(2)

AD-A233 692

DOT/FAA/CT-90/29

FAA Technical Center
Atlantic City International Airport
N.J. 08405

Controller Evaluation of Initial Data Link Terminal Air Traffic Control Services

Data Link Development Team

January 1991

Final Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No. DOT/FAA/CT-90/29	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle CONTROLLER EVALUATION OF INITIAL DATA LINK TERMINAL AIR TRAFFIC CONTROL SERVICES		5. Report Date January 1991
		6. Performing Organization Code ACD-320
7. Author(s) DATA LINK DEVELOPMENT TEAM		8. Performing Organization Report No. DOT/FAA/CT-90/29
9. Performing Organization Name and Address U.S. Department of Transportation Federal Aviation Administration Technical Center Atlantic City International Airport, N.J. 08405		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. T2001E
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Technical Center Atlantic City International Airport, N.J. 08405		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This document details the results the first Federal Aviation Administration Technical Center investigation of the initial terminal air traffic control services developed for transmission using Data Link technology. Initial Data Link services were evaluated in order to identify service delivery methods which optimize controller acceptance, performance, and workload.

17. Key Words ARTS IIIA Mode S Terminal	18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service, Springfield, Va. 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	71	

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

PREFACE

This report documents the first Federal Aviation Administration controller evaluation of a group of four terminal air traffic control services and functions which have been designed for implementation on the Data Link air-ground communication system. The research was conducted at the Federal Aviation Administration (FAA) Technical Center by the Airborne Collision Avoidance and Data Link Systems Branch, ACD-320.

ACKNOWLEDGEMENTS

The study reported in this document was conducted at the Federal Aviation Administration (FAA) Technical Center by the Ground Data Link Development Team. The execution of the study was the result of many months of planning and the cooperative efforts of many people.

Mr. Nicholas Talotta was the Data Link Technical Program Manager responsible for the overall management and development of the Data Link services.

Mr. John Zvanya was the project leader responsible for the terminal test bed activities of this study.

Mr. George Chandler provided test bed engineering and software in the development of these initial services.

Dr. Clark Shingledecker (NTI) provided all human factors research and analysis, and prepared the most significant portion of this report.

Mr. Bert Rossbach and Mr. Joseph Lunders, both of TMA Inc., designed the ARTS IIIA software.

Mr. Thomas Pagano and Mr. Leo Wapelhorst provided system engineering.

Mr. Evan Darby provided Air Traffic Control System expertise.

Mr. Henry Marek was responsible for documentation of Controller Design Issues (CDI's) and Coordination Trouble Reports (CTR's).

The Technical Center facility personnel supported this activity during development and testing.

Without the participation of the following members of the Air Traffic Data Link Validation Team (ATDLVT), this study would not have been possible.

Gregg Anderson, Ocean TRACON
Sam Bass, ATR-320
Michael Blomquist, Denver ATCT
Michael Bullington, Sacramento TRACON
Joseph D'Alessio, New York TRACON
Jerome Karrels, Madison, WI, Tower
David Lister, St. Louis Tower
Charlotte Long, Ontario, CA, TRACON
Tom Ray, Tulsa, OK, Tower
Jim O'Malley, ATR-320

TABLE OF CONTENTS

TABLE OF CONTENTS (cont't)

LIST OF ILLUSTRATIONS

LIST OF TABLES

EXECUTIVE SUMMARY

INTRODUCTION.

The Federal Aviation Administration (FAA) is pursuing an initiative to develop and implement a Data Link system intended to enhance communications between ground-based air traffic control (ATC) and aircraft operating within the National Airspace System (NAS). By providing digital information transfer along with the ability to discretely address individual receivers, Data Link is expected to relieve frequency congestion on existing voice radio channels while increasing the safety and productivity of ATC operations.

In order to insure that the introduction of Data Link will have an optimally positive impact on ATC, the FAA Technical Center is conducting a program of research and development to guide the design of effective ATC services, evaluate their impact on system performance, and promote the integration of Data Link with the air traffic controllers who will use it. Prior efforts under this program have focused on the design and operational evaluation of an initial group of ATC services for the en route ATC environment (Talotta, et al., 1988, 1989, 1990). This report presents the findings of the first FAA Technical Center investigation of terminal ATC services developed for transmission using Data Link technology.

The following ATC services and functions services were defined and conceptually designed by the terminal controller subgroup of the Air Traffic Data Link Validation Team (ATDLVT): Transfer of Communication, Initial Contact, Terminal Information, and Menu Text. For the present study, these initial capabilities were implemented in the Data Link Test Bed using the currently operational Automated Radar Terminal System (ARTS) IIIA equipment.

OBJECTIVES.

The overall goal of this research was to establish a developmental baseline for terminal services in the Data Link Test Bed which will support design evolution, operational evaluation, and eventual field implementation. Specifically, the study was conducted to determine the acceptability of the preliminary service designs, to identify requirements for design modifications and enhancements, and to elicit controller estimates of the operational suitability, user acceptance, and workload impact of these services in the terminal ATC environment.

APPROACH.

The objectives of the study were addressed in a series of training and ATC simulation test sessions conducted at the ARTS IIIA workstations in the Data Link Test Bed. During testing, nine terminal air traffic control specialists participated in a

simulation scenario involving arrivals and final approaches. The subjects completed a detailed design review of each of the four services and compared the current voice-only system to a system supplemented by the initial Data Link capability.

PRIMARY RESULTS.

The controllers who participated in this study indicated that Data Link would have strongly positive effects on terminal operations if implemented in the present ATC system. These effects were estimated to include a significant reduction in voice radio frequency congestion, simplified transfer of lengthy advisory messages and clearances, and a reduction in communication errors. Furthermore, quantified projections of average controller workload in a 60 percent Data Link aircraft equipage environment were found to be significantly lower than comparative estimates of workload in the exclusively voice radio communications environment.

The four services, as modified by controller inputs obtained during the study, received high ratings on the dimensions of operational effectiveness and estimated accepatability to field controllers. Enhancements and design changes agreed upon by the subjects included the addition of transaction status and history lists, as well as increased flexibility in the design and accessibility of items contained in the Menu Text and Terminal Information Service lists.

Finally, the findings of the study indicated that continued research attention will be required in the area of controller human factors issues to guarantee the effectiveness of Data Link services in a broad range of operational terminal ATC conditions. These issues include the control of visual search demands in the use of menu functions, insurance of optimal information content in transaction status displays, and minimization of short term memory requirements.

RECOMMENDATIONS.

The results of this study demonstrated that the initial terminal services have the potential to reduce frequency congestion and controller workload, and are compatible with the existing NAS terminal workstation and computer. Therefore, it is recommended that continued developmental and operational evaluation research be pursued in the Data Link Test Bed to support the implementation of these services at the earliest possible date. As a part of this effort, work should be initiated to verify the technical feasibility of implementing Data Link in the present and future operational ATC systems, including the conduct of empirical tests of ARTS IIIA capabilities as outlined in appendix A of this report.

1. INTRODUCTION.

1.1 PURPOSE.

This document presents the results of the first Federal Aviation Administration (FAA) Technical Center investigation of terminal air traffic control (ATC) services developed for transmission using Data Link technology. Preliminary designs for four ATC services were implemented in the currently operational National Airspace System (NAS) Automated Radar Terminal System (ARTS) IIIA computer and ATC workstation for review and evaluation by air traffic controllers. The controllers participated in simulated terminal airspace test trials to assess the utility of the Data Link services, recommend requirements for service design changes, and provide initial views regarding the potential impact of Data Link on terminal operations in the NAS. It is expected that this study will be the first in an iterative series of design simulation tests which will culminate in a full-scale operational evaluation and the production of design specifications for an operational Data Link communications system for the terminal ATC environment.

1.2 BACKGROUND.

1.2.1 The Air-Ground Communication Problem.

In response to the phenomenal growth of air traffic in the United States, the FAA has begun to develop and implement a broad range of initiatives aimed at updating and enhancing ATC technology. Many of these efforts are focused on improving the quality and quantity of information that will be needed to increase safety and productivity, and on insuring that this information is reliably and accurately transferred among the computers and humans that form the major components of the ATC system.

One of the primary information transfer problems that constrains the capacity of the current ATC system is the inherently limited communication channel that exists between the air traffic controller and the aircraft pilot. Because this voice radio link operates in a broadcast mode between a single controller and all aircraft operating in the airspace under his control, frequency congestion is a common occurrence when the volume of air traffic increases. Such saturation of the communications channel affects the performance of the ATC system by preventing the timely issuance of clearances and by restricting the vital exchange of information upon which safe and efficient operation of the NAS depend.

In addition to the limitations that it imposes through frequency congestion, the voice radio channel has been identified as a major contributor to errors in the ATC system. The FAA has noted that as many as 23 percent of all operational errors are caused either directly or indirectly by communications mistakes (New York Times, 1988). Similarly, compilations of voluntary reports provided to the Aviation Safety Reporting System by pilots and controllers have shown that a majority of all potentially hazardous incidents that are filed implicate ineffective verbal information transfer (Billings and Reynard, 1981).

Investigations of the nature of prevalent communications errors demonstrate that they are typically the result of an interaction between the characteristics of the voice radio system and the inherent perceptual and cognitive characteristics of its human user (Shingledecker, 1990). Acoustic confusions, alphanumeric transpositions, misinterpretation due to pronunciation and phraseology problems, poor memory for transient speech presentations of ATC information, and blocking of the radio channel caused by improper keying techniques are common sources of human-induced error found by these studies. In addition, many errors seem to be potentiated by the frequency congestion problem as users experience difficulty in monitoring for relevant messages on the crowded radio channel, and become reluctant to clarify suspected confusions in order to avoid further congestion.

1.2.2 Data Link Solutions.

Data Link is a digital communications technology which is being developed as a supplement to traditional voice radio for ATC communications. As shown in figure 1, Data Link communications can be supported by several transmission media. These include very high frequency (VHF) radio, satellite links, and the Mode Select (Mode S) secondary surveillance radar system currently proposed by the FAA for ATC Data Link communications. These multiple links will be integrated within a common Aeronautical Telecommunications Network to provide seamless air-ground communications throughout the NAS.

Regardless of the specific method used to create the channel, Data Link communications are distinguished from traditional voice radio links in two essential ways. First, unlike analogue voice messages, Data Link messages consist of digitally coded information. Thus, data may be entered for transmission either manually, or by direct access to information contained in airborne or ground-based computers. Furthermore, the capability of a digital system to provide automatic error checking of sent and received messages makes Data Link a highly reliable system which is not as susceptible to degradation by interfering noise sources compared to the existing voice communication frequencies.

The second way in which Data Link differs from the voice radio channel is its capability to discretely address individual receivers. Unlike the simplex radio system which permits only a single speaker to transmit on the broadcast frequency at any point in time, Data Link messages can be sent selectively, and transmission rates are not artificially bounded by the speaking and listening rates of the user. As a result, Data Link channels can

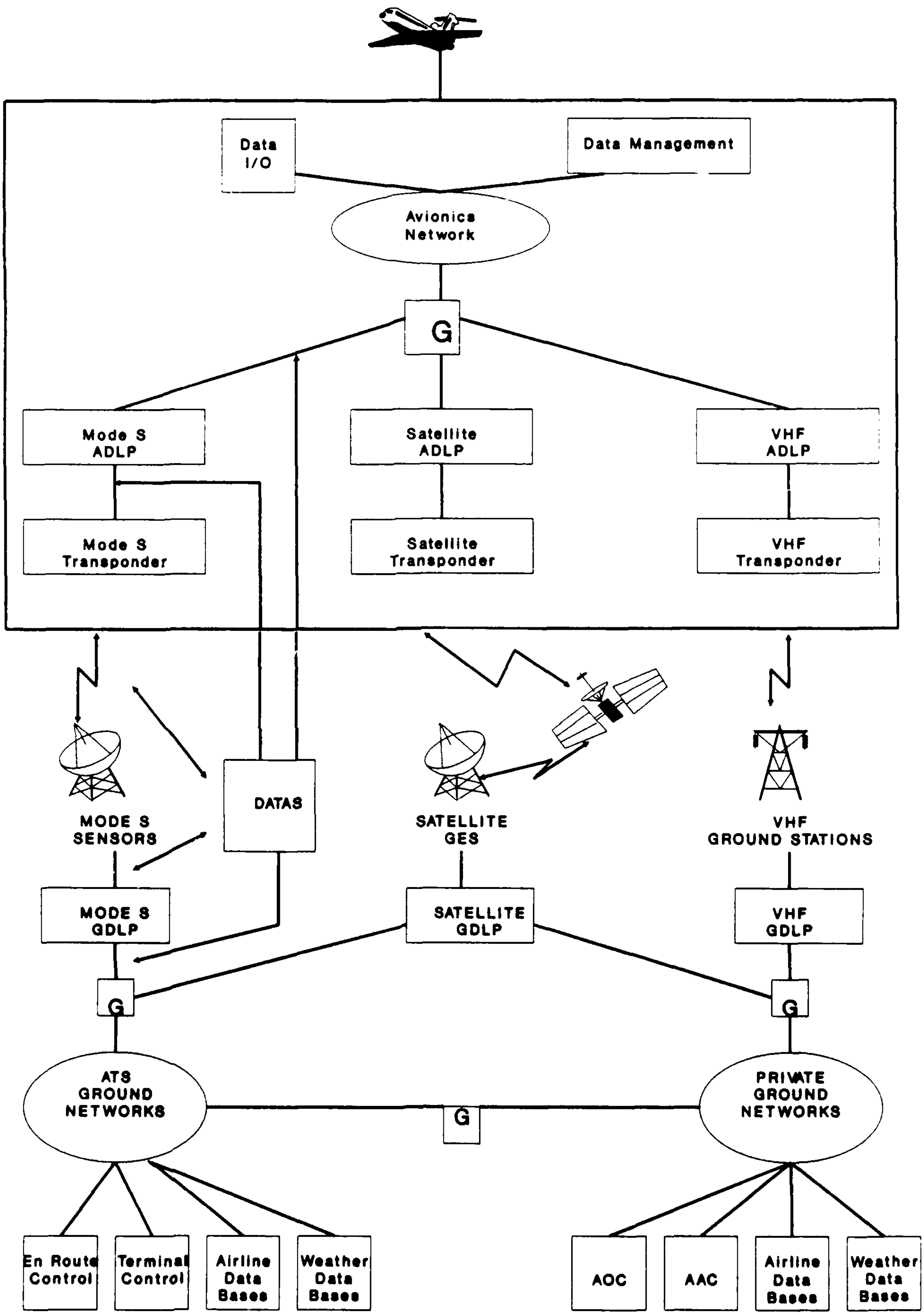

FIGURE 1. THE DATA LINK SYSTEM

have a much higher capacity than voice channels and critical messages sent by a controller are assured of receipt only by the intended aircraft.

These features of Data Link offer significant promise for alleviating both frequency congestion and errors that currently impair air-ground ATC communications. Demands on the voice channel should be relieved in proportion to the number of weather and ATC services that are assigned to the Data Link system. In addition, by automating or simplifying pilot and controller functions in the communication process that are subject to error, Data Link should improve the overall effectiveness of information transfer. For example, using Data Link it will be possible to reduce ambiguous message transmissions by storing standard clearances in computer memory for simplified uplink to an aircraft; failures to detect messages and accidental acceptance of clearances by unintended aircraft will be eliminated by discrete addressing; interpretation errors should be reduced by the availability of a persistent and recallable visual display of the received data; and the system will automatically verify the integrity of a message without human intervention.

1.2.3 Data Link Design and Evaluation Research.

As noted above, the technical characteristics of Data Link have the capability to significantly enhance the safety and productivity of the ATC system. However, Data Link also will introduce a profound change in the way in which ATC tasks are accomplished by controllers, and in the way aircrew will receive and respond to ATC instructions. Because of this, the ultimate success of Data Link will be critically dependent on the extent to which it is employed to create an effective communications system that is fully integrated with its human users and with the full range of tasks that they are required to perform.

Recognition of the need to consider operational suitability and human factors issues as primary drivers of the design process prompted the FAA Technical Center to initiate a program of manned simulation research to guide the development of Data Link ATC services. The overall goals of this research are to (1) define useful Data Link services, (2) determine the user information requirements for Data Link communications, (3) develop display formats, data entry methods and procedures which promote efficient controller performance, and (4) evaluate the impact of Data Link services on both human and system performance.

The Data Link Test Bed was assembled at the FAA Technical Center to address these goals. The Test Bed is a laboratory facility which uses actual NAS equipment in conjunction with simulation computers to create a system capable of realistically exercising Data Link applications in an end-to-end fashion. In its current form, the Test Bed is composed of the NAS en route and terminal laboratories, the NAS System Simulation Facility (NSSF), and the Data Link laboratory (figure 2). The NAS laboratory includes the HOST computer system used for en route ATC data processing as well as its primary terminal counterpart, the ARTS IIIA system. Both computers are linked to several suites of their respective operational controller workstations which are used to display radar data and to enter system inputs.

The NAS laboratory is linked to the NSSF through the ATC computers. The NSSF permits the NAS laboratory systems to act as functioning control facilities by providing simulated radar data and voice radio inputs from simulation pilots operating from computer terminals. Alternatively, the ARTS and HOST portions of the NAS laboratory can be used as self-contained simulation systems using the training functions included within the operational systems. In this configuration, pilot functions are performed by simulation operators working at additional controller workstations.

The Data Link laboratory houses a VAX 11/750 computer which acts as an emulation of the future ground Data Link processor. The VAX computer supports digital communication between simulation pilots and controllers. It can also provide two-way communication between controllers and high-fidelity aircraft simulators or actual airborne systems using Mode S or any other installed Data Link technology.

The central thrust of Data Link research in the test bed is manned simulation research aimed at defining and testing designs for ATC services. The general approach used in this research employs a two-stage methodology. In the first stage, field controllers who are members of the Air Traffic Data Link Validation Team (ATDLVT) participate in highly controlled, part task simulation studies to reduce the number of service design options to a reasonable set. These mini studies (Talotta, et al., 1988, 1989) focus on formal testing and review of display and procedural options rather than on high-fidelity simulation of the ATC environment. Test scenarios range from basic presentations of two or three aircraft to simplified air traffic problems derived from actual controlled airspaces. Using an iterative approach, feedback from the controllers is used to modify the designs for further test.

In the second stage of the process, operational evaluation studies are conducted to exercise refined service designs in the context of full-scale ATC scenarios. The goals of these studies are to confirm the optimality of the finalized service configurations and to examine controller performance issues which can only be addressed under test conditions approaching the realism of an operational environment.

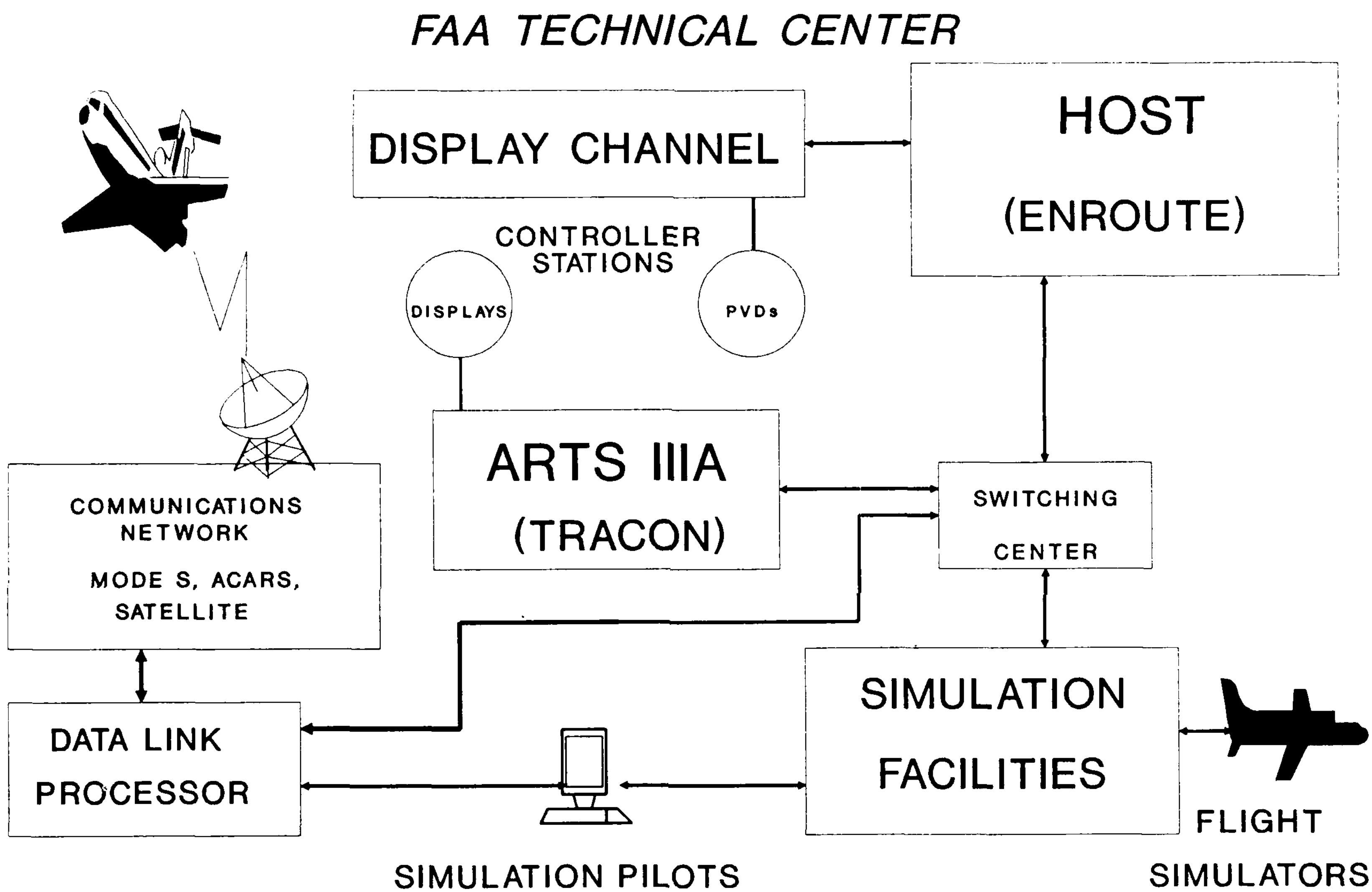

FIGURE 2. DATA LINK TEST BED

1.2.4 En Route Development.

Research and development efforts in the Data Link Test Bed began with the en route portion of the ATC system. Two mini studies were conducted to refine the transfer of communication and altitude assignment services as well as a menu text function for uplinking interim altitudes and an unformatted free text function (Talotta, et al., 1988, 1989). These efforts culminated in an operational evaluation in which complex test scenarios and high levels of air traffic were used to test the services under 20 percent and 70 percent levels of Data Link aircraft equipage (Talotta, et al., 1990). The operational evaluation study clearly demonstrated the benefit of the initial en route services on frequency congestion with a reduction in controller voice transmissions of up to 41 percent and in channel occupation time of up to 45 percent. This result was achieved at no observed loss in controller performance or increase in controller workload ratings.

Currently, en route development is expanding to the design and testing of controller interfaces for speed and heading clearances, the processing of pilot downlinks, and procedures for the utilization of assistant controllers.

1.3 DATA LINK FOR THE TERMINAL ENVIRONMENT.

1.3.1 Terminal Data Link Issues.

The potential benefits of Data Link communication technology to terminal ATC operations can be accrued in the en route environment. At present, the demands at busy airports often can result in a controller engaging in prolonged periods of non-stop verbal communication to convey all of the clearances needed to guide the pilots of arriving, departing, and transient aircraft. In addition, the requirement to convey lengthy advisory messages to aircraft entering the terminal area rapidly expends the limited communication time available to tactically control closely spaced aircraft on the approach and departure flightpaths.

While the need to reduce frequency congestion is similar in the terminal and en route environments, the problem of designing an effective Data Link system for the two is quite different. In general, terminal operations are more sensitive to timing issues than en route operations. Because of this, communications functions assigned to Data Link must be carefully selected, designed, and tested to ensure that transmission delays or display clutter do not interfere with controller performance requirements. In addition, unlike some en route clearances, current terminal procedures do not require the use of keyboard inputs to update the ATC computer data base. For this reason, the need to develop efficient methods for entering and uplinking control messages is essential.

1.3.2 Initial Terminal Services.

Drawing from their experience as terminal controllers and an awareness of the design issues outlined above, the terminal subgroup of the ATDLVT met with FAA engineers and supporting contractors in a series of meetings held in 1989 and 1990 to define an initial group of ATC services suitable for the terminal environment. The following services were designed during these meetings, and preliminary versions were demonstrated using a rapid prototyping system at The MITRE Corporation:

a. Transfer of Communication. Transfer of communication is the message sent to an aircraft after track control has been accepted by the new sector which instructs the pilot to change radio frequencies in order to communicate with the new controller. Using the designed Data Link service, this message is automatically prepared by the ATC computer and uplinked either automatically or upon a controller input action.

b. Initial Contact. When an aircraft receives a new radio frequency, current ATC procedures require the pilot to contact the new controller and to report the aircraft's currently assigned altitude. With Data Link, after the new controller obtains Data Link communication eligibility, a request for the initial contact report is sent automatically to the aircraft, and the downlinked report is presented to the controller on the radar display.

c. Terminal Information Service. When arriving aircraft enter a terminal airspace, they are typically given a report of the terminal operating conditions and of the approach clearance that they can expect to receive. Using Data Link, these commonly lengthy messages are provided by a simple controller action to initiate the uplink.

d. Menu Text. Menu text is a Data Link function which permits the controller to select and uplink a commonly used clearance from a menu list displayed on the radar screen. In the service design tested in this study, such clearances included speed, heading, and altitude change instructions.

1.3.3 Feasibility of Implementation in ARTS.

As discussed earlier in this introduction, the approach taken by the FAA Technical Center to Data Link service development has focused on the use of operational ATC computers and workstations to test the human factors of digital communications technology for ATC applications. The primary advantage of this approach is that it provides controllers with familiar equipment and a test environment which permits them to make maximum use of their operational experience to judge the suitability and acceptability of the service designs under evaluation. Because of this, the results derived from the approach are believed to be valuable not only for potential implementation of Data Link in currently operational NAS equipment, but also for the eventual implementation of Data Link in future equipment being developed under the FAA Advanced Automation System (AAS).

At the present time, it is uncertain whether Data Link ATC services will be installed in ARTS or be delayed until the AAS terminal workstation and computer enhancements are implemented. The advanced equipment is being designed with sufficient computing power and display capabilities to support Data Link functionality. However, because of the limited capacities of the aging ARTS system, consideration must be given to the technical feasibility of exercising the option to implement the initial Data Link terminal services in the near term.

Appendix A presents the results of an analysis of the projected impact on the ARTS IIIA operational system from the installation of the Data Link services which were implemented for the initial testing presented in this report. The analysis did not include projections of the communications overhead associated with the Aeronautical Telecommunications Network (ATN) implementation that is being specified for Data Link communications. The effect of the communications requirements on processing and memory resources depends upon the selected system configuration. Even if the ARTs IIIA would be required to handle all of the communications processing as an end state system, the communications functions could be accomplished by additional processor and memory resources independent of the ARTS IIIA processor and memory. With these assumptions, the analysis provides an empirical estimate of the display, data entry, and data processing requirements to provide the initial Data Link services. The analysis indicated that the services would require no more than 10K of the 80K to 128K of unused memory available under the most recent ARTS IIIA upgrade. Likewise, a five percent maximum increase in processing requirements was predicted, which appears to be well within the capabilities of the current upgrade. Although the Data Link services would place significant additional demands on the ARTS display capabilities, these were also projected to present no problem when using the latest Full Digital ARTS Display (FDAD) system.

In summary, the analysis indicates that the ARTS IIIA with planned upgrades has additional capacity to allow implementation of additional functions such as Data Link. The expected processing and memory utilization required to implement Data Link is well within the expected processor and memory capacities. The physical and functional interconnection of the ARTS system to the Data Link system and the communications functions required to accomplish the interface needs additional investigation to determine the impact on the ARTS system. The conduct of confirmatory engineering tests would be warranted if the option to implement Data Link in the ARTS system is exercised.

1.3.4 Organization of the Report.

The following sections of this report present the research methodology that was used and the findings that were obtained in the first FAA Technical Center controller evaluation study of Data Link terminal ATC services. Section 2 describes the specific objectives of the study and the testing approach that was used to achieve these objectives. Section 3 presents the detailed results of the testing. Sections 4 and 5 list the conclusions that were derived from the results and recommendations for future efforts toward the development of an operational terminal Data Link system.

2. TEST DESCRIPTION.

2.1 OBJECTIVES.

The Data Link mini study reported here was designed to meet three major objectives:

a. Determine the acceptability of the preliminary designs for Data Link terminal services as implemented in NAS (ARTS IIIA) equipment and software.

As noted in the introduction to this document, the four designs of the services tested in the study were defined by the terminal controller members of the ATDLVT, and reviewed using a dynamic prototyping system. For the present study, modified versions of these designs were transferred to the operational ARTS IIIA system maintained in the Data Link Test Bed. Because the rapid prototype system manual input and visual display devices differed significantly from the ARTS IIIA user interface, several design changes were made to complete the transition. In addition, selected display features including the transaction list and the history list were not implemented in the initial ARTS IIIA versions of the services. Finally, potential enhancements were added to the basic designs for evaluation by the test controllers.

b. Identify requirements for additional Data Link service design modifications and future controller testing.

Past experience with controller testing of en route Data Link services has shown that an iterative evaluation process is necessary to produce designs which are sufficiently robust for operational testing. Because of this, the second objective of the present study was to provide additional simulation experiences to the ATDLVT which would elicit any required modifications to the original designs that had not been foreseen during conceptual development.

c. Elicit controller estimates of the operational suitability, user acceptance, and workload impact of Data Link services in the terminal ATC environment.

The final objective of the research was to obtain an assessment of whether Data Link ATC services continue to appear feasible in the context of terminal operations. Based on formal simulation experiences with the initial services as implemented in the Data Link Test Bed, the controller subjects provided projective expert input regarding the effects of Data Link on ATC operations and controller performance capabilities.

2.2 APPROACH.

The approach that was adopted to meet the objectives of this mini study involved the participation of terminal air traffic controllers in a series of training and ATC simulation test sessions presented at the ARTS IIIA workstations in the Data Link Test Bed. During testing, the subjects controlled traffic in a scenario involving aircraft arrivals and final approaches. During the early test sessions, the subjects completed a detailed review of the designs for each of the four Data Link services. In the final repetitions of the scenario, the subjects compared the current voice-only communication system to a system supplemented by the initial Data Link services in order to make predictive judgments about the effects of Data Link on the ATC system and controller performance factors.

Extensive debriefings followed each test session. These debriefings were used to achieve a group consensus regarding required Data Link service design changes and to elicit controller opinions regarding future testing needs.

The general rationale underlying the test design was to provide a relatively uncomplicated ATC environment which would permit the controllers to devote their attention to an exhaustive analysis of the service designs, while providing sufficient realism to support their initial projections regarding the impact of the services under operational conditions. Highly structured questionnaires and quantified rating scales were used as primary assessment tools in order to provide an objective baseline against which future modifications to terminal Data Link functionality could be gauged.

2.3 TEST CONDUCT.

2.3.1 Subjects.

The subjects for this study were nine, full performance level, terminal air traffic control specialists. All subjects were members of the FAA ATDLVT which was formed to participate in the development and evaluation of Data Link ATC services. FAA field facilities represented by the subjects were Denver, Madison (WI), St. Louis, and Tulsa Airport Traffic Control Towers (ATCTs) and Ocean (NY), and Ontario (CA) Terminal Radar Approach Control Facilities (TRACONs).

Seven of the nine subjects had participated in a majority of all conceptual design exercises held during a 2-year period prior to the study. The remaining two subjects were new members of the ATDLVT who received their first experience with Data Link during the course of the study.

2.3.2 Test Scenario and Data Link Operations.

The ATC scenario developed for this study utilized the Atlantic City International Airport (ACY), NJ, Approach Control Airspace. (figure 3). For the purposes of the study, several modifications were made to the actual sectorization of the surrounding airspace and to the air traffic procedures used at the facility. Within the test scenario, ACY controlled the airspace vertically from surface to 8,000 feet. All existing restricted and warning areas were considered inactive, and the extensive airspace shelves to the north shared with Washington and New York Air Route Traffic Control Centers (ARTCCs) were eliminated and considered part of ACY approach. Runway 31 was active throughout the scenario.

The ACY approach airspace was divided into three sectors manned by alternating subgroups of three test subjects. The North Arrival sector included all airspace north of the active runway excluding the Final airspace. The South Arrival sector included all airspace south of the runway excluding the Final airspace. The Final controller was responsible for the area 5 miles to either side of the final approach course, from the airport to 15 miles, and from surface to 3,000 feet.

As shown in figure 3, inbound traffic was transferred to the North and South sectors over four Transfer of Control Points. Both the North and South controllers were required to blend two streams of aircraft and establish each aircraft on downwind for runway 31 at 4,000 feet. After any conflicts had been resolved, the North and South controllers handed off the aircraft to the Final controller. The Final controller then sequenced the two streams of traffic onto the final and cleared each aircraft for approach.

During each 30-minute repetition of the scenario, the North and South controllers each handled approximately 13 aircraft, while the Final controller was responsible for all arriving traffic.

Pilot functions for this study were provided using the ARTS Enhanced Target Generator (ETG) function. During each test run, three of the subjects manned the active control sectors. The remaining six subjects acted as simulation pilots using three additional ARTS workstations. Two simulation pilots were seated at each workstation. One of the pilots maintained voice radio communication while the other used a terminal interfaced to the VAX computer to respond to Data Link communications. Both pilots made ETG inputs to control the flightpaths of the aircraft.

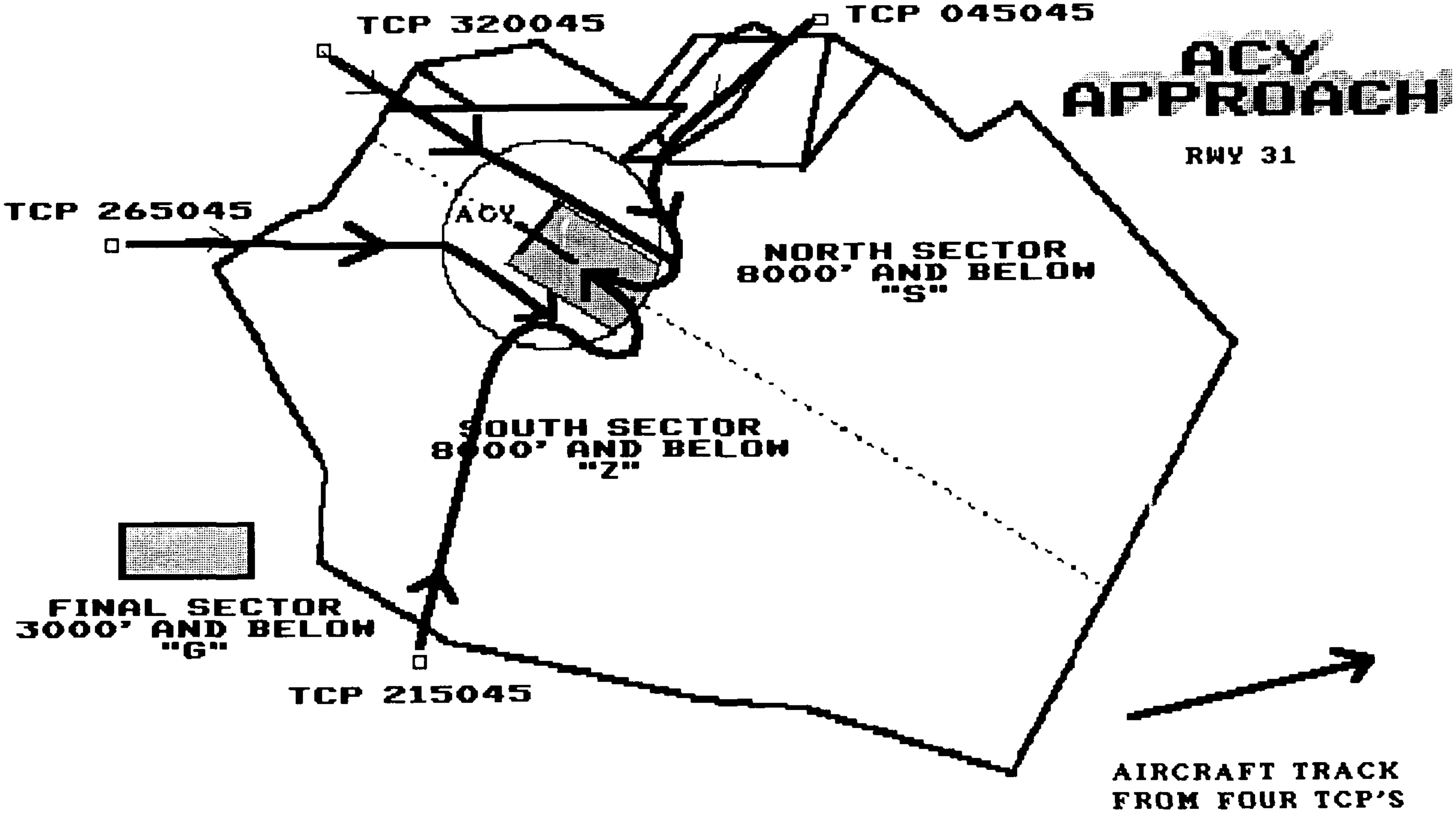

FIGURE 3. TEST SCENARIO

When using Data Link for ATC communications, the elapsed time between a message uplink command and receipt of a pilot initiated response was determined by the simulator pilot's response latency. This includes an uplink and downlink time which was introduced to simulate the delays that would be experienced with Mode S Data Link transmissions using the currently operational terminal antenna rotation rate of 4 seconds. Uplink delays ranged from 0 to 4 seconds. Downlink delays were determined by the timing of the simulator pilot's response, increasing from 0 in 4-second increments.

In order to exercise controller procedures for handling failed Data Link transmissions, 10 percent of all uplink attempts resulted in no technical acknowledgement (NAK) by the simulated aircraft Data Link avionics. Likewise, if a simulator pilot failed to respond to a Data Link message within 40 seconds after receipt, a time-out message was sent to the ARTS. In accordance with the preliminary service design specifications, either a NAK or a time-out resulted in a FAIL message in the aircraft's data block on the controller's radar display.

2.3.3 Test Procedures.

This study was conducted over a 3-day period in conjunction with a scheduled meeting of the full membership of the ATDLVT held at the FAA Technical Center. The first day was devoted to subject prebriefing and training. On the second and third days, testing was conducted to support a review of the Data Link services designs and projective evaluation of the operational impact of Data Link.

2.3.3.1 Familiarization and Training.

The prebriefing session began with a series of short presentations which were used to explain the objectives of the mini study and the testing activities. The subjects also received a briefing on the questionnaires and rating scales that would be used during data collection, and completed the scale development card sorting task required for the interpretation of workload judgments using the Projective Subjective Workload Assessment Technique (PROSWAT) (see section 2.3.4).

Familiarization with the Data Link service designs was accomplished in a 1-hour classroom session during which all data input procedures and displays were explained. Differences between the ARTS IIIA Test Bed implementation of the services and the preliminary design specifications also were discussed during this session. Finally, the subjects received a briefing on the airspace scenario, the ATC procedures that would be used during testing, and on the operation of the ETG simulation system.

Following the prebriefings, the subjects proceeded to the Data Link Test Bed for hands-on training. Subjects were assigned to a sector in one of the three subgroups and were given the opportunity to control traffic with several 30-minute test scenarios. In order to maximize the efficiency of training, all aircraft in the scenario were equipped with Data Link during this session. Facilitators were available at each sector to assist the subjects and answer questions.

2.3.3.2 Design Review.

Data collection began on the second day of the study with a formal review and verification of the Data Link service designs. The design review was accomplished in the Data Link Test Bed. Each subgroup of three subjects controlled traffic in the scenario during two 30-minute runs. The primary task of each subject during these runs was to thoroughly exercise each of the four Data Link service designs in order to evaluate them using a structured review booklet.

The review booklet was organized in two sections. The first focused on the primary differences between the ARTS IIIA implementation of the Data Link services and the specifications developed by the ATDLVT during earlier conceptual design efforts. These differences included the absence of a history list of completed Data Link transactions in the tested ARTS configurations, and of a list which tracked the status of transactions in progress. The first section also addressed differences in keyboard assignments for Data Link inputs and in the graphic symbols used in the data block to denote Data Link equipage and the controller's eligibility to communicate with the aircraft. Associated questionnaire items asked the subjects to evaluate the need for the display features not included in the tested ARTS versions, and the acceptability of the display substitutions that were made.

The second section of the design review addressed each of the service designs in detail. The subjects were given a text description of the operational features of each service (see appendix B), and were first asked to judge the accuracy of the description against their actual experience in the Test Bed. Succeeding questions required them to judge the similarity of the ARTS implementation to the original design specification, the acceptability of the design as presented in the Test Bed, and the need for future modifications to the Test Bed service designs. For each service, the subjects were asked to fully describe any design changes that were either desirable or required.

After all subjects had completed the Test Bed exercise and the individual design review booklets, they participated in a group debriefing session. This 3-hour session was led by a research staff member and consisted of a group discussion of each service design. The debriefing was aimed at identifying and resolving disagreements among the subjects regarding the fidelity and acceptability of the service designs, and at achieving a consensus regarding any recommended design changes.

2.3.3.3 Projective Evaluations.

The second day of testing required each subgroup of three controllers to participate in two simulation runs of the test scenario. In one of these runs, the subjects completed their ATC tasks using only the voice radio system. In the second run, 60 percent of the aircraft in the scenario were equipped for Data Link communications in order to simulate a relatively mature stage of system implementation. To minimize testing sequence bias in the subsequent rating tasks, two of the subgroups experienced the voice-only run prior to the Data Link run, while the third subgroup participated in the conditions in a reversed order. In both cases, the subjects were instructed to treat the ATC problem as realistically as possible and to focus on comparing the current voice radio system to the combined Data Link and voice system.

Following the completion of both runs, each subject completed a series of rating forms. The first form asked subjects for two workload ratings. The first of these was an estimate of the average workload experienced by a controller on a typically busy day in the responder's home facility using the current voice-only system. The second rating asked the subjects to make a comparative projective estimate of the controller's workload in the same situation with a 60 percent level of Data Link equipage in the aircraft fleet.

After completing the workload ratings, the subjects evaluated each of the four Data Link services on two dimensions. The first of these was the projected operational effectiveness and suitability of the service, while the second was the acceptability of the service to controllers and their predicted preference for the features of the service design. For both dimensions, the subjects were asked to base their ratings on the modified ARTS IIIA service design baselines established during the design review and discussions conducted on the preceding test day. The subjects were asked to provide written comments and a rationale for each of the ratings that were made.

After the subjects had completed the rating forms, a final group debriefing was conducted. This debriefing solicited any further design modification requirements that may have arisen during the second day of testing and presented several additional issues for discussion. These issues included the feasibility and desirability of implementing Data Link in the existing ATC system, the potential impact of Data Link transmission delays on controller performance, the conditions under which Data Link and voice communications would be used, and future requirements for Data Link testing.

2.3.4 Data Collection.

The data obtained in this study were collected using several methods designed to elicit structured and, where possible, quantified expert input from the air traffic controller subjects. As described in section 2.3.3.2, the design review was accomplished with a series of questionnaire forms which guided the subjects through an evaluation of the major alterations to the prototype Data Link service designs and provided them with the opportunity to record individual suggestions for design modifications. The object of this exercise and the following debriefing was to establish an initial ARTS IIIA design for Data Link services upon which future development will be based.

The projective data generated on the second day of testing was collected using three subjective rating instruments. Workload was estimated using a modification of the Subjective Workload Assessment Technique (SWAT) known as Projective SWAT or PROSWAT. SWAT and PROSWAT were developed in the early 1980's by the U.S. Air Force as a standardized method for obtaining quantified estimates of perceived workload in a broad variety of occupational tasks. The techniques have received extensive use in simulation and operational testing environments within the Department of Defense, and were used successfully with air traffic controllers in the en route Data Link mini studies and operational evaluation. SWAT is used to rate the actual workload experienced by a subject in a preceding period of work, while PROSWAT is the identical method used during the research and development process to estimate the workload that would be experienced in a fully implemented operational system.

Briefly, both SWAT and PROSWAT consist of three, 3-point rating scales referring to the dimensions of time load, mental effort, and psychological stress. Subjects indicate the workload associated with an activity by marking the appropriate point on each scale. A unique feature of this workload measurement technique is that the three ordinal ratings that are obtained are converted to single points on an overall interval measurement scale of workload with values ranging from 0 (low workload) to 100 (high workload) using a mathematical analysis method known as conjoint measurement. This method not only yields data which are amenable to powerful, parametric tatistical testing, but also tailors the measurement scale to each individual's (or homogeneous group's) concept of how the time, effort and stress dimensions combine to produce the overall perception of workload.

The interval scale used to interpret the ordinal ratings is created by having subjects generate an ordering of all 27 combinations of the time, effort, and stress levels on the scales which reflects their individual concepts of how the three dimensions combine to produce different workload levels. The card sorting task used during the scale development exercise was completed by all nine subjects in this study during the prebriefing session held on the first day. PROSWAT ratings of controller workload comparing the current voice-only system with an ATC system supplemented by Data Link were made by the subjects following the simulation runs on the final test day.

After completing their PROSWAT ratings, the subjects rated each of the four terminal services on two factors. The first scale required the subjects to assess the operational effectiveness and suitability of the service design. The data form permitted the subject to rate a service as "not operationally suitable" or on a 7-point scale ranging from 1 "minimally effective" to 7 "highly effective." Instructions for completing this scale asked the subjects to use their experience in the Test Bed and their prior background in terminal ATC operations to assess how well each service design could accomplish its intended task in the full range of potential field environments.

The second rating was an estimate of the acceptability and preferability of each of the service designs to air traffic controllers. The data form permitted the subjects to rate a service as "completely unacceptable" or on a 7-point scale ranging from 1 "acceptable, but not preferred" to 7 "highly preferred." Instructions directed the subjects to consider the extent to which the displays, input requirements, and procedures used to deliver a service would be usable by air traffic controllers.

Additional explicit instructions for these two scales indicated that the dimensions of effectiveness and preference should be treated independently from one another since a service might include all functions needed to meet operational requirements and still be poorly suited to the way in which controllers perform their functions. Likewise, a design could be easy to use, but have missing features which prevent it from meeting operational needs.

The instructions provided to subjects for the use of all rating scales and for the SWAT scale development task are included in appendix C along with examples of the actual rating forms.

3. TEST RESULTS.

3.1 TERMINAL DATA LINK SERVICE DESIGN REVIEW.

Two major objectives of the present study were to determine the acceptability of the Data Link service designs as implemented in the ARTS IIIA portion of the Data Link test bed, and to obtain controller inputs regarding desirable modifications to these designs. The following subsections summarize the combined results obtained from the individual design review booklets and from the debriefing discussion that was conducted following the review exercise.

3.1.1 Transaction Status List.

The preliminary design for the terminal services provided information regarding the status of ongoing Data Link transactions both in abbreviated form in the data block associated with each equipped aircraft, and in a combined list form. The status list was not included in the ARTS IIIA implementation tested in this study.

Individual subject responses regarding the need for a status list were mixed. Of the seven subjects who had participated in the conceptual design effort prior to the study and had worked with prototype data block and status list displays, three felt that the status list was unimportant, two indicated that it was a preferred but not a necessary feature of the design, and two indicated that it would be required. Those subjects who felt this feature was unimportant noted that it was redundant with the primary data block display of the menu item number sent and the outcome of the transaction. The subjects expressing some level of preference for the list felt that while the data block is a primary display, any requirement to quickly determine the content of the transaction in progress would be hampered by the need to scan to the menu text list to interpret the menu item number in the data block. In these cases, the list's inclusion of the full content of a clearance would simplify the task of rechecking the message.

Group discussion of the status list led to a consensus opinion that the status list should be included in the ARTS IIIA Data Link design for further testing. In addition, it was determined that the status list, as well as the data block display of transaction status, be modified to include more extensive information (see section 3.1.2 below).

3.1.2 Data Block Transaction Status Display.

During conceptual development of the Data Link ATC services, a majority of both terminal and en route members of the ATDLVT have argued that the controller should not be required to divert attention from the aircraft on the radar display in order to monitor the status of ongoing Data Link transactions. In the terminal effort, this led to the use of the third line of the data block as a transaction display. However, because the controllers expressed an equally strong belief that information inserted in the data block must be simplified to prevent display clutter and controller confusion, the data presented in the third line were limited to an abbreviation of the service in progress, and an alerting display if the transaction was not satisfactorily completed. No indication that an uplink had been successfully sent or delivered to the aircraft was included. Likewise, only removal of the transaction data from the third line was used to indicate that a pilot had confirmed message receipt and intended to comply, and no distinction was made among the several reasons for transaction failure.

During the design review, the subject controllers noted that more complete status information may be needed in the data block and in the status display to avoid potential errors and to permit the controller to appropriately deal with a failed transaction. Two potential sources of error were cited in support of this requirement. First, removal of the data in the third line as a means for indicating that a message had been WILCOed was considered a problem since it presents the opportunity for a busy controller to forget whether the message had been originally uplinked. One solution to this problem that was suggested is to display A "W" character or the word WILCO when the pilot responds positively, and for this data to remain in the status list and the third line of the data block for several seconds or until a new transaction is initiated.

The lack of a displayed distinction between causes for transaction failures was seen as second possible source of problems. The controllers noted that their decision to respond to a failed transaction by repeating the uplink or by contacting the pilot by voice radio may depend upon whether the failure was caused by a technical error in the digital transmission, a pilot's failure to respond to a message within the prescribed time limits, or a pilot downlink indicating that he was unable to comply with the uplinked clearance. As a result of this discussion, it was decided that the ARTS Test Bed Data Link design would be modified to present full failure information in the data block and in the status list.

3.1.3 Transaction History List.

The prototype design for the terminal services included a second list which displayed messages which had been successfully uplinked to each aircraft in the controller's sector. This feature was not included in the ARTS implementation evaluated during this study. The results of the design review indicated that although one subject felt that the history list was not an important feature of the services. Two indicated that the list was a necessary feature, and five felt that it was preferable, but not necessary. The majority preference for the history list was supported by individual comments suggesting that it may be valuable as a general memory aid which would prevent repeated transmissions and pilot inquiries. During debriefing, it was decided that the history list would be added to the ARTS Test Bed implementation of Data Link for future evaluation.

Subsequent discussion of the optimal number of items to be included in the list did not result in a consensus opinion. Requests ranged from only the last clearance received by each aircraft up to a total record of the messages received by an aircraft while in the sector. Arguments for lists containing only the last completed total record of the messages received by an aircraft while in the sector. Arguments for lists containing only the last completed uplink indicated that the list would be used primarily for resolving momentary lapses of short term memory, while subjects preferring longer lists felt that it would be necessary to capture sufficient past messages to determine an aircraft's current assigned heading, speed, and altitude. As a result of this split opinion, list length will be empirically investigated in a future mini study.

3.1.4 Data Link Equipage and Eligibility Display.

The basic design for both en route and terminal Data Link services requires a data block display indicating whether the aircraft is equipped for Data Link communications, and which controller is eligible to communicate with the aircraft. In both the HOST/plan view display (PVD) en route system and the terminal designs, this display is provided by graphic symbology located in the first position of the first line of the data block. The prototype terminal design used a plus sign to denote an equipped aircraft with which the current controller was eligible to communicate, and an asterisk to identify an equipped aircraft which was eligible to receive uplinks from the current controller. Because of concerns about the legibility and distinguishability of these symbols on the ARTS IIIA radar display, an open square and open triangle were used in the initial Test Bed implementation to provide the same information.

In the design review, none of the subjects indicated that the information offered by this symbology was inadequate and three controllers were completely satisfied by the use of the open geometric shapes. However, six subjects felt that the original symbology would be easier to use. One argument for this preference was that the square could be misperceived as an "0" used in military call signs.

During the debriefing session, the general problem of symbol confusability with other ARTS symbol assignments and the exacerbation of this problem caused by display misalignment led the group to suggest that alternate symbol sets be maintained as a variable feature of the Test Bed for review in subsequent research.

3.1.5 Keyboard Assignments.

The prototype demonstration of the conceptual terminal Data Link service designs used a generic, personal computer-type keyboard for Data Link inputs. Because of this, implementation on the idiosyncratic keyboard used in the ARTS system required changes in the location of the keys. Eight of the nine subjects found the assignments used in the ARTS implementation acceptable. A dissenting controller felt that the location of the Data Link key in the F9 position in the upper left quadrant of the keyboard could be somewhat inconvenient because right handed users would obscure most of the keyboard when pressing this key. Changing the assignment to the right hand extreme of the function key row was suggested as an alternative, and this option will be included for testing in future studies.

Debriefing discussions of the keyboard and general input procedures revealed a potential dilemma in Data Link integration with an operational system. While there was strong agreement that input sequences should be used which minimize the number of keystrokes required to initiate an uplink, the use of implied functions to accomplish this goal was seen as a potential source of controller error. Using the implied function features included in the original design and retained in the tested ARTS implementation, it is possible to initiate most uplinks without preceding the data command by the Data Link key input. While reducing keystrokes, this feature creates some inconsistencies which require the controller to remember when the Data Link key input is required. In addition, the existing use of implied functions for other ARTS functions makes it possible to initiate an unwanted function when an error is made in a Data Link entry.

No final design consensus was reached on this issue. It was determined that future tests should be conducted in which keyboard entries are recorded in order to identify and remediate any common keyboard entry errors that arise.

3.1.6 Initial Contact Service.

All of the subjects who had participated in the conceptual development process agreed that the Test Bed implementation faithfully reflected the original design specification and that the design was equal to, or better than, the prototype demonstration. All nine subjects also indicated that no modifications to this service were required.

3.1.7 Terminal Information Service.

Six of the seven subjects who participated in conceptual development indicated that the ARTS implementation of the terminal information (TI) service was equivalent to, or better than the prototype implementation. Of the full subject sample, four subjects indicated that no design changes were necessary. However, the remaining five subjects indicated that improvements were needed. In particular, these subjects felt that the option to combine a TI message with one or more menu text messages should be enhanced to permit the use of any of the TI messages rather than limiting this option to the default message.

The subjects also noted the requirement for a simplified method for changing the content of the default message. The default message feature was developed to permit simplified uplink of the most commonly used information at a sector. In order to accommodate changes in this message, the tested design permitted the controller to retype a new message in the default position of the list. Subjects who requested a change in this feature preferred an option to make an entry which would shift an existing message into the default position of the TI list. Both modifications were discussed in the debriefing session and adopted as Test Bed changes. In the modified version, TI list items will be numbered from 1 to N, with the default message denoted by its position at the top of the list. Selection of a new default item will move the item to the top position and retain its original number designation. The remaining items will then placed in succeeding positions determined by their numerical designations.

3.1.8 Transfer of Communication.

Two subjects indicated that no changes to the design for the transfer of communication (TC) service were needed, while the remaining seven noted changes that were either desirable or necessary. The most commonly required modification mentioned was the inclusion of an ability to maintain Data Link eligibility in the interim period between the completion of the sector handoff and the initiation of the radio frequency uplink through a manual input. The tested ARTS design did not permit an uplink while the TC HELD message was displayed in the third line of the data block. This modification is required to accommodate the common controller practice of completing the handoff well in advance of an aircraft exiting the sector.

Permitting other uplinks while a TC message is in the held state will require simultaneous use of the third line of the data block by the two services. Future studies will compare a timesharing approach to a display in which initiation of an uplink will replace the TC HELD message until the transaction is complete.

3.1.9 Menu Text.

All of the subjects rated the ARTS implementation of the menu text function equal to, or better than the original design specification. Unlike the original design, the ARTS implementation included a menu by-pass feature which permitted the subjects to uplink a speed, heading or altitude by typing the F9 key, then an S, H, or A followed by the three-digit numerical parameter for the clearance. In the individual reviews, five subjects specifically commented that the by-pass function was a definite enhancement to the menu text service. Subsequent debriefing discussions revealed a split preference for the use of the by-pass function and the standard menu text for uplinking clearances. While some subjects chose to work exclusively with clearances entered as menu items, others felt that this restriction would create lengthy menus in which the selection of a clearance would become a difficult task. These individuals felt that the menu should be limited to the most commonly used messages and that other clearances should be uplinked with the by-pass function. To accommodate both preferences, the menu by-pass feature will be retained along with the menu selections.

Suggested changes to the tested service which were agreed upon in the group discussion included the addition of single menu items which combine a speed, heading, and altitude clearance in order to reduce the number of keystrokes needed to uplink multiple messages. It was also agreed that the by-pass feature be modified to permit transmission of combined clearances.

The problem of selecting messages from potentially lengthy menus was treated in detail during the debriefing. While some subjects saw the by-pass as a partial solution to this problem, several suggestions were recorded for improving the controller's ability to make rapid and accurate menu selections. These included a modification to permit spatial separation of the menu text and terminal information lists on the radar display, limitation of the menu to ten items in order to eliminate the space bar keystroke between multiple menu selections, and the assignment of menu item number designators to clearances in a manner which would promote the ability to memorize needed items (e.g., using item number 5 for an altitude clearance of 5,000 feet).

It was determined that the ARTS implementation would be modified to permit separation of the lists. However, the controllers chose not to limit menu length until operational requirements are better understood. Since the existing design provides controllers with a limited ability to assign clearances to different item designators, the option to examine the use of mnemonic techniques in menu designs will be exercised in a future study. Regardless of the solutions which are adopted, continued research attention will be given to the issue of optimizing menu accessibility.

3.2 PROJECTIVE EVALUATIONS.

3.2.1 Controller Workload.

In the present study, the PROSWAT scaling and rating technique was used to obtain comparative estimates of the operational impact of the tested Data Link services on controller workload in the terminal environment. The PROSWAT scale development task performed prior to data collection yielded card orderings for each subject that were subjected to the computerized SWAT scaling routines. A Kendall's Coefficient of Concordance computed on the card sorts produced an index of association among the subjects' card orderings of .77. While this level of agreement would be acceptable for the development of a group scale, a prototype analysis was performed in order to determine whether meaningfully homogeneous subgroups could be identified. This analysis indicated that the sorts of six of the subjects were most consistent with a concept of workload in which time factors weigh most importantly, while the remaining three sorts were most consistent with a model in which stress factors more strongly drive the workload that they experience. It is of some interest to note that both of these models of workload appeared congruent with the personal observations of the terminal controllers who often report that it is the shortage of time, overlap among task requirements, and associated stress of the situation which can make their job of tactically controlling aircraft difficult to perform.

Because of the differences between these two subgroups, separate PROSWAT scale solutions were developed and used in transforming the subjects' ordinal ratings on the time effort and stress scales to single scores on the 0 (low workload) to 100 (high workload scale. Table 1 presents the converted scale value assigned to each possible PROSWAT rating for the subjects in the two prototype groups.

Following the Test Bed simulation runs on the second day of testing, the subjects made two workload estimates. The first was an estimate of terminal controller workload on a typically busy day at the subject's home facility using the current voice-only communication system. The second was a projective rating of the same situation where the available Data Link services were available to service 60 percent of the aircraft handled.

The median raw time load (T), mental effort (E) and stress (S) ratings produced by the subjects for the voice only system was T=3, E=2, S=2. Median ratings for the 60 percent Data Link environment changed to T=2, E=2, S=2, indicating an apparent reduction in the time demands of the controllers task. This projected effect also was reflected in the overall workload scores transformed to reflect the controller's original weightings of the importance of the three workload dimensions. As shown in figure 4, the mean PROSWAT score dropped from 79.36 in the voice radio estimate to 53.02 in the Data Link projection. Using these scores as a criterion, six of the nine subjects predicted an overall reduction in workload with Data Link, three subjects projected no change, and one indicated that workload may increase.

Statistical analysis of the SWAT scores indicated that the projected mean difference was statistically significant ($t= 2.59$, $p = .032$). It is noteworthy that although some earlier studies had shown either no impact or a trend toward lower workload estimates with Data Link, the present research yielded the first evidence for a significant reduction in workload.

Subject comments regarding their ratings were congruent with the quantitative results. The six subjects who envisioned lower workload with Data Link referenced its impact on reducing the time needed to communicate with aircraft, and, in some cases, the collateral effects of reduced time pressure on the effort and stress dimensions of workload. Both of the subjects whose ratings revealed no workload difference expressed uncertainty regarding the final impact of the trade off between voice and keyboard activities. The single subject predicting an increase indicated that stress and effort may rise because of the requirement to search a menu for the needed instruction and enter it. Two other subjects who mentioned the menu selection and keying issues in their written comments had predicted lower workload levels with Data Link, noting that menu items would be rapidly memorized in the operational environment and that keystrokes would become automatic with practice.

TABLE 1. TRANSFORMED PROSWAT SCALE VALUES FOR THE TIME AND STRESS PROTOTYPE SUBGROUPS

SWAT Rating Combination			Time Prototype	Stress Prototype
T	E	S	Scale Equivalent	Scale Equivalent
1	1	1	0	0
1	1	2	7.7	31.3
1	1	3	13.6	54.6
1	2	1	10.4	12.1
1	2	2	18.1	43.4
1	2	3	24.0	66.7
1	3	1	19.2	19.8
1	3	2	26.9	51.1
1	3	3	32.8	74.5
2	1	1	32.7	8.7
2	1	2	40.5	40.0
2	1	3	46.4	63.4
2	2	1	43.2	20.8
2	2	2	50.9	52.1
2	2	3	56.8	75.4
2	3	1	52.0	28.6
2	3	2	59.7	59.9
2	3	3	65.6	83.2
3	1	1	67.2	25.5
3	1	2	74.9	56.8
3	1	3	80.8	80.2
3	2	1	77.6	37.6
3	2	2	85.3	68.9
3	2	3	91.2	92.2
3	3	1	86.2	45.4
3	3	2	94.1	76.6
3	3	3	100.0	100.0

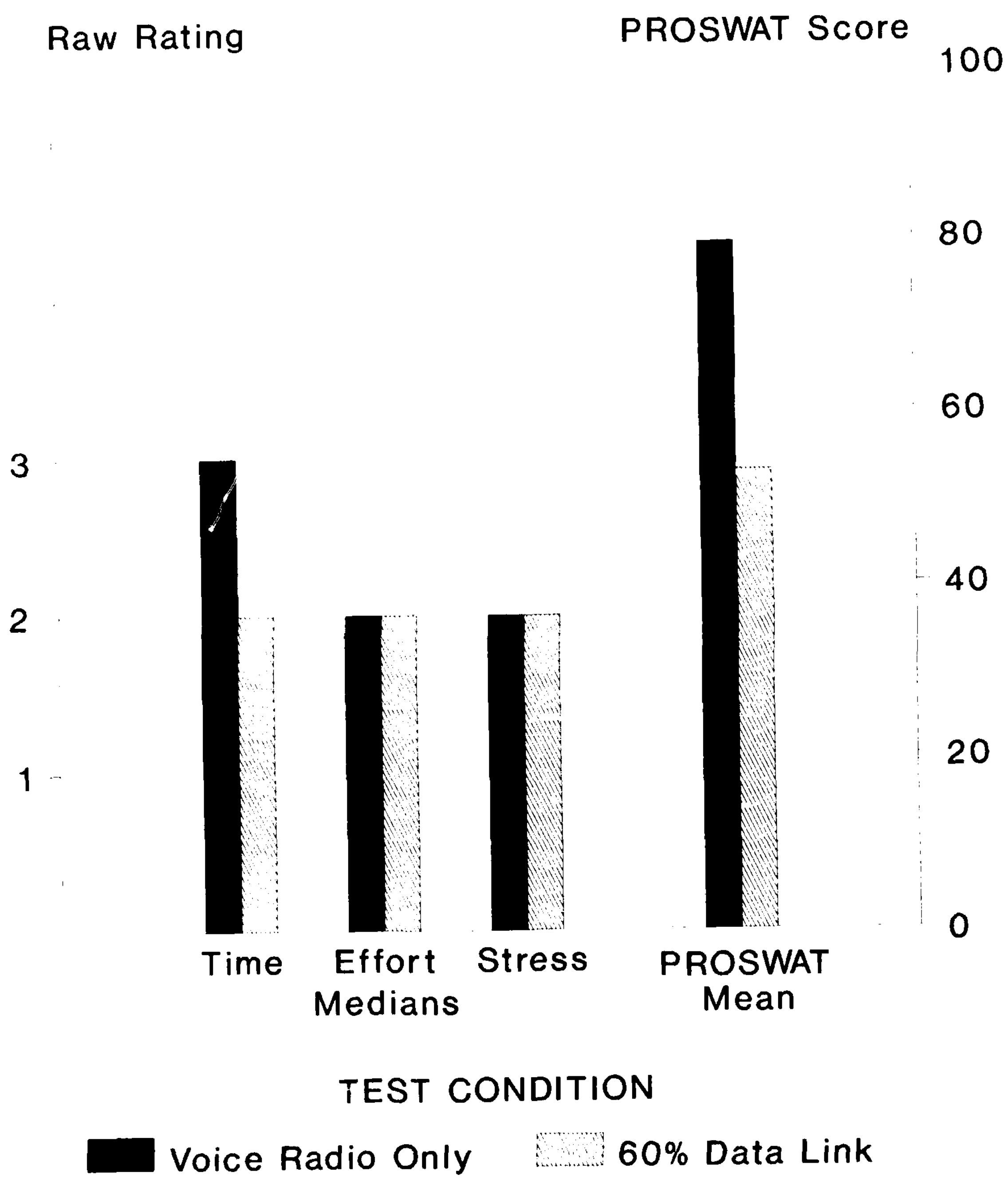

FIGURE 4. PROSWAT PROJECTED WORKLOAD ESTIMATES

3.2.2 Operational Effectiveness and Controller Acceptance.

Upon completing the workload estimates, the subjects were asked to predict operational effectiveness/suitability and controller acceptance/preference for each of the initial terminal Data Link services. Figure 5 presents the minimum, maximum, and median ratings that were obtained for each service. None of the subjects rated any of the services as "not operationally suitable" or as "completely unacceptable" to the controller users of the system. In addition, as shown in the figure, all four services received high median effectiveness and controller ratings. With the exception of Menu Text, all of the services were rated by all subjects at or above the center point of the two scales, indicating a strong and consistently positive opinion of the designs as tested and modified during this study. A single subject rated the Menu Text function below the midpoint of both scales (1 - minimally effective/acceptable, but not preferred). This subject's comments referenced the difficulty in rapidly locating desired menu items discussed earlier in the results. Two other subjects expressed similar concerns in their comments about this service and emphasized that additional testing must ensure that Data Link maintains its value as an aid to the controller and not become a source of distraction. The broad range of ratings and comments regarding Menu Text indicated that if the message selection tasks can be simplified, this service will be extremely valuable and highly acceptable to its users.

Primary comments supporting high ratings of both controller preference and operational effectiveness for the transfer of communication, terminal information and initial contact services cited the time saved and reduction in frequency congestion produced by converting these repetitive and/or lengthy communications to Data Link. Reasons cited for less than optimum ratings included the need for further testing of the services to insure their broad applicability.

3.3 FINAL DEBRIEFING.

The structured discussion session which followed the second day of simulation testing was focused on the subject's overall predictions about the impact of implementing Data Link in the terminal ATC environment, operational Data Link issues, and needs for future Data Link Test Bed Research to refine and evaluate terminal services.

3.3.1 Data Link Impact.

The subjects noted that implementing Data Link within the current ATC system would produce at least three positive effects. In agreement with their emphasis on the problems of time limitations in terminal airspace expressed earlier in the study and in their comments regarding workload, the test subjects felt that Data Link

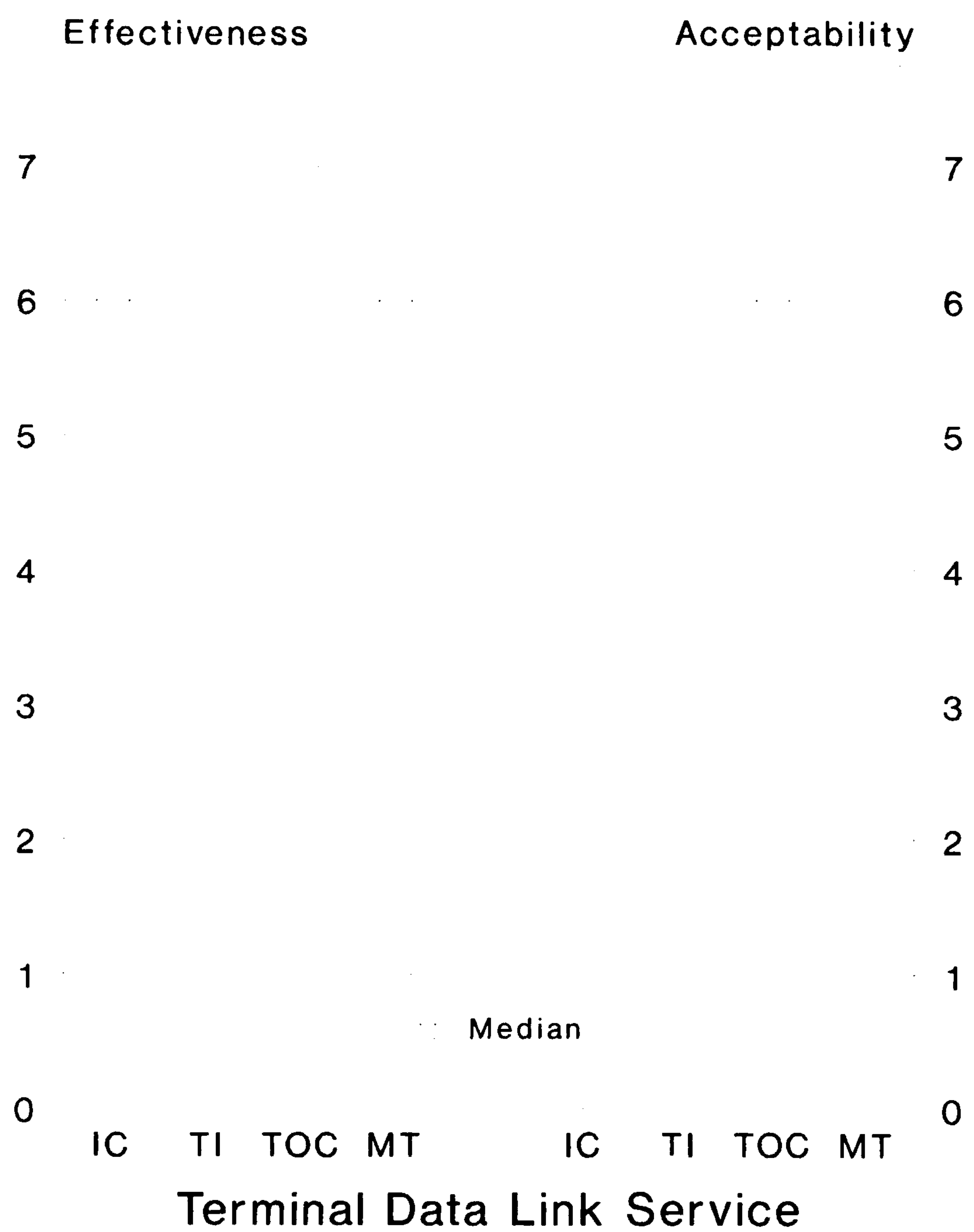

FIGURE 5. OPERATIONAL EFFECTIVENESS AND CONTROLLER PREFERENCES FOR THE INITIAL CONTACT (IC), TERMINAL INFORMATION (TI), TRANSFER OF COMMUNICATION (TOC), AND MENU TEXT (MT) SERVICES

would provide them with more available time on the radio frequencies to communicate important information to pilots. Beyond this direct effect of reduced frequency congestion, it also was noted that time pressures would be reduced by the ability to send lengthy clearances and advisories with a single manual action. Finally, Data Link's digital communication characteristics and persistent visual displays were predicted to have a positive impact on the accuracy of air-ground communications.

3.3.2 Data Link Delays and Voice Usage.

As a part of the debriefing, the subjects were asked to reflect on their Test Bed simulation experiences in order to discuss how voice and Data Link were used in the mixed equipage tests, and to obtain their reactions to Data Link transmission delays.

The subjects reported that they used voice procedures with Data Link equipped aircraft in order to adapt to time-critical situations, to resolve transmission failures in which the margin of available communication time had become too short, and, in one case, to correct an erroneous uplink. In subsequent discussion, one of the three controllers who had manned the final approach sector in the simulation runs noted that he was uncomfortable using Data Link during this phase of a flight since, in an operational situation, pilots may be reluctant to utilize a "heads down" visual display for communications. However, other controllers noted that Data Link may be useful for providing the final approach clearance. The group consensus that emerged from this discussion was that the optimal use of Data Link during final approach was an issue that would have to be addressed in a full scale operational evaluation in which actual pilots and high fidelity flight simulators were included.

The subjects reported no specific problems with Data Link transmission delays in the context of the relatively low complexity simulation scenario used in the present study. As in earlier simulations with en route controllers, the terminal controllers felt that they were able to accommodate delays by uplinking messages in a more anticipatory fashion and by switching to voice when necessary. However, it was agreed that future Test Bed evaluations would have to be conducted to determine the effect of delays.

3.3.3 Future Test Requirements.

Beyond an agreement that the service design modifications which emerged from the present study will require a second mini study evaluation, the controllers also emphasized a need to develop more complex simulation scenarios for future testing. Specific features of the testing environment that were noted as requirements included: (a) scenarios as long as 90 minutes to assess realistic, long term effects on controller performance, (b) increased traffic loads and tighter spacing requirements, and (c) the inclusion of anomalies and errors in the testing protocols to determine whether Data Link displays of information such as the initial contact downlink have sufficient alerting value to the controller under operational conditions.

4. CONCLUSIONS.

The results of the study presented in this report warrant a number of specific and general conclusions regarding the initial terminal ATC services and requirements for future research on this group of Data Link applications.

a. Based on their simulation experiences in the ARTS IIIA Data Link Test Bed, the controllers who participated in this study concluded that Data Link would have strong, positive effects on terminal operations if implemented in the current ATC system. These effects would include a significant reduction in voice radio frequency congestion, simplified transfer of lengthy advisory messages and clearances, and a reduction in communication errors.

b. The subjects estimated that terminal Data Link services would reduce controller workload. Projections of average controller workload in a 60 percent Data Link aircraft equipage environment were significantly lower than comparative estimates of controller workload in the current, exclusively voice radio, communications environment.

c. The Initial Contact, Transfer of Communication, Terminal Information, and Menu Text services, as modified by controller inputs during this study, received high controller ratings on the dimensions of operational effectiveness and acceptability to field controllers. None of the controllers rated any of the service designs as operationally unsuitable or completely unacceptable to users. In addition, the median ratings for all services were either the highest or second highest possible scores on the 7-point operational effectiveness and controller preference scales.

d. Several modifications and enhancements to the Data Link service designs were agreed upon during the study. In general, these alterations were suggested by the subjects as necessary for future evaluation, and not as final design specifications. The most important of the desired modifications included the following:

1. Both a Data Link transaction status list and a transaction history list should be added to the ARTS IIIA implementation as potential supplements to the tested data block transaction displays. Furthermore, all transaction displays should be expanded to provide more detailed, and in some cases more persistent, information regarding the outcome of each transaction.

2. The lack of a consensus on appropriate symbology for the Data Link equipage and eligibility display will necessitate the maintenance of a capability to manipulate available design options in future studies.

3. The Terminal Information service should be modified to permit the combined uplink of any available message on the list with Menu Text selections. In addition, the ability to reassign any of the messages in the list to the default status should be added.

4. The Transfer of Communication service should be modified to permit Data Link communications during the period between the acceptance of a sector hand off and the transferring controller's input to uplink the new radio frequency.

5. The menu by-pass feature introduced during the study should be retained and enhanced by permitting combined clearances in a single uplink. In addition, fixed menu items were requested which contain predetermined combined speed, heading, and altitude instructions.

e. Beyond the design enhancement recommendations and expert projections that were derived from this study, the results also revealed some open design issues which may have a large impact on the performance capabilities of the terminal Data Link controller. It is concluded that the following issues will require specific research attention in future design and operational evaluation research:

1. <u>Menu Usage and Design</u>. The results of the study indicate that individual differences may exist among controllers in their preferred approach to uplinking ATC clearance messages. Some of the test controllers preferred to develop a predefined menu of messages which would cover all clearances that they wished to issue. Others felt that the menu should be limited to only the messages which were used frequently and repetitively, and that the by-pass method be employed as needed for composing other speed, heading, and altitude clearances. If the option to permit lengthy menus is exercised, controller comments recorded during this study indicate that care must be used during continued design efforts to avoid the potentially excessive memory and visual search demands which can accompany the use of these data entry tools. Possible solutions may include the use of mnemonic devices for assigning messages to item designators and the spatial separation of menu items to facilitate the task of locating a required message.

2. <u>Information Display</u>. Data Link service design efforts in both en route and terminal environments have shown that information regarding the status of Data Link transactions should be presented in a display location which does not require diversion of attention from the radar targets. This finding led to the use

of the data block as a primary Data Link display area. However, controllers have tempered this requirement with a warning that the addition of information to the data block can carry a penalty of increased visual clutter, and present a source of distraction to the viewer.

These apparently opposing requirements have resulted in data block displays for Data Link transactions which are limited to the minimum information possible, and which tend to present data only when an exception to the normal sequence of events occurs. The results of the present study indicated that this design philosophy may require modification to insure that sufficient transaction information is available to the controller (e.g., the display of the cause of a transaction failure). Because of this, continued research attention will be needed to provide Data Link displays which provide all necessary information to support controller decisions while avoiding the disruption of other monitoring functions.

3. Short Term Memory. Effective monitoring and control of an aircraft's progress place a demand on the controller to remember the content of prior clearances. While this requirement applies equally to voice and Data Link communications, the subjects in the present study often emphasized the need for displays which will confirm that a message they had intended to send had, in fact, been sent and that the pilot had responded affirmatively. Examples of desired design features which reflect this requirement include the history list and a persistent display of the WILCO response in the data block.

At present, it is not clear whether these aids may be needed because of differential short term memory for spoken and manually entered messages, the visual nature of Data Link communications displays, or lack of long term experience with Data Link inputs. Since memory failures in the present voice-only communications channel are known to be common, it is also possible that the digital nature of Data Link communications simply makes it possible to provide a more generally needed memory aid to controllers which is not available in the current system. Regardless of the reason, the data collected thus far support the conclusion that continued attention be given in design evaluation studies to the requirement for controller information displays which can prevent short term memory lapses.

5. RECOMMENDATIONS.

The following recommendations for future efforts under the FAA terminal Data Link program are derived from the findings and conclusions of the present research:

a. The results of this study indicated that the initial terminal ATC Data Link services have the potential to reduce frequency congestion and controller workload and are compatible with the existing NAS terminal controller workstation and computer. Therefore, it is recommended that continued development and operational evaluation research be pursued to implement these services at the earliest possible date.

b. It is also recommended that work be initiated to verify the technical feasibility of implementing the Data Link services in the operational ATC system. These efforts should include the empirical tests on ARTS IIIA capabilities outlined in appendix A, as well as analyses of the impact on future terminal systems.

c. The service design modifications and enhancements identified during the present study should be implemented in the ARTS IIIA Test Bed for review and evaluation by the ATDLVT in a second mini study.

d. Simulation scenarios and testing protocols should be developed for operational evaluation purposes. These testing conditions should be designed to test the robustness of the Data Link service designs under high air traffic loads, minimum aircraft spacing distances, long duration controller work periods, and anomalous error conditions.

e. Future research should continue to focus on the human factors issues which may impact the effectiveness of terminal Data Link services. These include the control of visual search demands in the use of menu functions, insurance of optimum information content in transaction status displays, and minimization of short term memory requirements.

f. Future design and testing efforts should be devoted to resolving issues that are common between the terminal and en route Data Link designs. Future testing should include an integrated terminal and en route test effort to verify coherent system design between terminal and en route facilities.

6. BIBLIOGRAPHY.

Billings, C. E. and Reynard, W. D., Dimensions of the Information Transfer Problem, in C. Billings and E. Cheaney (Eds.), Information Transfer Problems in the Aviation System, NASA Technical Paper 1875, National Aeronautics and Space Administration, 1981.

Computers to Reshape Air Control Job in 90's, New York Times, July 29, 1988.

Nonparametric Statistics for the Behavioral Sciences, McGraw-Hill, pp 229-239, 1956.

Shingledecker, C. A., Human Factors Research in the Development of Data Link Air Traffic Control Services, Proceedings of the Aeronautical Telecommunications Symposium on Data Link Integration, ARINC/FAA, 1990.

Talotta, N., et. al., Controller Evaluation of Initial Data Link Air Traffic Control Services: Mini Study 1, DOT/FAA/CT-88/25, I, II, September 1988.

Talotta, N., et. al., Controller Evaluation of Initial Data Link Air Traffic Control Services: Mini Study 2, DOT/FAA/CT-89/14, I, II, March 1989.

Talotta, N., et. al., Operational Evaluation of Initial Air Traffic Control Services, DOT/FAA/CT-90/1, I, II, February 1990.

APPENDIX A

ANALYSIS OF DATA LINK IMPACT ON THE ARTS IIIA

EVALUATION IMPACT

The evaluation of a new function such as Terminal Data Link would not be complete without considering the impact it would have on the ARTS IIIA operational system. There are three considerations: available memory, available processing time, and display refresh.

MEMORY.

The ARTS IIIA system can be configured for a single sensor or a dual sensor system. The ARTS IIIA was originally equipped with 128k of core memory for a single sensor system and 160k of core memory for a dual sensor system, and was later increased to 160k and 192k, respectively. More recently as a result of the Interim Support Plan (ISP), currently under contract and in progress, the ARTS IIIA is being upgraded to 256k of semiconductor memory at all sites. Busy sites such as Chicago O'Hare and Dallas/Fort Worth are already operating with the new memory.

The ARTS IIIA system currently operating in the field, A3.04, requires 128k of memory for a single sensor and 176k for a dual sensor. This allows 128k for expansion in a single sensor system an 80 in a dual sensor system. The current Data Link services would require no more than 10k of the memory that is available.

PROCESSING TIME.

ARTS IIIA processing capacity caused a great deal of concern in recent years. However, as a result of several software changes to make the software more efficient and the implementation of the high speed semiconductor memory mentioned above, the concern of processing capacity has been put to rest. For example, Chicago O'Hare, one of the busiest airports in the country was at capacity prior to the software and memory improvements. That system is operating at approximately 65 percent during the busiest periods of traffic. The Data Link functions currently under test are predominately keyboard triggered. Keyboard entries have a low impact on processing time. It is the events triggered, such as uplink messages, that may cause somewhat of an impact. However, the impact is not expected to be more than 5 percent maximum. This is a best estimate. It would be necessary to run two simulations with identical traffic loads, one with Data Link and one without, utilizing the system performance monitor to determine the actual difference in processing time.

DISPLAY REFRESH.

The ARTS IIIA Display Entry Devices (DEDs) display are 1960's technology and were not designed to handle the data rates of the busier facilities in the 1990's. Many of the busier sites have complained of display flicker. Fortunately, the Interim Support Plan contract, mentioned earlier, includes the purchase of 150 Full

Digital Arts Displays (FDADs) to be installed at the busier facilities. As a result, the additional tabular lists of TI and MT messages and the occasional third line of the data block will not impact display refresh at sites using FDAD displays. In any case, should some medium traffic facility have a flicker problem, it could be resolved with the purchase of additional FDAD's.

TERMINAL DATA LINK FACT SHEET

The current services available with the A3.03 software modifications are Initial Contact, Terminal Information, Message Text, and Transfer Control. The following is a list of ARTS IIIA additional memory requirements for the current services:

Program Storage	2354 words total
Keyboard	758
Display Output	612
Data Link Input	263
Data Link Output	495
Misc. Patches	226

Data Storage	Single Sensor 3490 Words		Dual Sensor 6680 Words
Data Link Inter-facility Data	500		700
TI/MT Messages (4 TI, 12 MT), 86 Words Per Controller 10 Controllers	860	20 Controllers	1720
Central Track Store 5 Additional Words Per Track, 300 Tracks	1500	600 Tracks	3000
Display Output Buffers 63 Words Per Controller 10 Controllers	630	20 Controllers	1260

The ARTS IIIA System currently in the field (A3.04) requires approximately 128k of memory for a single sensor system and 176k of memory for a dual sensor system. The Interim Support Plan (ISP) contract with UNISYS provides for all ARTS IIIA systems to be upgraded to 256k of high speed semiconductor memory. This upgrade will easily allow sufficient space for all the Data Link functions to be added without interfacing with other enhancements.

APPENDIX B

DESCRIPTIONS OF THE TESTED DATA LINK SERVICES

DESCRIPTION

Operational descriptions of each of the Data Link services evaluated in this study are presented in the following sections of this appendix. These descriptions do not reflect enhancements and modifications to the designs which were recommended by the subject controllers during the design review.

The photographs which follow the descriptions present an overall view of the ARTS IIIA workstation in the Data Link Test Bed with Data Link displays shown on the radar screen, a closeup of the data block with eligibility and equipage symbology on the first line and transaction information presented on the third line, and a close up of the Terminal Information Service and Menu Text lists.

Note in the following service descriptions:

1. The SLEW command should be interpreted as the action sequence of acquiring the target with the trackball and pressing the trackball enter key.

2. The ENTER command should be interpreted as pressing the keyboard ENTER key.

3. Data, as shown in a display, are presented in quotation marks. The quotation marks are <u>not</u> part of the display.

4. For all services, only one Data Link transaction per aircraft may be in progress at a time -- the controller may not uplink a new message until the previous service has been WILCOed or a FAIL has been cleared from the data block display.

INITIAL CONTACT (IC)

<u>SERVICE DESCRIPTION</u>.

1. Initiation of IC.

The request for assigned altitude is automatically uplinked to an aircraft when the pilot downlinks a WILCO message to a preceding transfer of communication.

2. Display on Downlink of Assigned Altitude.

When the aircraft downlinks its assigned altitude, the third line of the data block displays the character IC followed by the altitude value (e.g., IC 110). The altitude value flashes to capture the controller's attention and signal a required response.

This response may be a Terminal Information (TI) message, initiation of a transfer of communication, one or more Menu Text

(MT) messages, or a combination of a TI message and MT messages. Initiation of the uplink immediately deletes the IC display in the third line of the data block.

3. Display on Failure to Downlink Assigned Altitude.

If the aircraft system fails to technically acknowledge the altitude request or fails to downlink the assigned altitude within 40 seconds of receiving the uplinked request, the third line of the data block displays the characters IC FAIL. FAIL flashes to signal a required controller response.

4. Inputs to Resend Altitude Request.

If a response failure occurs, the controller may resend the altitude request by a SLEW action.

5. Inputs to Clear IC FAIL Display.

The IC FAIL display may be manually deleted by pressing the D/L key (F9), followed by a SLEW action.

TERMINAL INFORMATION SERVICE (TI)

SERVICE DESCRIPTION.

1. Initiation of TI.

A TI message can be sent at any time through a controller input action. When used immediately after receiving an initial contact message from an aircraft (IC and an altitude value displayed in third line of data block), simplified SLEW inputs can be used to send commonly-used TI messages.

2. TI List Display.

TI messages are selected from a list display containing several optional items. Each message (up to 29 characters) is presented on a single line of the list preceded by a identifying digit or the letter D. The message identified by D is a commonly-used default message. The remaining items are numbered consecutively beginning with 1.

3. Inputs to Reposition TI List.

The TI list can be moved to any position on the ARTS display by pressing the MULTIFUNCTION key (F7), typing TC and SLEW to position the list.

4. Inputs to Suppress/Retrieve TI List.

The TI list can be removed from the ARTS display by pressing the D/L key (F9), typing T and ENTER. Repeating this sequence will retrieve the list.

5. Inputs to Send TI - Default Message.

When a successful initial contact has been completed and the third line of the data block displays IC followed by an altitude value, the default TI message may be uplinked by a SLEW action.

6. Inputs to Send TI - Non-Default Message.

Non-default messages can be uplinked by typing T, the message number from the TI list (e.g., 3) and SLEW.

7. Displays on TI Uplink.

If a TI message is sent when IC and an altitude value are shown in the third line of the data block, the entry deletes the third line and replaces it with TI followed by the message number selected from the list for uplink.

8. Displays After Pilot WILCO.

Upon receipt of a downlinked WILCO response from the aircraft, the TI message number display in the third line of the data block is deleted.

9. Displays on Failed Response.

If the aircraft does not technically acknowledge the uplink or the pilot fails to respond within 40 seconds after receiving the TI message, TI FAIL appears in the third line of the data block with the FAIL characters flashing.

10. Inputs to Resend TI.

The controller may resend a TI message after a response failure by a SLEW action.

11. Inputs to Clear TI FAIL Display.

The TI FAIL display can be deleted by pressing the D/L (F9) key and SLEW.

12. Inputs to Change Default Message.

The default message can be changed only by typing a new message on the default message line.

13. Combining TI with MT Message(s).

The default TI message can be sent together with one or more MT messages by typing T prior to the Menu Text entry (see MT description).

TRANSFER OF COMMUNICATIONS (TOC)

SERVICE DESCRIPTION.

1. Initiation of TOC.

The TOC message containing a new radio frequency for an aircraft is automatically prepared when the receiving controller accepts a sector hand off.

2. Inputs to Send TOC - Automatic.

The TOC is automatically uplinked upon acceptance of the handoff if the sending controller presses the HANDOFF key (F5), types the receiving sector's Controller Symbol, and SLEW. Any other currently acceptable ARTS input sequence normally used to initiate a handoff will result in the same automatic uplink of TOC (e.g., F5-ACID-Controller Symbol- ENTER).

3. Display on Automatic TOC Uplink.

TC is displayed in the third line of the data block when the TOC message is uplinked.

4. Inputs to Send TOC - Manual.

The controller may initiate the sector handoff but reserve communications eligibility until a later time by using a manual procedure. Pressing the HANDOFF key (F5), typing the receiving sector's Controller Symbol, the letter H and SLEW, initiates the handoff, but holds the TOC message until the controller takes a SLEW action.

5. Display on Manual TOC.

TC H is displayed in the third line of the data block when the manual TOC entry is made. When the controllers slews the aircraft, the H is deleted and the message is uplinked.

6. Display After Pilot WILCO.

In both automatic and manual procedures, the TC display in the third line of the data block is deleted when the aircraft downlinks a WILCO response.

8. Display on Failed Response.

If the aircraft fails to technically acknowledge the TOC or if the pilot fails to WILCO the message within 40 seconds of receipt, TC FAIL appears in the third line of the data block with the FAIL characters flashing.

9. Inputs to Resend TOC.

The controller may resend a failed TOC message by a SLEW action.

10. Inputs to Clear TOC FAIL Display.

The controller may delete the TC FAIL display by pressing the D/L key (F9) and a SLEW action.

11. Inputs to Acquire Data Link Eligibility.

The controller may acquire (steal) eligibility for Data Link communications by pressing the D/L key (F9), typing the letters OK and a SLEW action.

MENU TEXT (MT)

SERVICE DESCRIPTION.

1. Initiation of MT.

The MT service permits the controller to uplink one or more clearances contained in a menu list by manually selecting the required messages.

2. MT List Display.

Available MT clearances are displayed in a list containing several items. Each menu item (up to 29 characters) is displayed on a single line preceded by an identifying number. Messages are selected using the identifying numbers.

3. Inputs to Reposition MT List.

The position of the MT list on the ARTS display can be altered by pressing the MULTIFUNCTION key (F7), typing TC, and completing a SLEW action to move the list.

4. Inputs to Suppress/Retrieve MT List.

The MT list can be removed from the display by pressing the D/L key (F9) and typing M and ENTER. The list is retrieved using the same sequence of key strokes.

5. Inputs to Send a MT Message.

A single MT item can be uplinked by typing M followed by the menu item identifying number, and a SLEW action.

6. Inputs to Send Multiple MT Messages.

Up to three MT menu items can be sent in a single uplink by inserting spaces between the item numbers (e.g., M1 2 3 SLEW would send menu items 1, 2, and 3).

7. Inputs to Send MT Message(s) Combined with TI.

The default TI message can be sent in combination with up to two MT items by adding T as the first character of the MT input. (e.g., TM1 2 SLEW would send the default TI message and menu items 1 and 2).

8. Displays on MT Uplink.

When an MT uplink is initiated, MT appears in the third line of the data block followed by the identifying numbers of the messages sent. T MT followed by the MT messages sent is displayed when the default TI message is combined with MT messages.

9. Displays After Pilot WILCO.

A downlinked WILCO to an MT message or group of messages deletes the data in the third line of the data block.

10. Displays on Failed Response.

If the aircraft fails to technically acknowledge an MT uplink or the pilot fails to downlink a WILCO response within 40 seconds of its receipt, MT FAIL appears in the third line of the data block with the FAIL characters flashing.

11. Inputs to Resend MT.

Upon a failed response to a MT uplink, the controller may resend the message with a SLEW action.

12. Inputs to Clear MT FAIL Display.

The MT FAIL display can be manually deleted by pressing the D/L key (F9) and making a SLEW action.

13. Modifying Numeric Values in Menu Items.

The numeric value of a heading, speed, or altitude clearance can be changed by pressing the D/L key (F9), typing M and the one-digit identifying number of the menu item to be changed, typing the new numeric value (three digits), and pressing the ENTER key.

If a SLEW action is substituted for the keyboard ENTER, the menu item will be changed AND uplinked to the slewed aircraft.

14. Bypassing the Menu.

A heading (H), altitude (A) or speed (S) not contained in the menu can be uplinked by pressing the D/L key, typing H, A or S followed by the three digit numeric value of the clearance and SLEW. The third line of the data block displays MT, the clearance letter, and the three digit numerical value entered (e.g., MT A 110) until the message is WILCOed or FAILs.

FIGURE B-1. THE ARTS IIIA WORKSTATION IN THE DATA LINK TEST BED

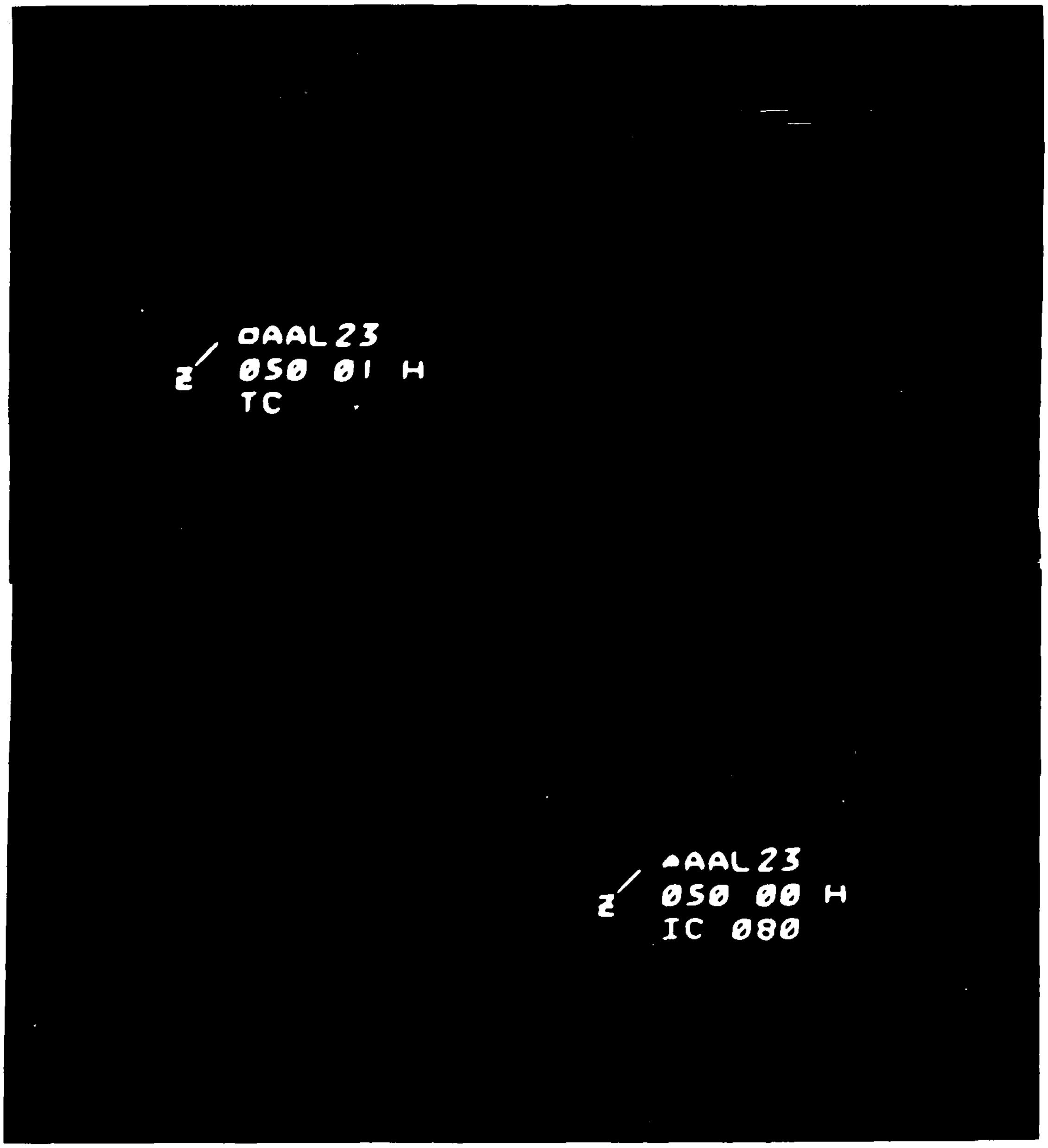

FIGURE B-2. THE DATA BLOCK TRANSACTION AND EQUIPAGE/ELIGIBILITY DISPLAY

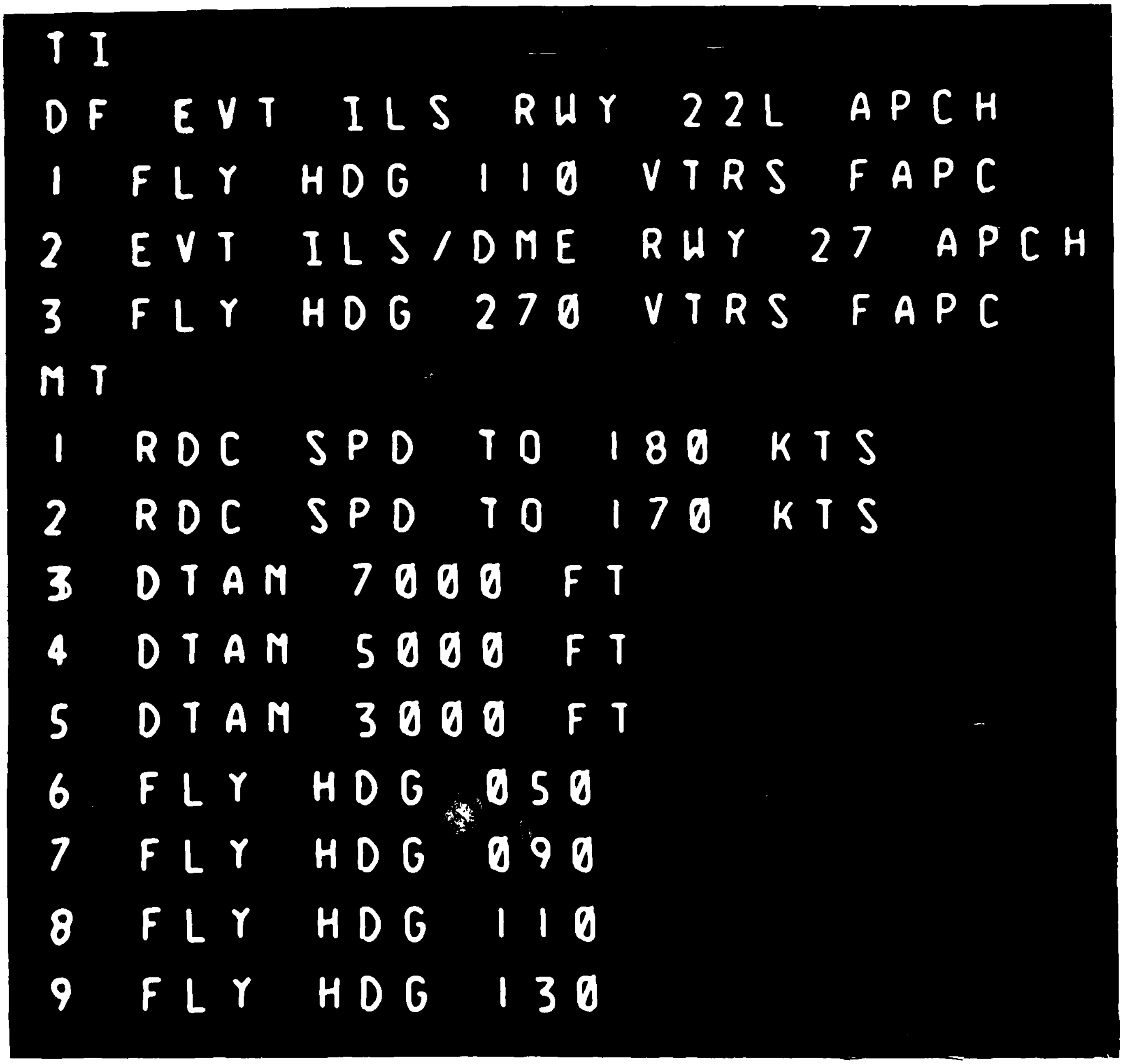

FIGURE B-3. THE TERMINAL INFORMATION AND MENU TEXT LISTS

APPENDIX C

PROJECTIVE RATING MATERIALS

INTRODUCTION TO THE RATING SCALES

During the second part of this mini study you will be controlling air traffic in a dynamic scenario using current voice radio procedures in one test run and the Data Link services in a second test run. The purpose of this exercise is to permit you to make some quantitative judgments about the Data Link services and their potential effects on the controller's task.

Because most of you have directly participated in the development and specification of the terminal Data Link services, it will be extremely important for you to make every effort to be as impartial as possible in making the ratings described below. In your capacity as subjects for this study, you are representing many other terminal controllers whose work will be affected by the introduction of Data Link. Do your best to base your ratings purely on your professional experience as controllers and on the exposure that you will be given to the initial Data Link services in the test bed.

Your judgments will be made using a set of three rating scales designed to measure three different factors; (1) the Operational Effectiveness and Suitability of each service, (2) the Acceptability and Controller Preference for each service design, and (3) the effect of the combined services on controller Workload. Each of these factors is described below:

OPERATIONAL EFFECTIVENESS AND SUITABILITY.

The first scale (figure C-1) asks for a rating of the effectiveness and suitability of each of the four Data Link services designs. To evaluate this factor you should assess the degree to which the service implementation that you have worked with in the Test Bed could effectively accomplish the task it was designed to do. Thus, you should consider whether the design provides all of the functions and capabilities that would be needed to meet operational requirements in a field setting.

To complete the scale, first decide whether or not the design is capable of meeting any of its operational requirements of the service. If it is not at all operationally suitable, place an X in the box. If the design can meet some, or all, operational requirements, place an X on the line below the number that best describes its effectiveness. Your rating can range from 1 (highly effective) to 7 (meets minimal requirements).

CONTROLLER ACCEPTANCE AND PREFERENCE.

The second scale (figure C-1) asks for a rating of the acceptability of a service design to controllers and of how preferable it is. To evaluate this factor you should consider the extent to which the displays, inputs, and procedures for the

DATA LINK SERVICE

Use the scales below to rate the terminal service indicated above. On the first scale, check the box if this service is unsuitable for operational use. If the service can meet some, or all operational requirements, check the space below the number that best describes its effectiveness.

OPERATIONAL EFFECTIVENESS / SUITABILITY

Highly Effective		Meets Most Operational Requirements			Minimally Effective		Not Operationally Suitable
↓		↓			↓		↑
___	___	___	___	___	___	___	☐

On this scale, regardless of the service's effectiveness, check the box if the way in which the service is designed would be completely unacceptable to controllers. If the service design is acceptable, check the space below the number that best describes your preference for the design.

CONTROLLER ACCEPTANCE / PREFERENCE

Highly Preferred			Moderately Preferred			Acceptable, But Not Preferred	Completely Unacceptable
↓			↓			↓	↑
___	___	___	___	___	___	___	☐

Please use the following page to comment on your ratings.

FIGURE C-1. EFFECTIVENESS/PREFERENCE RATING FORM service would be usable by field controllers and adaptable to their styles and methods of controlling air traffic.

To complete this scale, first decide whether the design would be acceptable or unacceptable to controllers. If it is completely unacceptable, place an X in the box. If it is acceptable, rate the design by placing an X on the line below the number which best describes your preference. Your rating can range from 1 (highly preferred) to 7 (acceptable, but not preferred).

Note: When making your ratings, remember to make independent judgments of controller preference and operational suitability. Although these two dimensions may tend to vary together, a service design could provide all of the functions needed to meet operational requirements and still be poorly suited to the controller's way of doing his job. Likewise, a design could be easy to use, but have loopholes which prevent it from covering all operational situations.

WORKLOAD.

The final rating that you will be asked to make is a projection about the effect that you think the four combined Data Link services will have on the workload of the terminal air traffic controller. To make this projection you will be asked to use your personal experience estimate the average workload of a controller's job on a typically busy day. Based on your experience in the Test Bed, you will then be asked to provide another estimate of the workload that would be experienced under the same conditions if the four tested Data Link services were available to the controller.

The scale that you will use to make these estimates is known as Projective Subjective Workload Assessment Technique (PROSWAT). PROSWAT was developed as a method for collecting quantified subjective data on how hard a person feels he would have to work when using different procedures and equipment to perform his duties.

If you examine the PROSWAT rating scale, you will notice that PROSWAT defines workload in terms of a combination of three different dimensions that contribute to the subjective feeling of "working hard." A workload rating in PROSWAT is accomplished by selecting a 1, 2, or 3 on EACH of the three scales representing the dimensions of TIME LOAD, MENTAL EFFORT, and PSYCHOLOGICAL STRESS.

Each of these dimensions and their levels are described below:

TIME LOAD.

Time Load refers to the fraction of the total time that you are busy. When Time Load is low, sufficient time is available to complete all of your mental work with some time to spare. As Time Load increases, spare time drops out and some aspects of performance overlap and interrupt one another. This overlap and interruption can come from performing more than one task or from different aspects of performing the same task. At high levels of Time Load, several aspects of performance often occur simultaneously, you are busy, and interruptions are very frequent.

Time Load is rated on the three point scale below:

1. Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

2. Occasionally have spare time. Interruptions or overlap among activities occur frequently.

3. Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

MENTAL EFFORT LOAD.

As described above, Time Load refers to the amount of time one has available to perform a task or tasks. In contrast, Mental Effort Load is an index of the amount of attention or mental effort required by a task regardless of the number of tasks to be performed or any time limitations. When Mental Effort Load is low, the concentration and attention required by a task is minimal and performance is nearly automatic. As the demand for mental effort increases due to task complexity or the amount of information which must be dealt with in order to perform adequately, the degree of concentration and attention required increases. High Mental Effort Load demands total attention or concentration due to task complexity or the amount of information that must be processed.

Mental Effort Load is rated using the 3-point scale below:

1. Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.

2. Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

3. Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

PSYCHOLOGICAL STRESS LOAD.

Psychological Stress Load refers to the contribution to total workload of any conditions that produce anxiety, frustration, or confusion while performing a task or tasks. At low levels of stress, one feels relatively relaxed. As stress increases, confusion, anxiety, or frustration increase and greater concentration and determination are required to maintain control of the situation.

Psychological Stress Load may be rated on the 3-point scale below:

1. Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

2. Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

3. High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

Each of the three dimensions just described contribute to workload during performance of a task or group of tasks. Note that although all three factors may be correlated, they need not be. For example, one can have many tasks to perform in the time available (High Time Load) but the tasks may require little concentration (Low Mental Effort Load). Likewise, one can be anxious and frustrated (High Stress Load) and have plenty of spare time between relatively simple tasks. Since the three dimensions contributing to workload are not necessarily correlated, please treat each dimension individually and give independent assessments of the Time Load, Mental Effort Load, and Psychological Stress Load that you estimate for the terminal controller's job with and without Data Link.

The form that you will be using to make your PROSWAT ratings during the Data Link test session is shown in figure C-2. Note that the descriptions for each level of time, effort and stress load have been removed to save space. Should you need to review these descriptions during testing, a copy of the full scale will be available at all times.

PROSWAT WORKLOAD RATINGS

Based on your operational experience, estimate the average workload of a terminal controller on a typically busy day in the current, voice-only system:

CURRENT SYSTEM

	1	2	3
TIME LOAD	____	____	____
MENTAL EFFORT	____	____	____
STRESS	____	____	____

Based on your experiences with the four Data Link services in the Test Bed, estimate the average workload of a terminal controller on a typically busy day under the following condition:

DATA LINK SERVICES - 60% EQUIPAGE

	1	2	3
TIME LOAD	____	____	____
MENTAL EFFORT	____	____	____
STRESS	____	____	____

Please use the space below to comment on your ratings.

FIGURE C-2. PROSWAT RATING FORM

PROSWAT SCALE DEVELOPMENT CARD SORT

Now that you are familiar with the three rating scales that will be used during the Data Link Test session, there is one last procedure that must be completed before testing can begin. This procedure is a card sorting task that will allow us to interpret your PROSWAT workload ratings. We will be asking you to do this task during the briefing that will take place to review the rating scales.

One of the most important features of PROSWAT is its unique scoring system. The developers of PROSWAT recognized that different people have different conceptions of how the time, effort and stress dimensions combine to produce an overall impression of low and high workload. Because of these differences, a special card sorting procedure is used in PROSWAT to define a distinctive workload scale for each person. This individualized scale greatly improves our ability to accurately interpret the actual workload ratings that you will be making during the test sessions.

In order to develop your individual scale, we need information from you regarding the amount of workload that you feel is produced by various combinations of the three levels on the time, effort, and stress dimensions. We get this information by having a person rank order a set of cards. Each card contains a different combination of the levels of time load, mental effort load, and stress load. Since there are three dimensions, and each dimension has three levels, there are 27 cards in the deck that you will be sorting. Your job will be to sort the cards so that they are ranked according to the level of workload represented by each card. Thus, the first card in the deck will represent the lowest workload and the last card will represent the highest workload.

In completing your card sorts, please consider the workload imposed on a person by the combination represented in each card. Arrange the cards from the lowest workload condition through the highest condition. You may use any strategy you choose in rank ordering the cards. One strategy that proves useful is to arrange the cards into a number of preliminary stacks representing High, Moderate, and Low workload. Individual cards can be exchanged between stacks, if necessary, and then rank ordered within stacks. Stacks can then be recombined and checked to be sure that they represent your ranking of lowest to highest workload. However, the choice of strategy is up to you and you should choose the one that works best for you.

There is no **school solution** to this problem. There is no correct order. The correct order is what, in your judgment best describes the progression of workload from lowest to highest for a general case rather than any specific event. That judgment differs for each of us. The letters you see on the back of the cards are to allow us to arrange the cards in a previously randomized sequence so that everyone gets the same order. If you examine your deck you will see the order on the back runs from A through Z and then ZZ.

Please remember:

1. The card sort is being done so that a workload scale may be developed for you. This scale will have a distinct workload value for each possible combination of Time Load, Mental Effort Load, and Psychological Stress Load. The following example demonstrates the relationship between the card sort and the resulting workload scale:

TIME	EFFORT	STRESS		WORKLOAD SCALE
1	1	1	------------	0.0
.	.	.		.
.	.	.		.
.	.	.		.
.	.	.		.
3	3	3	------------	100.0

Note that other than the fact that a 1-1-1 will always represent the lowest workload and that a 3-3-3 will always represent the highest workload, the remaining cards could occur in a number of orders. Your order will depend on how you weight the importance of Time, Effort, and Stress dimensions.

2. When performing the card sorts, use the descriptors printed on the cards. Please remember <u>not</u> to sort the cards based on one particular task (such as controlling air traffic). Sort the cards according to your general view of workload and how important you consider the dimensions of Time, Mental Effort, and Psychological Stress Load to be.

3. A PROSWAT rating for any situation consists of one number from each of the three dimensions. For example, a possible PROSWAT rating is 1-2-2. This represents a 1 for Time Load, a 2 for Mental Effort Load, and a 2 for Psychological Stress Load.

4. We are not asking for your preference concerning Time, Mental Effort, and Psychological Stress Load. Some people may prefer to be **busy** rather than **idle** in either Time Load, Mental Effort Load, or Psychological Stress Load dimension. We are not concerned with this preference. We need information on how the three dimensions and the three levels of each one will affect the level of workload as you see it. You may prefer a 2-2-2 situation instead of a 1-1-1 situation. However, you should still realize that the 1-1-1 situation imposes less workload on you and leaves a greater reserve capacity.

The sorting will probably take 30 minutes to an hour. Please feel free to ask questions at any time.

U.S. GOVERNMENT PRINTING OFFICE