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Human Factors Recommendations for Airborne Controller-Pilot Data Link Communications (CPDLC) Systems: A Synthesis of Research Results and Literature

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June 1997

DOT/FAA/CT-TN97/6

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U.S. Department of Transportation
Federal Aviation Administration
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

NOTICE

Technical Report Documentation Page

1. Report No. DOT/FAA/CT-TN97/6	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle HUMAN FACTORS RECOMMENDATIONS FOR AIRBORNE CONTROLLER-PILOT DATA LINK COMMUNICATIONS (CPDLS) SYSTEMS: A SYNTHESIS OF RESEARCH RESULTS AND LITERATURE		5. Report Date June 1997 6. Performing Organization Code ACT-350
7. Author(s) Albert Rehmann, ACT-350; Crew System Ergonomics Information Analysis Center (CSERIAC)		8. Performing Organization Report No. DOT/FAA/CT-TN97/6
9. Performing Organization Name and Address U.S. Department of Transportation Federal Aviation Administration William J. Hughes Technical Center Atlantic City International Airport, NJ 08405		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration William J. Hughes Technical Center Atlantic City International Airport, N.J. 08405		13. Type of Report and Period Covered TECHNICAL NOTE 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This document provides a synthesis of research results and literature culminating in specific human factors recommendations for Controller-Pilot Data Link Communications (CPDLC) systems. The report concentrates on two major human factors top areas; system operability, and system implementation. System operability includes issues such as display location, crew alerting, and message formatting, etc. System implementation includes issues such as situation awareness/party line, airspace environment, mixed modality communications, etc.

The findings provide a synthesis of past Data Link research and specifically address the work performed by or supported by the Technical Center's Airborne Data Link Group (ADLG) over the past several years. The goal of the Technical Center's research is to support rulemaking, certification, and the testing of air traffic control (ATC) systems in end-to-end environments.

17. Key Words Data Link Flight Information Services (FIS) General Aviation (GA)		18. Distribution Statement This document is available to the public through the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 92	22. Price

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

FOREWORD

This report documents a portion of the work performed by Crew System Ergonomics Information Analysis Center (CSERIAC) on the task titled "Federal Aviation Administration (FAA) Technical Center Task 1." The task was a provision of an Interagency Agreement between the Federal Aviation Administration Technical Center (Department of Transportation (DOT)), and the Defense Technical Information Center (DTIC). It was conducted under Department of Defense (DOD) Contract Number SPO900-94-D-0001, and the CSERIAC Task Number was 93700-11. The CSERIAC Program Manager was Mr. Don Dreesbach. The CSERIAC Task Leader was Mr. Michael C. Reynolds. The Federal Aviation Administration William J. Hughes Technical Center (FAA Technical Center) Technical Program Manager (TPM) was Mr. Albert J. Rehmann, and the FAA Technical Center project engineer was Mr. Pocholo Bravo.

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EXECUTIVE SUMMARY

This document provides a synthesis of research results and literature culminating in specific human factors recommendations for Controller-Pilot Data Link Communications (CPDLC) systems. The report concentrates on two major human factors topic areas; system operability, and system implementation. System operability includes issues such as display location, crew alerting, and message formatting, etc. System implementation includes issues such as situation awareness/party line, airspace environment, mixed modality communications, etc. The following briefly introduces the issues and presents the recommendations that were developed based on the results from the research investigated.

SYSTEM OPERABILITY ISSUES.

System Location

Background: Over 2,500 aircraft in the fleet now use Interactive Display Unit (IDU) for Airborne Collision Avoidance Radar System (ACARS), the majority located in the aft position. Airlines may drive the use of these displays for air traffic control (ATC) Data Link.

Issue: Economics versus safety implications of optimum placement.

Recommendations:

1. The Data Link display used for ATC tactical messages should be located in the pilot's forward field of view.

2. An aft-mounted Data Link display should not be used for ATC tactical messages.

Refer to the System Location section or the Conclusions and Recommendations section for more details and an examination of the research considered when making these recommendations.

Crew Alerting

Background: Aviation Safety Reporting System (ASRS) analysis revealed six crew alerting problem areas, e.g., nondistinguishable alerts. Longer term exposure to ATC Data Link may result in conditioning in that alerting severity is reduced.

Issue: Definition of minimum alerting requirements; modality, characteristics, etc.

Recommendations:

1. A distinct aural alert should be utilized for ATC Data Link message alerting.
2. Investigate candidate distinct aural alerts for ATC Data Link crew alerting.

Refer to the Crew Alerting section or the Conclusions and Recommendations section for more details and an examination of the research considered when making these recommendations.

Display/Message Format

Background: Past research has found that crew acceptance of ATC Data Link has a high sensitivity to the display page formats and menu tree structures.

Issue: Definition of minimum design standards to provide overall standardization, clarity/structure, etc.

Recommendations:

1. ATC Data Link should have one standard message set for the operations and services that are scheduled to be provided.

2. Feedback should be provided for each user input into an ATC Data Link display.

3. ATC Data Link Control Display Unit (CDU) display should have a smart menu structure that reduces the necessary number of keystrokes and page selection through automation.

Refer to the Display/Message Format section or the Conclusions and Recommendations section for more details and an examination of the research considered when making these recommendations.

Input/Output

Background: Fleet survey results have suggested an ATC Data Link input device being either an IDU (touchscreen) or a CDU (keyboard). The ATC Data Link output device will be one of many different text-based visual displays with varying characteristics such as characters per line, lines per page, etc.

Issues: Significant differences in response times and workload between CDU and IDU are of concern especially when considering system location, airspace, and other crew workload. Alternatives should be examined.

Recommendations:

1. A CDU keyboard device is suggested for inputting information into ATC Data Link displays.

2. A touchscreen device should not be implemented for inputting information into an ATC Data Link display.

3. Investigate the voice recognition technology as a possible candidate for inputting information into the ATC Data Link system.

4. At a minimum some form of text-based cockpit display should be available for presenting ATC Data Link messages.

5. A synthesized speech output system alone should not be used for presenting ATC Data Link messages, only as a supplement to a text-based presentation.

Refer to the Input/Output section or the Conclusions and Recommendations section for more details and an examination of the research considered when making these recommendations.

Gating

Background: Designers of ATC Data Link set requirements for crew initiated downlink reports during critical phases of flight. Information within Data Link clearances will require transfer to other flight deck systems, e.g., Flight Management System (FMS) and Mode Control Panel (MCP).

Issue: Manual transfer of Data Link ATC clearance instructions to flightdeck systems and compliance with ATC imposed reporting requirements can result in significant crew workload increases.

Recommendations:

1. Data Link ATC clearance information should be gated to the flight management system.

2. Data Link ATC clearance information should not be gated to autoflight systems on the mode control panel.

3. Investigate what type of ATC information should be gated and what effects gating has on the situation awareness and crew resource management of both crew members.

Refer to the Gating section or the Conclusions and Recommendations section for more details and an examination of the research considered when making these recommendations.

SYSTEM IMPLEMENTATION ISSUES.

Situation Awareness/Party Line

Background: Recent Data Link research efforts have resulted in pilots expressing major concern over the loss of party line and its effect on their situation awareness. Implementation of Traffic Alert and Collision Avoidance System (TCAS) in a recent study did not adequately compensate for the lost radio communications. However, it did add to the time the crew spent heads down looking inside the cockpit.

Issue: Actual versus perceived party line information requirements of the crew for adequate situation awareness need to be examined in full-mission extended-operations LOFT research.

Recommendations:

1. Investigate the feasibility of presenting additional operationally relevant information through Data Link to enhance situation awareness.

2. Investigate what type of party line information should be considered for transmission by Data Link to increase situation awareness

Refer to the Situation Awareness/Party Line section or the Conclusions and Recommendations section for more details and an examination of the research considered when making these recommendations.

Clearance Negotiations

Background: Airborne ATC Data Link systems and services in their present form do not lend themselves to clearance negotiations as in the current voice environment. In recent studies where simple downlink reports were required, cockpit operations were severely disrupted.

Issue: The criticality of Data Link negotiations will escalate with advanced flight deck and ATC systems such as free flight, required time of arrival (RTA), etc. Guidelines are needed defining the how and when for using Data Link for negotiations.

Recommendations:

1. Investigate the importance of interactivity between pilots and controllers.

2. Investigate the effect of composing Data Link downlinks for negotiating clearances in different phases of flight.

Refer to the Clearance Negotiations section or the Conclusions and Recommendations section for more details and an examination of the research considered when making these recommendations.

Airspace Environment

Background: The Data Link applications, for any given environment, cannot be a simple repeat of another environment; the airspace differences are obvious but the information requirements are more subtle. Several studies have been conducted indicating acceptance of Data Link in oceanic and en route sectors, while expressing concern with operations in the terminal environment.

Issue: The premise of Data Link to reduce frequency congestion and reduce errors appears most applicable to the terminal airspace, but it is this area where heads down time must be minimized.

Recommendations:

1. Data Link ATC communications should not be implemented in the high workload terminal environment near the airport, regardless of the currently available visual display based interfaces being considered.

2. ATC Data Link communications should be implemented in low workload periods of flight (i.e., enroute, cruise, oceanic).

Refer to the Airspace Environment section or the Conclusions and Recommendations section for more details and an examination of the research considered when making these recommendations.

Mixed Communications (Voice/DL)

Background: Initial implementation of Data Link will result in varying degrees of Data Link/voice mixed communications. From sector to sector there will be a different percentage of Data Link equipped aircraft and Data Link messages being transmitted.

Issue: Crew monitoring demands will increase in a mixed (Voice/DL) environment. Sector airborne Data Link equipage and services available will be necessary information for crews.

Recommendations:

1. Mixed mode communications should not be present in high workload phases of flight (near or on the airport surface.)

2. Regardless of phase of flight, pilots should always be in radio contact with an ATC facility.

3. Upon Data Link implementation, procedures and/or guidelines need to be determined to allow Data Link operational pilots to know what type (tactical, strategic, etc.) of Data Link messages they can receive in a particular phase of flight.

Refer to the Mixed Communications (Voice/Data Link) section or the Conclusions and Recommendations section for more details and an examination of the research considered when making these recommendations.

1. INTRODUCTION.

The Federal Aviation Administration (FAA) has recently begun mapping a plan for the building of an air traffic management (ATM) system for the domestic National Airspace System (NAS) (Data Link Benefits Study Team, 1996). The system will use advanced communications, navigation, and surveillance technologies to support future global flight planning, aircraft operation, and air traffic control (ATC) services. One of the most important components of this ATM system will be the use of digital Data Link communications to transmit ATC clearance information between the flightcrew in the cockpit and the air traffic controllers. Data Link technology is already being used for digital Automatic Terminal Information Service (ATIS), predeparture clearance (PDC), and oceanic ATC services.

The use of Data Link for ATC communications offers several benefits over conventional voice communications. These advantages include a reduction in miscommunications associated with voice interaction, a reduction in frequency congestion, and the potential for direct entry of data into an aircraft's autoflight systems. In addition, clearance messages will have more permanence in the cockpit with the capability to print and/or review messages after they have been received. The next phase in the FAA's ATM plan includes the implementation of domestic in-flight controller-pilot communications using Data Link in the en route and terminal ATC environments.

The FAA William J. Hughes Technical Center's Airborne Data Link Program (ADLP) is currently investigating the Controller-Pilot Data Link Communications (CPDLC) implementation phase of the plan. The airborne Data Link program conducts human factors simulator evaluations examining every facet of an ATC Data Link communications system, such as display location, type of display, message formatting, crew alerting, etc. These Data Link human factors issues are important to both the FAA Certification Office and the airline industry. Any avionics device that will be used for ATC Data Link communications will need to be certified by the FAA. In order to do this, the FAA will need to establish standards for minimum characteristics and capabilities that must be met to ensure a safe, efficient, and effective Data Link system. Many human factors principles must be included in these FAA Data Link advisories, therefore, identifying the need for human factors research to support the ATC Data Link communications implementation process.

The FAA William J. Hughes Technical Center has been conducting aviation human factors research for many years. The Airborne Data Link Group (ADLG) has been heavily involved in flight deck human factors research, including several groundbreaking studies. The Technical Center has also sponsored the gathering of key research on aircraft, pilots, and the interaction between them.

These research studies have run the entire range in terms of complexity. Studies involving a worldwide network of aircraft and ATC simulators operating in a real-time mode have been performed with much success. Conversely, part-task studies involving desktop control display devices have provided key human factors data; this part-task information was then built upon through higher fidelity studies.

Beyond the FAA William J. Hughes Technical Center, there are several organizations that have or are currently conducting Data Link research. The more prominent include NASA Ames Research Center, National Aeronautics and Space Administration (NASA) Langley, Boeing, The MITRE Corporation, and Honeywell.

While the results of these studies and information searches were (or are being) documented and disseminated, it was felt that a "*synthesis report*" would prove especially valuable. This report will thus provide a synthesis of past Data Link research and specifically address the work performed by or supported by the Technical Center's ADLG over the past several years. The goal of the Technical Center's research is to support rulemaking, certification, and the testing of ATC systems in end-to-end environments.

1.1 GOALS/OBJECTIVES.

The goal of this report is to synthesize the key Data Link research and provide specific recommendations regarding flight deck Data Link system design.

1.2 SCOPE.

The focus of the research discussed in this report is the commercial transport environment. While the primary focus of the research over the years has been the commercial transport environment, other areas have been addressed; that is, general aviation and military. Much of the research will be applicable to all environments.

The report will concentrate on two major human factors topic areas; system operability and system implementation issues. System operability will encompass design related issues such as controls and display location, crew alerting, and message formatting. System implementation will involve operational procedure areas of concern to Data Link researchers, and are not design related specifically. Topics discussed in this section will include, for example, situation awareness, clearance negotiations, and mixed modality communications. These issues were identified as critical in many key reports (FAA, 1995; Rehmann, Reynolds, and Neumeier, 1993; Airport Transport Association (ATA), 1991).

A survey by the ATA in 1991 was conducted to determine the perceived research priority of some 45 Data Link issues. The issues were grouped into four areas (Data Link implementation and usage procedures, errors, human interface design, and situation awareness). The human interface design topic was composed of 18 specific subtopics. The survey results are listed by various categories of respondents. Since, again, the primary customer of the Technical Center, ADLG are the Certification and Flight Standards offices within the FAA, the topic rankings and comments from this group were closely considered.

A significant part of the literature gathered for this report was collected by the authors over the past 8 years. Other literature was gathered as a result of comprehensive searches of various databases. The two main databases searched were the Defense Technical Information Center (DTIC) database and the National Technical Information Service (NTIS) database. It is thought that most of the publicly available literature on airborne Data Link human factors is included in the bibliography of this report. However, internal and proprietary research results are, for obvious reasons, unfortunately, not included in the bibliography.

The literature gathered for this report falls into one of four categories (1) specific Data Link research, (2) Data Link guidelines, (3) related research, and (4) related guidelines. The latter two categories (related research and guidelines) encompass general or open literature that have application within the aviation environment. A database was created in which the Data Link related literature was entered. Each report in the database is identified by title, author, source, performing organization, and so on.

1.3 MAJOR FAA TECHNICAL CENTER CONTRACTORS.

A list of those contractors that, over the years, have been the primary human factors contractors for the Technical Center's ADLG are listed in table 1.

TABLE 1. PRIMARY HUMAN FACTORS CONTRACTORS AT THE FAA TECHNICAL CENTER'S ADLG

Crew System Ergonomics Information Analysis Center (CSERIAC)
Midwest Systems Research, Inc.
CTA, Inc.
National Lucht-EN Ruimtevaartlaboratorium (Dutch National Aerospace Laboratory)

1.4 ORGANIZATION OF THE REPORT.

An introduction to the report was provided in section 1. Section 2 - Synthesis Topic Areas, defines the topic areas and presents the Data Link literature in summary. The following section, Section 3 - Conclusions and Recommendations, presents high level conclusions that provide the reader with an indication of what topics have and have not been thoroughly researched and specific recommendations for Data Link implementation based on the findings of the previous section. The next three sections, sections 4, 5, and 6, contain References, Acronyms and Abbreviations, and Bibliography upon which this report is based, respectively.

2. SYNTHESIS TOPIC AREAS.

This section provides detailed information for each of the major topic areas, system operability and system implementation. The introduction to each of these topic and major subtopic areas includes a discussion defining the topic and a justification of why the topic is included in the report. A summary of the research is then provided for each Data Link topic area. Bibliographical references for each paper, study, research, or guideline are provided in section 6 of the report; the references are to be sorted by topic area and date.

The Data Link research bibliography database contains approximately 150 entries, and is continually being updated. Within the library of reports are government, industry, and academic technical reports, various guidelines and standards, and symposium proceedings, and publications. The publication dates for the literature are concentrated in the period from the mid-1980's to today. The specific Data Link research and the standards and guidelines make up two-thirds of the database and the remainder of course, in related research, standards, and guidelines. Figures 1 and 2 show, respectively, the distribution of reports by type and by performing organization for the entire Data Link bibliography. Also, table 2 provides a list of the FAA William J. Hughes Technical Center sponsored research reports and a list of additional recent Data Link research reports found in the bibliography. The table also indicates which Data Link major topic areas are addressed in each report. Further discussion regarding the Data Link research findings in these specific reports is provided individually for each topic area.

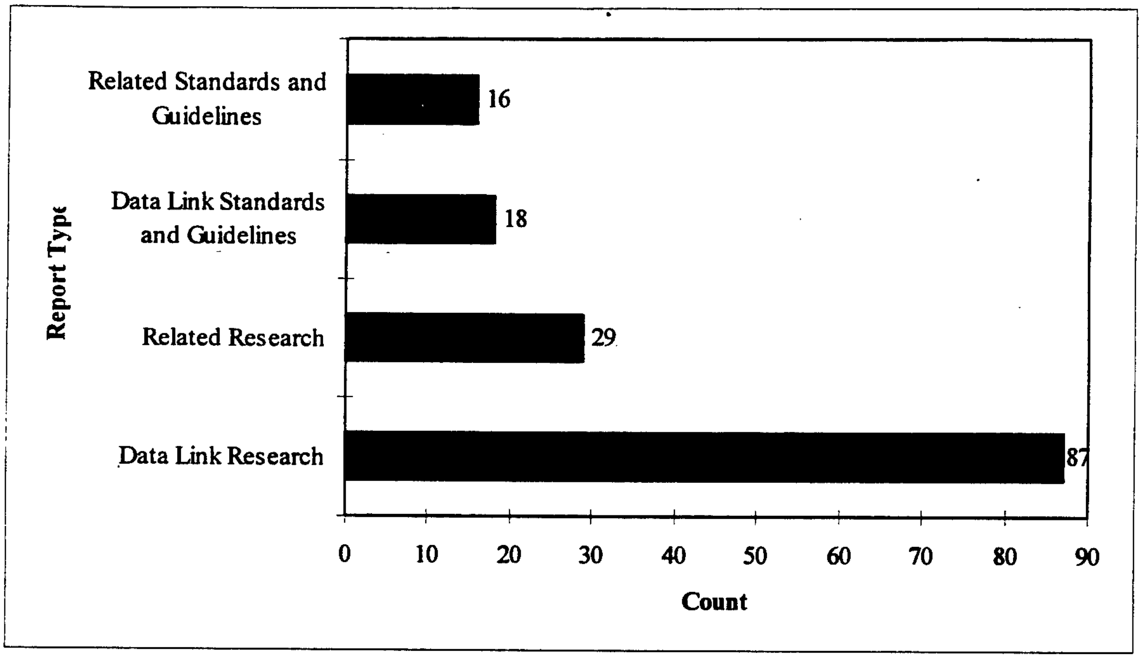

FIGURE 1. DATA LINK BIBLIOGRAPHY BY REPORT TYPE

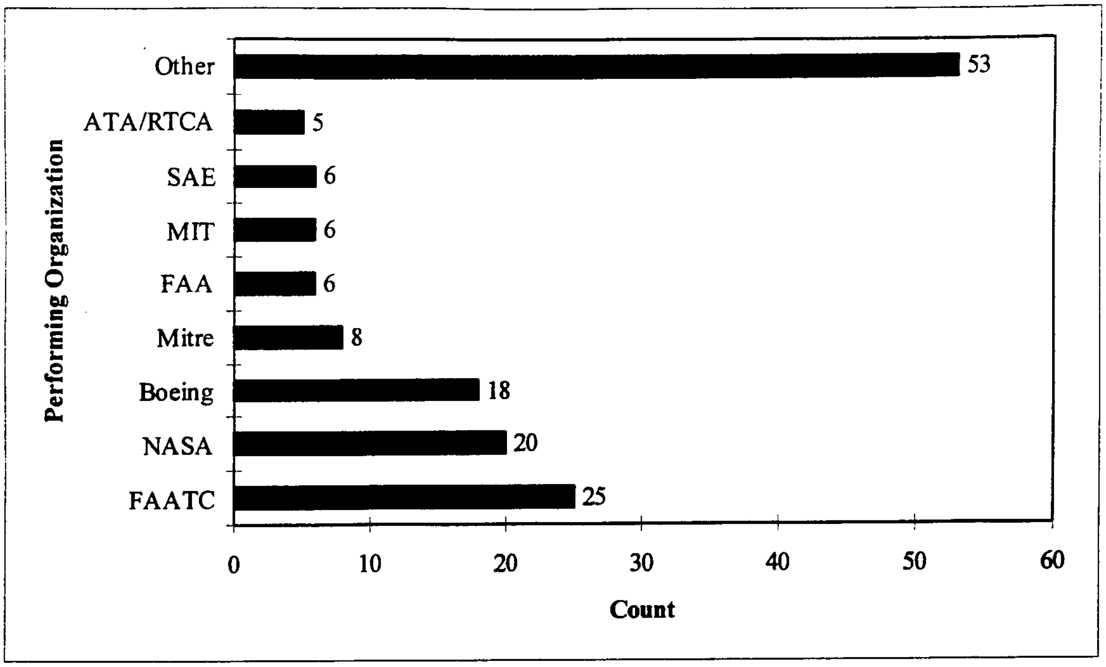

FIGURE 2. DATA LINK BIBLIOGRAPHY BY PERFORMING ORGANIZATION TYPE

TABLE 2 - SYNTHESIS PAPER FAA TECHNCIAL CENTER AND MOST RECENT RESEARCH BY TOPIC AREA

Title	Date	Biblio-graphy No.	System Location	Crew Alerting	Display/ Msg Format	Input/ Output	Gating	SA/ Partyline	Clrnc Negotiat	Airspace Environ	Mixed Comm
FAA Technical Center Reports											
Airborne Data Link Study Report (Rehmann, A., and Mogford, R.)	96/01	8	X	X	X	X		X			
Flightdeck Crew Alerting Issues: An Aviation Safety Reporting System Analysis (Rehmann, A., Mitman, R., Neumeier, M, & Reynolds, M.)	95/10	62		X							
Flightdeck Automation Issues: An Aviation Safety Reporting System Analysis (Rehmann, A., Neumeier, M., Mitman, R., and Reynolds, M.)	95/06	61				X	X				
Flightdeck Party Line Issues: An Aviation Safety Reporting System Analysis (Rehmann, A., Neumeier, M., Mitman, R., and Reynolds, M.)	95/06	60						X			
User Benefits of Two-Way Data Link ATC Communications: Aircraft Delay and Flight Efficiency in Congested En Route Airspace (Data Link Benefits Study Team)	95/02	180								X	
Flight Simulator Evaluation of Baseline Crew Performance with Three Data Link Interfaces (Rehmann, A., van Gent, R., Bohnen, H., and, Jorna, P.)	95	2	X	X		X		X		X	
Human Factors Issues with Data Link: Towards Increased Crew Acceptance for Both En-Route and Terminal Flight Operations (van Gent, R.N.H.W.)	95	233		X	X	X	X				
FAA Technical Center Reports											

TABLE 2 - SYNTHESIS PAPER FAA TECHNCIAL CENTER AND MOST RECENT RESEARCH BY TOPIC AREA

Title	Date	Biblio-graphy No.	System Location	Crew Alerting	Display/ Msg Format	Input/ Output	Gating	SA/ Partyline	Clrnc Negotiat	Airspace Environ	Mixed Comm
Domestic Airline Fleet Display Avionics Survey (Mitman, R., Neumeier, M., & Reynolds, M.)	95	256	X			X					
An Evaluation of Automatic Terminal Information Service (ATIS) Display Format (Rehmann, A.J.)	94/04	29			X	X					
Crew Alerting Standards: A Synthesis of the Research Literature (Neumeier, M.)	94/03	223		X							
Human Factors Guidelines for the Evaluation of Airborne Data Link (Rehmann, A., and, Vallerie, L.L.)	94/03	11		X	X	X					
FAA Airborne Data Link Human Factors Research Plan (Rehmann, A., Reynolds, M., Neumeier, M.)	93/07	94	X	X			X	X		X	
A Line Pilot's Perspective on Data Link Services in the Domestic and Oceanic Air Space Traffic Control (Brown, T., Bensel. B., and Rehmann, A.)	92/01	102	X				X	X	X		
Airborne Data Link Aviation Safety Reporting System Analysis I: Head(s) down Incidents. (Berkowitz, J., Roske-Hofstrand, R.)	91/09	241			X						
A Model Human Engineering Approach to the Development of Regulatory Standards for Digital Communication Technologies: Defining Safety from a Human-Machine Systems Perspective. (Roske-Hofstrand, Berkowitz, and Rehmann)	91/09	50	X								
FAA Technical Center Reports											
A Progress Report on Data Link ATC	91/05	43								X	

TABLE 2 - SYNTHESIS PAPER FAA TECHNCIAL CENTER AND MOST RECENT RESEARCH BY TOPIC AREA

Title	Date	Bibliography No.	System Location	Crew Alerting	Display/ Msg Format	Input/ Output	Gating	SA/ Partyline	Clrnc Negotiat	Airspace Environ	Mixed Comm
Service Development Research at the FAA Technical Center (Talotta, N. and Shingledecker, C.)											
Mode S Data Link Pilot-System Interface: A Blessing in De Skies or Beast of Burden? (Reynolds, M.C. and Neumeier, M.E.)	91/01	93			X		X	X		X	
A Pilot Evaluation of Text Display Formats for Weather Information in the Cockpit (Reynolds, M.C. and Neumeier, M.E.)	91/01	179			X	X					
Operational Evaluation of Initial Data Link Air Traffic Control Services, Vol. I (Talotta, N, Shingledecker, C. & Reynolds, M)	90/02	76			X	X		X		X	X
Presentations from the FAA Technical Center's Data Link Symposium (Rehmann, A.)	89/08	196				X	X				
An Operational Evaluation of a Prototype Airborne Data Link System (Reynolds, M.C. and Neumeier, M.E.)	89/06	91			X	X					
Recent Additional Reports											
Preliminary PETAL Conclusions (Barnetche, B., et al.)	95/11	227									
Party Line Information Use Studies and Implications for ATC Data Link Communications (Pritchett, A., Hansman, J., and Midkiff, A.)	95/11	31									
Recent Additional Reports											
Guidelines for Design Approval of Aircraft Data Communications Systems	95	181									

TABLE 2 - SYNTHESIS PAPER FAA TECHNCIAL CENTER AND MOST RECENT RESEARCH BY TOPIC AREA

Title	Date	Bibliography No.	System Location	Crew Alerting	Display/ Msg Format	Input/ Output	Gating	SA/ Partyline	Clrnc Negotiat	Airspace Environ	Mixed Comm
(Federal Aviation Administration, AIR-100)											
Cockpit Data Link Technology and Flight Crew Communication Procedures (Logsdon, E. W., Infield, S. E., Lozito, S., McGann, and, Possolo, A.)	95	1									
Situation Awareness: Its Role in Flight Crew Decision Making (Orasanu, J.)	95	80									
The effects of reduced party line information in a Data Link environment (Infield, S.E., Logan, A., Palen, L., Hofer, E., Smith, D., Corker, K., Lozito, S., Possolo, A)	95	105									
Flight demonstration of Data Link in an integrated airborne system (Richards, G.)	95	106									
The effects of ATC Data Link on instrument and environmental scanning during flight operations (Infield, S., Palen, L., Pepitone, D., et al)	95	107									
Human Factor Design Considerations for Air Traffic Control Information displays in a Modern Glass Cockpit (Huttig, G., Hotes, A. and Tautz, A.)	95	110									
Recent Additional Reports											
Flight Crew Performance in Automated air traffic management	95	108									

TABLE 2 - SYNTHESIS PAPER FAA TECHNCIAL CENTER AND MOST RECENT RESEARCH BY TOPIC AREA

Title	Date	Biblio-graphy No.	System Location	Crew Alerting	Display/ Msg Format	Input/ Output	Gating	SA/ Partyline	Clrnc Negotiat	Airspace Environ	Mixed Comm
(Corker, K., and Lozito, S., and Pisanich, G.)											
Distributed situation awareness: a concept to cope with the challenge of tomorrow (Javaux, D. and Fiarol, S.)	95	111									
Operational Requirements for the Aeronautical Data Link System, DRAFT (Data Link Operational Requirements Team)	94/06	14									
Human Engineering Recommendations for Data Link Systems (Society of Automotive Engineers)	94/02	9									

2.1 SYSTEM OPERABILITY ISSUES.

System operability is a broadly defined area encompassing areas such as display location, crew alerting, and formatting issues. This area has often been labeled as human computer interface (HCI) in other Data Link research documents (FAA, 1995; Rehmann et al, 1993). System operability (or human interface design) was identified in the ATA survey as a key research category. The 1995 FAA national plan defines Human Centered Automation and Information Management and Display as two of the five "thrust areas" for aviation human factors research. The Data Link bibliography contains 85 reports containing system operability relevant information or data. The topic of Data Link system operability has been split into five key areas; system location, crew alerting, message format, input/output, and gating.

2.1.1 System Location.

Location is important because of the nature of the information (ATC clearances), the variety of potential display systems on which Data Link may be hosted, and the potential frequency of usage. A domestic airline fleet avionics study performed by Mitman, Neumeier, and Reynolds (1995) showed that approximately 2,500 aircraft are equipped with electromechanical avionics. Approximately 90 percent of these older aircraft do carry some form of Airborne Collision Avoidance Radar System (ACARS). About 55 percent of this subset uses a touch sensitive device located in the center pedestal, mostly located in the rear of the pedestal. At issue is the belief that airline economics may drive the use of these ACARS displays for ATC Data Link communications.

Data Link system location was identified by the FAA William J. Hughes Techncial Center as research critical. Likewise, the issue was ranked as critical (highest level ranking of three levels) by the Socity of Automotive Engineers (SAE) (1991); SAE discusses the issue in terms of pilot head down time (issue number 24). In the 1991 ATA survey, the issue was ranked number 2 out of 45. ATA combines the issue into display surfaces, types, and locations. This topic area has been researched by many and 31 reports are contained in the Data Link bibliography which contain information regarding Data Link display location. Figures 3 and 4 provide information of report type and performing organization, respectively.

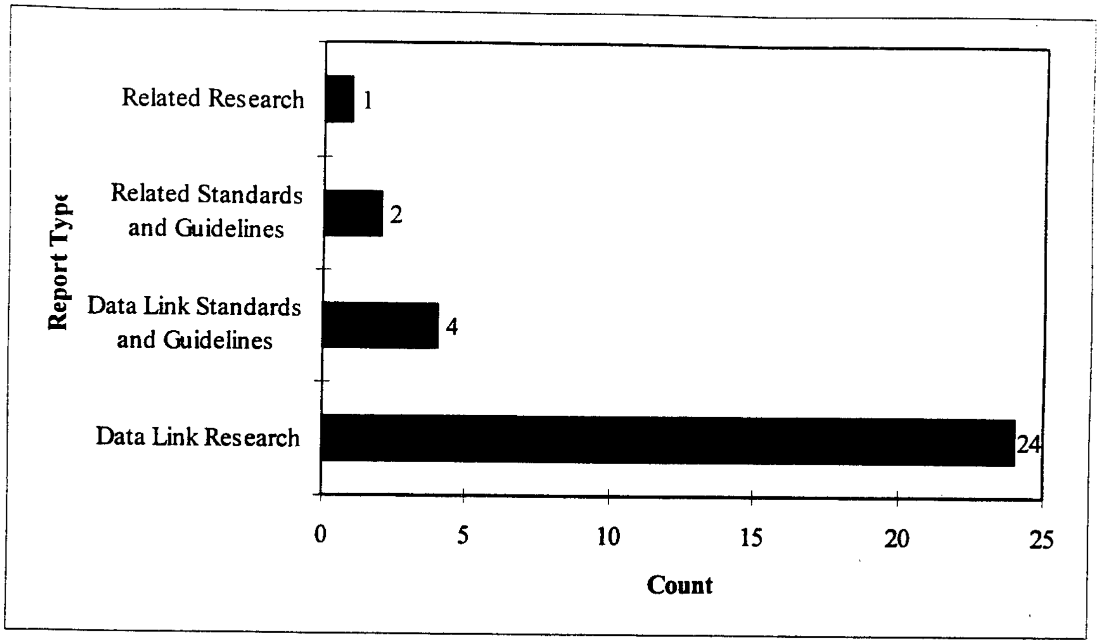

FIGURE 3. SYSTEM LOCATION REPORTS BY REPORT TYPE

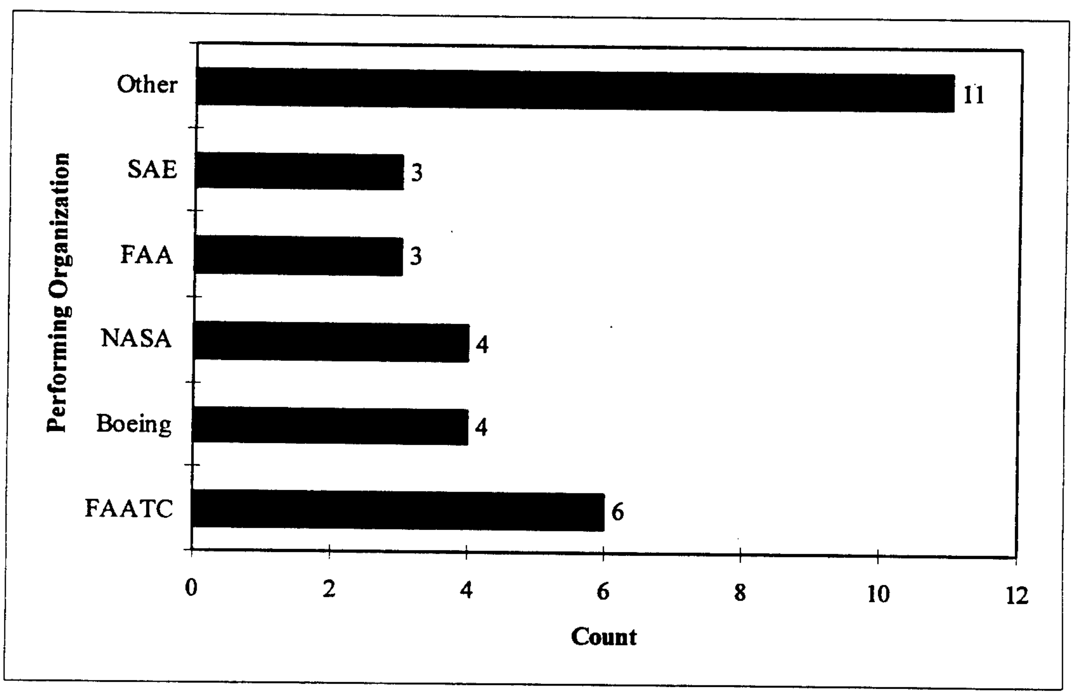

FIGURE 4. SYSTEM LOCATION REPORTS BY PERFORMING ORGANIZATION TYPE

Data Link display location research studies usually examine two different options for location -- forward mounted or aft mounted within the center pedestal. The forward mounted location is more associated with advanced glass cockpit aircraft with Flight Management System (FMS)/Control Display Unit (CDU)s located in the forward center pedestal, while the aft mounted location is considered more of a retrofit location for older electromechanical aircraft.

The Technical Center has conducted several studies investigating these location options. In a study by Rehmann and Mogford (1996) forward mounted Data Link display led to less time required to respond to DL messages, and an aft-mounted display rated higher on workload and visibility. Pilot subjective response data from the Rehmann, van Gent, Bohnen, and Jorna (1995) simulation study indicated that for readability, reachability, and cross-check, an interactive display unit (IDU) located in the aft pedestal area was rated lower than both the multifunction display (MFD) and FMS/CDU which had forward pedestal locations. Pilots in a study by Brown, Bensel, and Rehmann (1992) stated that it was necessary to have the Data Link device/display in a location that is in view for both cockpit members.

Other studies have been performed that provide the same results as found by the FAA Technical Center. Research by Kerns (1994), Knox and Scanlon (1991) has shown that forward mounted displays provide a more efficient system for pilots to perform Data Link communications operations. Subjects in the Knox and Scanlon (1991) study indicated that while space in the cockpit is at a premium, the Data Link display, when used for ATC tactical messages must be located in the pilot's forward field-of-view.

In a recent study by Logsdon et al (1995), the results might initially be seen as conflicting with the previous research introduced supporting the forward center pedestal location for a Data Link display. Comparisons were made between two Data Link device locations, an FMS-integrated Data Link forward display (DF) and a nonintegrated Data Link aft retrofit display (DR). The Data Link forward implementation was found to have significantly longer total transaction times than the Data Link aft location. It is possible that the differences between the two Data Link implementations in this study are in fact due to easier visual access to the message for both crew members in the DF condition. The reasoning was that for the DF condition because of its viewing accessibility, both pilots are looking at the display this enhances and/or improves shared information between pilots, provides a greater opportunity for crew situation awareness, and error trapping (Logsdon et al, 1995). Also, pilots addressed the DR display more quickly due to its distracting location and their desire to complete the task so they could again focus attention forward out-the-window or any other flightdeck systems.

2.1.2 Crew Alerting.

A survey of the Aviation Safety Reporting System (ASRS) database by Rehmann and Mitman et al (1995) characterized six problems with existing alerting systems. One problem area is non-distinguishable alerts, especially those that use subtle coding within the same aural tone, to indicate radically different levels of emergency conditions. Near-term ATC communications and farther term-free flight (RNP and airspace conflict) alerting mechanisms risk suffering the same types of problems already identified without careful consideration of flight deck integration.

Additionally, long-term exposure to ATC Data Link communications may result in flight crews becoming accustomed to the incidence of routine communications, and lessen the required alerting severity.

The FAA Technical Center has identified crew alerting as a key research issue. Similarly, the issue of crew alerting mechanisms ranked number 6 out of 45 in the 1991 ATA survey. Society of Automotive Engineers (SAE), under the issue of Definition of Human Interface Requirements, gave the issue a critical rating. The Data Link bibliography contains 38 reports on the topic of crew alerting. Figures 5 and 6 show the distribution of reports by report type and performing organization, respectively.

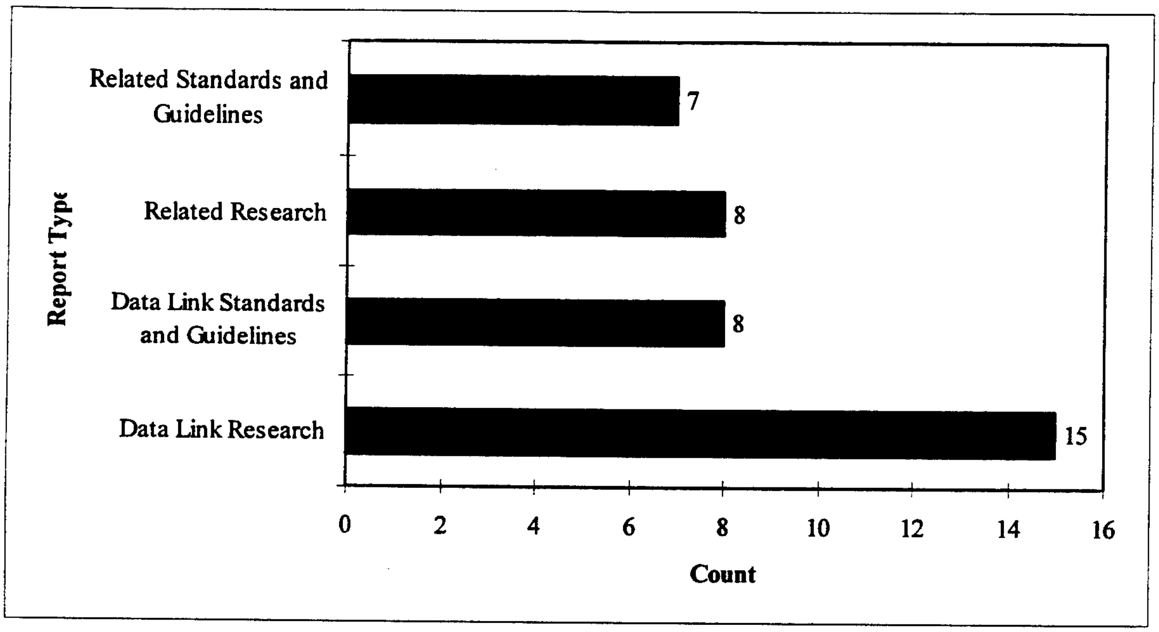

FIGURE 5. CREW ALERTING REPORTS BY REPORT TYPE

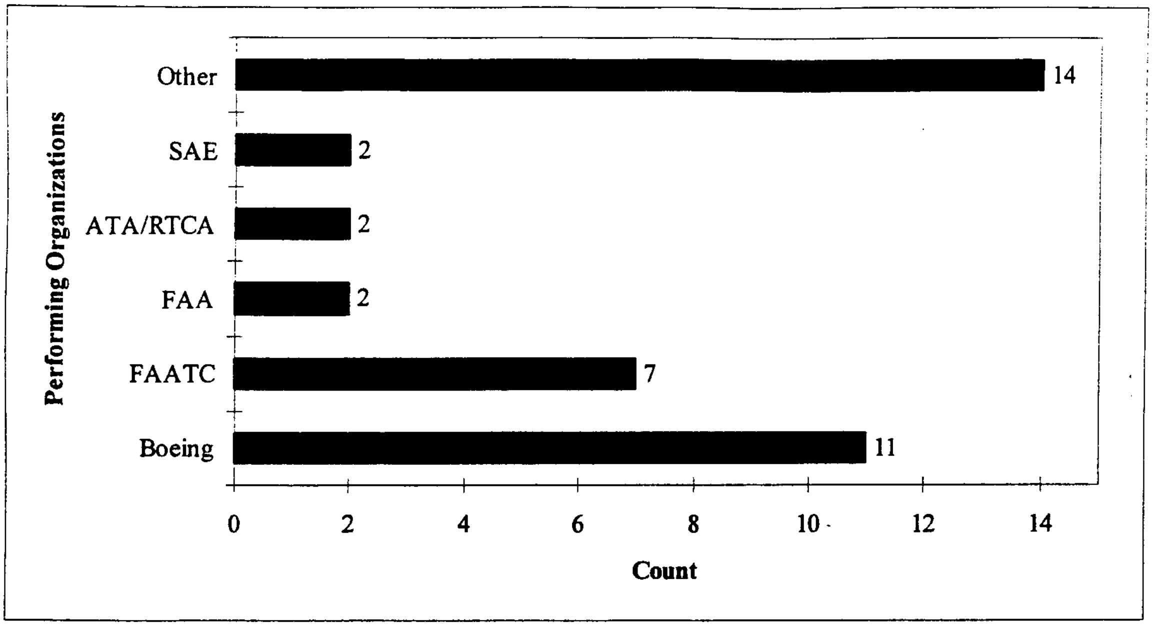

FIGURE 6. CREW ALERTING REPORTS BY PERFORMING ORGANIZATION TYPE

The FAA Technical Center has performed numerous studies investigating crew alerting designs for Data Link. Two recent studies by Rehmann and Mogford (1996) and van Gent (1995), and an ASRS analysis by Rehmann, Mitman, Neumeier, and Reynolds (1995) have examined various alerting schemes and indicated possible problems that should be addressed in Data Link crew alerting. The results from the three studies just mentioned and research by Murphy (1993) all found that an alerting scheme using a distinct alert for Data Link was preferred by the pilots.

Rehmann and Mogford (1996) compared response times of two alerting schemes, a nondistinctive alert and a nondistinctive alert with an annunciator lamp under the glareshield. The results did not favor one over the other. In post-hoc subjective tests pilots primary suggestion was to change the nondistinctive SELCAL sound to a unique sound distinguishable from other cockpit aural indicators.

Also, in a study by van Gent (1995) comparing a distinct versus a nondistinct aural alert results suggested that an alerting scheme using a distinct but 'nonannoying' aural alert is preferred. The nondistinct aural utilized was a SELCAL chime. This confused a large majority of pilots into incorrectly attending to the ACARS display when an ATC Data Link message was presented. Using another distinctive sound for the ATC Data Link functions should therefore be recommended to minimize confusion. When considering Data Link aural alerts the designer must be careful to provide a signal that is distinguishable from the many coded sounds already in the cockpit. It must be recognizable as the alert for the Data Link function, as opposed to another purpose (McCauley, Miles, Dwyer, and Erickson, 1992).

2.1.3 Display/Message Format.

The format of ATC clearance information to flight crews must be clear and quickly understandable. Complicating the issue is the fact that a variety of display types may be used for Data Link, e.g., FMS CDU, IDU, etc. While the format of the Data Link display interface is slightly dependent on the display, there are many characteristics related to the format of the display system that can affect its readability and ease of use. In fact, recent research performed by the National Aerospace Laboratory (van Gent, 1995) found that crew acceptance of Data Link is highly sensitive to the design of the displays page formats and menu tree structure.

The format of messages presented to flight crews was defined by the FAA Technical Center as a critical issue. The ATA survey ranked the issue of Format and Contents as number 10 out of 45. Display/message format falls under the Information Management and Display thrust of the 1995 National Plan for Civil Aviation Human Factors: An Initiative for Research and Application. The Data Link bibliography contains 56 reports on the topic of display/message format. Figures 7 and 8 show the distribution of reports by report type and performing organization, respectively.

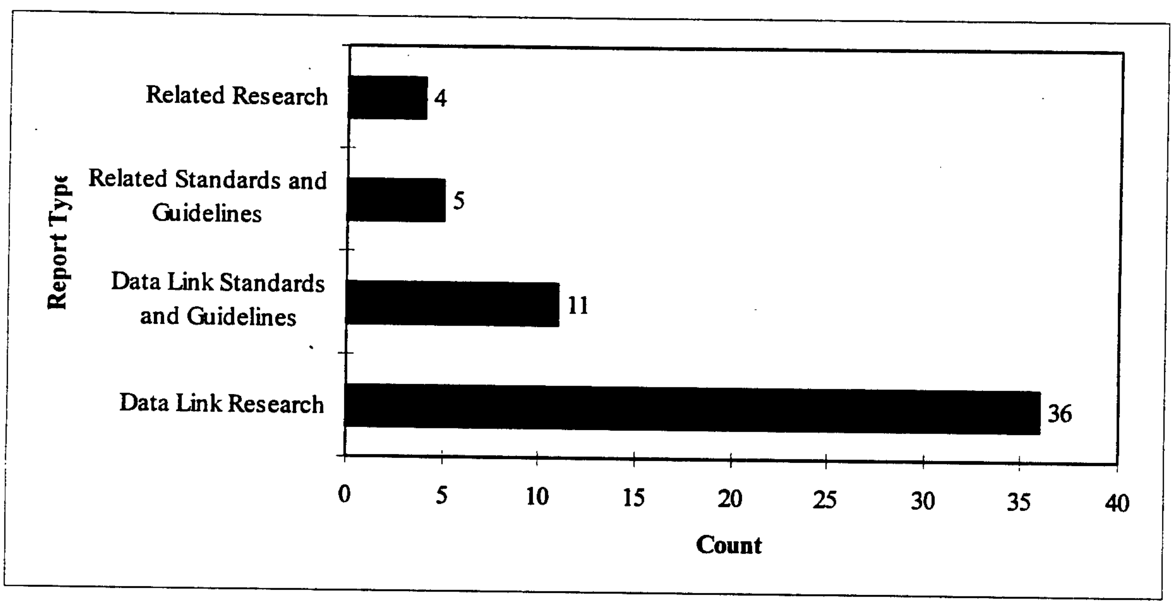

FIGURE 7. DISPLAY/MESSAGE FORMAT REPORTS BY REPORT TYPE

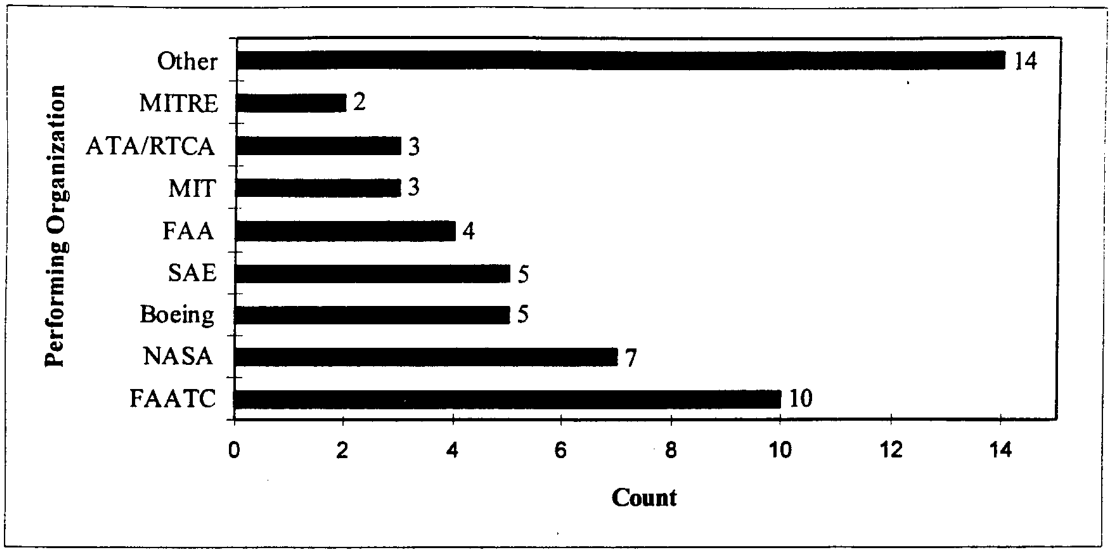

FIGURE 8. DISPLAY/MESSAGE FORMAT REPORTS BY PERFORMING ORGANIZATION TYPE

The research concerning display/message formatting for ATC Data Link communications will be discussed in detail in terms of Data Link message format and a menuing structure for the CDU. The format in which the ATC clearance is presented and the overall menu structure can have a significant affect on the efficiency and usability of the Data Link communications display device.

The format of a Data Link message is somewhat dependent on the display surface on which it is being presented. However, there are many characteristics related to the message and its contents that can be manipulated to provide better readability and ease of use for the pilots. Researchers have indicated issues such as using standard format message sets, abbreviations, feedback, text case, and symbology as being important to the overall success of the Data Link message format. Some of the specific research findings relating to Data Link message formatting are presented for review.

A message set should be developed using a vocabulary that is consistent with the current operational environment. If the system presents the messages visually, then visually similar words should be avoided and a visual analog to the phonetic library should be developed (SAE, 1991). Several reasons for having a standard format message set are as follows: (1) to avoid having many operational versions of a Data Link message set, a globally standardized message set must be established in a coordinated fashion at an early stage; (2) formatted, not free format messages are needed, one might consider transmitting uplink and downlink ATC messages as free format messages. But if this were done, it would be very difficult to do automatic processing (Wu, 1991). Abbreviations or acronyms should appear on the receiver's display only if they are more commonly used than the terms they replace, and they must not conflict with abbreviations in use on the flight deck or in the ATC environment.

Research findings have shown a benefit to providing feedback for every user input in time to prevent doubt about the status of the input. Weak feedback can increase cognitive workload in several ways: by increasing demands on pilots to remember information and by increasing the need to rely on mental models of FMS structure and function to assess or project FMS behavior (Sarter and Woods, 1993).

In a study by Rehmann (1994) mixed case text in situation relevant text (i.e., accepted airline text and abbreviations) was found to be more efficient when viewing messages. Also, Lee (1989) found that the development of Data Link display symbology will substantially reduce the reading time (and thus heads-down time) required by alphanumeric text.

Finally, results from a study by McGann, Lozito, and Corker (1993) showed evidence that negated the importance of Data Link message formatting. The findings from the evaluation of four textual formatting styles (T-Scan, Pilot Derived, ATC Standard, and Frequency Based) did not reveal any significant reaction time or accuracy differences among the four. The authors postulated that regardless of textual formatting style, the advantages of clarity and conciseness of printed clearances may outweigh subtle formatting differences

The menu of the Data Link display is an important issue because it provides the direction for the pilot when interacting with the ATC Data Link communications system. Research by Groce and Boucek (1988) and Mann and Schnetzler (1986) have identified many issues and characteristics that enhance the perception and usability of the CDU menu design. One way to control for access visual/motor loads as a result of Data Link is to adopt a structured menu design. Another important factor would be to have large display surfaces capable of displaying an entire message at once, without ambiguous abbreviations (Groce and Boucek, 1988). Researchers have found that minimizing processing and page selection time through smart menuing will be a significant factor in the design of a successful Data Link system using a CDU.

Because of the limited display size of most typical CDU's in the transport environment, it is crucial that the content, timing, and layout of required information must be optimized to facilitate information transfer and processing to the system user. Conclusions from a study by Mann and Schnetzler (1986) show that when developing a CDU page format design, it is important to mark the labels clearly, minimize the number of labels for each piece of data, and associate the main and sub-labels to the data. The designer's goal is to reduce the complexity of the data search process. In a study by van Gent (1995) researchers were able to increase Data Link acceptability by changing the page layout and optimizing some procedures. The page layout was designed to reduce the number of necessary key strokes through automation and integration.

2.1.4 Input/Output.

The interface between the pilot and the ATC Data Link communications system is defined by the output modality for viewing the Data Link message and the input modality used by the pilot to interact with the system. Implementation of an effective ATC Data Link communications system is based on how the input/output characteristics of the system interact with present cockpit systems and coordinate with current pilot activities.

Defining specific input/output characteristics of an ATC Data Link system was defined by the FAA Technical Center as a critical issue. The FAA's National Plan for Aviation Human Factors section on Flightdeck - Automation, Controls, and Displays identifies an objective to develop and evaluate advanced flight deck systems technologies that provide flight crews with safe and effective ways and means to plan and replan flights, manage aircraft systems, and effectively respond to the external environment when dealing with contingencies. Also, the issue concerning Data Link input and output devices was ranked as critical by SAE Issue #12 - Definition of Human Interface Requirements. The Data Link bibliography contains 75 reports on the topic of input/output. Figures 9 and 10 show the distribution of reports by report type and performing organization, respectively.

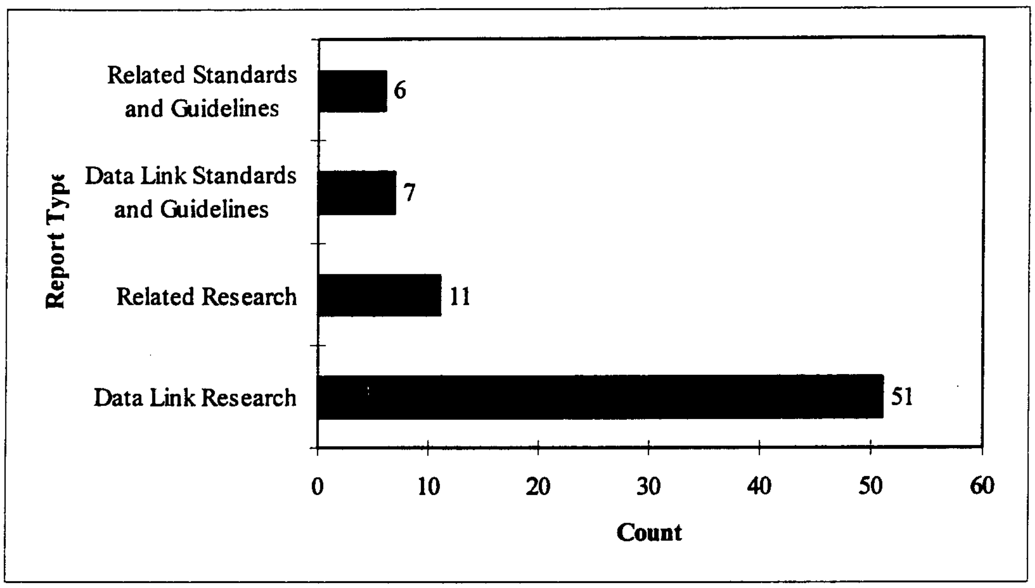

FIGURE 9. INPUT/OUTPUT REPORTS BY REPORT TYPE

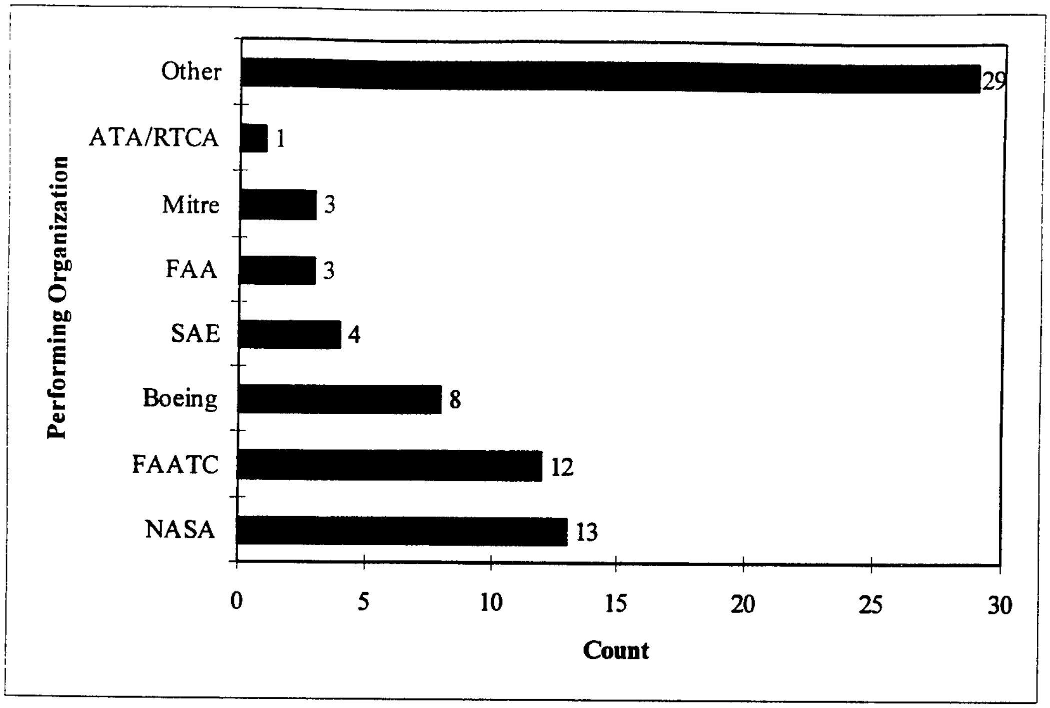

FIGURE 10. INPUT/OUTPUT REPORTS BY PERFORMING ORGANIZATION TYPE

The majority of ATC Data Link research studies examine Data Link while implementing either a keyboard or touchscreen interface for inputting information. This strategy is associated with the two main devices being considered for Data Link implementation. Keyboard input is consistent with the use of a CDU, while touchscreen capability usually accompanies the use of an IDU.

In a FAA Technical Center study by Rehmann, van Gent, Bohnen, and Jorna (1995) three Data Link input implementations were investigated. They included a FMS/CDU keyboard, an IDU touchscreen, and a MFD touchscreen for input responses and information to the Data Link system. Results favored the use of the CDU keyboard implementation. The CDU keyboard was ranked superior to the other interfaces in terms of time to access and ease of use. The results support the conclusion that in its present form only the CDU is acceptable as a communication device in low workload phases of flight (Rehmann et al, 1995).

Furthermore, the FAA Technical Center study found that pilots reported a suboptimal usability of a touchscreen in flight; negative affects were particularly evident for the IDU that also used a touchscreen for scratchpad entries. One of the recommendations of the study was "Preferably not using touch screens for text input. This experiment clearly showed the suboptimal properties of touchscreens in flight and if possible they should be avoided for text input" (Rehmann et al, 1995).

Other research has been performed by Waller (1992) and Degani, Palmer, and Bauersfeld (1992) where results have shown deficiencies in touchscreen technology for Data Link applications. Pilots had concerns with button activation and accidental touches, the associated response time, and the loss of tactile feedback. The majority of the pilots stated difficulties in determining exactly where to push to activate their desired function due to the parallax experienced as a result of the location of the touchscreen device. Furthermore, several pilots felt that adverse conditions such as turbulence might further reduce the efficiency of the touch-screen, as "this is a problem with the ACARS touchscreen display already in use" (Degani et al, 1992).

One other option being considered for Data Link input is that of voice recognition. This technology is being advanced and the potential is there for pilots to some day use speech to interface with a Data Link system. This capability is advantageous in that it would allow pilots more time to perform other manual tasks and spend more time heads up looking for traffic. However, the technology is just starting to be considered for the cockpit environment and many problems exist. Unlike human beings, current speech recognition systems use fewer types of linguistic knowledge and no extralinguistic knowledge. They also are not very flexible or adaptable to human variability in individual factors like the user's sex or personality, or to physical or psychological factors like noisy environments, user's mood, and so forth (Delogu, Paolini, and Pocci, 1991).

The output device for Data Link generally implemented for simulation research is some form of a display. The textual cockpit Data Link interface offers more permanence of information by making it visually available to the crews. Also, Data Link communications generally offers an ability to review the message at a later time, providing an ongoing opportunity to view the clearance (Logsdon et al, 1995). However, the increased heads-down time and visual requirements associated with viewing the cockpit display for Data Link messages had led to many researchers examining the feasibility of using synthesized speech to deliver information to pilots.

The FAA Technical Center has performed simulation studies examining synthesized speech as a potential substitute or enhancement for visual text presentation of Data Link message contents. In a study by Rehmann and Mogford (1996) results indicated that pilot response times to digitized speech were longer than with just text display. Even though the synthetic voice resulted in longer response times other results showed some benefits. With digitized speech, the Pilot Flying (PF) glanced at the CDU significantly less often and glance duration was shorter. Also, in digitized speech, the Pilot-Not-Flying (PNF) read the Data Link message out loud less frequently (Rehmann and Mogford, 1996).

Another study by van Gent (1995) showed a slight preference for using speech synthesis as a PF-informing mechanism. Instead of having a display in the forward visual field of view, this study showed that using speech synthesis could be an alternative, thus allowing interfaces such as the CDU which are not in the forward field of view of all operators (van Gent, 1995). Additionally, findings from Rehmann (1989) also support the use of both output mediums indicating that crews would prefer a cathode ray tube (CRT) message presentation and synthetic voice. These findings suggest that perhaps synthetic speech technology can be used to alleviate increased visual demands, retain the auditory nature of receiving instructions from ATC, and still provide a textual presentation of the information for review.

The use of digitized voice was not seen as a necessity in a study by Knox and Scanlon (1991), however pilots felt that it provided a unique message alerting device (as it was distinctive from regular voice communications). In another study by Waller (1990) pilots indicated that receiving ATC clearances spoken by a synthetic voice was usable, but did not prefer this mode over conventional voice radio communications. The use of synthetic voice may provide some benefit for a Data Link system replacing existing voice radio ATC transmissions. However, without some form of text based presentation, it would essentially be the same environment as pilots interact with presently.

2.1.5 Gating.

Gating will provide a reduction in workload and programming errors for pilots by not requiring them to manually transfer data from the Data Link message into the FMS and other flight control avionics. Information gating will also be advantageous when crews are required to compose and send downlink reports. Research has found that one of the most labor intensive aspect of the use of Data Link is air-initiated downlink reports. In the near-term tactical environment, downlink reports of assigned altitude are being considered. Gating is deemed necessary to at least preload data fields for the flight crew prior to sending a downlink report.

The direct transfer, or gating, of data from a Data Link message into the FMS or other cockpit avionics is a critical issue associated with Data Link implementation being considered by the FAA Technical Center. The ATA survey ranked the issue of gating as number 20 out of 45. ATA discussed gating in the issue of Data Link integration with other cockpit technologies. SAE, under the issue of Function Allocation (issue number 16), gave the issue a critical rating. The Data Link bibliography contains 40 reports on the topic of gating. Figures 11 and 12 show the distribution of reports by report type and performing organization, respectively.

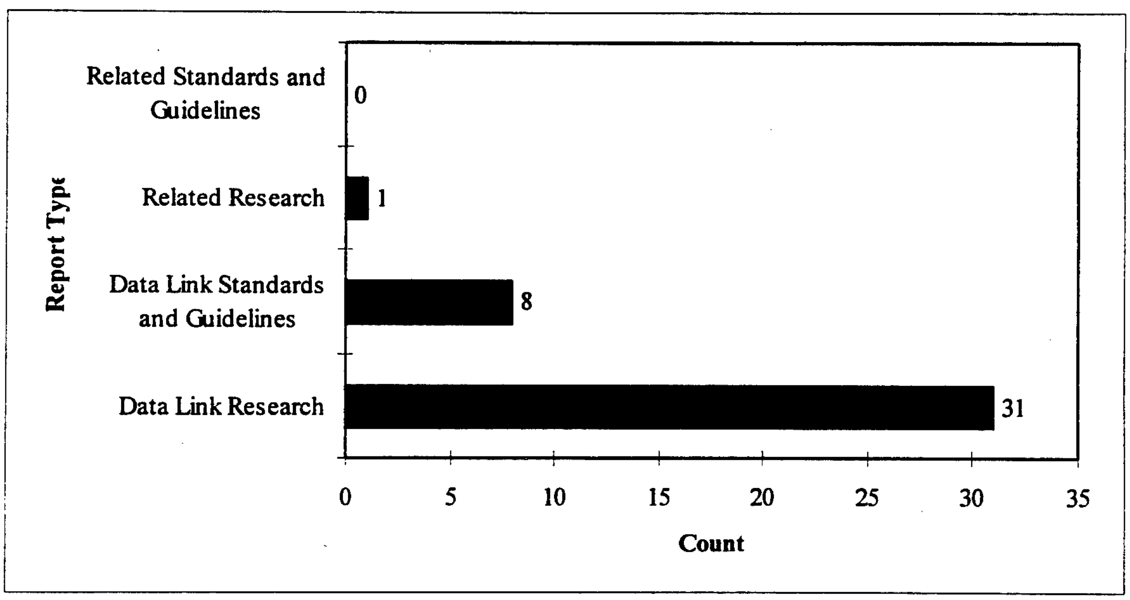

FIGURE 11. GATING REPORTS BY REPORT TYPE

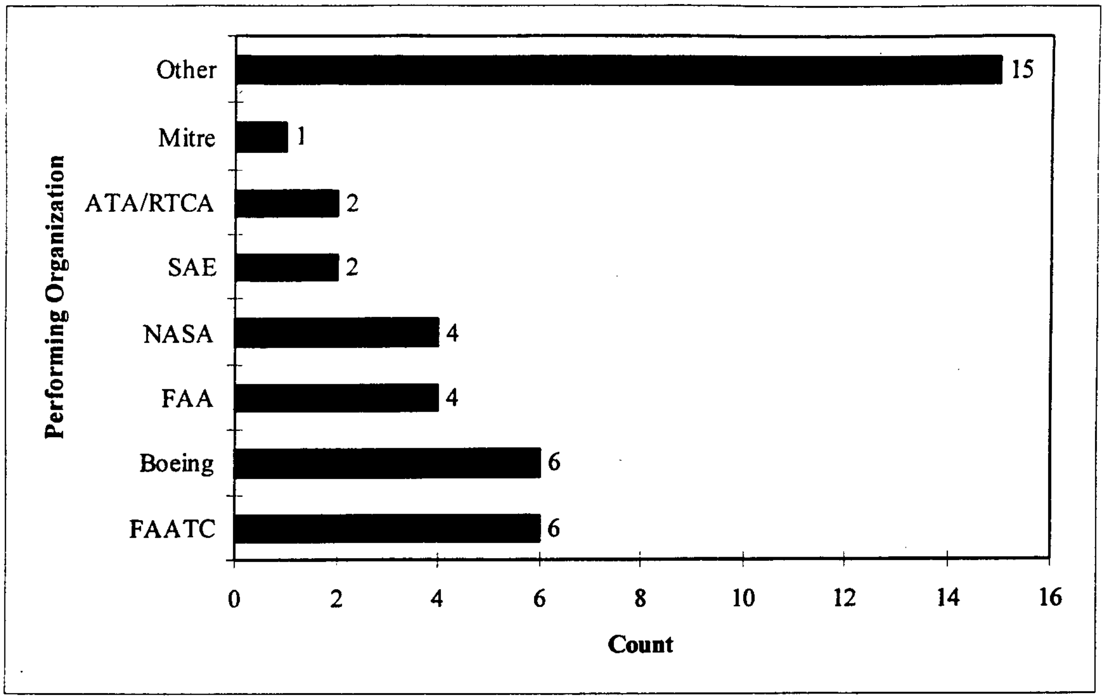

FIGURE 12. GATING REPORTS BY PERFORMING ORGANIZATION TYPE

Data Link research investigating gating has been conducted using many different interfaces and procedures. However, pilot subjective data results from numerous studies (Van Gent, 1995; Hahn and Hansman, 1993; Brown, Bensel, and Rehmann, 1992; Waller, 1992; Rehmann, 1989) suggest that pilots desire the ability to gate information automatically from Data Link. The concept of being able to check and download Data Link information directly into the flight management computer (FMC) was reported as attractive to pilots (Brown et al, 1992). The automatic programming associated with Data Link gating appears to allow the pilot to concentrate on evaluating the clearance on the strategic level (Hahn and Hansman, 1993).

In Waller's (1992) study, results included a 25-percent decrease in the amount of processing time between gating and normal voice radio communications (nongating). The pilots spent less time in the combined communication and data management process when Data Link ATC communications was integrated with other subsystems of the simulated aircraft.

While results have found that gating, in general, is an advantageous capability of Data Link communications, there is concern as to what type of ATC instructions should be available for automatic entry into flightdeck avionics systems. In a study by van Gent (1995) crews appreciated an FMS type of gating which allowed them to view potential route changes on the navigation display and transferred the information to the route pages within the FMS. When a flight plan change came in from ATC, it could be directly downloaded resulting in considerable less typing by the crew. But, they negatively rated a Mode Control Panel (MCP) type of gating that allowed Data Link information regarding speeds, headings, and altitudes to be directly transferred to the MCP. The main problem of gating MCP information lies in the Crew Resource

Management (CRM) area, since using this feature would effectively make the PNF, also the PF once he activates/flies the ATC instructions (Van Gent, 1995).

2.2 SYSTEM IMPLEMENTATION ISSUES.

System implementation issues differ from system operability issues in that they are more procedurally related to Data Link operations. The system operability issues were more design related physical device issues relating to a Data Link communications system. Data Link operational procedures and implementation characteristics are what is being categorized as system implementation issues. The system implementation issues addressed in this document encompass Data Link topics such as situation awareness/party line, clearance negotiations, airspace environments, and mixed communications types (voice/Data Link). The Data Link bibliography contains 58 reports containing system implementation issues. Figures 13 and 14 show the distribution of reports by report type and performing organization, respectively.

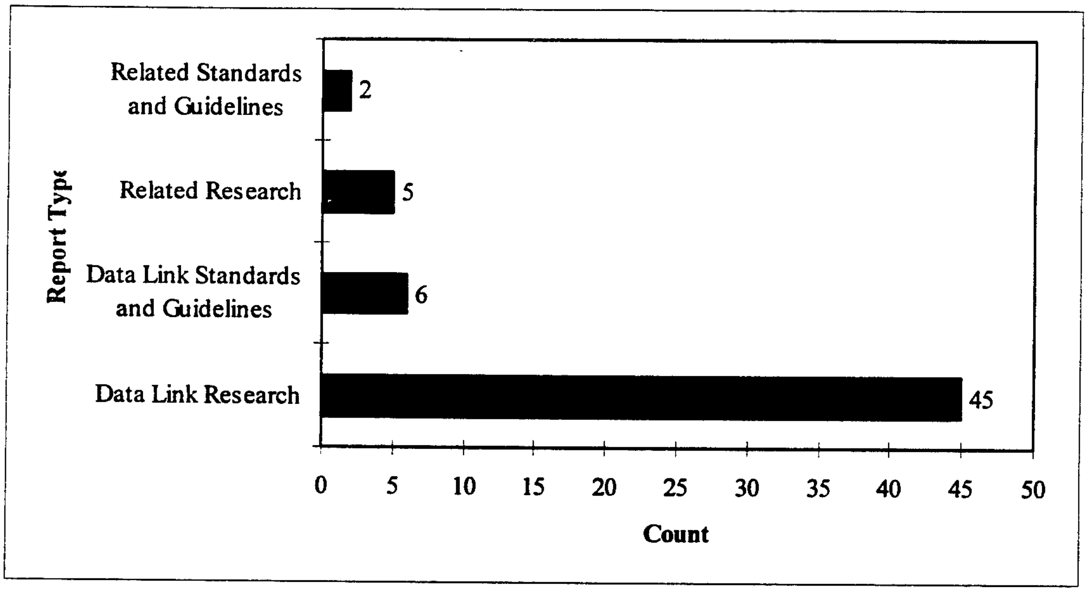

FIGURE 13. SYSTEM IMPLEMENTATION REPORTS BY REPORT TYPE

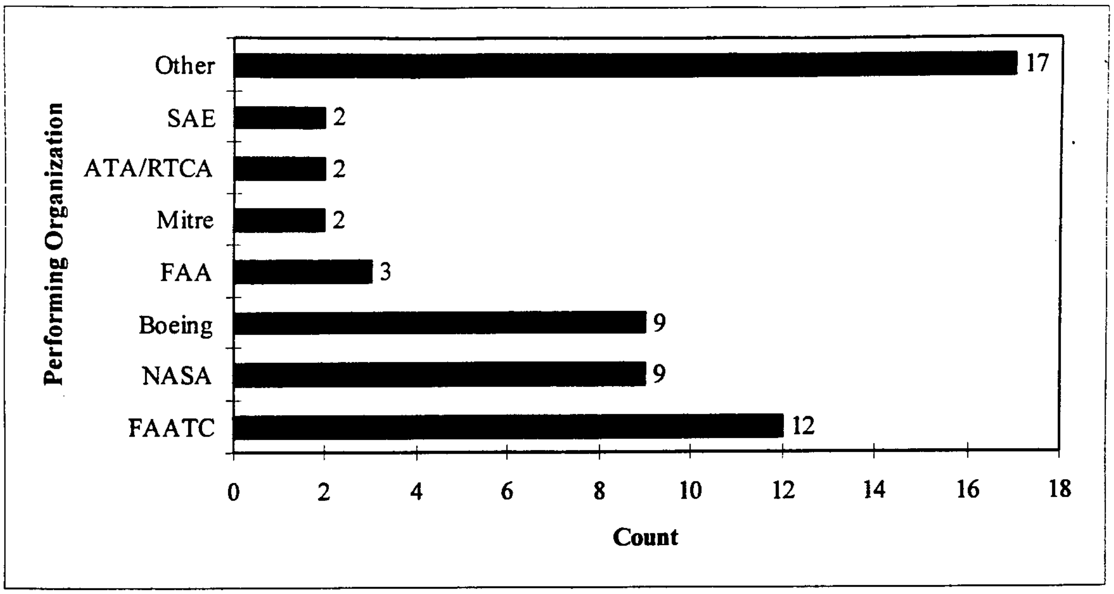

FIGURE 14. SYSTEM IMPLEMENTATION REPORTS BY PERFORMING ORGANIZATION TYPE

2.2.1 Situation Awareness/Party line.

Pilot situation awareness is a major concern for researchers investigating the effects of Data Link implementation. The benefits derived from enhanced situation awareness include: improved safety, reduced workload, enhanced pilot performance, an expanded range of operation, and better decision-making (Regal, Rogers, and Boucek, 1988). There is concern that Data Link may actually decrease the crew's situation awareness as a result of the potential loss of "party line" information currently being obtained from voice radio communications. It has been suggested that the availability of Traffic Alert and Collision Avoidance System (TCAS) may provide enough information to adequately compensate for the loss of information.

The FAA Technical Center identifies the need for adequate situation information in the cockpit and acknowledges it as a critical research issue. Additionally, the need to assess and resolve the effects of data communications on pilot/controller situation awareness was mentioned in the Information Management and Display thrust of the 1995 National Plan for Civil Aviation Human Factors: An Initiative for Research and Application. The issue of party line induced situation awareness was ranked number 22 of 45 by the 1991 ATA survey, under the issue of Party Line Compensation. Also, the issue of Crew's/Controller Situation Awareness (issue number 10) was ranked serious by SAE. The Data Link bibliography contains 38 reports on the topic of situation awareness/party line.

Research performed by the FAA Technical Center (Rehmann and Mogford, 1996; Rehmann, Neumeier, Mitman, and Reynolds, 1995; Brown, Bensel, and Rehmann, 1992) have proven the usability of party line information by pilots, and in the data collected from subject pilots, party line is deemed a necessity for safe flight. Pilots state that they receive party line information from listening to ATC communications with other aircraft and obtain advance knowledge of events and conditions that might affect their flight (i.e., traffic congestion, delays, weather, etc.).

Party line studies have been conducted investigating when and how pilots are more inclined to need and use this type of information. Results from Brown et al (1992) and Hansman et al (1992) have found that pilots find party line information to be more important during operation on or near the airport. In the domestic environment and at the lower altitudes with more traffic and decreased separation minimums, situation awareness gained by the party line effect from the ATC voice circuits was identified as necessary (Brown et al, 1992). This importance of party line information near the airport was supported by an ASRS analysis performed by Rehmann et al (1995) which revealed that the majority of party line information was transmitted near or on the airport surface. Pilots seem to use the party line to compose a mental picture of their immediate environment in hopes to avoid any adverse situations (Rehmann et al, 1995).

Because of the potential loss of party line information with the discrete addressing of Data Link communications, proposals have been introduced that would provide relevant information to the pilots over the Data Link. Researchers such as van Gent (1995) and Knox and Scanlon (1991) have actually tested this feature in Data Link simulations. Information such as turbulence reports, traffic delays, expected routing and speeds, and severe weather reports were welcomed by the crews to compensate for the lack of party line. In both research efforts pilots rated the presentation of extra information by means of Data Link to enhance situation awareness as acceptable.

In spite of these party line concerns several studies performed by the National Aeronautics and Space Administration (NASA) (Waller and Lohr, 1989; Knox and Scanlon, 1991) have indicated that crews have a strong preference for the quiet flight deck and the reduced frequency congestion associated with Data Link, stating that they were not certain that the party line benefits were as important to them. In other research by Infield et al (1995) and Hansman et al (1992) the ability to use party line information effectively is dependent on pilot workload, present state of pilot situation awareness, and the tactical/strategic nature of the situation. The findings that some pilots may prefer the quiet cockpit and that pilots apparently use this information most near the airport where workload and time pressures have been shown to effect their ability to monitor the voice radio transmissions, suggest that a Data Link environment may be acceptable with respect to the loss of the party line. In another study by Infield (1995), the conclusion was that no evidence was found that suggests an early Data Link environment poses a significant threat to situation awareness due to lack of party line or monitoring.

2.2.2 Clearance Negotiations.

In the current voice communication environment, the ability to negotiate an ATC clearance and the interactivity between controllers and pilots allows both parties to communicate approximations, estimates, and uncertainty instantaneously. The text based presentation of a Data Link message reduces this capability and using Data Link free text or menu message selection to downlink and negotiate headings and altitudes through high workload situations does not seem feasible. Clearance negotiations are an important issue concerning the implementation of Data Link communication into the current voice radio environment. The criticality of Data Link negotiations will escalate with advanced flight deck and ATC systems such as free flight, required time of arrival (RTA), etc.

The negotiation of clearances between ATC and pilots has been identified by the FAA Technical Center as a key research issue. In the 1991 ATA survey, the issue of clearance negotiations was ranked number 36 out of 45. SAE, under the issue of Procedural Guidelines for Using the System (issue number 6), gave the issue a critical rating. Furthermore, the need to set standards and procedures for negotiations and modifications to clearances is found under the Information Management and Display thrust of the 1995 National Plan for Civil Aviation Human Factors: An Initiative for Research and Application. The Data Link bibliography contains 14 reports on the topic of clearance negotiations.

In a study by Brown, Bensel, and Rehmann (1992), pilots expressed concern that the interactive benefits of voice communications would not be available through Data Link. How will the current ability to negotiate be affected? Additionally, will the pilot/controller lose the ability to communicate approximations, estimates, and uncertainty? These types of interactive benefits are especially useful for many types of communication. Konicke (1990) states that voice communication will continue to be relatively effective for long, ad hoc clearance negotiations and communication in critical flight phases, where the pilot's visual attention cannot be compromised.

Other studies have produced favorable comments regarding Data Link communications and clearance negotiations. A study by Williams, Arbuckle, and Green (1993) evaluated the use of a four-dimensional navigation FMS equipped aircraft for performing profile negotiations between controllers and pilots. Results found that both pilots and controllers agreed that digital Data Link is preferred over voice for Profile Negotiations Process (PNP) trajectory data exchange, and that Data Link should be a minimum requirement to support profile negotiations. In another study by Lee (1989), pilots stated one of the advantages of Data Link was the ability to make requests of the ATC system without having to wait for the frequency to clear. The issue of clearance negotiation receives a lot of comments from pilots participating in Data Link studies. However, as shown above, pilots have varying opinions on the best way to continue the capability to negotiate in a Data Link environment.

2.2.3 Airspace Environment.

The issue of airspace environment for Data Link implementation is an important topic in the Data Link research community due to the reduced frequency congestion being associated with Data Link communications. While the need to reduce voice frequency congestion is similar in the terminal and en route environments, the problem of designing an effective Data Link system presents some different problems for the two arenas. Data Link systems may increase internal visual requirements at precisely the time external vision is needed most, for example, during arrivals or departures at high-traffic air terminals.

The FAA Technical Center has identified airspace environment issues as a critical research area for investigation. In the Information Management and Display thrust of the 1995 National Plan for Civil Aviation Human Factors: An Initiative for Research and Application, the need is called out to prescribe communication policies related to flight phases and airspace, such as use in the terminal area and at low altitudes. Under the issue of Definition of Inhibit Logic, the 1991 ATA survey ranked Data Link airspace implementation number 33 out of 45. The issue of phase of flight inhibit logic for Data Link was given a desirable rating by SAE, under issue number 19 Definition of Inhibit Logic. The Data Link bibliography contains 38 reports on the topic of airspace environment.

The implementation of many different Data Link systems have been examined in high fidelity simulator research efforts over the years. Researchers have been interested in how Data Link operations will change pilots' responsibilities and activities in the cockpit, especially during times of high workload. The results from the following studies (Rehmann, van Gent, Bohnen, and Jorna, 1995; Knox and Scanlon, 1991; Talotta et al, 1990; Groce and Boucek, 1988) indicate that Data Link is acceptable during periods of low workload (i.e., En Route, Cruise). Results from Talotta et al (1990) stated that Data Link could effectively replace most functions currently served by voice in the en route and outer terminal environments.

However, regardless of the interface examined (CDU, IDU, MFD, etc.) none of the studies investigating the airspace environment indicated that Data Link is acceptable for high workload or terminal area ATC communications. In a study by Rehmann et al (1995), three different Data Link interfaces were investigated in a high fidelity full mission simulation and none of the interfaces were found to be acceptable for ATC applications during high workload situations such as descent. In another study by Knox and Scanlon (1991) crew members felt that when pilots operate in the terminal area, voice radio should be used as the primary communication device to reduce their heads down time (time when they should be visually monitoring for other aircraft traffic). However, the point where the pilots felt that the transition from Data Link to voice radio should occur varied between entering the terminal area and the final approach to the runway.

Other airspace research includes a survey and simulation exercise by Midkiff and Hansman (1993), in which they found that the importance of party line information appeared to be greatest for operations near or on the airport. This result indicates that caution must be exercised when implementing Data Link communications in these high workload, tactical sectors (Midkiff and Hansman, 1993). From the results presented above, pilots do not advocate the use of Data Link communication, which requires increased heads down time, when they are busy looking out the window for traffic or during any other high workload situations.

2.2.4 Mixed Communications (Voice/Data Link).

The implementation of Data Link will result in an operational environment with dual modes of information transfer between air and ground and there will be a mix of aircraft with and without Data Link capabilities. From one sector to the next pilots will be subjected to various mixes of voice and Data Link communications. The FAA Technical Center has identified there may be a problem with mixed communications and that it is a critical area for research. The issue of Mixed Environment was ranked number 28 out of 45 in the 1991 ATA survey. Mixed communications was rated as a serious issue for research by SAE, under issue number 23 identified as Implication of Dual System Operation. The Data Link bibliography contains eight reports on the topic of mixed communications.

The issue of dual modes of communication operating simultaneously has been examined with respect to the total number of transactions being transmitted in voice only systems compared to voice and Data Link systems. ATC studies have shown that a dual mode of communication requires fewer total transmissions when compared to an all voice system (Talotta et al, 1990; Hinton and Lohr, 1988). The results from these studies found a decrease in total transmissions (voice and Data Link) as the percentage of Data Link equipped aircraft in the scenario was increased. The reduction in frequency congestion on the voice channel as a result of the fewer total transmissions reduces the possibility of missed or blocked transmissions.

From the flightdeck perspective, the available research findings suggest that pilots desire to keep radio contact with the appropriate ATC facility throughout their flights using Data Link communications. Also, in a study by Hinton and Lohr (1988) pilots reported that the mix of voice and Data Link communications seemed completely natural. However, many pilots expressed concerns about these type of situations when experiencing critical weather or during terminal area ATC instructions. Pilots commented that any requests for deviations, for example, a heading to avoid thunderstorms, should be handled by voice to minimize pilot workload and to let other pilots in the vicinity know what is happening (Hinton and Lohr, 1988).

In another Data Link simulation study by Waller and Lohr (1989) pilots invariably objected to receiving a tactical clearance by voice when flying a scenario where Data Link was to be used for these types of transmissions. If Data Link is understood to be the primary mechanism for tactical clearance negotiation, they preferred that all routine messages be transmitted over the Data Link, or otherwise a convenient means of entering voice radio-derived clearance agreements into the CRT-displayed list of messages should be provided (Waller and Lohr, 1989).

3. CONCLUSIONS AND RECOMMENDATIONS.

The previous section identified past research efforts and discussed their findings in relation to the Data Link topic areas examined in this document. It was found that some of the topic areas have been addressed very thoroughly while others had only begun to be examined. Also, the findings from the various research in some cases were conflicting in terms of specific Data Link operational characteristics. This section will first draw conclusions regarding which topic areas have been adequately researched and which may still require additional evaluation. Based on the research findings recommendations will then be provided regarding the various issues related to a Data Link communications system.

SYSTEM OPERABILITY

System Location - Location is important because of the nature of the information (air traffic control (ATC) clearances), the variety of potential display systems on which Data Link may be hosted, and the potential frequency of usage. The potential locations for a Data Link display device within the cockpit are generally considered to be one of the following: forward-mounted or aft-mounted within the center pedestal. In a domestic airline fleet avionics study performed by Mitman, Neumeier, and Reynolds (1995) showed that approximately 2,500 aircraft are equipped with electromechanical avionics. Approximately 90 percent of these older aircraft do carry some form of Airborne Collision Avoidance Radar System (ACARS). About 55 percent of this subset uses a touch sensitive device located in the center pedestal, mostly located in the rear of the pedestal. At issue is the belief that airline economics may drive the use of these ACARS displays for ATC Data Link communications.

The research evaluating Data Link display locations is most conclusive, with all the findings reporting the same result. The forward-mounted display was found to require less time to respond to a message, provide a more efficient system and be more acceptable to the crew in all cases. Results indicated that even though space in the cockpit is at a premium, the data display, when used for ATC tactical messages, must be located in the pilot's forward field-of-view. Considering the visual time that would be spent inside the cockpit and the relatively difficult viewing and reach access, it is easy to see why the aft-mounted display location is unacceptable for receiving and acknowledging critical ATC tactical clearances. The research findings support the belief that the safety implications might outweigh the economic benefits of using displays located aft of the throttles in the center pedestal.

Recommendations:

a. The Data Link display used for ATC tactical messages should be located in the pilot's forward field of view.

b. An aft-mounted Data Link display should not be used for ATC tactical messages.

Crew Alerting - A survey of the Aviation Safety Reporting System (ASRS) database by Rehmann and Mitman et al (1995) characterized six problems with existing alerting systems. One problem area is non-distinguishable alerts, especially those that use subtle coding within the same aural tone, to indicate radically different levels of emergency conditions. Near-term ATC communications and farther term-free flight (RNP and airspace conflict) alerting mechanisms risk suffering the same types of problems already identified without careful consideration of flight deck integration. Additionally, long term exposure to ATC Data Link communications may result in flight crews becoming accustomed to the incidence of routine communications, and lessen the required alerting severity.

The Federal Aviation Administration (FAA) William J. Hughes Technical Center has performed numerous crew alerting studies investigating different alerting schemes for Data Link. Throughout all the research results one conclusion is continually being presented, a distinct aural alert is preferred for Data Link crew alerting. The majority of crew alerting studies utilize the SELCAL chime for Data Link as a nondistinct aural alert. The SELCAL chime is already associated with the ACARS display and pilots are confused as to which device to attend to when the alert is annunciated.

Further research should be conducted to examine acceptable alerting for an ATC Data Link alerting scheme. The findings would support the definition of minimum alerting requirements for ATC Data Link considering what type of alert (visual, aural, etc.), alert prioritization, and consistency within flight deck operations.

Recommendations:

a. A distinct aural alert should be utilized for ATC Data Link message alerting.
b. Investigate candidate distinct aural alerts for ATC Data Link crew alerting.

Display/Message Format - The format of ATC clearance information to flight crews must be clear and quickly understandable. Complicating the issue is the fact that a variety of display types may be used for Data Link, e.g., Flight Management System (FMS), control display unit (CDU), interactive display unit (IDU), etc. While the format of the Data Link display interface is slightly dependent on the display, there are many characteristics related to the format of the display system that can affect its readability and ease of use. In fact, recent research performed by the National Aerospace Laboratory (van Gent, 1995) found that crew acceptance of Data Link is highly sensitive to the design of the display's page formats and menu tree structure.

The research related to ATC Data Link display system formatting issues can be categorized in two main areas of investigation; the Data Link message format and the Data Link display menu structure. Numerous research efforts have been conducted investigating these issues and reporting a multitude of significant findings related to the ATC Data Link message format and display menu structure. Results have identified that a standardized Data Link message set should be developed using vocabulary consistent with the current operating environment. This would lead to a global standardized message set for all participants. Findings have also supported the use of feedback on the Data Link display for all CDU inputs to decrease the need to rely on mental models of the FMS structure and function.

Regarding CDU menuing, researchers have found that minimizing processing and page selection time through smart menuing will be a significant factor in the design of a successful ATC Data Link system using a CDU. Also, researchers have been able to increase Data Link acceptability by changing page layouts and optimizing some procedures to reduce the number of necessary keystrokes. Further research is needed to define minimum design standards for overall standardization, clarity/structure, etc., of an ATC Data Link communications system.

Recommendations:

a. ATC Data Link should have one standard message set for the operations and services that are scheduled to be provided.

b. Feedback should be provided for each user input into an ATC Data Link display.

c. ATC Data Link CDU display should have a smart menu structure that reduces the necessary number of keystrokes and page selection through automation.

Input/Output – The interface between the pilot and the ATC Data Link communications system is defined by the output modality for viewing the Data Link message and the input modality used by the pilot to interact with the system. Input device options currently available in the domestic fleet include keyboards, touch screens, and cursor control devices. Available output devices for presenting Data Link information include cockpit displays, voice synthesis, and cockpit printers. Implementation of an effective Data Link communications system is based on how the Input/Output characteristics of the system interact with present cockpit systems and coordinate with current pilot activities.

Most ATC Data Link research utilizes either a CDU keyboard or an IDU touchscreen device for inputting information to the Data Link system. The results indicate that the keyboard ranks superior to the touchscreen in terms of time to access and ease of use. These findings do not suggest that a keyboard is the optimum device for interfacing with the Data Link, but that it is much better than the touchscreen. Pilots had concerns with button activation, response times, and parallax regarding the use of touchscreen devices. Pilots stated that touchscreen devices present a suboptimal condition and should be avoided for text input.

Research is just beginning using voice recognition technology for Data Link input. This technology is being advanced and the potential is there for pilots to some day use speech to interface with a Data Link system. This capability is advantageous in that it would allow pilots much time to perform other manual tasks and spend more time heads up looking for traffic.

The output device most generally implemented for ATC Data Link research efforts is some form of a cockpit display. The textual interface offers more permanence of information by making it visually available to the crews for review at any time. However, the increased heads down time associated with cockpit displays is seen as a possible detractor and has led researchers to start examining the feasibility of synthesized speech for presenting Data Link messages. Results from synthesized speech studies are favorable. Findings include that the Pilot Flying (PF) glances less often and not as long at the CDU when digitized speech is available and that it provides a unique message alerting device. Furthermore, results favor redundant presentations of information such as text with speech. At a minimum, a textual format appears to be required for presentation of most messages. Addition of speech formats enhance individual and team comprehension of messages by allowing human access through multiple attentional resources.

Recommendations:

a. A CDU keyboard device is suggested for inputting information into an ATC Data Link display.

b. A touchscreen device should not be implemented for inputting information into an ATC Data Link display.

c. Investigate the voice recognition technology as a possible candidate for inputting information into the ATC Data Link system.

d. At a minimum some form of text-based cockpit display should be available for presenting ATC Data Link messages.

e. A synthesized speech output system alone should not be used for presenting ATC Data Link messages, only as a supplement to a text-based presentation.

Gating - The direct transfer, or gating, of data from a Data Link message into the Flight Management Computer (FMC), or other cockpit avionics, is a compelling concept associated with Data Link implementation being considered by the FAA. Gating will provide a reduction in workload and programming errors for pilots by not requiring them to manually transfer data from the Data Link message into the FMC and other flight control avionics. However, there are many concerns as to what type of information to gate and how the information is actually transferred. Pilots are opposed to any system that may, by default or design, diminish their aircraft command control.

Gating will also reduce workload when crews are required to compose and send downlink reports. Research has found that one of the most labor intensive aspects of the use of Data Link is air-initiated downlink reports. In the near-term tactical environment, downlink reports of assigned altitude are being considered. Gating is deemed necessary to at least preload data fields for the flight crew prior to sending a downlink report.

Research results suggest that pilots desire the ability to gate information automatically from Data Link. The concept of being able to check and download Data Link information directly into the FMC appealed to pilots. The automatic programming associated with Data Link gating appears to allow the pilot to concentrate on evaluating the clearance on the strategic level. Also, pilots spent less time in the combined communication and data management process when Data Link ATC commands were gated to other flight systems.

Additional Data Link research has addressed what type of information should be available for gating. Pilots desire an FMS type of gating which allows them to view proposed route changes on their navigation display and then transfer this information into the FMS. However, results have shown that pilots did not accept a form mode control panel (MCP) gating that allowed information regarding speeds, altitudes, and headings to be directly transferred into the MCP. The main concern among pilots was the issue of Crew Resource Management (CRM). There were no procedures to ensure both pilots were aware of the clearance instructions.

Future research should be conducted to investigate specifically what types of ATC clearance information should be gated and what type of effects do the various types of information have on each crew member's situation awareness and CRM. These findings could lead to the development of adequate CRM procedures to be followed by the flightcrew when gating ATC clearances.

Recommendations:

a. Data Link ATC clearance information should be gated to the flight management system.

b. Data Link ATC clearance information should not be gated to autoflight systems on the mode control panel.

c. Investigate what type of ATC information should be gated and what effects gating has on the situation awareness and crew resource management of both crew members.

SYSTEM IMPLEMENTATION

Situation Awareness/Party Line - Pilot situation awareness is a major concern for researchers investigating the effects of Data Link implementation. Enhanced situation awareness improves safety, pilot performance, and decision-making. There is concern, however, that Data Link will reduce the crew's situation awareness as a result of the loss of party line information currently being obtained from voice radio communications. The issue of party line deficiency in the Data Link environment has been the focus of numerous research studies.

Research has proven the usability of party line information by pilots to receive information about other aircraft and advance knowledge of events and conditions that might affect their flight. Pilots from many studies have deemed party line information necessary for safe flight. Furthermore, simulation and pilot survey results have found that pilots find party line information more important during operations on or near the airport. Since these operations are the most critical during a flight and this is when pilots tend to use the party line the most, it is determined that the party line information pilots receive provides a necessary benefit.

The fact that Data Link will effectively reduce the amount of information available on the voice channel has led some researchers to examining the ability to provide relevant party line information to pilots over the Data Link. Pilots have responded favorably to receiving extra Data Link messages containing information such as traffic delays, turbulence reports, and weather reports. If it does not result in too many additional messages being transmitted to make up for all the relevant party line information being missed because of Data Link, providing relevant information by Data Link may very well improve upon the pilots' current level of situation awareness with voice radio communications. Data Link implementation could be considered an opportunity to present the information currently available by party line communications in a more reliable, available, and intuitive manner. Carefully designed Data Link systems and procedures should be considered for their ability to provide pilot global situation awareness in order to support new methods of airspace management such as Automatic Dependent Surveillance (ADS) and free flight (Pritchett et al, 1995).

The majority of the research concerning Data Link and the loss of the party link has indicated that this information is important and pilots consider it necessary for safe flight. However, there have been some pilots who have a strong preference for the quiet flightdeck and the reduced frequency congestion associated with Data Link. The development and implementation of relevant information to present to the pilots through additional Data Link messages would still present both of the conditions while continuing to provide the necessary party line information.

Future research should address actual versus perceived party line information requirements of the crew for adequate situation awareness during different phases of flight in full-mission extended-operations LOFT study efforts.

Recommendations:

a. Investigate the feasibility of presenting additional operationally relevant information through Data Link to enhance situation awareness.

b. Investigate what type of party line information should be considered for transmission by Data Link to increase situation awareness.

Clearance Negotiations - Currently in the voice environment the ability to negotiate an ATC clearance and the interactivity between controller and pilots allows both parties to communicate approximations, estimates, and uncertainty instantaneously. The text-based presentation of Data Link diminishes this capability and the only option for negotiating is to downlink a free text message to the controller.

Present research efforts have not actually examined different options for negotiating clearances in a Data Link environment or even the effect of the loss of interactivity when trying to negotiate clearances with Data Link. The available findings are conflicting comments from pilots taking part in Data Link simulations investigating other issues. Some pilots are concerned with the loss of interactivity with the controllers and that voice communication is more effective for long ad hoc clearance negotiations, especially during critical phases of flight. While other pilots see Data Link clearance negotiations as advantageous due to the ability to make requests without having to wait for the frequency to clear.

Clearly, the issue of negotiating a clearance using Data Link communications has positive and negative aspects. Also, the criticality of Data Link negotiations will escalate with advanced flight deck and ATC systems such as free flight, required time of arrival (RTA), etc. Due to the lack of relevant research specifically addressing Data Link clearance negotiations, it is impossible to make detailed recommendations. Future research efforts should examine the issue more closely to see how important the interactivity between pilots and controllers is in the negotiating process, and how composing downlinks for negotiating clearances effects pilot performance in different phases of flight.

Recommendations:

a. Investigate the importance of interactivity between pilots and controllers.

b. Investigate the effect of composing Data Link downlinks for negotiating clearances in different phases of flight.

Airspace Environment - The issue of airspace environment for Data Link implementation is an important topic in the Data Link research community due to the reduced frequency congestion being associated with Data Link communications. While the need to reduce voice frequency congestion is similar in the terminal and en route environments, the problem of designing an effective Data Link system presents some different problems for the two arenas. Data Link systems may increase internal visual requirements at precisely the time external vision is needed most - for example, during arrivals or departures at high-traffic air terminals.

Numerous airspace environment research findings have consistently found Data Link to be unacceptable in high workload phases of flight. Regardless of the interface that has been tested, results suggest using radio transmissions for ATC communications in areas such as the terminal environment. Pilots feel that an incoming Data Link message will require too much attention (heads down) inside the cockpit when they should be visually monitoring for other aircraft traffic. In contrast, many studies have found that pilots find Data Link communications acceptable for use in low workload environments with any of the commonly Data Link associated display based interfaces (CDU, IDU, multi-function display (MFD), etc.). Pilots state that Data Link could effectively replace most functions currently served by voice in the en route and outer terminal environments.

The past research investigating airspace environment for Data Link implementation has always implemented some form of a displayed based interface. True, this type of device is likely to be the interface for initial Data Link operations in most, if not all, aircraft. Be that as it may, future research should examine the feasibility and acceptability of using speech synthesis technology in the terminal area. A non-display based interface may allow pilots to operate with the benefits of Data Link ATC communications while still being able to sufficiently monitor out the window for traffic.

Recommendations:

a. Data Link ATC communications should not be implemented in the high workload terminal environment near the airport, regardless of the currently available visual display based interfaces being considered.

b. ATC Data Link communications should be implemented in low workload periods of flight (i.e., En Route, Cruise, Oceanic).

Mixed Communications (Voice/DL) - Initial implementation of Data Link will result in varying degrees of Data Link/voice mixed communications. From sector to sector there will be a different percentage of Data Link equipped aircraft and Data Link messages being transmitted. Research has found benefits and some possible negative effects associated with presenting pilots with mixed modes of communication. Results indicate that pilots receiving voice transmissions are secure in knowing that they have constant radio contact. However, receiving a constant mix of voice and Data Link messages throughout a flight disrupts the flow of the Data Link log of past messages and pilots will not have a text version to recall if needed. The findings also suggest that mixed mode communications may provide benefit by transmitting information on the party line during certain necessary situations (i.e., weather avoidance, evasive action instructions) or phases of flight (i.e., descent, terminal, etc.). However, they may also confuse the flightcrew and increase attentional resource demands while trying to simultaneously monitor for the Data Link aural alert and their call sign on the voice channel.

Past research has examined mixed modes of communication in general, obtaining data from pilots on the acceptability of receiving both Data Link and voice messages throughout a flight. It is recommended that further research be conducted investigating the acceptability of mixed modes of communication in various phases of flight and for various types of messages. These findings could possibly lead to the formulation of procedures or guidelines that would stipulate situations when pilots could expect a Data Link or a voice message.

Recommendations:

a. Mixed mode communication should not be present in high workload phases of flight (near or on the airport surface).

b. Regardless of phase of flight, pilots should always be in radio contact with an ATC facility.

c. Upon Data Link implementation, procedures and/or guidelines need to be determined to allow Data Link operational pilots to know what type (tactical, strategic, etc.) of Data Link messages they can receive in a particular phase of flight.

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5. ACRONYMS AND ABBREVIATIONS

AC	Advisory Circular
ADLG	Airborne Data Link Group
ADLP	Airborne Data Link Program
ATA	Air Transport Association
ATC	Air Traffic Control
ATIS	Automated Terminal Information Service
ATM	Air Traffic Management
CDU	Control Display Unit
CPDLC	Controller Pilot Data Link Communications
CRM	Crew Resource Management
CSERIAC	Crew System Ergonomics Information Analysis Center
CTA	Computer Technology Associates
DL	Data Link
DOD	Department of Defense
DOT	Department of Transportation
DTIC	Defense Technical Information Center
FAA	Federal Aviation Administration
FMS	Flight Management System
HCI	Human Computer Interface
IDU	Interactive Display Unit
MCP	Mode Control Panel
MFD	Multi-Function Display
MIT	Massachusetts Institute of Technology
MSR	Midwest Systems Research
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NLR	National Lucht-EN Ruimtevaartlaboratorium (Dutch National Aerospace Laboratory)
NTIS	National Technical Information Service
PDC	Pre-Departure Clearance
PF	Pilot-Flying
PNF	Pilot-Not-Flying
PNP	Profile Negotiation Process
RTCA	Formerly the Radio Technical Commission for Aeronautics
SA	Situation Awareness
SAE	Society of Automotive Engineers
TCAS	Traffic Alert and Collision Avoidance System

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6.1 System Operability

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6.2 System Implementation Issues

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34	Integrative Thinking for High Tech Cockpit Development	Stahr, R. S.	91/05	Specific Data Link Research	Proceedings of the Third Annual International Aeronautical Telecommunications Symposium on Data Link Integration, Mclean Hilton Mclean, Virginia, May 20-23, 1991, pps. 3-11		United Airlines
38	Digital Communication in the Cockpit	Murphy, M. E.	91/05	Specific Data Link Standards and Guidelines	Proceedings of the Third Annual International Aeronautical Telecommunications Symposium on Data Link Integration, Mclean Hilton Mclean, Virginia, May 20-23, 1991, pps. 119-123		Boeing
43	A Progress Report on Data Link ATC Service Development Research at the FAA Technical Center	Talotta, N. J., and Shingledecker, C. A.	91/05	Specific Data Link Research	Proceedings of the Third Annual International Aeronautical Telecommunications Symposium on Data Link Integration, Mclean Hilton Mclean, Virginia, May 20-23, 1991, pps.223-229		FAATC, NTI
48	Flight Operations and Air Traffic Management Integration	Miller, C. A., and Chang, G. C.	91/09	Specific Data Link Research	Proceedings of the First Annual International Satellite Surveillance and Communication Symposium, September 24-26, 1991, pps. 357-363		FAA
52	Evaluation of Oceanic Flight Deck Workload and Error Reductions Through the use of Data Communications	White, V., and Heinrich, R. E.	91/09	Specific Data Link Research	Proceedings of the First Annual International Satellite Surveillance and Communication Symposium, pps. 445-452		ARINC

No.	Title	Author	Date	Document Type	Source	Report Number	Performing Organization
55	Considerations for the Retrofit of Data Link	Corwin, W. H., and McCauley, H. W.	90/10	Specific Data Link Research	Aerospace Technology Conference and Exposition Long Beach, California, October 1-4, 1990	SAE 901886	Douglas Aircraft Company, McDonnell Douglas Corporation
57	Human Factors: What are the human-factors issues in air-traffic control by Data Link?	Learmount, D.	94/11	Specific Data Link Research	Flight International 16-22 November 1994		
60	Flightdeck Party Line Issues: An Aviation Safety Reporting System Analysis	Rehmann, A., Neumeier, M., Mitman, R., and Reynolds, M.	95/06	Specific Data Link Research		DOT/FAA/CT-TN95/12	CSERIAC
61	Flightdeck Automation Issues: An Aviation Safety Reporting System Analysis	Rehmann, A., Neumeier, M., Mitman, R., and Reynolds, M.	95/06	Specific Data Link Research		DOT/FAA/CT-TN95/11	CSERIAC
63	Handbook - Volume II Digital Systems Validation, Chapter 19 Pilot-Vehicle Interface	Harrison, L., Janowitz, J., and Castronuovo, M.	93/11	Related Standards and Guidelines		DOT/FAA/CT-88/10	Galaxy Scientific Corporation

No.	Title	Author	Date	Document Type	Source	Report Number	Performing Organization
69	DATA LINK: A Conceptual Flight Deck System and Related Issues	Murphy, M. E.	93/01	Specific Data Link Research	Enhanced Situation Awareness Technology for Retrofit and Advanced Cockpit Design, SAE SP-933, Aerotech '92	SAE 922002	Boeing
71	Human Factors Issues of Data Link: Application of a Systems Analysis	Riley, V.	93/01	Specific Data Link Research	Enhanced Situation Awareness Technology for Retrofit and Advanced Cockpit Design, SAE SP-933, Aerotech '92	SAE 922021	Honeywell, Inc.
72	Experimental Studies on the Effect of Automation on Pilot Situation Awareness in the Data Link ATC Environment	Hahn, E. C., and Hansman, R. J., Jr.	93/01	Specific Data Link Research	Enhanced Situation Awareness Technology for Retrofit and Advanced Cockpit Design, SAE SP-933, Aerotech '92, pps 129-140	SAE 922022	MIT, Aeronautical Systems Laboratory
73	Identification of Important "Party Line" Information Elements and the Implications for Situational Awareness in the Data Link Environment	Midkiff, A. H., and Hansman, R. J., Jr.	93/01	Specific Data Link Research	Enhanced Situation Awareness Technology for Retrofit and Advanced Cockpit Design, SP933	SAE 922023	MIT, Aeronautical Systems Laboratory
76	Operational Evaluation of Initial Data Link Air Traffic Control Services, Volume I	Talotta, N., Shingledecker, C., and Rehmann, A.	90/02	Specific Data Link Research		DOT/FAA/CT-90/1, I	FAATC

No.	Title	Author	Date	Document Type	Source	Report Number	Performing Organization
80	Situation Awareness: Its Role in Flight Crew Decision Making	Orasanu, J.	95	Related Research			NASA Ames Research Center
92	Oceanic Clearance Delivery Via Air/Ground Data Link	Aitken, S.	88/10	Specific Data Link Research	AIAA/IEEE Digital Avionics Systems Conference, 8th, San Jose, CA, Oct. 17-20, 1988	AIAA 88-3994-CP	Transport Canada
93	Mode S Data Link Pilot-System Interface: A Blessing in De Skies or a Beast of Burden?	Reynolds, M. C., and Neumeier, M. E.	91/04	Specific Data Link Research	Proceedings of the 6th International Symposium on Aviation Psychology, Columbus, OH, Apr. 29-May 2, 1991, Proceedings. Vol. 1		Midwest Systems Research, Inc.
94	FAA Airborne Data Link Human Factors Research Plan	Rehmann, A. J., Reynolds, M. C., and Neumeier, M. E.	93/07	Specific Data Link Research		DOT/FAA/CT-TN93/5	Midwest Systems Research, Inc.
95	Human Factors Requirements for Data Link, Condensed Version	Air Transport Association	92/06	Specific Data Link Standards and Guidelines			ATA Information Transfer Subcommittee

No.	Title	Author	Date	Document Type	Source	Report Number	Performing Organization
100	Air Traffic Control (ATC) and Air/Ground Digital Communications; Demonstration and Evaluation	Fellman, L., and J. C. Moody	88/10	Specific Data Link Research	AIAA/IEEE Digital Avionics Systems Conference, 8th, San Jose, CA, Oct. 17-20, 1988	AIAA 88-3998-CP	MITRE
102	A Line Pilot's Perspective on Data Link Services in Domestic and Oceanic Air Space Traffic Control	Brown, T. L., Bensel, B., and Rehmann, A.	92/01	Specific Data Link Research			CTA Incorporated, FAATC
105	The effects of reduced partyline information in a Data Link environment	Infield, S. E., Logan, A., Palen, L., Hofer, E., Smith, D., Corker, K., Lozito, S., and Possolo, A.	95	Specific Data Link Research	Human factors in aviation operation; Proceedings of the 21st Conference of the European Association for Aviation Psychology (EAAP), pps. 51-56		Boeing, NASA Ames Research Center
107	The effects of ATC Data Link on instrument and environmental scanning during flight operations	Infield, S. E., Palen, L., Pepitone, D., Kimball, S., Smith, D., Possolo, A., Corker, K., and Lozito, S.	95	Specific Data Link Research	Human factors in aviation operation; Proceedings of the 21st Conference of the European Association for Aviation Psychology (EAAP), pp 63-68, Volume iii		Boeing, NASA Ames Research Center
111	Distributed situation awareness: a concept to cope with the challenge of tomorrow	Javaux, D., and Figarol, S.	95	Related Research	Human factors in aviation operation; Proceedings of the 21st Conference of the European Association for Aviation Psychology (EAAP), pps 293-298		University of Liege, CENA

No.	Title	Author	Date	Document Type	Source	Report Number	Performing Organization
112	Profile Negotiation: An Air/Ground Automation Integration Concept for Managing Arrival Traffic	Williams, D. H., Arbuckle, P. D., Green, S. M., den Braven, W.	93/10	Specific Data Link Research	AGARD, Machine Intelligence in Air Traffic Management, 22-1 thru 22-11	AGARD-CP-538	NASA Langley Research Center, NASA Ames Research Center, NLR, National Aerospace Laboratory
115	The Ultimate Goal of ATC/Data Link	Stahr, S.	90/04	Specific Data Link Research	ARINC/FAA Data Link Symposium, Planned to be presented		United Airlines
127	Challenges in Aviation Human Factors: The National Plan	AIAA/NASA/FAA/HFS - Sponsors	91/01	Specific Data Link Research	Book of Abstracts, 15-17 January, 1991 Sheraton Premiere Tysons Corner		AIAA, NASA, FAA, HFS
160	Proposed Research Agenda for Data Link	Air Transport Association, ATA	92/01	Specific Data Link Research	(Intended for Inclusion in the ATC/Flight Deck Integration Section of the National Plan for Aviation Human Factors), Submitted to ATA Last Revised 1/24/92		ATA Information Transfer Subcommittee
165	Boeing Works to Keep Pilot in Decision Loop on Board Advanced 777	O'Lone, R. G.	92/03	Related Research	Aviation Week & Space Technology, March 23, 1992, 136(12), 61		Boeing

No.	Title	Author	Date	Document Type	Source	Report Number	Performing Organization
166	Pilots, Human Factors Specialists Urge Better Man-Machine Cockpit Interface	Phillips, E. H.	92/03	Related Research	Aviation Week & Space Technology, March 23, 1992, pp 67-68		
171	Hazard Alerting and Situational Awareness in Advanced Air Transport Cockpits	Hansman, R.J., Wanke, C., Kuchar, J., Mykityshyn, M., Hahn, E., and Midkiff, A.	92/09	Specific Data Link Research	ICAS, Congress, 18th, Beijing, China, Sept. 20-25, 1992, Proceedings. Vol. 2		MIT, Aeronautical Systems Laboratory
172	Situational Awareness in the Commercial Flight Deck: Definition, Measurement, and Enhancement	Regal, D. M., Rogers, W. H., and Boucek, G. P.	88/10	Related Research	Aerospace Technology Conference and Exposition, Oct 3-6, 1988	SAE 881508	Boeing
175	Design and Evaluation for Situation Awareness Enhancement	Endsley, M. R.	88	Related Standards and Guidelines	Proceedings of the Human Factors Society 32nd Annual Meeting, 1988. pps. 97-101		Northrup Aircraft
180	User Benefits of Two-way Data Link ATC Communications: Aircraft Delay and Flight Efficiency in Congested En Route Airspace	Data Link Benefits Study Team	95/02	Specific Data Link Research		DOT/FAA/CT-95/4	FAATC

No.	Title	Author	Date	Document Type	Source	Report Number	Performing Organization
198	Cockpit Data Management	Groce, J. L., and Boucek, G. P.	88/02	Specific Data Link Research		NASA CR 178407	Boeing
215	Data Link Communications in the National Airspace System	Lee, A. T.	89	Specific Data Link Research	Proceedings of the Human Factors Society 33rd Annual Meeting, 1989		NASA Ames Research Center
228	Human Factors in ATC/Flight Deck Integration Implications of Data Link Simulation Research	Kerns, K.	94/09	Specific Data Link Research		MP 94W0000098	Mitre
233	Human Factors Issues With Airborne Data Link: Towards Increased Crew Acceptance For Both En-Route and Terminal Flight Operations	Van Gent, R.N.H.W.	95	Specific Data Link Research			NLR
242	A Flight Investigation of Simulated Data-Link Communications During Single-Pilot IFR Flight Volume 2 - Flight Evaluation	Parker, J.F. Jr., and Duffy, J.W.	82	Specific Data Link Research		NAS1-16037	NASA

No.	Title	Author	Date	Document Type	Source	Report Number	Performing Organization
247	Operational Evaluation of Initial Data Link Air Traffic Control Services. Volume 2: Appendices - Final Report	Talotta, Nicholas J., Shingledecker, C., and Reynolds, M.	90/02	Specific Data Link Research		DOT/FAA/CT-90/1-VOL-2, AD-A228554	FAATC
248	Flight Tests With a Data Link Used for Air Traffic Control Information Exchange	Knox, Charles E. and Scanlon, Charles H.	91/09	Specific Data Link Research		NASA TP-3135	NASA
250	A piloted Simulation Study of Data Link ATC Message Exchange	Waller, Marvin C. and Lohr, Gary W.	89/02	Specific Data Link Research		NASA TP-2859	NASA
255	Display-based communications for advanced transport aircraft	Lee, Alfred T.	89	Specific Data Link Research		NASA TM-102187	Ames Research Center
257	The Aeronautical Data Link System Vision: The Key to Future Air Traffic Services	Data Link Operational Requirements Team	94/01	Specific Data Link Standards and Guidelines			FAA
258	The Aeronautical Data Link System Operational Concept	Data Link Operational Requirements Team	94/06	Specific Data Link Standards and Guidelines			FAA

6.3 Other

No.	Title	Author	Date	Document Type	Source	Report Number	Performing Organization
3	Data Link Communication Between Controllers and Pilots: A Review and Synthesis of the Simulation Literature	Kerns, K	90/07	Specific Data Link Research		MITRE MP-90W00027	MITRE
4	Minutes of the Data Link Workshop held at the NLR (Amsterdam) May 3&4, 1994	van Gent, R.	94/05	Specific Data Link Research		NLR CR 94317 L	NLR, National Aerospace Laboratory
10	Human Factors Issues Associated with Data Link: Application of an Analytic Process to Identify System Level Issues and Requirement Areas, DRAFT	Riley, V.	91/04	Specific Data Link Research			Honeywell, Inc.
16	Data Link Communication Between Controllers and Pilots: State of the Knowledge	Kerns, K.	90/10	Specific Data Link Research	Aerospace Technology Conference and Exposition Long Beach, California, October 1-4, 1990	SAE 901887	MITRE

No.	Title	Author	Date	Document Type	Source	Report Number	Performing Organization
18	Data Link	Society of Automotive Engineers, SAE	93/06	Specific Data Link Standards and Guidelines		SAE ARP 4102/13	SAE S-7 Committee, Flight Deck and Handling Qualities Standards for Transport Aircraft
19	Development of an Air Ground Data Exchange Concept: Flight Deck Perspective	Flathers, G. W. II	87/06	Specific Data Link Research		NASA CR 4074	MITRE
32	Pilot-Air Traffic Control Communications: It's Not (Only) What You Say, It's How You Say it	Cushing, S.	95/07	Related Research	Flight Safety Digest, Flight Safety Foundation, July 1995		Intersystems Corporation
33	Potential Conflicts of Time Sharing the Flight Management System Control Display Unit with Data Link Communications	Williams, C. L.	95	Specific Data Link Research	Proceedings of the 8th International Symposium on Aviation Psychology, Columbus, OH: Ohio State Univ		San Jose State University
35	Airline and Civil Aviation Authorities Requirements for Global Data Link Services Progress & Issues	Ryan, P. R.	91/05	Specific Data Link Research	Proceedings of the Third Annual International Aeronautical Telecommunications Symposium on Data Link Integration, Mclean Hilton Mclean, Virginia, May 20-23, 1991, pps. 7-11		American Airlines, ATA

No.	Title	Author	Date	Document Type	Source	Report Number	Performing Organization
37	Flight Tests Show Potential Benefits of Data Link as Primary Communication Medium	Scanlon, C. H., and Knox, C. E.	91/05	Specific Data Link Research	Proceedings of the Third Annual International Aeronautical Telecommunications Symposium on Data Link Integration, Mclean Hilton Mclean, Virginia, May 20-23, 1991, pps.		NASA Langley Research Center
49	Communication Needs of the Future Air-Ground Interface	Martin, A. J., and Molloy, N. D.	91/09	Specific Data Link Standards and Guidelines	Proceedings of the First Annual International Satellite Surveillance and Communication Symposium, pp 385-406		Boeing
58	Human Factors for Flight Deck Certification Personnel, Final Report	Cardosi, K., and Huntley, S.	93/07	Related Standards and Guidelines		DOT/FAA/RD-93/5	John A. Volpe National Transportation Systems Center
63	Handbook - Volume II Digital Systems Validation, Chapter 19 Pilot-Vehicle Interface	Harrison, L., Janowitz, J., and Castronuovo, M.	93/11	Related Standards and Guidelines		DOT/FAA/CT-88/10	Galaxy Scientific Corporation
64	Cockpit Human Factors Research Requirements	Transportation Systems Center, Cambridge, MA, U.S. DOT Research and Special Programs Administration	89/04	Related Standards and Guidelines			Transportation Systems Center, Research and Special Programs Administration, DOT/FAA

No.	Title	Author	Date	Document Type	Source	Report Number	Performing Organization
65	Proceedings of the FAA/NASA/Industry Workshop on Data Link Communications, DRAFT	Lee, A. T.	88/12	Specific Data Link Research			NASA Ames Research Center
68	Airline Perspective on Data Link	Ryan, P. R.	93/01	Specific Data Link Research	Enhanced Situation Awareness Technology for Retrofit and Advanced Cockpit Design, SAE SP-933, Aerotech '92	SAE 922001	American Airlines
75	A Comparison of Data Link Guidelines listed in ATA's "Human Factors Requirements for Data Link" and CTA's "Human Factors Guidelines for the Evaluation of Airborne Data Link Systems	Mitman, R. D.	92/07	Specific Data Link Standards and Guidelines		MSR-WP-92-12625-02	Midwest Systems Research, Inc.
115	The Ultimate Goal of ATC/Data Link	Stahr, S.	90/04	Specific Data Link Research	ARINC/FAA Data Link Symposium, Planned to be presented		United Airlines
123	Aeronautical Data Link Applications	Peal, R. A.	91/05	Specific Data Link Standards and Guidelines	Proceedings of the Third Annual International Aeronautical Telecommunications Symposium on Data Link Integration, Mclean Hilton Mclean, Virginia, May 20-23, 1991, pps.		Boeing

No.	Title	Author	Date	Document Type	Source	Report Number	Performing Organization
125	Development of Applications for the Air Ground Data Exchange Using Mode S Data Link: FAA Program Status	Argyropoulos, A., and Mclaurin, H.	90/10	Specific Data Link Research	Aerospace Technology Conference and Exposition Long Beach, California, October 1-4, 1990	SAE 901955	MITRE, FAA
134	Human Factors in Aviation Operations: The Hearback Problem	Monan, W. P.	86/03	Related Research		NASA CR 177398	Battelle, Columbus Division
159	Future Aeronautic Environment FMS/ATC/Pilot	Deque, R., and Bachelier, P.	90/12	Specific Data Link Research	Aeronautical Journal, December 1990		Aerospatiale Aircraft Division
161	National Plan to Enhance Aviation Safety Through Human Factors Improvements	Human Factors Task Force in Cooperation with Industry and Government	89/04	Related Research			ATA
180	User Benefits of Two-way Data Link ATC Communications: Aircraft Delay and Flight Efficiency in Congested En Route Airspace	Data Link Benefits Study Team	95/02	Specific Data Link Research		DOT/FAA/CT-95/4	FAATC

No.	Title	Author	Date	Document Type	Source	Report Number	Performing Organization
202	Mode S Data Link Master Plan, Coordination Draft	Systems Engineering Service, US DOT/FAA	86/01	Specific Data Link Research			FAA, AES-210
213	A Systems Analysis to Identify Human Factors Issues and Requirements for Data Link	Riley, V.	91	Specific Data Link Research	Proceedings of the Human Factors Society 35th Annual Meeting, 1991		Honeywell, Inc.
235	Air Traffic Services Data Link Communications Equipment and Application Minimum Requirements	Murphy, M.E.	92/04	Specific Data Link Standards and Guidelines			RTCA
238	Communications Interface Problems Between Air Traffic Controllers and Pilots	Townsend, Robert K.	91/03	Related Research	Journal of ATC 3-91		Journal of ATC
239	Analysis of Problems in Routine Controller-Pilot Communication	Morrow, D., Lee, A., and Rodvold, M.	93	Related Research	The International Journal of Aviation Psychology, 3(4), 285-302		Decision Systems

No.	Title	Author	Date	Document Type	Source	Report Number	Performing Organization
252	Airborne Data Link operational evaluation test plan	Rehmann, Albert J. and Mogford, R. H.	93/8	Specific Data Link Research	DTIC	DOT/FAA/CT-TN93/30	CTA, Incorporated
253	Pilot-vehicle interface - Final Report	Harrison, L., Janowitz, J., and Castronuovo, M.	93/11	Related Standards and Guidelines		DOT/FAA/CT-92/21	Galaxy Scientific Corporation
254	FAA Technical Center Aeronautical Data Link Research Plan - Final Report, Oct. 1991 - Sep. 1992	Buck, F., Cratch, P., Fischer, T., Lunder, J., Shingledecker, C., Stahl, D., and Sweeny, D.	92/10	Specific Data Link Standards and Guidelines		DOT/FAA/CT-92/23	FAATC