL	DL	
5 TAB-S-Voice	A	.44877	1	1	2.1	1.7	12.4	11.1	5.4	5.6	3.9	.6	3.1	4.9	10.2	2.9	4
	B	.47634	1	0	1.8	2.0	13.2	12.2	6.1	6.6	3.8	.6	3.2	5.1	10.5	3.8	4
	C	.34588	3	0	2.4	1.4	10.8	9.6	4.6	4.1	3.3	.6	3.0	4.9	9.3	2.7	3
	D	.31207	1	0	2.8	1.3	10.1	9.4	3.3	3.7	3.4	.6	3.4	5.0	9.0	2.0	3
	E	.36371	1	1	2.3	1.5	11.0	10.9	4.7	5.2	3.5	.6	2.9	5.2	9.5	3.3	4
	F	.37019	0	2	2.4	1.1	11.2	10.1	4.3	4.5	3.6	.6	3.3	5.0	9.3	2.7	3
	G	.51694	1	1	1.6	1.3	14.8	13.0	5.9	7.4	5.2	.6	3.7	5.0	12.1	3.3	6
		.4048	1.1	.7	2.20	1.54	11.9	10.9	4.9	5.3	3.8	.6	3.2	5.0	10.0	3.0	3.9
6 TAB-S-Vosyn	A	.18991	2	0	3.8	.7	12.6	9.2	4.0	3.8	6.2	.6	2.4	4.9	12.3	3.1	3
	B	.14886	1	0	3.7	1.1	12.6	8.4	3.1	2.7	7.0	.6	2.5	5.0	12.2	2.0	3
	C	.15231	1	0	3.7	.7	11.9	8.5	3.1	2.9	6.6	.6	2.1	5.0	11.3	2.4	3
	D	.23085	1	2	3.5	1.4	15.4	9.4	5.4	3.7	6.3	.6	3.7	5.1	14.7	3.0	2
	E	.11857	1	1	4.1	.6	11.4	7.8	2.3	2.3	6.7	.6	2.5	4.9	11.0	1.8	2
	F	.19874	1	2	3.8	.6	13.6	9.6	3.9	3.8	6.9	.6	2.8	5.2	13.1	3.2	2
	G	.16405	1	3	3.5	1.2	11.9	9.1	3.1	3.4	6.6	.6	2.2	5.1	11.5	2.9	3
		.1719	1.1	1.1	3.73	.96	12.8	8.9	3.6	3.2	6.6	.6	2.6	5.0	12.3	2.6	2.6
7 CBE	A	.01823	1	0	5.1	1.1	10.0	5.3	1.4	0	5.6	.5	3.0	4.9	8.6	.5	2
	B	.00473	2	4	5.3	1.7	9.8	5.6	1.1	0	5.7	.5	3.0	5.1	8.7	.5	1
	C	.02144	2	0	5.1	1.3	9.9	5.5	1.2	0	5.7	.5	3.0	5.1	8.7	.5	4
	D	.01081	1	2	4.9	.9	10.0	5.5	1.1	0	5.9	.5	3.0	5.0	8.9	.5	3
	E	.01033	1	8	5.2	1.2	10.1	5.3	1.1	0	6.0	.5	3.0	4.8	9.0	.5	2
	F	.00682	1	2	4.5	1.5	11.0	5.6	1.8	0	6.1	.5	3.0	5.1	9.1	.5	1
	G	.01094	1	9	5.4	2.3	10.6	5.5	1.4	0	6.1	.5	3.0	5.0	9.1	.5	2
		.0119	1.3	3.6	5.06	1.52	10.2	5.5	1.3	0	5.9	.5	3.0	5.0	8.9	5	2.1

TABLE 39. SUMMARY OF TEST DATA FOR 80-PERCENT MIX

Mode	Subj.	Avg. Queue	Dis-engage	Tag Re-position	Inner Fix Arrival Time Error		Avg. MTT		Avg. CID		Avg. MDT		Avg. PRT		Service Time		Max. Queue
					Bias	Std. Dev.	VL	DL	VL	DL	VL	DL	VL	DL	VL	DL	
1	G	.58861	1	8	1.3	2.1	18.2	16.8	9.1	11.4	4.4	.5	4.7	4.9	9.1	1.7	5
FDB-M-	E	.53951	1	4	.8	1.5	12.5	15.0	4.8	9.4	3.9	.5	3.8	5.1	7.7	3.1	5
Voice	A	.54453	1	0	.6	2.7	15.2	16.1	6.5	10.6	3.8	.5	4.9	5.0	8.7	3.2	5
		.5576	1	4	.90	2.18	15.3	16.0	6.8	10.5	4.0	.5	4.5	5.0	8.5	2.7	5
2	A	.35713	3	1	3.0	2.5	17.7	12.5	9.0	7.1	6.6	.5	2.1	4.9	14.8	7.6	4
FDB-M	B	.29999	1	3	3.1	1.0	14.0	11.8	5.4	6.4	6.4	.5	2.2	5.0	9.1	.6	3
Vosyn	F	.46909	2	3	3.0	1.0	19.7	15.1	11.1	9.5	6.1	.5	2.5	5.0	11.9	3.0	5
		.3754	2	2.3	3.09	1.52	17.1	13.1	8.5	7.7	6.4	.5	2.3	5.0	11.9	3.7	4
3	H	.58310	1	2	.6	3.7	18.3	15.8	8.9	10.3	4.5	.5	5.0	5.0	9.5	1.8	4
Tab-M	B	.35554	1	0	2.2	1.3	14.9	11.4	5.7	5.8	3.3	.5	5.9	5.0	9.2	1.1	3
Voice	C	.32761	1	0	2.1	1.4	11.4	10.8	3.5	5.3	4.4	.5	3.5	5.0	8.0	1.1	4
		.4221	1	.7	1.63	2.52	14.9	12.7	6.0	7.1	4.1	.5	4.8	5.0	8.9	1.3	3.7
4	C	.25596	1	0	3.4	1.0	14.4	10.7	5.7	5.3	5.9	.5	2.7	4.9	9.6	1.0	3
Tab-M	A	.31599	2	0	3.5	1.8	16.1	12.4	7.0	6.8	6.1	.5	2.9	5.0	10.1	.9	3
Vosyn	D	.26771	1	0	2.9	1.7	14.0	10.6	5.4	5.1	6.1	.5	2.5	5.0	9.1	.4	5
		.2799	1.3	0	3.26	1.56	14.8	11.2	6.0	5.7	6.0	.5	2.7	5.0	9.6	.8	3.7
5	B	.26915	2	0	2.2	1.3	10.5	9.5	4.8	3.8	3.1	.6	2.6	5.1	9.5	2.5	4
Tab-S	E	.31402	1	2	2.4	1.5	13.0	10.7	5.3	5.0	4.0	.7	3.7	5.1	12.2	3.3	4
Voice	D	.38929	1	0	2.2	2.0	14.4	11.9	7.5	6.3	3.4	.6	3.5	5.0	13.5	4.4	4
		.3242	1.3	.7	2.27	1.62	12.6	10.7	5.9	5.0	3.5	.6	3.3	5.1	11.7	3.4	4
6	F	.15734	2	1	3.9	.7	11.9	8.7	3.5	3.2	5.8	.6	2.7	4.9	11.2	2.6	2
Tab-S	C	.18154	1	0	3.8	.6	13.0	8.9	4.4	3.5	6.0	.6	2.6	4.9	12.3	3.0	3
Vosyn	E	.22002	1	0	3.5	1.1	13.1	9.7	4.6	4.1	5.9	.6	2.6	5.0	12.7	3.0	3
		.1863	1.3	.3	3.72	.84	12.7	9.1	4.2	3.6	5.9	.6	2.6	4.9	12.1	2.9	2.7
7	F	.00713	1	4	5.0	1.0	9.5	5.6	.7	0	5.8	.4	3.0	5.1	8.8	.4	1
CBE	G	.00635	1	3	5.3	1.5	9.4	5.4	.7	0	5.7	.5	3.0	4.9	8.7	.5	2
	D	.00843	1	0	5.1	1.1	10.3	5.5	1.5	0	5.8	.5	3.0	5.0	8.8	.5	2
		.0073	1	2.3	5.14	1.21	9.7	5.5	1.0	0	5.8	.5	3.0	5.0	8.8	.5	1.7

TABLE 40. MODE RANKING BY AVERAGE QUEUE SIZE

Mix	Rank	Mode	Avg. Queue	Avg. Max. Queue	Avg. Overall MTT
20%	1	7	.0186	3	10.2
	2	6	.2708	3.3	13.4
	3	4	.3750	3.3	15.9
	4	2	.4768	4.7	18.2
	5	5	.5040	4.0	12.5
	6	3	.5379	4.3	12.9
	7	1	.6640	4.0	15.9
50%	1	7	.0119	2.1	7.9
	2	6	.1719	2.6	10.9
	3	4	.2717	3.1	12.9
	4	2	.3218	3.6	13.9
	5	5	.4048	3.9	11.4
	6	3	.4928	4.1	13.8
	7	1	.5777	4.3	15.0
80%	1	7	.0073	1.7	6.3
	2	6	.1863	2.7	9.8
	3	4	.2799	3.7	11.9
	4	5	.3242	4.0	11.1
	5	2	.3754	4.0	13.9
	6	3	.4221	3.7	13.1
	7	1	.5576	5.0	15.9

TABLE 41. RANKING OF MODES BY AVERAGE ARRIVAL TIME ERRORS AT THE INNER FIX

	20% Mix		50% Mix		80% Mix	
Rank	Mode	Average Inner Fix Arrival Time Error	Mode	Average Inner Fix Arrival Time Error	Mode	Average Inner Fix Arrival Time Error
1	7	4.60	7	5.06	7	5.14
2	6	3.33	6	3.73	6	3.72
3	2	2.90	4	3.31	4	3.26
4	3	2.80	2	3.23	2	3.09
5	4	2.68	5	2.20	5	2.27
6	1	2.48	3	1.87	3	1.63
7	5	1.93	1	1.44	1	.90

No particular significance should be attached to the absolute magnitude of the average arrival time errors. If this bias were known beforehand, it could be readily reduced to zero by adjusting the desired execution time of the last speed command. The magnitude of the error biases relative to each other, however, is significant because it is largely determined by the controller. To illustrate, the arrival time error at the inner fix is calculated as follows:

Arrival Time Error=Actual Arrival Time - Scheduled Arrival Time

The more quickly the controller evaluates and transmits the command to reduce speed to 160 knots, the more quickly will the simulated aircraft execute this instruction, and the later it will arrive at the inner fix. Thus, faster processing of commands should correspond to more positive arrival time errors. This effect is clearly demonstrated by the order of modes in table 41. Modes having the lowest average queue lengths and MTT values have the most positive arrival time errors as predicted.

Of even more significance is the dispersion of arrival time errors about their mean, since this is a measure of the degree of randomness in command-processing times exhibited by the seven modes. This characteristic is intrinsic to each mode and very little can be done to improve it. Rankings in order of increasing dispersion are given in table 42.

TABLE 42. MODE RANKING BY DISPERSION IN ARRIVAL TIME ERROR AT THE INNER FIX

	20% Mix		50% Mix		80% Mix	
Rank	Mode	Dispersion of Arrival Time Errors About Mean	Mode	Dispersion of Arrival Time Errors About Mean	Mode	Dispersion of Arrival Time Errors About Mean
1	6	1.23	6	.96	6	.84
2	7	1.34	2	.99	7	1.21
3	5	1.60	4	1.23	2	1.52
4	4	1.65	7	1.52	4	1.56
5	2	2.14	5	1.54	5	1.62
6	3	5.27	3	1.65	1	2.18
7	1	5.69	1	2.35	3	2.52

As in other rankings, the Vosyn modes (6,2,4) and CBE(7) dominate this listing also. Dispersions for all modes are higher at the 20-percent mix.

Dispersion in the delivery and execution of M&S commands contributes directly to dispersion in arrival times at the runway threshold, which is the key factor in determining runway capacity. The critical command is the final turn at the inner fix to intercept the localizer, since errors in timing here are effectively doubled at the runway threshold because of the trombone geometry.

In spite of the fact that one potential conflict at the inner fix was deliberately inserted in every scenario, only 10 serious violations of spacing minimums occurred during the 91 test runs. These are listed in table 19. The ranking of modes according to the number of serious conflicts is shown in table 43.

TABLE 43. RANKING BY NUMBER OF CONFLICTS

Rank	Mode	Number of Conflicts
1	1	1
2	2	1
3	3	1*
4	5	1*
5	6	1*
6	4	2**
7	7	3

* Less than 5-nmi spacing behind heavy jet.
** One of two conflicts involved heavy jet.

It is worth noting that the CBE mode (7) had a relatively high number of conflicts in spite of the fact that CBE commands are invariably delivered promptly and with little dispersion. This evidence suggests that controllers may, indeed, have difficulty maintaining an accurate traffic picture when they do not participate directly and continuously in the control of individual aircraft. The small number of samples, however, obviously precludes drawing a firm conclusion with this data.

As indicated in the analysis of variance data shown in table 16, the number of disengagements was not a statistically significant measure of mode merit. Most runs had only one disengagement corresponding to the one conflict situation deliberately inserted in each scenario. The data shows a greater correlation between particular subjects and disengagements, one controller having six in a single run.

Table 44 lists the average number of tag repositionings encountered with each mode and ranks modes in order of the overall average for all three mixes.

TABLE 44. SUMMARY OF TAG REPOSITIONINGS PER RUN AND CORRESPONDING RANKINGS

Mode	20% Mix Average Number of Tag Repositionings	50% Mix Average Number of Tag Repositionings	80% Mix Average Number of Tag Repositionings	Rank	Mode	Overall Average Number of Tag Repositionings
1	6.3	4.3	4.0	1	4	.75
2	.7	3.0	2.3	2	6	.82
3	.3	1.3	.7	3	5	.84
4	0	1.4	0	4	3	.93
5	1.3	.7	.7	5	2	2.31
6	.7	1.1	.3	6	7	2.70
7	1.0	3.6	2.3	7	1	4.69

The obvious deduction from this data is that the full-data block modes (1, 2, 7) require a greater number of tag repositionings than the tabular list modes. This is understandable, since the commands require a third line in the tags and the controllers must correct tag overlaps in order to read them. Even the two to five tag repositionings encountered in the FDB modes, however, is not excessive over a 1-hour run. These low figures were obtained in the simulation program because tags were automatically oriented to minimize overlaps. Each stage of each approach route employed a preselected tag orientation, and the DSF switched tags to this orientation when aircraft entered the stages. This is felt to be a worthwhile display format feature. Without it, tag repositioning can become a major workload item, especially if a trombone geometry is utilized prior to final approach. It should be noted that individual controllers vary greatly with respect to tag repositioning. One subject repositioned 13 times in a single run, whereas, almost half the runs did not have any repositionings at all.

COMPARISON OF INDIVIDUAL MODE OPTIONS.

By and large, the same data used in comparing modes will be regrouped and used in comparing the individual mode options. For example, to evaluate the full-data block option versus the tabular list option, the following data combination will be employed:

(Mode 1 Data + Mode 2 Data) - (Mode 3 Data + Mode 4 Data)
= Index of Merit

A positive index favors FDB and a negative index favors TAB. Similarly, to compare the multiple command option versus the single command, the following data grouping will be used:

(Mode 3 Data + Mode 4 Data) - (Mode 5 Data + Mode 6 Data)
= Index of Merit

A positive index favors the multiple command option and a negative index favors the single command option. To evaluate the voice option versus the Vosyn option, the following data grouping will be used:

(Mode 1 Data + Mode 3 Data + Mode 5 Data) - (Mode 2 Data + Mode 4 Data
+ Mode 6 Data) = Index of Merit

A positive index favors voice and a negative index favors the Vosyn.

In addition to the composite data comparisons just described, there were a number of questions on the postexperiment questionnaire that solicited a direct judgement with respect to specific mode options, i.e., FDB versus TAB, Multiple versus Single, and Voice versus Vosyn. These subjective responses will also be cited in the discussion that follows.

Recall that postexperiment question A.1.A asked the subjects how they rated the displaying and dispatching of commands in the mode tested with the present-day ARTS procedure applied to the same scenario. Question A.1.B asked them to compare the mode against ARTS with respect to workload, traffic-handling capacity, susceptibility to blunders, and stressfulness. By regrouping the data presented in table 32, the responses to these two questions can be used to compare the various mode options. The results of this regrouping are given in table 45.

The index values in this table show a relatively firm preference for the single command and Vosyn mode options, and a mild preference for full-data block formats.

The overall rank indices generated in table 30 from responses to summary question 1 can be combined in a similar fashion to deduce the relative ranking of the various mode options. The results of this analysis are presented in table 46 with the favored option indicated under each category.

TABLE 45. COMPARISON OF MODE OPTIONS USING QUESTION A.1.A AND A.1.B. RESPONSES

Data Comparison	Question A.1.A.				Question A.1.B.				
					Sum of Weighted Replies				
	Mix	Number of Subjects	Sum of Weighted Replies	Overall Normalized Index	Workload	Capacity	Blunders	Stress	Overall Normalized Index
FDB vs. TAB (M1 + M2) - (M3 + M4) + Favors FDB	20%	3	-1	.15	2	-1	-2	-1	-.08 Tab
	50%	7	7	FDB	0	0	3	1	.07 FDB
	80%	3	-2	Favored	-2	0	0	3	.04 FDB
Multiple vs. Single (M3 + M4) - (M5 + M6) + Favors Multiple	20%	3	-5	-.73	-4	-4	-3	-3	-.58 Single
	50%	7	-12	Single	-8	-5	-5	-4	-.39 Single
	80%	3	-2	Favored	-3	0	-1	-3	-.29 Single
Voice vs. Vosyn (M1 + M3 + M5) - (M2 + M4 + M5) + Favors Voice	20%	3	-1	-.56	-5	-3	1	0	-.19 Vosyn
	50%	7	-15	Vosyn	-15	-5	-12	-13	-.54 Vosyn
	80%	3	-6	Favored	-7	2	0	-1	-.17 Vosyn

TABLE 46. COMPARISON OF MODE OPTIONS USING SUMMARY QUESTION 1 RESPONSES FROM TABLE 28

Data Comparison	Net Overall Rank Index (Normalized)				
	Workload	Capacity	Blunders	Stress	Overall
FDB vs. TAB [(M1 + M2) - (M3 + M4)] ÷ 2	-1.03 FDB	-1.17 FDB	.00 Neutral	-.78 FDB	-1.17 FDB
Multiple vs. Single [(M3 + M4) - (M5 + M6)] ÷ 2	1.20 Single	1.45 Single	.67 Single	.98 Single	.72 Single
Voice vs. Vosyn [(M1 + M3 + M5) - (M2 + M4 + M6)] ÷ 3	1.52 Vosyn	.74 Vosyn	-.13 Voice	.37 Vosyn	.89 Vosyn

Again, the FDB, Single Command, and Vosyn mode options are favored with one exception. There is apparently a relatively weak feeling that the voice option would be less susceptible to blunders than the Vosyn. This is not borne out by the conflict data, however. The voice modes had one less conflict than the Vosyn modes (3 versus 4). The conflict data in table 43 does not favor the FDB modes (two conflicts) or the equivalent TAB modes (two conflict). The multiple command modes (two conflicts) are somewhat better than the single command modes (three conflicts).

The quantitative test data can be combined in the same fashion as the subjective test data to gain further insight into the relative performance of the mode options. Message transaction time data and average queue data from tables 37, 38, and 39, as well as dispersion data on arrival time errors at the inner fix from table 42, are recombined in table 47 for this purpose.

By every quantitative measure employed in table 47, the single command option outperforms the multiple command option at all mix levels. The TAB option outperforms the FDB option in every comparison except that the dispersion in arrival-time error at the inner fix is slightly lower for the FDB modes at the 80-percent mix level. It is difficult to get a fair comparison between FDB and TAB formats with multiple command data because the trackball slewing required by this option constitutes a much greater handicap in the FDB modes than it does in the TAB modes. In the TAB-Multiple modes, the controller can leave his trackball on the bottom line of the active command list throughout the test except for occasional slews to execute a handoff or

TABLE 47. COMPARISON OF MODE OPTIONS USING MTT, QUEUE, AND DISPERSION DATA

Data Comparison	Mix	Net Values (Normalized)				
		Avg. MTT Data Link	Avg. MTT Voice Link	Avg. MTT Combined	Avg. Queue	Dispersion Inner Fix Arrival Time Error
FDB vs. TAB (M1 + M2)- (M3 + M4)	20%	2.0 TAB	2.9 TAB	2.7 TAB	.114 TAB	.39 TAB
	50%	1.3 TAB	.9 TAB	1.1 TAB	.068 TAB	.35 TAB
	80%	2.6 TAB	1.4 TAB	2.4 TAB	.116 TAB	-.22 FDB
Multiple vs. Single (M3 + M4)- (M5 + M6)	20%	.6 Single	1.7 Single	1.5 Single	.069 Single	2.48 Single
	50%	2.1 Single	2.3 Single	2.2 Single	.094 Single	.17 Single
	80%	2.1 Single	2.2 Single	2.1 Single	.096 Single	.81 Single
Voice vs. Vosyn (M1 + M3 + M5) - (M2 + M4 + M6)	20%	1.7 Vosyn	-3.0 Voice	-2.1 Voice	.194 Vosyn	2.86 Vosyn
	50%	2.3 Vosyn	- .5 Voice	.8 Vosyn	.237 Vosyn	.81 Vosyn
	80%	2.0 Vosyn	- .6 Voice	1.5 Vosyn	.154 Vosyn	.79 Vosyn

disengagement. If he follows this procedure, the time lost in selecting commands with the trackball is reduced to zero. The TAB-Multiple and the TAB-Single modes operate almost identically under these conditions. In the FDB-Multiple modes, however, the controller must slew the trackball from one aircraft symbol to another to select the next command in sequence. The time lost in trackball slewing is inescapable in both FDB-Multiple modes, and it shows up in larger MTT values and longer average queues.

The results of the voice versus Vosyn comparison in table 45 are mixed. The processing of data link commands is apparently faster with the Vosyn, but the processing of voice link commands is faster using voice transmissions. The average MTT values for a combination of voice and data link messages favor voice at the 20-percent mix, but favor the Vosyn at 50- and 80-percent mixes. Shorter average queues occur with the Vosyn at all mix levels. The conclusion, therefore, is that the quantitative data generally favors the Vosyn mode option.

If two successive tests for a given controller involved a change of only one mode option, he was asked on the postexperiment questionnaire to judge the relative merits of the two options with respect to workload, capacity, susceptibility to blunders, and stressfulness. The results from these direct comparison questions are tabulated in the Subjective Data Analysis section of the report. Table 26, for example, indicates an overall preference for FDB over TAB. In addition, 73 percent of the subjects felt that monitoring the flow of traffic was distracted more by using the tabular list than by the additional clutter caused by commands in the third line of the data block. When asked directly in question C-11, 31 percent of the controllers admitted having problems relating a command in the tabular list with the appropriate aircraft in the TAB-Multiple modes (3, 4). In response to question C-12, 62 percent of the subjects never found it necessary to dispatch a command other than the bottom one on the active list. Table 27 indicates an overall preference for the single command option over the multiple command option. Only 18 percent of the subjects felt that the ability to select the desired command for transmission in the multiple command modes was worth the additional time required to identify the command with the trackball. Table 28 indicates a preference for the Vosyn over voice at the 20-percent mix (where voice link traffic is heaviest), indifference at the 50-percent mix, and a preference for voice over Vosyn at the 80-percent mix. All of the subjects answering question D-6 felt that the Vosyn, to some degree, permits simultaneous monitoring of the command being enunciated and the evaluation of the next command. Eighty-four percent of them believed that this look-ahead technique could be employed almost always or in the majority of cases. This opinion conflicts with the responses to question C-3, however, where the subjects were asked if they listened to the Vosyn deliver its message and to the pilot's reply before shifting their attention to the next command. If one assumes, arbitrarily, that "almost always" means 95 percent of the time, "in a majority of cases" means 75 percent, "about half the time" means 50 percent, "in a minority of cases" means 25 percent, and "rarely" means 5 percent, then the subjects listened to the Vosyn deliver its message and to the pilot's reply

89 percent of the time in the CBE mode (7), 73 percent of the time in the TAB modes (4, 6) and 60 percent of the time in the FDB mode (2). These percentages are directly correlated with the average MTT for those modes. Thus, the greater the average MTT, the less often did the subjects listen to the Vosyn complete its message before moving on to the next command, i.e., the greater their communications workload, the more inclined they were to look ahead during a Vosyn transmission.

In response to question C-2, 81 percent of the controllers found that the dispatching and monitoring of Vosyn commands was less tiring than voicing the commands themselves.

The final step in evaluating the mode options is to use the time interval data in table 48 in conjunction with the timelines in appendix C to identify the underlying reasons for the differences in performance between the various options. First of all, let us examine the voice and Vosyn options. The message delivery time (MDT) is a time measure of the time spent by a subject enunciating a command in the voice modes (1, 3, 5). The overall average MDT value for these modes at all mix levels is 3.8 seconds. This may be regarded as the average duration of command transmissions by voice. The MDT for the Vosyn modes, however, is measured between the DISPATCH (6) or ENTER (2, 4) key action and the end of the Vosyn transmission (VPTT). If the Vosyn is still tied up with the previous transmission when the proper key is pushed, then the MDT includes a Vosyn queue delay as well as the time spent articulating the command. The contribution of this queue delay can be seen from the fact that the Vosyn MDT values are higher at the 20-percent mix than at the 80-percent mix, and higher for the slow modes (2, 4) than for the fast mode (6). To get a true measure of the average time spent by the Voysn enunciating each command, it is necessary to use only the CBE MDT data in tables 37, 38, and 39. The average of these values at all mix levels is 5.7 seconds. This may be regarded as the average duration of actual command transmissions by the Vosyn. The Vosyn, therefore, requires 50 percent more time than voice on the average to enunciate commands. Data link MDT values for all modes and mixes average out to only .53 seconds.

In the discussion of Vosyn and voice performance that follows, a comparison of otherwise equivalent modes is implied, i.e., mode 1 versus mode 2, mode 3 versus mode 4, and mode 5 versus mode 6. The Vosyn modes compensate for their slower talking rate, to a degree, by having shorter pilot response times and, for all data link transmissions and some voice link transmissions, shorter command inititation delays. As a consequence, the average MTT value for combined data link and voice link messages is actually shorter for Vosyn modes at the 50- and 80-percent mix levels in spite of the fact that the Vosyn takes longer to enunciate a command than voice. The component time intervals listed in table 48 illustrate the relative performance of the Vosyn and voice modes. In interpreting this data, remember that:

$$MTT = CID + MDT + PRT$$

TABLE 48. COMPONENTS OF MTT FOR CBA MODES

Mix	Mode	Voice Link				Data Link				Combined
		AVG. CID	AVG. MDT	AVG. PRT	AVG. MTT	AVG. CID	AVG. MDT	AVG. PRT	AVG. MTT	AVG. MTT
20%	1. FDB-M-Voice	8.9	3.8	3.5	16.2	9.4	.5	4.9	14.8	15.9
	2. FDB-M-Vosyn	10.2	6.8	2.4	19.4	7.9	.5	5.1	13.5	18.2
	3. TAB-M-Voice	6.3	3.5	3.1	13.0	6.8	.4	5.0	12.3	12.9
	4. TAB-M-Vosyn	8.0	6.4	2.4	16.9	6.5	.5	5.0	12.0	15.9
	5. TAB-S-Voice	5.8	3.9	2.7	12.3	7.6	.6	5.1	13.3	12.5
	6. TAB-S-Vosyn	5.9	6.1	2.3	14.3	4.2	.6	5.0	9.8	13.4
50%	1. FDB-M-Voice	7.2	3.8	4.4	15.4	9.1	.5	5.1	14.6	15.0
	2. FDB-M-Vosyn	6.7	6.5	2.5	15.7	6.6	.5	5.0	12.0	13.9
	3. TAB-M-Voice	6.5	3.9	4.1	14.5	7.8	.5	5.1	13.1	13.8
	4. TAB-M-Vosyn	5.6	6.4	2.7	14.8	5.4	.5	5.0	10.9	12.9
	5. TAB-S-Voice	4.9	3.8	3.2	11.9	5.3	.6	5.0	10.9	11.4
	6. TAB-S-Vosyn	3.6	6.6	2.6	12.8	3.2	.6	5.0	8.9	10.9
80%	1. FDB-M-Voice	6.8	4.0	4.5	15.3	10.5	.5	5.0	16.0	15.9
	2. FDB-M-Vosyn	8.5	6.4	2.3	17.1	7.7	.5	5.0	13.1	13.9
	3. TAB-M-Voice	6.0	4.1	4.8	14.9	7.1	.5	5.0	12.7	13.1
	4. TAB-M-Vosyn	6.0	6.0	2.7	14.8	5.7	.5	5.0	11.2	11.9
	5. TAB-S-Voice	5.9	3.5	3.3	12.6	5.0	.6	5.1	10.7	11.1
	6. TAB-S-Vosyn	4.2	5.9	2.6	12.7	3.6	.6	4.9	9.1	9.8

The pilot voice link response time (PRT) in the Vosyn modes only involves the pilot pushing the ENTER key and verbally acknowledging the transmission with a "roger." In the voice modes, PRT involves the pilot's ENTER, the "roger," and the controller's depression of the ADVANCE (5) or ENTER (1, 3) key. The extra controller action on voice link messages explains why Vosyn PRT values are always shorter than voice PRT values.

The overt controller actions in dispatching data link commands in equivalent voice and Vosyn modes are identical. In spite of this, the data link CID values are always lower in the Vosyn modes. There appear to be two reasons for this:

1. In the voice modes, a controller must first decide whether a command refers to a data link or a voice link aircraft, i.e., he must check for the presence of an asterisk next to the aircraft identity. If the command is a data link message, he pushes the DISPATCH key (5) or executes the sequence DISPATCH-slew-ENTER (1, 3). If the command is a voice link message, he enunciates the message before pushing the ADVANCE key (5) or executes the sequence ADVANCE-slew-ENTER (1, 3). In the Vosyn modes, the controller's dispatch actions are the same regardless of whether the command is addressed to a data link or to a voice link aircraft; i.e., in either case, he executes DISPATCH (6) or the sequence DISPATCH-slew-ENTER (2, 4). Thus, in the Vosyn modes, the extra step of identifying voice link and data link aircraft is not necessary prior to dispatch; hence, CID values are correspondingly lower.

2. In the voice modes a controller is completely occupied while enunciating a voice link message and then terminating the transaction with ADVANCE (5) or ADVANCE-slew-ENTER (1, 3). In the Vosyn modes, the controller can initiate the processing of the next command. This look-ahead capability shows up in reduced CID values for the Voysn modes.

With respect to voice link messages, however, the above factors leading to reduced CID values for the Vosyn modes are counterbalanced by the fact that the controller must execute more steps to dispatch a Vosyn command, i.e., DISPATCH (6) or DISPATCH-slew-ENTER (2,4) precede the enunciation of the command. In the voice modes, he simply speaks the message without prior key action. In addition, of course, the controller might feel obligated to evaluate a Vosyn command completely before dispatching; whereas, he can evaluate a voice command as he enunciates it. As a consequence of these opposing effects, the voice link CID values shown in table 48 sometimes favor the Vosyn modes and sometimes favor the voice modes.

Now let us switch our attention to the underlying reasons for the differences in performance between the FDB and TAB modes. The equivalent modes to be compared here are mode 1 (FDB-M-Voice) versus mode 3 (TAB-M-Voice) and mode 2 (FDB-M-Vosyn) versus Mode 4 (TAB-M-Vosyn). The data in table 48 indicate that the TAB modes (3, 4) always have lower MTT values than the FDB modes (1, 2) and that this advantage is almost entirely due to shorter CID's. As discussed previously, the underlying cause of this CID difference is the greater amount of trackball slewing required in the FDB modes. To transmit data link or Vosyn commands, the controller theoretically executes DISPATCH-slew-ENTER in all

four modes, but he can leave the trackball on the bottom line of the new command list in the TAB modes (3, 4) if he chooses, thereby eliminating the slew action. He must slew from aircraft symbol to aircraft symbol in the FDB modes (1, 2); hence, their CID values are invariably greater. With respect to voice messages; the controllers apparently execute ADVANCE-slew prior to enunciating commands in mode 1, although these actions could also be taken during or after the delivery of the message. The same is true in mode 3, except that no slew action is required if the controller chooses to leave the trackball at one position in the tabular list of commands. Again, the result is a shorter CID value for mode 3 compared to that of mode 1.

In one important task, the FDB modes have an advantage over the TAB modes. It is clearly easier and quicker to correlate commands with the aircraft addressed in the FDB modes, since both are in the same location on the controller's display. Controllers can unconsciously cut corners on the command-evaluation task, however, and it is difficult to measure to what degree this was done. The fact that the TAB tests (3, 4) resulted in three conflicts and the FDB tests (1, 2) had two conflicts infers that command evaluation was being carried out as thoroughly in both modes.

In seeking to explain the difference in performance between the single and multiple command modes, the equivalent modes to be compared are mode 3 (TAB-M-Voice) versus mode 5 (TAB-S-Voice) and mode 4 (TAB-M-Vosyn) versus mode 6 (TAB-S-Vosyn). The data in table 48 indicates that the single command modes (5, 6) almost always have lower MTT values than the multiple command modes (3, 4). For data link messages, the MDT and PRT values are approximately equal for equivalent modes, hence, the differences are due entirely to CID variations. In the multiple modes (3, 4), the controller must execute the sequence DISPATCH-slew-ENTER to transmit a command; whereas, in the single modes (5, 6), he only pushes one key, DISPATCH. By leaving the trackball on the bottom line of the tabular list, the controller can eliminate most of the slewing action in the multiple modes, but not all of it. About 29 handoffs must be accepted during a 1-hour run, and each of these require a trackball slew to one of the two feeder fixes. This number is an appreciable fraction of the 120 to 150 commands handled by a controller during the same period. After the handoff, the trackball must be returned to the tabular list near the bottom of the display. Disengagements employ a trackball slew, but there are so few of these that they do not have a significant effect on average timing. In the single command modes, the controller can leave the trackball near the busiest feeder fix and minimize the slewing distances. A second factor reducing the CID values of the single command modes (5, 6) is the fact that the appropriate aircraft symbol blinks concurrently with a command, making it easier for the controller to evaluate the situation before dispatching the command. In the multiple modes, the controller must first search for the aircraft addressed by a command before he can pass judgment on it.

For voice link messages, the MDT values are the same for equivalent modes. In mode 4, the controller must execute DISPATCH-slew-ENTER before the Vosyn enunciates the command, whereas in mode 6, he only depresses one key, DISPATCH. This difference results in lower CID values for mode 6. In mode 3, the controller executes the sequence ADVANCE-slew before, during, or after he enunciates the command, and then he must push his ENTER key when the pilot's "roger" has been received. In the equivalent single command mode (5), the controller pushes just one key (ADVANCE) after the pilot's "roger." The extra key and slew action in mode 3 results in either a longer CID or a larger PRT depending on when the ADVANCE-slew takes place. The blinking aircraft symbol in the single command modes (5, 6) also reduces CID values for voice link messages.

The last mode option to be discussed is control-by-approval (modes 1-6) versus control-by-exception (mode 7). Because of the great variation in performance among the six CBA modes, it is not useful to combine the subjective and objective results for all six CBA modes and to compare the composite data against the corresponding CBE data. Instead, the best of the six modes tested (mode 6) will be taken as representative of the CBA option and only its data will be compared to mode 7 data. Except for the time necessary to correlate commands with targets, it is believed that the quantitative performance of mode 6 (TAB-Single-Vosyn) would not differ significantly from that of the FDB-Single-Vosyn mode, which appears to be the optimum CBA mode, but for which no test data exists. In fact, if the controller, without prior evaluation, immediately pushes DISPATCH key whenever a blinking command is displayed, the quantitative performance of mode 6 would approach that of mode 7 (CBE). This ability to process a large number of commands quickly provides a safety valve during short peiods of intensive traffic activity. Only the TAB-Single-Vosyn (6), TAB-Multiple-Vosyn (4), and FDB-Single-Vosyn modes, however, permit this "machine gun" dispatching of commands.

In examining the subjective data, a comparison of mode 6 and mode 7 produces mixed results. Relative to present-day ARTS, mode 6 achieved the highest positive score, whereas mode 7 was tied with mode 2 at the fourth rank (question A.1.A, table 32). Relative to present-day ARTS with respect to workload, capacity, blunders, and stress, mode 6 ranked first among the 20-percent mix subjects, first at 50-percent mix and fifth at 80-percent mix. Mode 7 was respectively ranked second, fourth, and tied for first (question A.1.B, table 32).

In the final ranking of all modes, however, mode 7 ranked second and mode 6 ranked third (summary question 1, table 33). Under specific categories, mode 7 ranked above mode 6 with respect to workload and stress, but mode 6 ranked above mode 7 with respect to capacity and susceptibility to blunders (summary questionnaire, table 34). In the direct comparison of various CBA modes against the CBE mode (7), the CBE mode was generally favored, the preference being strongest at the 80-percent mix (table 29).

The more important quantitative measures in tables 37, 38, and 39 favor CBE (7) over CBA (6):

(a) Message transaction times are lower for mode 7 than mode 6 at all mixes.

(b) Average and maximum queue lengths are lower for mode 7 at all mixes.

(c) Average service times are lower for mode 7 at all mixes.

At the 80-percent mix, for example, the combined average service time of mode 6 is more than twice that of mode 7; i.e., mode 7 has more than twice the message throughput capacity. However, there are more tag repositionings in mode 7 than in mode 6; there are more disengagements and the dispersion of arrival time errors at the inner fix is greater. Three serious violations of spacing minimums occurred during mode 7 tests, whereas, only one occurred during mode 6 tests. This latter difference is not statistically significant with the small sample size.

Control-by-exception would clearly reduce workload and would result in a substantially greater command throughput rate. This would enable the controller to handle a greater instantaneous aircraft load if other constraints such as intrail spacing minimums, arrival time dispersion at the runway threshold, and runway occupancy times did not countervail. In the CBE mode, command processing and transmission times would have a much lower effect on the limitation on capacity. According to the test observers, the problem with the CBE mode is the apparent difficulty of maintaining an accurate "picture" without the stimulation and reinforcement provided by constantly generating and enunciating commands. This problem could become critical, they believed, in the event of an M&S failure, which would force the controller to suddenly start directing traffic on a manual basis after a prolonged period as a passive monitor. If this criticism is valid, one might predict that controllers would not accept a procedure in which a CBE M&S system must be backed up by manual techniques, especially if the traffic levels were beyond their manual capacity. In actual fact, however, the controllers' responses to question B-8 on the postexperiment questionnaire were roughly the same for both CBA and CBE modes; i.e., about 90 percent felt they could at least clear the terminal area safely after a M&S failure in either case. However, in response to question C.18, 43 percent of the 50-percent mix subjects felt that the low workload under CBE might cause a controller to lose concentration, and, therefore, be less likely to detect a blunder or malfunction when it does occur. Since the test program made no attempt to actually evaluate backup procedures experimentally, no final conclusion can be drawn on the adequacy of the CBE mode in this regard. Additional testing is obviously required to settle this issue, which is crucial to the ultimate acceptance of CBE procedures.

Another possible version of CBE allows the controller to disapprove a command prior to its transmission. In response to question C.15, 57 percent of the controllers found it disconcerting not to have pretransmission approval of commands in the CBE mode tested. All six subjects employing the CBE mode at the 20- and 80-percent mix levels, felt that a DISAPPROVE key would be desirable (questions C.18 and C.20). On the other hand, five of these same six subjects believed that eliminating the manual dispatch of commands in CBE was an improvement (question C.19) and that the automatic dispatch of commands would be very helpful in handling a high traffic density for a prolonged period (question C.21).

Providing a DISAPPROVE key in the CBE mode, however, would greatly reduce message throughput. Sufficient time must then be allowed prior to the dispatch of each command for the controller to evaluate it and exercise his option to disapprove if he so desires. Only one command at a time can be displayed for evaluation, otherwise the specific command being disapproved would have to be identified by the trackball. The time required to process a command in this procedure would approach that required in mode 6 (TAB-Single-Vosyn). Little or no capacity advantage could be achieved with the CBE mode if prior disapproval of commands were incorporated as a standard feature. In fact, if the controller employed "machine gun" dispatching in mode 6, the capacity of that mode would exceed the capacity of mode 7 with the "prior disapproval" option.

COMPARISON OF DATA LINK AND VOICE LINK.

Having tested various mixes of data link and voice link aircraft in a M&S environment, it is now possible to specify the benefits derived from the introduction of data link in some detail.

In comparing the seven data link modes against present-day ARTS in postexperiment question A.1.A, the controller responses were favorable to all the modes tested except mode 3 (table 32). However, this question is not particularly useful for a strict comparison of data link with voice link because it encompassed two inseparable procedural changes. For example, (1) Automatic computer generation of M&S commands instead of controller generation of radar vectors, and (2) Transmission of a significant percentage of the commands via data link instead of by voice.

In question A.1.B, the subjects were asked if the use of data link would increase or decrease workload, capacity, susceptibility to blunders, and stressfulness relative to present-day ARTS procedures. The responses were generally favorable to data link, except with respect to mode 1 and 3. More than half of the negative responses concerned susceptibility to blunders (table 32). Assuming that all of the aircraft in each scenario had been equipped with data link, the subjects felt even more positive about the seven test modes relative to the current ARTS system than they did in the mixed data link-voice environment actually tested (postexperiment questions A.2.A and A.2.B).

In summary question 4, the subjects were asked to assume that some form of M&S already existed at all the major airports. They felt that the addition of data link, under those circumstances, would help decrease controller workload (table 31). All in all, the subjective controller opinions generally favored the introduction of data link.

In figure 24, it can be seen that as the percentage of data link-equipped aircraft increases at full load, the average MTT decreases for all modes except mode 1. Since only three subjects were tested using mode 1 at the 80-percent mix level, the rise in the MTT value at this mix will be regarded as a statistical anomaly in this report. This assumption is supported by the fact that the MTT for mode 1 should be equal to those of mode 2 when the mix level is at 100 percent since the two modes are then functionally identical (all data link).

Three measures drawn from tables 37, 38, and 39 are also indications of message-handling capacity. These are (1) the average MTT, (2) the average ST, and (3) the average queue length. The pertinent data is repeated in table 49 for the best of the voice modes (TAB-Single-Voice, mode 5).

TABLE 49. THREE MEASURES TO COMPARE DATA LINK AGAINST VOICE LINK (MODE 5 - TAB-SINGLE-VOICE)

Measure	% Mix	Combined Average	Data Link Average	Voice Link Average
Message Transaction Time (Seconds)	20%	12.5	13.3	12.3
	50%	11.4	10.9	11.9
	80%	11.1	10.7	12.6
	Change*	-11%	-20%	+2%
Service Time (Seconds)	20%	8.2	3.0	9.5
	50%	6.5	3.0	10.0
	80%	5.1	3.4	11.7
	Change*	-38%	+13%	+23%
Queue Length	20%	.5040		
	50%	.4048		
	80%	.3242		
	Change*	-36%		

*Percentage change between the 20% and 80% mix levels.

In figure 24, the combined average MTT at peak loads for mode 5 decreased from 13.8 seconds at the 20-percent mix to 10.7 seconds at the 80-percent mix, a 22-percent reduction. Thus, as load goes up, there is an improvement in the percentage decrease in the combined average MTT value caused by the introduction of more data link aircraft. However, if it can be assumed that in most cases the controller does not need to wait for the data link WILCO response before going on to the next command, the average queue length and combined average service time are better measures of actual message throughput capabilities than the combined average MTT value. The latter includes queue delays and WILCO delays, and, hence, is not indicative of the actual time spent by a controller in servicing a command. Of these two measures, queue length is the more reliable because service time is defined to include the enunciation of messages and, in the Vosyn modes (2, 4, and 6), the controller may actually be looking ahead to the next command during this period. Extrapolating the mode 5 data (in table 49) shows that the percentage decreases in queue length and service time should approach 55 percent in going from a zero-percent data link mix (all voice) to a 100-percent data link mix (all data link); i.e., the message processing capability of mode 5 should more than double. Since a data link transmit/receive sequence takes only 0.153 seconds to complete, and a voice link command, on the average, takes 3.8 seconds to enunciate, one might intuitively expect that the message processing advantage of data link would be even greater. However, when voice link is employed, the controller can evaluate a command as he enunciates it, and, simultaneously, the pilot is listening to the command and evaluating it also. With data link the controller must fully evaluate a command before he dispatches it, and the pilot can start his evaluation only after the command has been received and displayed in the cockpit; i.e., the principal steps in processing a command occur in sequence rather than in parallel. The net result is to reduce, somewhat, the intrinsic throughput advantage of data link compared to voice link.

Data link communications, of course, utilize the frequency spectrum more efficiently than voice link. A simplified analysis of their advantage follows:

T = Average time aircraft is under the jurisdiction of approach control (handoff from enroute to ILS gate) in seconds

n = Number of commands issued during approach

A = Average arrival rate (aircraft per hour)

$\frac{n}{T}$ = Commands per second for each aircraft

$\frac{TA}{3600}$ = Average instantaneous load

$\frac{nA}{3600}$ = Average number of commands per second for all aircraft under the jurisdiction of approach control

In the test scenarios:

A = Peak average arrival rate - 40 aircraft/hour

T = Average flying time between Roggen handoff and gate = 1020 seconds

n = number of commands = 8

Substituting these peak load values:

$$\frac{TA}{3600} = 11.3 \text{ aircraft (average instantaneous load)}$$

$$\frac{nA}{3600} = 0.089 \text{ commands per second}$$

In other words, to direct an instantaneous load of 11.3 aircraft, the M&S system must process an average of 0.089 commands per second, i.e., an average of one command every 11.3 seconds. Since, in this simulation program, a voice message took an average of 3.8 seconds to enunciate, and the average pilot response time was 2.4 seconds (table 37; modes 2, 4, and 6), each voice message used the channel for 6.2 seconds; i.e., the channel occupancy is 55 percent (6.2 ÷ 11.3).

With data link, the ground system must not only transmit each command, but it must also periodically poll each aircraft from which a WILCO response is expected. For example, if a command has just been dispatched to a data link aircraft, it would be polled every second until the reply is received. On the average, the pilot response delay is 5 seconds. Therefore, about five transmit/receive sequences would be required for polling. With fast-acting transceivers, each of these would use the channel for 0.153 seconds. Thus, each data link transaction (message plus polls) utilizes the channel for about 0.918 seconds; i.e., the data link channel occupancy averages about 8 percent (0.918 ÷ 11.3). This is an upper boundary because some of the polls would be eliminated by the transmission of commands that have a higher priority in accessing the channel.

These same relationships may be used to estimate the limits placed on approach control capacity by a finite command service time. The model will be a single server having a constant service time (S) with random message arrivals (Poisson) at an average rate λ. The well known formula for average waiting time with this model is:

$$W = \frac{\lambda}{2\mu(\mu - \lambda)} = \frac{S\lambda}{2(\frac{1}{S} - \lambda)} = \frac{\rho S}{2(1 - \rho)}$$

where

$$\mu = \text{max service rate} = \frac{1}{S}$$

$$\rho = \text{utilization factor} = \lambda S$$

To find the service time (S) required to achieve a given average waiting time (W) at various message arrival rates, we expand the relationship above as a quadratic:

$$S^2 + 2WS - \frac{2W}{\lambda} = 0$$

The root having practical significance is

$$S = -W + \sqrt{W^2 + (\frac{2W}{\lambda})}$$

Previously, we found that

$$\lambda = \text{average message arrival rate} = \frac{nA}{3600}.$$

Substituting this expression, we obtain S in terms of W and A, the aircraft arrival rate:

$$S = -W + \sqrt{W^2 + \frac{7200\ W}{nA}}$$

The variation of aircraft capacity (A) with message service time (S) is plotted in figure 25 for average message delays in queue of 2 seconds, 4 seconds, and 6 seconds. This plot assumes that eight commands are issued to each aircraft while they are under the jurisdiction of approach control (n=8).

Using the measured service times presented in tables 37, 38, and 39 in conjunction with figure 25 enables us to judge the adequacy of various modes and options over a range of aircraft arrival rates. For example, if the aircraft arrival rate is 40 aircraft per hour, a message service time of less than 7.1 seconds would be required to keep the average message queue delay below 6 seconds. As we saw previously, messages are generated, on the average, every 11.3 seconds at this load, and a 6 second queue delay is an appreciable

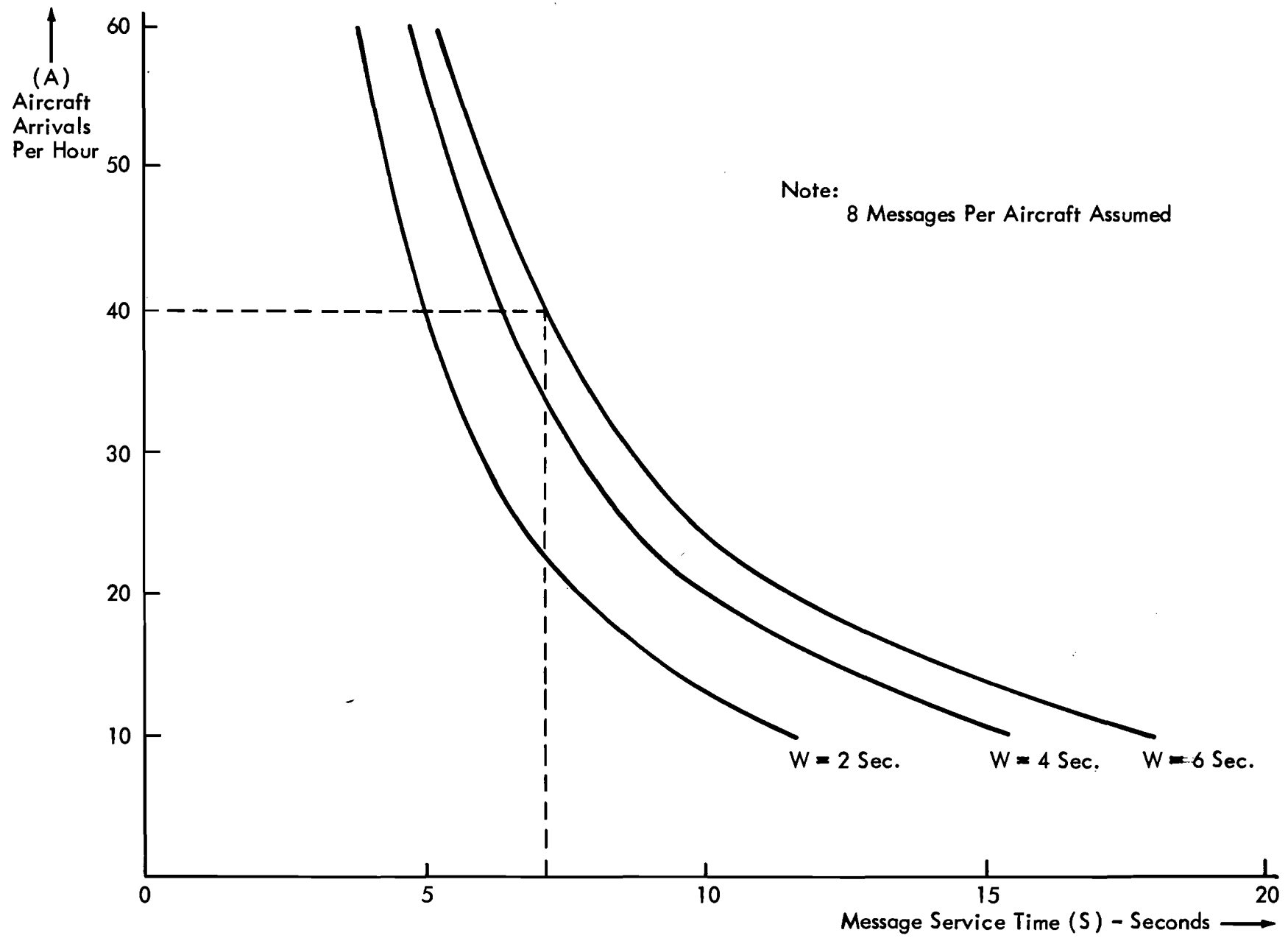


FIGURE 25. ALLOWABLE AIRCRAFT ARRIVAL RATE VS. MESSAGE SERVICE TIME FOR VARIOUS AVERAGE MESSAGE QUEUE DELAYS (W).

fraction of the total interval. According to the data link and voice link service times in table 37, only the voice modes 1 and 3 and the CBE mode 7 can meet this requirement at the 20-percent mix level. None of the CBA-Vosyn modes (2, 4, 6) are acceptable, and even the CBE mode is just barely acceptable. All modes are adequate at the 80-percent mix level. The general implication is that for high-capacity operations (greater than 40 aircraft per hour), some form of data link capability is necessary to keep message queue delays at an acceptable level. For example, at 60 aircraft per hour (the probable ultimate capacity permitted by runway occupancy time and delivery precision at the runway threshold), commands would be generated, on the average, every 7.5 seconds. To achieve an average message queue delay of 4 seconds, a service time of 4.7 seconds would be required. Such a service time cannot be realized unless at least half of the traffic is data link-equipped and, even then, only by mode 7 and mode 1. At an 80-percent mix, all the modes could handle this traffic level except mode 2 and mode 5.

Obviously the message queue delay will vary with the aircraft arrival rate; hence the command lead time should not be a fixed constant, but should be adjusted online automatically to compensate for variations in the average message queue delay. The leadtime should also be adapted to the message-processing capabilities of individual controllers. Needless to say, the lead time for data link commands will not necessarily be the same as that for voice link commands.

The variation of MTT with aircraft load (test time) in figures 19a through 21b requires some explanation, since one might expect that MTT values should always rise with increased load because of longer queue delays. For example, at the 20-percent mix level, data link MTT values for the Vosyn modes 2 and 4 drop with increased load; whereas, MTT for the voice modes M1, M3, and M5 rise (figure 19a). It is believed that the explanation for this phenomenon is that the controllers adapt to increased loading by speeding up their processing of commands and by cutting corners where possible. In the Vosyn modes, they can reduce processing time by looking ahead to the next command while the Vosyn is enunciating the present command and by spending less time in evaluating the situation and the commands prior to dispatch. In the voice modes, only the latter option is available, since the subject must enunciate the current command himself, and he is fully occupied until the transaction is complete. The extra step of identifying whether an aircraft is voice link or data link-equipped also increases the processing time of the voice modes and leads to greater queue delays. On the other hand, the Vosyn takes 50 percent longer to enunciate a command than voice, and this increases the queue delays for voice link aircraft using the Vosyn modes. The fact that the controllers can maintain their message throughput by reducing the time spent on situation monitoring and message evaluation makes it unwise to judge capacity solely on the basis of MTT or service time measurements. This data should be augmented by evidence that the subject has not allowed the level of safety to degenerate by resorting to dangerous shortcuts.

It must be assumed that the use of data link transmissions will result in fewer errors and misunderstandings than transmissions over the often noisy voice party line. Pilot workload will be reduced because he will not be forced to monitor a stream of voice messages to pick out those messages addressed to his aircraft. On the other hand, some pilots find a party line is a useful source of information on the aircraft around them.

The last important comparison of purely data-link operation to the current voice link operation can be obtained by an interpolation of the combined MTT curves in figure 24 to the zero percent and 100 percent mix values. At these limits, the MTT correspond respectively to purely voice and data link operations, providing the following significant results:

1. CBE (mode 7): MTT reduced from 12.2 seconds (zero-percent data link) to 5.2 seconds per message (100-percent data link). This represents a reduction to less than half of the purely voice link value (-57 percent referenced to voice link operation).

2. TAB-Single-Vosyn (mode 2): MTT reduced from 15.5 to 8.3 seconds per message (a 46-percent improvement).

3. FDB-Multple-Vosyn (mode 2): MTT reduced from 19.5 to 14.6 seconds (25-percent improvement).

4. All other modes (except mode 1): Improvements ranging from 14 percent to 37 percent.

5. FDB-Multiple-Voice: An improvement that has been assumed to be roughly the same as mode 2 (25 percent) when the bad 80-percent mix data point is discarded and the equivalent mode 1 point is used.

SUMMARY OF RESULTS

The summary of results is presented in four parts: (1) the mode RANKINGS, (2) preferences for each of the DESIGN ALTERNATIVES, (3) improvements obtainable as the percentage of data link aircraft is increased (IMPROVEMENTS WITH A DATA LINK), and (4) OTHER INFORMATION on performance and procedures that will be helpful to follow-on data link programs.

RANKINGS.

1. The best modes were the CBE, FDB-Multiple-Vosyn, and TAB-Single-Vosyn.

2. The worst modes were the FDB-Multiple-Voice and TAB-Multiple-Voice.

The control-by-exception (CBE) mode resulted in much lower communication delays (message transaction times, queue lengths, etc.), but caused some controller concern over its potential susceptibility to blunders. The FDB-Multiple-Vosyn mode was given the highest overall ranking after the controllers were exposed to all modes but its quantitative performance was the worst because of the delays of the trackball action. This action was not required in the TAB-Single-Vosyn mode which was also aided by a blinking target symbol for target correlation with the active command. In addition to the trackball action, the low rankings of the FDB-Multiple-Voice and TAB-Multiple-Voice modes were caused by the requirement for different voice and data link procedures for servicing the commands. The servicing consisted of controller identification of an asterisk (*) character for data link aircraft and a subsequent depression of a DISPATCH (data link) or ADVANCE (voice link) function key. This time consuming and annoying procedure was not required for the single key operation in the Vosyn modes.

DESIGN ALTERNATIVES.

1. Subjective data favored FDB, and quantitative data favored the tabular list.

2. Single command modes were strongly preferred over multiple command modes (mainly due to the elimination of the trackball action).

3. Vosyn modes were mildly preferred over voice modes (mainly due to procedural simplicity).

4. The CBE mode was subjectively preferred over all but one of the control-by-approval (CBA) modes and was strongly preferred over all modes by the quantitative data.

5. The contradiction in the subjective and quantitative comparisons of FDB-Multiple with TAB-Multiple modes was due to differences between the delay measurements and the questionnaires. Although the TAB modes minimized the motion of the trackball, the controllers customarily worked with the FDB and valued the close proximity of the command to the target symbol.

6. The preferences for single over multiple commands and the Vosyn over voice strongly suggest that the FDB-Single-Vosyn mode would have performed extremely well if it had been tested. The Vosyn option has been selected here because it was favored by the controllers. Moreover, even though the Vosyn was less flexible and slower than voice communications, the delay measurements indicated that a busy controller would look ahead to the next command during a Vosyn transmission.

IMPROVEMENT WITH A DATA LINK.

1. If all of the aircraft in the simulation scenario were data link equipped, the controller's message transaction times at maximum load would compare to a purely voice link operation as follows:

a. CBE; 57-percent improvement, from 12.2 to 5.2 seconds per message,
b. TAB-Single-Vosyn; 46-percent improvement, from 15.5 to 8.3 seconds,
c. FDB-Multiple-Vosyn; 25-percent improvement, from 19.5 to 14.6 seconds,
d. All other modes; improvements ranging from 14 percent to 37 percent.

The overall result from the above comparison is that a data link capability definitely improved the controller's communications efficiency. This was especially true for the CBE mode where the delays in the initiation of a command were effectively eliminated. CBE therefore permitted a much faster operation in a predominantly data link environment and was ranked best at the 80-percent mix by the controllers. The improvements in most of the other modes are also significant and were substantiated by the results from the questionnaires.

2. The controllers generally accepted a data link as an operational benefit. They also preferred the automatic generation of M&S commands over their current procedures for manual vectoring provided that the simulation scenario contained a majority of data link aircraft.

OTHER INFORMATION.

Other results of this simulation study indicate the following:

1. The majority of the controllers indicated that only 1 to 3 hours of additional training would be necessary to make them feel comfortable with the operational procedures.

2. A 3-second holdover of the "W" character to indicate pilot compliance on the data link is satisfactory, but not absoulutely required. However, pilot noncompliance and data link failures should be prominently displayed until the controller resolves them.

3. Voice commands should be held over in a nonblinking state for 20 seconds in case the pilots request a repeat of the message.

4. Eighty-five percent of the controllers felt that the workload at the maximum density (44 approaches per hour) was at (22 percent) or below (63 percent) their maximum capacity. Controllers indicated that it was also relatively easy to maintain a "picture" of the traffic situation and monitor for conflicts at the reduced 2-nmi separation. However, if the M&S and the data link parts of an ARTS system failed, even though a hazard would not exist, the maximum load could not be handled indefinitely.

5. The variation in controller message transaction delays did not show a sharp increase as the traffic density steadily increased to the maximum value of 11 instantaneous aircraft. The actual variation was linear with delay increases that were generally less than 30 percent of the delays at light loads.

6. The display presentations (formats, video map, etc.) and function key operation were considered adequate by a large majority of the controllers. The preorientation of the full data block was particularly helpful in reducing the repositionings to within two to five per hour.

7. Eighty-one percent of the controllers felt that Vosyn operation was less tiring than voice.

8. Measurements of arrival time errors at the inner fix indicated that prompt delivery of the last heading command was critical to a timely arrival of aircraft on the runway. Since the delay of commands in the message queue will vary with aircraft load, the command lead time for a given mode should not be a fixed constant, but should be adjusted online automatically to compensate for queue delays and for the processing speed of each individual controller. If constant lead times are used, the specific values recommended for each mode are:

a. CBE; 2 seconds before desired execution time,
b. TAB-Multiple-Voice, TAB-Single-Vosyn, and FDB-Multiple-Vosyn; 9 seconds lead time,
c. TAB-Multiple-Vosyn, TAB-Single-Voice, and FDB-Multiple-Voice; 10 seconds lead time.

9. The real time conflict detection program revealed a total of 10 separation violations in the 91 hours of testing. This number is considered low in the face of the requirement for reduced separation criteria and the conflict situations that were deliberately inserted in each test run.

CONCLUSIONS

Four major conclusions were drawn from this simulation study. Each of these may be expressed precisely in the context of the experiments as follows: IF ATC APPROACH CONTROL COMMANDS ARE AUTOMATICALLY GENERATED BY A METERING AND SPACING SYSTEM WITH A DATA LINK COMMUNICATIONS CHANNEL, THEN:

1. A control-by-exception (CBE) mode (with computer-generated speech on the voice channel) is by far the most efficient mode tested, but it raises some questions on blunder susceptibility. This mode had message transaction times between 28 and 50 percent lower than the other modes tested and resulted in the lowest queue lengths of messages pending delivery.

2. If a control-by-approval (CBA) mode is implemented, the best operation, on the basis of both efficiency and controller acceptance would have been achieved with computer-generated speech and one-at-a-time activation of commands that are displayed in the ARTS III full-data block (FDB-Single-Vosyn). Two other favored modes, confirmed in the tests, also include computer-generated speech and are ranked as follows:

   a. Single command display in a separate tabular list.
   b. Multiple command display in the full data block.

3. If all of the aircraft in the airspace were equipped with a data link, the controller's message transaction times would decrease between 14 and 57 percent (depending on the mode employed). The data link would also produce significant improvements in the precision and timeliness of message delivery.

4. The optimization of display formats and operating procedures has a significant effect on communications efficiency and the controller's ability to provide separation assurance in dense traffic.

RECOMMENDATIONS

It is recommended that further investigation of a data link be accomplished in the following areas:

1. Simulation with the prototype version of the ARTS III M&S system involving computer-generated speech with the CBE, FDB-Multiple, and TAB-Single modes of operation. If it is possible to modify the current M&S software, the FDB-Single mode should also be investigated.

2. Verification of adequate failure recovery and traffic monitoring capabilities if a CBE mode is to be implemented in future systems. Particular attention should be addressed to the possibilities for dual-mode operation to insure continued controller familiarity with backup manual vectoring procedures. One suggested method involves the use of CBA when the traffic density is low, and a shift to CBE during peak loads.

3. Optimization of the throughput and intelligibility of computer-generated speech, particularly as it relates to speech rates, tone, and standardization within the ATC System.

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APPENDIX A

DIGITAL SIMULATION FACILITY CONCEPT

GENERAL DESCRIPTION.

The Digital Simulation Facility (DSF) was established to serve as a tool in research, development, and evaluation of air traffic control (ATC) concepts and subsystems. This section briefly provides the users of this document with background information, support requirements, and a functional description of the DSF so that the tests and their objectives are understood.

BACKGROUND. The DSF is an advanced generation of simulation facilities at the National Aviation Facilities Experimental Center (NAFEC). The Federal Aviation Administration (FAA) has performed ATC and flight simulation for more than 15 years using various analog devices as target generators. Simulation has proved to be a most valuable tool in determining and testing safe and adequate aviation systems to meet the increasing demand for air transportation.

The predecessor to the DSF was developed by NAFEC with contract support by Thompson-Ramo Woolridge, Inc., for the FAA. The facility proved the feasibility of employing digital computers as the essential components. With the advancements in computer technology, digital simulation offers many advantages that were unattainable with analog simulation. Among these are:

1. More aircraft can be simulated for studies requiring increased air traffic involving more complex problems;

2. More realistic input for radar processing, automatic tracking, and driving digital displays are attainable;

3. Modeling of airborne or ground-based computerized subsystems is facilitated;

4. Changeover time between projects is reduced;

5. Precise control of error parameters is possible, thereby enabling more accurate results;

6. Experiments are repeatable and results (controller/pilot workload message entries, conflictions, etc.) are easily recorded; and

7. Experiments may be run in either the fast time or the real time mode.

The DSF was designed and established to take advantage of those improvements. The system was designed to be flexible and to have three different modes of operation: fast time, real time, and compressed time. The system originally consisted of 12 alphanumeric digital displays, a keyboard data entry system, the Xerox Sigma 5 computer with standard equipment, a voice communication system, a data link subsystem, and communication interface with the Terminal Automation Test Facility (TATF).

PROJECT STUDIES. The facility has been used to evaluate advanced concepts in ATC systems and procedures. It is also used to support studies, evaluations and testing of NAS Stage A and ARTS III facilities at NAFEC and, in turn, projects which are supported by those facilities. In these modes, the DSF provides simulator "pilots" and their interface with NAS or ARTS air traffic controllers, and generates radar and beacon data for the simulated air traffic. Table A-1 provides a list of the self-contained ATC simulation studies and target generation studies run on the DSF. In addition to supporting major studies, the facility has been and is scheduled to be used for in-service improvement projects. These are projects that are scheduled to support studies of problems that face facilities within the ATC system. The effects on ATC of relocating navigational aids, new routes, multiple runway configurations, noise abatement procedures, and so forth, are examples of problems in this category.

FUNCTIONAL DESCRIPTION.

The following subsections present the major software programs that make up the DSF system along with a brief functional description of each.

TEST INPUT PREPARATION PROGRAM. The Test Input Preparation Program (TIPP) generates the traffic sample and the associated flight strips, flight plan cards, event tapes, and listings necessary to perform an ATC simulation. The system allows an analyst several options in which he can create a traffic sample: from controller's records, from a master file of flight plans on magnetic tape, or from synthetic flight plans by statistical generation.

EXECUTIVE AND SYSTEM PROGRAMS. System initialization, which involves the reading of key parameter values from data cards and then storing the values in common blocks, is performed by the link 1 program. Another program, link 2, controls the fast time or real time operation of the system. In fast time, the keyboard and display programs are not used, and time is advanced when the program cycle is completed, rather than upon a real time clock-interrupt.

TARGET GENERATION PROGRAMS. The heart of the DSF system is a group of target generation programs which allow use of the facility as a target generator only, or as a supply of simulated radar and beacon information to other systems being supported, such as the NAS enroute system or the ARTS III terminal system. Included are a program to simulate the aircraft flights, a program to simulate the data acquisition system (including radar and beacon acquisition and digitizing), a program to format and transmit digitized radar and beacon information to the test system, and the programs necessary to provide data for displaying at the pilot displays.

The aircraft flight program updates the aircraft positions each cycle. The aircraft flight model includes pilot and aircraft response distributions and navigational distributions for altitude, heading, and velocity variations. Aircraft have a predetermined flight path generated by TIPP. This includes

TABLE A-1. PROJECTS RUN ON DSF

PROJECT NUMBER	TITLE	START	COMPLETION
	ATC SIMULATOR		
147-172-000	EVALUATION OF ARTS III LEVEL OF AUTOMATION	12/70	3/71
052-241-03X	SIMULATION & ANALYSIS OF ATC-ADSA SYSTEM DESIGN (CAS)	6/71	7/71
015-190-01X	DOWNTOWN STOL PORT SIMULATION-PART I	3/71	5/71
015-190-02X	CTOL-STOL AIRPORT SIMULATION-PART II	5/72	7/72
052-241-03X	SIMULATION & ANALYSIS OF ATC-ADSA SYSTEM DESIGN (CAS IIA)	9/72	11/72
013-601-01X	LOS ANGELES BASIN TRAFFIC STUDY	10/72	12/72
052-241-03X	SIMULATION ANALYSIS OF ATC-ADSA SYSTEM DESIGN (CAS IIB)	11/72	12/72
142-177-07X	TRIPLE PARALLEL RUNWAY SIMULATION	12/72	1/73
012-603-020	CONTROLLER PERFORMANCE MEASURES STUDY	7/73	CONTINUING
013-601-040	LOS ANGELES ARTCC TRAFFIC STUDY	8/73	9/73
	TARGET GENERATOR		
142-172-01X	METERING AND SPACING SUPPORT TO ARTS III	5/72	8/73
121-A12-00X	NAS SYSTEM ENGINEERING & FAILURE RECOVERY SUPPORT	5/72	CONTINUING
121-A06-00X	NAS 3d SYSTEM SHAKEDOWN	7/72	3/73
121-A01-07M	NAS SUPPORT TO MITRE 3d TESTS	10/72	1/73
122-111-010	NAS CONFLICT ALERT	5/73	8/73

ADSA-AIR DERIVED SEPARATION ASSURANCE
CTOL-CONVENTIONAL TAKEOFF AND LANDING
STOL-SHORT TAKEOFF AND LANDING
CAS -COLLISION AVOIDANCE SYSTEM
NAS -NATIONAL AIRSPACE SYSTEM

their horizontal path traced over the ground, plus the vertical profile. The aircraft can perform almost all the maneuvers as directed by air traffic controllers in real life; for example, standard instrument departures, entering and leaving holding patterns, intersecting and following the Instrument Landing System (ILS) to touchdown, and so forth.

The data acquistion program that simulates radar and beacon returns has been designed for flexibility. Any combination of several features may be selected to be simulated depending on the realism desired for a given project. Some of these features are multiple numbers of radars, earth curvature, elevation errors of beacon, beacon garble, loss of targets due to weather, and so forth. A data link program is included when the DSF is being used as a target generator in support of NAS projects. It provides radar and beacon inputs to another system being tested.

AIR TRAFFIC CONTROL AND OPERATIONS PROGRAMS. The air traffic control and operations programs service the air traffic controller's consoles. They display information on the controller's scopes and service the data entry functions of the controller's keyboards and trackballs.

PILOT DATA ENTRY AND DISPLAY PROGRAMS. The pilot data entry and display programs accept message entries by the pilots; validate the entries; display aircraft status, fix lists, reports, errors, syntax, and message previews on the display screens; and transmit completed messages to the simulator programs.

CONFLICT DETECTION PROGRAM. The conflict detection program operates offline and provides a detailed listing of all violations detected in a conflict region which is specified by program input. For each conflict detected, the listing provides identification of aircraft in conflict, the location and status of both aircraft at the start and end of the conflict, the separation at the closest point of approach, and the duration of the conflict.

DATA REDUCTION AND ANALYSIS PROGRAMS. Data reduction and analysis programs execute offline and can provide the following reports and summaries:

1. Test input parameters,
2. Aircraft position history,
3. Aircraft delays and holds,
4. Communications and controller activity,
5. Pilot data entries and summary,
6. Controller data entries and summary,
7. Radar and tracking data,
8. CAS alarm summary,
9. Operations and fix activity summaries, and
10. Aircraft position plots and CAS alarm status.

HARDWARE CONFIGURATION. The current computer hardware configuration as depicted in figure A-1, is the culmination of a three-phase program for the development of the DSF. The major components of the system are as follows:

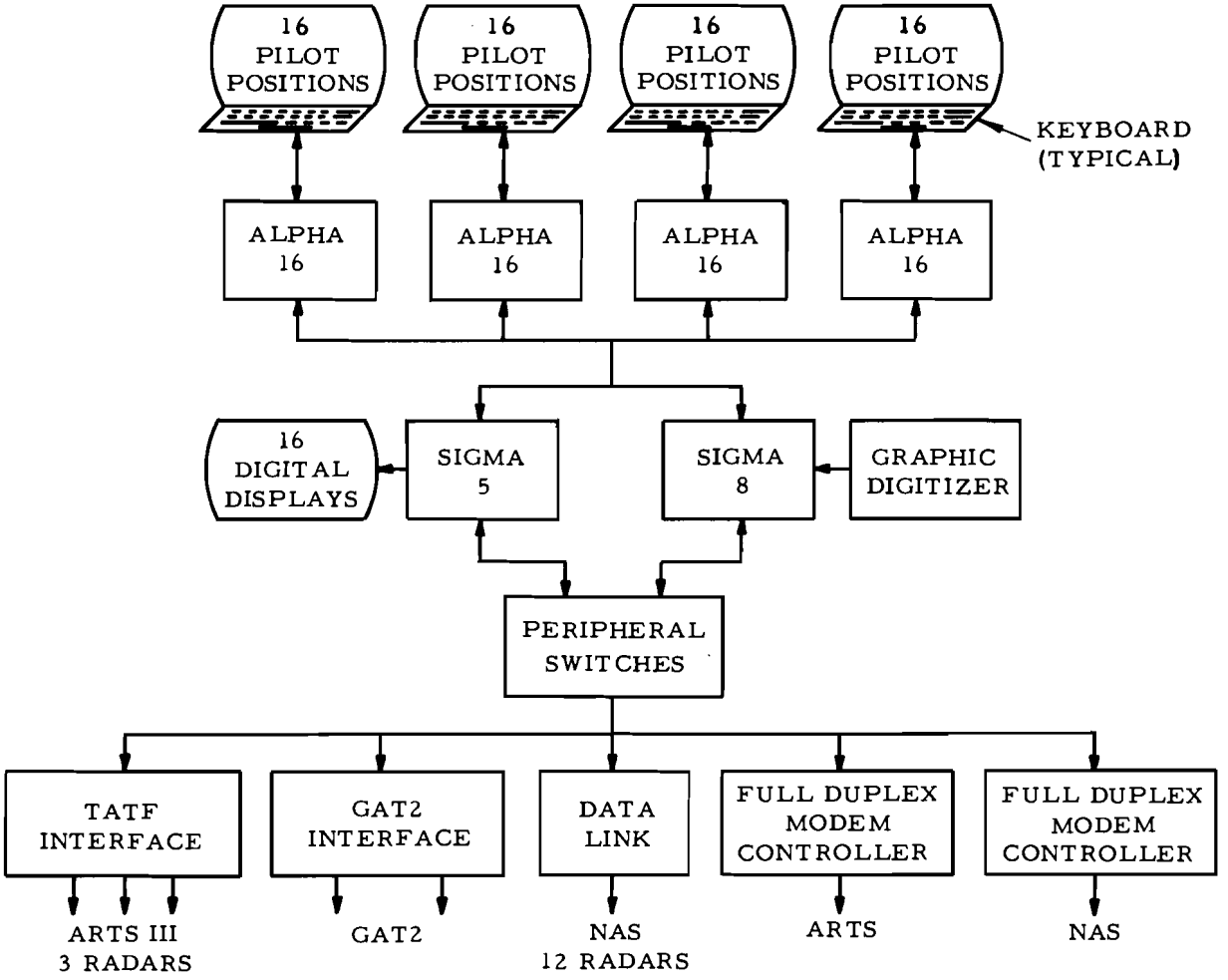


FIGURE A-1. DSF COMPUTER SYSTEM BLOCK DIAGRAM

1. Sigma 5 and Sigma 8 computers. The Sigma computers are the heart of the DSF system. Sigma programs perform all simulation functions required to simulate aircraft within the ATC environment. These dual computers can support studies individually or concurrently.

2. ALPHA 16 Computers. Four Alpha 16 minicomputers drive the pilot displays, interpret and validate pilot keyboard messages, and communicate with the Sigma computers.

3. Communication Equipment. Communications equipment provides for the transmission of digitized and formatted data between the DSF and the NAS, ARTS, and GAT-2 facilities and for the reception of digital data from the Langley Research Center. Controller-to-controller, controller-to-pilot, and pilot-to-controller voice communications also are provided.

4. Target Capacity. As indicated in figure A-1, 64 individual pilot consoles can be used with both processors to conduct a single simulation study or to simultaneously support more than one study (depending on the core storage and complexity of each) this configuration effectively doubles the target capacity from 150 to 300 aircraft.

SUPPORT SERVICES.

In addition to the software and hardware capability, the DSF maintains a technical staff of government and contractor personnel to provide support in all phases of simulation experiments activity. These activities include assistance in:

1. Problem definition and scoping,
2. Design of statistical experiments,
3. Simulation planning,
4. Traffic sample generation,
5. Development of software for unique aspects of the prospect, and
6. Statistical and operational analysis.

APPENDIX B

VOICE SYNTHESIZER SYSTEMS

BACKGROUND.

Human speech consists of a series of relatively continuous but rapidly changing analog waveforms. These waveforms represent a variety of different sounds. The individually different sounds are called phonemes, and spoken English employs about forty such phonemes, which can be combined in different ways to produce the vocabulary of spoken English.

In early voice response systems, the words of the vocabulary required for a specific application were recorded as individual tracks on a drum equipped with a separate optical or magnetic readout head for each track, such that by switching from one track to another, the vocabulary could be combined to form sentences. However, since all words are not the same length, and since the drum diameter had to be sufficiently large to accommodate the longest word in the vocabulary, the synthesized sentences had awkward gaps after the shorter words.

To avoid these gaps, and to avoid the reliability problems of devices having moving mechanical parts, the analog speech waveforms have been digitized and stored in a computer memory, such that they can be accessed under computer control in a continuous fashion. The quality of speech recorded and played back in this manner can be excellent if enough bits are stored to provide an excellent digital representation of the original analog waveform. The various existing voice response systems each represent a tradeoff between speech quality and bit storage requirements. Certain techniques have reduced bit storage requirements while maintaining reasonable speech quality by noting the presence of certain recurring analog waveforms which occur particularly with the long vowel sounds, and by storing a digital representation of only a single waveform and a digitial record of how many times this waveform is to be repeated when the stored speech is resynthesized.

Even with such compression systems, the amount of computer storage required for a vocabulary of any reasonable size is so large that such systems are efficient only when they can fill the needs of multiple simultaneous users, each getting different messages from the system.

One existing voice response system using somewhat different principles for speech generation made its use efficient for the present experiment where only a small specialized vocabulary was required and where simultaneous access by different users was not required. The VOTRAX or Vosyn manufactured by the Vocal Interface Division of Federal Screw Works, is a collection of noise generators which generate the sounds of the English phonemes. Under computer control, the phoneme generators can be addressed digitally and the

phonemes combined into words. While the voice quality of the device does not compare favorably with the better systems employing digitized speech, the words are completely recognizable. Moreover, a new vocabulary can be programmed easily if required, and the cost of the device is more than an order of magnitude less than that of digitized systems. (The experiment used a model 5 VORTRAX: The newer model 6 which has recently become available has greatly improved voice quality.)

VOSYN REQUIREMENTS.

The voice synthesizer system consists of the Vosyn itself, a hardware interface, and a software program entitled "The Vosyn Text Translator".. The text translator is capable of creating appropriate phonetic codes based on a prespecified vocabulary of English words. Each phonetic code is eight bits in length, and consists of one phoneme and an inflection level. The inflection level is designated in the two most significant bits.

The text translator is made up of two parts; a Vosyn table lookup routine and a Vosyn service module.

The table lookup routine obtains the aircraft ID and the appropriate message text. Based on this information, the lookup routine selects the appropriate words from the Vosyn vocabulary. Each word shall have been assigned a unique combination of eight-bit phonetic codes.

The English word combinations to be ennunciated by the Vosyn are completely defined below for each possible message. (Note: If more than one command at a time is given to an aircraft, e.g., an altitude and a heading, then the complete Vosyn message consists of both commands with a comma-length pause between them.)

Heading Command: "(ID) TURN LEFT/RIGHT TO HEADING ____, OVER."

Altitude Command: "(ID) DESCEND TO ____ THOUSAND FEET, OVER."

Speed Command: "(ID) REDUCE SPEED TO ____ KNOTS, OVER."

Turn Onto Final, With Approach Clearance: "(ID) TURN LEFT TO HEADING CLEARED FOR ILS RUNWAY 08 RIGHT APPROACH, OVER." The ILS approach phrase is appended to the final head command.

"Handoff" to Tower: "(ID) OUTER MARKER THREE MILES, CONTACT STAPLETON TOWER ON ONE ONE NINER POINT ONE, OVER."

The vocabulary is structured in three subsets; ID, command phrase, and numerical command values (i.e.: American, turn to heading. The table lookup obtains a three- or four-numeric aircraft identifier from the traffic sample and sets up the phonetic codes for the full ID by selecting a word from the following list:

ALPHA	FRONTIER	NOVEMBER	UNIFORM
AMERICAN	GOLF	OSCAR	UNITED
BRANIFF	HOTEL	PAPA	VICTOR
BRAVO	INDIA	QUEBEC	WESTERN
CENTRAL	JULIET	ROCKY MOUNTAIN	WHISKEY
CHARLIE	KILO	ROMEO	X-RAY
DELTA	LIMA	SIERRA	YANKEE
ECHO	MIKE	TANGO	ZULU
FOXTROT	NORTH		

The phonetic alphabet (e.g. "NOVEMBER") words are used for the single and twin prop aircraft, and the proper nouns (e.g., "Western") are used for the heavy and medium jets. The appropriate words for numerals are contained in the "numerics" subset of the vocabulary.

A master vocabulary is shown in table B-1. The phonemes and inflection codes for some words have already been devised and are indicated in the table.

Table B-2 shows the (uniquely) assigned octal code for each phoneme.

Each phoneme group, representing a single English word is followed by the eight-bit code for the phoneme PAØ. This phoneme represents a pause so that the words do not run together. The eight-bit code for the phoneme PA2 is appended to the end of a complete message. This phoneme produces a period-length pause and is used to indicate the end of a statement. A comma in the message requires the phoneme PA1.

The Vosyn Service Module accepts the phonetically coded message from the 100k-up routine and places it in an 80-phoneme-maximum-length buffer. Any remaining part of the buffer is filled with zeros.

If the message consistes of more than 80 phonemes, the software places the excess in the next buffer load. The module places only complete phoneme groups (each group representing an English word) in each buffer load (i.e., words are not split).

The Vosyn accepts one phoneme (eight-bits) at a time into its buffer, over an eight-bit parallel input line. After reading the eight bits (which could be a comma, a period or eight zeros, as well as a regular phoneme), the Vosyn returns a signal to the computer indicating that it should send the next phoneme.

When the Vosyn comes to a string of zeros in its buffer (indicating end of the message), it reads through the zeros very rapidly, stops enunciating, and sends the signal to the computer to completely load its buffer again. The time it takes to read through the string of zeros is in the order of milliseconds. The Sigma 5 computer is capable of transferring its buffer contents within 0.2 seconds.

When the Vosyn is enunciating, it will engage the push-to-talk (PTT) button and on completion, release the button. This action is required for all Vosyn messages except when the HALT button is pressed by the controller; in which case, the Vosyn audio output line is opened and enunciation stops immediately.

When the RESUME button is depressed, the Vosyn will repeat any message which may have been interrupted and continue to transmit any backlogged messages (not to exceed 10 such messages).

The Vosyn service module places a 3-second pause between successive messages. This pause allows the DSF pilots to voice their WILCO response or permits a controller to voice his own extemporaneous message.

TABLE B-1. PHASE 2A VOSYN MASTER VOCABULARY

ALPHA	2/AE1 1/UH2 1/L 1/F 2/UH1
AMERICAN	1/UH1 2/M 2/AH1 2/R 1/UH1 1/K 2/AE 2/N
APPROACH	1/UH3 2/P 2/R 1/O2 1/O2 2/T 2/CH
BRANIFF	2/B 2/R 1/AE 2/N 1/IH 1/F
BRAVO	4/B 2/R 1/UH2 1/AH1 1/V 2/UH2 3/O1
CENTRAL	2/S 1/EH 2/N 2/T 1/R 2/L
CHARLIE	1/T 1/CH 2/AH1 1/R 2/L 3/Y
CLEARED	2/K 2/L 1/IY 1/ER 4/D
CONTACT	2/K 1/AH 2/N 2/T 1/AE 1/K 2/T
CONTINENTAL	2/K 1/AH 2/N 2/T 1/IH 2/N 1/EH1 2/N 1/N 2/T 1/UH3 2/L
DELTA	4/D 2/EH1 1/UH2 1/L 1/T 2/UH1
DESCEND	2/D 1/E 2/S 2/EH 2/N 1/N 2/D
ECHO	1/EH 1/K 2/UH2 3/O1
EIGHT	1/A 3/Y1 3/T
FIVE	2/F 1/AH 2/IY 3/V

TABLE B-1. PHASE 2A VOSYN MASTER VOCABULARY (continued)

FOR	1 1 2 F O R
FOUR	1 2 3 F O R
FOXTROT	3 2 1 1 1 1 1 2 3 3 F UH3 AH1 K S T R UH3 AH1 T
FRONTIER	1 2 1 2 2 2 2 2 F R UH2 N T IE E ER
GOLF	2 1 1 3 4 G UH2 AW1 L F
HEADING	4 2 1 1 2 3 H EH2 EH2 D I1 NG
HOTEL	1 1 1 1 2 2 3 H O T T EH1 UH2 L
ILS	1 3 1 1 3 1 3 4 AH LY EH1 UH2 L EH1 EHH S
INDIA	1 3 1 2 3 I N D E UH1
JULIET	3 3 2 1 1 1 2 4 D J IU U1 L Y EH1 T
KILO	2 2 1 1 1 3 K IE E L UH1 O1
KNOTS	3 2 1 2 2 3 N UH3 AH1 T T S
LEFT	2 2 2 2 L EH F T
LIMA	3 1 1 1 3 L IE E M UH1
MARKER	1 1 1 2 1 M AH1 R K ER
MIKE	1 1 2 2 4 M AH IY EHQ K
MILES	1 1 2 2 2 1 M AH1 IY L Z Z

TABLE B-1. PAHSE 2A VOSYN MASTER VOCABULARY (continued)

NINER	2/N 1/AH 2/IY 2/N 2/ER
NORTH	2/N 2/N 1/O 2/R 1/TH
NOVEMBER	3/N 2/UH2 1/O2 1/V 2/EH2 1/EHH 1/M 1/B 2/ER
ON	1/AW1 1/AW1 2/N
OSCAR	2/UH2 1/AH1 1/S 1/K 3/ER
OUTER	1/AH 1/O1 2/T 1/ER
OVER	2/O 1/V 1/ER
POINT	2/P 2/O 2/IY 2/N 2/T
QUEBEC	4/Q 3/W 1/E 1/B 2/EH 4/K
REDUCE	1/R 1/E 1/D 2/IU 2/U 2/S
RIGHT	3/R 1/AH1 1/IY 2/T 2/T
ROCKY MOUNTAIN	2/R 1/AH1 1/AH1 2/K 1/IE 1/E ___/PAØ 1/M 1/AH1 1/O2 2/N 2/T 1/IH 2/N 1/N
ROMEO	3/R 2/UH2 1/O2 1/M 1/E 2/UH2 3/O1
RUNWAY	1/R 2/UH2 2/N 2/W 1/A 1/AY
SEVEN	4/S 2/EH1 1/V 2/EH2 3/N
SIERRA	1/S 1/IE 1/IY 1/AH1 1/R 2/UH3 3/UH3
SIX	1/S 2/I 3/K 3/S

TABLE B-1. PHASE 2A VOSYN MASTER VOCABULARY (continued)

SPEED	1/S 1/P 2/IE 2/E 1/D
STAPLETON	2/S 2/T 1/A 2/AY 2/P 1/UH2 1/L 1/T 1/UH 2/N 1/N
TANGO	4/T 2/AE1 1/AY 1/NG 1/G 1/UH2 3/O2
THOUSAND	3/TH 2/AH1 1/O1 1/Z 2/IH 3/N 3/D
THREE	2/TH 1/R 2/IE 3/Y
TO	2/T 2/IU 1/U
TOWER	2/T 1/AH1 2/O1 2/W 1/ER
TURN	3/T 2/R 2/R 1/N
TWA	1/T 1/IE 3/Y 3/D 4/UH3 1/B 1/L 1/Y 2/OOH 3/U1 1/A1 1/A1 4/Y1
TWO	1/T 1/IU 2/U
UNIFORM	3/Y1 2/OOH 1/U1 1/N 2/I2 1/F 2/O1 3/R 3/M
UNITED	3/Y1 2/OOH 2/N 1/AH 2/IY 2/T 2/EH2 2/D
VICTOR	3/V 2/I2 1/IH 1/K 1/PAØ 1/T 1/OOH 3/R
WESTERN	2/W 2/EH 2/S 2/T 1/ER 2/N 1/N
WHISKEY	2/H 2/W 1/I1 1/IH 1/S 1/K 3/Y
X-RAY	1/EH1 1/K 1/S 1/PAØ 1/R 1/A1 3/AY
YANKEE	3/Y1 2/AE1 1/AY 1/NG 1/K 1/IE 3/Y

TABLE B-1. PHASE 2A VOSYN MASTER VOCABULARY (continued)

ZERO	4/Z 2/IE 1/R 2/UH1 3/O1
ZULU	3/Z 1/IU 1/U1 1/L 1/IU 3/U

TABLE B-2. VOTRAX PHONETIC CODES

PHONEME	HEX	OCTAL	*ASC II	PHONEME	HEX	OCTAL	*ASC II
PAØ	Ø3	ØØ3	'SP'	G	1C	Ø34	'LQ'
PA1	3E	Ø76	'NS'	H	1B	Ø33	'KQ'
PA2	3Ø	Ø6Ø	'PS'	I	27	Ø47	'WR'
A	2Ø	Ø4Ø	'PR'	11	ØB	Ø13	'KP'
A1	Ø6	/Ø0	'VP'	I2	ØA	Ø12	'JP'
AE	2E	Ø56	'NR'	I3	3C	Ø74	'LS'
AE1	2F	Ø57	'OR'	IH	Ø5	ØØ5	'UP'
AH	24	Ø44	'TR'	IU	36	Ø66	'VS'
AH1	15	Ø25	'UQ'	IY	Ø9	Ø11	'IP'
AW	3D	Ø75	'MS'	J	1A	Ø32	'JQ'
AW1	13	Ø23	'SQ'	K	19	Ø31	'IQ'
AY	21	Ø41	'QR'	L	18	Ø3Ø	'HQ'
B	ØE	Ø16	'NP'	M	ØC	Ø14	'LP'
CH	1Ø	Ø2Ø	'PQ'	N	ØD	Ø15	'MP'
D	1E	Ø36	'NQ'	NG	14	Ø24	'TQ'
E	2C	Ø54	'LR'	Ø	26	Ø46	'VR'
EH	3B	Ø73	'KS'	Ø1	35	Ø65	'US'
EH1	Ø1	ØØ1	'QP'	Ø2	34	Ø64	'TS'
EH2	ØØ	ØØØ	'PP'	ØØ	17	Ø27	'WQ'
EHH	Ø8	Ø1Ø	'HP'	ØØ1	16	Ø26	'VQ'
ER	3A	Ø72	'JS'	ØØH	Ø4	ØØ4	'TP'
F	ID	Ø35	'MQ'	P	25	Ø45	'UR'

TABLE B-2. VOTRAX PHONETIC CODES (continued)

PHONEME	HEX	OCTAL	*ASC II
Q	Ø2	ØØ2	'RP'
R	2B	Ø53	'KR'
S	1F	Ø37	'OQ'
SH	11	Ø21	'QQ'
T	2A	Ø52	'JR'
TH	39	Ø71	'IS'
THV	38	Ø7Ø	'HS'
U	28	Ø5Ø	'HR'
U1	37	Ø67	'WS'
UH	33	Ø63	'SS'
UH1	32	Ø62	'RS'
UH2	31	Ø61	'QS'
UH3	23	Ø43	'SR'
V	ØF	Ø17	'OP'
W	2D	Ø55	'MR'
Y	29	Ø51	'IR'
Y1	22	Ø42	'RR'
Z	12	Ø22	'RQ'
ZH	Ø7	ØØ	'WP'
*NULL CODE =	FF	377	'OO'

*For use with RS-232 Only

NOTE: The above table is assuming Inflection Code 3.

INFLECTION LEVELS

To add inflection levels, add the selected level below to the phoneme value above.
(i.e., 1AH1 = Hex 95 Octal 225

LEVEL	HEX	OCTAL
1	8Ø	2ØØ (lowest)
2	CØ	3ØØ
3	ØØ	ØØØ
4	4Ø	1ØØ (highest)

*ASC II

To add Inflection Code, Change Second Character

FROM	P	Q	R	S	(Inflection Code)	3
TO	H	I	J	K	(Inflection Code)	1
TO	L	M	N	O	(Inflection Code)	2
TO	P	Q	R	S	(Inflection Code)	3
TO	T	U	V	W	(Inflection Code)	4

APPENDIX C

FUNCTIONAL MODEL OF THE ATC SYSTEM

AIRSPACE GEOMETRY AND CONDITIONS OF OPERATION.

The Denver Stapleton terminal area shown in figure C-1 is used as a model for the simulation tests. The conditions of operation are:

1. Single Runway (08R);

2. Single approach-controller handling traffic from two feeder fixes (Roggen and Longmont);

3. Airspace segregation of low-performance and high-performance aircraft before merging at the inner fix;

4. No wind;

5. Instantaneous controller loads ramping up to a maximum of 11 aircraft over a 1-hour period;

6. Realistic traffic samples with aircraft characteristics ranging from heavy jets to low performance, general aviation classes;

7. Variable mix of both data link-equipped and voice-controlled aircraft;

8. Pilot and data link delays simulated;

9. Off-normal conditions are incorporated for realism--such as potential conflicts, data link failures, pilot repeat requests, delayed compliance, and pilot replies of "Unable to comply;"

10. Other controller workload items such as handoffs, changing aircraft to the tower frequency, and clearing aircraft for final approach are incorporated;

11. Targets originate at the maximum radar range of 55 nautical miles (nmi), but are not necessarily visible to the controller at that range.

The actual radius of the controller's display corresponds to a range of only 30 nmi, but the Stapleton radar site is offset from the scope center as shown in figure C-1 to better utilize the display area for Longmont and Roggen approaches.

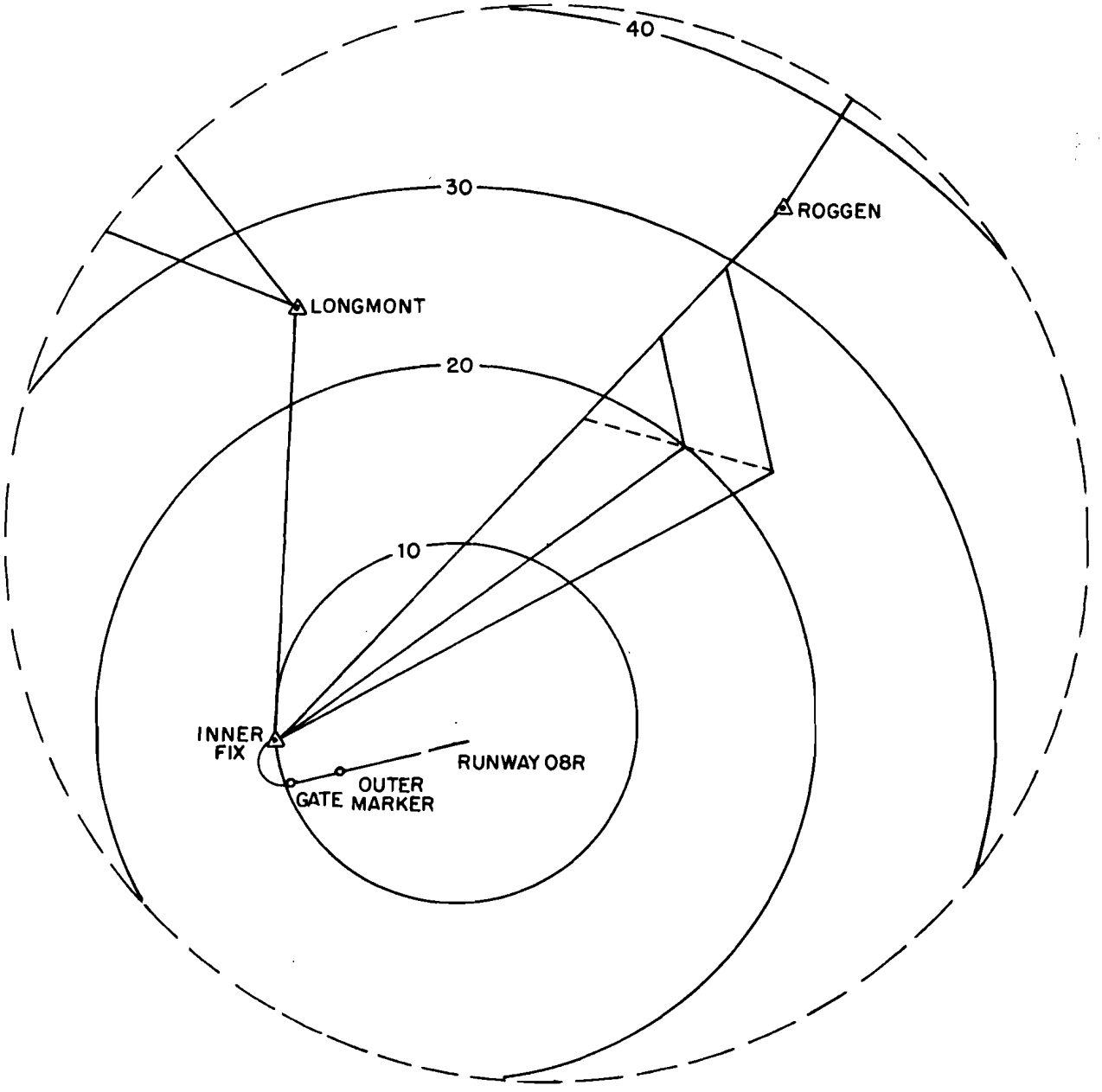


FIGURE C-1. SIMPLIFIED M&S AIRSPACE STRUCTURE FOR DENVER

The time at which each aircraft is created at its point of origin is simply the scheduled departure time at the feeder fix minus the time required to fly from the origin point to the feeder fix following a speed/altitude profile typical of the transition stage for the aircraft type.

When a target first penetrates the perimeter of the display, its position is marked by the en route controller symbol C. Five miles from the feeder fix, the following ARTS tag appears blinking to initiate the handoff procedure with the approach controller (A):

```
C——UA731
   170A21
```

The approach controller slews his trackball to the aircraft position symbol and pushes the ENTER key signifying acceptance of the handoff. The A symbol disappears from the tag, the C symbol changes to A, and the tag stops blinking. From this point to the outer marker, the aircraft is under the approach controller's jurisdiction. Metering and spacing commands during this period are displayed and transmitted, employing one of the seven formats being evaluated. Appropriate speed and heading changes are executed automatically at the feeder fix; i.e., the initial commands to an aircraft in departing a feeder fix are not included in the approach controller's workload.

If the approach controller does not accept a handoff by the time the aircraft is 3 nmi inside the feeder fix, the tag is erased, the target symbol changes to C, and the aircraft automatically turns to the north and flies out of the terminal area.

Targets appear on a feeder fix list when they are 5-minutes flying time from the feeder fix. The format is:

```
23 TW327* 17
24 UA401  16 CO911*
27 OZ981  15
```

The targets listed in the second column have been respectively assigned the altitude levels 17,000, 16,000, and 15,000 feet above mean sea level (MSL) at the feeder fix, and departure times 23, 24, and 27 minutes after the hour. Denver Stapleton airport is at 5,331 feet above MSL. The target on the right (CO911) will occupy the 16,000-foot slot after UA401 has left the fix. An asterisk (*) indicates a data link-equipped aircraft. High-performance aircraft pass through at the Roggen feeder fix, and low-performance aircraft pass through the Longmont feeder fix. All traffic lands on runway 08R. Targets pass the feeder fixes approximately at their assigned time of departure (ATD). Departure errors up to ±1 minute will occur at Roggen, and these will be corrected by path-stretching and speed control. With a ±1-minute spread in departure times, it is theoretically possible for three aircraft to leave Roggen simultaneously. To avoid conflicts, three altitude slots are provided (15,000, 16,000, and 17,000 feet). At Longmont, entries occur between 13,000 and 10,000 feet. In either case, successive departures from the same fix

always have altitude separation initially. To simplify the model, there is no holding at either fix. The approach controller's responsibility for each aircraft commences at handoff and terminates after the aircraft has been delivered to the outer marker. Flights continue to the runway threshold at final approach speeds. Statistics on the dispersion of arrival times at the inner fix and runway threshold and the incidence of missed-approaches are collected and used as system performance measures.

Only four aircraft types are used in the data link scenarios: Heavy commercial jet, medium commercial jet, light twin-propeller aircraft, and light single-propeller aircraft. The performance characteristics of these four aircraft types in the terminal area as defined by the Digital Simulation Facility are shown in the following tabulation.

	Prop-Light Single	Prop-Light Twin	Medium Comm. Jet	Heavy Comm. Jet
Descent Rate (ft./min.)	1000	1000	1600	1600
Climb Rate (ft./min.)	1000	1500	1500	1500
Altitude Rate Change (ft./sec/sec)	6	6	6	6
Deceleration (kt./min.)	60	60	60	60
Acceleration (kt./min.)	60	70	60	65
Transition Speed (kt.)	140	170	330	330
Holding Speed (kt.)	140	170	200	200
Final Approach Speed (kt.)	90	120	150	150
Climb Speed (kt.)	130	145	250	250
Turn Rates (°/sec)	3	3	3	3

For added safety at the inner fix, the high-performance aircraft from Roggen are assigned to 7,000 feet MSL and the low-performance aircraft from Longmont are assigned to 8,000 feet MSL. Minimum in-trail spacing behind the heavy jets is 5 nmi. For all other aircraft combinations, however, the minimum allowable in-trail spacing is 2 nmi. This reduction was required to provide the necessary traffic load on the controller.

The nominal approach profile for the high-performance aircraft types within the jurisdiction of the subject controller is shown in figure C-2. The approach procedure is as follows:

1. Handoff from en route to approach controller occurs when aircraft is 5 nmi from the Roggen feeder fix.

2. Aircraft speed is automatically reduced to 200 knots, and the aircraft automatically executes a heading change to 220° at the feeder fix to align itself with the inbound track to the inner fix. Departure from Roggen is at an altitude of 15,000, 16,000 or 17,000 feet MSL.

3. For a distance of 4 nmi after departing the feeder fix, no commands are issued. This interval is provided to assure that a firm ARTS track has been reestablished after the aircraft has left the holding stack area.

4. The path-stretching maneuvers are bounded by two extremes. If the aircraft is 45 seconds to 1 minute late in departing the feeder fix, it proceeds straight to the inner fix along the minimum path route shown in figure C-2. If the aircraft is approximately 1-minute early leaving the feeder fix, it will follow the maximum path route. In between these limits, the criterion for the first turn is that traversing the path to the dotted line and thence radially to the inner fix at a speed of 200 knots will place the aircraft at the inner fix at its scheduled time. A small empirical correction is made in this criterion to compensate for the kinematics of the turn.

5. The second heading change is governed by a classic DICE calculation. A turn toward the inner fix occurs when the direct path flown at 200 knots will place the aircraft at the inner fix 40 seconds before its scheduled arrival time. This lead time guarantees that the next speed command will be a speed reduction instead of a speed increase.

6. To compensate for errors in executing the two previous heading changes and for the subsequent deceleration at the inner fix, a modest speed correction is transmitted at the beginning of the downwind leg.

7. A descent rate of 1,600 feet per minute at an airspeed of 200 knots corresponds to a descent angle of 4.528° or 2.077 nmi horizontal travel per 1,000 foot loss of altitude. A jet descending from 15,000, 16,000, or 17,000 feet to 7,000 feet at this rate would cover respectively 16.615, 18.692, and 20.769 nmi on the ground. Descents are initiated so that jet aircraft reach the 7,000-foot level 5 nmi from the inner fix. Thus, an aircraft at 15,000 feet starts descending 21.615 nmi from the inner fix; one at 16,000 feet starts descending 23.692 nmi from the inner fix; and one at 17,000 feet starts descending 25.769 nmi from the inner fix. In the geometry shown, the descent commands are not given until the aircraft are flying on a radial path to the inner fix, hence have either a safe lateral or in-trail separation from other aircraft when their letdown commences. Descent commands are based on each aircraft's true airspeed (TAS) and not on the nominal 200 knots.

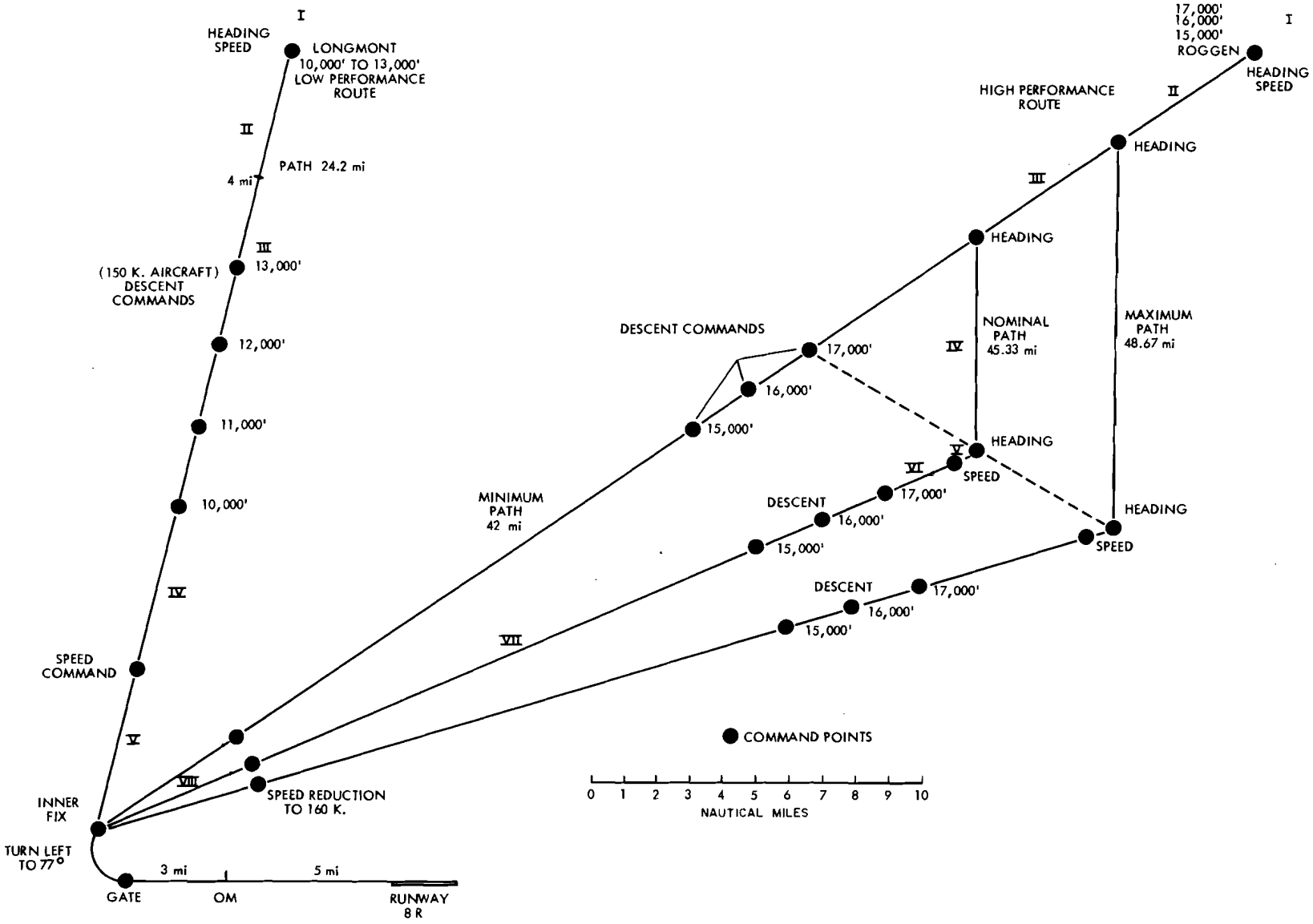


FIGURE C-2. SIMPLIFIED DENVER GEOMETRY

8. The high-performance aircraft level off at 7,000 feet MSL approximately at the time they are 5 nmi from the inner fix. At this distance from the inner fix, a command to reduce speed to 160 knots is issued. Speed commands are in terms of TAS instead of indicated airspeed (IAS), even though IAS would have to be employed in actual operations because pilots employ IAS almost exclusively in the approach phase of flight. Since real pilots are not involved in the simulation, however, the conversion of TAS to IAS would have served no useful purpose. This simplification has no effect on controller workload or experimental results since the controllers have to transmit a speed value in any case.

9. Just prior to the inner fix, a standard left turn to a heading of 077° is ordered and each aircraft is cleared for approach to runway 08R. The ability of the DSF to have targets home on waypoints and to automatically acquire and track a given route segment is utilized during the ILS acquisition phase to simulate the pilot's use of a course deviation indicator or flight director in aligning his aircraft with the localizer centerline.

10. At the gate, pilots are given the distance to the outer marker (3 nmi) and the tower frequency. A speed reduction to the aircraft's final approach speed (150 knots) also commences automatically at this point. Aircraft tracks follow the localizer to the runway threshold.

11. At the outer marker, the alphanumeric tag disappears and the controller symbol changes from approach (A) to tower (T).

The nominal approach profile for the low-performance aircraft types within the jurisdiction of the subject controller is simpler since only speed control is employed:

1. Handoff from en route to approach controller occurs when aircraft is 5 nmi from the Longmont feeder fix.

2. A speed range from 135 to 170 knots is utilized for the twin-propeller aircraft with the scheduled departure time from the feeder fix based on 150 knots. The aircraft may be up to 40 seconds early or late at the feeder fix, in which case it will automatically decelerate from its cruise speed of 170 knots to an appropriate speed below or above the nominal 150 knots. A speed range of 140 to 110 knots is utilized for single-propeller aircraft with the scheduled departure time from the feeder fix based on 130 knots is utilized for single-propeller aircraft with the scheduled departure time from the feeder fix based on 130 knots. An aircraft up to 40 seconds early or late at the feeder fix will automatically decelerate from its cruise speed of 140 knots to an appropriate speed below or above the nominal 130 knots. Speed changes are initiated after handoff.

3. Aircraft automatically execute a heading change to 180° at Longmont to align themselves with the inbound radial to the inner fix.

4. Longmont arrivals are at 13,000, 12,000, 11,000 or 10,000 feet MSL.

5. For a distance of 4 nmi after departing the feeder fix, no commands are issued.

6. The descent commands are timed to bring each aircraft down to 8,000 feet altitude 5 miles from the inner fix. Both aircraft types descend at 1,000 feet per minute.

7. Five miles from the inner fix, a speed command is issued to reduce the speeds to 140 knots for the twin- and 110 knots for the single-propeller aircraft.

8. Just prior to the inner fix, a 077° heading command is issued and each aircraft is cleared for approach on runway 08R. Targets automatically acquire and track the ILS localizer during this phase of the approach just as real aircraft would be able to do in practice.

9. At the gate, pilots are given the distance to the outer marker (3 nmi) and the tower frequency. A speed reduction to the aircraft's final approach speed commences automatically at this point. Final approach speed for the twin-propeller aircraft is 120 knots and for the single propeller is 90 knots. Aircraft tracks follow the localizer to the runway threshold.

10. At the outer marker, the alphanumeric tag disappears and the controller symbol changes from approach (A) to tower (T).

THE SIMPLIFIED METERING AND SPACING ALGORITHM.

The scheduling function is actually carried out prior to run time in the process of specifying the exact time at which targets are scheduled to depart the feeder fixes. These times are calculated from a table of nominal flying times for each leg, taking into account in-trail spacing restrictions and the desired instantaneous controller loading. Deviations of up to ± 1 minute from the assigned departure time for each jet aircraft are randomly imposed, and these are corrected by path stretching and speed control commands inbound. The errors in departure time from the Roggen feeder fix correspond to a truncated normal distribution with $\pm 2\sigma = \pm 1$ minute (σ = standard deviation). From the Longmont feeder fix, the errors in departure time $\pm 2\sigma = \pm 40$ seconds.

A list of time-to-fly values required to schedule the heavy and medium jets originating at Roggen is given below in seconds. These values were measured directly on the DSF prior to setting up the master schedule from which all other scenario schedules were derived by perturbation. A total of 21 target scenarios were generated corresponding to three data link mixes for each of the seven test formats. In addition, one training scenario was prepared.

	Heavy Jet (sec)	Medium Jet (sec)
Creation Point to Roggen	289	289
Roggen to Inner Fix (nominal path)	856	856
Inner Fix to Runway Threshold	259	259

With a 5-mile spacing minimum behind a heavy jet and jet final approach speed of 150 knots (2.5 nmi/minute), the scheduled arrival time of both heavy and medium jets at the runway threshold must be 120 seconds or more behind that of a preceding heavy jet. When a 2-mile spacing minimum applies (medium jet or heavy jet behind a medium jet, twin propeller, or single propeller) the time separation between scheduled arrival times at the runway threshold must be 48 seconds or more. In the actual scheduling of arrivals, no time separation at the runway threshold less than 60 seconds was employed.

A similar list of measured time-to-fly values for scheduling the low-performance aircraft from Longmont is given below in seconds:

	Twin Propeller (sec)	Single Propeller (sec)
Creation Point to Longmont	652	398
Longmont to Inner Fix (nominal speeds)	617	744
Inner Fix to Runway Threshold	321	381

With a 5-mile spacing minimum behind a heavy jet, the scheduled arrival time of a twin propeller at the inner fix must be 128 seconds or more behind that of a preceding heavy jet. Because of the greater final approach speed of the heavy jet, this time separation at the inner fix is equivalent to a 190-second separation at the runway threshold.

The 2-mile spacing minimum behind a medium jet requires the twin propeller to be scheduled at least 51 seconds behind a medium jet at the inner fix. Because of the greater final approach speed of the medium jet, this time separation at the inner fix is equivalent to a 113-second separation at the runway threshold.

The 2-mile spacing minimum behind a single propeller or another twin-propeller aircraft dictates a time separation at the runway threshold of 60 seconds for the twin propeller.

With a 5-mile spacing minimum behind a heavy jet, the scheduled arrival time of a single propeller at the inner fix must be 162 seconds or more behind that of a preceding heavy jet. Because of the greater final approach speed of the heavy jet, this time separation at the inner fix is equivalent to a 284-second separation at the runway threshold.

The 2-mile spacing minimum behind a medium jet requires the single propeller to be scheduled at least 64 seconds behind a medium jet at the inner fix. This is equivalent to a 186-second separation at the runway threshold.

The 2-mile spacing minimum behind a twin propeller aircraft requires the single propeller to be scheduled at least 51 seconds behind a twin propeller at Longmont, assuming that the two aircraft have altitude separation or route separation prior to the feeder fix. Because of the higher approach speeds of the twin propeller, this is equivalent to a 238-second separation at the runway threshold. A single propeller behind another single propeller must be separated by at least 80 seconds at the runway threshold.

Using the foregoing separation requirements for all possible sequences of the four aircraft types employed in the target sample, the following four-by-four matrix of minimum scheduling intervals at the runway threshold was derived (table C-1). As stated previously, no interval less than 1 minute was allowed.

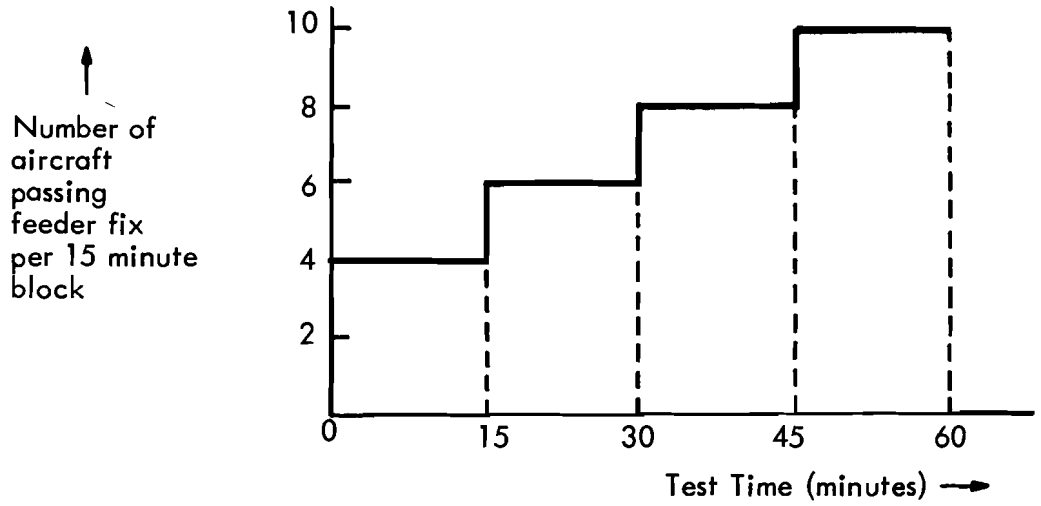
TABLE C-1. MINIMUM SCHEDULE INTERVALS AT RUNWAY THRESHOLD

	First Aircraft			
Second Aircraft	Heavy Jet (sec)	Medium Jet (sec)	Twin Propeller (sec)	Single Propeller (sec)
Heavy Jet	120	60	60	60
Medium Jet	120	60	60	60
Twin Propeller	190	113	60	60
Single Propeller	284	186	238	80

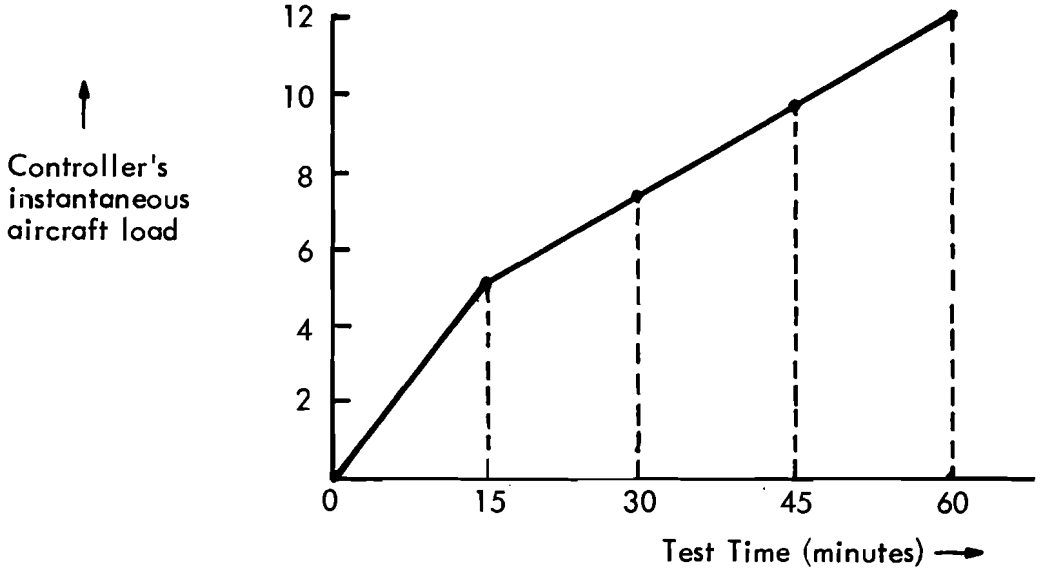
After a scheduled clock-arrival time at the runway threshold was assigned to a given aircraft by the use of the minimum intervals above, the corresponding clock-scheduled times at the inner fix, feeder fixes, and creation points was found by subtracting the measured flying times given previously from the threshold times.

Using the numbers presented above, it was relatively easy to assemble a sequence of targets that exhibit the desired characteristics with respect to controller loading, aircraft mix, and percentage of data link-equipped aircraft. Aircraft mix and controller loading cannot both be taken as independent test variables. Any increase in the percentage of heavy jets or low-performance aircraft automatically decreases the controller loading because of the greater in-trail spacing required. (For example, to achieve an instantaneous controller load of 11 aircraft, it was necessary to select a sequence of almost all medium jets.) Once a sequence of targets was selected to achieve the proper controller loading, an arbitrary assignment of data-link capabilities to specific aircraft is made in the desired proportion (20, 50, or 80 percent).

For the initial test series, a ramp load was used which builds up gradually from zero instantaneous aircraft to a maximum of 11. In terms of the number of targets passing the feeder fixes in each 15-minute block of time, this profile over the 1-hour test period is approximated by the following plot. In order to fill up the pipeline between the points of creation and the feeder fixes, the simulation runs about 5 minutes prior to time zero:



Since the average aircraft is under approach control for 17 minutes, the corresponding instantaneous controller load is plotted in the following way:



Scheduling to achieve the desired traffic entry rate and the desired percentage of data link aircraft is carried out for each 15-minute time block. For example, 4 targets are scheduled to pass the feeder fixes during the first 15-minute time block, 6 targets during the second 15-minute time block, etc. If the test calls for 50 percent of the aircraft to be data link aircraft, then two of the first 4 aircraft will have data link, 3 of the next six aircraft will have data link, 4 of the next 8 aircraft will have data link, and 5 of the next 10 aircraft will have data link. Of the total target sample of 28 aircraft, 14 or exactly 50 percent will be data link-equipped. Subject to this block by block constraint, the sequence of data link and voice aircraft within a block are randomized.

To illustrate the scheduling procedure, the following target sequence over a 15-minute period produces an instantaneous controller loading of approximately 10 aircraft, 80 percent of which are data link-equipped (table C-2). To generate a set of test scenarios from the master schedule, the actual departure times from the feeder fixes arbitrarily deviate from the scheduled values in table C-2 by as much as ± 1 minute. The path-stretching and speed control algorithm in the DSF corrects these errors and delivers each aircraft to the inner fix approximately at the scheduled time. In addition, the identities of all aircraft were changed from scenario to scenario, and the specific set of off-normal events included in each scenario was varied. These variations were necessary to prevent the subject controllers from memorizing certain situations and utilizing this prior knowledge in later tests. The off-normal events are described in detail in the section on the seven candidate command modes.

A predetermined trajectory was utilized for each aircraft type from its en route point of origin (55 nmi from the radar site) to the point inside the feeder fix where it receives the first heading command. From there to the gate, each aircraft is normally controlled dynamically by a sequence of metering and spacing (M&S) commands dispatched by the controller. After passing the gate, each aircraft automatically tracks the localizer to the runway threshold, reducing its speed to the final approach value.

As each aircraft progresses from stage to stage in the Roggen approach, the simplified M&S algorithm performs the following distinct calculations in turn (the stages are indicated on figure C-2):

Handoff - Is the target 5 nmi from the feeder fix? If so, initiate the handoff to the approach controller.

Stage I - Is the target 30-seconds flying time from the feeder fix? If so, initiate a heading change to the inbound radial to the inner fix.

Stage II - Is the target 4 miles beyond the feeder fix? If so, advance to stage III.

TABLE C-2. ILLUSTRATIVE SCHEDULE

Aircraft Identity	Type	Data Link	Feeder Fix	Initial Altitude (feet)	Scheduled Times (Seconds after hour)			
					Creation Point	Feeder Fix	Inner Fix	Runway Threshold
UA 857	MJ	*	R	16,000	-289	0	856	1115
N 7701	TP		L	12,000	-362	290	907	1228
TW 193	MJ	*	R	17,000	-116	173	1029	1288
UA 719	HJ	*	R	15,000	- 56	233	1089	1348
CO 911	MJ		R	16,000	64	353	1209	1468
N 6717	TP	*	L	10,000	- 9	643	1260	1581
OZ 981	MJ	*	R	17,000	237	526	1382	1641
CO 930	HJ	*	R	15,000	297	586	1442	1701
WA 214	MJ	*	R	16,000	417	706	1562	1821
UA 766	MJ	*	R	17,000	477	766	1622	1881

Stage III - Will traversing a path to the dotted line and thence radially to the inner fix at a speed of 200 knots deliver the target to the inner fix at its scheduled time plus 40 seconds? (Empirical corrections for delays and aircraft radius of curvature.) If so, issue the appropriate heading command: "Initial direct course error (IDICE)."

Stage IV - Will traversing a path directly to the inner fix at a speed of 200 knots deliver the target to the inner fix at its scheduled time minus 40 seconds? (Empirical corrections for delays and aircraft radius of curvature.) If so, issue a heading command: "Direct course error (DICE)."
Stage V - Taking into account the deceleration to 160 knots that commences 5 miles from the inner fix, what present speed will deliver the target to the inner fix at its scheduled time? Issue speed command.

Stage VI - Will the standard descent rate cause the target at its present speed to be at an altitude of 7,000 feet MSL when it is 5 miles from the inner fix? If so, issue altitude command.

Stage VII - Is the target 5 miles from the inner fix? If so, issue a speed command of 160 knots.

Stage VIII - Is the target 30 seconds flying time from the inner fix? If so, issue a heading command of 077°.

Stage IX - Acquire and track the ILS localizer to the runway threshold. Has the target passed the gate? If so, transmit the message specifying the tower frequency and distance to the outer marker. Decelerate to final approach speed (150 knots).

Stage X - Has the target passed the outer marker? If so, change the controller symbol from A to T and erase the tag.

The corresponding stages for the Longmont approach are:

Handoff - Is the target 5 nmi from the feeder fix? If so, initiate the handoff to the approach controller.

Stage I - Is the target 30 seconds flying from the feeder fix? If so, initiate a heading change to the inbound radial to the inner fix. Decelerate to speed which will get target to inner fix at scheduled time.

Stage II - Is the target 4 nmi beyond the feeder fix? If so, advance to stage III.

Stage III - At the standard descent rate will the target at its present speed reach an altitude of 8,000 feet 5 nmi from the inner fix? If so, issue 8,000 feet altitude command.

Stage IV - Is the target 5 nmi from the inner fix? If so, issue speed command of 140 knots for a twin- and 110 knots for a single-propeller aircraft.

Stage V - Is the target 30 seconds flying time from the inner fix? If so, issue heading command of 077°.

Stage VI - Acquire and track ILS localizer to the runway threshold. Has the target passed the gate? If so, transmit the message specifying the tower frequency and distance to the outer marker. Decelerate to final approach speed (120 knots for twin- and 90 knots for single-propeller).

Stage VII - Has the target passed the outer marker? If so, change the controller symbol from A to T and erase the tag.

Some formal criterion must be specified that will advance a given aircraft from one stage to the next at the appropriate time. For both data link and voice commands, the criterion was the completion of the execution of the current computer-generated command to that aircraft. For example, in stage IV for the jets, a heading command along the inbound radial to the inner fix is issued. In stage V, the speed correction will not be entered until the heading change has been completed. The DSF program detects the completion of the last computer-generated command for a given target and automatically advances that target to the next M&S stage.

Complications arise when a computer-generated command is not executed, or when a controller-generated command is executed. This might happen in the case of a pilot reply of UNABLE or CAN'T COMPLY, or in the case of a conflict. Normally, an aircraft will be disengaged from the M&S algorithm when such situations arise. In the test series, such aircraft cannot be reengaged with M&S.

The DSF maintains a problem time clock with a resolution of 1/8 second. The creation of targets, event timing, and arrival times at the feeder fixes, inner fix, and runway threshold are measured by reference to this clock. After a target receives the speed command 5 nmi from the inner fix, the DSF computes an estimate of its arrival time at the inner fix in terms of the problem time clock. This estimate is compared to the scheduled arrival time for the particular aircraft. If the error exceeds ± 20 seconds, the target is considered to be out of sequence. If such is the case, the controller's symbol A for the target is changed to a blinking 2. Simultaneously, the controller symbol for the target ahead and the target behind the out-of-sequence aircraft changes to 1 and 3, respectively. In practice, this event rarely happens, but the subject controllers in the tests did have the benefit of an automatic sequence check near the inner fix.

APPENDIX D

SYSTEM DISPLAY AND CONTROL PROCEDURES

CANDIDATE CONTROLLER MODES.

The major objective of the DSF test series was to experimentally evaluate various methods of handling data link information at the controller's display console and to select the most suitable format for more intensive testing with the actual ARTS III M&S configuration at NAFEC. The major test mode options that had to be considered were:

Full data block (FDB) versus tabular list (TAB),
Single commands versus multiple commands,
Voice versus voice synthesizer (VOSYN), and
Control-by-approval (CBA) versus control-by-exception (CBE).

Various combinations of these options defined the 10 original candidates that were to be evaluated on the DSF for the general case in which there is a mixture of data link- and voice link-aircraft. The combinations were:

FDB - Multiple Command - Voice
FDB - Single Command - Voice*
FDB - Multiple Command - Vosyn
FDB - Single Command - Vosyn*
TAB - Multiple Command - Voice
TAB - Multiple Command - Vosyn
TAB - Single Command - Voice
TAB - Single Command - Vosyn
CBE (FDB - Vosyn)
Composite (FDB and TAB - Single Command - Vosyn)*

To reduce the number of hours of test time, a policy decision was subsequently made not to test the modes marked by an asterisk (*). These modes will be described, however, even though no experimental data was collected on them.

The functional details of each of the test mode options will now be discussed individually.

CONTROL-BY-APPROVAL.

FULL DATA BLOCK (FDB). In the FDB mode, commands to a given aircraft are presented in the third line of the aircraft's alphanumeric tag as shown:

AA223*	American Airlines Flight 223
140 25	*Data link-equipped
200	Altitude 14,000 feet
	Groundspeed 250 knots
	Command: Change Heading to 200°

The three-digit heading command has no identifying prefix, but speed commands are preceded by an S and altitude commands by an A. Heading commands, when presented, always occupy the first three digits of the third line, and altitude commands always occupy the last four digits. The possible command combinations in the third line of the FDB are therefore:

Digit Positions

1	2	3	4	5	6	7	Commands
1	7	0	S	1	6		Heading 170°; 160 knots IAS
0	5	0	A	1	4	0	Heading 50°; altitude 14,000 feet
3	4	0					Heading 340°
S	2	0					200 knots IAS
S	1	3	A	0	7	0	130 knots IAS; altitude 7,000 feet
			A	1	5	0	Altitude 15,000 feet
O	M	3					Outer marker 3 miles; contact tower

If no other commands are being serviced, a data link command appears blinking 12 seconds before the desired execution time and continues to blink until the controller pushes the DISPATCH button. The 12-second lead time is based on an average controller delay of 7 seconds plus an average pilot delay of 5 seconds. Following DISPATCH, the commands becomes nonblinking (solid). Pilot "will comply" (WILCO) responses to a command are automatically displayed by the DSF computer an average of 5 seconds after DISPATCH. The WILCO delay has a normal distribution about the average, however. The standard deviation of this distribution is 1 second. The WILCO response is indicated by a W in the first line of the data block:

AA223*W
140 25
200

The command and the WILCO symbol (W) remain solid in the tag for 3 seconds after the WILCO appears, and then both are erased:

AA223*
140 25

In the single command mode, only one blinking command is displayed at a time. When DISPATCH is pushed, this is the command that is transmitted. No additional identification is necessary. The next command in sequence does not appear until its predecessor has been dispatched. If several commands are generated concurrently, a queue is formed and delays occur in the execution of the last command of the set. For this reason, every command held in a queue is automatically updated every 12 seconds; i.e., a new command is computed based on an anticipated execution time 12 seconds in the future. To limit the error due to a delay in execution, a blinking command is also updated every 12 seconds.

As targets approach the inner fix, errors in execution time can no longer be compensated for by a subsequent command. Consequently, targets are given priority in the command queue according to their distance from the inner fix. The closer to the inner fix they are, as determined by the M&S control stage they are in, the higher their priority. After the current blinking command is transmitted, the highest priority command in the queue is displayed blinking in the appropriate data block. Priority in the command queue, therefore, is determined by three considerations in all the single command test modes. In order of importance, they are:

1. Current blinking command cannot be displaced until serviced or skipped.

2. UNABLE and LINK FAIL messages have equal priority with the critical 077° heading command at the inner fix.

3. Remaining commands have priority in accordance with the M&S control stage and, within a given stage, in accordance with the generation time.

If a target is not data link-equipped, the controller transmits its command by voice and receives a verbal acknowledgement from the DSF keyboard pilot. Depressing an ADVANCE button at this point causes the voice link command to stop blinking and the next command in the queue to appear. The voice link command is not erased until 20 seconds after the ADVANCE button has been pushed so that the controller can refer back to the command if the pilot should request clarification. If the controller makes a mistake in that he identifies the voice link aircraft as a data link aircraft, pushing the DISPATCH button has no effect. The continued blinking of the command notifies the controller of his error. If the target is data link-equipped and the controller pushes the ADVANCE button, the command stops blinking and the next command in sequence appears. The ADVANCE button, can therefore provide the controller with a means to skip an active command which he does not wish to transmit, either via the data link or verbally, and move on to the next command in the queue. All commands which have been skipped remain solid in their tag for 20 seconds and are then erased.

In actual data link transmissions, a NAK signal is generated if a data link message is received at the target with a parity or check sum error. Three successive NAKS constitute a link fail (F). Since the retransmission of messages occurs automatically and quickly without controller intervention, the NAK alert is not shown on the controller's display to minimize distractions. Three NAKS still constitute an F, however, and this condition is brought to the attention of the controller in the following manner.

With respect to display protocol, F and Unables (U) are treated like separate commands, but they are assigned a high priority in the command queue. For example, assume that an F or U response has been generated. After the current blinking command has been serviced by pushing either DISPATCH or ADVANCE, an F or U symbol will appear blinking in the WILCO symbol position of the appropriate tag. The command that the data link failed to deliver correctly, or that the pilot is unable to execute, is still displayed in the third line:

AA223*F	AA223*U
140 25	140 25
200	200

The standard procedure, in the case of link failure, is for the controller to repeat the undelivered command verbally and receive a verbal acknowledgement. After the transaction is completed, the controller pushes the ADVANCE button, the F stops blinking, and the next command in the command queue starts to blink. Twenty seconds after the ADVANCE button is activated, the F symbol and the old command are erased. In the case of a U alert, the controller must resolve the situation by verbal communication with the pilot. If the pilot agrees to comply, the controller pushes the ADVANCE button, the U stops blinking, and the next command in the command queue starts to blink. Twenty seconds later, the U and the old command are erased.

It may happen, however, that the pilot is still unable or unwilling to comply with an M&S command, even after verbal communication with the controller. For example, the pilot may spot a thunderstorm and refuse a heading command in that direction, but agree to turn after he has passed the region of severe turbulence. In such cases, the controller must halt the flow of M&S commands to the particular aircraft and assume manual control, at least temporarily. The mechanism employed is to address the aircraft position symbol with the trackball and push the DISENGAGE button. The U symbol and the command are erased immediately and no further commands are displayed for the disengaged target. The controller manually vectors the aircraft from that point on.

In the multiple command mode, all commands appear (blinking) 12 seconds before the desired execution time and the controller must identify which command he wishes to transmit with his trackball. In the case of a data link aircraft, for example, he pushes the DISPATCH button, slews the trackball to the target position symbol, and pushes the ENTER button. The command stops blinking. The pilot WILCO is delayed an average of 5 seconds, with a standard deviation of 1 second. The command and the WILCO symbol remain solid in the tag for 3 seconds after the WILCO appears, and then both are erased. Here again, if several commands arise simultaneously, the last command serviced by the controller will incur a substantial delay. To limit this error, all blinking commands are automatically updated every 12 seconds.

If the aircraft is not data link-equipped, the controller pushes the ADVANCE button, slews the trackball to the target position symbol, transmits the command by voice, and receives a verbal acknowledgement from the DSF keyboard pilot. Depressing the ENTER button at this time causes the voice link command to stop blinking. Twenty seconds later the command is erased. Note that it is necessary to identify even voice commands with the trackball in the multiple command mode to make sure that the correct command stops blinking. Pushing ADVANCE, addressing a data link command with the trackball, and pushing the ENTER button, stops the command from blinking, but does not transmit it. Twenty seconds later, the command is erased. This action is equivalent to skipping the command.

Link fails and U in the multiple command mode are handled as separate voice link commands. In the case of an F, for example, a blinking F appears in the WILCO position in the tag. The command is transmitted verbally by the controller. Concurrently, he pushes the ADVANCE key, slews the trackball to the target symbol, and, when the pilot has acknowledged receipt of the message with a "Roger," pushes the ENTER key. This action stops F from blinking and 20 seconds later it is erased. A similar sequence is employed when a blinking U appears.

TABULAR LIST (TAB). In the TAB test mode, commands awaiting service appear in one table called the new command list, and commands that have already been serviced transfer to a second table called the storage list as indicated here:

New Command List (top loading)	N51037	A080	Voice link aircraft command: Change altitude to 8,000 feet.
	AA223	OM3	Outer marker 3 miles, contact tower.
	TW327*F	S19	Data link aircraft* Link failed to deliver speed command (190 knots IAS)
	UA107*	H170	Data link aircraft* Current top priority command (H170 blinking) change heading to 170°.
Storage List (bottom loading)	TW175*W	S16	WILCO received for speed command (160 knots IAS)
	AA123*	H210	Heading command waiting for WILCO reply.
	N1267	A060	Voice command in 20-second storage.

In all cases, a command appears on the new command list 12 seconds before the desired execution time. In the single command mode, however, only one command at a time will blink. For data link commands, blinking will cease after the controller has pushed the DISPATCH button and the entire line is moved to the storage list. The reason for this transfer is to segregate commands that have been serviced from those that are being serviced or are waiting in the command queue to be serviced. The next command in the new command list queue starts blinking immediately after DISPATCH. The entire data link command line will be erased from the storage list 3 seconds after the appearance of the WILCO (W) for the command. Only one command is presented on each command line. If two or more commands are generated simultaneously for the same aircraft, each command will appear on a separate line. These lines will not necessarily be adjacent in the list.

If the target is not data link-equipped, the controller transmits the command by voice and receives a verbal acknowledgement. Depressing ADVANCE at this point causes the voice link command to stop blinking and the entire line is moved to the storage list below. The next command in the queue starts blinking immediately. Twenty seconds later the entire line is erased from the storage list. Every command held in a queue (prevented from blinking), is automatically updated every 12 seconds. A blinking command is also updated every 12 seconds to limit errors due to a delay in execution. Priority in the new command queue is established for the TAB format by the same set of rules used for the FDB format. The top priority command is always at the bottom of the new command list.

The F symbol and the U symbol appear in the WILCO (W) position. Link fail and U are treated like separate voice commands, but they are assigned a high priority in the command queue. When they become the active command, they start blinking. Any command for which a F or U is generated, of course, is immediately transferred back to the new command list. In the case of F, the controller repeats the undelivered command verbally and receives a verbal acknowledgement. Pushing the ADVANCE button stops F from blinking and allows the next command in sequence to start blinking. The line is returned to the storage list. Twenty seconds later, the entire line is erased.

In the case of a U, the controller must resolve the situation verbally. If the pilot agrees to comply to the verbal instructions, the controller pushes the ADVANCE button, the U stops blinking, the line returns to the storage list, and the next command starts blinking. Twenty seconds later, the line is erased. Addressing an aircraft position symbol with the trackball and pushing DISENGAGE halts the flow of M&S commands to the aircraft. TAB list entries referring to that aircraft are erased immediately. The aircraft would be reinstated by addressing it with the trackball and pushing the ENGAGE button. This latter capability was not employed in these tests.

One inherent drawback of the TAB format is the difficulty of correlating a command on the list with the situation of the corresponding aircraft. In the single command mode, this problem is partially alleviated by blinking the aircraft positions symbol at the same time that the command in the TAB is blinking.

In the multiple command mode, all commands appear in the new command list 12 seconds before the desired execution time, but they do not blink. The controller must identify which command in the list he wishes to transmit with his trackball. For a data link aircraft, he pushes DISPATCH, slews the trackball to any position on the chosen command line, and pushes the ENTER button. The command line is immediately transferred to the storage list below. After the standard 5-second average delay, the W symbol is displayed. Three seconds later, the command is erased from the list. All commands in the new command list are updated every 12 seconds.

If the target being serviced employs voice link, the controller pushes ADVANCE and slews the trackball to the chosen command line in the TAB before he enunciates the command verbally. After acknowledgement is received from the keyboard pilot, the controller depresses the ENTER key causing the command addressed by the trackball to be transferred to the storage list. It is held for 20 seconds and then erased. If the command addressed by the trackball refers to a data link aircraft, activating the ENTER button will cause it to be transferred to the storage list also. It too is held for 20 seconds and erased. This is equivalent to a skip, since the command is not executed.

An F or U causes the corresponding command line to be transferred back to the new command list with an F or U displayed in the W symbol position. Both are serviced in exactly the same way as a new voice link command. In the case of the F, for example, the command is enunciated by the controller. Concurrently, he pushes the ADVANCE key, slews the trackball to the command line, and, when the pilot has acknowledged the message with a "Roger," pushes the ENTER key. This action drops the entire line into the storage list and 20 seconds later it is erased. A similar sequence is used for a U response.

One advantage of the TAB is that the controller can tell how many commands are in queue at any given instant. In addition, the slewing of the trackball requires less time if commands from a compact list are being selected instead of commands spread out over the entire display screen. However, the TAB, multiple command mode has some disadvantages. It is not practical to correlate the aircraft position symbol with a command in the TAB by blinking both simultaneously. Several commands and several position symbols might be blinking simultaneously. The matching of a command with the correct aircraft position symbol would be difficult under these circumstances. The principal argument for the multiple command mode is that the controller can select and transmit from several commands in queue any command which he considers to be of highest priority. The commands are ordered in the new command list by the same priority rules governing the single command format, with the top priority command appearing at the bottom of the list. In practice, many controllers left the trackball symbol at the bottom line between handoffs and, in this way, minimized the time delays that would have been caused by trackball slewing from line to line in the new command list.

VOICE SYNTHESIZER (VOSYN). To minimize the procedural differences in servicing voice link and data link aircraft, verbal commands were generated by a voice synthesizer in some of the modes. With a Vosyn, the controller transmits all commands like data link commands. For voice link aircraft, activation of his DISPATCH button causes the synthesizer to enunciate the active or trackball-selected command on a voice channel. Both voice and data link commands stop blinking after the DISPATCH button is activated. In the single command mode, the next command in the queue starts blinking immediately. The controller no longer has to make a decision whether to speak a given command or push the DISPATCH button. In all cases, DISPATCH is the proper action for transmitting the command to the pilot.

If a command is sent to a voice link aircraft, the controller can listen directly to the synthesizer's message and to the pilot's acknowledgement. If the command is not received properly, the pilot will request a repeat and the controller is able to transmit the same message again. In the FDB format, voice commands are displayed in the tag for 20 seconds after DISPATCH, and then erased. Data link commands are erased 3 seconds after the W response is received. In the TAB format, command lines that have been dispatched are transferred to the storage list and erased from that list 20 seconds later or 3 seconds after the receipt of a W, as the case may be.

A hardware interface was assembled to allow the DSF computer to transmit the proper digital message codes to the voice synthesizer.

CONTROL-BY-EXCEPTION (CBE).

The CBE format represents the ultimate reduction in controller workload that is possible if the controller's communication functions are automated, thereby enabling him to concentrate on monitoring the overall traffic flow and resolving abnormal situations. The CBE procedure used in the test series automatically transmits an M&S command to the target 5 seconds prior to the desired execution time. Simultaneously, the command appears (nonblinking) in the target tag. Normally, for data link aircraft, after a 5-second average delay, the pilot's W symbol also appears in the tag. The command and the W symbol are erased 3 seconds after receipt of the W. For example, if the last data link command to a target called for speed change to 180 knots and the pilot has indicated compliance, the tag would have the following solid format for 3 seconds, then the W and S18 would be erased:

```
AA223*W
080 22
S18
```

Off-normal situations are indicated by appropriate symbols on the display. For example, if a command is not transmitted accurately on three successive tries, an F symbol appears in the W position. The Vosyn automatically enunciates the command over the voice link. Twenty seconds after the F appears, the F and the command are erased.

If the pilot is unable to comply with a command, a blinking U symbol appears in the W position of the tag. In this case, the controller must communicate verbally with the pilot to resolve the situation. In the test series, resolution was accomplished by simply repeating the command verbally, receiving the pilot's acknowledgement, and pushing the ADVANCE key. This stops the blinking of the U symbol. Twenty seconds later both the command and the U are erased. No new commands are dispatched during the period in which the U symbol is blinking.

Since the controller's main task is to monitor the overall traffic flow and resolve off-normal situations, his communications functions are greatly reduced unless abnormal events are inserted into the scenario from time to time. If the event requires it, the flow of M&S commands to a given aircraft can be halted by slewing the trackball to the aircraft position symbol and pushing the DISENGAGE key. Thereafter, that particular aircraft in the test series is directed by verbal instructions from the controller. No ENGAGE key is used to reinstate the flow of M&S commands in these tests.

When the traffic sample is a mixture of voice and data link aircraft, the voice synthesizer provides a convenient means for implementing CBE. Commands to voice link aircraft are transmitted automatically via the Vosyn 5 seconds before the desired execution time, and the commands are simultaneously displayed in the corresponding aircraft tag. The controller monitors the Vosyn transmissions and the pilot replies, but otherwise he is free to watch the overall traffic picture for off-normal events. The commands to voice link aircraft appearing in the target tag are erased automatically 20 seconds after the transmission. Since several voice link commands can be generated simultaneously, a voice message queue is necessary. Commands are updated every 5 seconds while waiting in the queue to be transmitted. The same priority rules employed in the CBA formats are used to establish the sequence of commands in the Vosyn queue; for example:

1. The current command being enunciated cannot be displaced until the message is completed. A message can be halted, however, and subsequently repeated in its entirety.

2. UNABLE and LINK FAIL messages have equal priority with the critical 077° heading command at the inner fix.

3. Remaining voice commands have priority in accordance with the M&S control stage and, within a given stage, in accordance with the generation time.

Voice channel discipline presents a problem when one of the communicators is a computer-controlled Vosyn. If the pilot and/or controller wish to make extended remarks on the voice channel, interference with the automatically generated voice synthesizer messages must be prevented. To this end, a 3-second gap is deliberately inserted between successive Vosyn transmissions. During the gap, a pilot can acknowledge a command or initiate extended remarks that require controller intervention. When the controller hears the start of an extended message, he can temporarily halt the transmission of Vosyn messages by pushing a HALT button. After the pilot-controller transaction is completed, pushing the RESUME button allows the flow of Vosyn messages to continue. The Vosyn is also halted when the controller is asked to repeat a command or a delayed compliance reply is received from the pilot.

In the CBE modes, the controller exercises the same positive control over the acceptance of new traffic from en route, as in the CBA formats. To initiate a handoff, the entire data tag blinks when the aircraft is 5 miles from the feeder fix. The approach controller slews his trackball to the aircraft position symbol and pushes the ENTER key to signify acceptance of the handoff. The tag stops blinking and the aircraft position symbol changes from C to A.

DSF PILOT PROCEDURES.

In each test run, two subject controllers were tested independently and concurrently at two separate display consoles. Three keyboard operators at a single pilot's console handled the aircraft appearing in one subject's scenario. The total load was divided more or less equally among the three. At a second pilot's console, three additional keyboard operators handled the aircraft appearing in the other subject's scenario. This load was also divided evenly. At a third pilot's console, one keyboard operator was responsible for all the first subject's disengaged aircraft, and another keyboard operator was responsible for all the aircraft disengaged by the second subject controller. Thus, each test run employed a total of eight keyboard "pilots" who entered aircraft identities and commands when necessary and provided verbal responses on the pilot-controller voice link.

For a normal data link command, a pilot is not required to take any action. When the controller or CBE system dispatches a data link command, the DSF computer automatically initiates the execution of the command after a delay interval corresponding to the data link and pilot delays. For a normal voice link command, however, a pilot types the last three digits of the aircraft's identity (ACID) as it is being enunciated by the controller or Vosyn and pushes her ENTER key when the verbal message is completed. In this sequence, the ENTER causes the DSF computer to initiate the execution of the command addressed to the aircraft identified by the ACID. Execution is preceded by appropriate data link and pilot delays as before. The command itself need not be entered by the pilot because the DSF computer already knows the exact commands which have been generated for each aircraft and displayed to the controller.

For normal voice commands, a pilot enunciates a verbal acknowledgement, such as "Roger," after the command has been transmitted by the controller or Vosyn. Normal commands are not repeated back to the controller by the pilot. For exception cases, the pilot's reply is dictated by the scenario. The interaction between the pilot and the controller, for various exception cases, is discussed in the next section.

Available to each pilot is a display list of all aircraft assigned to her with their current heading, speed, and altitude. Keyboard entries also appear on the display so that they can be previewed prior to ENTRY. Finally, messages were prescripted to alert the pilot to upcoming STANDBY, APPROACH or REQUEST REPEAT replies associated with the next command to a particular aircraft.

All commands to a disengaged aircraft are controller-generated and transmitted over the voice link. Consequently, both the ACID and the commands must be typed on the pilot's keyboard, and the ENTER key pushed, to cause the execution of such commands.

EXCEPTION CASES.

In recognition of the possiblility in the real world of equipment failures, pilot blunders, adverse weather, etc., four types of off-normal situations occur at random times in the test scenarios. For data link aircraft, these off-normal events are a data link failure and an "unable" reply to a command. For voice link aircraft, the off-normal events are a repeat message request and delayed compliance with a command. In addition, each test includes one deliberately staged conflict to check the subject's diligence in monitoring his traffic.

DATA LINK FAILURE. A data link failure causes an F to appear blinking in the appropriate data block or the new command list of the tabular format as shown:

AA223*F 150 20 200	FDB
AA223*F H200	TAB

In either format, when this occurs, the command (change heading to 200°) must be enunciated by the controller over the voice link. The pilot types in the aircraft ACID as she hears it and, when the controller has completed the message, she pushes her ENTER key. Immediately thereafter, she acknowledges the command with a "Roger." In the CBE mode, the Vosyn automatically enunciates the command after a failure, but this does not change the subsequent action of the pilot as described above. In all cases, the aircraft returns to the normal data link status for subsequent commands.

UNABLE. If a data link-equipped aircraft cannot comply with a command, the symbol U appears blinking in the same location occupied by the F symbol as previously listed. The controller contacts the pilot over the voice link to find out what the difficulty is. For this test series, the pilot has been instructed to type in the aircraft ACID as she hears it, accept the original command, and push her ENTER key when the controller message is completed.

REPEAT REQUEST. This exception case is the voice link equivalent of a data link failure. On the basis of a prescripted cue message, the pilot requests the controller to repeat a designated command. The pilot types in the ACID as she hears it, but does not push the ENTER key until the controller has repeated the command. The pilot then acknowledges the repeat with a "Roger."

DELAYED COMPLIANCE. This case is the voice link equivalent of the data link "Unable." On the basis of a prescripted cue message, the pilot replies to a command with the statement, "Standby approach." Approximately 5 seconds later, the controller reissues the same command, at which time the pilot responds with a "Roger."

CONFLICTS. The M&S algorithm is designed to provide the required separation between all aircraft if they adhere to the conflict-free schedule generated by the algorithm. However, conflicts can occur accidentally due to message delivery delays, blunders, equipment failures, and slow pilot responses. The minumum spacing that defines a conflict is 5 nmi behind any heavy jet or 2 nmi spacing between any other aircraft pair. In addition to conflicts that might occur accidentally, one conflict is deliberately inserted in each test run. Erroneous M&S commands are issued that cause one aircraft to be 45 seconds late at the inner fix and the next aircraft in sequence to be somewhat early. As a consequence, the two aircraft converge on the inner fix, creating a conflict that develops gradually and becomes more acute as they approach the fix.

To resolve conflicts by issuing extemporaneous commands, the controller must first halt the flow of computer-generated M&S commands to the aircraft involve He does this by slewing the trackball to the appropriate aircraft and pushing the DISENGAGE key. This action erases any current commands addressed to that aircraft and no additional commands are generated for it. On the voice link, the controller vectors the aircraft back to the vicinity of the entry feeder fix, or to the runway if the traffic situation permits. To initiate the execution of each controller-generated command, the pilot must type in the ACID and the commands, pushing the ENTER key to register the information in the DSF computer. After ENTER, the pilot acknowledges each command with a "Roger."

The M&S agorithm computes the arrival time for each aircraft as it approaches the inner fix and compares this value to the scheduled time. If the error exceeds 20 seconds, the aircraft is considered out of sequence. In this event, a blinking number 2 will replace the target symbol of the concerned aircraft for a period of 60 seconds and the blinking numbers 1 and 3 will be displayed for the aircraft ahead and behind it in the landing sequence. This is not necessarily a notification of impending violation of separate criteria, since the aircraft ahead and behind may be considerable distances away. It is just an alert to the controller that the scheduled execution by a particular aircraft is not as expected and that he should evaluate the situation. If the controller determines that a potential conflict exists, he will disengage the number 2 aircraft and vector it back to the feeder fix. The DISENGAGE function will remove the sequence numbers. If the controller decides that no conflictiion will occur, he will ignore the alert and it will be removed in 60 seconds.

In formats employing the Vosyn, that device sometimes is enunciating a command at a time when the controller must utilize the voice channel to resolve a conflict. For this reason, assuming that the Vosyn has been activated by pushing the DISPATCH key, a HALT key is provided which interrupts the message being enunciated and allows the controller to transmit extemporaneous messages as required by the situation. Pressing a RESUME key causes the interrupted message to be enunciated in its entirety by the Vosyn. After a complete message has been delivered by the Vosyn, however, and a repeat is requested by the pilot, the controller must repeat the message himself. The Vosyn control logic used in the tests does not incorporate the capability of repeating messages already delivered.

SIMULATION OF DATA LINK DELAYS.

In an operational system, a communication processor would be necessary at the ground facility to serve as an interface between the ARTS III and the data link transceiver(s). Similarly, a small communications processor would be required in each data link-equipped aircraft. Both processors would introduce additional delay in handling commands via the data link, hence an attempt was made to incorporate these delays in the simulation. Each component of the total delay encountered by a ground-generated message and its reply will now be discussed individually.

At the ground terminal, an M&S command will encounter a message-in-process (MIP) delay when the processor is tied up with another message. Such messages, in general, represent fictitious uses of the data link; i.e., uses other than approach control. The probability of the processor being tied up by a fictitious message, at the instant a "real" message occurs, is defined as:

$$P = \lambda \bar{\chi}$$

where λ = arrival rate of fictitious messages (number per second)
$\bar{\chi}$ = the average length (in seconds)

The message length (x) is assumed to have a Gaussian distribution about the mean of the form:

$$p(x) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{(x-\bar{\chi})^2}{2\sigma^2}}$$

where σ = standard deviation of the distribution
distribution is truncated at $\pm 3\sigma$

The DSF computer agorithm for assigning an MIP delay to a "real" message is as follows:

1. Sense the occurrence of a real message (depression of the DISPATCH key).

2. Calculate the probability $P = \lambda \bar{\chi}$

3. Draw a random number of, R, from a uniform distribution (0.0 - 1.0)

4. If R >P consider that the processor is <u>not</u> tied up, and assign and MIP = 0 for the real message.

5. If R <P consider the processor to be tied up.

6. If (5) applies, draw an x from the Gaussian distribution of fictitious-message lengths.

7. Draw a random number, R, from a uniform distribution (0.0 - 1.0).

8. Assign an MIP = RX for the real message.

Step 7 is necessary because the portion of the x-length message which has been processed is not known. Note that an MIP = Rx implies that the real message has a higher priority than any fictitious message in the queue, and would not have to wait any longer than x seconds, at most.

In the test series, the following parameters are employed:

$$\lambda = 1$$
$$\bar{X} = .4$$
$$\sigma = .1$$

The uplink delay (EQD), which is identical to the downlink delay, includes the time necessary to warm up the transmitter and generate the message overhead, such as prekey signal, aircraft address, mode and lable characters, start of text, end of text, and message number. If the scenario calls for a link failure, the message must be transmitted three times, hence three uplink delays are added for such cases. A constant value of 0.0767 seconds was utilized for uplink and downlink delays. (These parameters were derived in Message Queue Delay Simulation, KHL/TSC-43-72-977.)

An average sampling delay of 0.5 seconds is introduced when the DSF computer's realtime clock reading is rounded off to the next highest whole second.

Finally, the time spent by the pilot in evaluating a command and activating his W button is assumed to be a normal distribution with a mean value of 5 seconds and a standard deviation (σ) of 1 second. The distribution is truncated beyond $\pm 3\sigma$.

The summation of delay components to obtain the overall round-trip message delay differs with message type:

W - Message requiring a WILCO reply
U = Message requiring an UNABLE reply
F = Message scripted for LINK FAILURE

A table showing the number of component delays for each of these message types follows. A total delay is computed by the DSF and this becomes the interval between the dispatch of a data link command and the appearance of the reply (W, U, or F) on the controller's display.

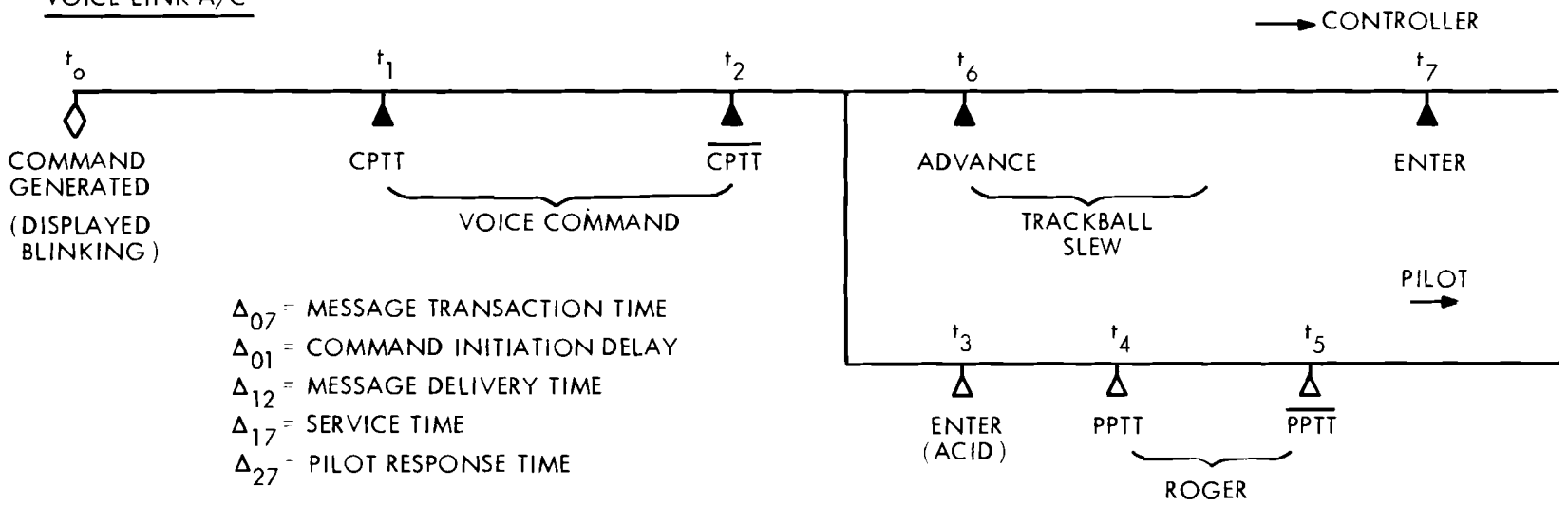
MESSAGE		Ground Terminal		Airborne Terminal	
RESPONSE	MIP	EQD	SAMPLING	EQD	WILCO
W	1	1	1	1	1
U	1	1	1	1	1
F	3	3	3	3	0

TIMELINES FOR EACH FORMAT.

The verbal explanation of the sequence of events for the seven modes employed in the test series can be clarified by referring to the following set of timelines. Each mode has one timeline for data link aircraft and one timeline for voice link aircraft. The sequence of actions by the DSF computer, the controller, the Vosyn and the pilot is indicated by coded markers on the timeline. Certain intervals of special importance in evaluating the formats are defined on each sheet. These timelines are referred to in the section on Test Conduct.

1. FULL DATA BLOCK, MULTIPLE, VOICE

VOICE LINK A/C



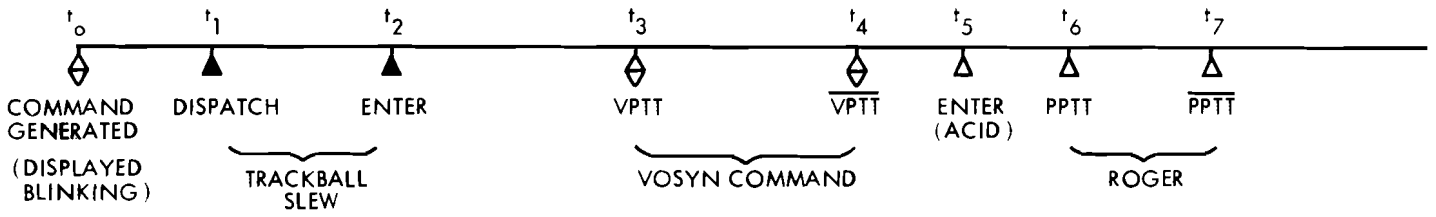
Δ_{07} = MESSAGE TRANSACTION TIME
Δ_{01} = COMMAND INITIATION DELAY
Δ_{12} = MESSAGE DELIVERY TIME
Δ_{17} = SERVICE TIME
Δ_{27} = PILOT RESPONSE TIME

DATA LINK A/C

Δ_{04} = MESSAGE TRANSACTION TIME
Δ_{02} = COMMAND INITIATION DELAY
Δ_{23} = MESSAGE DELIVERY TIME
Δ_{12} = SERVICE TIME = TRACKBALL TIME
Δ_{34} = PILOT RESPONSE TIME

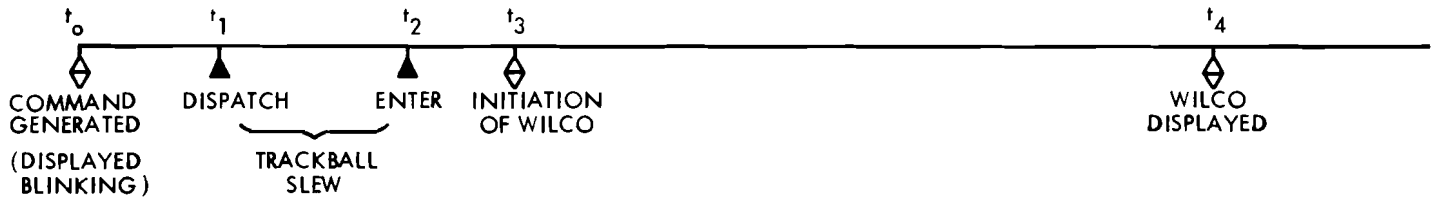
2. FULL DATA BLOCK, MULTIPLE, VOSYN

VOICE LINK A/C



Δ_{07} = MESSAGE TRANSACTION TIME
Δ_{02} = COMMAND INITIATION DELAY
Δ_{24} = MESSAGE DELIVERY TIME
Δ_{17} = SERVICE TIME
Δ_{12} = TRACKBALL TIME
Δ_{47} = PILOT RESPONSE TIME

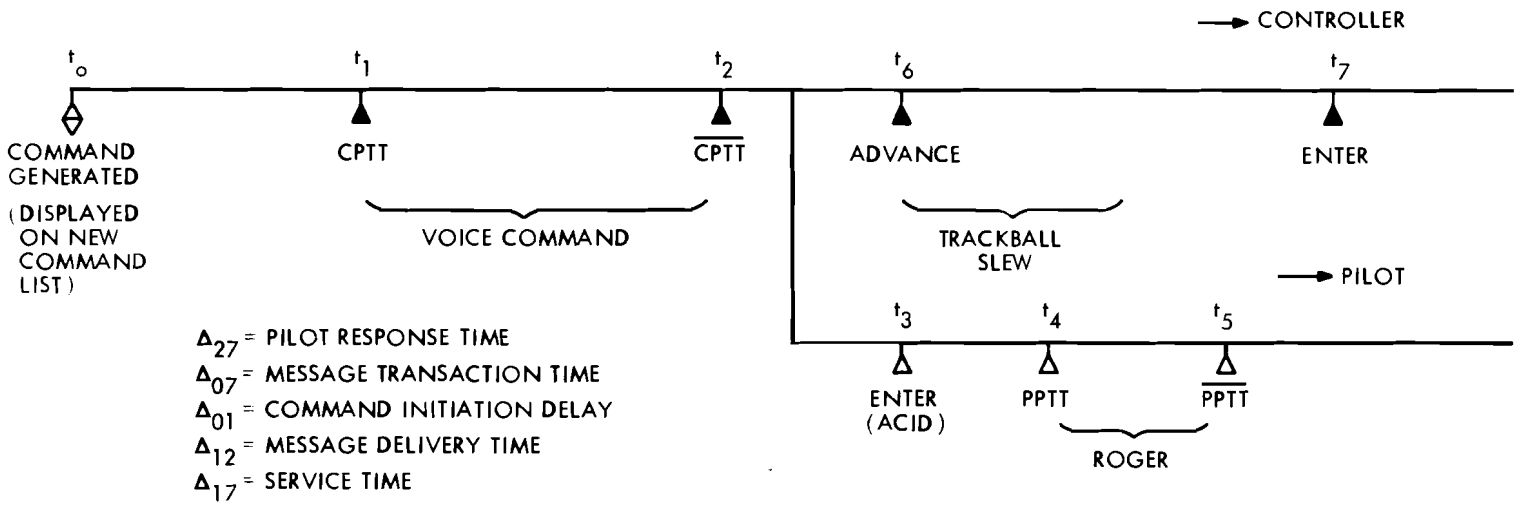
DATA LINK A/C



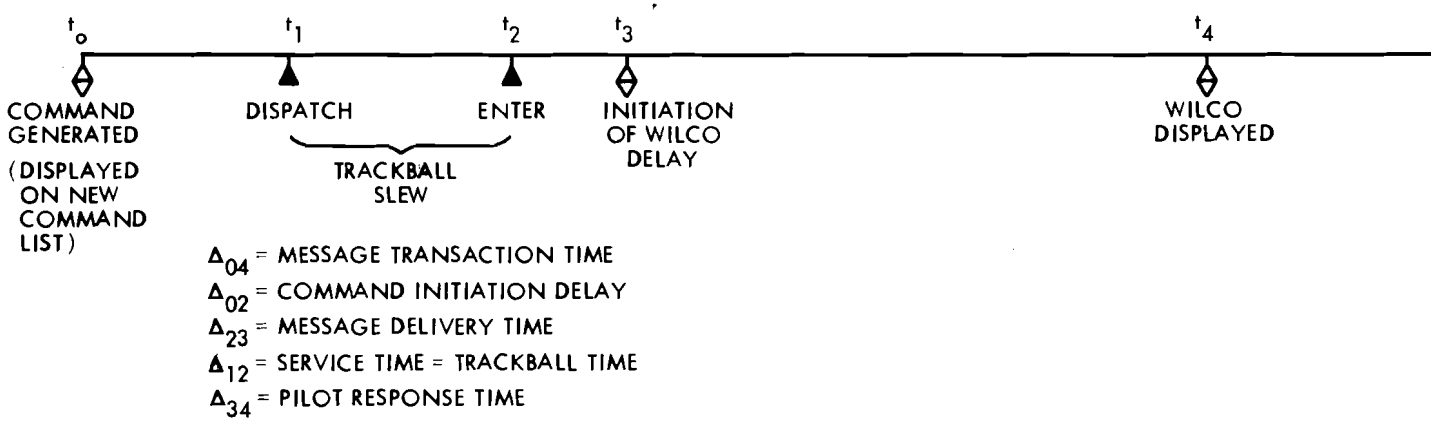
Δ_{04} = MESSAGE TRANSACTION TIME
Δ_{02} = COMMAND INITIATION DELAY
Δ_{23} = MESSAGE DELIVERY TIME
Δ_{12} = SERVICE TIME = TRACKBALL TIME
Δ_{34} = PILOT RESPONSE TIME

3. TABULAR, MULTIPLE, VOICE

VOICE LINK A/C

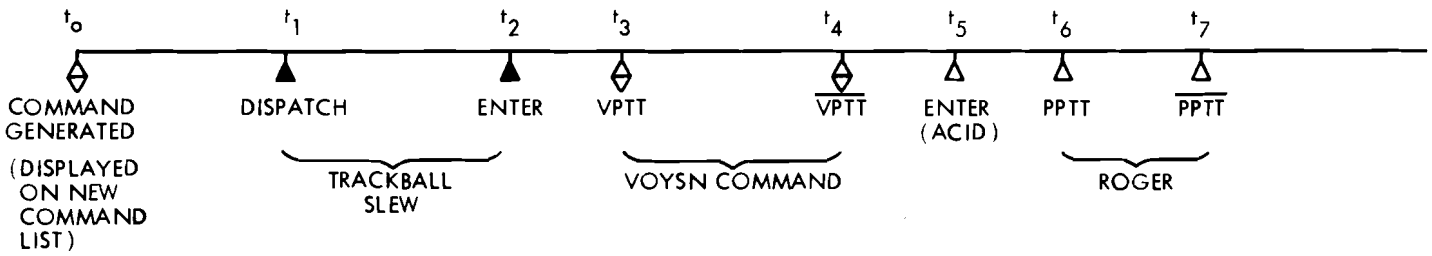


DATA LINK A/C



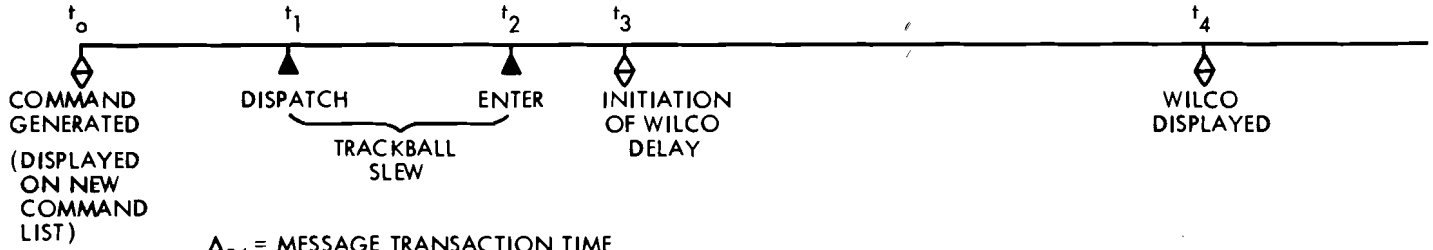
4. TABULAR, MULTIPLE, VOSYN

VOICE LINK A/C



Δ_{47} = PILOT RESPONSE TIME
Δ_{07} = MESSAGE TRANSACTION TIME
Δ_{02} = COMMAND INITIATION DELAY
Δ_{24} = MESSAGE DELIVERY TIME
Δ_{17} = SERVICE TIME
Δ_{12} = TRACKBALL TIME

DATA LINK A/C



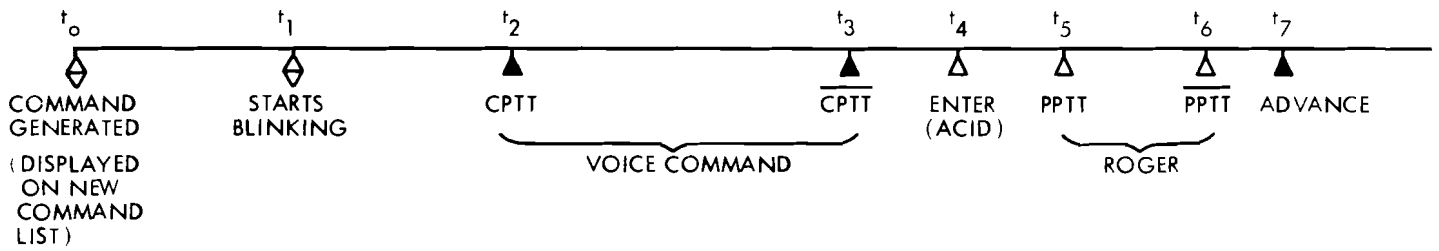
Δ_{04} = MESSAGE TRANSACTION TIME
Δ_{02} = COMMAND INITIATION DELAY
Δ_{23} = MESSAGE DELIVERY TIME
Δ_{12} = SERVICE TIME = TRACKBALL TIME
Δ_{34} = PILOT RESPONSE TIME

5. TABULAR, SINGLE, VOICE

▲ CONTROLLER ACTION
△ PILOT ACTION
◊ COMPUTER ACTION

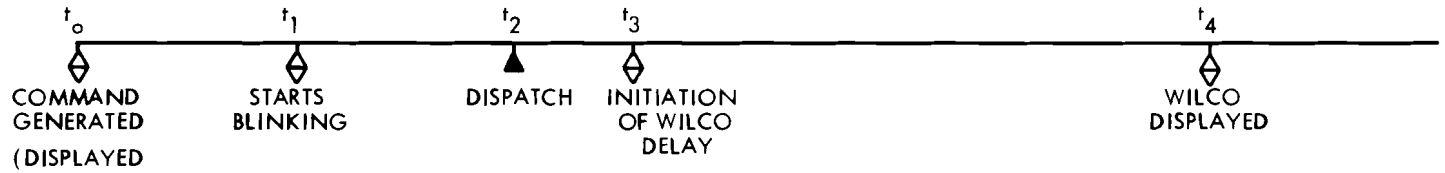
t_k = time tag
$\Delta_{ij} = t_j - t_i$ = time interval
CPTT = controller push-to-talk
$\overline{\text{CPTT}}$ = controller release push-to-talk
PPTT = pilot push-to-talk
$\overline{\text{PPTT}}$ = pilot release push-to-talk

VOICE LINK A/C



Δ_{37} = PILOT RESPONSE TIME
Δ_{07} = MESSAGE TRANSACTION TIME
Δ_{01} = QUEUE DELAY
Δ_{02} = COMMAND INITIATION DELAY
Δ_{23} = MESSAGE DELIVERY TIME
Δ_{17} = SERVICE TIME

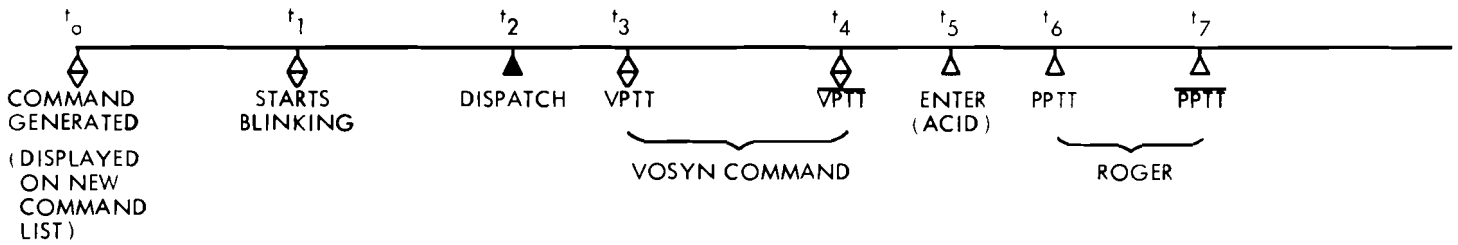
DATA LINK A/C



Δ_{34} = PILOT RESPONSE TIME
Δ_{04} = MESSAGE TRANSACTION TIME
Δ_{01} = QUEUE DELAY
Δ_{02} = COMMAND INITIATION DELAY
Δ_{23} = MESSAGE DELIVERY TIME
Δ_{12} = SERVICE TIME

6. TABULAR, SINGLE, VOSYN

VOICE LINK A/C



Δ_{47} = PILOT RESPONSE TIME
Δ_{07} = MESSAGE TRANSACTION TIME
Δ_{01} = QUEUE DELAY
Δ_{02} = COMMAND INITIATION DELAY
Δ_{24} = MESSAGE DELIVERY TIME
Δ_{17} = SERVICE TIME

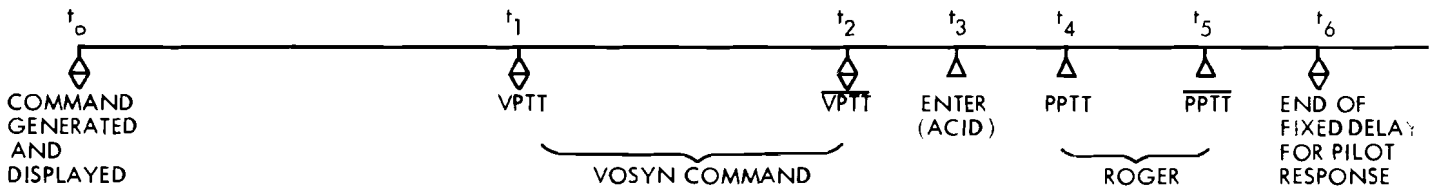
VPTT - vosyn push-to-talk
$\overline{VPTT}$ - vosyn release push-to-talk

DATA LINK A/C

Δ_{34} = PILOT RESPONSE TIME
Δ_{04} = MESSAGE TRANSACTION TIME
Δ_{01} = QUEUE DELAY
Δ_{02} = COMMAND INITIATION DELAY
Δ_{23} = MESSAGE DELIVERY TIME
Δ_{12} = SERVICE TIME

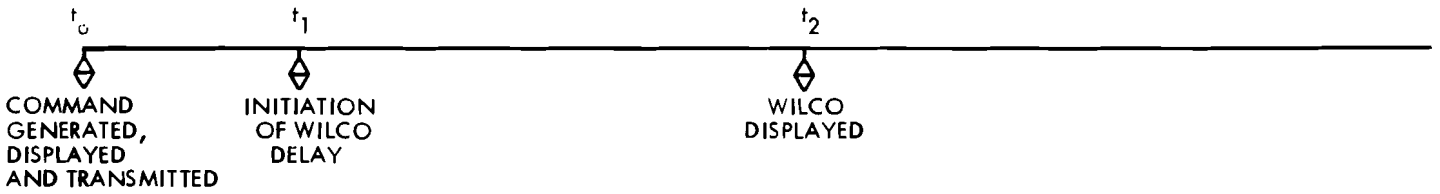
7. CONTROL - BY - EXCEPTION (FULL DATA BLOCK, SINGLE, VOSYN)

VOICE LINK A/C



Δ_{26} = PILOT RESPONSE TIME
Δ_{06} = MESSAGE TRANSACTION TIME
Δ_{01} = QUEUE DELAY = COMMAND INITIATION DELAY
Δ_{12} = MESSAGE DELIVERY TIME
Δ_{16} = SERVICE TIME

DATA LINK A/C

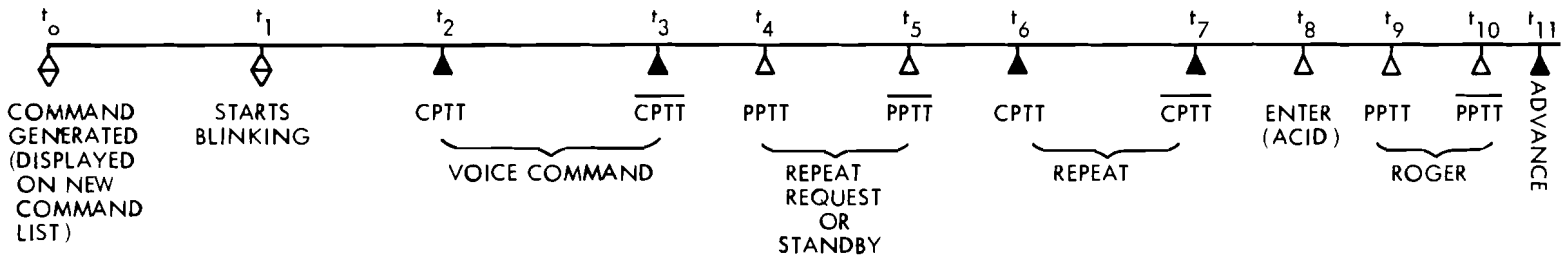


Δ_{02} = MESSAGE TRANSACTION TIME
Δ_{01} = MESSAGE DELIVERY TIME = SERVICE TIME
Δ_{12} = PILOT RESPONSE TIME
0 = COMMAND INITIATION DELAY

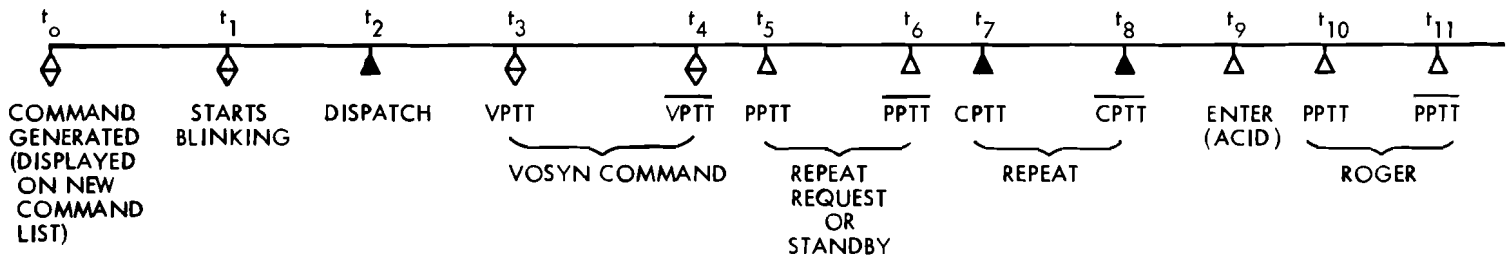
DELAYED COMPLIANCE AND REPEAT REQUEST EXCEPTION CASES

(Voice Link Aircraft Only)

5. TABULAR, SINGLE, VOICE



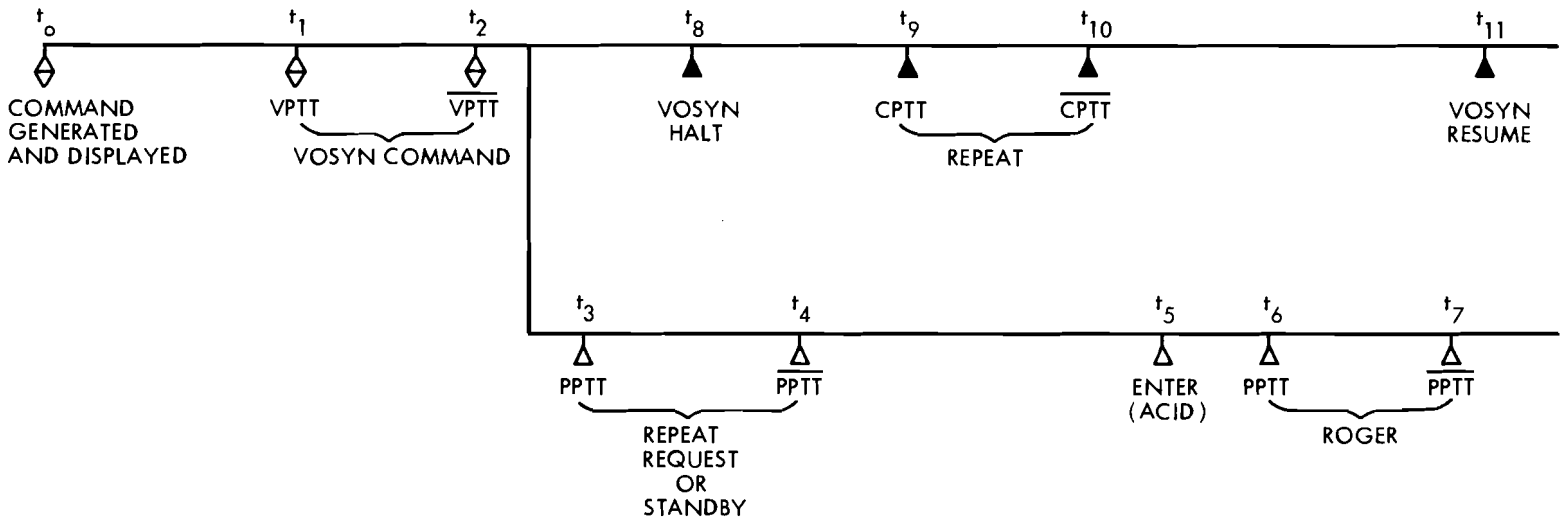
6. TABULAR, SINGLE, VOSYN



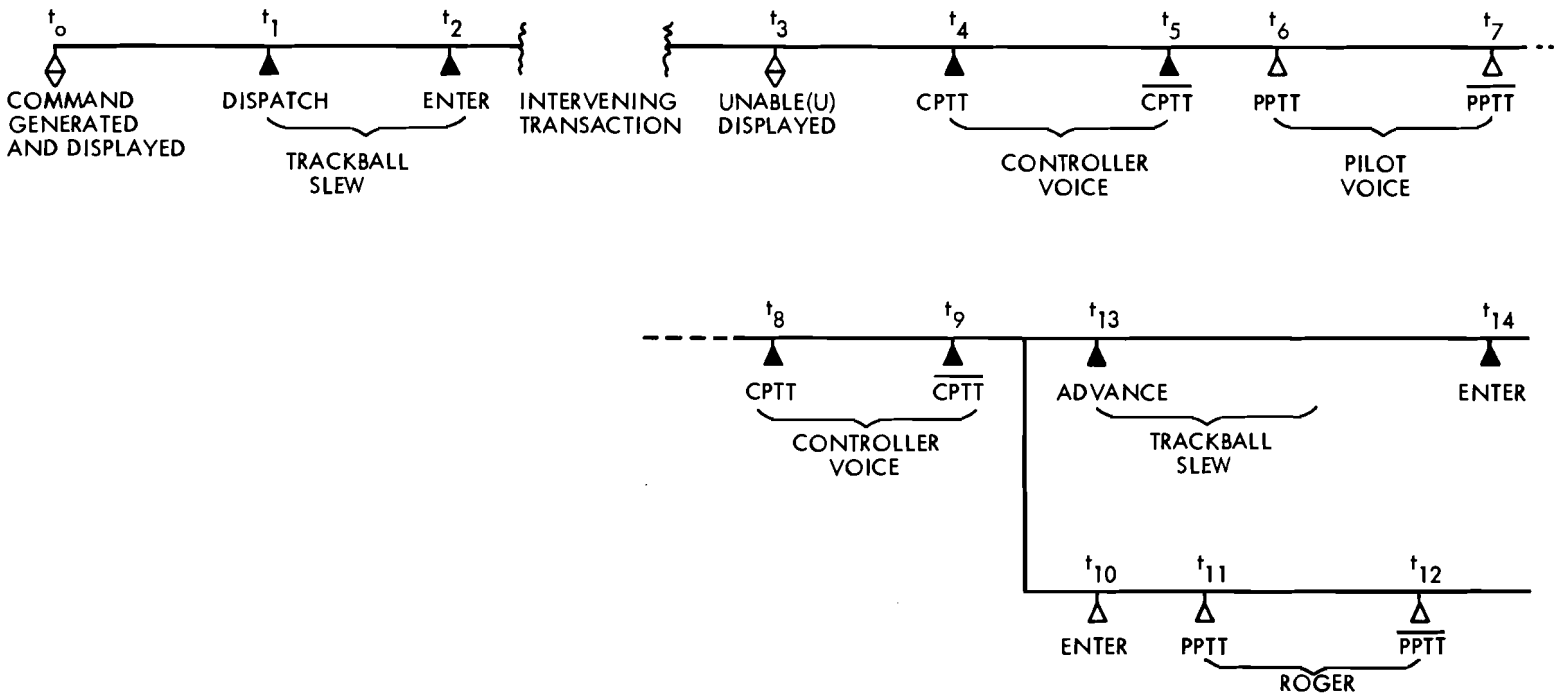
1. FULL DATA BLOCK, MULTIPLE, VOICE (SAME AS MODE 4)

2. FULL DATA BLOCK, MULTIPLE, VOSYN (SAME AS MODE 3)

7. CONTROL-BY-EXCEPTION



4. TABULAR, MULTIPLE, VOSYN



3. TABULAR, MULTIPLE, VOICE (SAME AS MODE 3)

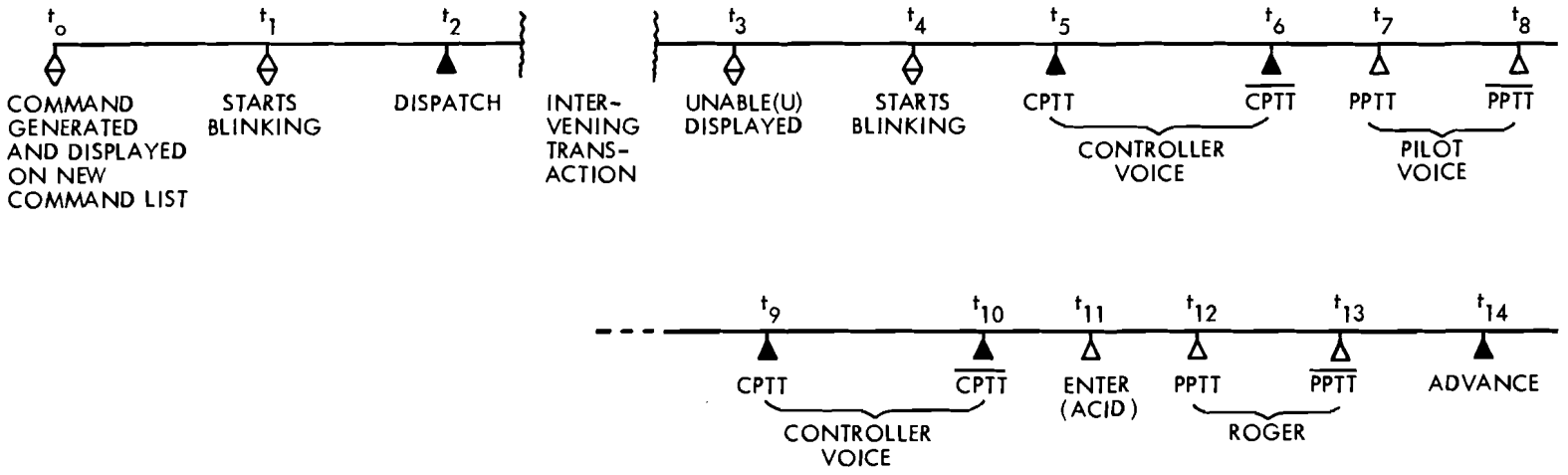
1. FULL DATA BLOCK, MULTIPLE, VOICE (SAME AS MODE 3)

2. FULL DATA BLOCK, MULTIPLE, VOSYN (SAME AS MODE 3)

UNABLE EXCEPTION CASE

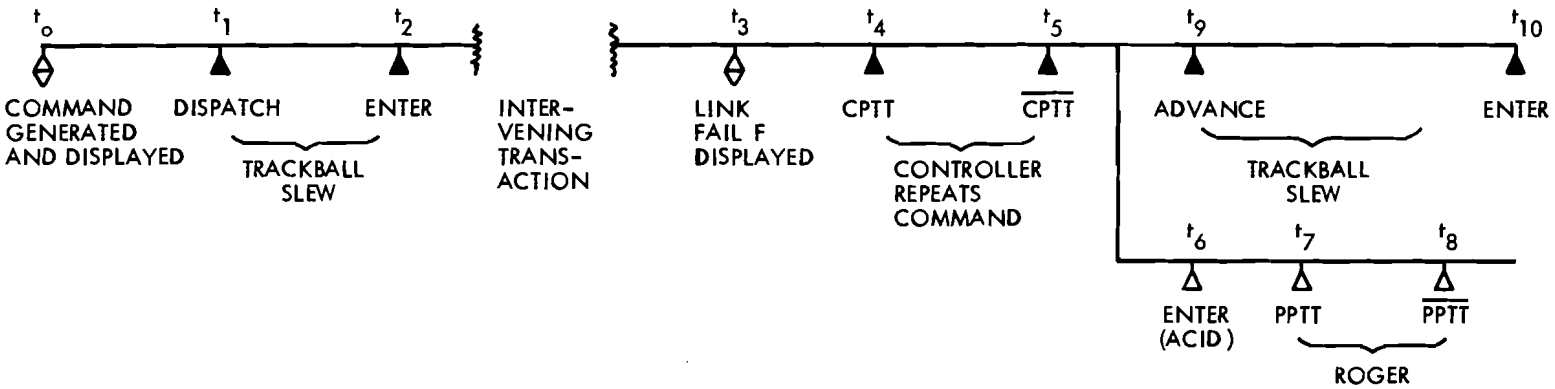
(Data Link Aircraft Only)

5. TABULAR, SINGLE, VOICE



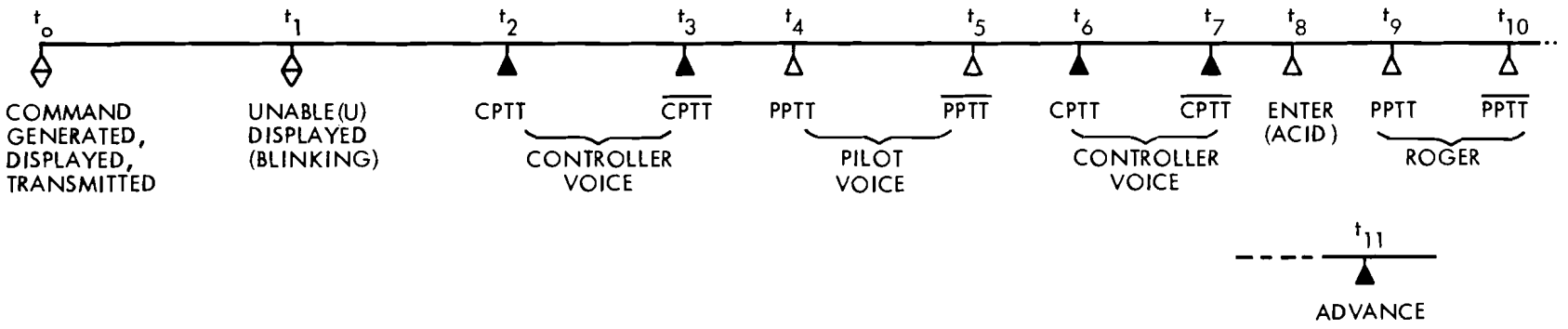
6. TABULAR, SINGLE, VOSYN (SAME AS MODE I)

4. TABULAR, MULTIPLE, VOSYN



3. TABULAR, MULTIPLE, VOICE (SAME AS MODE 3)
1. FULL DATA BLOCK, MULTIPLE, VOICE (SAME AS MODE 3)
2. FULL DATA BLOCK, MULTIPLE, VOSYN (SAME AS MODE 3)

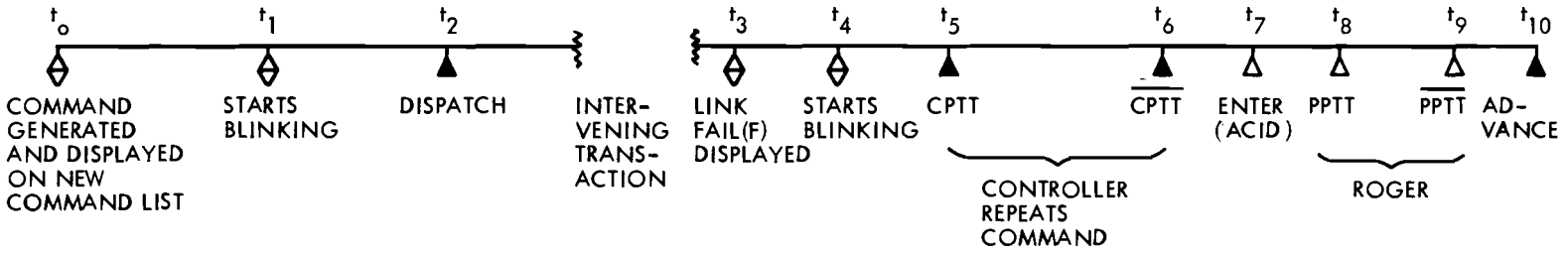
7. CONTROL-BY-EXCEPTION



LINK FAIL EXCEPTION CASE

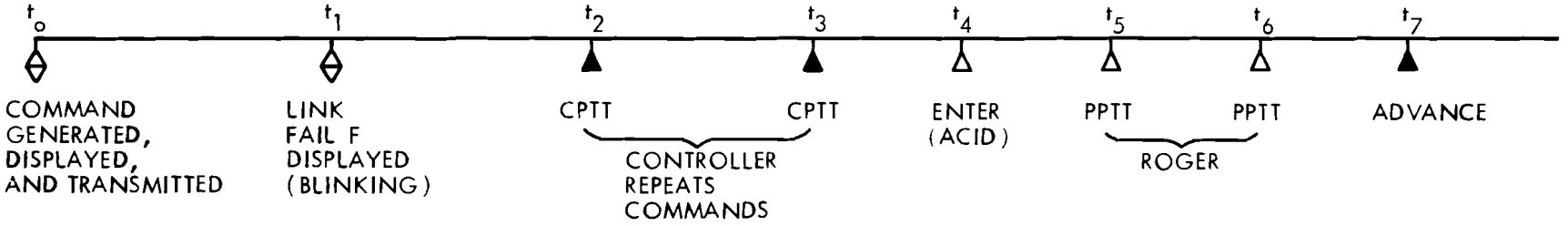
(Data Link Aircraft Only)

5. TABULAR, SINGLE, VOICE

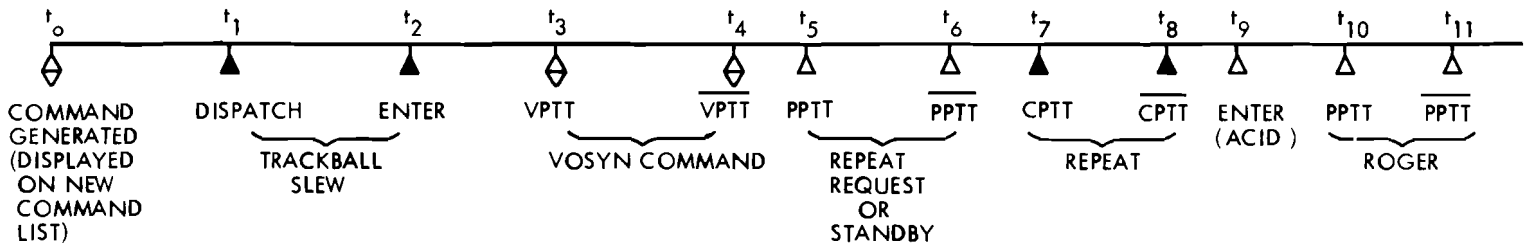


6. TABULAR, SINGLE, VOSYN (SAME AS MODE 1)

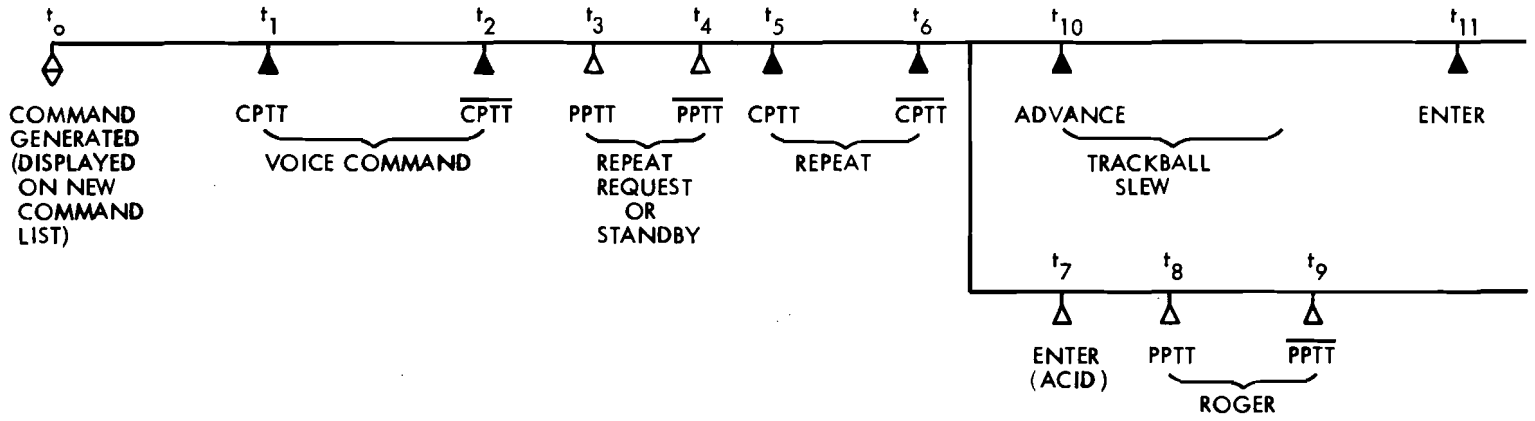
7. CONTROL-BY-EXCEPTION



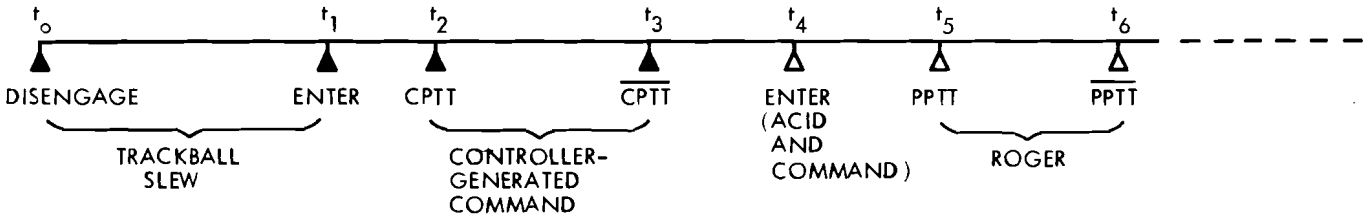
4. TABULAR, MULTIPLE, VOSYN

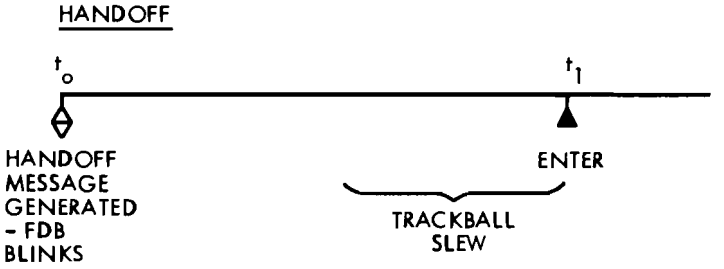


3. TABULAR, MULTIPLE, VOICE

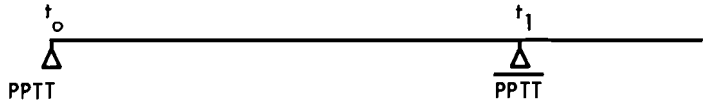


DISENGAGEMENT AND RESOLUTION OF CONFLICT BY CONTROLLER-GENERATED VOICE COMMANDS

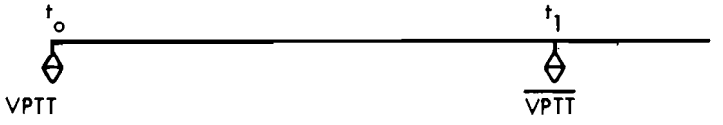




(a) Controller Voice



(b) Pilot Voice



(c) Vosyn

APPENDIX E

SELECTION OF REGRESSION MODEL

One of the major decisions made during the experimental design phase was to include a dynamically changing load during each run, rather than to use a single load in all runs or to include load as a factor, thereby increasing the number of runs required. The major complication added by this approach is to account for the effect of the changing load in order to determine that portion of the variance attributable to error and that caused by the load effect.

Prior to the collection of data, several conjectures were offered as to the nature of the functional relationship between the data link measures and the instantaneous aircraft load. Among those advanced were (a) no change, (b) linear increase, and (c) exponential (or quadratic) increase. To test these conjectures, regression runs of every measure were made for every test using a polynomial regression analysis program, LSR, from the Xerox Statistical Subroutine Library. Linear, quadratic and cubic (in time) models were fitted for each measure. Since the exact aircraft load was not known, the time of the event was used as a proxy. The aircraft load was planned to increase linearly over the duration of the test. To provide a visual indication of the relationship, CalComp plots were made for each test and measure.

Obviously, a great deal of data was generated by these regression runs. This analysis will focus on the 50-percent series, voice link message transaction time measure. Those data exhibit relationships typical of all the other measures.

In the general polynomial relationship $y = a + bx + cx^2 + dx^3 + \ldots.$, the characteristic shape of the curve depends upon the signs of the coefficients. The sign of a coefficient simply determines whether the curve will intercept the y-axis above or below the origin. The effect of combinations of different signs of the other parameters on the shape of the curve is shown in figure E-1.

Table 1 gives the 50-percent voice link aircraft results for message transaction time in terms of the characteristic shape of the curve and its statistical significance. The most readily apparent characteristic of table E-1 is the relative sparcity of significant relationships. The second obvious characteristics is the number of different shapes obtained. Table E-2 gives the relative frequency of the different shapes for each level of the polynomial.

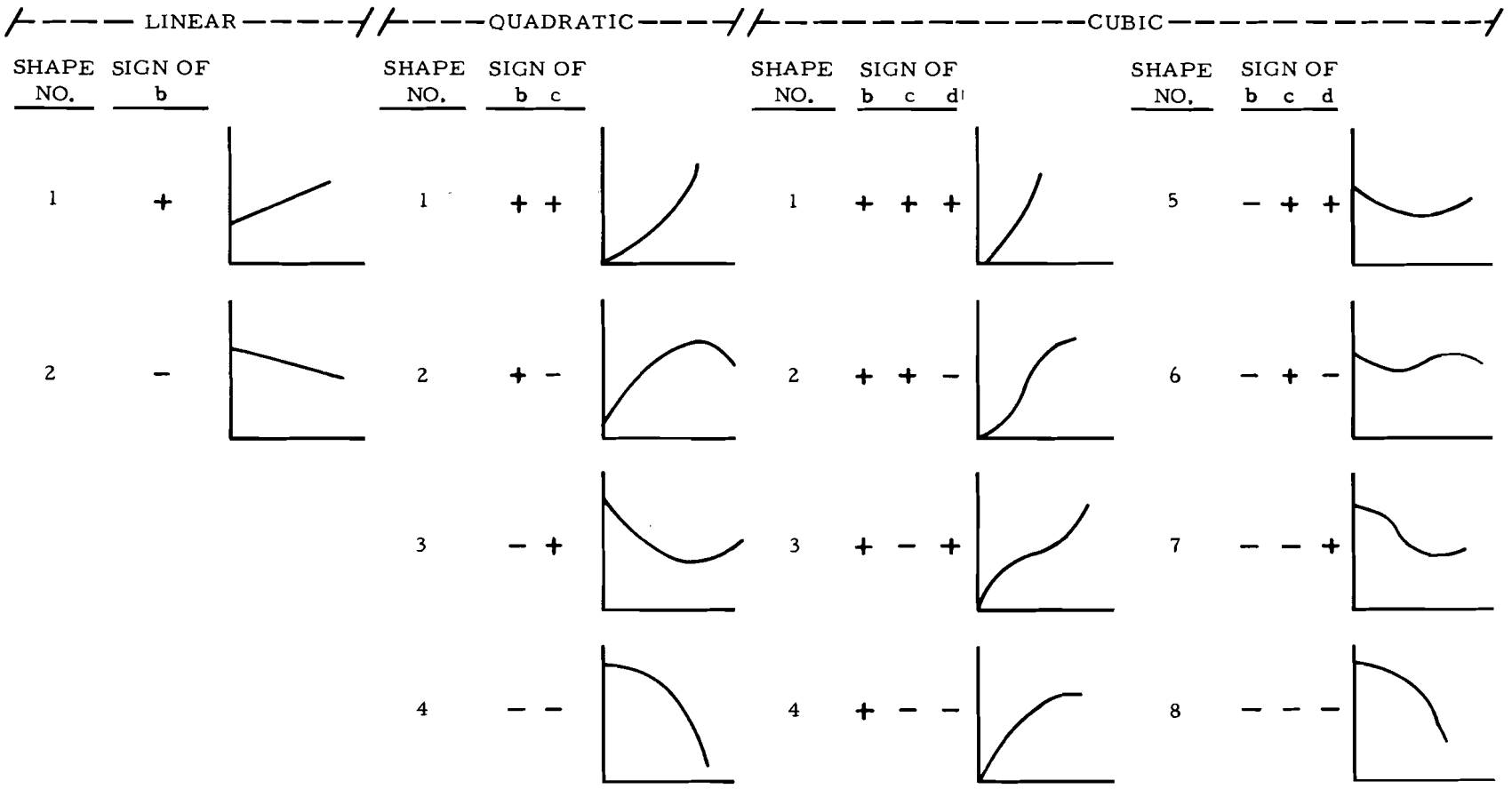


FIGURE E-1. CHARACTERISTIC SHAPES OF POLYNOMIAL

TABLE E-1. FIFTY-PERCENT VOICE LINK AIRCRAFT RESULTS FOR MESSAGE TRANSACTION TIME

		Linear		Quadratic		Cubic	
Mode	Subject	Shape	Significance	Shape	Significance	Shape	Significance
1	A	1	.99	2	.999	3	.95
	B	1	-	2	-	6	-
	C	1	.95	2	.90	6	.90
	D	1	-	3	-	6	-
	E	1	.95	2	.95	3	-
	F	2	-	2	-	2	-
	G	1	-	2	.95	6	.90
2	A	2	-	3	.95	6	-
	B	1	-	3	-	6	-
	C	1	-	3	-	3	-
	D	2	-	2	-	3	-
	E	1	-	2	-	3	-
	F	1	-	2	-	3	-
	G	1	.90	2	.999	2	.999
3	A	1	-	3	-	6	-
	B	2	-	3	.90	6	.99
	C	1	-	2	.95	3	.90
	D	2	-	3	-	6	.99
	E	2	-	3	-	6	-
	F	1	-	2	-	3	-
	G	2	-	2	-	3	-
4	A	1	-	3	-	3	-
	B	1	-	2	-	3	-
	C	1	-	2	.99	2	.99
	D	2	-	2	-	3	-
	E	2	.999	3	.999	6	.999
	F	2	-	2	-	3	-
	G	1	-	2	-	6	-
5	A	1	.90	2	-	6	-
	B	1	-	2	-	3	-
	C	1	.99	2	.95	6	.95
	D	2	-	2	-	6	-
	E	2	.999	3	.999	6	.999
	F	1	-	2	.95	3	-
	G	1	-	2	-	6	-
6	A	2	.95	3	.90	6	.99
	B	1	-	2	-	3	-
	C	1	-	2	-	6	-
	D	1	-	2	.95	2	.95
	E	1	-	1	-	6	-
	F	1	.95	2	-	3	-
	G	1	.99	2	.95	6	.95
7	A	1	.90	2	-	2	-
	B	1	-	2	-	3	-
	C	1	-	2	-	3	-
	D	1	.90	2	-	3	-
	E	1	.95	1	-	6	-
	F	1	-	2	.90	4	-
	G	1	-	2	.90	6	.95

TABLE E-2. FREQUENCY OF CHARACTERISTIC SHAPES BY POLYNOMINAL LEVEL

Shape	Frequency	Shape	Frequency	Shape	Frequency
1	74%	1	4%	2	10%
2	26%	2	71%	3	41%
		3	25%	4	2%
				6	47%

Of the eight characteristic shapes observed, only the linear shape 1, quadratic shape 1, and cubic shapes 2 and 3 meet the prior expectations of a monotonically increasing measure as a function of time. Since the primary objective of this analysis is to select a reasonable model which will account for a significant portion of the variance due to the functional relationship between the measure and the load, no attempt will be made to explain how these shapes arise. However, figures E-2 through E-10 give examples of each of the shapes in terms of CalComp plots of the data points. Figure E-11 gives an example of a test in which no significant relationship was detected.

Since both the quadratic and cubic models have such a wide variety of unexplained shapes, primary consideration must be given to the linear form simply on the basis of reasonableness. In addition, many of the significant higher order relationships are also significant in the linear form. Based on both these considerations, the linear form of the model was used in all the remaining analyses.

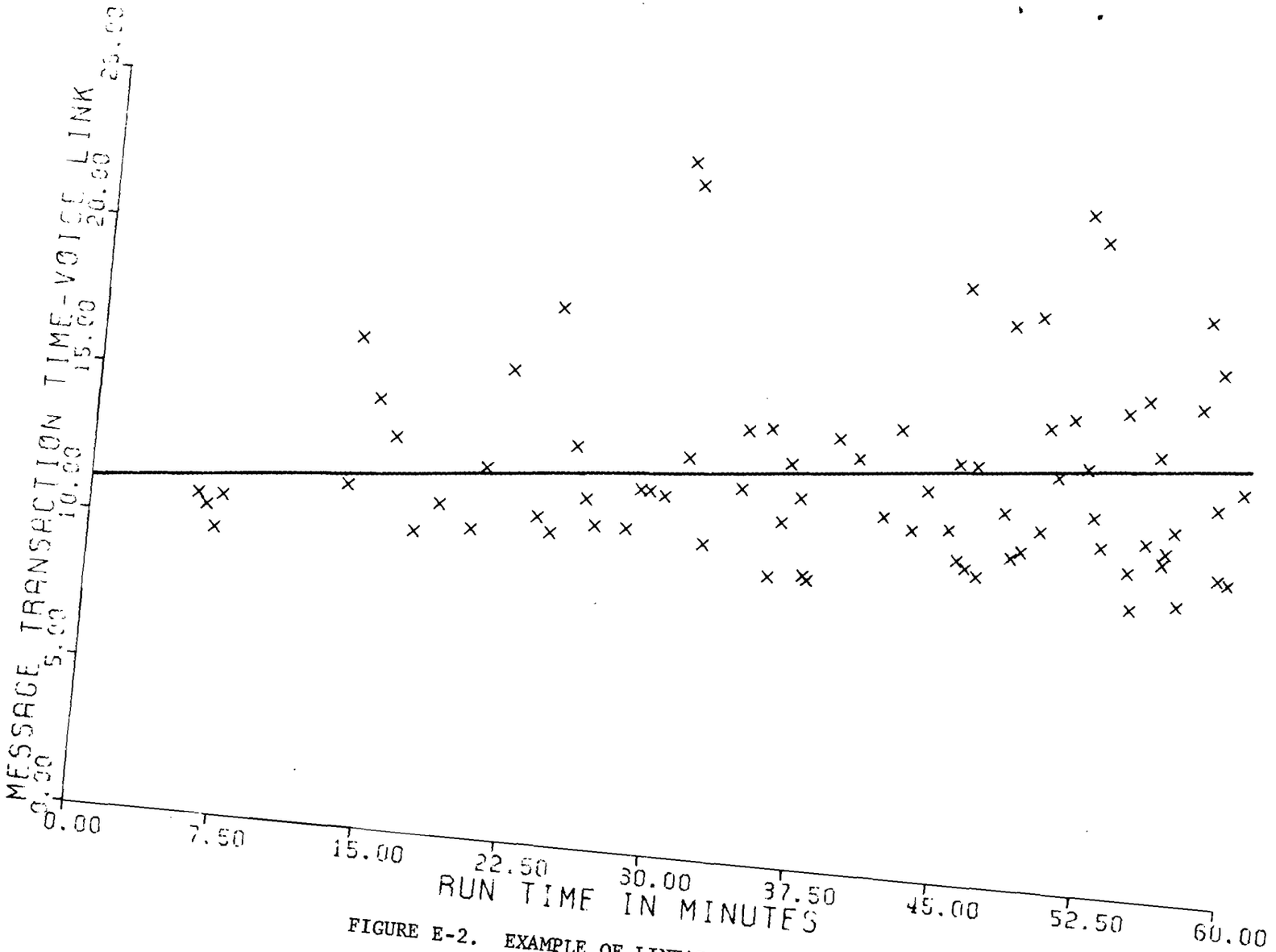


FIGURE E-2. EXAMPLE OF LINEAR SHAPE 1

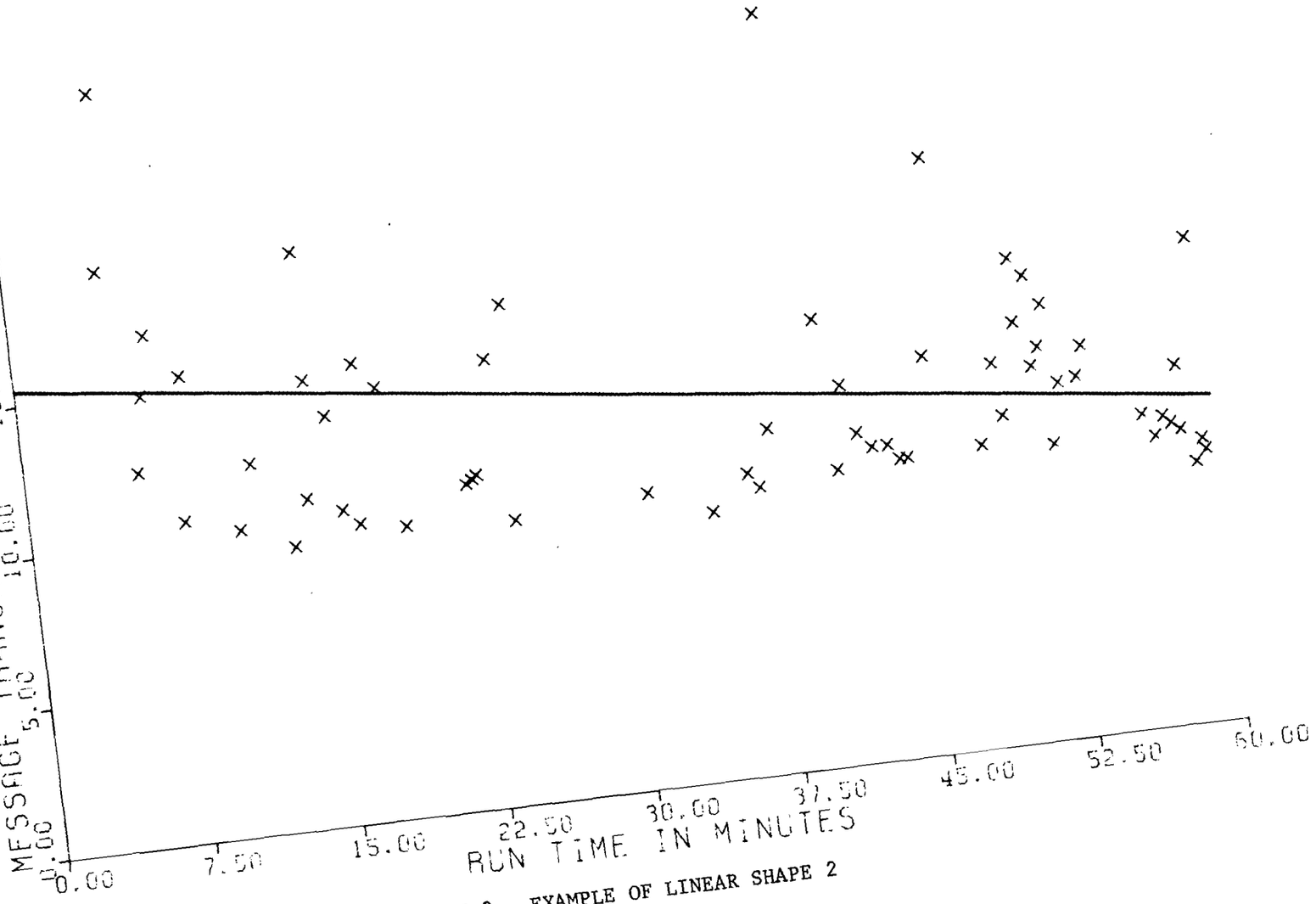


FIGURE E-3. EXAMPLE OF LINEAR SHAPE 2

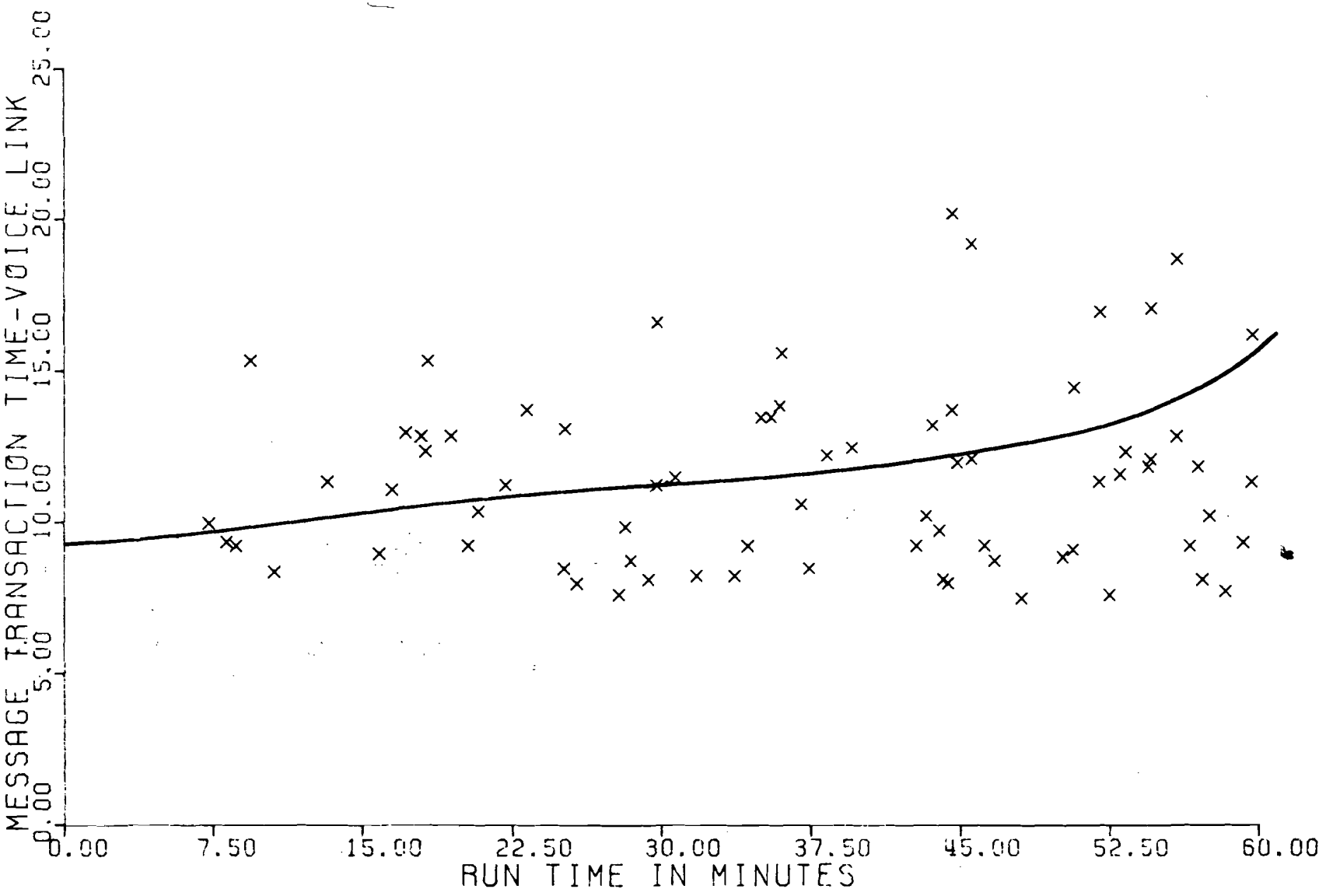


FIGURE E-4. EXAMPLE OF QUADRATIC SHAPE 1

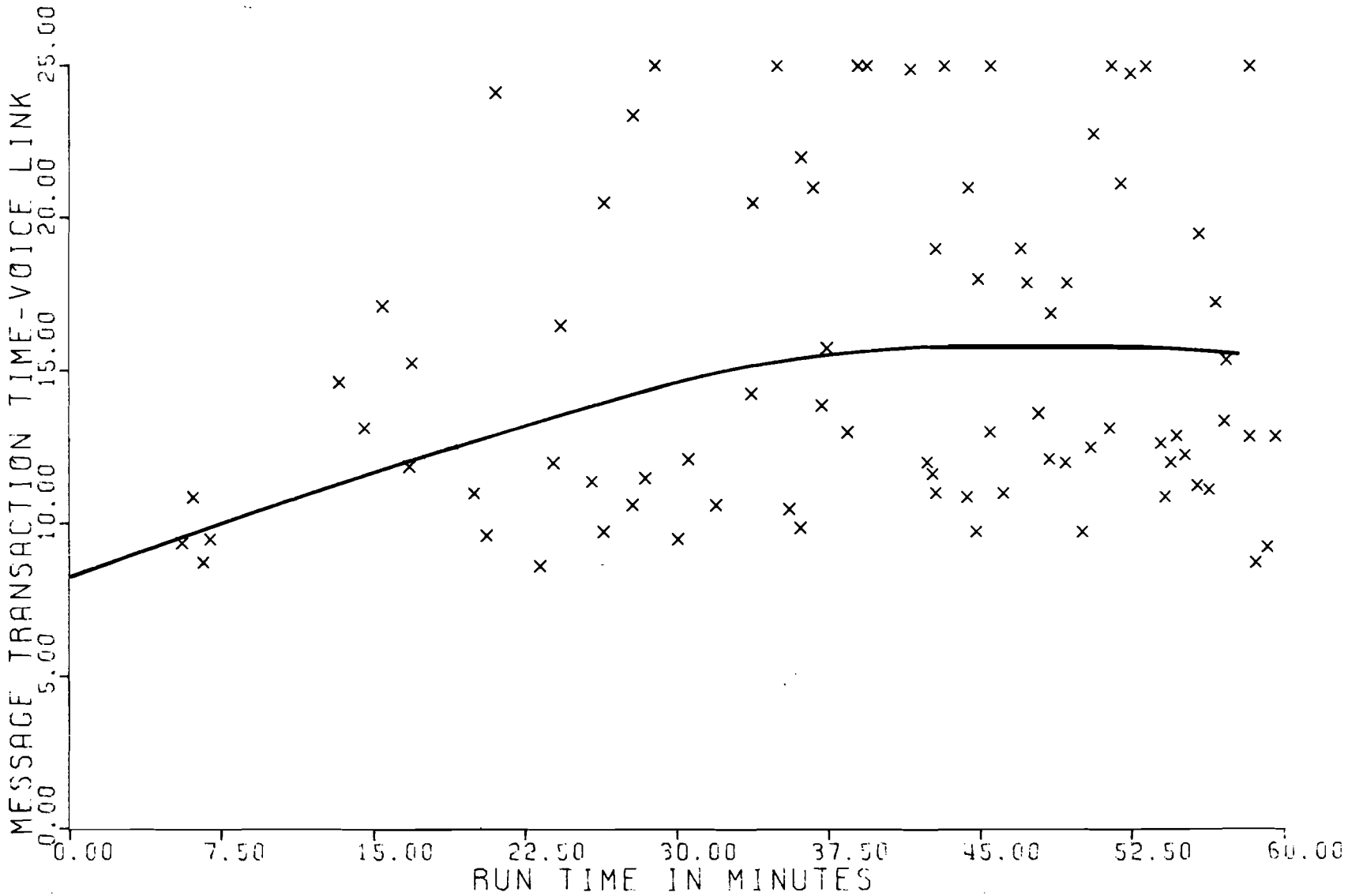


FIGURE E-5. EXAMPLE OF QUADRATIC SHAPE 2

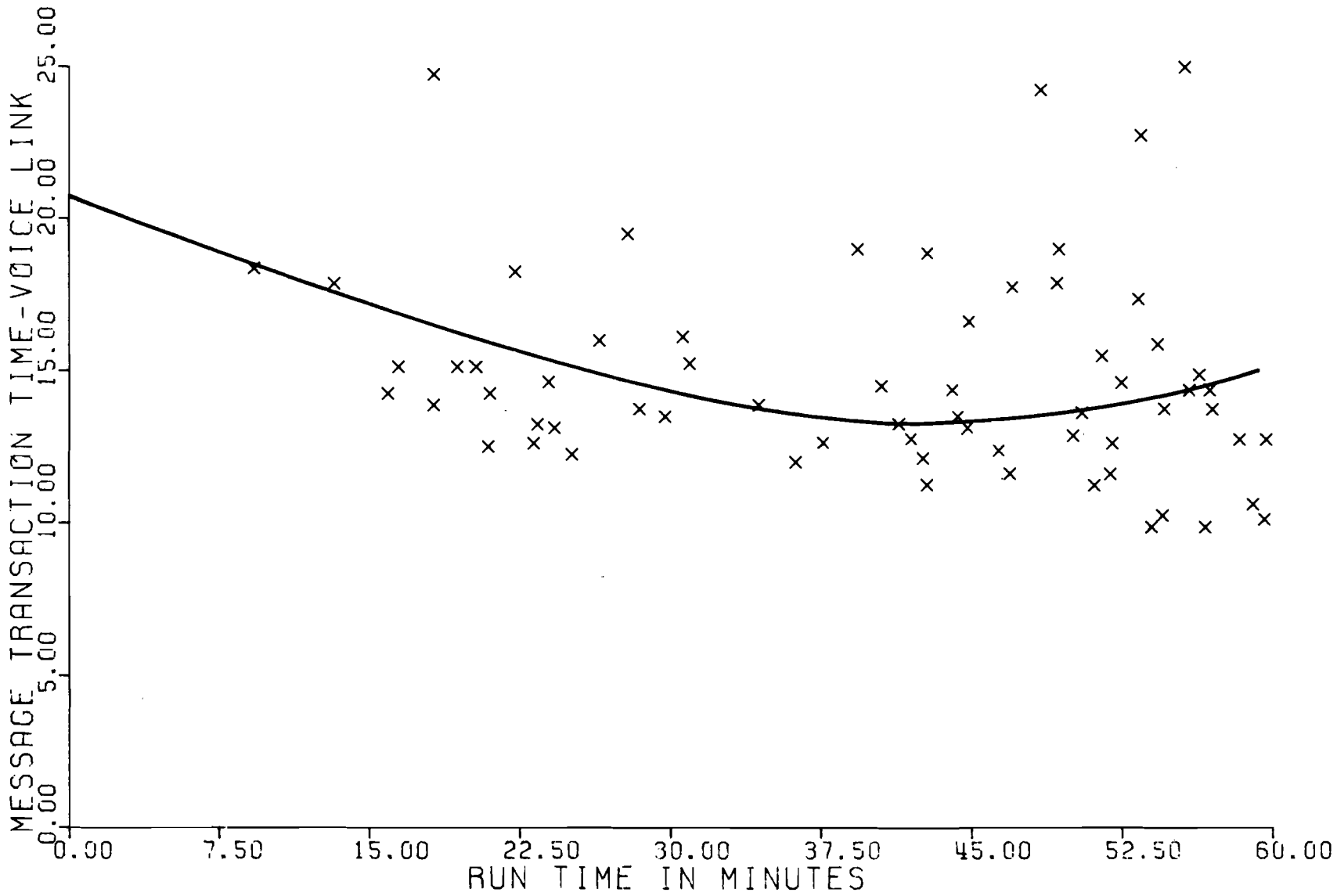


FIGURE E-6. EXAMPLE OF QUADRATIC SHAPE 3

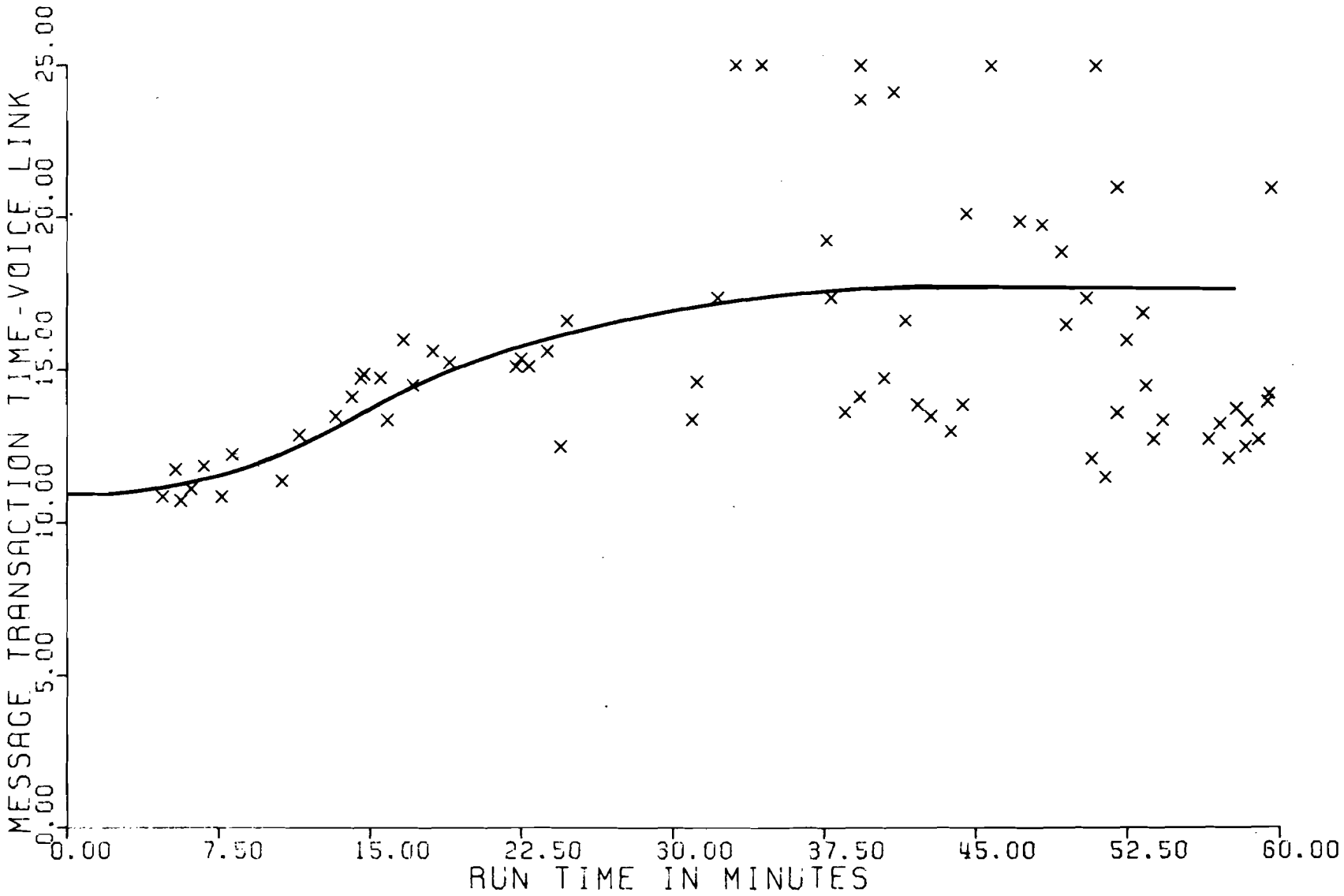


FIGURE E-7. EXAMPLE OF CUBIC SHAPE 2

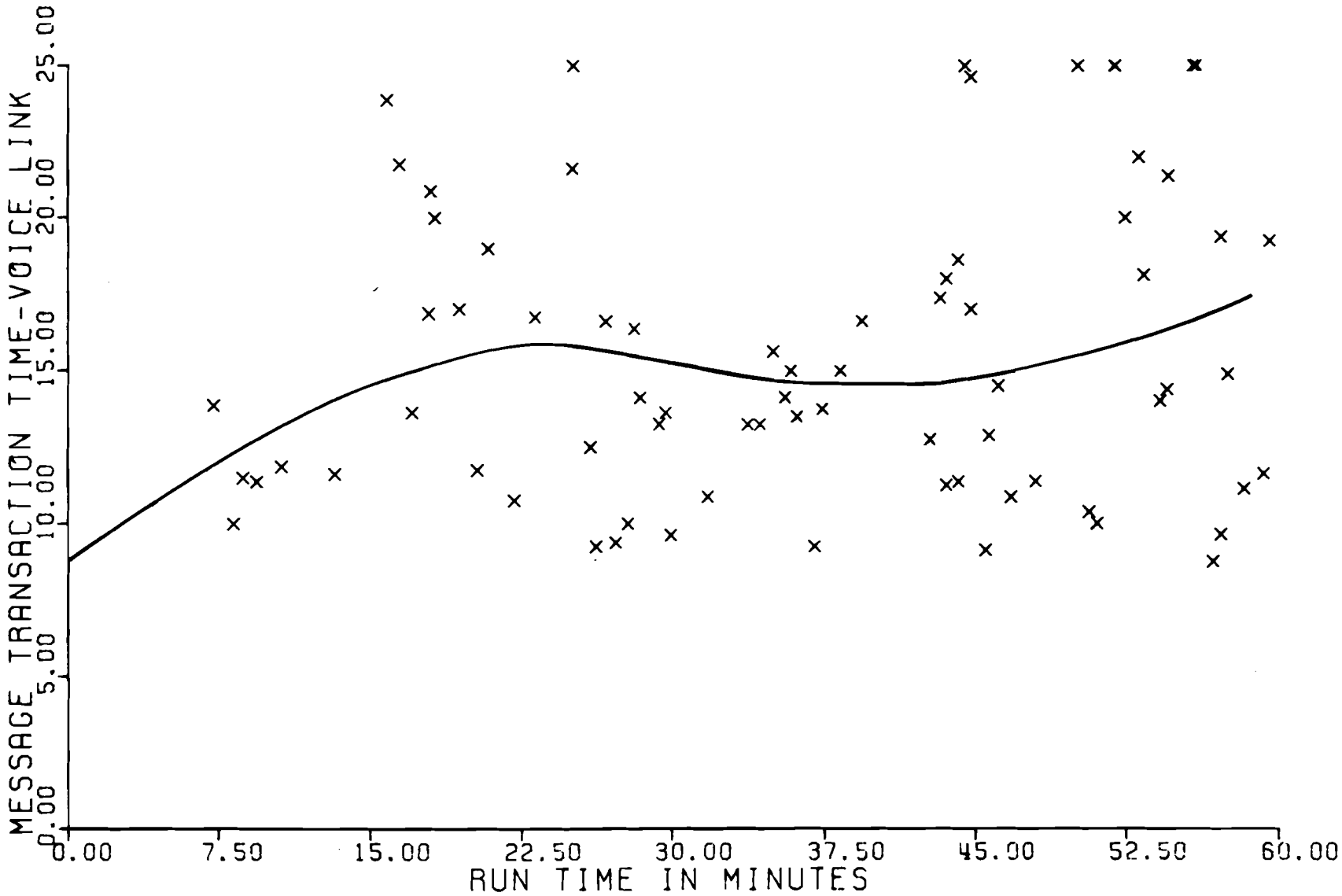


FIGURE E-8. EXAMPLE OF CUBIC SHAPE 3

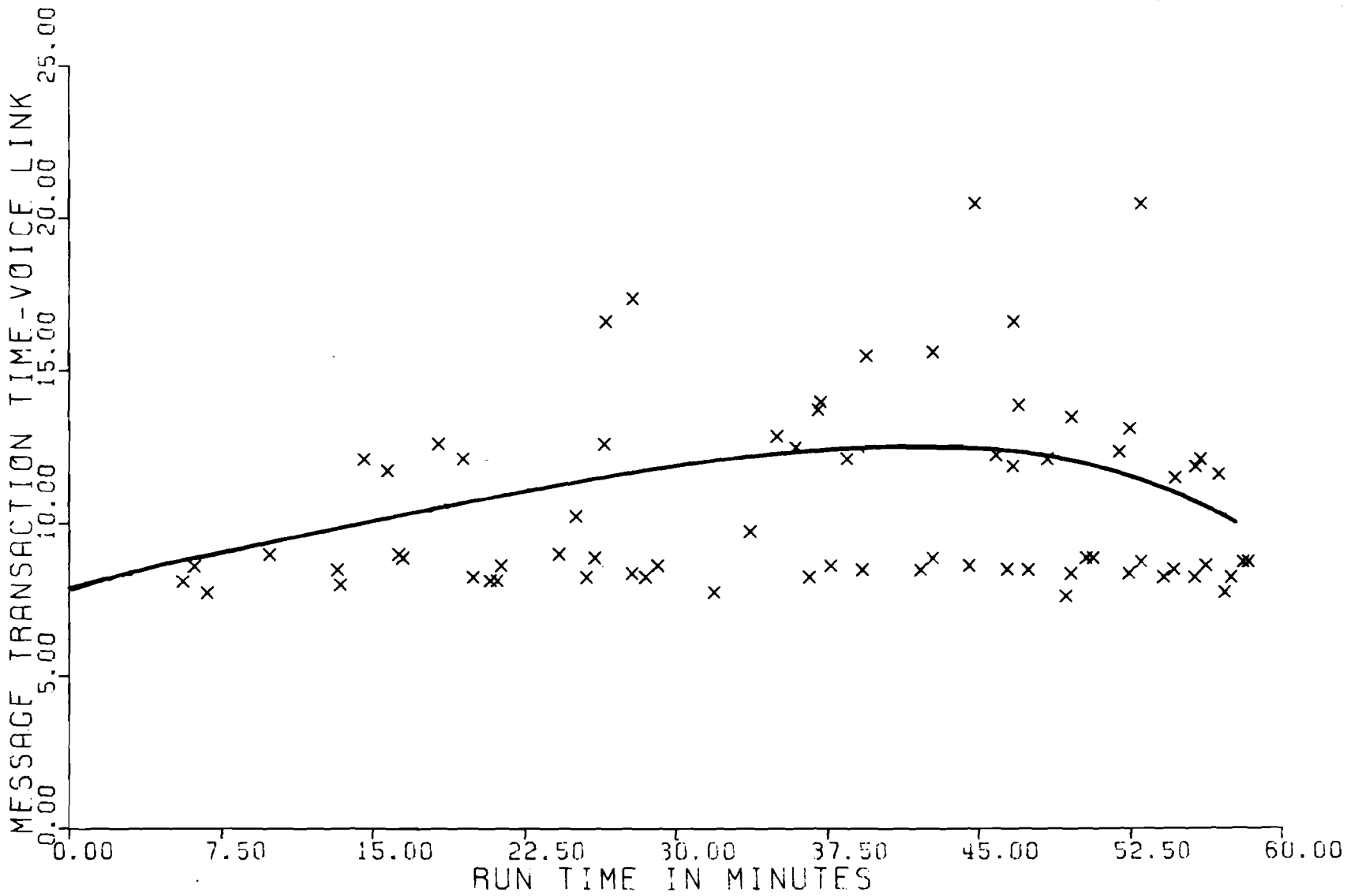


FIGURE E-9. EXAMPLE OF CUBIC SHAPE 4

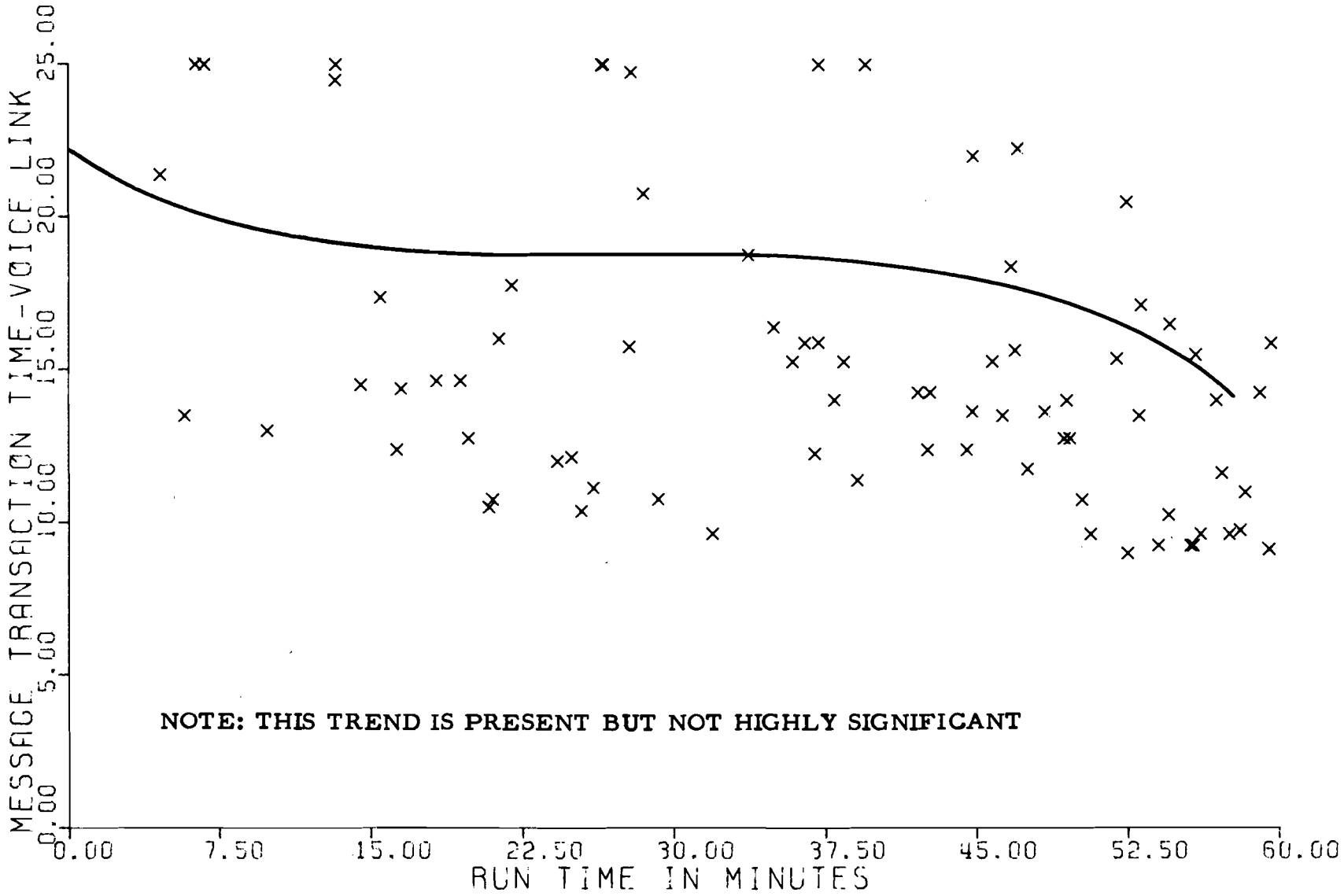


FIGURE E-10. EXAMPLE OF CUBIC SHAPE 6

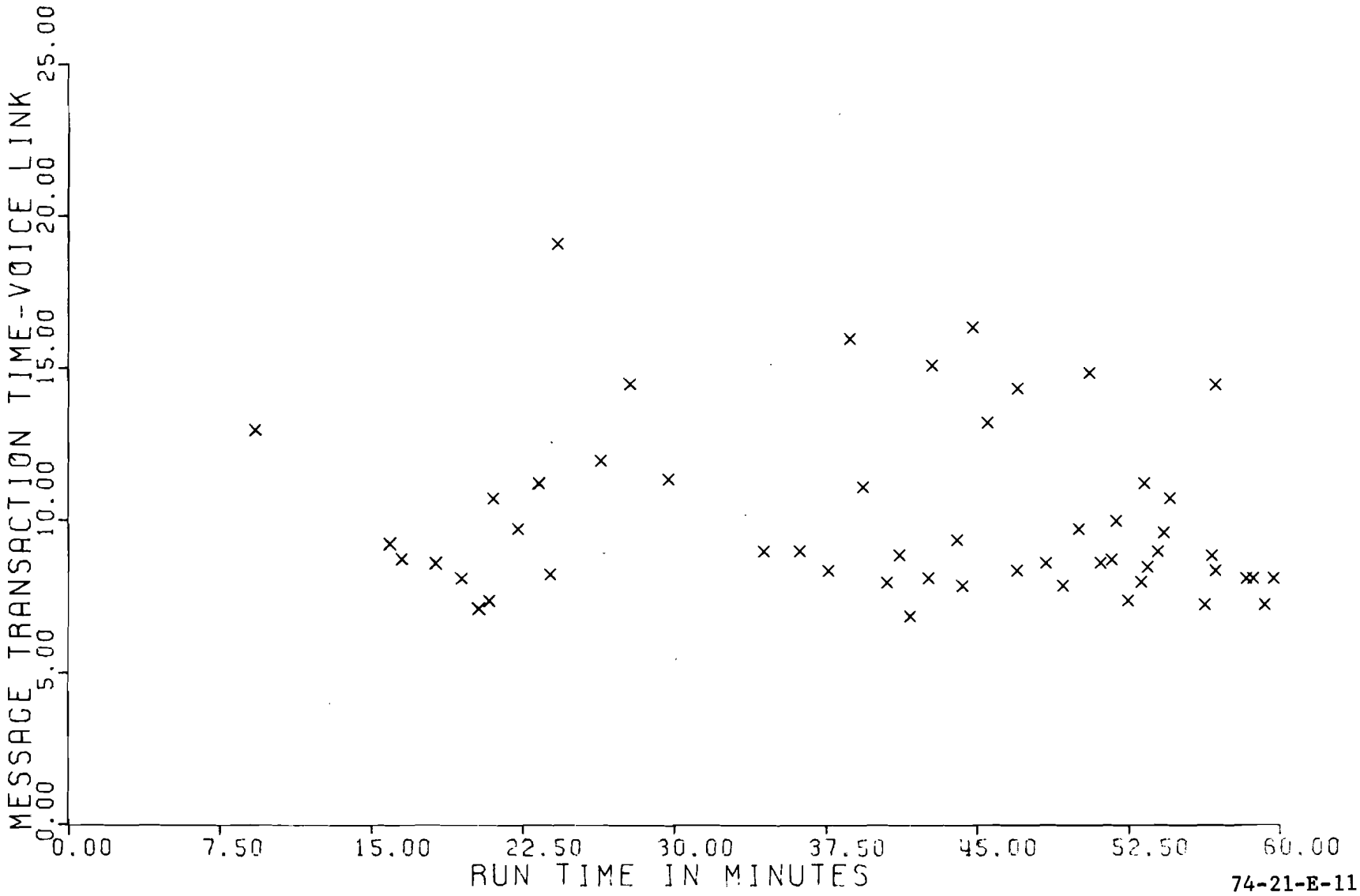


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FIGURE E-11. EXAMPLE OF TEST IN WHICH NO SIGNIFICANT RELATIONSHIP WAS DETECTED.