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DISCRETE ADDRESS BEACON SYSTEM DATA LINK APPLICATIONS STUDY

FINAL REPORT

Michael White
Thomas Berry

July 1980

84-0208

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
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16. Abstract

This study assesses the impact on ATC controller productivity and capacity and on pilot workload of applications of the DABS data link proposed by the FAA. New applications are also set forth as examples of how data link can serve pilot needs and contribute to the solution of issues facing the aviation community.

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METRIC CONVERSION FACTORS

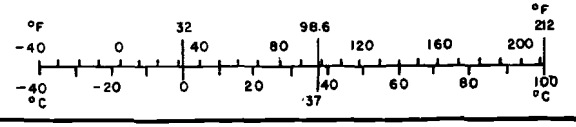
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FOREWORD

This report, submitted by ARINC Research Corporation in accordance with the provisions of Contract DOT-FA79WA-4386, addresses the impact of FAA-proposed applications of the DABS data link on ATC controller productivity and capacity and on pilot workload. This report also sets forth new applications of the data link as examples of ways in which data link could be used to serve pilot needs. The study was performed during the period from October 1979 through April 1980.

SUMMARY

The Federal Aviation Administration (FAA) is developing the Discrete Address Beacon System (DABS) as an eventual replacement for the current Air Traffic Control Radar Beacon System (ATCRBS). Inherent in the DABS design is a digital data link (DL) capability that will permit messages and data to be transferred between the ground ATC system and the aircraft. The FAA is investigating ways in which the DL could be used. One proposed use is in connection with the Automatic Traffic Advisory and Resolution Service (ATARS), a collision avoidance system. Other applications are also being investigated with the goals of enhancing safety, increasing aircraft throughput, reducing aircraft delays, and providing new capabilities. A set of specific applications has been proposed by the FAA, and this study provides preliminary assessments of their impact on controller productivity and capacity and on pilot workload. The study also develops and evaluates a few additional data link applications that may be very desirable for flight operations although they have no direct impact on controller or pilot workload.

The impact of DL on the workload of controllers and pilots is primarily determined by the nature of the man-machine interface. Two controller interfaces were studied: a voice recognition system (VRS) that would format spoken commands and transmit them by DL, and an automatic message generation and transmission system. For pilots, preformatted message terminals and voice recognition terminals were considered.

The use of a VRS interface would require the controller to speak commands and code words into a microphone. A computer would recognize their semantic content and format a DL message. This message would be displayed to the controller for approval prior to transmission. ARINC Research Corporation determined that such a scheme would save very little communication time; most messages currently transmitted by voice radio are already reduced to a practical minimum. On the average, perhaps 17 percent of the words used in routine messages could be deleted without introducing ambiguity. This small improvement would, however, be more than negated by the addition of the message verification task. This task is essential because the VRS will never be capable of 100 percent accuracy in translating spoken words. Thus this scheme would probably lead to an increase in overall workload, with a corresponding decrease in productivity and capacity (P&C).

The use of an advanced computer system to perform surveillance and automatically transmit commands via DL without intervention or review by the human controller has also been proposed. It is certain that such a system would provide greater controller P&C, but it is unclear whether comparison of fully automated system performance with human baseline performance is meaningful; the two systems are almost entirely dissimilar in operation, philosophy, cost, and capability. The increase in P&C with such a system would in large part be due to factors other than DL. Hence, for this study only, a lesser degree of automation was examined for direct comparison with human baseline performance. Referred to variously as Controller Autopilot or Automatic Standard Terminal Approach Route (AUTOSTAR), this scheme automates some of the controller's tasks while leaving intact his authority and responsibilities. Under AUTOSTAR, a controller can set up within an approach, departure, or en-route sector a series of "windows" and can preprogram a message to be transmitted automatically when an aircraft arrives at that window. Figure S-1 shows a series of windows and messages within an approach sector. The controller vectors aircraft to an entry window with proper speed and spacing; from then on, instructions needed to vector the aircraft along the desired path are transmitted automatically by DL. This relieves the controller of having to make repetitive routine transmissions. This scheme could save as much as 50 percent of the controller's communication time, as shown in Figure S-2.

The impact of DL on pilot workload varies from task to task, but overall, it is estimated that about a 50 percent reduction in communication time could be achieved by using either the preformatted message or the VRS terminal. Although this percentage seems large, it must be viewed in the context of the other tasks a pilot performs. Communications account for only 2 percent of a pilot's usual workload (see Figure S-3). This 50 percent reduction in communications represents only 50 percent of 2 percent of the total workload. It is not clear that this small reduction in overall workload is by itself sufficient to justify a DL system. There are, however, other benefits to be derived from DL besides workload reduction that could prove to be of great value. Several new applications are proposed in this study as examples of ways in which DL can benefit pilots and controllers by providing new capabilities; these are summarized below.

The DABS sensor tracks each aircraft and continuously monitors its position. This information could be sent by DL to the aircraft, thereby providing an accurate navigational fix. In response to a downlink request specifying some point relative to the DABS sensor, the system could compute and transmit RNAV or DME-type information to the aircraft, duplicating the function of these systems for any aircraft within a DABS service area. This would be accomplished at little or no additional cost beyond that of the basic DABS/DL transponder, and the system would perform the same function as a DME or an RNAV -- each of which could cost $3,000 or more. This would be a valuable service to pilots, especially general aviation (GA) owner pilots and would be a strong incentive for them to equip their aircraft with DABS/DL.

Many aircraft carry weather radar to detect the presence of storm cells. These radar sets, however, are quite expensive, costing $8,000 or

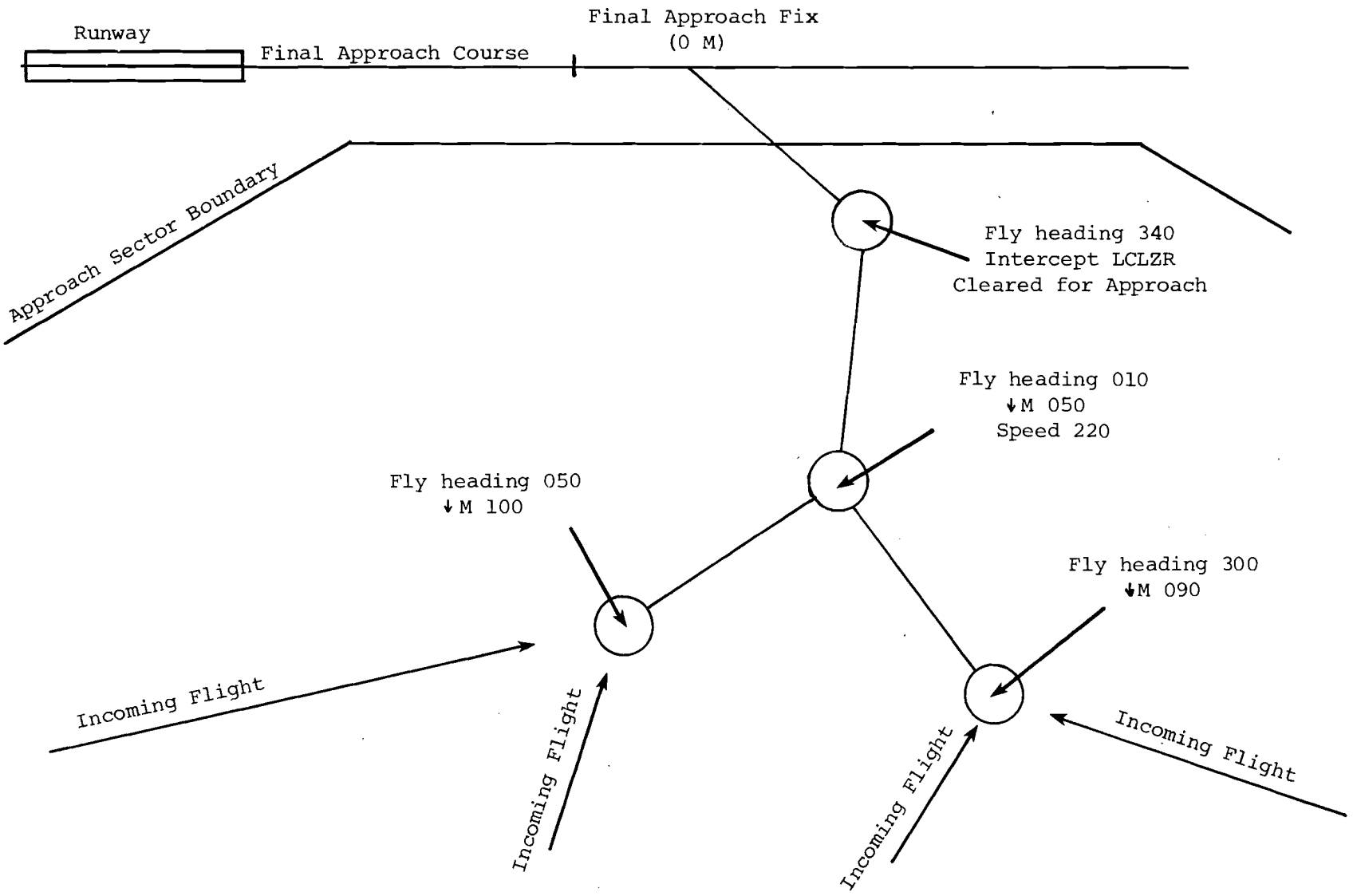
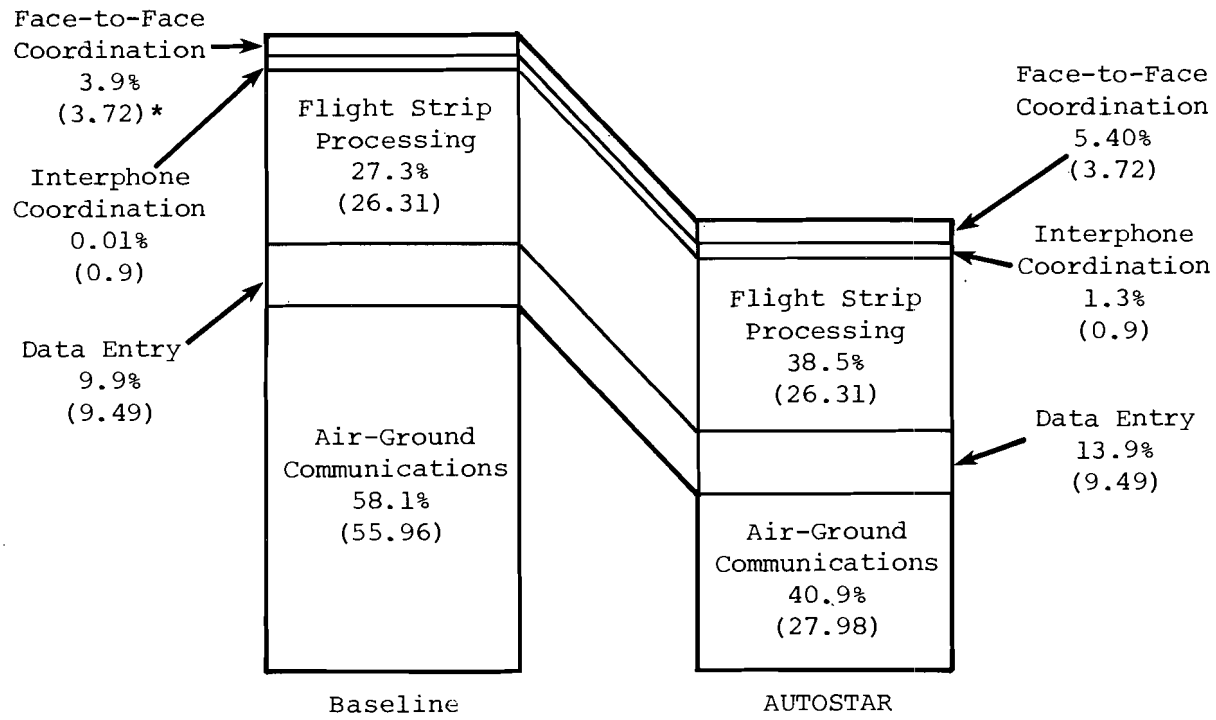
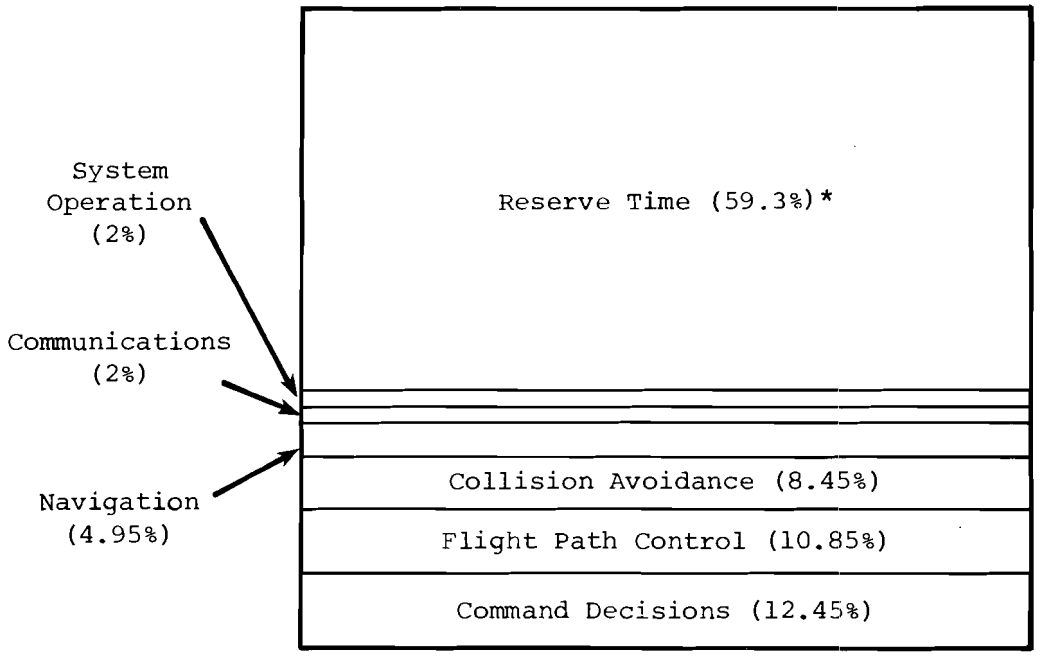


Figure S-1. AUTOSTAR



*Values in parentheses represent the average number of seconds spent by controllers on each task.

Figure S-2. CONTROLLER WORKLOAD



*These values are taken from FAA *DC-9/50, 2/3 Man Cockpit Study*.

Figure S-3. PILOT TASK BASELINE: AVERAGE WORKLOAD

more installed. Weather data from ground units could be transmitted by DL to an aircraft on DL request. The display could be oriented along the aircraft's heading, in much the same way as a radar display. This scheme could provide information similar to that provided by radar, but at much lower cost. The capability also exists to display weather at greater distances, not just that immediately ahead of the aircraft, allowing a pilot to preview conditions at his planned destination or at an alternate site. The provision of this radar-like service would be another powerful inducement to an aircraft operator to equip his aircraft with DABS/DL.

One of the problems confronting the GA community today is the difficulty of transiting terminal control areas (TCAs). Traffic densities within the TCA often preclude transit by VFR aircraft. Some TCAs incorporate "tunnels" of VFR airspace through the TCA to provide routes for VFR flights. However, most TCAs do not lend themselves to the establishment of such permanent tunnels. Through the use of DL, however, adaptive tunnels might be designated that would change with traffic flow and winds. DL could keep pilots informed of the exact course and altitude of the tunnel, allowing transit without direct intervention by the controller.

The last example of new applications is the scheme called AUTOSTAR. As discussed earlier, it provides for automatic transmissions of preprogrammed messages as aircraft reach "windows" set up within a sector.

These four new applications are presented to show that there are ways in which DL-based service can be of great value to pilots and controllers other than by directly reducing their workloads.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The Federal Aviation Administration (FAA) is developing the Discrete Address Beacon System (DABS) as an eventual replacement for the current Air Traffic Control Radar Beacon System (ATCRBS). DABS represents a significant improvement in that it interrogates each aircraft within its service area individually by means of a code unique to that aircraft, assigned at the time of the aircraft's manufacture. ATCRBS interrogates all aircraft within the effective antenna beamwidth indiscriminately, eliciting overlapping replies when aircraft are close to each other.

Because DABS addresses aircraft discretely, and because digital data must be passed both to and from the aircraft in order to accomplish this, a digital data link (DL) capability is inherent in the DABS design. While a DL might loosely be defined as any means of transferring information, in this context it refers to a radio circuit that carries digitized, nonvoice data. Because DL capability was recognized as being a highly desirable feature for DABS, provisions were made in the DABS design to accommodate data in addition to what is required for the surveillance function for which DABS was originally designed.

The message format provided in the system does not specify or limit the type of message or data to be sent over the DL. Virtually any kind of information can be transmitted, provided it is digitally encoded in the proper format.

The FAA is currently investigating ways in which the DL could be used. One of its major applications is expected to be in the Automatic Traffic Advisory and Resolution Service (ATARS), a collision avoidance system. The FAA is, however, investigating applications in addition to ATARS to enhance safety, increase throughput, reduce delays, and provide new capabilities for pilots and controllers. A number of specific applications of the DL that address these issues have been set forth by the FAA*. These proposed applications are directed toward replacing certain routine voice messages with digital DL messages, providing faster access

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*Report No. FAA-ED-06-02, *Engineering and Development Program Plan for Data Link Applications Development*, FAA-SRDS, Washington, D.C., January 1979.

to data such as weather reports and forecasts, and generally streamlining the entire air-ground information-transfer task.

DL is expected to affect two specific issues: controller productivity and capacity (P&C) and pilot workload. In determining the overall suitability of DL and the preferred modes of implementing it, the FAA required an assessment of the impact of DL on these two issues. In addition, the FAA sought new applications serving the needs of both pilots and controllers.

This report examines the impact of the DL applications proposed in the E&D plan on controller P&C and on pilot workload. New applications of the DL are also set forth, and their impact is estimated.

1.2 OBJECTIVES

The present study has three objectives:

- Determine the impact of the proposed DL applications on controller P&C
- Determine the impact of the proposed DL applications on pilot workload
- Set forth new DL applications that serve the needs of pilots and controllers, and estimate their impact on controller P&C and pilot workload

1.3 APPROACH

This study was organized into three tasks. The first task addresses the impact of the proposed DL applications on controller P&C. The second addresses the impact of the proposed applications on pilot workload, and the third addresses new applications and their impact on controller P&C and pilot workload. The following paragraphs summarize the approaches taken in each task.

1.3.1 Task 1: Impact of Proposed DL Applications on Controller P&C

ARINC Research categorized the tasks that a controller performs and developed a baseline of controller P&C. This baseline was derived in part from Stanford Research Institute (SRI) studies* of controller performance in a DL and automation environment. Subsequently, we addressed the impact of introducing DL into two terminal configurations and three levels of automation. The impact was gauged in terms of task time saved as the direct result of DL. Other factors which also may reduce task time but are not related directly to DL, such as flight strip automation, were

*Couluris, G.J., and Johnson, J.M., *Oakland Bay TRACON and Los Angeles TRACON: Case Studies of Upgraded Third Generation Terminal ATC Operational Impact*, FAA-AVP-77-23, Stanford Research Institute, Menlo Park, Calif., March 1977.

considered. Findings were summarized by an overall task-time reduction figure for DL-related savings, and the impact of non-DL savings factors were discussed.

1.3.2 Task 2: Impact of Proposed DL Applications on Pilot Workload

Pilot workload and the factors contributing to it were defined. We characterized the tasks that a pilot performs in routine and emergency conditions and established a baseline of pilot workload, defining the percentage of the total workload represented by each of the tasks identified. Each proposed DL application was then taken in turn and, partly on the basis of guidelines set forth by SRI, the reduction in task time resulting from the introduction of DL techniques was estimated for scenarios for two user terminals.

1.3.3 Task 3: New Applications

We examined the entire range of pilot and controller tasks to determine which could be reasonably addressed by means of DL. Specific applications were set forth, and an estimate was made of their impact on P&C and workload. In addition, a hierarchy of pilot and controller needs and new or additional capabilities and their relative importance were established. Applications addressing these needs were developed, and their impact was estimated. We discussed DL capabilities replacing or supplementing present capabilities and the overall place of DL in the cockpit of the future.

1.4 REPORT ORGANIZATION

The remainder of this report is organized as follows: Chapter Two contains the assessment of the impact of the proposed DL applications on controller P&C. Chapter Three covers the impact of the proposed applications on pilot workload, and Chapter Four sets forth new applications. Chapter Five summarizes the findings of this study and provides general discussion material.

CHAPTER TWO

IMPACT OF PROPOSED DL APPLICATIONS ON ATC CONTROLLER PRODUCTIVITY AND CAPACITY

This chapter assesses the impact of DL on controller productivity and capacity. The extent of this impact is determined primarily by two factors: the uses to which DL is put, and the nature of the man-machine interface device or system used by the controller. Therefore, the impact assessment is prefaced by a discussion of the DL applications proposed by the FAA, the assumptions made that bear on the study results, and the two interface schemes addressed in this study. In addition, a characterization of present controller workload is presented to provide a standard against which the impact of DL may be judged.

This assessment will show that (1) differences between the performance of a totally automated ATC system and human baseline performance are, for the most part, due to factors not directly related to DL, but (2) lesser degrees of automation are possible in which DL is a vital factor and which would reduce the communication workload up to 50 percent.

2.1 PROPOSED DL APPLICATIONS

The concept of an air-ground DL is neither new nor unique. A number of civil and military DL systems are in use today. The DABS DL concept, however, is the first to promise the extension of uniform, low-cost DL services to virtually all aircraft in the United States. Because of the great promise of DABS DL, the FAA is taking special care in formulating applications of the DL so as to be responsive to the widest possible range of pilot and controller needs and to provide the greatest additional capability for the greatest number of aircraft. For this reason, applications directed toward general aviation (GA) operations have been proposed along with those that apply to air carrier operations. (Of course, many applications apply to both.)

The proposed applications considered in this study are those listed in the engineering and development plan cited earlier. As stated in that plan, the objectives of the applications are the following:

- Reduce controller workload through automation
- Ease communications channel congestion

- Provide hard-copy messages to the pilot
- Provide real-time weather data to the pilot
- Provide confirmation of ATC clearances
- Transmit weather data from air to ground

To these ends, a number of specific applications have been set forth. They are listed below, with comments where appropriate:

- Acknowledgment -- This function would replace the currently used "Roger" plus identification.
- Beacon Code Assignment -- The assigned code could be displayed to the pilot in some way or, alternatively, the transponder code could be set automatically, requiring no action on the part of the pilot.
- Altimeter Setting -- The setting could be displayed, or the altimeter could be set automatically.
- Heading Assignment
- Altitude Assignment
- Airspeed Assignment
- Holding Instructions
- Approach Clearance
- Minimum Safe Altitude Warning (MSAW)
- Conflict Alert
- Request for Position Report
- Metering and Spacing -- This function would be used to assign airspeed, holding, and spacing maneuvers.
- Takeoff Clearance Confirmation -- This would be used in conjunction with voice clearances.
- Altitude Assignment Confirmation -- This would be used in conjunction with voice.
- Runway Visual Range (RVR) -- RVR would be linked to aircraft during final approach, giving real-time data.
- Airborne Situation Display
- Altitude Echo -- This function would inform the pilot of the altitude his encoder is reporting. Comparing that with the cockpit altitude readout could identify a malfunction or an incorrect altimeter setting.
- Flight Plan Clearance -- This would deliver a flight plan in hard copy to the pilot.
- Taxi Instructions
- Standard Terminal Approach Route Assignment

- Gate Assignment -- This would apply primarily to air carriers.
- Landing-Aid-Inoperative Alert -- This would provide a backup to cockpit instrument flags.
- ATIS/NOTAM Delivery -- This would deliver ATIS to the pilot in hard copy.
- Pre-Departure Weather Delivery
- Severe Weather Advisory
- En-Route Weather Delivery
- Threat Traffic Advisory -- This would be an anti-collision measure.
- Resolution Advisory -- These would provide maneuvers and vectors to resolve potential collision situations.
- High Altitude Winds -- Each report could be customized to the route of flight.
- Center Field Winds
- Threshold Surface Winds -- This would provide a real-time approach aid.
- Vector Wind Change
- Wind Shear Existence
- Maximum Shear
- Flight Plan Filing
- Weather Reporting -- This would replace the present voice PIREPS.
- Airspeed Reporting
- Heading Reporting
- Air Temperature Reporting
- Frequency Assignment -- The assignment could be displayed, or the frequency could be set automatically.

2.2 KEY ASSUMPTION INVOLVING MICROPHONES

In assessing these proposed applications and establishing baseline performance, an important assumption is that the controller and pilot employ microphones that allow hands-free operation; that is, microphones such as boom microphones attached in some way to a headset. It is also assumed that the pilot has a push-to-talk switch on the left-yoke horn and the controller has a foot-switch to activate the microphones. This assumption is important because using a hand-held microphone would add considerably to baseline communication time and to performance time under DL schemes requiring a microphone. This is especially true for the pilot workload; flying often is a manually intensive activity. Figure 2-1 illustrates typical boom microphones.

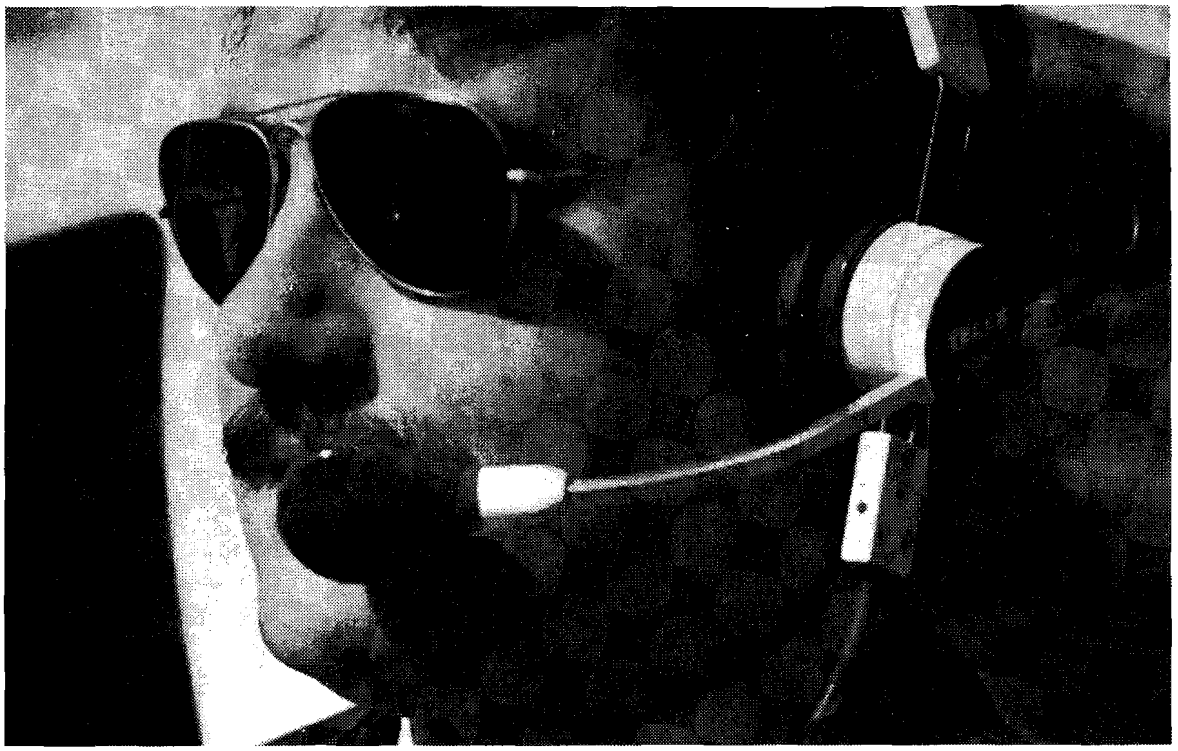

Figure 2-1. EXAMPLES OF BOOM MICROPHONES

2.3 AUTOMATION

In considering applications of the DL and its impact on controller P&C and pilot workload, it is important to distinguish between DL per se, and automation dependent on the DL. As the E&D plan points out, there are numerous ways in which automation can be used to reduce controller and pilot workload. The ultimate in workload reduction is, of course, 100 percent: it may be possible to automate all tasks completely, reducing workload to zero, but this may never be practical. There is, however, much practical, implementable automation that would materially reduce workload. These applications of automation would be made possible by the availability of DL; without it the automation would be impractical. Metering and spacing are good examples. Spacing commands generated by the computer could be automatically sent via DL to the aircraft. Without DL, each command would have to be relayed by voice to the aircraft by the controller; as the SRI study points out, this would be a cumbersome, basically unworkable solution. The important point here is that it is the *automation* that decreases the workload; the DL simply makes possible the use of automation. Automation made possible by DL provides the benefit, not DL itself.

2.4 INTERFACE

2.4.1 Requirement

As was pointed out in the previous section, the combination of automation and DL decreases workload. The degree to which the automation can decrease workload depends highly on the nature of the man-machine interface.

The DL itself is a means whereby one machine can "talk" to another machine; a human cannot use the DL directly. It is necessary to provide some sort of man-machine interface (e.g., a keyboard). The ease with which data can be entered into or read from the system will depend almost entirely on the nature of the interface device and the specific actions a user must perform in the context of the other tasks in which he is involved.

The design of man-machine interface devices is a science in its own right, involving human engineering, physiology, and psychology, and is far beyond the scope of this study. However, since this consideration is a key concern in the development of DL, the following section contains a brief discussion of the fundamental constraints on interface devices.

2.4.2 Human Engineering Limitations

The human being may be considered as a system consisting of a processor (mind), that receives inputs by means of the senses of vision, hearing, touch, smell, and taste, and generates outputs through speech, hand and body signs, and manipulation (writing, pushing buttons, setting switches).

Thoughts and actions originate in the mind and are coupled to the outside world by the inputs and outputs available. Data must reach the mind through one of the inputs, and actions must be initiated by means of

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one of the outputs. Therefore, no matter what kind of information is sent over a data link, it must eventually be reduced to a form useful to a human. Similarly, information must be entered into the data link by means a human can operate.

The air traffic controller-to-pilot communications path is a mind-to-mind link: instructions that originate in the mind of the controller must be transferred to the mind of the pilot, and vice versa.

The ease with which the controller can interface with the data link by means of one of his output capabilities will determine the impact of the system on his workload. It is interface design, then, that will determine whether, and how much, a given data link application will reduce the workload of a pilot or a controller.

2.4.3 Interface Considered

Given the strong dependence of workload reduction on interface design, it was necessary to select specific configurations for study. After consultation with the FAA, two controller terminal configurations were selected for study: a voice recognition terminal and an automatic message generation and transmission terminal.

2.4.3.1 Voice Recognition System (VRS)

In recent years, VRSs that allow the interpretation of spoken words by a computer have become available. Techniques center on digital sampling of input voice and comparison with stored vocabulary speech patterns. Such devices are capable of correctly interpreting more than 95 percent of spoken words when the machine can be adapted to work with a single individual's speech patterns.

In the ATC application, it is assumed that the controller would speak formatted commands into a microphone activated by a hand or foot switch. The VRS computer would detect the semantic content of the message and compose a DL message. This message would be displayed to the controller for approval before transmission. It would not usually be a word-for-word copy of the spoken command. Symbols and shorthand would be used in most cases. For instance, the spoken command "climb to and maintain flight level two five zero" might be encoded as "↑M FL250" for DL transmission. Confirmation by the controller before transmission is essential because the VRS is not, and probably never will be, 100 percent efficient in recognizing words; errors are almost unavoidable.

2.4.3.2 Automatic Message Generation and Transmission

The second controller terminal configuration studied is that in which DL messages are automatically generated by a computer and transmitted to the aircraft. Within this class of terminal, two different configurations were studied, involving two different levels of automation.

The first level of automation studied is that defined in the SRI report. In that system, the computer performs most of the functions now performed by the controller. The computer performs routing, altitude assignment, metering and spacing, and collision avoidance functions, and issues appropriate clearances. The human controller becomes a traffic flow monitor who is not involved in minute-to-minute decision-making. He intervenes only in cases of computer failure or to resolve problems not satisfactorily resolved by the computer. He does *not* review each message the computer transmits.

The second level of automation studied is a scheme sometimes referred to as "controller autopilot." Another name, used throughout the rest of this report is "AUTOSTAR" (automatic standard terminal approach route; however, although the term "approach" is used, the scheme could also apply to departure and en-route sectors). AUTOSTAR is discussed at greater length in Chapter Four of this report. In general, AUTOSTAR allows the establishment of "windows" at various places within the sector. As an aircraft enters a window, AUTOSTAR automatically sends a message by DL to the aircraft. (The message is preprogrammed by the controller.) The message will direct the aircraft to turn, climb, etc., so as to follow the desired route without the controller having to transmit the same instructions repeatedly to each consecutive aircraft. With this system, the controller can benefit from automation while still retaining full authority and responsibility for aircraft spacing, sequencing, and separation.

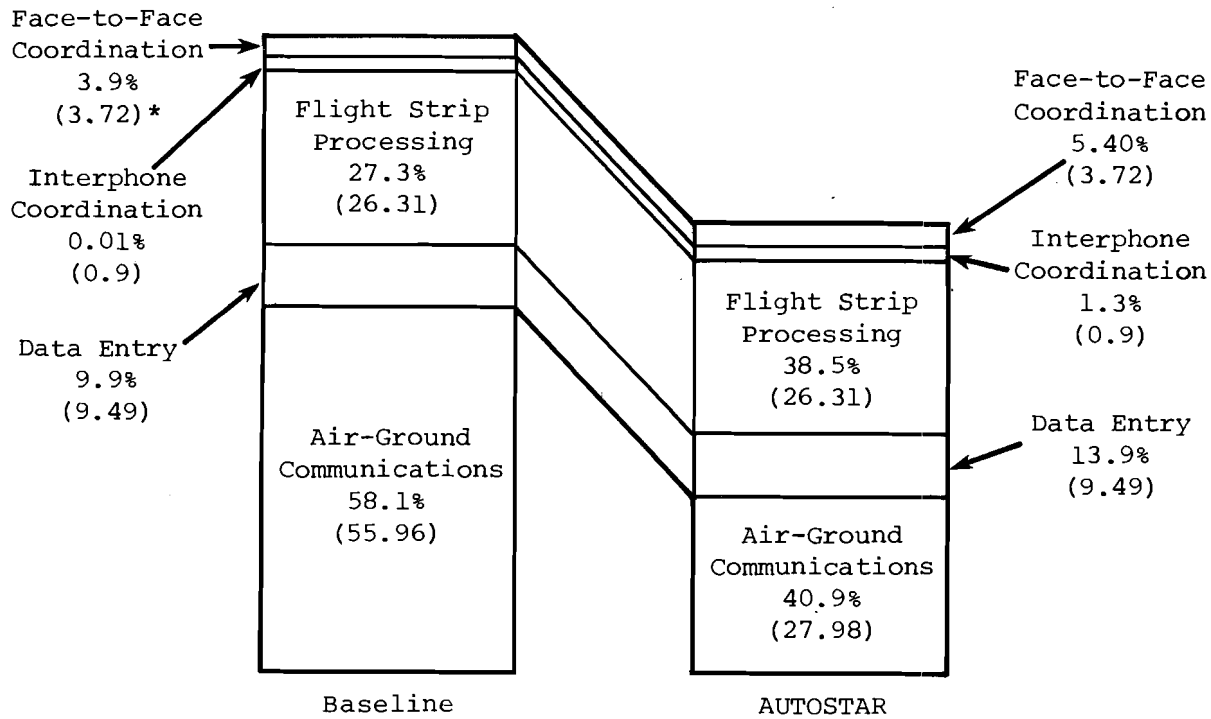
It is important to distinguish between AUTOSTAR and work under way involving automated metering and spacing (M&S). In the M&S scheme, the sequencing and spacing of aircraft is performed by computer, with the human controller acting in a monitoring and supervisory capacity. Under AUTOSTAR none of the decisions affecting the placement of aircraft need be relegated to the computer; the human controller retains full active control. He specifies the location of the windows and the messages to be sent and directs the spacing and sequencing of the aircraft.

2.5 VRS IMPACT

2.5.1 Controller Workload

In assessing the impact of the proposed DL application on controller P&C, it was first necessary to characterize the controller's workload and the tasks he performs. The SRI studies define five active tasks for controllers: air-ground communications, data entry, flight strip processing, interphone coordination with other controllers, and face-to-face coordination with other controllers. In addition to these tasks, there is an "operational cognizance" task. This refers to the controller's responsibility to observe the radar plan position indicator (PPI) and be aware of aircraft movements. The controller is usually engaged in this cognizance task whenever he is not engaged in any of the other five active tasks.

Figure 2-2 shows the five tasks in bar graph form. The graph indicates the percentage of the total time required to handle an aircraft that each task occupies. As is evident from this figure, the bulk of the workload is



*Figures in parentheses represent the average number of seconds spent by controllers on each task.

Figure 2-2. CONTROLLER WORKLOAD

related to air-ground communication and flight strip processing. The numbers in parentheses indicate the number of seconds per aircraft each task occupies for a typical Los Angeles arrival sector (see Section 4.3). This factor was determined by examining tape recordings made at Los Angeles arrival and departure sectors. It was found that the average aircraft was under the control of the sector controller for about 5.5 minutes, during which an average of 96.38 seconds was spent in active tasks related to that aircraft.

2.5.2 Assessment

The use of VRS would allow the controller to speak commands and data into a computer for transmission to the aircraft. The degree to which such a system would reduce his workload, thereby allowing him to accommodate more aircraft, would depend on how much less he must say and do under VRS than he must now say or do without VRS. There is, however, an irreducible minimum to which a message can be shortened before semantic meaning is lost and ambiguity results.

For the purpose of this analysis, it was assumed that VRS input messages would take the following three-part form: aircraft identifier, instruction designator, and instruction specifier.

The aircraft identifier is the flight or N-number of the aircraft to which the message is addressed: "American one twenty-three," or "November one two three four alpha." The instruction designator is the type of command: "climb," "turn," "report," or "cleared." The instruction specifier indicates how much or how far: (climb to) "5,000 feet," or (turn left heading) "360 degrees."

Consider the following command message: "Eastern one twenty-three, climb to and maintain flight level two five one." Under the present voice system, the controller speaks these words into a microphone connected to a radio transmitter. To initiate that message from a VRS-DL system, the controller would have to speak words that would (1) identify the aircraft ("Eastern one twenty-three"), (2) designate the instruction ("climb to and maintain"), and (3) specify the instruction ("flight level two five one"). Thus, he would have to say virtually everything he currently says in order to avoid ambiguity and completely specify the instruction. All four words of the aircraft identifier are needed to uniquely identify the aircraft; in the instruction designator, the words "to" and "and" might be eliminated, and in the instruction specifier, the word "flight" might be eliminated. Thus, of the 13 words the controller must now speak, perhaps 3 could be eliminated. Eliminating any other words would alter or render ambiguous the meaning of the message. For instance, if the word "level" were removed from the instruction specifier, it would be unclear whether the instructor referred to a flight level or an altitude in feet.

Table 2-1 shows a sample of 10 additional representative ATC messages taken from the FAA ATC manual.* Words and phrases that could possibly be eliminated without introducing ambiguity are underlined. As the table shows, of the 146 words in these 10 messages, perhaps 26 words could be deleted. This amounts to a reduction of less than 18 percent. The controller's messages have already been reduced to their minimum in order to reduce voice channel congestion. With a VRS, the controller would have to say practically everything he says now in order to avoid ambiguity.

The use of a VRS would, as mentioned earlier, require the verification of each DL message prior to transmission, an additional task. This would probably be accomplished by means of an alphanumeric display coupled to a keyboard for corrections. Table 2-2 shows possible DL messages that could result from the correspondingly numbered messages in Table 2-1. It would be necessary for the controller to read, understand, and approve each message prior to transmission. It is estimated that this new task would add three to five seconds to each ground-to-air transmission. Since a typical message is also about three to five seconds in length, introduction of this additional task could effectively double the controller's overall communication time. This estimate does not include correcting erroneously translated messages; corrections would require reentering a command by voice, or manually entering a correction by means of the keyboard. Either way would easily double again the communication task time.

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*FAA 7110.65, *Air Traffic Control.*

Table 2-1. ATC MESSAGES
1. "Cessna One Two Alpha, contact tower one two three point four"
2. "United Four Seventeen, descend and maintain six thousand"
3. "Beech One Two Bravo, cleared to land runway 27 left; caution wake turbulence Boeing 747 departing runway 27 right"
4. "American Two Thirty Four, taxi straight ahead to end of runway, then turn left"
5. "Cessna One Two Charlie, all runways covered by compacted snow six inches deep"
6. "Eastern One Twenty Three, seven miles from outer marker, cleared for ILS runway three six approach"
7. "Bonanza One Two Alpha, turn left heading three six zero"
8. "American Four Fifty Six, traffic, twelve o'clock one zero miles southbound, altitude unknown"
9. "Eastern One Twenty Three, expect ILS runway 9, radar vectors to localizer course"
10. "American One Twenty Three, cleared as filed except change route to read south Boston Victor 20 Greensboro, south Boston one departure maintain eight thousand report leaving four thousand"

Table 2-2. DATA LINK MESSAGES
1. CSNA12A CON TWR 123.4
2. UA417 ↓↓ 060
3. BECH12B CLR LND RWY 27L CTN WAKE B-747 T/O RWY 27R
4. AA234 TAXI END RWY THEN ←
5. CSNA12C ALL RWYS COURD 6 IN COMPACTED SNOW
6. EA123 7MI FRM OM CLR ILS RWY 36
7. BON12A ← 360
8. AA456 TFC 12 OCLK 10MI SOUTHBND ALT UNK
9. EA123 XPT RWY 9 ILS VCTR LOC
10. AA123 CLR AF EXCP CHNG ROUTE SBY V20 GRN SO BOS 1 DEP ↑↑ 080, RPT 040

There is another difficulty in the use of this DL scheme that is also common to all DL scenarios: the controller would have no assurance that the pilot had correctly understood the message. Currently, the pilot's voice read-back provides some measure of assurance that the pilot has both received *and understood* the message. With DL, even if an active acknowledgment by the pilot is required (e.g., pushing a "roger" button), the controller is assured only that the pilot received some message, not necessarily the right message. Even assuming that the correct message was in fact displayed, there is no assurance to the controller that the pilot's mental perception of the message is correct. The only sure way of confirming correct reception and understanding is for the pilot to reenter the message and transmit it back to the controller. This, however, could add greatly to a pilot's workload, thereby negating much of the value of DL. Research is needed to identify some quick and simple means of verifying receipt and understanding of a DL message.

2.5.3 Conclusions

Although voice computer input is often thought of as a good "human engineering" approach to computer interface, the issues discussed in the foregoing sections indicate that voice input is not a preferred mode for controller DL use, at least not as a way to reduce workload. Since communications are currently effected by means of voice, and since voice messages within the ATC system are already reduced to a practical minimum, practically no saving in communication time would accrue. Furthermore, the added task of verifying DL messages prior to transmission could easily double communication time. This would translate directly into a reduction in overall controller productivity and capacity.

2.6 AUTOMATIC MESSAGE GENERATION

2.6.1 Definition

Automation, as applied to ATC functions, refers to machine (computer) performance of tasks previously performed by human controllers. This definition encompasses a wide range of applications, such as automated flight strip processing and alphanumeric readouts replacing manual identification tags ("shrimp boats"). These applications of automation, while not dealing directly with the DABS data link, can contribute greatly to controller P&C, and they are considered in later sections of this report. There is a class of automation, however, that does depend directly on DL, and it is with these applications that this report is mainly concerned.

Two levels of data link-related automation are addressed in this study. The first is that described in the SRI studies (denoted as System VI) in which much of the minute-to-minute decision-making currently performed by the human controller is taken over by the computer. The second level studied (designated AUTOSTAR) involves a lesser degree of automation,

leaving the controller's responsibilities virtually unchanged, but providing a means of preprogramming routine messages for later repetitive transmission.

2.6.1.1 SRI System VI Automation

In the previously cited studies of UG3RD operational impact, SRI defines an automation scenario that relieves the controller of virtually all routine, minute-to-minute decision-making concerning vectoring, separation, metering and spacing, and altitude assignment. The functions are assumed to be carried out by a computer using highly advanced software and communicating with the aircraft by means of DL. Under this scheme, the human controller is cast more in the role of system manager, monitoring overall traffic flow and watching for possible computer errors. He does not review each message the computer sends and actively intervenes only in cases of emergency or system failure.

2.6.1.2 AUTOSTAR

The second level of automation studied involves less machine control than does the SRI System VI. Under this scheme, called AUTOSTAR, the controller can set up a series of "windows" within a sector. When a designated aircraft arrives at a window, a DL message, which has been preprogrammed by the controller, will be automatically transmitted to the aircraft. Consider the arrival sector shown in Figure 2-3. The controller's job consists for the most part of vectoring incoming aircraft to a point a few miles out from the final approach fix, having established proper spacing and altitude relationships among them. After establishing the windows and messages shown in the figure, the controller would need only to vector aircraft, with proper spacing and altitude, to the first window. From there, the rest of the messages, which the controller would otherwise have to send separately to each aircraft by voice, are automatically transmitted to the aircraft as they enter successive windows. The controller must monitor the progress of the aircraft, actively intervening only if an aircraft deviates from predicted spacing.

2.6.2 Automation Impact

2.6.2.1 SRI System VI Automation

The automation scenario postulated by SRI would, if implemented, represent a revolution in ATC procedures. The human controller would in fact not be a "controller" as he now is, but rather would be a "system manager," monitoring the overall flow of traffic. He would not normally be involved in minute-to-minute control of aircraft for separation, metering and spacing, and other control measures. Those functions, which are currently performed by the human controller, would be taken over by the computer. The human monitor would, of course, retain emergency override capability for cases of system error or malfunction, or for nonstandard situations.

Given the great computational speed and vast reserves of memory available to the computer, it is only to be expected that such an ATC system would yield an increase in system productivity and capacity. Figure 2-4

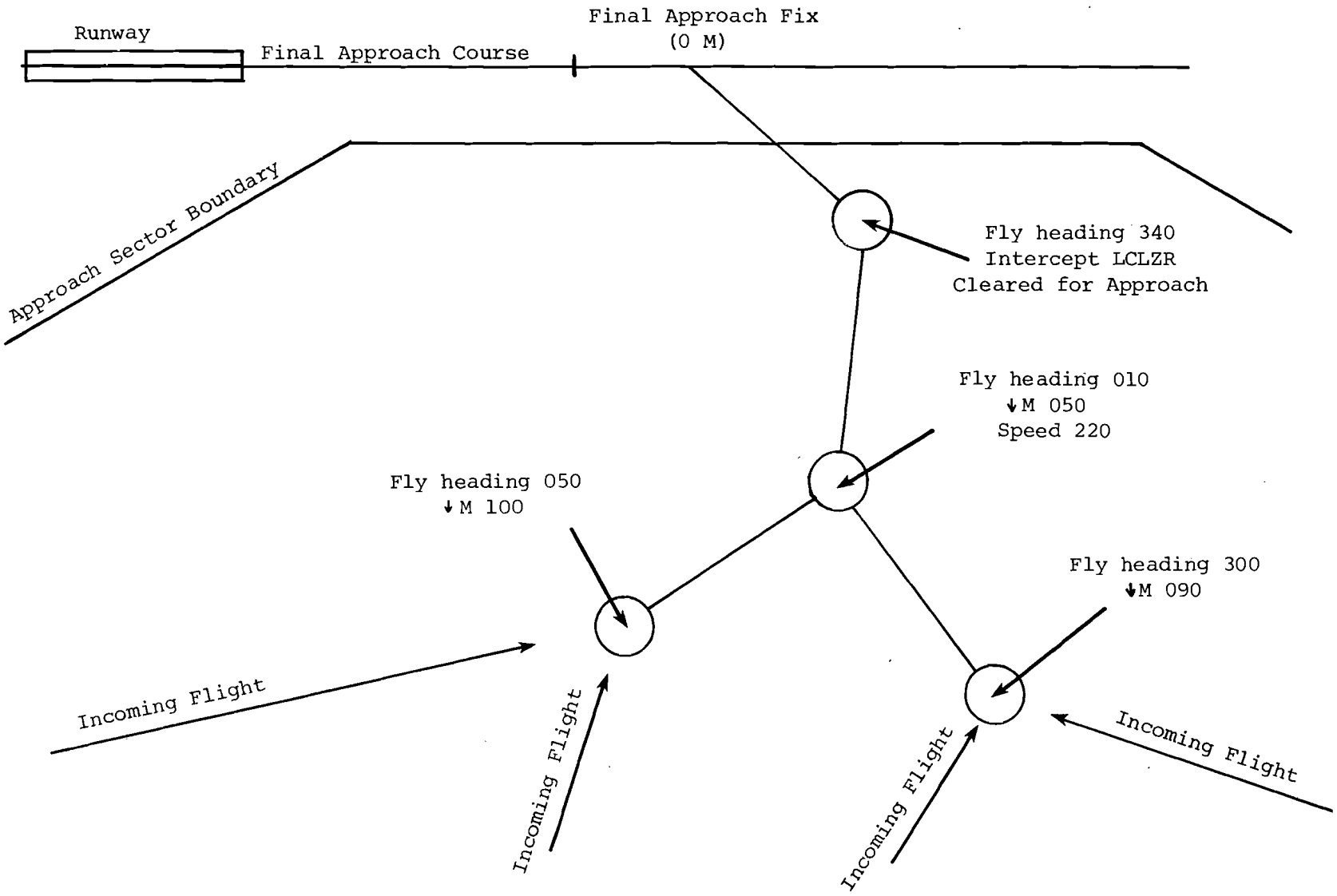

Figure 2-3. AUTOSTAR

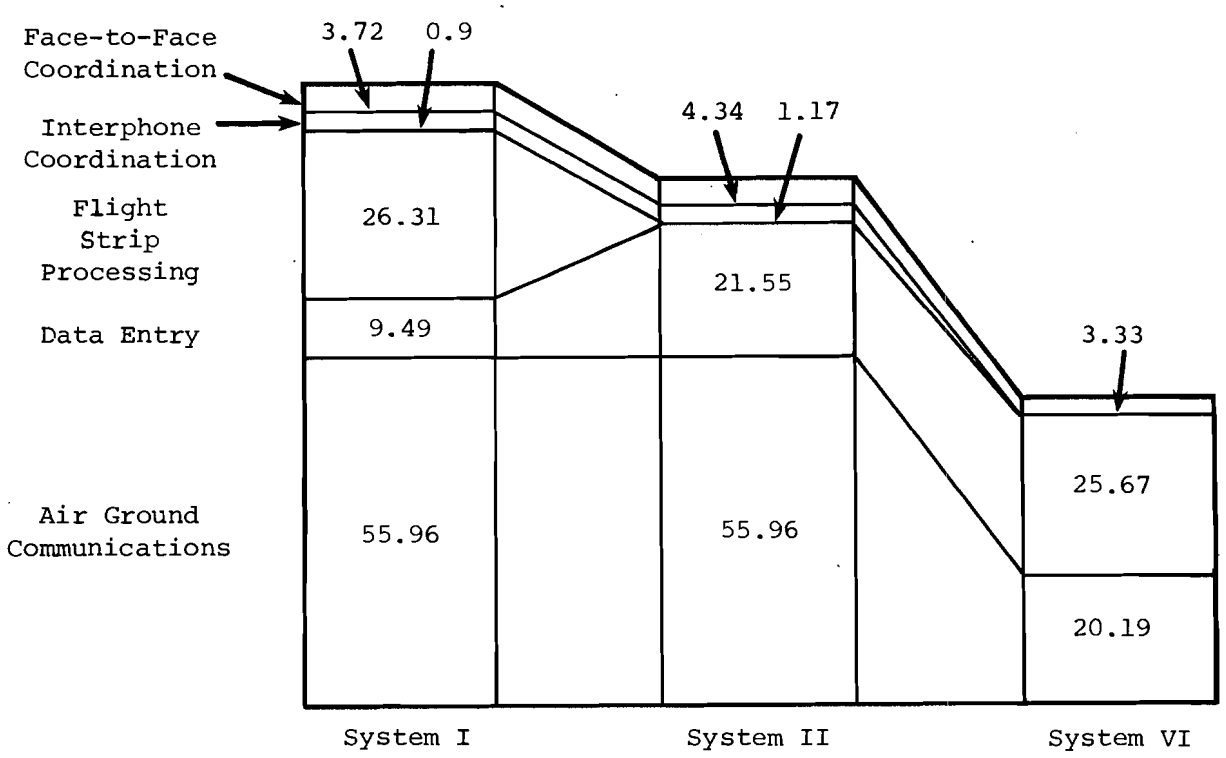

Figure 2-4. COMPARISON OF CONTROLLER HANDLING TIMES SHOWING IMPACT OF SYSTEM VI AUTOMATION

shows the impact of System VI automation predicted by SRI. As this figure shows, total average task time for the controller is reduced from the present (System I) 96.38 seconds per aircraft to 49.19 seconds per aircraft, a decrease of more than 50 percent. The SRI study points out, however, that 13.36 seconds (average) of this reduction is due to the elimination of the flight strip processing (System II), an automation function not directly related to DL.

The key point to be considered in assessing the P&C impact of System VI automation is the fact that it is the system *automation*, made possible by the availability of DL, that provides the P&C increase. Because the system, and not the human controller, is performing control functions, a comparison of System VI P&C values with baseline values developed from human performance alone and attribution of the P&C benefits to the introduction of DL may not be valid; the dissimilar characteristics cannot be reasonably compared. The human baseline is developed from a set of circumstances involving human reactions, psychology and physiology, and specific tasks, devices, software, and automation aids. To compare this baseline directly with the automation environment is to ignore the fundamental differences between the two schemes, as well as the very large investment in hardware, software, training and user education that would be required to make a System VI system operational.

The overall impact of System VI automation was estimated in the SRI studies; this study did not duplicate that estimate. ARINC Research did review SRI's findings, however, and compared them with ATC channel data on hand. We found them to be reasonable.

2.6.2.2 AUTOSTAR

Since the System VI automation was deemed not to be suitable for comparison with baseline P&C values, a second automation scenario was addressed. As discussed earlier, AUTOSTAR is a postulated automation scheme made possible by DL, which leaves the role of the controller virtually intact while providing him with some of the important advantages of automation. The preprogramming of DL messages leaves the controller in complete cognizance and control of all flight activities but frees him from having to transmit repetitious routine messages.

A typical arrival in the arrival sector shown in Figure 2-2 might involve the following dialog:

A: Baltimore Approach Control, Eastern 123 with you level at 10,000.

C: Eastern 123, ident Baltimore altimeter 29.95.

C: Eastern 123, radar contact turn right heading 040 degrees, descend to and maintain 6,000.

A: Eastern 123, right to 040 leaving 10,000 to maintain 6,000.

C: Eastern 123, reduce speed to 220 knots.

A: Eastern 123.

C: Eastern 123, traffic at two o'clock northeast bound, slow moving.

A: Eastern 123, traffic in sight.

Communications time to this point: 35 seconds

C: Eastern 123, fly heading 350, descend to and maintain 4,000.

A: Eastern 123, leaving 6,000 for 4,000, heading 350.

C: Eastern 123, fly heading 300 degrees, descend to and maintain 2,500, intercept the localizer and track it inbound.

A. Eastern 123, heading 300, out of 4,000 for 2,500, intercept localizer.

C: Eastern 123, you are cleared for the ILS approach Runway 27, contact the tower now on 123.4.

A: Eastern 123 copies cleared for the approach.

Communications time for this segment: 40 seconds

In this example, Eastern flight 123 arrives at Baltimore-Washington International Airport. The 14 transmissions between aircraft (A) and controller (C) are typical; some cases will involve more, some less. The transmissions

above the middle line occupy about 35 seconds of communications time and might be required even in an AUTOSTAR environment. The transmission below the line are those that in this example are common to all arriving flights and could be programmed for AUTOSTAR transmission. These transmissions occupy an additional 40 seconds of communications time during which the controller is transmitting or receiving a message. This is the portion of task time that could be saved by AUTOSTAR. Under this automation scheme, these messages would be preprogrammed for DL transmission at appropriate points, relieving the controller of the task. The controller would monitor the progress of the various aircraft and intervene only in case of emergency or unusual circumstances, or if aircraft began to "bunch up" along the AUTOSTAR route.

As this example shows, this scheme could save on the order of 50 percent of routine communications task time for the controller (see Figure 2-2); the exact magnitude of the savings would vary from case to case, depending on AUTOSTAR route configuration and the proportion of DL-equipped aircraft in the sector; obviously, aircraft without DL could not participate in AUTOSTAR. This reduction in task time per aircraft translates directly into an increase in P&C. The relationship, however, is not linear; halving the communication task time does not double P&C. Other tasks such as operational cognizance must still be performed for each aircraft.

2.7 SUMMARY

In this chapter we have examined the impact of the proposed DL applications on controller P&C. Two terminal configurations were considered: VRS and automation.

On the basis of the considerations discussed in this study, VRS appears not to be the preferred mode for controller-DL interface. Most of the controller's radio messages are already reduced to a semantic minimum; VRS will reduce spoken messages very little. The additional message-verification task required by VRS would more than negate any small decrease in message length that might result, giving an overall negative impact; such a scheme would actually increase controller workload, decreasing his P&C.

Two automation scenarios were considered; SRI System VI and AUTOSTAR. System VI, involving computer decision-making, is certainly expected to increase *system* P&C. However, since it is the computer and not a human controller performing the control task, it may not be valid to compare System VI P&C values with baseline data for human controllers.

AUTOSTAR is an automation scheme in which the automation, made possible by DL, aids rather than replaces the controller. The automatic transmission of DL by preprogrammed ATC messages upon the arrival of aircraft at preprogrammed "windows" could save as much as 50 percent of a controller's communication task time, with an attendant increase in P&C.

CHAPTER THREE

IMPACT OF PROPOSED APPLICATIONS ON PILOT WORKLOAD

This chapter addresses the impact of the proposed applications on pilot workload. Workload is defined, and the configurations of DL aircraft terminals are discussed. The impact of the introduction of the DL applications is assessed, and a discussion of factors affecting the interpretation of the results is presented.

This chapter will show that DL will have only a very small impact on overall pilot workload because the pilot's entire communication task accounts for only two percent of the total workload. It is not clear that this small reduction in workload should be used to justify the implementation of DL. However, the proposed applications might be justified on the basis of factors beyond the scope of this study, such as safety or pilot convenience. Further, there are factors other than reduction of communications time that can indirectly reduce pilot workload through the introduction of new services by means of DL.

3.1 WORKLOAD

As currently configured, most aircraft require the pilot to actively manipulate controls and systems in order to achieve safe, efficient flight. These necessary actions, taken in the overall context of other tasks the pilot must perform, constitute the pilot's workload.

The definition of workload is somewhat dependent on context. A NASA study* first characterizes workload as "any definition of workload not in conflict with common English usage and which lends itself to measurement." The study goes on to narrow this somewhat broad approach and characterizes workload as "an integrative concept for evaluating the effects on the human operator associated with the multiple stresses occurring within man-machine environments." In the absence of a clear-cut, analytical definition of

*Garther, W.B. and Murphy, M.R., *Pilot Workload and Fatigue: A Critical Survey of Concepts and Assessment Techniques*, NASA TN-D-8365, Ames Research Center, November 1976.

workload in the literature, we have used the following operational definition of workload in this study: workload is the sum of all tasks performed by the pilot, as measured by the time it takes the pilot to perform them. An additional factor considered in this definition of workload is the pilot's subjective feeling of how busy he is independently of actual task-time measurements. This is somewhat more difficult to quantify; our assessment of this factor is based primarily on interviews with experienced pilots.

The FAA defines six general pilot tasks*:

- Flight Path Control
- Collision Avoidance
- Navigation
- Communications
- Aircraft Systems Monitoring and Operation
- Command Decisions

Figure 3-1** shows the percentage of total available time a pilot is, on the average, engaged in each of these activities. The reserve time, which accounts for an average of 59.3 percent of the total time, represents the time spent in straight and level flight, with no active engagement in any of the other six tasks.

In assessing the impact of the proposed DL applications, we considered each application in turn. In some cases it was necessary to interpret the basic application idea and postulate a particular operational configuration. The sensitivity of the results of the study to changes in these assumptions is discussed in a later section. The assessment was made by determining how long it takes the pilot to perform each task addressed by the proposed applications without DL. Then task times were estimated for the same tasks for two DL user terminal configurations.

3.2 DL USER TERMINALS

As discussed earlier, the impact of DL on user workload will depend in large part on the nature of the user terminal. For the purposes of this study, two user-terminal configurations were considered: (1) a preformatted message terminal and (2) a VRS terminal.

3.2.1 Preformatted Message Terminal

The preformatted message terminal was assumed to consist of an alphanumeric display device, a numeric keyboard, and a set of message keys representing preformatted messages. It was assumed that there were, for instance, a "request" key, a "climb" key, and "turn right" and "turn left" keys. If

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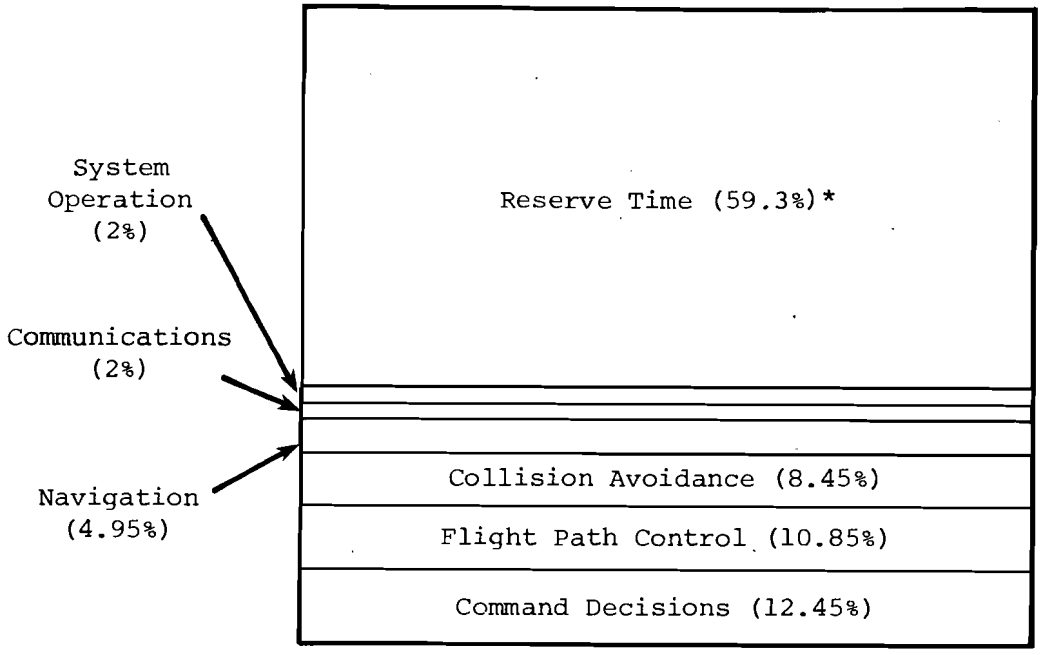
*FAR 25, Appendix D.

**From FAA *DC-9/50 2/3 Man Cockpit Study*. This study illustrates a median case between complex air transport and IFR general aviation aircraft.



*These figures are taken from FAA *DC-9/50, 2/3 Man Cockpit Study*.

Figure 3-1. PILOT TASK BASELINE: AVERAGE WORKLOAD

a pilot wished to request a climb to 8,000 feet, he would press the "request" key, then the "climb" key, followed by 8-0-0-0 on the keyboard, and last the "transmit" key. Uplink messages would be presented on the display panel; an "acknowledge" or "roger" button would be placed on the left side of the control yoke. This terminal is similar to one designed for an FAA DL study performed earlier by ARINC Research*. It allows for quick entry of routine messages without the need to type them letter by letter. Messages not covered by the preformatted message keys are assumed to be handled by voice.

3.2.2 Voice Recognition System

The second assumed terminal configuration is a Voice Recognition System (VRS). This application is the same as that described for controller use. The pilot, instead of pressing message keys, would speak code words into a boom microphone activated by an entry switch located on the left side of the control yoke. The VRS would recognize the code words, format the appropriate message, and transmit it by means of DL. The technology necessary to accomplish this is only now becoming commercially available; it represents the most current state of the art. It is assumed that problems such as operation in an environment with high noise and vibration levels

*Diehl, J.M.: *Human Factors Experiments for Datalink, Interim Report No. 6, An Evaluation of Datalink Input/Output Devices Using Airline Flight Simulators*, FAA-RD-75-160, ARINC Research Corporation, 1975.

will have been solved by the time a cockpit VRS is employed and that reliabilities greater than the FAA-required minimum of 90 percent will have been achieved.

3.3 IMPACT ASSESSMENT

Table 3-1 shows the results of the impact analysis. The heading assignment (Item 4 in Table 3-1) is used as an example: a heading-command exchange consists of the receipt of a command and an acknowledgment of it by the pilot. In the case of DL, since the command is displayed on a panel, there is an additional task of reading and understanding the message. This task is designated "becoming cognizant." Table 3-1 also contains the sample baseline text and assumed preformatted message key sequence where appropriate and shows the percentage improvement over baseline for each user terminal for each application. For several new DL applications, no similar services are not offered. Those cases cannot be compared with a baseline, and NA (not applicable) is thus entered in the Percentage Improvement Over Baseline columns.

3.4 DISCUSSION

As is evident from Table 3-1, DL can reduce communication task time in most applications. Notable exceptions are position reports and flight plan filing. These tasks can involve relatively large amounts of free-form text, making preformatted entry impractical.

The total saving in communications task time, as shown in Table 3-1, is 225 seconds (43.02 percent of the baseline total) over all applications for the preformatted message terminal, and 265 seconds (50.67 percent) for VRS. While these figures suggest an impressive improvement, several caveats apply to their interpretation. First, the results are highly dependent on the analysis assumptions. Small changes in the operational scenario would have profound effects on the results. For instance, if a standard alphanumeric keyboard (typewriter/terminal style) were substituted for the preformatted message terminal, the task time for that configuration would increase many times, yielding an overall increase, rather than decrease, in pilot workload. Similarly, if a hand-held microphone were substituted for the assumed boom microphone, both baseline and VRS task times would increase considerably. Therefore, the results should be judged as meaningful only within the context of the specific set of assumptions under which they were developed.

Another important consideration in interpreting the results is that *typical* message exchanges were used in determining task times. In practice, some messages will be longer, some shorter. However, since the same message exchange was used in assessing both baseline and DL scenarios, only the absolute values of task time would change; the relative task times among the various scenarios would remain the same.

(text continued on page 3-12)

Table 3-1. DATA LINK IMPACT

Application and Task Elements	Time to Perform* (Seconds)			Percentage Improvement Over Baseline	
	BL	DL_1	DL_2	DL_1	DL_2
1. Acknowledgment					
Push button on yoke	1	1	1		
Say "1 2 alpha, Roger"	2	0	0		
Total	3	1	1	66.70	66.70**
2. Beacon Code Assignment					
Receive uplink message	4	0	0		
Become cognizant	0	3	0		
Transmit acknowledgment	5	1	1		
Set transponder	7	7 (0†)			
Total	16	11 (0†)	1	31.25	93.75**
3. Altimeter Setting					
Transmit request	5	3	2		
Receive reply	5	0	0		
Become cognizant	0	3	3		
Set altimeter	5	5 (0†)	5 (0†)		
Total	15	11 (6)	10 (5)	26.67	33.33
4. Heading Assignment					
Receive command	5	0	0		
Become cognizant	0	3	3		
Acknowledge	3	1	1		
Total	8	4	4	50.00	50.00
5. Altimeter Assignment					
Same as 4					
Total	8	4	4	50.00	50.00
6. Airspeed Assignment					
Same as 4					
Total	8	4	4	50.00	50.00

*BL = baseline, DL_1 = preformatted message terminal, DL_2 = airborne voice recognition system terminal.
**These improvements presume settings are not automatic.
†No time required if the system sets itself automatically.

(continued)

Table 3-1. (continued)

Application and Task Elements	Time to Perform* (Seconds)			Percentage Improvement Over Baseline	
	BL	DL_1	DL_2	DL_1	DL_2
7. Holding Instructions					
Receive command	7	0	0		
Become cognizant	0	5	5		
Acknowledge	3	1	1		
"N34A hold west of alpha intersection, expect further clearance at 15."					
Total	10	6	6	40.00	40.00
8. Approach Clearance					
Receive clearance	8	0	0		
Become cognizant	0	5	5		
Acknowledge	3	1	1		
"N1234A intercept the localizer, cleared for the approach. Notify crossing outer marker."					
Total	11	6	6	45.45	45.45
9. MSAW Alert					
Receive alert	4	0	0		
Become cognizant	0	3	3		
Acknowledge	3	1	1		
Total	7	4	4	42.86	42.86
10. Conflict Alert					
Same as 9					
Total	7	4	4	55.56	55.56
11. Request for Position Report					
Receive request	4	0	0		
Become cognizant	0	3	3		
Transmit position	7	10	5		
"N1234A is 20 west of MAL on Victor 43."					
2 0 west of M A L on V 4 3					
"2 0 WEST OF MIKE ALPHA LOVE ON VICTOR 4 3"					
Total	11	13	8	-18.18	27.27

*BL = baseline, DL_1 = preformatted message terminal, DL_2 = airborne voice recognition system terminal.

(continued)

Table 3-1. (continued)

Application and Task Elements	Time to Perform* (Seconds)			Percentage Improvement Over Baseline	
	BL	DL_1	DL_2	DL_1	DL_2
12. Metering and Spacing					
Receive command	7	0	0		
Become cognizant	0	4	4		
Acknowledge	3	1	1		
"N1234A do a 360 to the right for spacing on traffic."					
Total	10	5	5	50.00	50.00
13. Takeoff Clearance Confirmation					
Receive confirmation and become cognizant	0	1	1		
Total	0	1	1	NA	NA
14. Altitude Assignment Confirmation					
Receive confirmation	0	1	1		
Total	0	1	1	NA	NA
15. Runway Visual Range (RVR)					
Request RVR	5	2	2		
Receive RVR report	4	0	0		
Become cognizant	0	2	3		
Acknowledge	3	1	1		
"Tower, N1234A requests RVR."					
REQ RVR					
"Request RVR."					
"RVR 1,000."					
Total	12	5	6	58.33	50.00
16. Altitude Echo					
Request Echo	0	1	1		
Receive Echo	0	1	1		
Become cognizant	0	1	1		
Total	0	3	3	NA	NA
17. Flight Plan Clearance					
Request clearance	7	2	1		
Receive clearance	30	5**	5**		
Become cognizant	0	15	15		

*BL = baseline, DL_1 = preformatted message terminal, DL_2 = airborne voice recognition system terminal.
**Hard copy.

(continued)

Table 3-1. (continued)

Application and Task Elements	Time to Perform* (Seconds)			Percentage Improvement Over Baseline	
	BL	DL_1	DL_2	DL_1	DL_2
17. Flight Plan Clearance (continued)					
Read back clearance	20	0	0		
Receive OK	3	0	0		
Acknowledge	3	0	0		
"Clearance delivery, N1234A, IFR to Washington, request clearance."					
"N1234A I have your clearance; notify when ready to copy."					
"34A ready to copy."					
"ATC clears N1234A to DCA via flight planned route. Friendship 3 departure, Swann Point transition. Climb to and maintain 5,000 feet, squawk 1234 prior to departure, departure frequency will be 120.65."					
Total	63	22	21	65.51	66.67
18. Taxi Instruction					
Call-up	4	0	0		
Designate destination	3	10	3		
Receive taxi instructions	6	0	0		
Become cognizant	0	5	5		
Acknowledge	3	0	0		
"Turn right to Echo, cross Runway 4, proceed to ramp."					
Total	16	15	8	6.25	50.00
19. Standard Terminal Arrival Route Assignment					
Receive assignment	7	0	0		
Become cognizant	0	4	4		
Acknowledge	3	1	1		
"N1234A is cleared to Baltimore via Friendship 3 arrival, Swann Point transition."					
Total	10	5	5	50.00	50.00
20. Gate Assignment					
Receive assignment	5	0	0		
Become cognizant	0	2	2		
Acknowledge	3	1	1		
"United 123, use Gate 1-A."					
Total	8	3	3	62.50	62.50

*BL = baseline, DL_1 = preformatted message terminal, DL_2 = airborne voice recognition system terminal.

(continued)

Table 3-1. (continued)

Application and Task Elements	Time to Perform* (Seconds)			Percentage Improvement Over Baseline	
	BL	DL_1	DL_2	DL_1	DL_2
21. Landing Aid Inoperative					
Receive advisory	5	0	0		
Become cognizant	0	2	2		
Acknowledge	3	1	1		
"N1234, be advised ILS is now out of service."					
Total	8	3	3	62.50	--
22. ATIS Delivery					
Request (tune-in) ATIS	5	2	2		
Copy ATIS	40	5**	5**		
Become cognizant	--	15	15		
"This is Baltimore-Washington International information alpha. 1200 weather 7 thousand scattered, 15 thousand broken, visibility 15 wind 270 degrees at 10 knots. Altimeter 29.92. Expect landing Runway 28, IFR departure Runway 33L. Notice to Airmen: ILS Runway 33L out of service. Notify controller on initial contact that you have received information A."					
BWI-ATIS 1200Z 070 I 150 11/7/2710/2992 XPCT RW28, IFR Dep RW33L NOTAM: ILS RW33L INOP.					
Total	45	22	22	51.11	51.11
23. Predeparture Weather					
Request weather	NA	3	3		
Receive weather sequence	--	5	5		
Become cognizant	--	5	5		
Req WX D C A					
"Request Weather Delta Charlie Alpha."					
Total	--	13	13	NA	NA
24. Severe Weather Advisory					
Receive advisory	8	0	0		
Become cognizant	0	4	4		
Acknowledge	3	1	1		
"N1234A be advised DCA reporting severe thunderstorms all quadrants."					
SEV WX					
"DCA RPT SVR Thorm all Quad."					
Total	11	5	5	54.55	54.55

*BL = baseline, DL_1 = preformatted message terminal, DL_2 = airborne voice recognition system terminal.
**Hard copy.

(continued)

Table 3-1. (continued)

Application and Task Elements	Time to Perform* (Seconds)			Percentage Improvement Over Baseline	
	BL	DL_1	DL_2	DL_1	DL_2
25. En-Route Weather					
Notify center leaving frequency	8	0	0		
Copy acknowledgment	3	0	0		
Call FSS	4	0	0		
Copy acknowledgment	4	0	0		
Request weather	5	5	4		
Copy weather	12	5**	5**		
Become cognizant	0	7	7		
Acknowledge	3	1	1		
Report back on frequency	5	0	0		
Copy acknowledgment	3	1	1		
REQ WX D C A					
"Request Weather Delta Charlie Alpha."					
"DCA weather 5000 scattered wind 270 at 10 altimeter 29.95."					
DCA 50 1 100 11 S 270 2995 1000 broken vis 5					
Total	47	19	18	59.57	67.27
26. Traffic Advisory					
Receive advisory	7	0	0		
Become cognizant	0	3	3		
Acknowledge	3	1	1		
"N1234A, traffic one o'clock 3 miles northbound altitude unknown."					
TFK 1 o'clock/3/N					
Total	10	4	4	60.00	60.00
27. Resolution Advisories					
Receive advisory	7	0	0		
Become cognizant	0	3	3		
Acknowledge	3	1	1		
"N1234A turn left 45 degrees. Do not climb."					
← 45°, ⊥					
Total	10	4	4	60.00	60.00

*BL = baseline, DL_1 = preformatted message terminal, DL_2 = airborne voice recognition system terminal.
**Hard copy.

(continued)

Table 3-1. (continued)

Application and Task Elements	Time to Perform* (Seconds)			Percentage Improvement Over Baseline	
	BL	DL_1	DL_2	DL_1	DL_2
28. High Altitude Winds					
Same as 25					
Total	47	19	18	59.57	67.27
29. Centerfield Winds					
Request winds	4	1	1		
Copy winds	4	2	2		
Become cognizant	0	1	1		
Acknowledge	3	1	1		
Total	11	5	5	54.55	54.55
30. Threshold Winds					
Same as 29					
Total	11	5	5	54.55	54.55
31. Vector Wind Change					
Same as 29					
Total	11	5	5	54.55	54.55
32. Shear Existence					
Receive report	7	0	0		
Become cognizant	0	1	1		
Acknowledge	3	1	1		
"N1234A be advised wind shear exists on your approach path."					
Total	10	2	2	80.00	80.00
33. Maximum Shear					
Same as 32					
Total	10	2	2	80.00	80.00
34. Vortex Existence					
Same as 32					
Total	10	2	2	80.00	80.00

*BL = baseline, DL_1 = preformatted message terminal, DL_2 = airborne voice recognition system terminal.

(continued)

Table 3-1. (continued)

Application and Task Elements	Time to Perform* (Seconds)			Percentage Improvement Over Baseline	
	BL	DL_1	DL_2	DL_1	DL_2
35. Flight Plan Filing					
Request filing	6	0	0		
Copy go ahead	3	0	0		
File flight plan	45	60**	45		
Copy acknowledge	3	0	0		
"IFR, N1234A, B55/U, 185, BAL, 1200Z, 5000 feet, V3, ABC, V4, Able Intersection, Direct, XYZ, 3 + 40, 4 + 30, ZZZ, Smith, on file DCA, 250B, W/Blue."					
Total	57	60	45	- 5.26	59.82
Total	523	298	258	43.02	50.67

*BL = baseline, DL_1 = preformatted message terminal, DL_2 = airborne voice recognition system terminal.
**Assumes prompting.

Finally, and perhaps most important, the results must be viewed in their relationship to all other pilot tasks. Most of the proposed applications are directed toward reducing communication task time. However, the communication task, as shown in Figure 3-1, amounts to only 2 percent of a pilot's average workload. If somehow DL could replace *all* communication tasks, it would reduce the pilot's workload only 2 percent under average conditions. The results of the study show, however, that only about a 50 percent reduction of that 2 percent is realized.

In other-than-normal conditions, task time can expand to fill the reserve time shown in Figure 3-1. In almost all instances, however, the tasks that fill the reserve time are flight path control, command decisions, collision avoidance, and systems management. In any kind of emergency situation, flight discipline is always "fly the plane first and talk about it later." Communications receive very low priority during in-flight emergencies or other times of unusually high workload level. When communications do occupy part of the reserve time, they are almost by definition nonstandard or emergency communications that would probably not be covered by DL message formats; virtually all DL schemes provide for the use of voice communication in times of emergency.

Therefore, DL-replaceable communications are expected to occupy at most 2 percent of pilot workload, limiting the ultimate improvement in this area to 2 percent.

Within the context of the normal communication task, DL could be expected to save about 50 percent of communication task time. In a typical flight from Los Angeles to San Francisco, it is estimated that time actually spent sending and receiving messages totals about 310 seconds. If DL yields, as expected, about a 50 percent reduction, task time would be reduced to 155 seconds. This represents a saving of about 2.5 minutes over a flight that lasts almost 2 hours. It is at this point not clear that this small reduction of communication task time alone, when viewed in the larger context of overall pilot workload, would justify the expense of a DL system. There are, however, other areas not directly related to reduction of communication task time that may have a more profound impact on a pilot's perceived workload by providing capabilities not now available to or affordable by some segments of the aviation community. These applications are discussed in Chapter Four.

The main contribution of DL to the reduction of communication task time is that it can provide a hard copy of lengthy messages such as clearances and ATIS messages. As Table 3-1 shows, these applications allow dramatic reduction in performance time due to their hard-copy capability. A previous study of DL human factors noted, however, that automatic hard-copy printout of all messages produced an overabundance of paper in the cockpit, creating a large paper-management problem. Perhaps a better approach would be a "push to print" key that would allow selective printout of messages.

3.5 SUMMARY

In this chapter, we have examined the impact of the proposed DL applications on pilot workload.

For the purposes of this study, workload was defined as the overall set of tasks required of the pilot. The FAA describes six pilot tasks: flight path control, collision avoidance, navigation, communications, system operation, and command decisions. FAA studies place the communication task at 2 percent of total pilot workload.

The proposed DL applications could reduce communication task time as much as 50 percent. However, since the entire communication task is only 2 percent of the pilot's total workload, the 50 percent reduction may not be significant. The main positive benefit of DL relative to the communication task would be its provision of hard-copy printouts of lengthy messages such as clearances and ATIS reports.

Given the small overall impact on pilot workload of the proposed applications, it is not clear that this reduction will justify the expense of a DL system. Other potential applications addressing different pilot needs exist, however, and these may prove to have a greater impact on overall pilot workload. They are discussed in Chapter Four.

The conclusions of this and the previous chapter are somewhat disparate; DL offers a sizable reduction in controller workload, but only a small

reduction in pilot workload. There exist, however, other potential uses of the DL beyond those specific applications proposed by the FAA that may have a large positive impact on pilots, thereby making DL a highly desirable system, especially for the GA owner/pilot. Chapter Four presents several such applications and discusses their overall impact.

CHAPTER FOUR

NEW APPLICATIONS FOR DATA LINK

This chapter discusses applications of the DL beyond those specifically set forth by the FAA. In the development of these applications, the total range of pilot and controller tasks was considered and evaluated for addressability by means of DL, and the impact of DL on them was assessed. The result of this process was a set of applications addressing specific pilot and controller needs and issues. These are set forth below, following a discussion of the preliminary considerations mentioned, and the impact of the introduction of DL on each of the applications is assessed.

4.1 GENERAL CONSIDERATIONS

An air-ground data link offers two general applications: automation of existing communications tasks and implementation of new services. While the traditional concept of communications between aircraft and ground installations is limited to voice communications, several other types of air-ground cooperative communications are already in place. Each of these becomes a candidate for inclusion in a digital data link.

In addition to automation of existing air-ground communications applications, a digital data link offers the possibility of implementing new services that are labor intensive or technically difficult to implement with existing communications systems.

Most applications of air-ground data link will consist of a combination of these areas -- the applications would be technically possible with existing systems, but such applications would impose high workloads on the humans in the system. Data link, with its inherent high-data-rate capability, offers a practical method for implementing automated information exchange systems with little increase in hardware costs or operator workload.

4.2 PILOT TASKS

This study examines the tasks performed by flight crews (single pilot and multipilot) during instrument flights between two cities. The selected city pairs were Los Angeles and San Francisco for the large aircraft and

Santa Monica and San Francisco for the small aircraft. Cockpit activities included for aircraft with multiman crews were taken from a previous study that evaluated crew workload associated with various data link input/output devices (ARINC Research Publication 1304-01-2-1402, dated May 1975). Cockpit activities for the single-pilot aircraft were developed from an analysis of current cockpit and air traffic control procedures over the planned route. All phases of flight were examined to develop an unconstrained list of possible data link applications. Six pilot tasks were addressed: communications, navigation, control, systems management, collision avoidance, and decision-making.

The first task, communications, encompasses all verbal and nonverbal exchange of information with other humans. This includes communications between crew members in a multiman crew as well as air-ground communications with air traffic controllers. While the intelligence carried by the communications is normally related to one of the other task areas, it is separately evaluated in this study. Therefore, in an assessment of the workload impact of data link, apparent communications workload reduction may be the result of a transfer of workload to another task area, e.g., from communications to systems management.

Navigation includes the actions necessary to determine the route that should be flown, any deviation of the aircraft from that route, and the course that should be flown to return to or maintain the desired route. Navigation includes both horizontal and vertical paths, and may include time-controlled rate adjustments of course progress.

Control is the exercise of authority over the aircraft whereby the heading, attitude, velocity, and altitude are maintained at or changed to the value the pilot desires. Control is accomplished by determining the present altitude, heading, and velocities from various instruments or outside visual cues and manipulating the manual control system or autopilot to change those parameters as necessary.

Systems management consists of managing the propulsion, electrical, navigation, communication, environmental control, hydraulic, pneumatic, or other mechanical or electrical systems installed in the aircraft. Generally, larger aircraft have more systems and more complex systems than small aircraft. However, because larger aircraft generally carry multiman crews, the average effort imposed by systems management on each crew member does not differ significantly.

Collision avoidance is the task of determining the relative position between one's own aircraft and other aircraft and ground terrain features so as to plan a flight course that provides safe passage among these objects. Collision avoidance, as opposed to navigation, is a short-term task. The collision avoidance task requires more attention for aircraft at low altitudes where the aircraft density is greater and the clearance from ground objects is less. The collision avoidance task is greater for small aircraft than for large aircraft.

Decision-making is the task of evaluating a number of observed factors and formulating a course of action to correct any factors that are unsatisfactory. Decision-making requires the pilot to make judgments based on his training and knowledge or on reference to manuals, charts, tables, or calculations.

4.3 CONTROLLER TASKS

The study examined the tasks performed by air traffic controllers at all the facilities that would control aircraft on flights between Los Angeles and San Francisco. Those locations were selected for analysis on the basis of data availability, continuity with the SRI studies allowing comparison, and traffic densities. The control facilities were the Los Angeles TRACON, Los Angeles ARTCC, Oakland ARTCC, and San Francisco TRACON. Workload data were developed from report FAA-AVP-77-23, which provides frequency of task performance and average task performance times for these facilities. In addition, these frequencies and times were verified against a set of ATC controller tapes from Los Angeles TRACON and Los Angeles ARTCC. Five controller task areas were examined: control jurisdiction transfer, traffic structuring, response to pilot request, general intersector coordination, and general systems operation.

Control jurisdiction transfer encompasses the events required for handing off the control of an aircraft from one sector to another. Both sector controllers may be located in the same facility or they may be in separate facilities many miles apart. This transfer requires a notification of impending transfer from one controller to another, an agreement on the transfer, and a confirmation of a successful transfer.

Traffic structuring is the task of safely moving aircraft through a sector and to the appropriate transfer points at sector boundaries. (Sector boundaries may be either horizontal or vertical.) Traffic structures generally allow the majority of aircraft to fly through the sector with minimum interference with each other and, therefore, require a minimum of controller workload.

Responses to pilot requests generally require some immediate modification to the traffic structure or a coordination with adjacent sector controllers, or both. In some cases, pilot requests require retrieval of information from a source not immediately available to the controller, e.g., delivery of weather data for a specific location.

General intersector coordination includes informational transfers that are performed to maintain cognizance of multisector traffic movement. These activities are less time-critical than those involved in traffic structuring or control jurisdiction transfer.

General system operation activities are those tasks involved in operator adjustment of displays, communication system operation, and all other supporting activities.

4.4 EVALUATION OF DATA LINK IMPACT

Before performing a quantitative evaluation of productivity, capacity, or economic impact of data link, we reviewed the pilot and controller tasks to eliminate from further consideration any tasks that offered no apparent probability of being affected by data link. For pilots, the tasks of system management and control were eliminated even though current technology would permit systems management and control to be effected from the ground. These techniques are routinely used for remotely piloted vehicles (RPV) in military applications, but it is unacceptable to carry commercial passengers without pilots aboard the aircraft.

For controllers, the tasks of control jurisdiction transfer, general intersector coordination, and general systems operation were not considered, except for the air-ground communications portion of the task. While it is obvious that ground-to-ground data link would be helpful for these tasks, such applications are beyond the scope of this study.

The effect of data link on decision-making was likewise not considered. Access to more information, more current information, and better organized information will certainly have a beneficial impact on decision-making for both pilots and controllers. There will be a similar impact on system capacity resulting from better application of separation criteria and better utilization of the available airspace, but these effects were beyond the scope of this study.

Replacement of voice communications with digital data link is the most natural application. However, because voice communications currently occupy such a small percentage of pilots' time (see Figure 3-1), such a change is not perceived by pilots as representing a significant workload reduction. Controller workload reduction is dependent on the other automation that would be concurrently implemented. The major advantage to replacement of voice communication with data link lies in the capability of data link to provide an interface between the aircraft and an automated ATC system in an economical manner.

Navigation occupies somewhat more flight-crew time than communications. Current practice is for the crew aboard the aircraft to determine its relative position by means of an electronic signal from a transmitter on the ground. Data link applications would permit the ground-based determination of the absolute position of the aircraft and transmission to the aircraft of its position, either in actual coordinates or relative to a geographical location designated by the pilot. This technique will provide better position determination and allow quick computation of relative position to many geographic locations. It will also allow simultaneous graphic display of an aircraft in relation to geographic features and other aircraft.

There will be little workload impact in transferring the navigation task from the current techniques to the data link. System setup and track following will remain the same as now, with both manual and autopilot track following possible. Ground-based navigation guidance could include vertical guidance, a capability not normally available with the present systems.

The techniques used to determine position information for navigation also will provide aircraft position information for ground-based collision avoidance decisions. This is one of the primary applications contemplated for early implementation. The application, called ATARS (Automatic Traffic Advisory and Resolution Service), is intended to provide a collision avoidance capability to all suitably equipped aircraft within terminal areas with heavy traffic.

4.5 VIABLE DATA LINK APPLICATIONS

The major applications of air-ground data link for early implementation appear to be for communications, navigation, and collision avoidance. Data link communications can easily replace routine air-ground voice communications, but there appears to be a requirement for voice communications for nonroutine and emergency communications for the foreseeable future. Therefore, because voice communications will be available, there appears to be little economic incentive for small aircraft operators to install data link for communications only.

There does appear to be an economic incentive for light aircraft operators to install data link systems for navigation uses. Data link navigation services can provide several current services at significantly reduced prices and can provide additional services that are not currently available. This combination of services at lower-than-current prices is the type of incentive that may be necessary to entice light aircraft operators to install data link.

In the assessment of DL applications for viability, a hierarchy of pilot desires concerning equipment and capabilities was established. The minimum IFR equipment for a single-engine aircraft consists of an audio distribution panel-marker beacon receiver unit, two 720-channel NAVCOM units, two VOR displays, one with glideslope, and an ATCRBS transponder. In our study, we learned that most pilots would next add an ADF, followed by a DME set. Then, if it was available for his aircraft, a pilot would add a weather radar set, followed by an RNAV set with one or two way points. Finally, the pilot might add a radar altimeter. This configuration is, generally speaking, the most sophisticated avionics panel likely to be found in GA aircraft.

4.6 NEW APPLICATIONS

Four new applications of the DABS DL are set forth in this section. They were selected on the basis of their ability to fill an operational need or to address a key issue. They are proposed as examples of ways in which DL can be used to address pilot and controller needs, but not as recommendations for actual implementation. Such a recommendation could be made only as the result of a careful cost-benefit study, which is beyond the scope of the present study.

4.6.1 Navigation

The DABS sensor determines the position of an aircraft by eliciting a reply from the on-board transponder. Range to the aircraft is determined by measuring the time delay between the transmission of an interrogation and the receipt of a reply. Azimuth is determined by the antenna pointing angle, perhaps augmented by a monopulse off-axis correction. Knowing the range and bearing of the aircraft, the system can specify its position in polar coordinates.

On-board aircraft navigation is also usually performed in the polar, range, and bearing format. The VOR-DME system, for instance, gives the bearing relative to magnetic north and the range from the station in nautical miles.

The range and bearing determined by the DABS sensor could be transmitted to the aircraft by means of DL, giving range and bearing information relative to the DABS sensor. This could be accomplished with even the simplest type of DL display, requiring no additional equipment in the aircraft. Of course, as with all DL applications, the aircraft must be within range of a DABS sensor in order to use the services. Thus the utility of any such scheme will depend in part on the location and density of DABS sensors.

This idea can be refined to provide additional features. A facility other than the DABS sensor, say a VOR station or an airport, could be designated as the navigational point of reference. Designation of that point could be broadcast to the ground by means of a three-letter identifier, or a point could be specified simply by range and bearing from the DABS sensor, allowing the generation of true way points. The ground computer would compute range and bearing to the aircraft relative to the designated facility or point and transmit the information to the aircraft by DL. Course line information could also be computed and transmitted, giving complete RNAV-like service. Again, no special equipment or displays would be needed to implement this function.

This application of DL could prove to be a very valuable one. It would provide a pilot with a powerful tool that would greatly simplify his navigation task. In the absence of DME or RNAV, the pilot must take frequent VOR cross bearings to triangulate his position. DME and RNAV equipment are available, but only at considerable expense. (A typical DME set costs about $3000 plus installation; an RNAV set can cost from $3000 up to $30,000.) Given that the aircraft is to be equipped with a DABS/DL terminal, the DME-RNAV function can be provided by DL at no additional expense to the user. This factor could prove to be a strong incentive to operators to equip their light aircraft with DABS/DL terminals. Even if the aircraft already has DME and/or RNAV, the DABS/DL services might be perceived as a good back-up for the primary systems. As noted earlier, the DME function rated relatively high on the pilots' "want list." It is expected that RNAV would rate much higher were it not for the high cost. The fact that DL can provide essentially the same service at little or no extra cost is expected to be a powerful inducement for operators to equip their aircraft with DABS/DL.

4.6.2 Weather Detection

Pilots flying in or through clouds often experience difficulty in seeing areas of extreme turbulence associated with thunderstorms. In an effort to alleviate this problem, many pilots equip their aircraft with weather-detection radar. These systems use radar pulses to detect precipitation; there is good, although not perfect, correlation between the presence of intense rainfall and storm cells. These radar systems are routinely carried aboard most commercial airline aircraft, but have historically been limited to heavier multiengine GA aircraft. Recently, however, small, light systems have become available that are suitable for use in light twin-engine and single-engine aircraft.

Radar systems used to locate weather-related precipitation, however, have several problems. First, they are quite expensive. Even the most inexpensive system, meant for wing-mounting on light singles, costs about $8000, including average installation costs. This cost can represent a sizeable fraction of the value of the aircraft on which the system is installed. Other, more sophisticated systems for GA aircraft range upward in cost to $10,000 or more. Another drawback is that these radar systems are subject to shielding; one area of heavy precipitation can mask other areas behind it. Even if shielding is not encountered, the range and resolution of the airborne unit is limited by the power and size of the antenna that can be accommodated on board the aircraft. Finally, airborne radars usually are quite complex, involving moving antennas and cathode ray tubes. They are exposed to extremes of temperature and vibration that often lead to high repair and maintenance costs.

Ground-based weather detection equipment is in most respects superior to airborne equipment in range and resolution because it can use higher power levels and larger antennas. Data from a number of such facilities can be collected at a single location, giving detailed information over wide areas. This information could be formatted and processed for transmission to the aircraft by DL.

For an aircraft flying along an airway within a DABS sensor service area, the sensor would keep a record of the aircraft track and use it to predict the future position or course of the aircraft. Upon DL request from the aircraft, a "snapshot" of radar returns could be prepared showing an area ahead of the aircraft out to the requested range. As in a radar display, the aircraft would be centered at the bottom of the display, and the projected course would run vertically up the center. Appropriate range and off-courseline angle marks could be included, closely simulating a radar display. Radar returns would be displayed by a grid of symbols, probably letters, keyed to different return intensities. This radar-like display, with which most pilots are familiar, would be based on the higher-quality ground-derived data. It is possible that geographical areas other than that directly ahead of the aircraft could be requested and displayed. For instance, a pilot might preview conditions at his destination and alternate destinations while still en route, a practice not possible with present systems.

Some display device beyond a simple alphanumeric readout would be required to make this scheme workable. At the very least, a multiline display is needed to allow some measure of graphics capability. Another approach is to provide a hard-copy printer that can assemble the display one line at a time in print. This has the advantage of providing a permanent copy for study and also makes a printer available for other uses. Small printers are currently available for a few hundred dollars, keeping the additional cost low.

The advantages of such a DL-based weather detection system are numerous. First, at a very small incremental cost, it provides service as good as or better than radar. This is especially significant because many GA IFR flights are made without any radar or weather-detection equipment at all. The data provided would be more accurate and of higher resolution than air-derived data, and the capability would exist for displaying weather in distant areas. These factors are expected to greatly enhance the desirability of DABS/DL to GA operators.

4.6.3 TCA Tunnels

One of the major objections of general aviation pilots to the establishment of terminal control areas (TCA) is the restrictions placed on their free transit of TCA airspace. The general aviation pilot who cannot penetrate a TCA because his aircraft does not have the necessary equipment or the controllers cannot handle his flight is faced with two options: either fly around the TCA or climb over it. Either alternative generally imposes a time or fuel penalty on the flight and may, in some weather conditions, effectively prohibit the flight. Even outside TCAs, transit of control zones is authorized only at the discretion of the controller, regardless of the equipment carried aboard the aircraft. In an effort to accommodate the requirements of general aviation, some of the TCAs have been designed with a "tunnel" to permit VFR transit without reference to the control agency. The Los Angeles TCA provides a good example of such a tunnel, a designated airspace between 2500 and 5000 feet MSL crossing over the control tower at Los Angeles International Airport (see Figure 4-1). This north-south tunnel provides VFR transit without contact with the ATC system, thereby expediting transit of the TCA and minimizing controller workload caused by VFR TCA transit requests. The Los Angeles airport, with all its parallel runways lying near the coast line and having well defined cultural features (freeways) to delineate the tunnel boundaries, lends itself to the tunnel concept.

Most other terminal control areas do not have a permanently designated VFR corridor. The Washington TCA does not provide any means for VFR aircraft to transit the TCA except with the approval of the controller, and then only when equipped with an altitude-reporting transponder. The Washington TCA (Figure 4-2) encompasses two primary airports, making it somewhat larger than usual. Washington National Airport normally conducts operations from crossing runways, creating a more complex traffic pattern than that of Los Angeles. While there are extended periods when a VFR corridor could be designated the traffic management problems within the Washington TCA do not permit full-time designation of such a corridor or tunnel.

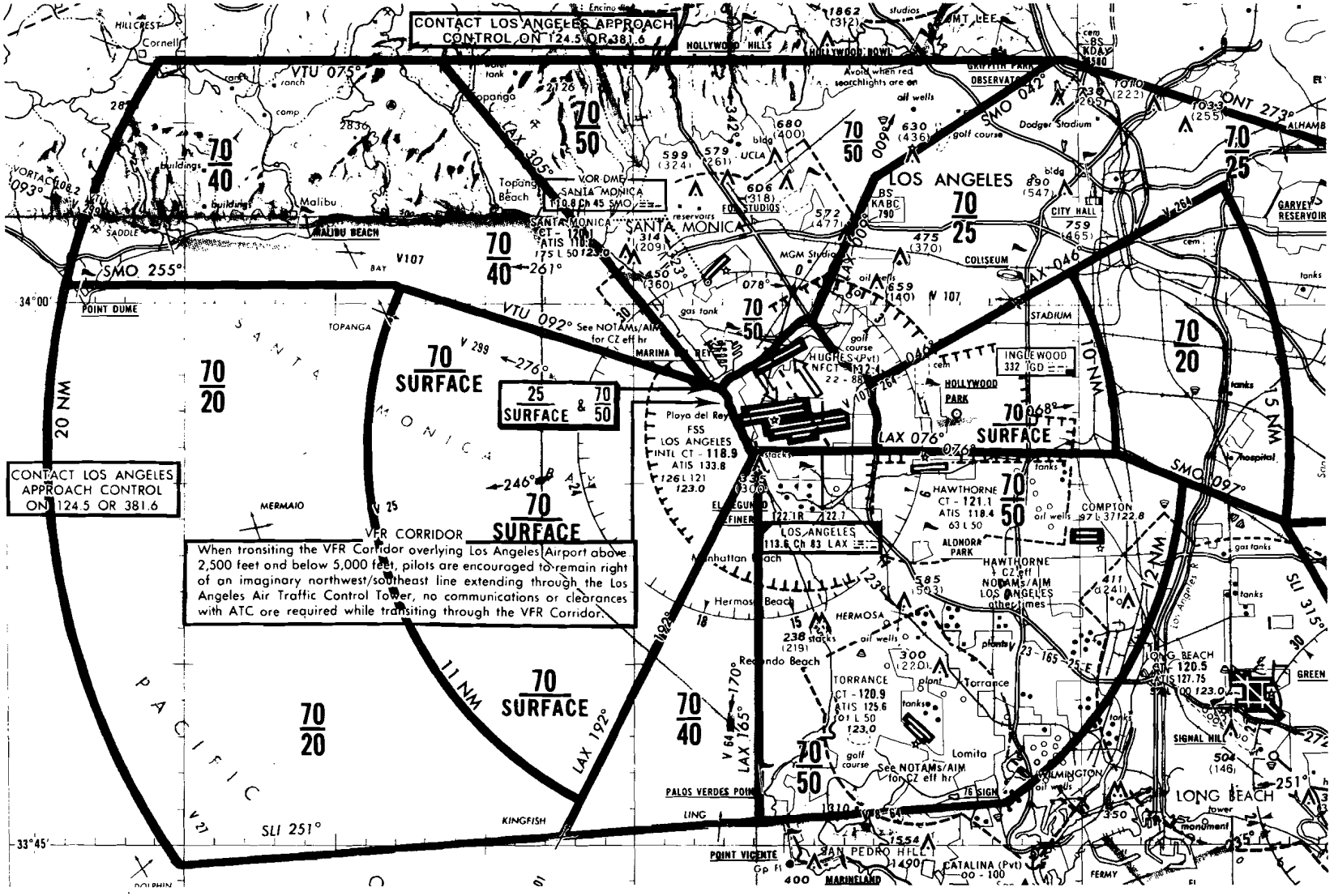


Figure 4-1. LOS ANGELES TCA

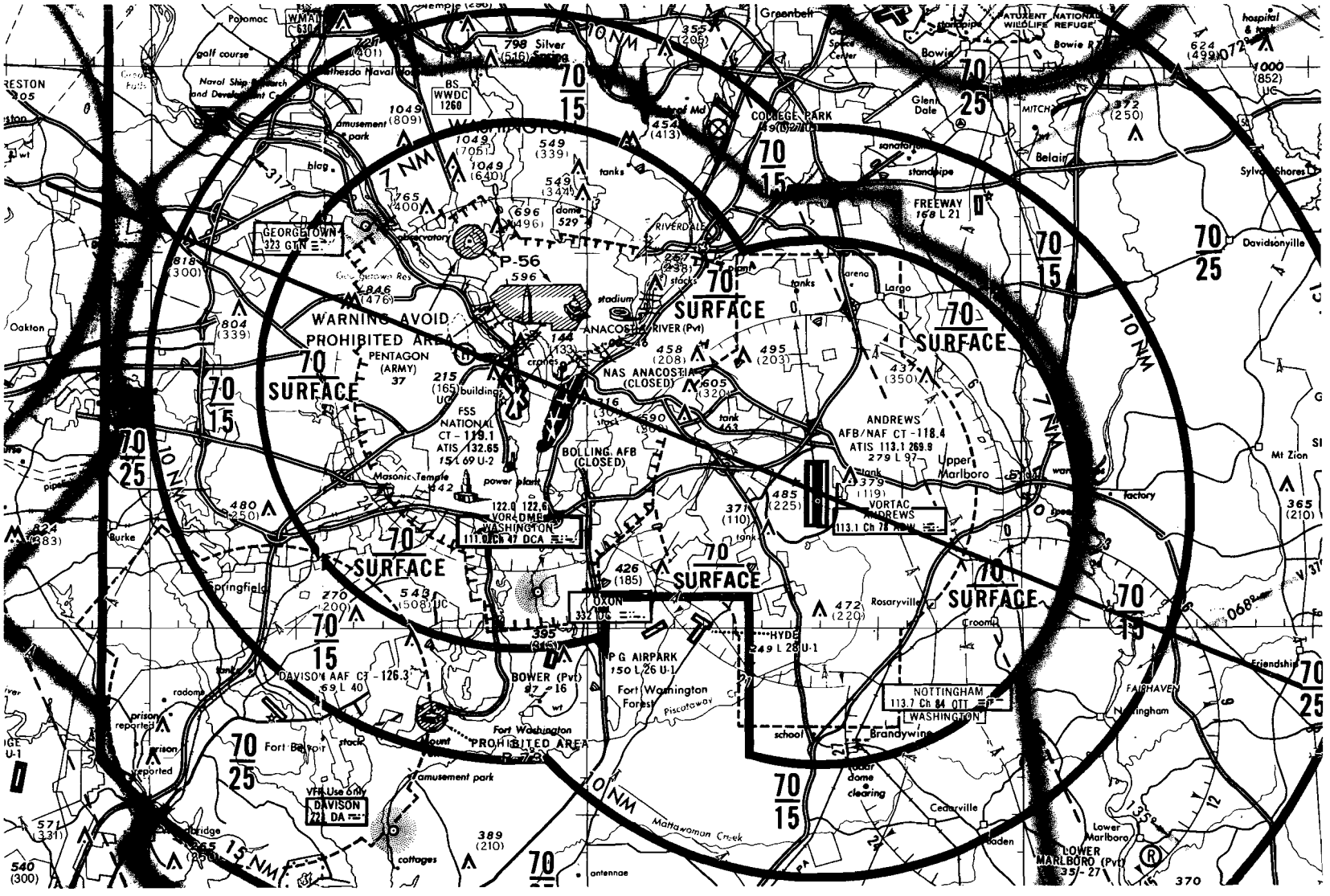


Figure 4-2. WASHINGTON TCA

The establishment of VFR corridors or tunnels in a TCA currently requires that the tunnel be continuously operational so that it can be published on the area charts. Only a very limited number of TCAs can accommodate such a permanent restriction on the controller's control of the traffic flow.

Most of the TCAs could accommodate a VFR corridor or tunnel under most traffic conditions. For example, the Washington TCA might accommodate a tunnel along a 120° - 300° track across Washington National and Andrews AFB under some wind conditions and might be able to accept VFR traffic through a corridor from Davison AAF along the Anacostia Freeway and Penn Central Railroad tracks under other conditions if the controller was not required to provide individual clearances to each aircraft that wished to transit the TCA.* Such tunnels could represent considerable savings in time and fuel to GA pilots. For example, a flight from Shannon Airport at Frederick, Virginia, to Baltimore would be 66 nautical miles through a corridor, but 80 nautical miles, more than 20 percent farther, outside the TCA.

The TCA tunnel concept would provide for automated transmission of non-permanent TCA transit information. The controller would establish or activate a standard tunnel on the basis of the terminal traffic flow and weather. The tunnels would be depicted on the area charts in the same way as restricted areas, and the current tunnel would be indicated on the ATIS. When an aircraft wished to cross the TCA, the pilot would monitor the ATIS, which would advise of the tunnel in use. The pilot would then transmit his TCA transit intention by data link and proceed along the corridor. His position would be monitored by DABS and traffic advisories transmitted by the data link.

TCA tunnels would save time and money for GA pilots without increasing the workload of the controllers. The resultant freedom of operation through TCAs should make the imposition of airspace restrictions less objectional to GA pilots.

4.6.4 AUTOSTAR and AUTOSID

The most complex traffic management problem for controllers occurs in the terminal airspace. During heavy traffic periods at major airports the final approach control sector controller is fully occupied with issuing routine instructions to aircraft, even with a well-developed traffic flow plan in effect. For this reason, procedures for standard terminal arrival routes (STAR) and profile descents have been established. These allow the pilot to anticipate the routing and altitude assignments he will receive during his descent to landing. Even with these procedures, final controllers must monitor and issue instructions to each aircraft at each point in the approach, a task that occupies a very large part of the controller's time and virtually all the communications channel time. Data link delivery of routine approach instructions would free the controller to monitor traffic flow along the designated routes and free him and the communications channel for emergencies.

*This case is presented only as an example; it has not been reviewed or approved by the FAA.

AUTOSTAR would work as follows:

- The air traffic controller would establish the flow procedures he wished to use to manage the terminal traffic. These procedures would include designation of feeder fixes, flight paths, intermediate fixes, altitudes, vector paths, and control transfer points. He would develop specific control messages for each segment of the terminal flow pattern and designate the point where each message should be delivered to the aircraft. This detailed flow management plan would be entered into the terminal system computer after coordination with the appropriate adjacent sector controllers.
- Feeder controllers would clear aircraft to the appropriate entry point at the planned altitude and with standard spacing. When the aircraft crossed the feeder fix, or window, control would be transferred to the final controller.
- The final controller would advise the aircraft that clearances will be delivered by data link. Thereafter, the controller would monitor the voice communication channel for nonroutine communications. He would also monitor the progress of traffic to correct the flow as necessary. This controller task may be computer-aided to any extent. AUTOSTAR is basically a data link application for delivery of messages necessary to implement profile descent and STAR procedures. An example of a profile descent with possible AUTOSTAR messages is shown in Figure 4-3.

AUTOSID (Automated Standard Instrument Departures) would be implemented in the same manner. Departing aircraft identified as they cross the departure end of the runway would automatically receive routing and altitude messages to deliver the aircraft to its designated point of entry into the en-route system.

AUTOSTAR would significantly reduce the workload of the controller, allowing him to operate as a traffic monitor. The transfer of routine ATC instructions to data link would free the voice channel for emergency communications and reduce the time needed for pilots and controllers to coordinate actions. AUTOSTAR would permit aircraft without data link to be mixed with aircraft with data link by providing controllers with automated reminders to deliver by voice the same message the system would deliver by data link.

4.7 AVIONICS IMPACT

The availability of DL-based communications and navigation functions may have an impact on the avionics configuration found in most aircraft, especially GA light aircraft.

Currently, a typical basic light aircraft IFR panel includes an audio distribution panel/marker beacon receiver combination, two 360-channel or 720-channel VHF communication transceivers, two 100-channel or 200-channel navigation (VOR) receivers (one with glide slope), an ATCRBS transponder, and an ADF receiver. More advanced panels would include a DME set, a weather

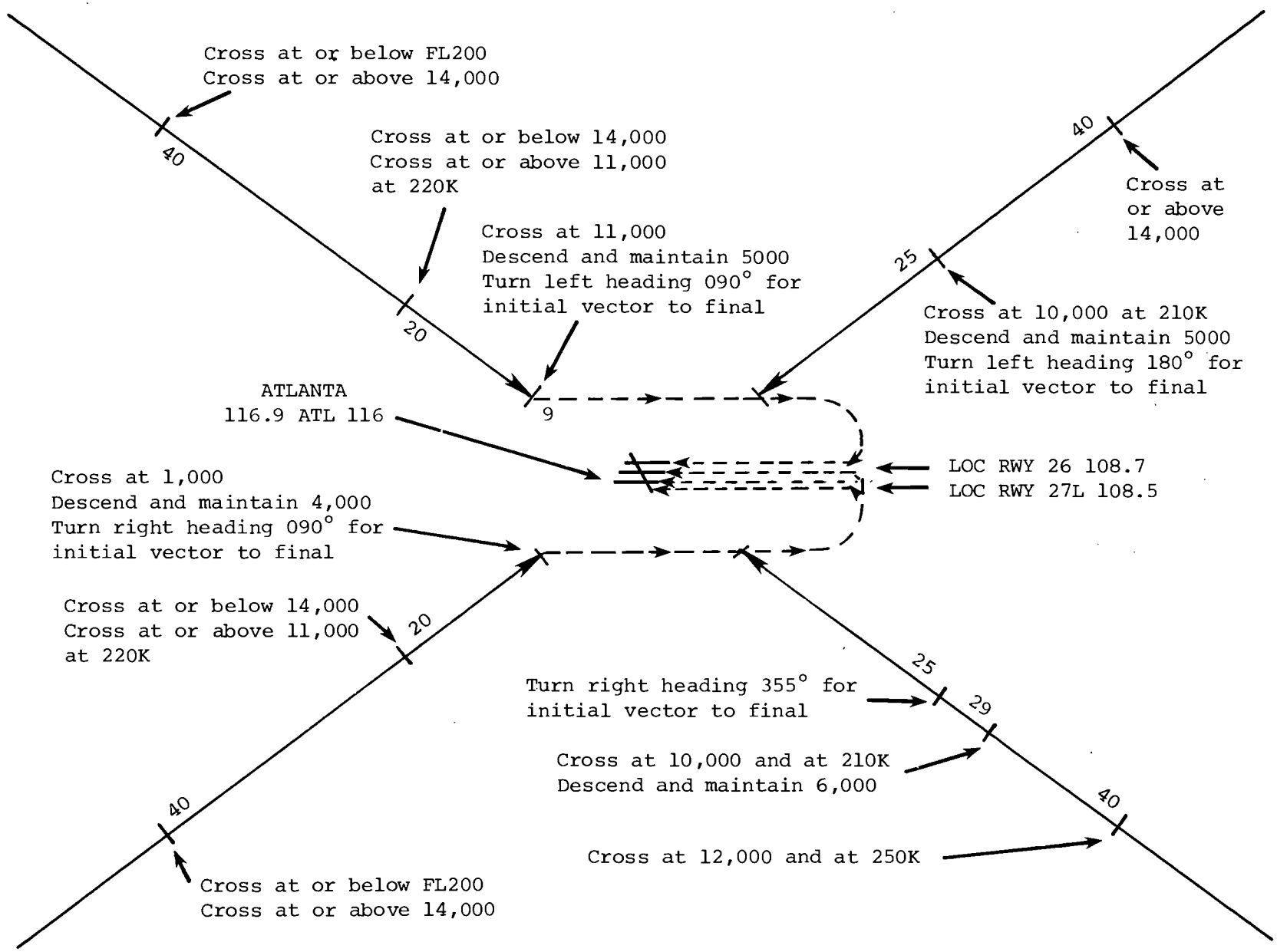


FIGURE 4-3. PROFILE DESCENT

radar, and an RNAV set. The cost of the basic panel is estimated at about $8000 plus installation. ADF, DME, radar, and RNAV could easily add an additional $10,000 to the avionics cost.

The redundancy in communication transceivers has two purposes: it provides a back-up capability in case of the failure of either transceiver, and it allows the pilot to pre-set a frequency on the second radio, enabling him to switch to that frequency by simply switching the control on the audio distribution panel. (This latter function is becoming less important as transceivers that can store a second frequency for later instant recall gain in popularity.) Redundancy of the navigation receiver also provides a back-up capability against the possibility of failure, but, in addition, it facilitates the taking of cross bearings for position determination. This latter function is, however, less important when DME is available.

As discussed in the previous sections of this chapter, it is possible that DL, in addition to its communication function, could provide navigation services that closely parallel those provided by DME and RNAV, and a weather detection function that could in many ways outperform on-board weather radar. The availability of these services could render unnecessary the redundant communication and navigation units, the ATCRBS transponder, and the DME, RNAV, and radar units. The panel of the future could conceivably consist of a single communications transceiver, a single VOR receiver with glide slope, an ADF, and a DABS/DL unit. This panel could perform substantially the same function as the panel it replaces and provide much the same level of redundancy, but at far lower cost; assuming a DABS/DL unit cost of about $1200, the estimated panel cost would be about $3000, or $15,000 less than the conventional panel with the same capability.

There are compromises inherent in this approach. The DL function will work only when the aircraft is within range of a DABS sensor or remote facility. Thus the success of this scheme would depend on the availability of a widespread system of sensors, as is planned for the mature system. Another drawback is that failure of the single DABS/DL unit would remove all DL functions, leaving only one communication and one navigational unit; this however, should be sufficient for emergency procedures.

Another issue concerns DL navigation functions. The philosophy concerning radio navigation is that the navigation system should involve only the passive reception of broadcast signals; the system should not have to do anything to receive position-determining signals. The DL navigation functions are, of course, dependent on the transmitted replies of the DABS transponder and on the sending and receiving of DL messages. There is, however, precedent for such an approach. The currently used RNAV systems rely on DME information. The DME operates by interrogating a ground-based DME transponder of known location. Distance is determined by measuring the time delay between transmitted interrogation and received reply. Thus, navigation with RNAV is an active, rather than passive, process in almost exactly the same way in which DL navigation would be an active process.

Within the context of the aforementioned limitations, DL is capable of bringing about large savings in avionics cost with virtually no loss of capability.

CHAPTER FIVE

SUMMARY AND CONCLUSIONS

This study has addressed the improvement in controller productivity and capacity (P&C) and pilot workload that might be realized by the introduction of proposed DL communications applications. These benefits, however, represent only a portion of the total benefit of DL to pilots and controllers; there are many ways in which DL can help a pilot or controller in addition to reducing his communications task. DL can make possible the provision of valuable services not currently available, or it can provide at lower cost services which, although available, are prohibitively expensive. These aspects of DL are discussed in the following sections.

5.1 P&C AND WORKLOAD REDUCTION

The essence of P&C increase for controllers and workload reduction for pilots is the reduction of the time necessary for each task required of them. Reducing task time *per aircraft* could help a controller to pass more aircraft through his sector (productivity) and to handle more aircraft at one time (capacity). Reducing task time can also reduce a pilot's workload in terms of the number and complexity of required tasks, freeing him for more important activities, such as collision avoidance.

The overall value of these DL task-time-reduction applications, in the context of total system cost, will be dependent on how substantially they reduce task times.

Regarding controller P&C, DL can make possible the use of automation that relieves the controller of routine, repetitive tasks, making that time available for accommodating more aircraft. It may be possible to automate most, or even all, controller tasks, leading to a completely automatic ATC system. Without addressing the question of whether this is desirable, it is not clear that it is appropriate to judge and compare the performance of such an automated system with one operated by human controllers. The vast differences in the circumstances, bases, and philosophies of the two systems may make comparison meaningless. A much more pertinent case is that in which automation, made possible by DL, is used to aid the controller rather than replace him. A scheme that would permit the controller to preprogram routine messages (that he would otherwise have to transmit repeatedly) to be sent as aircraft reach defined "windows" could reduce

the controllers' communication task by as much as 50 percent. This is a significant reduction since communication is the single largest task a controller performs. Also, comparison with human baseline performance is still appropriate since all decisions and messages would still originate with the controller.

This latter point is the central issue in comparing human-based ATC systems with machine-based systems. When the human is no longer the source of the tactical ATC decisions, he is no longer truly a "controller." Comparison of machine-based ATC system performance with human-based performance is not valid because of the dissimilarities in performance characteristics.

The DABS DL makes it possible to implement automation that could materially reduce a controller's communication task time, thereby making possible an increase in P&C.

5.2 PILOT WORKLOAD

One of the tasks a pilot usually must perform, especially when flying in the ATC system, is communications with the ground; he must transmit and receive radio messages.

The use of DL to replace voice messages and exchanges could conceivably reduce communication task time by as much as 50 percent. Digital messages displayed in some fashion on the panel could replace voice messages in many applications. Although the DL is very fast as far as data transmission itself is concerned, some of the advantage is lost to the need for the pilot to read and understand the DL message. Nevertheless, a saving of about 50 percent in time could be achieved.

This saving, however, may not be significant in light of the relationship of the communication task to the overall average pilot workload. This task makes up only 2 percent of the pilot's total workload; elimination of half of this small amount may not by itself justify the expense of DL.

There are, however, other applications of DL which, while not directly related to workload reduction, could be of great value to a pilot and indirectly reduce his workload by providing additional services. The DL gives the cockpit access to enormous reserves of data and computing power. Functions not currently available or available only at great cost could be performed through the use of DL at only small incremental cost. Functions largely duplicating the function of DME/RNAV, weather radar, and radar altitude could be provided, and access to extensive weather data, forecasts, and summaries could be provided. The inclusion of such functions would enhance the desirability of DABS and DL to users, especially GA operators for whom the cost of avionics can be a major consideration.

The inclusion of communications and navigation functions in DL will provide a measure of back-up for the usual NAVCOM systems. It may prove to be

feasible to configure an aircraft, say a high-performance single-engine airplane, to include only one NAVCOM radio and integrated DABS/DL terminal package, instead of the present two redundant NAVCOMs and separate audio panel, ATCRBS transponder, ADF, DME, weather radar, and radar altimeter. This would represent a large saving in cost, complexity, and panel space, while affording, in many ways, enhanced capabilities.

The direct impact of DL on overall pilot communication workload is expected to be small because of the small relative size of the total communication task. The true value of DL to the pilot, especially the GA operator, is expected to lie in providing enhanced capabilities not currently available, or available only at high cost.

5.3 CONCLUSIONS

The DABS DL can be of great value in increasing controller productivity and capacity when used in conjunction with automation that frees the controller from having to make repetitive routine transmissions. Communication task time could be reduced by 50 percent or more, depending on route structures, traffic flow, and the occurrence of anomalous events.

The direct impact of the proposed DL applications on pilot communication workload is expected to be minimal, since the entire communication task represents only about 2 percent of a pilot's total workload. The true value of DL to pilots is expected to lie in enhanced capabilities and the provision of services not currently available, or available only at high cost.