Office of Inspector General

Audit Report

FAA's Progress and Plans for Implementing Data Link for Controllers and Pilots

Federal Aviation Administration

Report Number: *AV-1999-057*
Date Issued: *February 24, 1999*

Memorandum

U.S. Department of Transportation
Office of the Secretary of Transportation
Office of Inspector General

Subject: ACTION: Report on FAA's Progress and Plans for Implementing Data Link for Controllers and Pilots, AV-1999-057

Date:

Reply to Attn of: JA-10

From: Lawrence H. Weintrob
Assistant Inspector General for Auditing

To: Federal Aviation Administrator

This report summarizes our review of the Federal Aviation Administration's (FAA) progress and plans for implementing a data link for controllers and pilots. We are providing this report for your information and use. An executive summary of the report follows this memorandum.

As you know, an effective and reliable data link is an important technology for Free Flight. A consensus has emerged on the initial steps for implementing data link in domestic airspace. However, implementing this technology is a complex, long-term effort that has far reaching implications for controllers and pilots. Our report examines the risks and challenges that FAA and industry face in implementing this new technology. We are making recommendations aimed at improving FAA's management of data link efforts, mitigating risks, and making future efforts more cost effective.

During our work, we periodically met with members of your staff, including officials from Research and Acquisitions, Aircraft Regulation and Certification, and Air Traffic Services as well as the Free Flight Phase 1 Program Office and have taken their comments into consideration in preparing this report. We held an exit conference with your staff on January 20, 1999, and have incorporated their comments as appropriate. At that meeting, FAA program officials generally concurred with our analysis and recommendations.

In accordance with Department of Transportation Order 8000.1C, we would appreciate receiving your written comments within 30 days. Please indicate

for each recommendation the specific action taken or planned and the target dates for completion. If you do not concur, please provide your rationale. Furthermore, you may provide alternative courses of action that you believe would resolve the issues presented in the report.

We appreciate the cooperation and assistance provided by you and your staff during our review. If you have any questions or need further information, please contact me at (202) 366-1992 or Alexis Stefani, Deputy Assistant Inspector General for Aviation at (202) 366-0500.

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Attachment

EXECUTIVE SUMMARY

Modernizing the Nation's air traffic control system to meet the growing demand for air travel is an urgent issue. The National Civil Aviation Review Commission warned that without improvements, the U.S. air transportation system will suffer from system-wide delays and gridlock soon after the turn of the century. The Federal Aviation Administration (FAA) and the aviation industry have embarked on an effort known as Free Flight[1] that offers the possibility of reducing delays, more fuel efficient routes, and avoiding gridlock. Free Flight calls for air traffic controllers and pilots to make extensive use of new digital communication technology, commonly referred to as data link, to improve the safety and efficiency of the National Airspace System. This report discusses FAA's efforts to develop and implement new data link technology for controllers and pilots.

The objective of our review was to evaluate FAA's efforts to develop Controller-Pilot Data Link Communications. We focused our work on (1) current plans for implementing a data link for controllers and pilots in domestic airspace, (2) risks and challenges the program faces, and (3) FAA's management of the program.

BACKGROUND

Today, voice radio is the only way controllers and pilots communicate during flight in domestic airspace. Controllers and pilots rely on voice radios to share routine flight information (changes in altitude, speed, and heading), warnings, and weather updates, that are essential for the safe and efficient operation of aircraft. While this system has served aviation well, some problems exist with respect to communication errors and misunderstandings between controllers and pilots. Additionally, when a controller must share a single radio channel with up to 25 aircraft, competition for the channel can lead to substantial delays and frustration by pilots. To alleviate these problems, FAA and others have long argued the need for data link communications.

Data link technology offers controllers and pilots a new way to exchange information that is expected to be faster and more reliable than current voice communications. *In its simplest form, data link is analogous to electronic mail, where a person can send a message to other people without speaking to them*. The potential benefits of controller-pilot data link communications

[1] Free Flight changes the philosophy of FAA and aircraft operators from that of air traffic control to air traffic management. It will allow pilots and controllers to share information and work together to manage air traffic. With Free Flight, pilots will not have to fly routes structured around ground-based navigation.

include increased controller efficiency, reduced voice congestion, and reduced communication errors.

Data link is a complex technology that has been under development at FAA for the past 15 years. Controller-Pilot Data Link Communications is one use of data link technology. We focused on FAA's efforts to develop a data link for controllers and pilots to share information during flight in domestic airspace. In the near term, only commercial airlines are expected to equip with this new technology. FAA intended to have data link in use at select air traffic control facilities by late 1996 but now estimates that data link will be in use at only one location in mid 2002--six years later than anticipated.

RESULTS-IN-BRIEF

An effective and reliable data link for controllers and pilots is an important technology for Free Flight. After significant delays and lack of agreement between FAA and industry, a consensus on the initial steps for implementing Controller-Pilot Data Link Communications[2] in domestic airspace is emerging. However, implementing this new technology is a complex, long-term effort that represents an extraordinary integration challenge because both air and ground systems must work together and exchange information on a near real-time basis. Changes in program content, cost, and milestones are likely.

Data link is early in the development phase and faces a number of challenges, such as significant human factors concerns and sophisticated software development, that have led to cost increases and delays in other modernization projects. FAA has the opportunity to proactively address these issues to better ensure the success of the acquisition. Specifically, we found:

- The cost to fully implement data link throughout the National Airspace System for both FAA and the airlines is substantial but uncertain. FAA estimates that data link will cost the agency $645 million over and above the $420 million spent thus far on various data link efforts through 2015. *These estimates include costs for en route facilities but do not include costs for implementing data link at other types of air traffic control facilities.* FAA plans to spend almost $25 million in Fiscal Year 1999 and about $42 million in Fiscal Year 2000 on various data link efforts. While no firm estimates exist, the cost to modify an aircraft for data link, which includes new avionics and modification of cockpits, ranges from $100,000 to over $1 million. FAA needs to provide Congress with a comprehensive plan along with the agency's budget request that includes the status of data link

[2]For the purposes of this report, we refer to Controller-Pilot Data link Communications as "data link".

efforts, future funding requirements, milestones, and how human factors concerns are being addressed. This plan, once it is developed, will need to be updated regularly because data link is in the early stages of development and there will be changes in program costs and schedule.

- Considerable development, overall integration work, and test and evaluation remain to be done before data link can be implemented in domestic airspace. FAA intends to implement data link at Miami en route center in June 2002 leading to a national deployment beginning in June 2003. These milestones are ambitious given the scope and complexity of the effort. For example, testing of sophisticated software has slipped 7 months from June 1999 to February 2000. Once this software is completed and tested, it must be integrated with aircraft avionics and FAA ground systems.

- The introduction of data link has profound implications for controllers and pilots and will fundamentally change the way they communicate. For example, *an important issue is how controllers and pilots will use two distinct communications systems (voice and data link) to share important information. Controllers will be expected to handle both data link and non-data link equipped aircraft in the same airspace, which could lead to additional workload for both controllers and pilots*. Human factors issues must be given a high priority with sufficient funding to ensure that controller and pilot concerns are addressed early and throughout the process and do not result in safety problems or extensive delays.

- FAA does not intend to mandate the use of data link but rather intends to build on planned airline investments in new digital technology over a number of years. *It is important to recognize that relying solely on voluntary airline action could prolong the transition to data link and when benefits can be realized.* This will have a corresponding impact on cost, schedule, and human factors concerns.

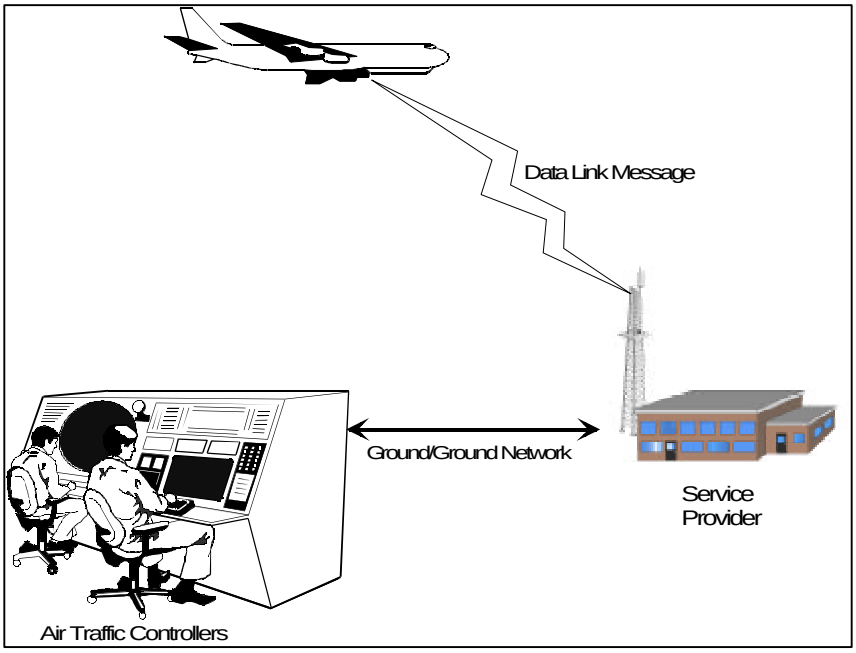
- FAA has viewed data link from four distinct operational perspectives--en route, terminal, tower, and oceanic environments. There was little effective coordination among them. FAA is beginning to address these concerns and is preparing an agreement between the organizations responsible for implementing data link at domestic and oceanic facilities.

FAA generally agrees with our analysis and acknowledges that changes are needed in the overall management of data link. FAA officials told us that the agency is requesting that RTCA--an advisory body to FAA--form a special committee to aid in implementing data link.

PLANS FOR IMPLEMENTING DATA LINK IN DOMESTIC AIRSPACE

FAA intends to implement data link through a series of phases, or builds, beginning with a test site at the Miami en route center in June 2002. American Airlines has agreed to participate and has committed to install new data link equipment on some of its aircraft. Figure 1 illustrates how controllers and pilots will use data link.

Figure 1: Planned Use of Data Link Communications for En Route Facilities



Since December 1997, FAA has made significant changes in how it will implement data link in domestic airspace that focus on, among other things, a new data link technology and efforts to comply with international standards for aeronautical data communications. First, FAA and industry have abandoned attempts to use an existing airline data link system known as the Airline Communications Addressing and Reporting System (ACARS) in favor of a new digital data link technology. The new data link technology is called Very

High Frequency Digital Link Mode 2 (VDL Mode-2).[3] FAA will use a communications network owned and operated by a third party--Aeronautical Radio Incorporated (ARINC)--to transmit data link messages. We did not review the selection of the service provider as part of this audit.

Second, FAA and industry intend to develop systems (for both ground systems and aircraft) that comply with international standards; a step that was initially intended to take place several years in the future. The goal is to develop systems based on these standards which would allow aircraft to seamlessly transition from one region of the world to another as well as operate within domestic airspace.

Costs and Benefits of Implementing Data Link Are Uncertain

FAA estimates that data link (Builds 1 and 1A for en route facilities only) through 2015 will cost the agency $645 million[4] over and above the $420 million spent thus far on various data link efforts. These estimates do not include costs for future enhancements at en route facilities (Builds 2 and 3), or costs for implementing data link at tower, terminal, or oceanic air traffic control facilities.

At the heart of implementing data link is how and when FAA and industry can realize benefits that justify the cost of investing in the new technology. Although FAA and industry officials agree that data link will play an important part in aviation's future, they cannot quantify specific benefits with confidence at this time. FAA recognizes that it will have to make a strong, convincing business case where benefits outweigh costs for investing in new avionics for data link.

FAA does not intend to mandate the use of data link but rather intends to build on planned airline investments in new digital technology over a number of

[3]Because ACARS does not have the performance characteristics for controllers and pilots to share information during flight, FAA and industry have agreed that Very High Frequency Digital Link Mode 2 (VDL Mode 2) technology will be used for data link communications. VDL Mode-2 provides for faster and more reliable data exchange between aircraft and ground systems than ACARS. As part of a gradual transition to new digital technology, ARINC (the communications service provider that operates the ACARS network) has committed to install the necessary ground infrastructure beginning in 1999, and avionics manufacturers are developing new avionics.

[4] The $645 million includes $177 million in acquisition costs and $468 million in operations costs for sending and receiving data link messages. This estimate assumes that FAA will pay for all data link messages, but presumably FAA will pass some costs to airspace users if user fees are established. Message costs are relatively low until 2005 but increase significantly beginning in 2006 due to the increase in message traffic.

years. Airlines are planning to make the transition to new digital technology but costs and time frames have yet to be determined. FAA and industry officials caution that to realize the full expected benefits of data link, significant numbers of aircraft will need to be equipped with new data link systems and controllers and pilots will need to accept the new technology. FAA's current approach that relies on voluntary airline action could prolong the transition to data link and when benefits can be realized. This will impact the overall cost and schedule of the program and may present additional human factors concerns.

IMPLEMENTING DATA LINK FACES SIGNIFICANT RISKS AND CHALLENGES

Data link will fundamentally change the way controllers and pilots communicate and represents a complex integration effort because both air and ground systems must work together and exchange information on a near real-time basis. We analyzed a number of issues facing data link that could cause significant schedule delays and cost growth. In each instance, work is underway or planned by FAA or industry but unresolved issues exist.

Human Factors Are Critical

The human factors issues for controllers and pilots represent the biggest challenge facing the implementation of data link. Because voice communications play such a large role in current controller and pilot interactions, experts agree that data link will fundamentally change the way controllers and pilots communicate with each other.

An important workload related issue is how controllers and pilots will use two distinct communications systems (voice and data link) to share important information. Controllers will be expected to handle both data link and non-data link equipped aircraft in the same airspace. Similarly, pilots will fly in and out of airspace where data link is not universally used. This could lead to confusion, stress, and additional workload for both controllers and pilots. FAA studies have examined the impacts of working with a mix of data link and non-data link communications but additional work remains to be done, particularly for pilots. This also has implications for the controller workforce and will likely require close coordination between labor and management.

The amount of "*head down*" time required of pilots and controllers to compose and send, or read and respond to data link messages is a concern. "Head down" refers to the time a controller or pilots' attention is diverted from primary tasks. For the pilot, there is concern that responding to data link

messages will impact time spent on primary flight duties and monitoring the instrument panel. Another concern is the loss of *"party line"* for pilots. With the existing voice communication system, pilots can tune to a particular frequency to hear air traffic control instructions to and pilot responses from other aircraft. For example, a pilot can benefit from hearing that an aircraft ahead encountered turbulence or had been placed into a holding pattern. Since data link messages are delivered to individual aircraft, there is concern that data link will deprive pilots of important information pertaining to surrounding airspace.

The human factors issues with data link have important safety implications. To avoid repeating past mistakes, such as problems experienced with the Standard Terminal Automation Replacement System, FAA needs to follow the principles outlined in its new process for incorporating human factors into the acquisition of new technology. FAA is developing a human factors plan for data link and simulations at the agency's technical center are planned. We believe early and continued involvement by pilots and controllers in these efforts is essential. FAA needs to focus attention and resources on (1) new air traffic control procedures for using data link, (2) controller and pilot training programs and (3) the design of new data link equipment for displaying and sending messages.

In addition to human factors issues, FAA and industry face other challenges, including:

- Certifying Data Link: FAA must resolve important questions about how to certify new data link systems to ensure that safety is not compromised. FAA will conduct an "end-to-end" certification where both air and ground systems are assessed from a safety perspective. It is possible that new safety requirements could be identified which could impact the cost and schedule of the effort. The responsibilities for approving the air and ground components of data link are shared between FAA organizations (Aircraft Regulation and Certification and Air Traffic Services) with different roles and functions. Decisions need to be made about what data are required, how safety assessments will be conducted on various components, and by whom.

- Software Development and Harmonization with International Standards: FAA is committed to developing systems that comply with international standards that are complex and were only recently finalized. An FAA/industry consortium is developing software for aircraft systems that would allow an aircraft to send and receive data link messages anywhere in the world regardless of the technology used (satellite or ground based

systems) to transmit the message. Testing of key software was expected to occur in June 1999 but this has slipped 7 months to February 2000.

- Security: Past studies have cautioned that the implementation of "silent" data link systems removes some of the protections of the current voice system (i.e., the ability to confirm information) and there are some concerns about the possibility of outsider interference. The working group on data link has not yet focused attention on security issues and only limited safeguards will be incorporated into the initial phases of data link. Because security requirements will be incorporated into later builds, these requirements could add costs and impact the schedule of the program.

- Cost of aircraft avionics: Although no firm cost information exists, FAA and industry estimate that the cost to modify an aircraft for data link, which includes new avionics and modification of cockpits, ranges from $100,000 to over $1 million.[5] This wide range exists because it would require significant work to reconfigure the cockpits of older aircraft to accommodate new data link displays. Some newer aircraft, such as the Boeing 777, have data link displays integrated in the cockpit and will require less modification. Thus, the transition to data link will likely occur as airlines take delivery of new aircraft. Most general aviation aircraft are not expected to equip. FAA must continue to work with airlines and avionics manufacturers to clarify costs.

FAA has opportunities to build on the ongoing experience with data link in Europe to help mitigate risks, reduce costs, and prevent duplication of effort. Several European nations are participating in tests of data link that can help shape FAA's efforts. Test results indicate that European controllers do not believe data link is suitable for situations where quick action is needed to ensure the safe separation of aircraft. In the next several months, additional testing will occur in Europe that will generate data that will prove useful in future FAA and industry deliberations.

FAA MUST ADDRESS LONGSTANDING MANAGEMENT PROBLEMS WITH DATA LINK

Various data link systems have been under development at FAA for 15 years at a cost of $420 million. Although FAA and industry have made important progress over the past year, FAA must change the way it manages its

[5]These estimates include costs to transition to VDL Mode 2 technology and the incremental cost of investing in new hardware and software for Controller-Pilot Data Link Communications.

Controller-Pilot Data Link efforts to ensure the successful implementation of the technology.

Management: FAA has viewed data link from four distinct operational perspectives (en route, terminal, tower, and oceanic environments). According to FAA officials, there was little effective coordination among them. Several different and distinct FAA groups are responsible for developing and implementing data link. FAA's Air Traffic Services, the sponsor of data link, is responsible for defining its operational requirements. Under the auspices of the Office of Communication, Navigation, and Surveillance, FAA's Aeronautical Data Link Team is responsible for managing and acquiring data link in the en route, terminal, and tower environments. Oceanic Data Link, on the other hand, is the responsibility of the Office of Air Traffic Systems Development. FAA program officials told us that routine coordination problems with acquisition projects are amplified by the complex nature of data link, the agency's current management approach, and linkages to other efforts. FAA is now exploring ways to ensure that future domestic and oceanic data link efforts are coordinated.

FAA has established a Free Flight Phase 1 Program Office to manage the various Free Flight Phase 1 initiatives. However, the Director of FAA's Free Flight Phase 1 Office told us that the new office would not be responsible for managing data link at this time because of the recent changes to the program. FAA believes the responsibility of the office extends only to projects that are clearly achievable by 2002--not for projects, such as data link, that begin after that time and still require detailed planning. Thus, FAA intends to manage data link as a related, but separate effort.

In our view, the complex nature of data link demands a more straightforward and unified approach. Until the Free Flight Office is responsible for managing data link, we believe FAA needs a single agency official that is responsible for data link across all operational environments. This official should, among other things, play a key role in setting priorities and ensuring that activities are effectively coordinated and integrated. In addition, a joint FAA/industry team composed of FAA, airline, and avionics manufacturers could help identify and resolve problems regarding how the various data link components will work together.

Planning: FAA does not have a comprehensive plan with milestones for implementing data link throughout the National Airspace System. Airlines and avionics manufacturers are looking to FAA to define a comprehensive strategy with transition paths and milestones. This plan should address: (1) milestones for implementing data link at all facilities, (2) resources requirements for FAA

and industry, (3) transition strategies for all facilities, (4) incentives for airlines to equip, and (5) impacts of international developments on U.S. airlines. This plan will take time to develop and will need to be updated regularly because data link is in the early stages of development and some uncertainty exists about how to implement the technology at all facilities.

Investment Decision-making and Documentation: FAA has not made sound investment decisions in the past regarding data link. *Our analysis shows that FAA spent over $100 million on a Data Link Processor (computer hardware and software) that will never be used for its intended purpose of supporting data link communications for controllers and pilots.* The total loss to the Federal Government from this effort is uncertain because FAA is seeking other uses for the technology and believes some of the software may be usable in future efforts. In addition, FAA has not followed its own guidelines for investing in new technology. We found fundamental changes regarding cost, schedule, and technical issues were made without required documentation and approvals. For example, realistic cost and schedule baselines were not prepared and various alternatives were not analyzed.

RECOMMENDATIONS

We recommend that FAA:

1. Place a high priority for funding and conducting human factors work for Controller-Pilot Data Link Communications. Attention and resources need to be focused on assessing how controllers and pilots will interface with the new technology, new air traffic control procedures, new training programs for pilots and controllers, and improvements in the design of new data link equipment.

2. Designate a single FAA official for data link with clear lines of responsibility and accountability to be responsible for coordinating and integrating the various air and ground elements of data link.

3. Establish a joint FAA/industry integration team (composed of FAA, airlines, avionics manufacturers, and other appropriate parties) to identify and resolve technical and operational problems that occur regarding how the various air and ground segments of data link work together.

4. Develop a comprehensive plan for implementing data link for all air traffic control facilities (en-route, terminal, tower, and oceanic) that establishes milestones, financial resources, transition strategies, incentives for airlines to equip, and impacts of international developments on U.S. airlines. This

plan should be a living document and be updated regularly to reflect changes in direction and operational experience.

5. Submit the comprehensive plan for implementing data link with annual budget requests to the Congress.

6. Develop a formal strategy for using the results of European data link efforts to reduce costs and potential duplication of effort.

We make additional recommendations in the body of this report.

AGENCY COMMENTS

During our work, we periodically met with FAA officials from Research and Acquisitions, Aircraft Regulation and Certification, and Air Traffic Services as well as the Free Flight Phase 1 Program Office and have taken their comments into consideration in preparing this report. On January 20, 1999, we held an exit conference with FAA program officials and have incorporated their comments as appropriate. At that meeting, FAA program officials generally concurred with our analysis and recommendations.

FAA recognizes that changes in the management of data link are needed and actions are underway. FAA has made personnel changes and is in the process of reorganizing its data link communications efforts to reflect the technology's linkage to other modernization projects. FAA is also developing a memorandum of understanding between FAA organizations to ensure that data link efforts for domestic and oceanic air traffic control facilities are better coordinated.

Also, FAA officials told us that the agency is requesting that RTCA form a special committee on data link implementation to, among other things, refine technical standards, address human factors concerns, and develop a plan for implementing data link throughout the National Airspace System. A decision on the status of the RTCA special committee is anticipated in March. In addition, FAA officials informed us of a recent Joint Resources Council decision that states the agency will pay for all data link messages.

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CHAPTER I: CURRENT AND PLANNED USES OF DATA LINK COMMUNICATIONS

To meet future growth in air traffic, the Federal Aviation Administration (FAA) and the airline industry intend to use data link communications between controllers and pilots to supplement existing voice communications. Data link offers controllers and pilots a new way to share a wide range of information that is expected to be faster and more reliable than current voice communications. FAA has spent $420 million on various data link technologies for communication, navigation, and surveillance over the past 15 years. The most successful application of this technology in the United States is FAA's Tower Data Link Services Program that provides pilots with pre-departure clearances and other airport specific information.

Based on the suggestions of a joint industry/government working group, FAA intends to implement a data link for controllers and pilots through a series of phases (hardware and software builds) beginning with a test site in 2002 leading to a nation-wide deployment of the new technology by June 2004. FAA estimates the initial phases of Controller-Pilot Data Link Communications (CPDLC) will cost the agency $645 million over and above the $420 million spent thus far. This cost estimate lacks precision and does not include costs for enhancements at en route facilities or costs for implementing data link at other FAA facilities.

WHAT IS DATA LINK?

Today, controllers and pilots use voice radios to communicate during flight in domestic airspace. Controllers and pilots rely on voice radios to share routine flight information (changes in altitude, heading, and speed), warnings, and weather updates, that are essential for the safe and efficient operation of aircraft in all facets of flight. While this system has served aviation well, some problems exist with respect to communication errors and misunderstandings between controllers and pilots. In addition, when a controller must share a single radio channel with up to 25 aircraft, competition for the channel can lead to delays and frustration. To address these concerns, FAA has long argued the need for data link communications.

New digital communications--commonly referred to as data link--offer controllers and pilots a new way to share a wide range of information that is expected to be faster and more reliable than current voice communications. Data link will replace or supplement many of the routine voice conversations between controllers and pilots. The potential benefits of data link communications include increased controller efficiency, reduced voice radio

channel congestion, and fewer controller-pilot communication errors. For example, data link technology can offer significant safety benefits for all airspace users by providing pilots with timely weather information.

FAA has pursued many different uses of data link technology under one umbrella program called Aeronautical Data Link. Although they are all based on the same basic concept, the individual applications of data link differ dramatically in complexity and intended use. For example, some uses of data link broadcast weather information to all properly equipped aircraft within a certain distance from an airport. Others, such as CPDLC, are more complex and allow for a two-way dialogue. Exhibit A summarizes the uses of data link for commercial aviation. The following highlights some of the different applications of data link technology.

- Tower Data Link Services (TDLS) electronically provides pilots with pre-departure clearances[6], current weather, airport, and facility conditions. TDLS is in use at 57 airports. This is the first and most successful application of data link in the United States. Over 16 million pre-departure clearances have been issued via data link. TDLS is based on the technology used for internal airline communications.[7] FAA has invested $51 million in equipment at airport towers but airlines pay for transmitting TDLS messages.

- Terminal Weather Information for Pilots provides for near real-time terminal hazardous weather information (such as gust fronts, storms, and precipitation) in text form to pilots. This capability is currently operational at 20 airports and FAA has plans to implement it at 24 additional airports.

- Flight Information Services provide weather and flight information (notices to airmen and the status of airspace that can be shared by civilian and military aircraft) to pilots. Although commercial pilots may find this useful, Flight Information Services were developed primarily for the general aviation community. FAA intends to implement Flight Information Services at 119 locations by 2002.

[6] Pre-departure clearance provides automated delivery of clearance and flight information to the commercial airline dispatch center, which in turn delivers the information to the aircraft. A pre-departure message includes aircraft identification, approved departure time, assigned altitude, and route information.

[7] Many of the Nation's airlines have considerable experience with a data link system called the Airline Communication Addressing and Reporting System (ACARS). About 4,800 commercial aircraft in North America are equipped with the ACARS system and over 350,000 data link messages are sent on a daily basis.

- Controller-Pilot Data Link Communications will allow controllers to communicate clearances and instructions to pilots and to receive pilot requests. Data link for controllers and pilots is analogous to electronic mail, where a person can send an electronic message to other people without speaking to them. FAA intends to use data link at all four types of its air traffic control facilities - en route, terminal, tower, and oceanic. A type of data link is in limited use today for properly equipped aircraft flying some international routes over the Pacific. FAA intends to have CPDLC in operation at one domestic en route center in June 2002.

FAA'S INVESTMENT IN DATA LINK TECHNOLOGY

FAA has made significant investments in data link technology over the years. Our analysis shows that FAA has invested $420 million and continues to invest in a wide range of data link applications for communications, navigation, and surveillance. The following table provides information on FAA's investments in data link technologies by type of FAA facility.

Table 1.1: FAA's Investment in Data Link Technologies
(Dollars in Thousands by Fiscal Years)

Program Element	Total Through 1998	1999 (estimated)	2000 Budget Estimate
EN ROUTE			
CPDLC Build 1	$ 10,246	$14,210	$13,200
CPDLC Build 1A	1,390	1,490	9,200
Infrastructure (related computer hardware and software)	56,207	4,600	1,000
TERMINAL	20,576	0	0
TOWER (TDLS)	51,561	0	2,300
OCEANIC (Future Air Navigation System)	94,479	0	10,000
Other Applications of data link (Weather, Flight Information Services)	52,183	4,374	6,200
Other Infrastructure	123,624	0	0
Program Support	10,015	0	0
TOTAL	**$420,281**	**$24,674**	**$41,900**

Source: OIG analysis of FAA data

The $420 million includes $115 million in Research, Engineering, and Development funds; $281.6 million in Facilities and Equipment funds; and

$23.6 million in Operations and Maintenance funds. FAA did not track costs specifically related to CPDLC for domestic airspace until 1997.

IMPLEMENTING CPDLC IN DOMESTIC AIRSPACE

A consensus on the initial steps for implementing CPDLC in domestic airspace is emerging. In late 1997, the FAA Administrator established a Modernization Task Force comprised of senior departmental officials as well as executives and experts from the aviation community to assess FAA's modernization needs. To address data link issues in greater detail, this task force established a joint industry/government data link working group (the working group).

Based on the working group's suggestions, FAA has made significant changes in how it plans to implement CPDLC in domestic airspace. These changes include, among others, a new data link technology and an effort to comply with international standards for aeronautical data communications.

First, FAA and industry have abandoned attempts to use an existing airline data link system known as the Airline Communications Addressing and Reporting System (ACARS) in favor of a new digital data link technology that some airlines intend to purchase.[8] This decision was made because ACARS does not have the performance characteristics for controllers and pilots to share information during flight. The new data link technology is called Very High Frequency Digital Link Mode 2 (VDL Mode-2) and is expected to be used for both air traffic control and company purposes. FAA plans to use a communications network owned and operated by ARINC to transmit CPDLC messages.

Second, FAA and industry intend to develop data link systems (for both ground systems and aircraft) that comply with international standards, a step that was initially intended to take place several years in the future. The goal is to develop systems based on these standards which would allow aircraft to seamlessly transition from one region of the world to another as well as operate within domestic airspace. This is particularly important for airlines with international routes.

[8]FAA and industry have tentatively agreed that Very High Frequency Digital Link Mode 2 (VDL Mode 2) technology will be used for CPDLC. VDL Mode-2 provides for faster and more reliable data exchange between aircraft and ground systems than ACARS. As part of a gradual transition to new digital technology, ARINC has committed to install the necessary ground infrastructure beginning in 1999. Avionics manufacturers are in the process of developing new avionics.

FAA and industry intend to begin with four messages and gradually increase the number and type of messages[9] that can be used as more experience is gained. For example, one of the first messages focuses on the transfer of communication from one controller's airspace sector to another. A controller will send a message informing the pilot to contact another controller or to monitor a specific radio frequency for further instruction. Table 1.2 summarizes FAA's plans.

Table 1.2: Planned En Route CPDLC Implementation
(As of January 1999)

	Build 1	**Build 1A**	**Build 2**	**Build 3**
Test Location	Miami	To be determined	To be determined	To be determined
Launch Airline	American Airlines	American Airlines	American Airlines	To be determined
Number of Messages	4 messages	18 messages	114 messages	To be determined
Estimated Start	June 2002	June 2003	December 2004	To be determined
Estimated Completion	Not Applicable	National deployment complete by June 2004	National deployment complete by June 2006	To be determined

Costs and Benefits for Controller-Pilot Data Link Communications Are Uncertain

The cost to implement CPDLC throughout the National Airspace System at all types of FAA air traffic control facilities is substantial but uncertain. FAA estimates that CPDLC (Builds 1 and 1A for en route facilities only) will cost the agency $645 million over and above the $420 million spent thus far on various data link efforts. These costs include $177 million in acquisition costs and $468 million in operations costs. These estimates do not include costs for airlines to equip with new avionics, future enhancements at en route facilities (CPDLC Builds 2 and 3), or costs for implementing CPDLC at tower, terminal, or oceanic air traffic control facilities.

At the heart of implementing CPDLC is how and when FAA and industry can realize benefits that justify the cost of investing in the new technology.

[9]Controllers, and pilots to a lesser extent, will have a menu of common messages to choose from and be able to tailor and send messages (instructions to change radio frequency) to specific aircraft. The CPDLC message set contains several hundred messages that includes uplink messages (from the controller to the pilot) and down link messages (from the pilot to the controller).

Although FAA and industry officials agree that CPDLC has significant long term benefits and will play an important part in aviation's future, they cannot with confidence quantify specific benefits in terms of reduced congestion on voice channels, reduction in controller workload, or more efficient operations at this time. Simulations conducted at FAA's Technical Center suggest that CPDLC can improve controller productivity and efficiency as well as reduce communication errors.[10] Increased controller efficiency could, in turn, allow controllers to handle more aircraft. FAA recognizes that it must make a strong, convincing business case where benefits outweigh costs for investing in new avionics for CPDLC. In the near term, benefits from CPDLC may focus exclusively on providing controllers and pilots hands-on experience with the new technology.

Because of the uncertainty regarding costs and benefits, FAA does not intend to mandate the use of CPDLC but rather intends to build on planned airline investments in new digital technology over a number of years. FAA program officials caution that to realize the full expected benefits of CPDLC, significant numbers of aircraft will need to be equipped with new data link systems and controllers and pilots will need to accept the new technology.

FAA's current approach that relies on voluntary airline action could prolong the transition to CPDLC. FAA faces a major policy question about how to speed the introduction of the new technology once it has been tested and sufficient experience is gained. It is not too soon for FAA to explore alternatives and incentives for airlines to equip with data link equipment.

[10] See User Benefits of Two-way Data Link Communications: Aircraft Delay and Flight Efficiency in Congested Airspace (February 1995, Report No. DOT/FAA/CT-95/4) and Benefits of Controller-Pilot Data Link ATC Communications in Terminal Airspace (September 1996, Report No. DOT/FAA/CT-96/3).

CHAPTER II: RISKS AND CHALLENGES FACING THE IMPLEMENTATION OF CONTROLLER-PILOT DATA LINK COMMUNICATIONS

FAA and industry face significant risks and challenges that must be resolved to field CPDLC and obtain expected benefits. CPDLC represents a fundamental change in the way controllers and pilots communicate and a complex integration effort because both air and ground systems must work together and exchange information. We analyzed six major issues facing CPDLC that range from the human factors concerns for controllers and pilots to the cost of new avionics for sending and receiving CPDLC messages. The issues include:

- Human factors for controllers and pilots
- Certifying air and ground components of CPDLC
- Harmonization with international standards
- Integration with other National Airspace Systems (NAS) projects
- Security
- Avionics costs

In each instance, some work is underway or planned by FAA or industry. These risks and challenges could cause significant schedule delays and cost growth. FAA needs to develop a comprehensive plan to guide FAA and industry efforts.

HUMAN FACTORS ISSUES ARE CRITICAL

FAA, the National Aeronautics and Space Administration (NASA), and industry officials believe the human factors issues for both controllers and pilots are the biggest risks facing the implementation of CPDLC. A lesson from other FAA modernization efforts is the need for the agency to develop a structured, scientific human factors discipline throughout the acquisition process. Human factors evaluations must be performed early and throughout the process of developing and fielding new air traffic control technology--this is particularly true as FAA and the aviation community transition to Free Flight. If not addressed soon, the human factors issues with CPDLC could jeopardize the successful implementation of the technology.

At the core of CPDLC is how controllers and pilots communicate and exchange information. Because voice communications play such a large role in all controller and pilot actions, experts agree that CPDLC will fundamentally change the way controllers and pilots communicate. FAA and NASA have been conducting human factors research on these issues for several years and, according to the National Research Council, the results have

generally been favorable to introducing data link into the National Airspace System. However, FAA and industry officials we spoke with believe that continued and focused attention is needed on several issues to gain a better understanding of how data link technologies will affect controllers and pilots.

- Workload - CPDLC must be designed with care to minimize workload and guard against overly distracting pilots and controllers from their primary tasks. While both pilot and controller organizations generally support CPDLC, they must be assured of a proven technology that will not degrade safety or increase workload. For example, messages requiring many keystrokes will involve a much higher workload than if the messages were delivered verbally. One way to overcome this burden is to continue to refine pre-defined messages so the pilot or controller only has to type a few keystrokes to communicate complex messages.

- Dual Systems - An important workload related issue is how controllers and pilots will use two distinct communications systems (voice and data link) to share important information. Controllers will be expected to handle both data link and non-data link equipped aircraft in the same airspace. Similarly, pilots will fly in and out of airspace where data link is not universally used. This could lead to confusion, stress, and additional workload for both controllers and pilots. FAA studies have examined the impacts of working with a mix of data link and non-data link communications but additional work remains to be done, particularly for pilots. This also has implications for the controller workforce and will likely require close coordination between labor and management.

- "Head Down" Time - Another major human factors issue is the amount of "head down" time required of the pilot and controller to compose and send, or read and respond to data link messages. "Head down" refers to the time a controller or pilot's attention is diverted from primary tasks. For the pilot, there is concern that responding to data link messages will impact time spent on primary flight duties and monitoring the instrument panel. Likewise, there is concern that CPDLC will impact a controller's ability to maintain safe separation between aircraft and monitor the radar display. The National Research Council cautions that these are not trivial issues. These issues are of utmost importance in the terminal environment, where air traffic is much more congested than the en route environment. One proposed cockpit procedure would be for the co-pilot to read the message text to the pilot. While this would minimize the pilot's "head down" time, it would re-introduce the potential for voice errors.

- Location of Display - Location of the cockpit data link display is another significant factor that must be addressed, especially given the limited space available in aircraft cockpits. Several studies indicate that displays mounted in the pilot's forward field of view are essential for performing data link communications. Also, studies have indicated that it is necessary to locate the display in view of both the pilot and co-pilot to facilitate crew cross checking. Boeing views data link as a key part of future communication, navigation, and surveillance operations and has incorporated the data link display unit in the pilot/co-pilot's forward field of view on the Boeing-777 aircraft.

  For aircraft that are currently equipped with ACARS[11] (the airlines' internal data link system for company messages), the location of the display varies. For example, one major carrier has the ACARS unit positioned towards the back of the center pedestal between the pilot and co-pilot. The messages displayed on the unit are not easily readable because the display is situated at an awkward angle for viewing by the flight crew. Another major carrier has a printer located behind the pilot, which requires a flight crewmember to get up and retrieve the message printout. While this situation may be acceptable for internal airline communications, it is not acceptable for air traffic control messages.

- Loss of "Party Line" - Loss of "party line" is also an issue of great concern for pilots. With the existing voice communication system, pilots can tune to a particular frequency to hear ATC instructions and pilot responses to other aircraft. This enhances the pilot's situational awareness of other aircraft and environmental conditions in the vicinity. For example, a pilot can benefit from hearing that an aircraft ahead encountered turbulence or had been placed into a holding pattern. Since data link messages are delivered to individual aircraft, there is concern that CPDLC will deprive pilots of very important information pertaining to surrounding airspace.

- Routine versus time critical messages - Some FAA and industry officials we spoke with question whether it is realistic to believe CPDLC can be effectively used in situations where quick action is needed to ensure the safe separation of aircraft. Recent trials in Europe suggest that controllers and pilots find CPDLC most useful for messages that do not require quick action or involve the safe separation of aircraft. Similarly, a study by the National Research Council noted that a consensus may be emerging that controller-pilot data link systems should be used for routine

[11] ACARS is used to transmit a wide range of information, such as passenger and aircraft maintenance data, that does not involve the safety of flight.

communications (e.g. standard clearances, airport terminal information services).[12] Also, the Council believes voice communications should be used for more urgent instructions and requests.

- Development of new procedures and training programs - FAA intends to begin testing CPDLC with a small number of messages, which will be refined and expanded as additional testing and experience is gained in domestic airspace. Ultimately, FAA envisions that over 100 messages will be used. Recent experiences with oceanic CPDLC indicate that pilots and controllers rely on a much smaller number of messages than originally thought. For example, of 180 messages that oceanic controllers can send to properly equipped aircraft, 10 messages, such as climb and maintain, account for 75 percent of the message traffic. FAA and industry officials believe that significant work must be done to develop new procedures and training programs (specific guidelines for how and when controllers and pilot will use the technology) that correlate with the intended use of the technology.

A significant lesson of past modernization efforts, particularly the Standard Terminal Replacement System and the Advanced Automation System, is the need for FAA to pay sustained attention to human factors. In our view, FAA has to follow the principles outlined in the agency's new process for incorporating human factors into the acquisition of new technology.[13] FAA is developing a human factors plan for CPDLC, and simulations at the agency's William J. Hughes Technical Center are planned. We believe early and continued involvement by pilots and controllers in these efforts is essential. In addition, FAA needs to focus attention and resources on (1) new air traffic control procedures for using CPDLC, (2) controller and pilot training programs and (3) the design of new data link equipment for displaying and sending messages.

CERTIFYING CPDLC PRESENTS NEW CHALLENGES

Because data link communications between controllers and pilots will involve safety of flight, aircraft and ground systems must be certified by FAA to ensure they are performing to requirements, and there is no adverse impact on safety. A goal of the certification process is to ensure that safeguards are in place to prevent controllers and pilots from acting on misleading information. In our opinion, the certification of CPDLC represents an important departure from

[12] See The Future of Air Traffic Control: Human Operators and Automation, National Research Council, 1998.

[13] For additional details on this process, see The Management of Human Factors in FAA Acquisition Programs (March 2, 1998)

past agency efforts and will require a change in the way FAA conducts business.

The working group recommended that CPDLC Build 1 (for domestic en route airspace) be certified. To do so, FAA certification officials believe that CPDLC must undergo an operational safety analysis. This analysis would examine all individual components of CPDLC to assess how potential problems will be mitigated and their potential for affecting the safety of flight. A report prepared by FAA's National Resource Specialist for Aeronautical Communications illustrates the importance and complexity of the process:

> Our experiences show that while our intentions are always to build a system that works exactly as we have expected it to, this is rarely the case. A top-level safety assessment evaluates abnormal behavior of operational scenarios based on known hazards. Such an assessment will allow for assessing alternatives for mitigating the effects of abnormal behaviors while considering costs associated with each mitigation strategy evaluated.[14]

Part of this analysis will examine "worst case" scenarios, such as a pilot receiving a message intended for another aircraft and taking action without realizing the message was in error. FAA officials emphasize that the certification of such a technology involves the equipment, the procedures, and the airspace characteristics (traffic density and routing complexities) that guide the day-to-day use of the technology. From a certification perspective, the fundamental safety-related issues for CPDLC focus on several basic and straightforward questions.

- Is there an acceptable level of confidence that the message gets to the right aircraft?

- Is there an acceptable level of confidence that messages get to the aircraft without errors?

- Is there an acceptable level of confidence that the messages get delivered in the proper sequence?

- How long does it take for the message to be sent and replied to?

- How many aircraft can be accommodated in a given segment of airspace?

[14] Report on Streamlining Aircraft Certification, prepared by FAA's Aircraft Certification Service (May 27, 1997).

FAA has little experience with "end-to-end" certification where both airborne and ground segments must be assessed and it is possible that new safety requirements will be identified which could impact the cost and schedule of the effort. Currently, certification of CPDLC is the responsibility of two different FAA organizations, Aircraft Regulation and Certification (for avionics) and Air Traffic Services (for FAA ground systems), with different roles and functions. Decisions need to be made about what data are required, how safety assessments will be conducted on various components, and by whom. FAA recognizes that certification of new technology can be difficult and is working with RTCA, the International Civil Aviation Organization (ICAO)[15], and other entities to develop guidelines for certifying air traffic services that are supported by data link communications. RTCA is expected to finish its work on certification sometime in early 1999. Once RTCA has completed its work, the agency must use RTCA's recommendations to strengthen processes and procedures for FAA organizations that must certify CPDLC air and ground components.

HARMONIZATION WITH INTERNATIONAL STANDARDS IS A TECHNICAL RISK

Developing new software for air and ground systems that comply with international standards is a technical risk to the cost and schedule of implementing CPDLC. FAA is committed to developing systems for both ground and aircraft that are compliant with international standards for data communication. These standards are known in the aviation community as the Aeronautical Telecommunications Network (ATN) protocols.[16]

ATN standards, developed by ICAO, provide the specifications to ensure that information is shared across national boundaries, and is consistently interpreted by systems at both ends. The standards are technically complex and are spelled out in a 1,100-page document. FAA's goal is to develop systems based on these standards that would allow aircraft to seamlessly transition from one region of the world to another as well as within domestic airspace. This is particularly important for U.S. airlines with extensive international routes.

[15] ICAO is an international body that promotes international aviation. ICAO has developed and adopted a number of technical documents involving such varied fields as security, airworthiness, and aeronautical telecommunications. ICAO documents contain standards that member countries must meet and that are intended to produce a degree of technical uniformity that enables international aviation to function in a safe, orderly, and efficient manner.

[16] ATN comprises application and communication protocols that allow different ground, air-to-ground, and avionics networks to smoothly operate by adopting common interfaces and protocols.

Experience has shown that it is difficult to translate ATN standards into practical applications. After approximately 10 years of development, these standards were finalized this past year. Although the standards are complete, FAA Certification staff told us that some refinements would undoubtedly occur as more operational experience is gained. Moreover, a 1997 independent assessment of the Aeronautical Data Link Program cautioned that FAA's efforts to develop ATN-compliant systems faced a number of important risks that are still valid today. For example, the assessment noted that ATN does not allow for the use of commercially available products and key security and network functions are planned as future enhancements.

Recognizing the difficulty in developing ATN-compliant systems, FAA entered into a consortium in 1995.[17] The consortium is developing software for aircraft systems that would allow an aircraft to send and receive data link messages anywhere in the world regardless of the technology used (satellite or ground based systems) to transmit the message. In addition, this software is expected to be used in FAA ground systems to process ATN-complaint messages. To date, FAA has spent $12.9 million on this effort.

Testing of key software was expected to occur in June 1999 but this has slipped 7 months to February 2000 and additional slips are likely. The president of the consortium now estimates that a total of about 700,000 lines of complex computer code may have to be developed--an increase of 250 percent over initial estimates. This increase occurred because consortium staff underestimated the complexity of the work required. Once this code is completed and tested, it must be integrated with aircraft avionics and FAA ground systems, which could lead to additional technical difficulties.

INTEGRATION WITH OTHER NAS EFFORTS NEEDS TO BE MONITORED

The interdependencies between CPDLC and other NAS modernization efforts are critical to the successful implementation of the new data link. Currently, FAA and industry efforts are focused exclusively on introducing CPDLC at en route facilities. CPDLC will interface with the Display System Replacement (DSR) and relies on software up-grades to the Host Computer System (Host)--the nerve center of en route air traffic control facilities. Schedule changes to either Host replacement efforts or DSR will impact CPDLC milestones.

[17] FAA entered into a consortium with ATN Systems, Inc (ATNSI). ATNSI is a privately held corporation owned by 11 U.S. airlines.

- Host Computer System - Because of the Year-2000 problem and supportability concerns, FAA is in the process of replacing the Host at the Nation's 20 en route air traffic control centers. FAA has identified four phases to the Host replacement schedule related to hardware and software development. CPDLC software is a candidate for inclusion in the later phases of the Host replacement schedule. FAA program officials do not believe this will impact CPDLC because needs can be reprioritized as necessary. However, important technical issues need to be addressed. For example, it is unclear if the Host can provide sufficient processing power to fully satisfy all CPDLC capacity and performance requirements at this time. FAA needs to examine this issue in greater detail.

- Display System Replacement (DSR) - DSR is FAA's $1.0 billion program to modernize computer equipment at air route traffic control centers. DSR is planned to be operational at Miami, the test site for CPDLC, in March 2000. FAA officials are confident about meeting the milestones for the DSR and told us that the majority of the changes necessary to accommodate CPDLC can be done through adaptation at the center level. For example, a couple of keyboard keys will have to be reassigned for data link functions. However, the recent changes to CPDLC require human factors prototype work on DSR that focuses on how to display message information at controller workstations. Some technical issues remain to be resolved. For example, there is concern that DSR will be unable to handle all situations where CPDLC messages must use information from the DSR's display of flight information. FAA needs to conduct more detailed engineering analysis to resolve this issue.

SECURITY ISSUES NEED TO BE ADDRESSED

FAA's air traffic control system is a complex collection of interrelated systems that rely on complex communications networks that separately transmit both voice and data. The use of these systems provide benefits in improved operations, but they also increase the vulnerability to intruders who may manipulate data to commit fraud, obtain sensitive information, or severely disrupt operations. The President's Commission on Critical Infrastructure examined these issues in considerable detail and recommended that FAA act immediately to develop, establish, fund, and implement a comprehensive systems security program to protect the modernized NAS from disruptions, intrusions, and attacks.

The introduction of data link systems for air traffic control represents a major transition for both FAA and the industry and requires a change in thinking about the security of data communications. A 1997 vulnerability assessment

cautioned that the implementation of "silent" digital systems removes some of the protection provided by the current voice system (i.e., the ability to confirm information) and there is concern about the possibility of outsider interference with the data link message system.[18] The assessment also noted that some form of encryption might be required. Because of the time critical nature of some air traffic control messages, such as those associated with the separation of aircraft, CPDLC was given a high-risk rating. The overall protection from malicious attack was judged to be low to medium, due to the potential for undetected loss or corruption of messages. A successful penetration of CPDLC could result in the loss of the air-to-ground link or insertion of false information.

The working group on data link has not yet focused attention on security issues and only limited safeguards will be incorporated into the initial phases of CPDLC. Security requirements will be incorporated into later builds, which could add costs and impact the schedule of the program. We believe FAA and industry should expeditiously examine this issue and its impact on the program.

AVIONICS COSTS ARE UNCERTAIN

The cost to equip aircraft with new avionics for CPDLC is uncertain. Several airlines told us that while the cost of implementing CPDLC could be substantial, these costs can be managed by careful planning. FAA is seeking to leverage planned airline investments in new digital technology for data communications.

Although no firm cost estimates exist, FAA staff have estimated the cost to modify an aircraft for CPDLC, which includes new avionics (for VDL Mode 2 and CPDLC enhancements) and modifying cockpits, range from $100,000 to over $1 million. This wide range in cost exists because it would require significant work to reconfigure the cockpits of older aircraft to accommodate new data link displays. Some newer aircraft, such as the Boeing 777, have data link displays integrated in the cockpit (in the pilot's forward view) and will require less modification. Thus, FAA officials believe the transition to CPDLC will likely occur as airlines take delivery of new aircraft. Most general aviation aircraft are not expected to equip with CPDLC.

Acquisition of new avionics into an airline's fleet can take several years. It is not unusual for the cost of removing the aircraft from service for retrofit to

[18] See Vulnerability Assessment of the FAA National Airspace System (NAS) Architecture prepared for the President's Commission on Critical Infrastructure Protection by Science Applications International Corporation (October 10, 1997).

exceed the purchase cost of the avionics. Therefore, airlines plan major changes in avionics and communications equipment, such as CPDLC, to coincide with regularly scheduled aircraft maintenance cycles. One airline with more than 400 aircraft told us that the optimum planning period and upgrade cycle for communications equipment is about 5 years. The costs of pilot training must also be considered. One major airline told us that pilot training costs would probably equal equipage costs.

Airlines generally expect to enjoy some benefits almost immediately from investments in new avionics and to recover their investment in as little as 3 years but FAA and industry officials recognize that this will not be the case with CPDLC. Airline officials we spoke with believe that the near-term benefits associated with CPDLC will be minimal for the industry but that the potential long-term pay-off may be significant. The avionics and related costs are important because FAA cannot expect airlines to equip with new technology without reliable information. In our view, FAA must continue to work with the airlines and avionics manufacturers to clarify costs. In addition, FAA must also consider how and when it intends to transition to Next Generation Air/Ground Communication Systems, commonly referred to as NEXCOM, for both voice and data communications. A policy is needed on this matter to help shape expectations for all stakeholders, including the airlines, aircraft manufacturers, service providers, and the general aviation community.

FAA CAN BUILD ON EXPERIENCES OF OCEANIC DATA LINK AND EUROCONTROL TESTS

The risks and challenges facing CPDLC are not easily resolved. To help meet these challenges, we believe FAA has unique opportunities to build on the ongoing experience with data link in the oceanic environment and in Europe.

Lessons From Oceanic Data Link

In the early 1990s, FAA, airlines, and other nations agreed to implement elements of the Future Air Navigation System (FANS) as set forth by the International Civil Aviation Organization. The goal of this effort was to capitalize on the potential benefits of satellite-based communications, navigation, and surveillance technologies for air travel over the Pacific Ocean. In response, Boeing developed the FANS-1 avionics package, which includes the capability for pilots and controllers to use data link to communicate clearances, advisories, requests, and information on aircraft position. As part of FANS-1, Oceanic Data Link is now used 24 hours a day in one of seven air traffic control sectors at the Oakland Air Route Traffic Control Center for

properly equipped aircraft operating in the South Pacific. Controllers and pilots exchanged over 11,000 data link messages in June 1998, such as pilot requests to change altitude. Because oceanic data link was designed for use over oceans and as part of a larger avionics package, the working group recommended a different approach for domestic airspace.

Recent FAA and industry experiences in implementing FANS-1 technology for flights in the Pacific offer important insights for implementing CPDLC in domestic airspace. In our view, these experiences underscore the need for careful planning, strong FAA and industry commitments, and focused attention on the operational impacts on controllers and pilots.

Controllers we spoke with at Oakland Center who use CPDLC have mixed views of the system but believe it is an important step forward. These controllers emphasized the need for better planning, training on new equipment, and more controller involvement early in the process. A draft study conducted by FAA on Oceanic Data Link suggests that safety is not compromised by the introduction of data link but noted that it significantly changes the way controllers perform their work.[19] Some pilots, however, have raised concerns about certain aspects of the system, such as the format of messages, and have suggested that problems exist with FANS-1 in terms of sending messages to the wrong aircraft that have resulted in safety-related incidents. A report prepared last year by FAA's National Resource Specialist for Aeronautical Communications noted:

> The FANS-1 operations in the South Pacific is experiencing some problems, but there is no apparent means to identify the problems and resolve them.…Despite numerous attempts to establish a monitoring system, we have not been able to adequately capture problems in operational service. This is primarily because air traffic service providers, communication service providers, and flight crews are hesitant to report the problems because of associated liabilities and responsibilities.[20]

To begin to address FANS-1 concerns, FAA and industry formed a FANS interoperability team. This group has identified 98 problems (technical and operational) with FANS thus far, and have identified solutions to 44 of the problems. Analysis is underway on the 54 open items, which include the effects of message delivery times and the receipt of duplicate messages. In our

[19] See Computer-Human Interface Evaluation of the Multi-Sector Oceanic Data Link System (July 1998) prepared for the Office of Air Traffic Systems Development.

[20] Report on Streamlining Aircraft Certification, prepared by FAA's National Resource Specialist for Aeronautical Communications (May 27, 1997).

view, FAA and industry need to monitor FANS-1 activities to avoid repeating past mistakes with oceanic data link.

In addition, there are three important lessons learned from the FANS-1 experience that need to be factored into FAA's plans for implementing CPDLC in domestic airspace.

- Financial commitments from FAA and the industry with realistic, achievable milestones are key to success. FAA and industry efforts must be closely coordinated and synchronized.

- Strong system engineering and integration skills are needed because of the interdependent nature of the technologies. In other words, FAA found it difficult to integrate all the complex pieces of FANS-1 and underestimated its complexity.

- The operational impact on controllers and pilots cannot be overlooked. FAA underestimated the time and complexity of determining exactly how controllers would use the technology in day-to-day operation. Initially, data link caused a small increase in controller workload. In response to controller concerns, FAA required changes to software that simplified tasks for controllers. FAA officials responsible for implementing FANS-1 strongly emphasized the need to simplify all aspects of CPDLC.

European Tests of CPDLC

Several European nations are participating in tests of CPDLC technology, known as the Preliminary Eurocontrol Test of Air/Ground Data Link (PETAL). The first test, known as PETAL 1, was a joint Eurocontrol/Aerospatiale project that began in 1994 with the objective of obtaining first-hand, factual data on the operational benefits, requirements, human factors, procedures, and problems associated with using CPDLC. Between May 1995 and April 1996, pilots and controllers used CPDLC during routine flight operations over Belgium, Germany, Luxembourg, and the Netherlands. The test results provide important insights into how controllers and pilots view the new technology.[21] For example, European controllers do not believe CPDLC is suitable for situations where quick action is needed to ensure the safe separation of aircraft.

[21] For additional details, see Preliminary EUROCONTROL Test of Air/ground Data Link: Operational Air /Ground Data Link Trials Description, Conclusions, and Recommendations Volumes I, II, III (August 1996).

Some FAA and airline officials are concerned about FAA's lack of participation in the PETAL trials, fearing that the United States is losing its leadership position in developing new air traffic control technology. On May 21, 1998, American Airlines expressed these concerns with regard to CPDLC at the working group meeting and recommended that FAA begin to play a much more active role in future tests. We agree that the PETAL trials represent an important step in the development of CPDLC and believe that FAA must actively monitor these tests to reduce future costs and prevent duplication of effort. Although the PETAL trials rely on somewhat different technologies than the working group recommends, the Europeans are exploring the human factors issues with both controller and pilot and making important progress in determining what the CPDLC message set should be. At a minimum, these tests will generate data that will prove useful in future deliberations about CPDLC.

Implementing CPDLC is a complex, long-term development effort that will require FAA and industry to address a wide range of issues. FAA and industry are working on the details of implementing CPDLC but important issues remain unresolved. Given the complexity of the effort and uncertainty regarding controller and pilot issues, revisions to cost and schedule are likely. The challenges and risks we have outlined in this report are not insurmountable and can be addressed through careful planning and effective risk mitigation. FAA needs to develop a comprehensive plan to guide government and industry efforts. This plan should address: (1) milestones for implementing CPDLC at all facilities, (2) resources requirements for FAA and industry, (3) transition strategies for all facilities, (4) incentives for airlines to equip, and (5) impacts of international developments on U.S. airlines. This plan, once it is developed, will need to be updated regularly because data link is in the early stages of development and there will be changes in program costs and schedule.

RECOMMENDATIONS

We recommend that FAA:

1. Develop a comprehensive plan for implementing CPDLC for all air traffic control facilities (en route, terminal, tower, and oceanic) that establishes milestones, financial resources for FAA and industry, transition strategies, incentives for U.S. airlines to equip, and impacts of international developments. This plan should be a living document and be updated regularly to reflect changes in direction and operational experiences.

2. Place a high priority for funding human factors work for CPDLC. Attention and resources need to be focused on assessing how controllers

and pilots will interface with the new technology, new air traffic control procedures, new training programs for pilots and controllers, and improvements in the design of new data link equipment.

3. Establish the roles and responsibilities of Aircraft Regulation and Certification and Air Traffic Services for operationally approving CPDLC.

4. Continuously monitor consortium software development efforts to prevent schedule slips and cost growth.

5. Assess security requirements for CPDLC, potential safeguards, and impacts on the cost and schedule of the program.

6. Leverage the experiences of FANS-1 by monitoring operational experiences of pilots and controllers on a regular basis.

7. Develop a formal strategy for using the results of European data link efforts to reduce development costs and potential duplication of effort.

CHAPTER III: FAA MUST ADDRESS LONGSTANDING MANAGEMENT PROBLEMS WITH CONTROLLER-PILOT DATA LINK COMMUNICATIONS AND RELATED EFFORTS

Various data link systems have been under development at FAA for 15 years at a cost of $420 million. While there have been some successes, FAA and the aviation community remain several years away from having a data link system for controllers and pilots to use in domestic airspace. Although FAA and industry have made important progress over the past year, we believe FAA must fundamentally change the way it manages, plans, and funds its data link efforts to ensure the successful implementation of CPDLC. We found:

- FAA has viewed CPDLC from four distinct operational perspectives (en route, terminal, tower, and oceanic environments) with little effective coordination among them.

- FAA does not have a comprehensive plan for implementing CPDLC throughout the NAS.

- FAA has not made sound investment decisions. FAA spent over $100 million on hardware and software that will never be used for supporting data link between controllers and pilots.

- Fundamental changes regarding cost, schedule, and technical issues were made to various data link efforts, including CPDLC, without documentation and required approvals.

MANAGEMENT OF CPDLC NEEDS TO BE STRENGTHENED

FAA has viewed CPDLC from four distinct operational perspectives (en route, terminal, tower, and oceanic environments). According to FAA officials, there was little effective coordination among them.

Three different and distinct FAA groups are responsible for developing and implementing CPDLC. FAA's Air Traffic Services, the sponsor of CPDLC, is responsible for defining its operational requirements. Under the auspices of the Office of Communication, Navigation, and Surveillance Systems, FAA's Aeronautical Data Link Team is responsible for managing and acquiring CPDLC in the en route, terminal, and tower environments. Oceanic CPDLC, on the other hand, is the responsibility of the Office of Air Traffic Systems Development. FAA officials told us that routine coordination problems with acquisition projects are amplified by the complex nature of CPDLC, its linkages to other efforts, and the agency's current management approach.

FAA has established a Free Flight Phase 1 Program Office to manage the various Free Flight Phase 1 initiatives. However, FAA program officials told us that the new office would not be responsible for managing CPDLC because of the recent changes to the program. FAA officials believe the responsibility of the office extends only to projects that are clearly achievable by 2002--not for projects, such as CPDLC, that begin after that time and still require detailed planning. Thus, FAA intends to manage CPDLC as a related but separate effort. This has resulted in confusion and concern about how the program will be managed and by whom.

In our view, the complex nature of CPDLC demands a more straightforward and unified approach. We believe FAA needs a single agency official that is responsible for CPDLC across all operational environments and can proactively identify problems. This official should play a key role in developing plans and budgets, setting priorities, and ensuring that activities are effectively coordinated and integrated. In addition, as evidenced by the FANS-1 experience, strong systems integration skills will be needed to identify and resolve problems about how and when the individual components of CPDLC are expected to work together. Therefore, we believe that a joint FAA and industry integration team would help resolve technical and operational problems as they arise.

PLANNING NEEDS TO BE IMPROVED

As we pointed out in Chapter 2, FAA does not have a comprehensive plan for implementing CPDLC throughout the NAS that sets out milestones and resources requirements. Airlines are looking to FAA to develop a plan with transition paths for using CPDLC and other applications of data link technology. Past planning efforts have failed to establish realistic milestones and gain industry support.

In 1993, FAA intended to have CPDLC in use at select en route, terminal, and tower locations by late 1996 with use throughout the NAS at some unspecified time in the future. FAA now anticipates that CPDLC will be in use in 2002 for testing purposes at one domestic en route center--6 years later than anticipated. Early CPDLC projects were intended to work with key segments of the multi-billion dollar Advanced Automation System that were planned for FAA's en route, terminal, and tower facilities.[22] According to FAA officials, the dramatic restructuring of the Advanced Automation System in late 1994 resulted in confusion about how, when, and if CPDLC would be implemented

[22] For additional details on Advanced Automation System, see our report Advanced Automation System (Report Number AV-1998-113, April 15, 1998).

in domestic airspace. Controller-pilot data link communications are now planned as product improvements for the Standard Terminal Automation Replacement System and the Display System Replacement--the successors to the Advanced Automation System.

Delays in implementing CPDLC also stem from the agency's inability to reach a consensus with the aviation community on the use of the Mode S radar as a vehicle for CPDLC.[23] FAA planned to use Mode S for transmitting weather and air traffic control messages to pilots. By 1996, however, it was clear that FAA could not find common ground with the industry because of the high cost to equip aircraft, questions about the performance of Mode S for data link communications, and uncertainty about benefits. FAA has abandoned Mode S as a vehicle for transmitting CPDLC messages. This experience underscores the need for FAA to work closely with the user community to obtain commitment before deciding on a solution and spending funds.

"Who Pays?" for CPDLC Messages Needs to be Addressed

An important policy issue facing FAA and industry is the question of "who pays?" for CPDLC messages. In addition to the installation of new equipment, CPDLC will generate transmission costs. FAA and industry officials believe this is one of the most salient issues and requires resolution because, in the long-term, per message costs could total millions of dollars annually. On December 9, 1998, FAA's Joint Resource Council decided that FAA will pay for all CPDLC messages costs in the near-term for planning purposes, but agreed to consider the long-term issue in discussions with the Congress and industry regarding the establishment of user fees.

Currently, FAA pays for all voice and some data communications in the NAS at a cost of about $ 350 million annually. CPDLC is an entirely new service and as such will place additional financial demands on FAA. Of the $645 million estimated thus far for CPDLC Builds 1 and 1A, over $400 million through 2015 is associated with message costs. According to FAA program officials, CPDLC is an excellent candidate for a user fee because, unlike other air traffic control services, FAA and industry officials believe it will be easy to determine who is receiving and sending messages on a per message basis and therefore determine who to bill. Once CPDLC has been tested and experience gained, FAA needs to develop a policy regarding how CPDLC message costs will be paid for.

[23] Mode S is a secondary surveillance radar, which identifies, locates, and tracks aircraft by using its signals to interrogate transponders on aircraft.

INVESTMENT DECISION-MAKING AND DOCUMENTATION NEEDS TO BE IMPROVED

In the past, FAA has made poor decisions about what technologies to invest in and when to invest in them. For example, a key element of FAA's data link efforts in the 1980s and early 1990s was the development of a Data Link Processor (DLP) and the software for en route air traffic control facilities.[24] The DLP was intended to provide weather and air traffic control information to properly equipped aircraft. FAA spent over $100 million on various DLP projects through three different contracts but DLPs will not be used for the intended purpose of supporting data link communications for controllers and pilots. FAA abandoned DLP in 1996 because it was designed to rely on a technology (Mode S) that was no longer considered feasible for data link communications. The total loss to the Federal Government from this effort is unknown at this time because FAA is in the process of finding other uses for the equipment and believes some of the software may be used in future efforts.

Key Documentation Was Not Prepared

A 1997 independent assessment of FAA's data link efforts raised serious concerns about the acquisition management of the program.[25] Specifically, the assessment noted that fundamental changes regarding cost, schedule, and technical issues were made to various data link efforts, including CPDLC, without documentation and required approvals. Our analysis confirmed these problems. Documents we reviewed from 1990 to the present reference the status of various data link projects under the prior acquisition system, but we found no supporting documentation for key decisions, and it appears that required documentation was not prepared. For example, realistic cost and schedule baselines were not prepared and various alternatives were not analyzed for CPDLC or other data link projects.

CPDLC is now progressing through FAA's Acquisition Management System. As a first step, FAA completed the investment analysis process for CPDLC Build 1 and 1A in October 1998. This was not a classic investment analysis, as defined by FAA's Acquisition Management System, whereby a number of alternatives are defined and evaluated. Instead, the analysis relied on the previous work and recommendations of the working group. An investment analysis for Build 2 is expected to be more comprehensive, and completion is

[24] FAA purchased 25 DLPs for en route facilities and support purposes, deployed some of them, and then withdrew them from service.

[25] See Independent Assessment on the Aeronautical Data Link (ADL) Program, Science Applications International Corporation (March, 31, 1997, FAA contract No. DTFA01-96-C-00027).

planned for April 1999. FAA involved industry in the initial investment analysis and plans to continue to involve industry officials in subsequent analyses of CPDLC. Because CPDLC success depends on both FAA and industry investments, we believe industry's participation is critical.

In the final analysis, CPDLC is an important technology for Free Flight. Without an effective and reliable data link for controllers and pilots, the full expected benefits of Free Flight cannot be realized. FAA needs to change the way it manages CPDLC, capitalize on recent working group efforts, and take concrete steps to plan for and implement CPDLC in domestic airspace. We are making recommendations aimed at improving FAA's management, mitigating risks, and to make future efforts more cost effective.

RECOMMENDATIONS

We recommend that FAA:

1. Designate a single FAA official for CPDLC with clear lines of responsibility and accountability who is responsible for coordinating and integrating the various air and ground elements of CPDLC.

2. Establish a joint FAA/industry integration team (composed of FAA, airlines, avionics manufacturers, and other appropriate parties) to identify and resolve technical and operational problems that occur regarding how the various air and ground segments of CPDLC work together.

3. Continue to include industry and stakeholders in the investment analysis of CPDLC for all types of FAA facilities (en route, terminal, tower, and oceanic) to fully identify costs and benefits.

4. Once CPDLC has been tested and experience gained, develop a policy on who will pay for CPDLC messages.

CHAPTER IV: OBJECTIVES, SCOPE, AND METHODOLOGY

Our objective was to evaluate FAA's plans for implementing CPDLC throughout the NAS. During the course of our review, the House Science Committee asked us to evaluate FAA's past and present efforts to develop CPDLC, and we adjusted our work accordingly. As agreed with the Committee, we focused on (1) current plans for implementing CPDLC in domestic airspace, (2) risks and challenges facing the program, and (3) how FAA's management of the effort could be improved. We performed our work at FAA headquarters in Washington, D.C. and other locations between February and November 1998 in accordance with Government Auditing Standards as prescribed by the Comptroller General of the United States. There was no prior audit coverage by the Office of the Inspector General (OIG). We focused our work on FAA's efforts from 1990 to the present.

CPDLC is an element of a much larger program called Aeronautical Data Link (ADL). The ADL program currently is developing a wide range of data link products for different segments of the aviation community, and has had responsibility for several others over the period of our review. We focused our efforts on CPDLC in the terminal, tower, oceanic, and, particularly, the en route environments.

- We reviewed (1) selected reports and testimonies issued by our office and the General Accounting Office; (2) FAA policies on acquisition management; (3) ADL program files from 1990 to the present; (4) relevant reports and other literature on topics such as aviation communications, human factors, air traffic control modernization, NAS architecture, and computer security; (5) independent assessments of FAA data link efforts; and (6) information on current and past data link activities from searches of FAA and other aviation-related web sites.

- We analyzed financial data on the ADL and Oceanic Programs and verified our results with FAA's budget office.

- We analyzed multiple operational concepts on how new communication, navigation, and surveillance technology will affect controllers, with specific focus on CPDLC.

- We interviewed (1) current and past FAA managers and staff of the ADL and Oceanic Programs; (2) managers and staff of other relevant FAA offices including those with responsibility for certification, air traffic operations, communications spectrum, air traffic requirements, human factors, budgeting, and investment analysis; (3) airline managers

(American, United, Delta, Northwest, U.S. Airways, Southwest, and United Parcel Service) and pilots; (4) representatives of Boeing, Raytheon, ARINC, and Mitre Corporations; (5) representatives of industry groups such as the Air Transport Association and RTCA; and (6) representatives from pilot and air traffic controller associations.

- We attended meetings of the Modernization Task Force's Data Link Working Group and the CPDLC Investment Analysis team.

- We observed air traffic operations in all four environments (tower, terminal, en route, and oceanic) and spoke with controllers, including those who participated in the Technical Center en route data link simulations.

- We conducted site visits and participated in flight simulations of CPDLC at Boeing, NASA Ames Research facility, and FAA’s Technical Center.

EXHIBIT A

Selected Applications of Data Link for Civil Aviation

Application	Description	Implementation
Automatic Dependent Surveillance-broadcast (ADS-B)	Periodically broadcasts an aircraft's position (such as latitude, longitude, and altitude) and other information from the aircraft for air-to-air and air-to-ground surveillance.	Planned implementation in 10 years.
Cockpit Display of Traffic Information (CDTI)	Provides for automated, mutual airborne surveillance of traffic information (such as relative position, altitude, and collision avoidance) between aircraft.	Relies on the development and implementation of ADS-B.
Controller-Pilot Data Link Communications (CPDLC)	Allows controllers to communicate instructions to commercial pilots and to receive pilot requests and reports through computer terminals in the en route environment.	2002 planned implementation at one en route center.
Datalink Display of Taxi Clearance (DDTC)	Automatically delivers taxi route clearance information to commercial aircraft to improve gate/terminal management.	Currently being tested at Detroit.
Digital-Automatic Terminal Information Service (D-ATIS)	Provides a text copy of basic information about the airport (weather, landing direction, winds, altimeter, etc.) to commercial pilots.	Currently operational at 53 airports with plans to expand to 57 airports.
Flight Information Services (FIS)	Disseminates weather and flight information to both private and commercial pilots.	2002 planned implementation at 119 terminals.
Future Air Navigation System (FANS)	A means for commercial pilots and controllers to share digital information on aircraft position as well as clearances, advisories, and pilot requests over the oceanic environment.	Currently operational at one en route center.
Graphic Weather Service (GWS)	Provides cockpit display of weather in full color graphics.	Has been rolled into the FIS implementation plan.
Pre-Departure Clearance (PDC)	Provides automated delivery of clearance and flight information to the commercial airline dispatch center, which in turn delivers the information to the aircraft or gate printer.	Currently operational at 57 airports as part of the Tower Data Link Services Program.
Terminal Weather Information for Pilots (TWIP)	Provides near real-time aviation terminal hazardous weather advisory information to pilots in the form of text and character graphic messages over ACARS. Weather data includes gust fronts, storm motion, and precipitation intensity.	Currently operational at 20 airports. Total implementation planned for 44 locations.
Traffic Information Service (TIS)	Provides surveillance information, such as automatic traffic advisories, to pilots via Mode S.	Currently operational at 80 sites. Total implementation at 119 sites planned by the end of 1999.

EXHIBIT B

MAJOR CONTRIBUTORS TO THIS REPORT

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