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Controller Evaluation of Initial Data Link Air Traffic Control Services, Mini Study 1, Volume 1

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16. Abstract

This report details the results of Mini Study 1. This mini study was conducted at the Federal Aviation (FAA) Technical Center utilizing the Data Link testbed. Initial Data Link air traffic control services were under part task simulation conditions in order to identify service delivery methods which optimize acceptance, performance, and workload. This report delineates the results for the first of two mini studies research and development operational evaluation which comprise the Phase I Data Link services

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PREFACE

This report documents the first Federal Aviation Administration controller evaluation of a group of three en route air traffic control services planned for implementation on the Mode S Data Link system. The report is organized in two volumes.

Volume I contains the main body of the report. This includes a detailed description of the objectives of the study and of the technical approach and test methods that were used. In addition, the combined results of the study, conclusions, and recommendations are presented.

Volume II is comprised of a set of seven appendixes to the report. These appendixes are referenced in Volume I and include complete documentation of the test scenario and of the assessment procedures used in the study. Separate appendixes are also devoted to detailed analyses of the data that were collected using each of the assessment procedures. These appendixes formed the basis for the combined results portion (section 3) of Volume I.

This report delineates the results for the first of two mini studies and a Research and Development Operational Evaluation - all of which comprise the Phase I Data Link Services package.

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The study reported in this document was conducted at the Federal Aviation Administration (FAA) Technical Center under the direction of Nicholas Talotta, Technical Program Manager, Airborne Collision Avoidance and Data Link Systems Branch (ACT-170).

The planning and execution of the study were the results of cooperative efforts of several members of the Data Link Development Team. In particular, the following individuals played key roles in this research.

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Haim Gabrieli (MITRE) - MITRE Coordinator

Henry Marek (FAA Technical Center) - Test Documentation

William VanCampen (MITRE) - Scenario/Script Coordinator

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Data Link Simulations Pilots:

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This report is the product of inputs submitted by the FAA Technical Center, MITRE and NTI, Inc. Sections 2.3.2, 2.3.3 and other portions of section 2 were based on materials written by Bill VanCampen of the MITRE Corporation. Appendix F was written by Thomas Zurinskas and Bruce Rosenbeng of the FAA Technical Center.

Appendix C was written by Karol Kerns of the MITRE Corporation. The remainder of the report was prepared by Clark Shingledecker of NTI, Inc.

Special appreciation is extended to the 10 air traffic controllers who served as subjects and observers. Without the professional and thoughtful contributions of the following individuals, this study and the follow-on Data Link activity would not have been possible:

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EXECUTIVE SUMMARY

INTRODUCTION.

The Federal Aviation Administration (FAA) Test Plan for the Mode S Data Link defines a two-stage process for controller evaluation of candidate air traffic control (ATC) services. In the first stage, "mini" design studies will be conducted under controlled conditions which simulate only the essential components of the controller's tasks associated with the services (Part Task Simulation). These studies will be used to identify service delivery methods which optimize controller acceptance, performance, and workload. In the second stage, full-scale simulation studies will be performed in order to verify the safety and efficiency of Data Link within the context of realistic operational scenarios. This report presents the results of the first FAA controller mini study of en route ATC services developed for implementation on the Data Link system.

OBJECTIVES.

The specific objectives of this mini study were: (1) to evaluate and refine Data Link controller procedures and displays for the Altitude Confirmation, Transfer of Communication, and En route Minimum Safe Altitude Warning (EMSAW) services, and (2) to solicit initial opinions from controllers regarding the general utility of the Mode S Data Link.

DATA LINK OPERATION.

Data Link functions were integrated with the Host Computer System (HCS) operational software and the Computer Display Channel (CDC) displays. Capabilities included radar data processing, tracking, and flight data inputs. Operational Data Link functions and procedures were integrated with current operational procedures and computer functions. Data base updates followed altitude clearances; handoffs between sectors included radio frequency assignments; EMSAW alerts were generated upon HCS notification; and altimeter settings were automatically uplinked.

Two modes of operation were evaluated, manual and automatic. In automatic mode, a Data Link message was initiated and delivered via standard National Airspace System (NAS) entries. The message was displayed to the controller as "sent" (transmitted to aircraft transponder), "delivered" (received by the aircraft transponder), and "wilco" (pilot affirmative reply). In manual mode, the status indication "held" was displayed beside the message that appeared in the preview area: Plan View Display (PVD) or Computer Readout Device (CRD). Another sequence of entries resulted in the message triggering the "sent," "delivered," and "wilco" status indicators as appropriate. No pilot composed downlink were tested. Pilot "unable" and no reply ("timeout") conditions were also tested.

APPROACH.

Ten full-performance level air traffic controllers from Dallas/Fort Worth (D/FW) participated in the study as subjects and observers in a series of ATC scenarios presented at work stations at the FAA Technical Center Data Link test bed. In order to permit the evaluation of Data Link concepts

without distracting or overburdening test participants, test scenarios were limited. There were few tracks and no interfacility activity. Traffic

flows were repetitious in nature and control tasks were restricted. No overall system delays were simulated. Figure ES-l projects the expected workload for a Data Link environment in comparison to present ATC field conditions.

Initially, the scenarios required the controllers to complete several altitude assignment/confirmation, transfer of communications, and EMSAW tasks, varying the displays and procedures used to accomplish the three services. Both central (PVD) and peripheral (CRD) locations were tested for the Data Link transaction status display. Various ATC procedures were also evaluated which differed in the number of controller actions required to deliver the services, the requirements for voice interactions between the controller and the pilot, and the requirement for downlinked pilot confirmation of service message delivery.

Following each test condition, the subjects rated the workload that would be induced by the tested options under operational conditions. The technique, called projected subjective workload assessment technique (PROSWAT), asked the controller to project the effect of each test condition on the difficulty of their job during a moderately busy workday. A score of 0 (low workload effort) to 100 (very high workload effort) was derived through a conjoint analysis of PROSWAT ratings. This technique results in interval data capable of being analyzed by parametric means.

Another rating scale was used after each condition to assess controller preferences for each condition. In addition, these formal data were supplemented by group debriefing interviews, a wrap-up questionnaire, and written narrative comments following the test sessions.

PRIMARY RESULTS.

General opinions of Data Link were strongly positive. A majority of the controller subjects felt that Data Link would definitely reduce controller workload and enhance ATC system capacity and safety. Whereas the findings were positive, it should be noted that the acquired data are preliminary and that the simulation environment and scenarios were limited with respect to ATC operations in this mini study.

The specific results of the study clearly show that the subjects preferred the Data Link message preview area in the PVD rather than the CRD display. All subjects felt that Data Link transaction status information should be displayed in a position that does not distract the controller's attention from primary radar data. Furthermore, because the list format of this display may became difficult to monitor when multiple aircraft and services are presented, the subjects indicated that further improvements may be achieved with key transaction data indications in the full data block (FDB). The positive response to Data Link FDB utilization suggests strongly that this function should be included in subsequent evaluations. This capability was not tested, implemented, or evaluated in this mini study.

In general, automated procedures produced lower workload and higher preference ratings than those which required the subjects to manually initiate uplinks and delete completed transactions from the display (see figure ES-1). However, controllers also indicated that a manual option to inhibit automated uplinks per controller action should be available. This inhibit option would control whether a message would be sent to pilot only, NAS computer only, or both. The subjects suggested that it should be

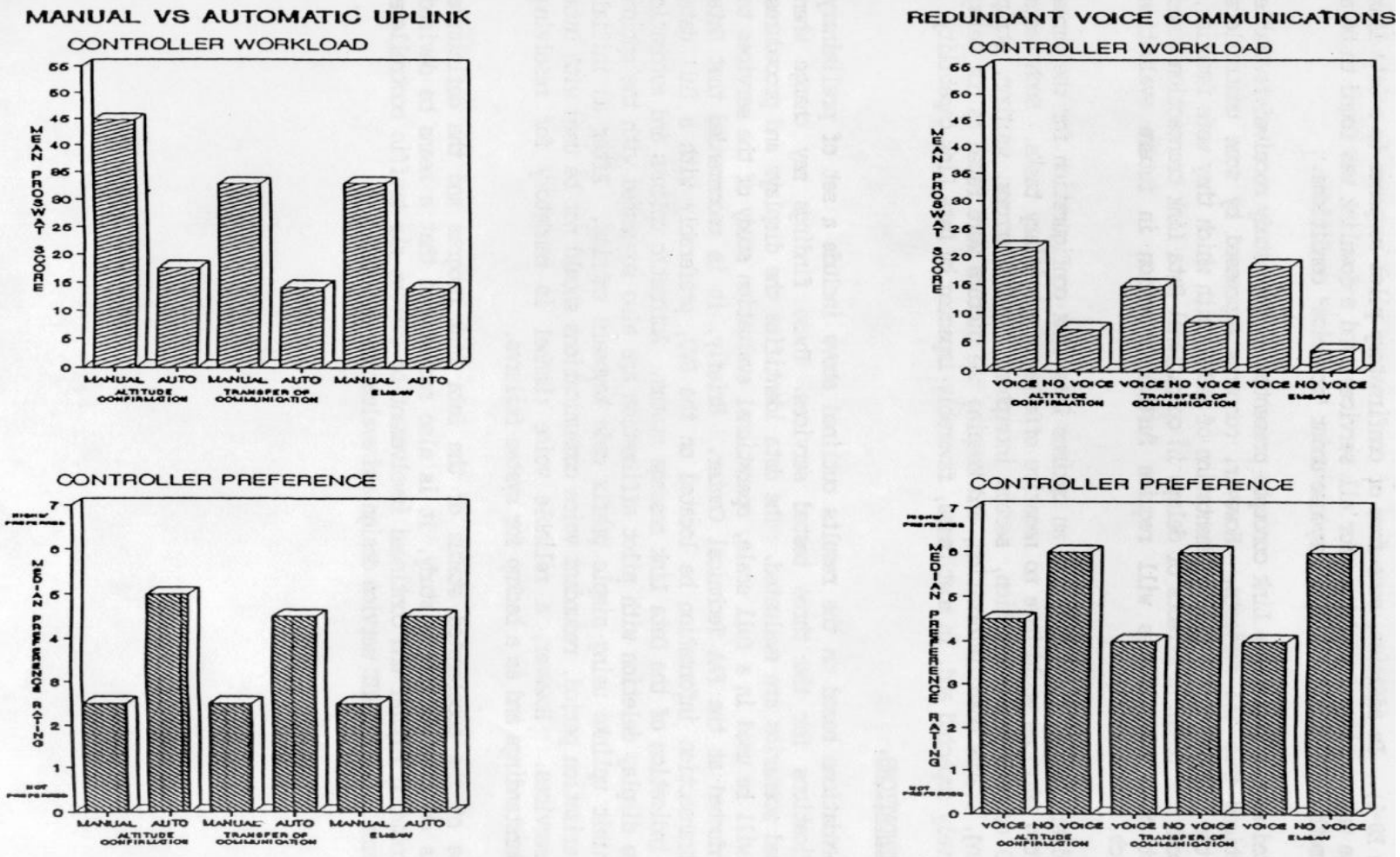

FIGURE ES-1. EFFECTS OF AUTOMATIC PROCEDURES AND ELIMINATION OF REDUNDANT VOICE ON CONTROLLER WORKLOAD AND PREFERENCE

possible to exercise such proactive control over uplinks by sector, service type, and individual transaction.

Although the continued availability of a reliable voice radio channel was considered essential, voice communications between the pilot and controller were redundant with Data Link and were not preferred because of increased workload (see figure ES-l). In addition, some form of confirmatory pilot response to a Data Link message was considered mandatory for all services, and a downlink was found to be a valid method for providing this response under "no voice" conditions.

As noted earlier, the Data Link concepts presented in this study received favorable evaluations from the subjects. However, concerns expressed by some controllers about the reliability of the implementation of EMSAW, with which they were familiar, and about the possible effects of delays in operational Data Link transaction times suggest that these issues will require further attention in future evaluation research.

Controllers judged that utilizing an optimum Data Link configuration for the three evaluated services would have no negative effects on subsidiary tasks. Such tasks as R-D controller coordination, sector interphone, system errors, weather, strip handling, status board information, and keeping the picture were rated as not being negatively impacted and, in most cases, favorably impacted by Data Link capability.

RECOMMENDATIONS.

Recommendations based on the results outlined above include a set of preliminary specifications for the three tested services. These findings may change when enhanced scenarios are evaluated. The data identifies the displays and procedures which will be used in a full scale, operational evaluation study of the services to be conducted at the FAA Technical Center. Briefly, it is recommended that Data Link transaction information be located on the PVD, preferably with a full data block indication of the Data Link message status. Automatic uplinks and automatic message display deletion with pilot affirmation are also suggested with the option to inhibit uplinks using simple prefix code keyboard entries. After an initial familiarization period, redundant voice communications should not be used with Data Link services. However, a reliable voice channel is mandatory for resolving and as a backup for system failures.

Because of the accelerated status of the Data Link program and the definitive results obtained from this study, it is also recommended that a means be devised for providing regular and continued involvement of current air traffic controllers in future Data Link ATC service design and evaluation efforts.

1. INTRODUCTION.

1.1 PURPOSE.

This document presents the results of the first Federal Aviation Administration (FAA) air traffic controller evaluation of en route air traffic control (ATC) services designed for implementation in the Mode S Data Link system. Specifically, this initial study was conducted to evaluate controller procedures and displays for the altitude confirmation, transfer of communications, and En Route Minimum Safe Altitude Warning (EMSAW) services. Controller inputs were also solicited during this study to assess the perceived utility of Data Link and its impact on the ATC system.

1.2 BACKGROUND.

The Mode Select Beacon System (Mode S) is a secondary surveillance radar which will replace the current Air Traffic Control Radar Beacon System (ATCRBS). The ATCRBS a ground-based rotating antenna that transmits continuous radio frequency (RF) interrogations to which a transponder equipped aircraft will respond. The replies provide the ATC system with an aircraft identification code or the aircraft altitude. Aircraft location information is provided by the rotational position of the antenna and the transponder response delay at the time a reply is received.

The Mode S will provide the same functions as the ATCRBS, but will do so more accurately while offering the additional capability of transmitting digital information across a two-way, air-ground Data Link. These enhancements are possible because each aircraft will be assigned a unique address code which will be used in the system's interrogations to select only the requested aircraft to respond. The primary components of the Mode S are illustrated in figure 1.

Because of its flexibility and capacity, the Mode S Data Link promises to be a key to increased automation of the ATC system, and, therefore, has the potential to significantly enhance ATC safety and productivity. One of the primary ways in which this potential will be achieved will be through the impact of Data Link on the tasks of the air traffic controller.

The first service to be provided by Data Link will be automated delivery of weather advisories to aircraft. This function alone will reduce the already burdened controller's task load by eliminating any requirement to verbally relay these data to pilots via voice radio. However, the accelerated Data Link program also calls for the Data Link to mediate a variety of primary ATC services which are currently accomplished in a completely manual fashion using voice radio. The proposed ATC services will include transfer of communications, clearance delivery, inflight plan amendment, and a variety of other interactions among controllers, pilots, and automated systems.

The study reported in this document was conducted as an initial controller evaluation of the first three en route ATC services scheduled for implementation on Data Link. The first service in the initial Data Link package is altitude confirmation. This new service will transmit digital altitude data directly to an aircraft display after a new altitude has been assigned by the controller. The second service tested in this study was transfer of communications. This action is currently accomplished through voice communication between the controller and a pilot following transfer of control between sectors. Using Data Link,

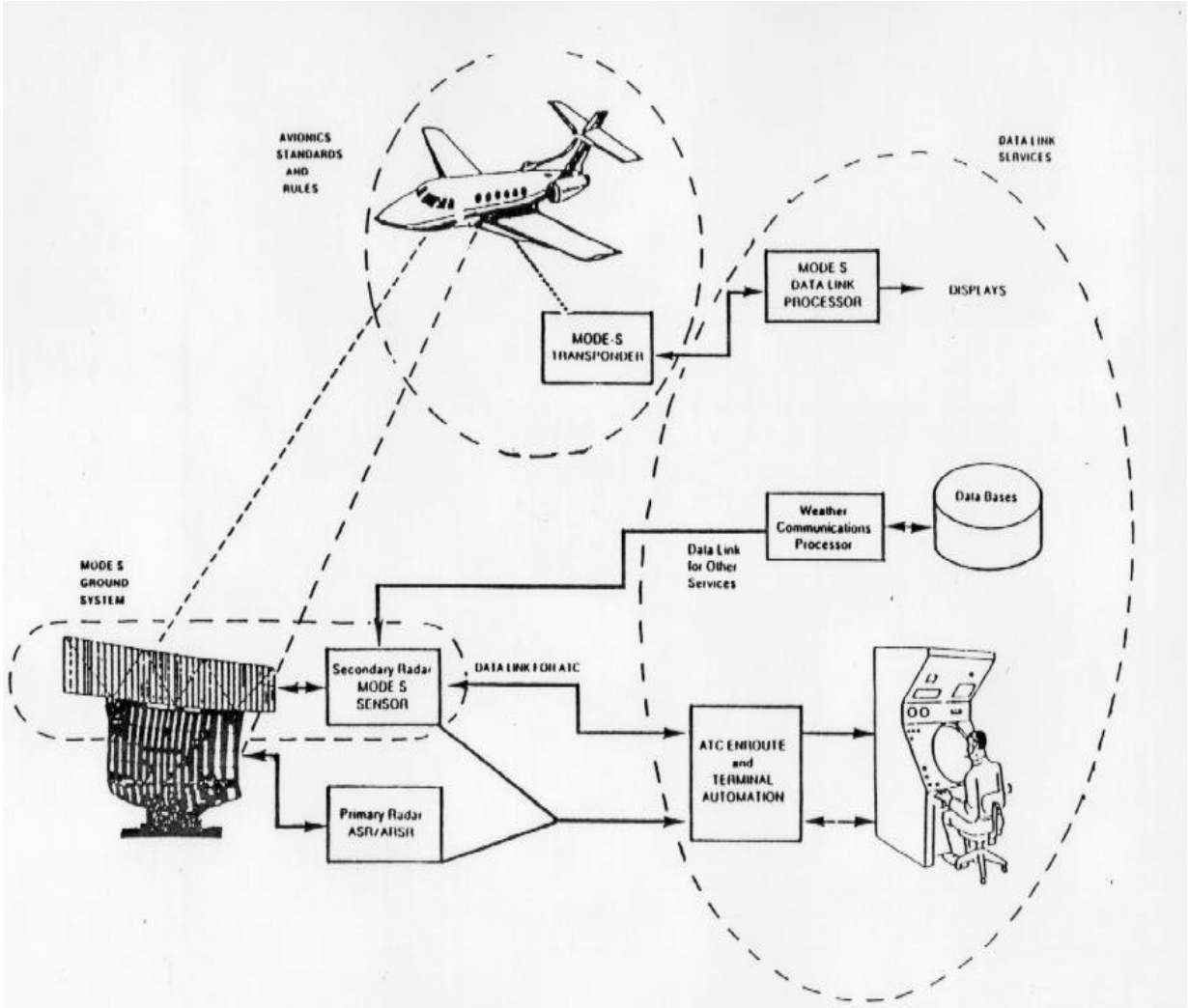

FIGURE 1. MODE S SURVEILLANCE AND DATA LINK

this service will permit the transferring controller to send a digital message to the aircraft in order to inform the pilot of the voice RF on which the receiving controller will be communicating. The final service evaluated in this study is EMSAW. This is a warning service provided to pilots by ATC when it is predicted that predetermined minimum flight altitudes will be violated. Using Data Link, this service will be accomplished by sending the EMSAW message digitally upon detection of a predicted violation, rather than by a voice radio message.

The ultimate success of Data Link and other FAA automation initiatives are critically dependent on the extent to which these technologies are employed to produce a system that is well integrated with the human operators who will be required to control and supervise its function. Because Data Link will profoundly affect the manner in which air traffic controllers accomplish their duties, it is imperative that service delivery procedures, and the displays and controls used to interact with the system, are designed with careful consideration of their impact on the performance capabilities of the controller. The intent of the controller evaluation study reported in this document, and of future studies planned for the program, is to insure that controller workload, performance, and acceptance are used as primary inputs to the development and implementation of the Data Link system.

1.3 DATA LINK TEST BED.

The present study was conducted in the Data Link test bed facility located at the FAA Technical Center. The Data Link test bed was assembled to provide both engineering testing and evaluation capabilities for Data Link services during controller-in-the-loop simulation. Figure 2 presents a functional diagram of the main components of the test bed and their interconnections.

During the simulation study described in this report, the subject controllers operating at National Airspace System (NAS) laboratory work stations were presented with simulated radar data and ATC system information from the Host computer. The voices and Data Link inputs of aircraft pilots were provided by trained test personnel serving as dynamic simulation (DYSIM) pilots. The VAX l1/750 computer generated all Data Link outputs and permitted flexible variation of the procedures used to deliver the services under evaluation.

2. TEST DESCRIPTION.

2 1 OBJECTIVES

The overall test plan for controller evaluation of Data Link ATC services calls for research to achieve two major objectives. First, the evaluation studies must determine the operational procedures and data display methods for each of the subject services. Second, these studies must evaluate the integration of the Data Link services with other controller duties and ensure the acceptability of controller and system performance under operational conditions.

These objectives imply that optimization and validation of Data Link ATC services will require research to address a large number of human factors design variables, as well as the impact of various operational and environmental factors. Because the inclusion of all of these parameters in a single, factorially defined study would result in an unmanageable large test matrix, a two-stage process was developed for the evaluation of Data Link services.

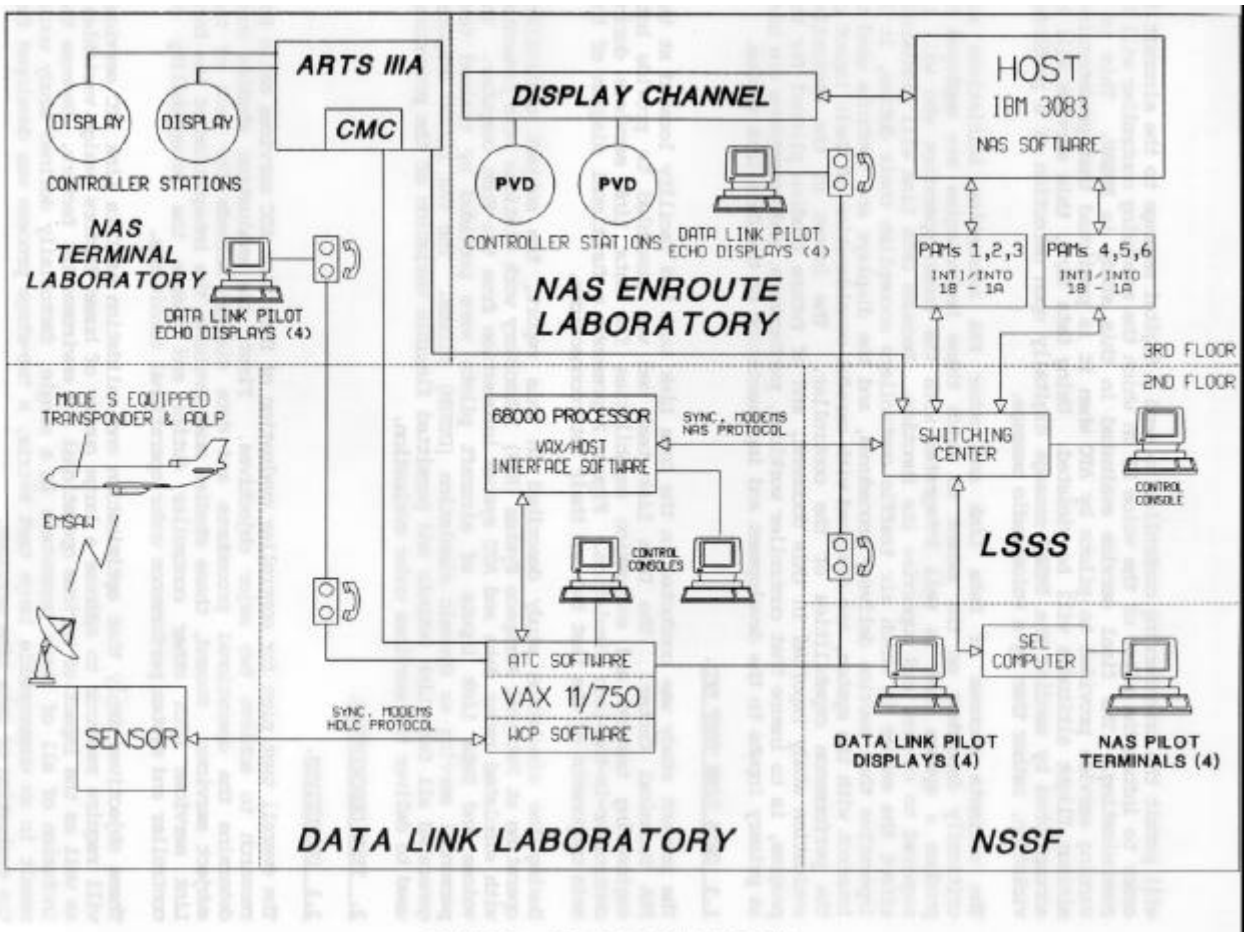

FIGURE 2. ATC DATA LINK TEST BED

In the first stage, highly controlled, part-task simulation studies will be conducted with en route controllers to reduce the number design alternatives to a reasonable set. These "mini" design studies will involve the formal testing of display and procedural options as well as structured interviews designed to elicit expert controller opinions on the operational suitability of the services. The formal criteria for option evaluation will be measures of controller workload and acceptance.

In the second stage of the evaluation process, operational evaluation studies will be performed in the context of full-scale ATC simulation. The specific goal of this stage will be to confirm the optimality of the design of each Data Link service, and to verify the safety and efficiency of Data Link under various operational conditions. Operational evaluation studies will assess overall system effectiveness, performance, and controller workload within en route ATC test scenarios that present both nominal and high levels of controller task demand.

The study reported here is the first mini study performed under the test plan outlined above. The primary objective of this study was to reduce the number of potential procedural and display design options to an acceptable set for use in operational evaluation of the altitude confirmation, transfer of communications, and EMSAW Data Link service. Because this mini study represented the first formal introduction of Data Link to current en route air traffic controllers, a secondary objective of the research was to solicit controller opinions regarding the general utility and operational suitability of the Mode S Data Link.

2.2 TEST APPROACH.

The approach that was adopted to meet the objectives of this mini study involved the participation of a team of 10 en route air traffic controllers in a series of short ATC scenarios at the Data Link test bed work stations. Each of these scenarios required four of the subjects to actively control individual sectors with identical traffic loads. The scenario script in each case contained six altitude assignment tasks, one EMSAW event, and two hand-offs with transfer of communications. The highly standardized and simplified test conditions differed only in the means by which the three subject services were accomplished. These methods consisted of the current approach without Data Link (baseline), as well as variations in the location of the Data Link transaction display and in the controller and pilot actions required to complete a Data Link transaction.

During the test runs, four additional subjects passively observed one of the controlling subjects as he completed the required ATC tasks. Following each run, both the active and passive controllers were asked to rate the projected workload that would be induced by the tested options under operational conditions. In addition, controller preferences for the tested options were elicited after each run using a second rating scale. The formal data were supplemented by group debriefing interviews, a wrap-up questionnaire, and written narrative comments following the testing sessions. The two remaining controllers monitored the formal data collection and participated in the post-test interviews.

The rationale underlying this testing approach was to utilize the rapid reconfiguration capability of the Data Link test bed to efficiently filter-out untenable design options. Using both quantified subjective measures of workload and preference, and less formal interview responses, the object of the study design was to produce an design configuration for each service which would optimize controller acceptance, workload, and operational suitability.

2 3 TEST CONDUCT.

2.3.1 Subjects.

The subjects for this study were 10 current, full performance level (FPL) air traffic controllers from the Dallas/Fort Worth Center. None of the controllers had prior experience with the implementation options for the Mode S Data Link ATC services under investigation. All subjects were volunteers.

Of the 10 controllers, 8 served as subjects in the formal test bed evaluation acting as passive operational observers and active subject controllers. The remaining two subjects observed the test bed data collection on an informal basis, but provided data only in the debriefing interview, wrap-up questionnaire, and final narrative comments.

The eight subjects who participated in the formal testing had an average of 15.7 years experience as FPL air traffic controllers. Four of the subjects had prior experience as aircraft pilots (16 years average). Three of the subjects indicated that they had some preliminary familiarity with the Data link program.

2.3.2 DESCRIPTION OF TEST OPTIONS.

In this study, two basic display location options and five procedural options were prepared for controller evaluation. A sixth procedural option was developed as a result of the debriefing interviews conducted after Day 1 testing. This modified system option was programmed and evaluated during Day 2 testing. All test options which were exercised in the experimental design, discussed later in this report, are described below:

2.3.2.1 Location of the Data Link Transaction Display.

The Data Link system will provide the controller with a list display which permits monitoring of the current status of any ongoing service transaction. In this study, each line on the display provided an indication of the service in progress, the aircraft receiving the service (AID), and the status of the transaction. The following is a list of words displayed to indicate the status of a Data Link transaction:
HELD - Indicated that an uplink was ready for transmission (used only in manual uplink conditions).

SENT - Indicated that an uplink had been initiated.

DELIVERED - Indicated that a valid uplink had been received by the aircraft (technical acknowledgment).

WILCO - A downlink indicating that the pilot had received the message and intended to comply with the instruction or warning.

UNABLE - A downlink indicating that the pilot was unable to comply with the message.

TIMEOUT - A system indication that the pilot had failed to reply to the uplinked message within a fixed time parameter (60 seconds in this study).

Two options for the location of the display were tested:

a. On the Plan View Display (PVD List)

b. On the Radar Position Computer Readout Device (R-CRD List)

2.3.2.2 ATC Data Link Service

Several optional Data Link procedures were used to deliver the three initial services. These differed in the number of overt controller actions (data entries) required to deliver the service, the requirements for voice interactions between the controller and the pilot, and the requirement for downlinked pilot confirmation of service message delivery. The following procedural conditions were prepared for presentation.

2.3.2.2.1 Voice - Full Manual Control - Pilot Response Required.

In this procedure, Data Link entries followed the normal voice communications currently used to assign a new altitude, inform a pilot of the RF for a receiving controller after a hand-off, or warn the pilot of a minimum safe altitude violation. Entry of an altitude amendment to the system, completion of a transfer of control to a new sector or system, and detection of an EMSAW event made the appropriate uplink available for transmission. The controller manually initiated the uplink using a quick action key to designate a Data Link transmission and keyboard inputs or the track ball (PVD only) to identify the appropriate line on the list display.

In all cases, after a technical acknowledgment (DELIVERED status indication) was received from the aircraft, the controller was required to monitor the transaction status display for a WILC0 downlink, indicating that the pilot had received the message and intended to comply. The status line on the Data Link transaction display was cleared by the controller by designating the status line and making a "delete" entry. In the case of the transfer of communications, the display was cleared by the receiving controller after the hand-off was completed by the transferring controller.

2.3.2.2.2 Voice - Full Manual - No Pilot Response Required.

This procedure was identical to that described in 2.3.2.2.1 with the exception that the Data Link activity terminated following receipt of a technical acknowledgment from the aircraft. Thus, the controller was not required to monitor for a WILCO response from the pilot.

2.3.2.2.3 Voice - Automatic Control - Pilot Response Required.

This procedure was identical to that described in 2.3.2.2.1 with the exception that the entry of an altitude amendment, completion of a hand-off between sectors or system detection of an EMSAW event automatically initiated the appropriate uplink. Thus, the controller's task in providing altitude confirmation, EMSAW, and transfer of communication involved no new manual actions compared to the current baseline system other than to delete completed list entries. However, all Data Link transactions continued to be redundant with traditional voice communications, and the controller was required to monitor the transaction display for a WILCO downlink indicating that the Data Link message has been received by the pilot.

2.3.2.2.4 Voice - Automatic Control - No Pilot Response Required.

This procedure was identical to that described in 2.3.2.2.3 with the exception that the Data Link transaction was terminated after receipt of a technical acknowledgment as in 2.3.2.2.2.

2.3.2.2.5 No Voice - Automatic Control - Pilot Response Required.

This version of the procedure eliminated all voice communication between the controller and the pilot. Thus, entry of an altitude amendment, completion of a hand-off, or system detection of an EMSAW event automatically uplinked the appropriate information as in procedures 2.3.2.2.3 and 2.3.2.2.4. However, the uplink was not redundant with a voice contact. Since this redundancy was eliminated, a pilot WILCO downlink was required to inform the controller of pilot response.

2.3.2.2.6 Modified System.

A final procedural condition tested in this study was developed as a result of controller suggestions contributed after testing on the options described above.

This procedure combined features of the automatic and manual procedures and eliminated controller data entries required to delete display list lines for completed transactions. Receipt of a WILCO message automatically deleted list entries. In addition, the transfer of communications procedure was redesigned so that the uplink was under the control of the transferring controller. Transfer of communications messages were also displayed in the Data Link list for both the sending and receiving sectors. Manual control of the transfer of communications uplink was used in order to permit independent control over the hand-off and the transmission of a new RF. Automatic control was used for the altitude confirmation and EMSAW services.

2.3.3 Test Scenario Description.

The test scenario created for this mini study consisted of a highly constrained ATC situation designed to focus on the three services under evaluation. Four separate Universal Data Set (UDS) sectors were simulated, with two sectors involved in high altitude control and two sectors involved in low altitude control. Each sector contained three aircraft moving through its airspace during the 10-minute scenario. Each of the three

aircraft received only one of the three services under evaluation. No other ATC events occurred in the scenario.

The scenario script included six altitude assignment events, one EMSAW event, and two handoffs. Handoff events took place between sectors contained in the overall scenario so that each active controller transferred and received control of two aircraft during a single test run. All transfer of communications and EMSAW Data Link transactions occurred with successful technical acknowledgment and WILCO responses. However, in order to examine the impact of potential variations, only four of the altitude confirmation events proceeded successfully. The remaining two resulted in a system timeout for the pilot response or a pilot "unable" response to the altitude confirmation message. The scripts used to direct controller and pilot activities in each sector are contained in appendix A.

2.3.4 Test Procedures.

This mini study was conducted over a 4-day period. The first 2 days were used for subject familiarization and training, while the last 2 days (Day 1 and Day 2 testing) were used for all data collection.

The first familiarization day was devoted to a 2-hour series of briefings designed to acquaint the subject controllers with the Data Link concept and the test conditions. Individual briefings included: (a) an introduction to the Data Link program and the Data Link test bed, (b) a description of the test scenario and the options to be evaluated for each service, (c) a presentation of Data Link Host operations and the procedures used for interacting with Data Link, and (d) the functions that would be served by various test personnel.

On the second day, the subjects received a briefing on the workload and preference/acceptability rating scales to be used during formal data collection. This 2-hour session included completion of the projected subjective workload assessment technique (PROSWAT) card sort task by each controller. The object of the card sort task was to collect the data required to tailor the quantitative interpretation of workload ratings to the concepts of workload held by individual controllers.

After the card sorting task was completed, the subjects were taken to the Data Link test bed for hands-on training. The 2-hour training session included five practice runs using the scenario constructed for the data collection sessions. The five practice runs were conducted under baseline/current system conditions and under two of the manual and two of the automatic test options.

During Day 1 testing, the two display test options and the first seven procedural options described in section 2.3.2 were combined to produce seven Data Link test conditions. In addition, an option was created as a comparative baseline in which the subjects were required to control the traffic in the test scenario using current procedures. All eight conditions were presented in 10-minute scenarios in the order listed below:

1. Baseline

2. Voice - Manual - Pilot Response Required - PVD Display

3. Voice - Manual - Pilot Response Required - CRD Display

4. Voice - Manual - No Pilot Response

5. Voice - Automatic - Pilot Response Required

6. Voice - Automatic - No Pilot Response

7. No Voice - Automatic - Pilot Response Required

8. Modified System

As shown above, conditions 2 and 3 were procedurally identical in order to permit an unconfounded comparison of the PVD and CRD displays. Conditions 4 through 8 were conducted with the display selected by the controllers after completing conditions 2 and 3. In all cases the subjects chose to perform the last five conditions using the PVD display.

During testing, two controllers were assigned to each of the four sector work stations in the Data Link test bed. One of the controllers actively performed the ATC tasks required in the test script. The second controller acted as a passive operational observer. During the 15-minute periods that elapsed between testing conditions, both the active and passive controllers completed the rating forms for the PROSWAT workload and preference/acceptability scales.

Primary test personnel responsible for the formal data collection included the data link facilitators and the DYSIM pilots. One Data Link facilitator was assigned to each of the four active/passive controller teams. These individuals were responsible for all controller training as well as subject guidance during testing. The subject guidance included explanation of the options to be tested during each condition, using the scenario script to cue the subjects regarding the type of ATC service to be delivered and the time at which it should be delivered during the data collection runs, and aiding the subjects in accomplishing he appropriate procedures.

The four DYSIM pilots acted as simulation pilots during training and testing. They were seated at additional work stations in the test bed which were configured to permit control over the simulated aircraft in the scenarios. One DYSIM pilot was assigned to provide all radio responses and Data Link inputs to each sector.

Following the Day 1 formal data collection, the eight subjects and the two controllers, who informally observed the data collection runs, attended a group debriefing session. This debriefing was structured by presenting the controllers with a series of questions on individual overhead projection slides. Each controller was given a printed copy of the slides in order to record his response and comments. Open discussion of the topics and questions raised in the debriefing was encouraged, and resulted in a group

consensus for a modified test condition to be evaluated during Day 2 formal testing.

On Day 2 of testing, the modified procedural option described in section 2.3.2.2.6 was tested. The modified test condition was run twice in order to permit all eight subjects to actively participate. Each controller completed the workload and preference/acceptability scales for this modified system option after the test run.

In a final debriefing session on Day 2 the subjects completed a wrap-up questionnaire and wrote individual narrative comments on their preferred configurations for the Data Link services.

2.3.5 Data Collection.

Five different instruments were used during this study to acquire data from the subject controllers regarding the tested services and the data link concept: (a) the PROSWAT workload scale, (b) a controller preference/acceptability scale, (c) a group discussion debriefing, (d) a wrap-up questionnaire, and (e) a written narrative description of the preferred system configuration.
Formal data collection on the Data Link test bed was conducted using the PROSWAT workload scale and a preference/acceptability scale. Following each test run the subjects were asked to project the workload that would be experienced for each service on a moderately busy work day if the display and procedural option were used. The PROSWAT technique used by the controllers to rate the projected workload required them to check the appropriate descriptor on each of three, 3-point scales. The individual scales refer to time load, the level of mental effort required, and the degree of psychological stress experienced. A sample of the form used to make the PROSWAT ratings and a complete scale with formal descriptions of each level are contained in appendix B.

The three ordinal level ratings obtained from a subject for each service were transformed to a single interval value ranging from 0 to 100 on a combined workload scale. The mapping of the time, effort, and stress ratings to the combined scale was determined through conjoint measurement and scaling analysis of the PROSWAT card sorts performed by the test subjects prior to data collection. A description of the conjoint scaling method and a copy of the instructions used to guide the controller subjects in the card sorting task are included in appendix B.

After completing the PROSWAT ratings for each test option, the subjects were also required to rate the acceptability of each test option. The form used to make these ratings is also contained in appendix B.

This form actually required the subjects to make two ratings. First, the controller judged whether or not an option was acceptable in terms of ATC safety and efficiency. If the option was rated "completely unacceptable" for any service, the rating was terminated. However, if the option was acceptable, the controller provided a preference rating on a 7-point scale ranging from 1 (highly preferred) to 7 (acceptable, but not preferred). The data collection booklet in which the rating scales were bound, provided space for the controller to write brief comments explaining the rationale underlying each preference/acceptability rating. Instructions to subjects

for using the preference/ acceptability scales emphasized that the PROSWAT and preference ratings should be made independently since the two dimensions are not necessarily correlated.

The remaining three assessment instruments used in this mini study were employed during the debriefing sessions which followed the formal data collection in the test bed. On Day 1 of testing, the debriefing was conducted in a group discussion format. The session was structured using a series of overhead projection slides (see appendix C). Each slide contained a single question for group discussion. The controllers were supplied with printed copies of the slides in order to record individual comments.

The topics covered in the debriefing slides included specific questions about the services under evaluation, the effects of operational variations on the selection of appropriate procedures, preferred displays and procedures, and general issues related to the utility of the Data Link concept.

The last two measurement techniques were employed during the debriefing session which followed Day 2 testing. The first part of this session was devoted to the completion of a wrap-up questionnaire. The questionnaire covered issues relating to the adequacy of the simulation and controller measures, the operational value of the service displays and procedures tested, the effects of Data Link on various aspects of controller performance, and suggested future services for implementation on Data Link. A copy of the wrap-up questionnaire is contained in appendix D.

During the Day 2 debriefing session, each controller was asked to write a final narrative description of his preferred design for each service. The purpose of this exercise was to capture any individual comments and suggestions that might not have been elicited during the previous day's group format discussions.

2.3.6 Data Reduction and Analysis.

Ratings of controller workload and preference/acceptability were analyzed using standard tests of statistical significance appropriate to the measurement scale characteristics of the data collected. Because of the interval scale nature of the PROSWAT scores, these data were analyzed using parametric tests. All option combinations were compared using a single factor, repeated measures analysis of variance (ANOVA). One ANOVA was run for each of the three services to evaluate overall significance of differences in projected workload produced by the test conditions. Post-hoc student's t tests for correlated samples were used to evaluate the significance of individual and combined group mean differences relevant to the design issues under investigation.

Since the preference/acceptability rating data had ordinal scale characteristics, they were treated using nonparametric methods. Overall significance tests were performed using the Friedman Two-Way Analysis of Variance by Ranks. Post-hoc nonparametric comparisons equivalent to the workload t tests were performed using Wilcoxon's test.

The 7-point rating data obtained from a portion of the wrap-up questionnaire were evaluated using a Student's t procedure designed to evaluate the significance of differences in ratings from the scale midpoint and from the grand mean ratings.

All remaining questionnaire and narrative responses obtained for the preference comments and from the debriefing sessions were summarized to provide concise descriptions of the types and frequency of occurrence for each comment received. In all cases, the goal of these descriptive analyses was to determine the strength and direction of controller opinions regarding the study issues.

3. TEST RESULTS.

The detailed results obtained with each of the measurement methods employed in this mini study are contained in Volume II of this report. The analyses of the PROSWAT card sorts and the results for the PROSWAT workload and preference/acceptability ratings are presented in appendix E. The analysis of the Day 1 group debriefing results are presented in appendix C. Appendix F contains the analyses for the wrap-up questionnaire and appendix G presents a summary of the final written narrative comments.

This section of the report draws upon the contents of all of the detailed results to address the findings which are pertinent to each of the following topics.

3.1 SPECIFIC RESULTS REGARDING THE DESIGN OF THE THREE INITIAL ATC SERVICES.

3.1.1 Data Link Controller Displays.

The combined assessment methods used in this study provided consistent results regarding the appropriate transaction display for the tested services. As shown in figure 3, mean PROSWAT workload scores were lower for the PVD display than with the peripheral CRD display for the altitude confirmation and transfer of communication services. No effect of display location on controller workload was apparent for EMSAW.

While the PROSWAT workload differences for all three services were not statistically significant, the preference ratings showed a statistically significant preference for the PVD list in all three services (see figure 4). Analysis of controller comments regarding their preference ratings indicated that all eight subjects felt the PVD list was superior because the CRD list distracted a controller's attention from the primary ATC display. The subjects also noted that the CRD list was not accessible by trackball inputs, would produce congestion on this display, or would make it unavailable for presentation of aircraft beacon codes.

Results from the Day 1 group debriefing, the wrap-up questionnaire, and the final narrative comments fully supported the overwhelming subject preference for displaying primary Data Link information on the PVD list. However, analyses of these results also indicated a strong controller preference for further enhancement of Data Link displays. General preference comments on the tested displays expressed a concern that the list format display may become difficult to monitor and interpret when multiple aircraft and services are represented. Furthermore, these comments indicated that the list display may detract the controller's attention from the principal aircraft radar data on the PVD.

Subject's suggestions for alleviating these problems were derived from comments obtained during both debriefing sessions. The final narrative comments indicated that a majority of the controllers would prefer same form of Data Link transaction display in the data blocks on the PVD. Such a display could take the form of a single character code timesharing with other data block information that would indicate the status of a particular service transaction (e.g., “W” for WILCO). Although no controllers indicated that all Data Link transaction data should be presented in the data block, the general consensus appeared to be that for the type of services tested in this study, the data block should be used for ensuring that messages have been transmitted and received by the appropriate aircraft. Alternate PVD list displays may be preferable for noncritical pilot downlinks and Data Link menus.

3.1.2 Controller Procedures for Altitude Confirmation Transfer of Communications and EMSAW.

The results for the options tested in this study yielded a strong level of agreement regarding the most suitable procedures for providing all three tested services. The largest measured impact on controller workload that was detected during the tests was produced by comparisons between the manual and automatic options (see figure 5). PROSWAT workload scores were

significantly higher in the manual uplink versions of the procedure than in the automatic versions. All three services were also more highly preferred when the automatic mode was used (figure 6).

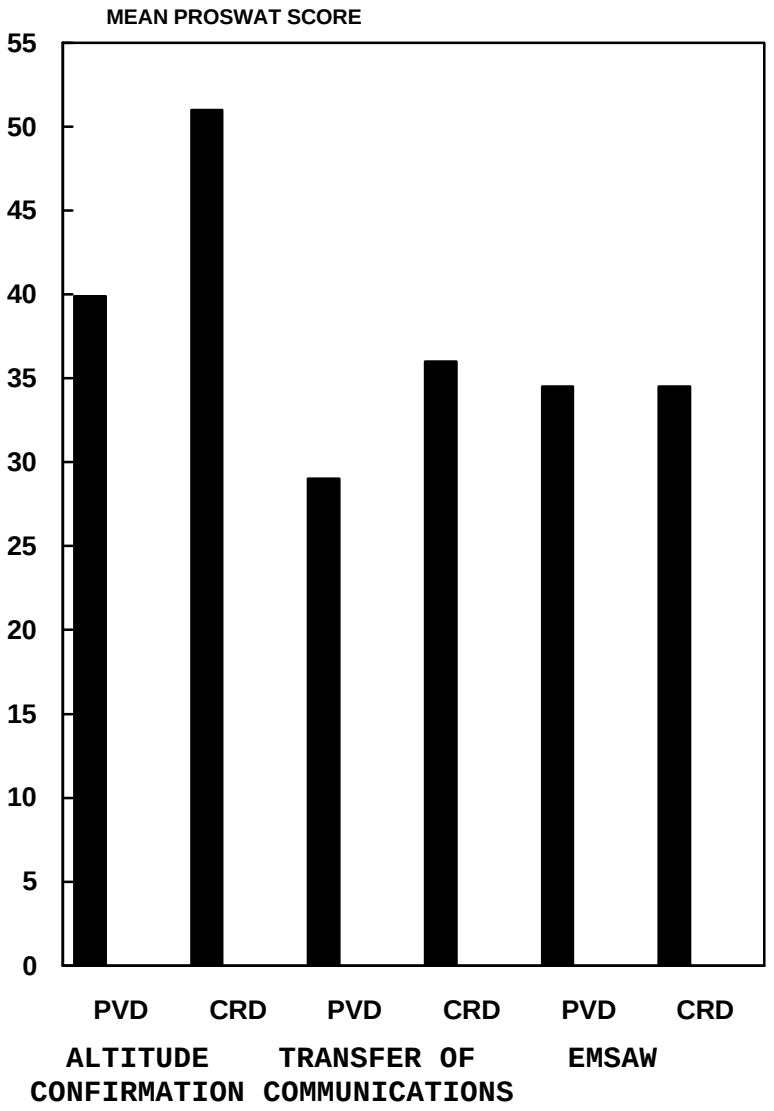

FIGURE 3. DATA LINK CONTROLLER WORKLOAD DISPLAY LOCATION

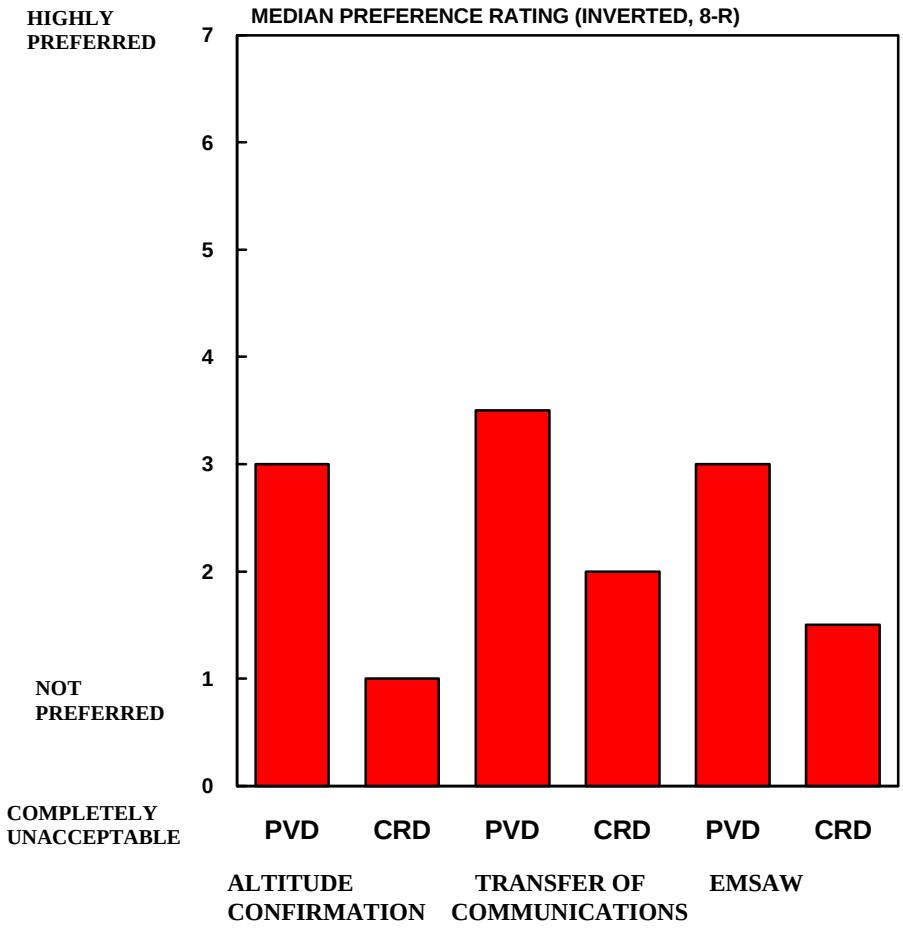

FIGURE 4. DATA LINK CONTROLLER PREFERENCE DISPLAY LOCATION

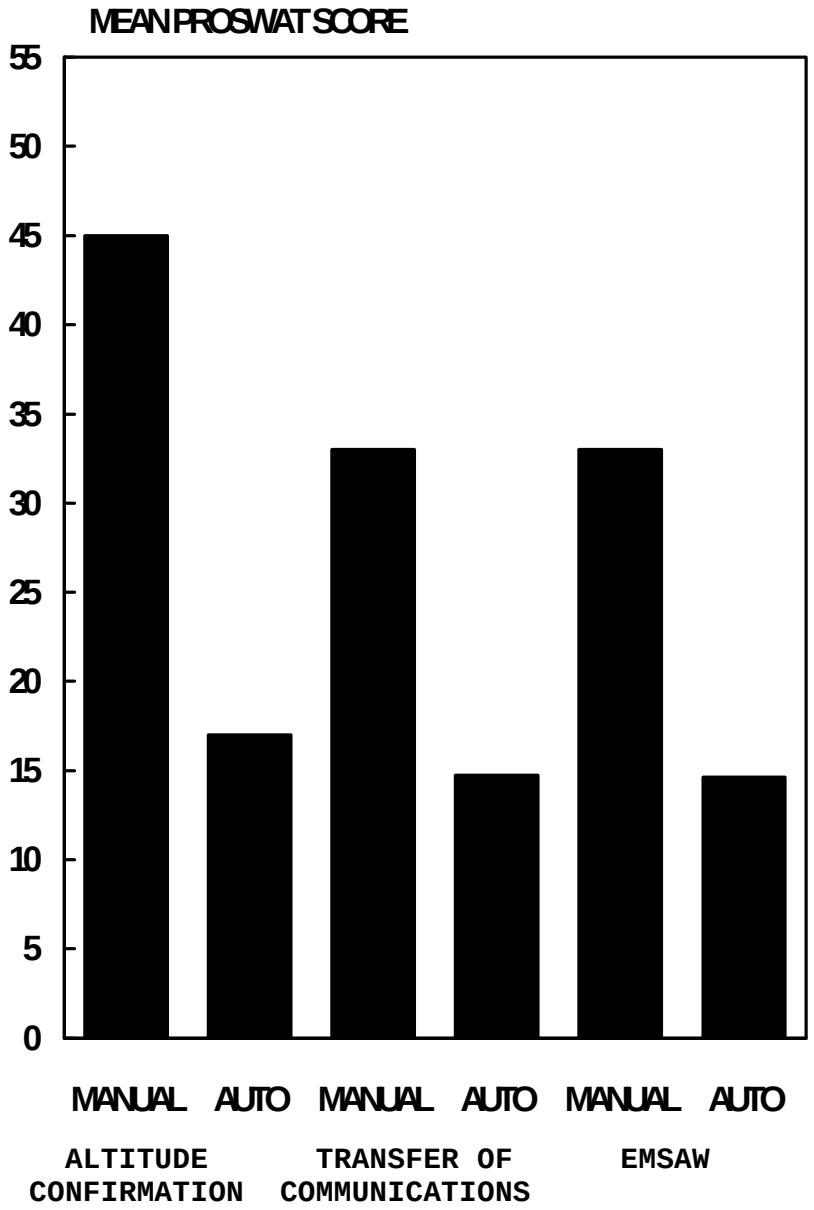

FIGURE 5. DATA LINK CONTROLLER WORKLOAD, MANUAL VS. AUTOMATIC UPLINK

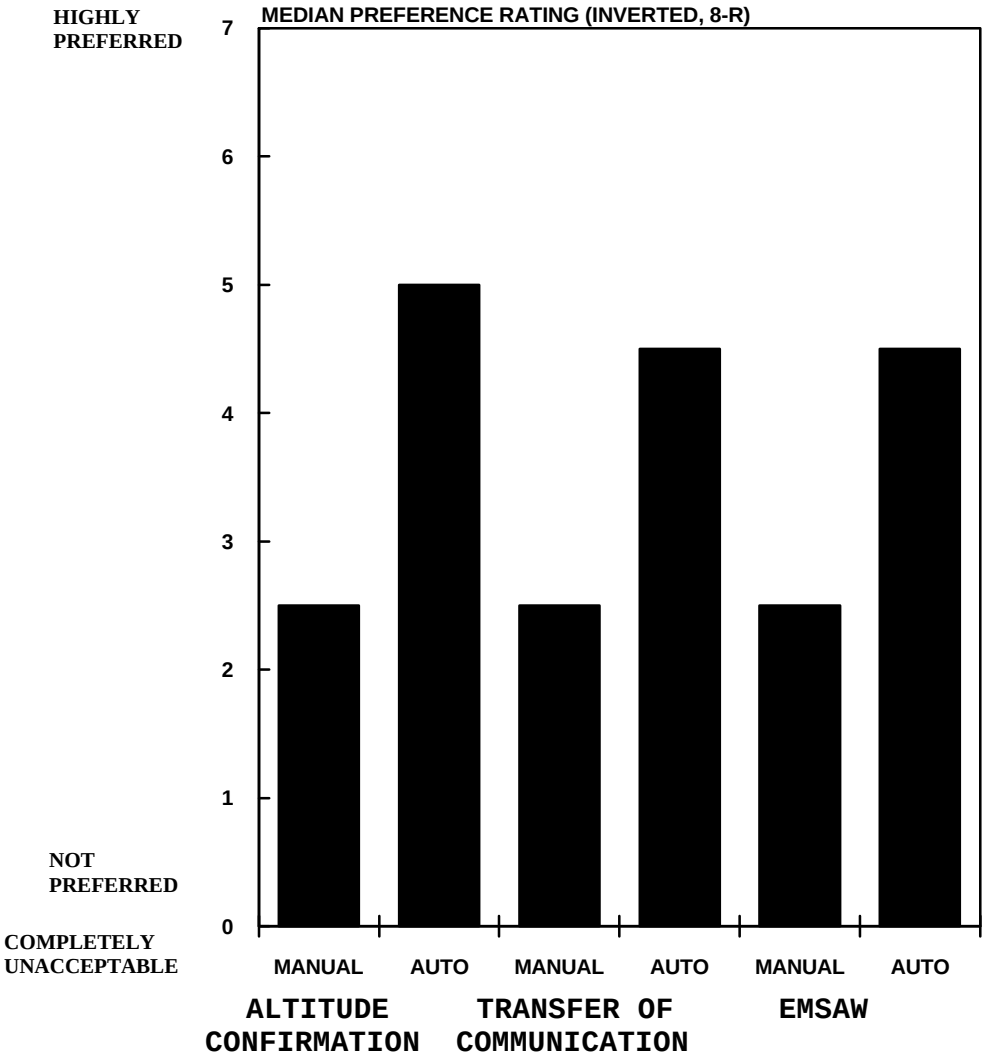

FIGURE 6. DATA LINK CONTROLLER PREFERENCE, MANUAL VS. AUTOMATIC UPLINK

The preference comments indicated that the effect of automation was primarily due to the difference in data entry requirements for the two versions. Additional improvements in workload and preference were gained when these keyboard entries were reduced even further in the modified system option evaluated on Day 2 of testing. In this case, both the data entry required to designate and send an uplink and the entries necessary to delete completed transaction lines from the display were reduced.

Analysis of subject comments from the debriefing sessions showed that although the automatic uplink was preferred for all services, the system should be enhanced by permitting controllers to gain additional control over the initiation of an uplink. The most common suggestion for providing this control was an "inhibit" function. In this case, the uplink would be automatic unless the controller entered a single character prefix to an altitude amendment or hand-off computer entry which would hold the message for future uplink. Other suggestions included a set of single character entries which would send data to the NAS only, to the NAS and the pilot, or to the pilot only. The uplink inhibit function was considered necessary by most controllers in order to permit handling of delayed transfer of communication after a hand-off.

Controller workload and preference were also enhanced for all three services when the procedures were conducted without voice communications between the pilot and the controller, which were redundant with a Data Link transaction. As shown in figure 7, PROSWAT workload scores were consistently higher in the voice test conditions. This effect was highly significant for the altitude confirmation service, and similar trends were observed for the other services. The preference ratings were significantly higher for the no voice conditions in all cases (figure 8).

Preference comments and debriefing indicated that normal Data Link transactions should be conducted without voice after an initial transition period.

The requirement for a downlinked pilot response in the Data Link procedure for the three services had an equivocal effect on controller workload and preference. No statistically significant effect of requiring the downlinked confirmation on controller workload was detected in conditions where the response was redundant with a voice communication. The preference data indicated a slight controller bias for the no response option in these conditions. However, this was statistically significant only in the automatic version of the EMSAW service.

When assessed in reference to the clearly superior ratings assigned to all no voice conditions, these nonsignificant findings appear to indicate only that some type of pilot confirmation is required, either by voice or Data Link, and that a data linked response is both acceptable and preferable. This conclusion was confirmed by controller responses to the debriefing interview. All nine of the responding subjects indicated that a downlink would be a preferable method for confirming the receipt of a Data Link message.

The optimality of the procedures suggested by the data reviewed above was confirmed by comparing the workload and preference scores

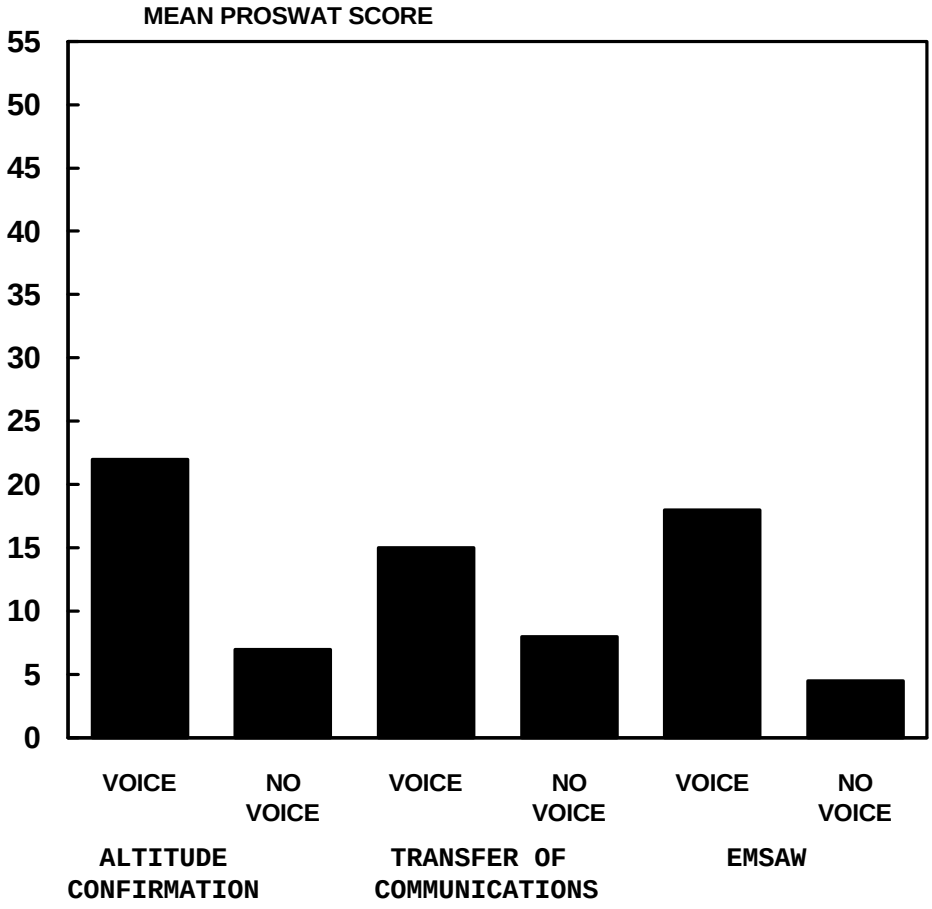

FIGURE 7. DATA LINK CONTROLLER WORKLOAD, REDUNDANT VOICE COMMUNICATIONS

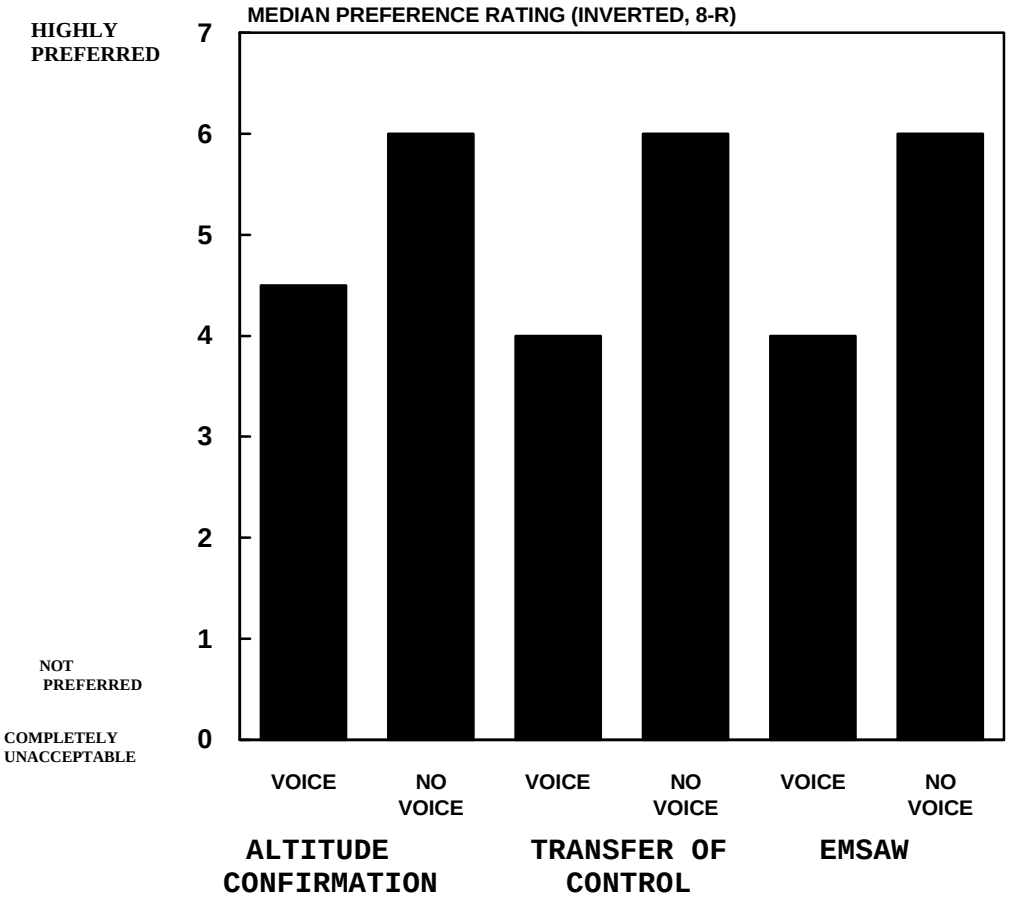

FIGURE 8. DATA LINK CONTROLLER PREFERENCE, REDUNDANT VOICE COMMUNICATIONS

preferred configuration produced the highest preference scores and the lowest projected workload estimates.

Although the subject controllers selected identical optimum displays and procedures for the three services tested, noteworthy comments regarding the design of the individual services were elicited in the debriefing session. In particular, the controllers indicated that the transfer of communications service must present Data Link displays to both the transferring and receiving controllers, and that the uplink of the new RF should be under control of the transferring controller only.

The subjects also frequently commented that the EMSAW service was a cause for concern. The source of this concern was primarily the implementation of EMSAW with which they were familiar. The controllers argued that this implementation produced a high false alarm rate. In addition, they felt that the use of Data Link for EMSAW should be further investigated with controllers from en route centers which contain more terrain obstacles than the Dallas/Fort Worth area.

3.2 GENERAL RESULTS ON DATA LINK.

3.2.1 Data Link Utility and Impact on ATC.

In general, the subject controllers expressed a strongly positive opinion about the potential effects of the Mode S Data Link, both on the controller's task load and on the overall effectiveness of the ATC system. Results obtained from the wrap-up questionnaire indicated that, if optimally configured, Data Link would have overwhelmingly positive effects on workload, system capacity, communications, and overall safety. Specific positive aspects of Data Link mentioned by the controllers in the debriefing discussion included reduction of voice congestion and reduction in workload.

The final narrative comments elicited at the end of the study confirmed the high level of acceptance for Data Link. A significant majority of the subjects independently noted that Data Link will enhance the ATC system.

Very few negative comments regarding Data Link were generated during the post-ons. In particular, these controllers felt that the operational version of Data Link will have to operate in a reliably rapid fashion in order to support critical positive control services.

3.2.2 Automatic vs. Manual Uplinks.

As described in section 3.1.2, automatic uplinks produced significantly lower workload and higher preference ratings for the three tested services. The general consensus of controller remarks in the preference comments, debriefing interviews, and questionnaires was that Data Link service should be provided in an automatic fashion as a default condition. However, they also agreed that, although manual data entries should be minimized, it will be essential to permit manual inhibition of uplinks. Most of the subjects suggested that this be accomplished by a single character prefix to a transfer of control or altitude assignment NAS entry which would inhibit the uplink until released by a second entry.

The lack of preference for automatic uplinks of EMSAW expressed by some subjects appears to have been the result of a concern over the perceived reliability of the current EMSAW function rather than any problem with Data Link.

In general, the subjects indicated that workload reduction with Data Link services will be accomplished only if the system permits flexible operation with the minimal number of controller inputs to send data and manage the list of Data Link transactions.

3.2.3 Treatment of Pilot Responses.

Although the results of the workload and preference ratings revealed only a minimal impact of requiring pilots to confirm the receipt of a message using an overt downlink, it should be noted that the comparison of the pilot response and no response conditions was possible only in cases where the downlink was redundant with pilot voice confirmation. Both conditions in which the services were delivered automatically without voice were judged preferable by the controllers, and the downlinked WILCO was considered a valid method of confirming message receipt.

The debriefing interviews and preference comments did, however, suggest that the TIMEOUT and UNABLE messages may be inappropriate labels for Data Link pilot responses. In the case of a TIMEOUT, controllers felt that the verbiage was unclear, and that NO REPLY would be a better indicator of a pilot's failure to promptly acknowledge an uplink. The UNABLE downlink from a pilot was also considered inappropriate since this type of response to a positive control instruction would not be acceptable in operational settings. In both of the situations, the controllers felt that the most appropriate status indicator would be a salient display of the terms CALL or VERIFY.

3.2.4 Voice in Conjunction with Data Link.

The workload and preference data collected during this study clearly show that the subject controllers felt that the optimal Data Link system should operate under normal conditions without redundant voice communications. However, the debriefing data also indicated that Data Link will continue to require a reliable voice communications system as a backup. A majority of the controllers noted that voice will be essential to deal with Data Link problems, excessive delays, pilot confirmation failures, and misunderstandings.

In general, the majority of controller responses to the group debriefing indicated that the future ATC system would be best operated under a system in which Data Link is the primary mode for most messages or in which Data Link and voice are assigned to different types of communications tasks. Furthermore, the subjects agreed that, after a familiarization period, redundant voice and Data Link transmissions would defeat the primary advantages of workload reduction and productivity enhancement that are offered by the Data Link system.

3.2.5 Additional Candidate Services.

The wrap-up questionnaire and final narrative comments solicited suggestions from the controllers regarding additional services that could be advantageously implemented on Data Link. The following is an abbreviated list of the most commonly suggested services:

a. Downlink of indicated airspeed, mach number, groundspeed, and heading.

b. Uplink of turns (vectors).

c. Uplink of field 10 (route) amendments.

d. Coded standard route and altitude assignments common to a sector.

3.3 EVALUATION OF MINI STUDY TEST ADEQUACY.

The wrap-up questionnaire and final discussions also gave the subjects an opportunity to evaluate the utility of the mini study and the procedures used during the test conduct. These comments are summarized below.

3.3.1 Training and Simulation Quality.

Subject comments regarding the type and adequacy of the mini study training were positive. Both the preliminary briefings and the test bed lab training were considered useful. Recognizing that the intent of the study was to provide an austere simulation which focused on Data Link procedures, the mean subject rating of the realism of the simulation as "good." None of the subjects rated the simulation as lower than "fair."

3.3.2 Value of the Mini Study.

The final narrative comments and an open discussion conducted at the end of the test provided a number of general inputs from the subject controllers regarding the approach underlying the mini study and directions for future work. Several comments were received that indicated that the subjects regarded the study as an important opportunity to make inputs to the design of Data Link services. Several controllers noted that because of its significance, Data Link should have a controller evaluation team assigned to the program in order to facilitate further development.

Finally, when asked specifically about the value of the mini study format, the controllers strongly agreed that the hands-on evaluation of service options permitted them to make expert judgments about the Data Link design that would not have been possible using descriptive materials or their prior knowledge of the system.

4. CONCLUSIONS

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The results of the study presented in this report warrant a number of specific and general conclusions about the Data Link program and the design of the three Air Traffic Control (ATC) services that were investigated:

a. The Mode S Data Link system was perceived by the subject controllers as an extremely positive enhancement to the ATC system. The implementation of Data Link services can be expected to reduce controller workload and voice frequency congestion while increasing system capacity, safety, and efficiency.

b. Data Link displays for the three ATC service tested in this study should be centrally located and easily interpreted. In comparison to the Computer Readout Device (CRD) list, the Plan View Display (PVD) list tested in this study was preferred by controllers for display of the status of Data Link transactions. Further improvement would be achieved with the display of critical transaction status information in the full data block.

c. The specific findings of the study indicate that controller workload will be reduced and acceptability enhanced using procedures which minimize the number of data entries required to accomplish Data Link transactions. Current controller inputs and system events should be used to generate Data Link messages, and status displays should be automatically deleted upon completion of a Data Link transaction. As few keyboard inputs as possible should be used to transmit and manage Data Link services.

d. Automatic message uplinks produced lower workload and were more preferable to the controllers who participated in this study. However, a clear majority of the subjects indicated that automatic uplinks should be a default condition. The system must permit the controller to inhibit automatic uplinks. This could be accomplished with a single character keyboard input as a prefix to a system altitude change or transfer of control entry. Alternatively, a set of prefix codes could be used to determine the destination(s) for any entry (e.g., NAS only, NAS and aircraft, pilot only).

e. Voice radio communications which are redundant with Data Link transactions are neither necessary nor desirable after an initial familiarization period. However, a reliable voice link must be maintained in parallel with Data Link for emergencies and for resolving misunderstandings.

f. A downlinked pilot response is essential when voice communications are eliminated from Data Lank transactions. Unambiguous aircraft and pilot should be used to indicate compliance, Data Link failure, or misunderstandings. Voice communications should be used to resolve transactions which do not result in a pilot WILCO.

g. The subject controllers were least certain about appropriate methods for providing the EMSAW service via Data Link. EMSAW accuracy and reliability issues produced some objections to automatic uplink of this service.

h. Data Link transaction time and time variability was a concern to some of the subject controllers. Positive ATC functions will require contact with an aircraft and a definitive, easily interpreted response within a time period that is comparable to current voice communications.

i. The subject controllers concurred that the approach and assessment methods employed in the mini study format were appropriate and valid for

achieving the research goals of identifying a minimized set of acceptable design options for the operational evaluation stage of the Data Link program.

j. The results of this study were positive, highly definitive, and were not fully predictable prior to the start of data collection. In addition, rapid reconfiguration of the Data Link test bed ,made it possible to design and test procedures based on controller inputs that were provided within the context of the study. This resulted in significant progress toward the definition of useful controller procedures that might not have been achieved under other circumstances. For these reasons, it is essential that continued, regular involvement of field controllers be an integral part of the accelerated Data Link development effort.

5. RECOMMENDATIONS.

The results and conclusions of this study are the basis for the recommendations listed below. These recommendations are intended to guide preliminary controller procedure and interface designs for the initial package of Data Link Air Traffic Control (ATC) services, and to identify issues and approaches relevant to the conduct of future controller evaluation research on Data Link applications.

a. The findings of this mini study indicate that the altitude confirmation, transfer of communications, and En Route Minimum Safe Altitude Warning (EMSAW) services should be configured according to the following general specifications for the full scale operational evaluation study:

1. The Data Link transaction list display should be located on the Plan View Display (PVD). It is also strongly recommended that a display of the current status of each transaction be placed in the full data block. This single character code may be time shared with other data block information and should indicate the availability of a message for uplink as well as the occurrence of a confirmatory or failed response. Acceptable coding characters and locations for this display in the data block are contained in the appendixes describing the detailed results of this report.

2. Data Link messages should be prepared automatically and transaction list entries should be deleted automatically following a successful uplink and pilot confirmation. In addition to providing track ball access, list entries should be labeled by single character codes to enable designation of an entry with a single key stroke.

3. Uplinks should be automatic unless a prefix code is used when entering an altitude or completing a hand-off to inhibit the uplink. Controller suggestions for these prefix codes are contained in the detailed results.

4. Because of remaining questions regarding the EMSAW service, both automatic and manual uplinks should be available as test options in the operational evaluation study.

5. After an initial familiarization period, redundant voice radio communications should not be used. However, specific protocols regarding the use of voice should be developed to standardize the resolution of emergency system failures and failed up/downlinks. These should specify the conditions under which a message should be retransmitted using Data Link and those in which an immediate voice radio contact should be made.

6. Downlinked pilot response should be mandatory for each service.

7. The transfer of communications service should display transaction status information to both the transferring and receiving controllers. However, the service transmission should be under the exclusive control of the transferring sector.

b. Additional inputs from en route controllers are recommended to resolve questions regarding the implementation of EMSAW on Data Link. Specifically, controllers should be consulted who operate from centers covering mountainous terrain.

c. Because of the accelerated status of the program and the valuable data which were collected in the current study, it is recommended that a national team of air traffic controllers be appointed for continued input to Data Link controller design and evaluation efforts.