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Final Report on Task A Surveillance and Communication Issues in the Transition to a Discrete Address Beacon System

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16. Abstract

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SUMMARY OF RECOMMENDATIONS

This report discusses the transition from the ATCRBS-based surveillance function with voice radio only to a DABS-based surveillance function with integral digital communication capability to support IPC and automation. Recommendations are directed toward alleviation of certain problems already evident and toward preparation for the deployment of DABS beginning in the late 1970's.

An evaluation of the present ATCRBS system indicates basic adequacy in the present environment for the current mode of operation of the ATC system. The introduction of automation into the ATC system requires capability in the areas of data link and enhanced surveillance reliability for automatic tracking that the DABS system will provide. On this basis it is concluded that the ATCRBS system does not need major modifications to continue its role into the DABS period at locations where the environment and operation will be similar to that presently encountered.

A number of recommendations are made regarding radar where new technology can provide significantly enhanced performance at little added cost. The introduction of a digital data link provides many opportunities and challenges. Most of them associated with tactical message handling are being addressed within the DABS program but attention is called to a related set of issues for messages originating from or destined for other than ARTS or NAS (e.g., FSS).

ATCRBS

The recommendations for improvements to ATCRBS are aimed primarily at alleviating certain controller annoyances even though problems of a widespread nature affecting aircraft safety or system capacity are not foreseen within the context of the early transition to DABS. These recommendations are generally for the development of techniques to solve particular problems. Implementation of these solutions may be on a selective or universal basis as determined within the larger framework of field experiences and implementation costs. Certainly a number of suggested approaches have already been under active investigation in such programs as the ARTS Enhancement Program, the ATCRBS Improvement Program, the TSC Antenna Improvement Program, etc. In addition, the very effective policing of the ATCRBS environment by the Beacon Interference Management Team has been most beneficial to system operation and is anticipated as continuing. The principal areas of continued development to improve the ATCRBS system within the above context include:

a. False target reduction via software mods in ARTS.

b. Improved degarbling through more extensive code checking and scan-to-scan correlation.

c. Continued development of large vertical aperture antennas for those sites experiencing severe multipath.

d. Continued analysis of ATCRBS data from ARTS III and extension of analysis to NAS Stage A.

RADAR

Primary radar will continue to have a role throughout a long DABS transition, and beyond. Techniques are currently available which can result in a major improvement in clutter performance of radars. Thus a number of recommendations are made to improve primary radar performance, especially in clutter, and to provide integrated DABS/primary radar sensors. These recommendations, for immediate action and widespread implementation, are:

a. Introduce immediately the techniques of Moving Target Detection (MTD).
   - Amend the ASR-8 procurement to include MTD.
   - Develop retrofit MTD for klystron equipped ARSR's.
   - Develop retrofit MTD for magnetron radars.
   - Develop new siting criteria to take advantage of the improved performance in sub-clutter visibility.
   - Develop techniques for deriving weather data from the MTD radars for remoting to controllers.

b. Develop an integrated DABS and improved radar for all of the early DABS deployment. Consideration for this radar should include step-scan and lower frequency operation.

c. Determine if a low-cost radar based on advanced techniques is achievable for reduced capability application to small airports.

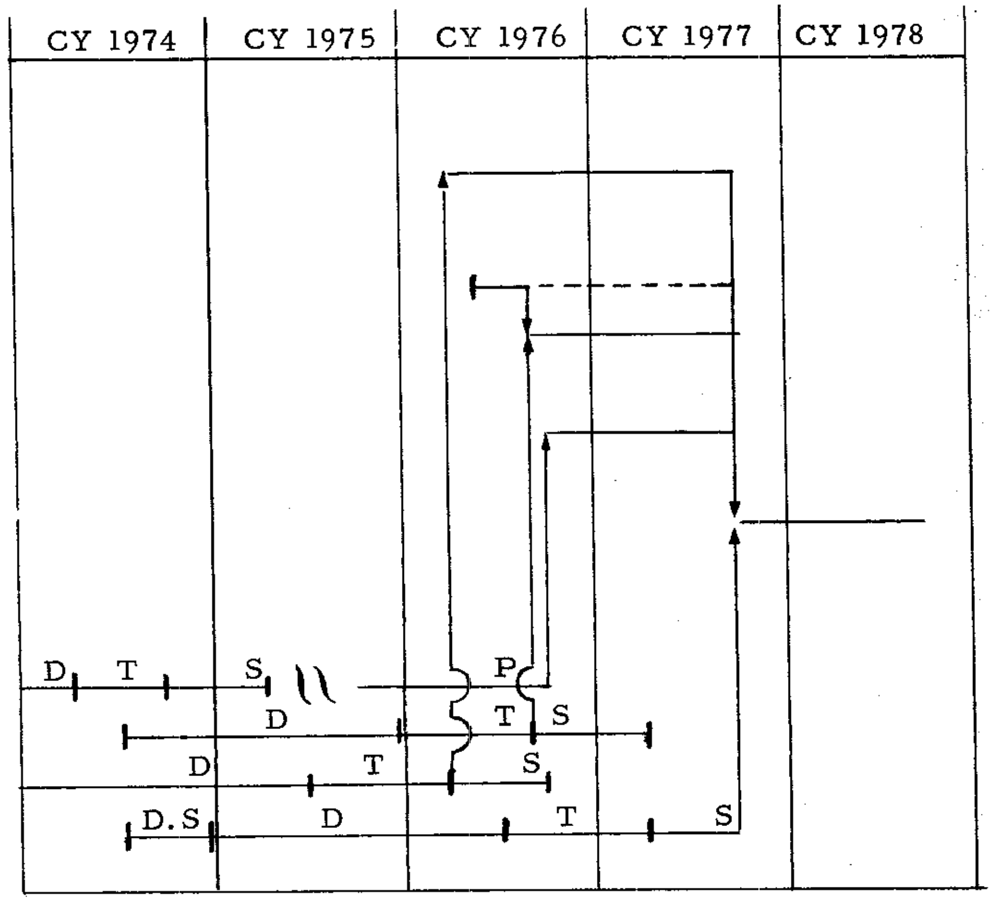
Table S. 1 combines a schedule of those recommended radar improvements that must dovetail in time with the Phase II DABS testing and production procurement activities. DABS testing will employ a production model of the ASR-8/MTD and developmental models of MTD's with the ASR-7 and ARSR-2.

DATA LINK

The introduction of a digital data link into the ATC system with the advent of DABS represents a major new departure for which adequate preparation must begin. Ground routing and management functions must be formulated compatible with the tactical message handling requirement of IPC, ARTS, and NAS. Consideration must also be given to the broader delivery of non-tactical data such as flight clearances, NOTAMS, weather, etc.

DABS Milestones
- Sensor No. 1 at NAFEC
  - Begin tests vith ASR-7/MTD
- Sensor No. 2 at ELWOOD
  - Begin tests with ARSR-2/PCD
  - Begin tests with ARSR-2/MTD
- Sensor No. 3 at Philedelphia
  - Begin tests with ASR-8/MTD
- Production Specification Preparation to Contract Award

RADAR Improvements Program
- Improved MTD for ASR-8
- Improved MTD for ARSR-2
- Improved MTD for ASR-7
- Combined DABS/ASR Sensor



P = Procure
D = Development of Breadboard Hardware and Software
T = Test Program
D.S. = Design Study
S = Specify

Table S.1. Schedule of Radar Improvements.

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1. INTRODUCTION

This report summarizes the work done, and the conclusions and recommendations arising therefrom, on Task A of Surveillance and Communications (S/C) Interagency Agreement DOT-FA72WAI-242. Under this agreement, MIT Lincoln Laboratory has provided assistance and support to the FAA in preparation of the Discrete Address Beacon System (DABS) Technical Development Plan. Beginning in January, 1972, all DABS work was placed under a separate agreement, and the tasks remaining in the S/C Agreement were redefined.

Task A was concerned with the broad issue of how the surveillance and communications capability for Air Traffic Control should evolve to meet the needs throughout the next 20 years.

As the work progressed, a number of factors, some arising from interim results of this TASK [1, 2, 3] and some from parallel work by other organizations, combined to cause a shift in objective for this study itself. Very simply stated, at the beginning, there was a dual objective,

(a) Examine the surveillance and communications issues associated with a transition to DABS and make recommendations pertaining thereto.

(b) Examine alternatives to DABS.

Toward the middle of the study, the emphasis was shifted almost entirely to the "transition to DABS." In this final report, those studies that relate more to alternate system approaches are brushed over very lightly, though in certain cases some of the work is summarized in an appendix.

When the study was begun, three major options were being considered. First, was an ATCRBS based system with separate data link, that could be extended through improvements indefinitely without ever going to DABS. This is the true alternate system concept that was to be examined. The second option assumed that ATCRBS could be extended for several years thereby permitting a delay in the deployment of DABS. One of the questions that arose in studying that system was, "how many years could we wait, by improving ATCRBS, before being required to change to a Discrete Address Beacon System?" This option had two sub-categories relative to the data link. It would be required, of course, that a separate data link be installed initially. The question then was, "should that data link be continued in operation indefinitely, or should the data link that comes along integral with DABS be put in at a later time?" The third major option considered was an early deployment of DABS. This deployment would be made in time so that the surveillance and data link capability of DABS would be in place when the control automation required it.

As one can imagine, there are many issues to be addressed in trying to decide which of these options and sub-options is best. Work was undertaken in a number of areas early in the study. Appendix A summarizes the requirements for surveillance and communication during the next 20 years. VHF versus DABS data link was compared. (See Appendix D.) We examined: how much fruit can ATCRBS stand, how can the effects of synchronous garble be reduced in an improved ATCRBS system, what other ATCRBS problems exist and how can they be alleviated? (See Appendix B.) Also, how does radar, or how could improved radar, assist ATCRBS and DABS in a more automated environment? (See Appendix C.)

As DABS cost data began to become available, and comparative DABS performance factors determined, the FAA authorized a study by the Mitre Corporation to be done for the Office of Systems Engineering Management, to address the question of DABS versus an ATCRBS based system with separate data link.

In the remainder of this report, with the exception of the Appendices as referred to previously, we will consider the transition to DABS at an early date. Section II will describe what the surveillance and communication system based on DABS will look like, from the point of view of a complete system that would be achieved in the late 1980's. Section III of the report then discusses the transition. It will be realized from the things that have been said so far that the transition recommendations cover primarily three issues.

(1) What shall we do with ATCRBS to improve it until such time as it is replaced?

(2) What changes, if any, should be made to the radar equipment or to anticipated new radar equipments to best suit them to work with the DABS system?

(3) What is the relationship between DABS, the radars, ARTS and NAS, automation, etc., and how will this marriage take place?

II. ATC IN THE DABS ERA

A. Introduction

The ATC process involves three basic functions:

Surveillance,

Control, and

Communication.

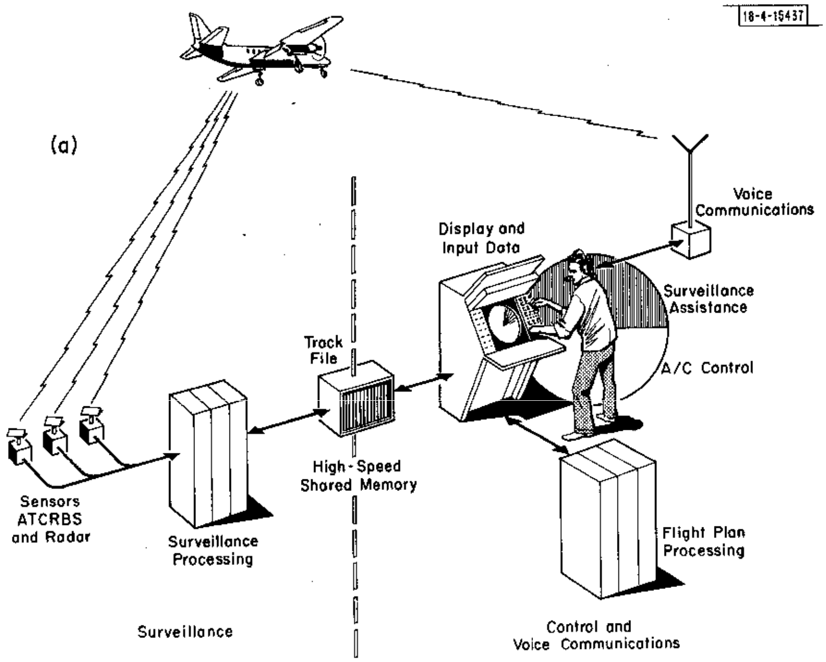
Surveillance is the function which results in locating and keeping track of aircraft in the designated airspace volume. Control is the function which determines where each controlled aircraft should be permitted to go, or directed to go, to accomplish sage, expeditious flow of air traffic. Communications is the means of exercising control. In an "automated" ATC system, such as ARTS Phase I or NAS Stage A, the surveillance "picture" is created in a computer memory, where for each aircraft several computer words are maintained which indicate the name (number, address), location (x, y, z), velocity ($\dot{x}$, $\dot{y}$, $\dot{z}$), and various auxiliary indicators such as past history, confidence in the data, etc. This set of computer words, commonly called the track file, is the natural interface between Surveillance and Control. The function of Surveillance is to keep the track file correct and up to date. The Control function uses the track file as a basis for deciding which aircraft should be vectored, told to hold, change altitude, etc. These control decisions are communicated to the aircraft pilot to effect control over the traffic flow.

Figure II-1(a) presents a simplified diagram of the arrangement of these functions today.* One or more sensors provide the surveillance data for each control facility; controller assistance is used in the surveillance function for data editing and track initiation. Control is exercised by an Air Traffic Controller making decisions based on flight plans plus the observed surveillance data. These control decisions are communicated to the pilot on the VHF voice link.

The Discrete Address Beacon System provides an improved capability for carrying out two of these functions; surveillance and communication. These improved capabilities are essential to the evolution of ATC to automated control.

Figure II-1(b) shows the automated control system of the future. Controller intervention in the surveillance process is not required. Automated control of IFR aircraft has been introduced and control messages are delivered automatically over the digital data link via the DABS sensors. The controller now has a "management-by-exception" role permitting greater use of his capabilities in handling non-routine situations.

*Throughout this volume are references to capability "today." In most cases, we are attributing to ARTS III and NAS Stage A certain capabilities (such as automatic tracking of primary as well as secondary targets, use of data from multipath sensors, etc.) which are in late stages of development or easy deployment though literally not quite here "today."



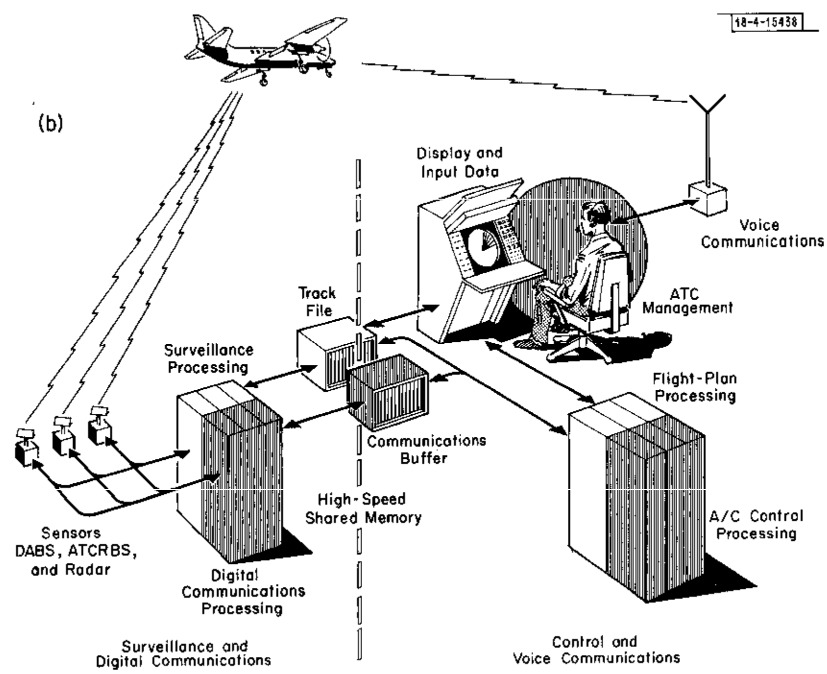


Fig. II-1. (a) Current System. (b) Future System.

As Control automation is implemented, it has been recognized that the role of the controller must change in three important ways. First, he must be relieved of the role of assisting the Surveillance function. This is the basis of one DABS requirement, i.e., a much more reliable, automated Surveillance function providing uninterrupted continuity of tracking. Second, the controller must be relieved of the task of communicator for all control messages. Here is the second need to be met by DABS, i.e., to provide a two-way digital data channel for the computer to communicate directly with the aircraft unless the controller chooses to intervene. Third, and what in effect drives the other two changes, the controller must gradually be withdrawn from making all routine Control decisions personally. Instead they will be made by computer and the controller will manage by exception.

Controller activity is and will continue to be concerned with IFR flights. With the advent of automation, additional, automated services can be provided VFR flights. VFR aircraft will be able to receive conflict advisories and collision avoidance commands based upon DABS capabilities, completely automatically, without controller involvement. DABS is currently being developed to support two forms of conflict detection. Both need extensive test and evaluation prior to establishing their operational suitability. Intermittent Positive Control (IPC) is ground based and centralized; and Synchro-DABS is a form of airborne CAS.

In order to provide conflict advisories and collision avoidance information to all VFR aircraft, the DABS will support a fully automatic Intermittent Positive Control (IPC) function. IPC calculates potential conflicts, and issues avoidance instructions via the DABS digital data channel to uncontrolled (VFR) aircraft. In conflicts involving an IFR aircraft with a VFR one, maneuver control is first exercised with the VFR aircraft with the controller being alerted to the developing situation. Only if the situation still fails to be resolved does the IPC system exercise positive control over the IFR aircraft. In conflicts involving only IFR aircraft, the controller is alerted and expected to resolve the conflict. Only if at the last minute the conflict is still unresolved will the IPC system direct control messages to the aircraft involved. In this latter mode, IPC can serve as a back-up in the event of failure in the controller-based ATC system. While IPC operation can actively control only DABS-equipped aircraft, it can, none-the-less, recognize and help resolve conflicts involving a DABS-equipped aircraft and aircraft with only an ATCRBS transponder or, to a lesser degree, aircraft without any beacon that are tracked by primary radar. Of course, the degree of service that can be provided suffers severely when aircraft without DABS transponders are involved and would be at all useful only if the number of such aircraft were very small in a largely DABS equipped population. For IPC to work well, the population involved must almost all be DABS equipped including altitude reporting. For this reason it is expected that IPC will be applied in areas where rule making restricts the aircraft population to be DABS or Mode C transponder equipped. Nevertheless, should failure of these transponders occur or unequipped aircraft accidently intrude, the IPC algorithm would continue to provide conflict resolution and PWI to the DABS equipped aircraft population.

Systems to resolve air-to-air conflicts generally fall into two categories: 1) Ground-based systems wherein the recognition and resolution of the conflict is accomplished on the ground with commands transmitted to the ments made in the air by each aircraft reveal to the pilot the impending conflict and leave to the pilot the decisions on how to resolve the situation. IPC belongs to the former; generally, CAS belong to the latter. Synchro-DABS is a hybrid of DABS operation wherein each DABS sensor schedules its interrogations so as to synchronize the reply times of the aircraft transponder. Then each aircraft, by listening to the replies of all its neighbors can determine range, and from successive replies, the range rate. This, along with a simple airborne directional antenna, permits the equipped aircraft to compute its own avoidance maneuvers. Synchro-DABS, however, is effective vis-a-vis other DABS equipped aircraft only, not against ATCRBS equipped aircraft.

B. Elements of the DABS Surveillance and Communication System

Having described the relationship of the DABS-based surveillance and communication system with the control system functions of ATC, more detail on DABS itself may be given.

Figure II-2 is a simplified diagram of DABS, showing the functional relationship among its parts. This figure in effect expands the left side of Figure II-1(b), the surveillance and digital communications part of the ATC System. Shown are the functions performed in the airborne transponders, the DABS sensors, and the processing functions colocated with ARTS and NAS.

This is a functional diagram and certain processing functions that are shown separately may be performed in the same computer with other functions. The DABS functions at the central facility may be located in the

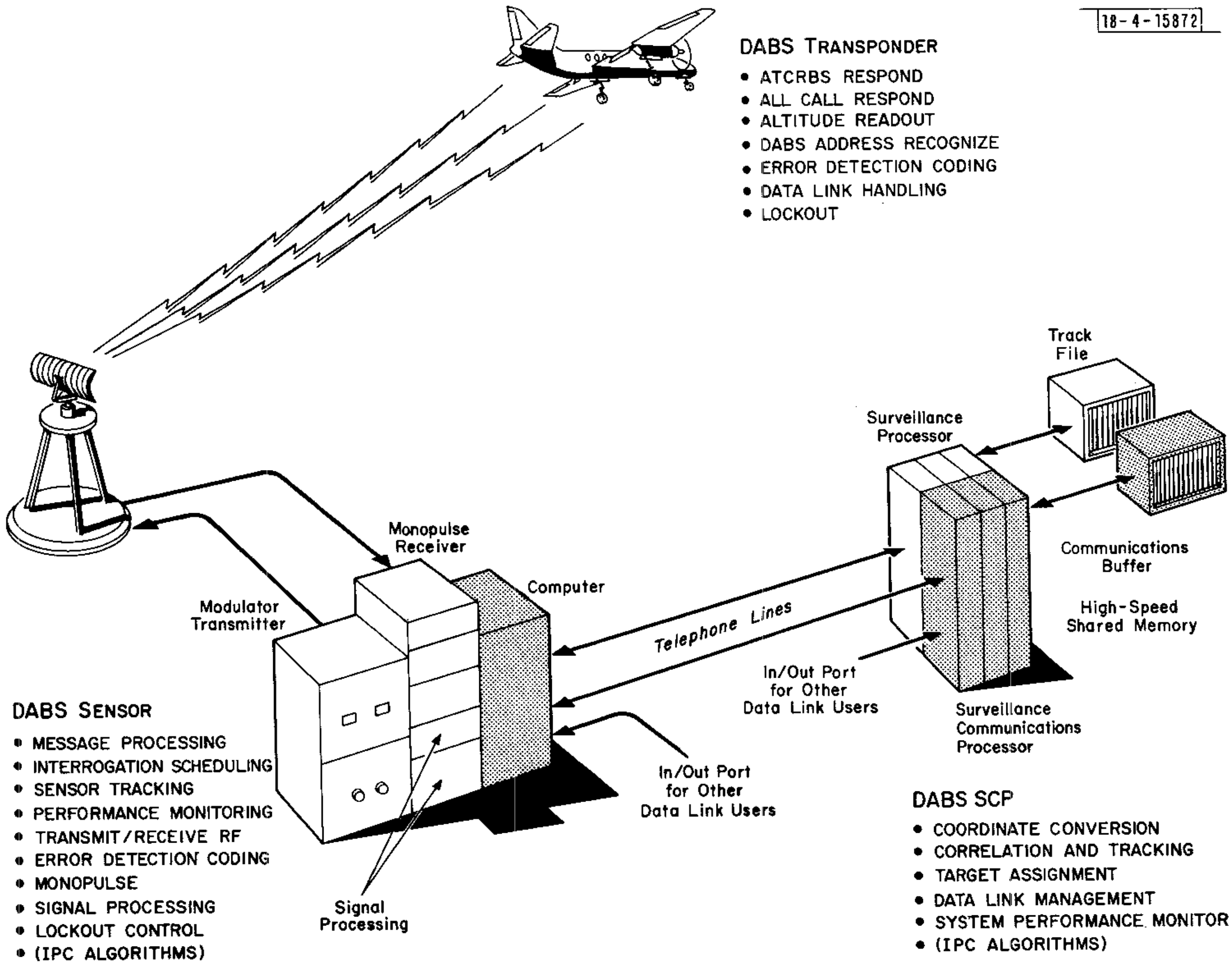


Fig. II-2. DABS Elements.

ARTS and NAS computers, and the IPC functions could be done in the sensor computer, in a separate one standing alongside, or in the ARTS or NAS En Route Stage A computers.

A short description of each of the individual elements of DABS follows:

1. Transponders

DABS transponders will have both surveillance and communication capabilities. All transponders will have essentially the same surveillance characteristics. Each will respond to four types of interrogation- all ATCRBS modes, DABS All Call, DABS Roll Call, and Synchro-DABS. There will be unique responses to each controlled by the interrogation. The transponder will, in addition, be capable of being inhibited from responding to either or both ATCRBS or DABS All Call interrogations by uplink messages.

The communications capabilities are manifested in the digital data link - up and down - and three levels are envisioned. Two of these will be principally for use by general aviation, and the third type primarily by the air carriers. The different degrees of capability and of services that can be encompassed include:

(a) Uplink for IPC and downlink for pilot acknowledge.

(b) All of (a) plus standard length messages- uplink and downlink.

(c) All of (b) plus extended length messages both up and down.

The type (a) transponder will provide a ground based collision avoidance service to VFR aircraft. The type (b) transponder will include in addition a downlink message capability. This, when interfaced to cockpit input output devices, in addition to IPC, will provide a complete two-way digital communication capability. This transponder will serve all the short-message needs of VFR and IFR flight activity with respect to ATC. The type (c) transponder will have a long message capability, uplink and downlink, and is expected to be used principally by air carriers.

2. Ground-Air-Ground Link

(a) Uplink formats

Each DABS interrogation (on 1030 MHz) begins with a preamble containing an ATCRBS sidelobe suppression and appropriate synch and initializing waveforms. Following the preamble is a multi-bit format with DPSK modulation at a four megabit/sec rate.

There are several types of transmissions that can be used, for example:

interrogate for surveillance;

send an IPC message;

send a normal length data link message;

send long (segmented) data link messages;

send synchronization for synchro-DABS;

etc.

In each case, the link control field indicates the nature of the uplink transmission and the type of reply expected. A reply, generated wholly within the transponder, is returned within several microseconds.

(b) Downlink formats

Downlink transmissions (on 1090 MHz) use a redundant form of PAM at an information rate of one megabit/sec. The formats also contain three fields: a 24-bit address field, a link control field, and a variable length message field.

3. The DABS sensor

All DABS sensors perform similar functions. However, it is expected that several versions of sensors will be designed and implemented. The choice will depend upon many factors, including terrain, traffic, and the relation of the sensor to colocated primary radar. The computer size will depend upon total traffic, the need to perform radar correlation at the site, the implementation of IPC at the site, and any need to format data specially for different users. It is further visualized that some DABS sensors will be deployed in a nearly stand-alone mode (e.g., supporting ARTS-II) while others are part of a network controlled by the automated users, NAS Stage A and ARTS III. Figure II-3 is a simplified sensor block diagram.

4. Control Facility DABS Processing

Figure II-1(b) indicates that at each ATC control facility there are functions which use and exercise control over several sensors. Sensors can serve more than one central facility, and by using this multi-sensor network each aircraft can be reached (for surveillance and communication) by more than one sensor.

Figure II-4 is a functional block diagram of typical DABS processing functions to be done at the central facility. On the left are interfaces with DABS sensors and with ATCRBS/radar sensors. On the right is depicted

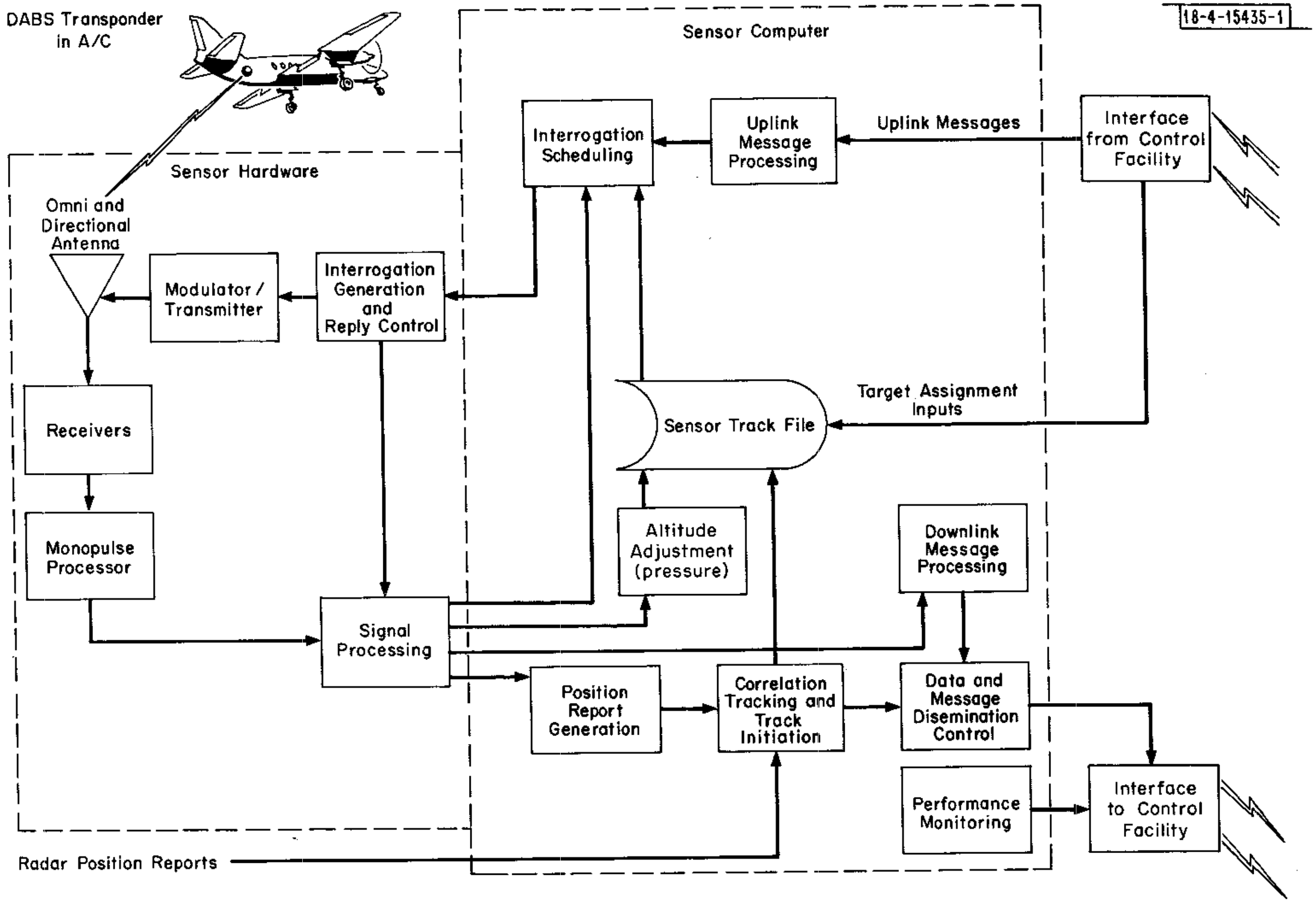


Fig. II-3. DABS Sensor Block Diagram.

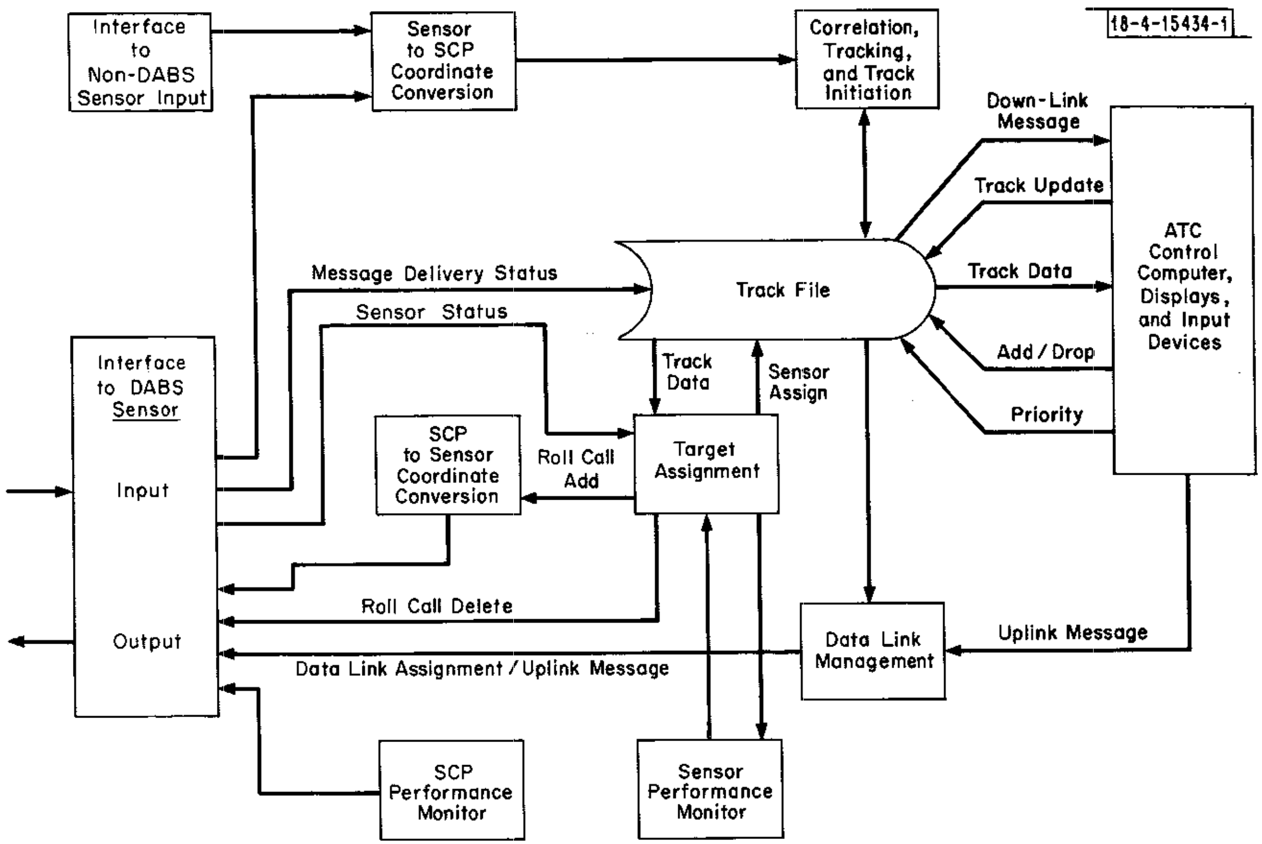


Fig. II-4. DABS Processing Functions at the Control Facility.

the ATC facility. In Figure II-4, the track file (for surveillance) and the communications buffer have been combined into one block.

C. Surveillance and Communication Network

1. Netting

The intial phases of DABS deployment will involve replacement of ATCRBS on a nearly one-for-one basis providing surveillance and data link capability in a local region. As the number of deployed sensors increases, a netting of sensors can begin to acheive the benefits of higher link reliability based on ground diversity, system protection against individual sensor failure, improved tracking accuracy, etc.

It is visualized that this netting will come about slowly, but ultimately will evolve into a configuration as depicted in Figure II-5. This figure shows an interconnected network of DABS sensors, ARTS terminals and ARTCCs. The terminals and the ARTCCs share the same sensors, many of which will be physically located near terminals to provide the needed low altitude coverage there.

2. Implementation Schedule

The method of deployment of DABS and the time schedule are important parameters in defining the transition designed to be essentially compatible with ATCRBS.

The current 10-year plan [4] calls for expansion of the ATCRBS surveillance services through the installation of about 100 new ATCRBS interrogators and associated ASR-8's at terminals and 25 Interrogators and ARSR-3's at en route sites. This represents roughly a doubling of terminals covered with beacon and radar surveillance.

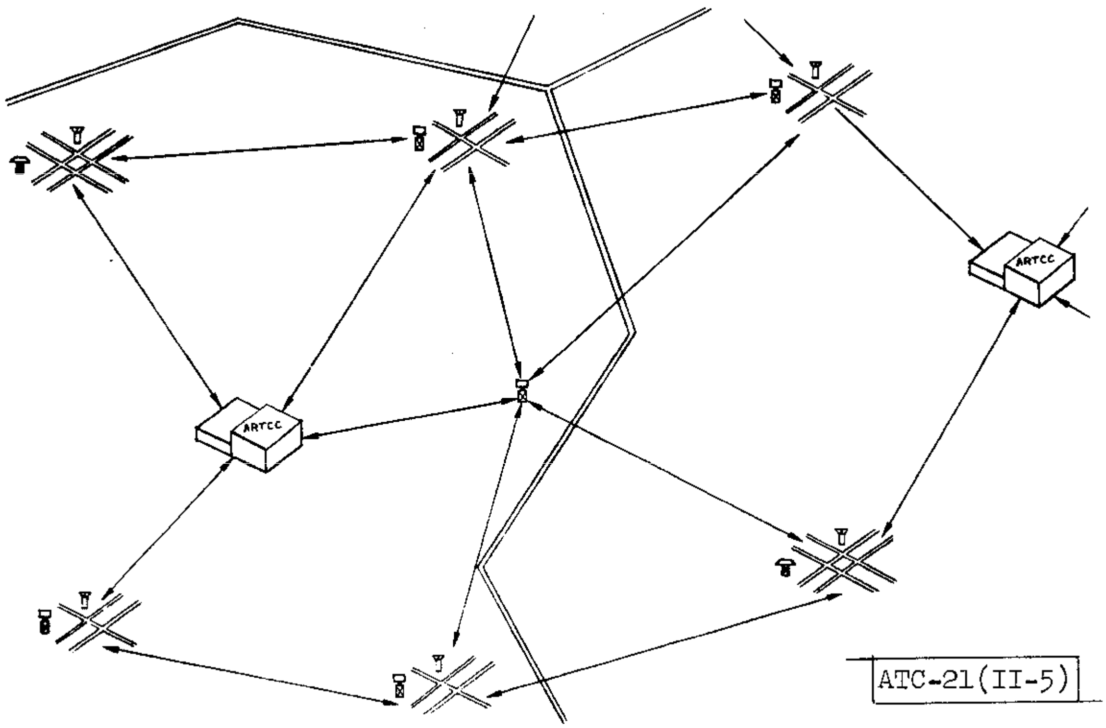


Fig. II-5. Surveillance and Communication Network.

It is anticipated that DABS will be available for initial deployment about 1977 - in the middle of this 10-year expansion program. Specifications for a general procurement of the DABS sensor would be available based upon the development work at Lincoln Laboratory and in-depth testing of several DABS sensors at NAFEC.

It was this possibility of the early availability of DABS sensors for deployment that served as the basis for considering the transition to DABS beginning relatively early - in latter part of this decade. This led to the recognition that DABS could provide the improved surveillance necessary early in the most active terminals thereby relieving ATCRBS of major changes that might be required to bridge a later transition.

Therefore, it is anticipated that DABS sensors with radars will be ready for procurement after 1977-78 instead of ATCRBS interrogators with radars. The DABS units will be installed not at expansion locations but at the high activity ARTS III sites needing improved performance. The ATCRBS Interrogators and radars from these terminals can then be relocated to the expansion site.

By the early 1980's, automated air traffic control can profitably be extended to provide service to a significant fraction of air operations. To meet this goal, there should by then be significant DABS surveillance and communications coverage. Sensors should be concentrated at terminals since this is the primary area where initial automation will take place. Strategically located gap-filler sensors will provide added coverage at high altitudes for en route segments.

The goal of this initial deployment should be to provide coverage for most of the high activity IFR routes and the major terminals. It is estimated that such coverage could be provided by as few as 75 sensors. Approximately 50 of these sensors would be at ARTS III terminals with the balance being distributed at either other terminals or en route sites to provide coverage above 18,000 feet for en route aircraft in regions not covered by the terminal sensors.

These sensors would provide both an improved ATCRBS mode as well as complete DABS service to DABS equippped aircraft. In both modes there would be monopulse tracking with lowered PRF. DABS service would include both discretely addressed surveillance as well as digital data link.

For this initial deployment the sensors would operate with a 4 sec data rate and a maximum range of 150 nmi. This would provide the data rate necessary for terminal operation and still give coverage for long ranges necessary to provide the coverage desired for this initial deployment. The long range (150 nmi) operation is basically a software parameter and would be reduced as soon as significant deployment of additional sensors provide the necessary coverage to permit shorter range operation. The surveillance data obtained from each of these sensors would be distributed to the terminals and to the en route centers for shared coverage.

Initially, in the deployment, the DABS sensor would simply replace the ATCRBS sensor as a source of ATCRBS type interrogations and surveillance. The controller would sense no change in his operations except that the improved surveillance would reduce the need for his intervention in the surveillance and tracking operation. Discrete interrogation of aircraft equipped with DABS transponders could also take place without direct consequence to the controller. Automatic IPC service would become available to properly equipped aircraft in the area, and would provide a backup in case of failure at a control facility. As the automated control functions were introduced at the control facility however, the controller would have the opportunity to adapt to the new procedures gradually. The DABS system provides the basic capability of surveillance and communications necessary for introduction of automated control functions but does not itself modify the operating procedures. This allows gradual introduction of those automated functions suitable to providing a graceful transition from the present semi-automatic mode to a fully automatic mode of operation of the Air Traffic Control System.

III. TRANSITION PHASE ISSUES

A. Introduction

ATCRBS and radar are currently the surveillance sensors. Pending the transition to DABS, ATCRBS will continue to be improved. RADAR will be improved and modified to more closely complement DABS. If DABS were simply an improved beacon sensor, that would just about cover the transition issues. Such is not the case, however.

DABS achieves some of its improved surveillance performance by the use of multiple sensors. Ground diversity is employed to overcome aircraft fading during maneuvers. Assignment of targets to specific sensor roll calls is done to assure the requisite multiple coverage as well as limit the interference that would result if every sensor called every aircraft. Facilities using DABS surveillance data must take a more active role in sensor coordination then they do now to achieve the total surveillance objectives.

In the case of digital data link, this is a new capability and how it is interfaced to its users is a matter of concern broader than the DABS program alone.

B. ATCRBS

From the general time scale of this projected deployment of DABS, two salient features are evident.

(1) Within 10 years, a significant deployment of DABS can be accomplished covering essentially all the major com-

mercial terminals and IFR routes. En route coverage for the major IFR routes will be provided by data from the terminal DABS plus a few gap-filler DABS installations. ATCRBS en route surveillance will continue to be to be used until supplemented by expanding DABS coverage.

(2) ATCRBS-based surveillance will remain at smaller terminals until the late 1980's and early 90's.

The first item takes the pressure off of ATCRBS. The initial DABS deployment should take place primarily at the major commercial terminals where automation will be introduced and where traffic induced problems of the ATCRBS system will begin to be felt. These are precisely the items DABS is intended to address. DABS will perform the target azimuth mesurement using monopulse for both DABS and ATCRBS targets permitting a significantly lower PRF thereby reducing fruit levels. Significant deployment of DABS will encourage conversion to DABS transponders further alleviating fruit and garble problems. And, of course, DABS with improved surveillance and data link will early support automation at its most critical places - dense terminal areas.

The second item indicates that ATCRBS will be the basis for surveillance in lower activity areas for many years to come and in the higher activity areas for less than ten years. In our review of the performance of ATCRBS we have concluded that ATCRBS/ARTS is performing quite well in today's environment and with today's type of ATC System. There are a few modifications that can be recommended to improve its performance with respect to false targets and some garble situations. However, no major changes seem indicated to maintain the level of surveillance required either in high density areas until the initial deployment of DABS or in the lower density areas for a longer period of time. Of course, as long as ATCRBS remains as the surveillance system for a given locale, there will be no data link capability available there.

The performance of ATCRBS has been examined analytically and experimentally as well as from a review of the literature. An estimate of fruit levels at both the Los Angeles and New York areas for the early 1980's was made based upon projections of peak instantaneous airborne count and fruit measurements made for Lincoln Laboratory by the Mitre Corporation. These predictions indicate fruit levels of 22,000 and 12,000 fruit/sec respectively with short term peaks 50% higher. Other studies [5] indicate that until fruit levels approach the 30,000 fruit/sec level, the degradation of ATCRBS performance is not severe. An analysis was made of synchronous garble mechanisms and the probablities of occurrences. Garbling is well tolerated in the present ATC system, but may be a major problem in a more fully automated system.

Runlengths of selected targets were examined for the effects of vertical lobing. Such effects were not seen but it is not certain that the runlength was a sensitive enough parameter for the region where these targets were operating. While vertical lobing was not observed in the limited data taken, it is recognized as an existent problem but one of strong dependence upon site characteristics. Careful RF measurements would have to be made to determine the degree of fading loss caused by vertical lobing. Missing hits were also examined. A reply probability of 98.2% was estimated for high altitude aircraft at Andrews AFB. In addition, some 3.5% of the replies were rejected by the BDAS -- probably because of out-of-tolerance framing pulses. Some data has been obtained on loss of track with aircraft in turns caused by transponder antenna shielding. Data were obtained both under this task as well as Task C [6] (military aircraft) of this agreement. This data indicated that the number of scans lost while in 360° turns could range from zero to 25% of the potential scans (some 30 per turn). The number lost was very strongly dependent upon the nature of the aircraft and location of the antenna on the fuslage with respect to various external protuberances. It would appear that careful positioning of the antenna on the aircraft could minimize loss of scan data. Furthermore, the loss of successive scans probably can be kept low enough so that the tracker need not lose track. Model tests are under way now, under the DABS program, to explore quantitatively the coverage obtainable from antennas on general aviation aircraft. It is anticipated that antenna patterns for commercial aircraft installations are available.

As a result of these studies of ATCRBS performance, certain conclusions can be drawn and recommendations made. The surveillance system based upon ATCRBS is quite adequate for the present mode of operation of the ATC system; the controllers can adapt to the existing limitations. Within the context of an early transition to DABS, no extensive modifications to the ATCRBS system are seen as being required. Recommendations are made below for certain modifications which would help ease some of these (minor) problems. Many of these may already be under consideration under the ATCRBS Improvement and ARTS Enhancement and other programs. No attempt was made here to evaluate such programs. Neither were the logistic and operational problems of applying these recommended changes to the systems in the field. The recomendations are from the technical point of view only. In addition, there were indications of special, localized problems which because of their local character were not included here but which must continue to be pursued on an individual site by site basis.

Traffic dependent problems such as fruit and multiple aircraft synchronous garble will become important in the 1980's in high traffic areas if the prediction of traffic growth are accurate. Levels of PIAC (Peak Instantaneous Airborne Count) in the range of 500-1000 aircraft within 50-100 miles of the terminal may be enough to cause problems. Fully automated control systems will be more sensitive to these problems.

There are recommendations for a few modifications to the ATCRBS system which would alleviate some of these problems and ease the controller's task a bit further.

The most prominent of the problems seen in this review was that of false targets caused totally by RF reflections from flat surfaces. The mechanism is deterministic and to a significant degree can be predicted once measurement has been made of the pricipal offending surfaces. With such behavior it should be possible to include in the software processing a correlation of false and real target based upon these measurements and the geometry of the situation.

(a) The sofware (ARTS III and En route Stage A) should be modified to include a geometrical correlation of pop-up targets in false-target-prone azimuth sectors to eliminate false targets from the controllers display.

In garbling, as well as false target situations, more extensive code checking would enhance the situation. This is especially true if more used is made of discrete codes. Certainly, the determination that a pop-up target is a reflection of an existing target is eased when discrete codes are used. In the azimuth overlap case, code checking during the run would prevent a lost target. In general garbling situations, scan-to-scan correlation of the codes would reduce the number of questionable code declarations.

(b) The software should be modified to make more extensive use of ATCRBS code checking for garbling and false target problems. This would include checks using previous scan data to help decipher garbled codes as well as checking code more than once during a hit sequence to minimize loss of targets due to azimuth overlap.

(c) Increased use should be made of discrete codes. Though not an R&D consideration, it is to be noted that if other operational considerations permit, a more extensive use of discrete codes would enhance the usefullness of the above code checking techniques.

A number of targets having short runlengths (4-6 bits) were observed to display reliable, if short reply sequences. Tracks were not established on these because their runlength was below the threshold which was set to discriminate against false targets. If the false target situation is cleared up, then this threshold could be reduced providing increased coverage of low-flying aircraft.

(d) Consideration (and testing) should be given to reducing the runlength required for target declaration.

The question of vertical lobing and large vertical aperture is a difficult one. We saw no evidence of lobing at the two sites at which data was taken; we are not certain our measurement, which was an indirect one, would have been sufficiently sensitive. Certainly extensive measurements were not made and there is much evidence in the FAA that it is a real problem at some sites. Vertical lobing is strongly site dependent and, indeed, may vary from azimuth to azimuth. With interrogator power at the 500 W level as is currently common, and normal airborne sensitivities, loss of coverage would be at elevation angles below about 3 degrees beyond 50 nmi. If the airborne sensitivity dropped by 10 dB (antenna fades) the the coverage losses would move in to less than 20 miles. Installation of a large vertical aperture at a site to alleviate vertical lobing problems is a promising solution but so too is it a major cost item. Development of a family of large vertical aperture antennas is presently under way. As their characteristics become quantified it will be possible to match them on a site by site basis to the kind of difficulty being expressed there.

(e) Careful RF measurements should be made at suspect sites to evaluate the contribution of multipath to the problems as a step in determining the most suitable antenna for that site.

The storage tube defruiter has been a source of decoding errors caused by spots on the tube face.

(f) Replacement of this defruiter by one less susceptible to such problems is recommended.

(g) Furthermore, consideration might be given to elimination of the defruiter in the data acquisiton chain with software processing being used instead, at sites where fruit levels are not excessive.

The diagnostic capabilities now available in the ARTS III digital system are extremely valuable in determining system performance. Controller reports of specific problems can be quantitatively evaluated and the source determined. General problems can be determined by careful review of sample data.

(h) These capabilities ought to be exploited and perhaps extended to the En Route State A system.

C. Radar

In Appendix C, the role of radar is discussed in a summary fashion. Radar is playing a definite, if supportive role, in todays surveillance by providing data when beacon returns are missing or questionable. Such service will continue to be desirable well into the 80's and 90's as long as ATCRBS continues to provide surveillance. As time goes on, of course, that role will tend to be confined to the smaller, less critical areas. Second, radar currently provides the surveillance for unequipped aircraft flying IFR. The degree to which such service requests will be honored in the future as DABS deployment spreads is not clear. In mixed airspace, radar will continue to provide surveillance data on unequipped aircraft to the controller (and control system) for traffic advisories and PWI. In regions which are restricted to transponder-equipped aircraft--such as critical TCA's, the role may change primarily to one of intrusion detection. It is clear, however, that radar surveillance will continue to be required well into the 1980's and will linger on in the lower density areas. If a significant fraction of the GA population does not carry a transponder, radar may be required indefinitely to provide needed surveillance of these aircraft.

With this need for radar continuing, it behooves the FAA to obtain performance consistent with current techniques from their radars, both ASRs and ARSRs, which are in the current 10-year procurement plan [6] as well as from existing installations.

In the past several years, a new radar technology has come within the economic grasp of the civil aviation community. These issues are discussed in References [1, 7, 8]. Fundamentally, the new technology, available at what is believed a negligible increase in cost, will permit significant improvement in the Moving Target Detection (MTD) capability of air traffic control radars in the presence of ground clutter and weather clutter--these being the most limiting draw backs to present day radar. Improvement of 25 dB for ground clutter and 15 dB for rain clutter are possible with these new MTD systems. Such an improvment would enhance considerably the usefulness of radar to the controllers especially for small aircraft without beacons. As automation is introduced such improvement would be a prerequisite if radar is to serve a role in such a new automated environment. One of the recommendations of this report is for the FAA to engage in programs aimed at achieving that kind of radar performance.

In considering the transition to DABS, the relationship of DABS to radar--present and higher performance--was studied. In most of the first deployments, DABS will essentially take over the functions now performed by a particular ATCRBS, that is, have the same area of coverage. The present ATCRBS sensors are co-located with either an ASR or an ARSR. Consequently, combining the DABS replacement with the radar that is there, or with a new or improved radar as discussed above was examined. For that reason, DABS configurations are being developed for accommodating various radar configurations. One such makes use of a combined radar and DABS antenna. This problem of integrating DABS with the radar should be addressed specifically and undertaken jointly between the DABS program and radar improvement programs.

There are some ramifications of doing this that need to be addressed. First of all, it is common practice today to site the radar antenna (with the beacon antenna) low to the ground to overcome the ground clutter problems of the radar. This is poor from the point of view of blockage by local obstructions. One would like to put the beacon (and radar) up higher to get better coverage by reducing blockage. When radar improvements are made to overcome the ground clutter situation, then such higher siting of beacon and radar can be considered. Consequently, new siting criteria will have to be developed to permit more optimum siting of new radar-DABS (or ATCRBS).

Another issue that must be faced is the correlation of the DABS data with the radar data. Under the current ARTS Ehancement program, both beacon data and radar data are converted to digital form and entered into the ARTS computer where the correlation is made to determine which beacon replies are radar reinforced and which are not. Since the new MTD systems employ digital techniques, the radar output is already digitized eliminating the need for the separate RDAS portion of the Enhanced ARTS and, similarly the BDAS is not appropriate to DABS. The DABS configuration suitable for this type of installation would include acceptance of the digital radar data and correlation with beacon returns with the output being combined surveillance data. At the ARSR, the beacon and radar correlation is currently performed within the Production Common Digitizer (PCD). In the en route situation, ARSR data and beacon data are digitized and correlated within the Production Common Digitizer (PCD). When DABS is located near an en route radar with a PCD, the DABS sensor will accept the primary radar declarations from the PCD and perform the correlation with ATCRBS and DABS. An application of MTD to the ARSR would merely replace the PCD as it relates to the DABS.

Radars scheduled to be operational when DABS deployment begins include the ASR's up through ASR-8, the ARSR's through ARSR-3, and the FPS 20's.

Recommendations

Current technology based on work performed at Lincoln Laboratory under Task B indicates that for coherent radars, such as the ASR-8, improvements are possible in sub-clutter visibility by about 25 dB for ground returns and 15 dB for rain returns at little cost impact. Such improvement would permit reliable surveillance of small targets such as representative of many GA aircraft in regions where clutter now dominates. Hardware and software suitable to modify ASR-8's to this method of MTD could be specified shortly.

(a) It is recommended that such a specification be prepared, and current contracts for the procurement of ASR-8's be amended as soon as possible to include this improved MTD capability.

Similar techniques are applicable to the ARSR-3 and to the FPS-20 since they have coherent klystron transmitters.

(b) It is recommended that development work be initiated to modify the MTD system being designed under Task B to work with the ARSR-3 and FPS-20/60 series, followed by appropriate retrofitting.

In addition, improved performance can be achieved in noncoherent radars by the application of some of the MTD techniques. Benefit and cost of retrofitting has not been examined.

(c) It is recommended that a program be undertaken to develop and specify MTD systems for possible retrofitting to en route and terminal magnetron radars. The program should include a benefit and cost evaluation.

The radar improvements recommended above, in addition to upgrading significantly the performance of the radars, provide a first step in achieving an integrated DABS/radar sensor. Another step being pursued both in the DABS and ATCRBS improvement programs is the definition of a new combined feed for existing radar antennas which would permit DABS or ATCRBS to utilize the same aperture as the radar.

In the longer term, a new ASR should be procured, and its design should reflect, from the onset, the intended DABS/Radar integration as well as further radar improvements. This radar could incorporate a step-scan antenna and lower frequency of operation as well as simplified MTD processing. The lower frequency operation will reduce the clutter from birds and weather, permitting simplified processing for surveillance of desired targets. The lower frequency of operation also makes economically attractive the use of electronically scanned arrays and step scanning. The step scanning of the antenna will reduce the size of the notch of blind speeds below that obtained with a scanning antenna. Lower frequency operation entails some problems whose impact must be thoroughly assessed. One problem is that of frequency allocation. The crowding of the radio spectrum is recognized as is the long hardtask of obtaining a new allocation. The problems and possibilities must be more fully explored and weighed against the technical benefits. At the lower frequency of operation, the radar is no longer sensitive to rainfall thus removing the capability of displaying rain areas to the controller. The impact of this must be assessed as well as alternate and/or better sources of such data explored.

(d) It is recommended that a joint program be undertaken to develop an integrated DABS/primary radar facility with a joint use antenna feed, all digital processing, and with the radar to DABS target correlation being done at the site

This particular development program would be the first step in arriving at a radar/DABS integrated sensor both for terminal and en route use. It is felt that developing and testing the terminal version of the combined sensor first would permit working out the details to the point where developing an en route version could go much faster.

When the improved radar performance is achieved, ground clutter will cease to be the very difficult problem that it is today with the air traffic control radars. This then would permit resiting of the integrated DABS/radar sensor in order to overcome the effects of local obstructions. It is desirable in many cases to site the sensor high off the ground. This has not been possible to date because of the characteristics of the ASR. However, the new sensor will not be so disadvantaged, and new siting criteria can be developed.

(e) New siting criteria should be developed for the integrated DABS/radar sensor permitting maximum coverage at the lowest elevation and overcoming local obstructions, taking into account the improved sub-clutter visibility achievable in the new radar design.

A low-cost unit for use at general aviation airports should be examined. There are and will continue to be a large number of general aviation airports with towers and with significant traffic levels but without benefit of radar surveillance. In the future DABS era, transponders may be so widespread that only beacon surveillance is required. Until then, however, there will be a definite transition period in which radar surveillance of unequipped aircraft at these airports would be desirable if the cost of providing this service could be reduced. The techniques described above for the new ASR could provide a basis for a low cost surveillance system.

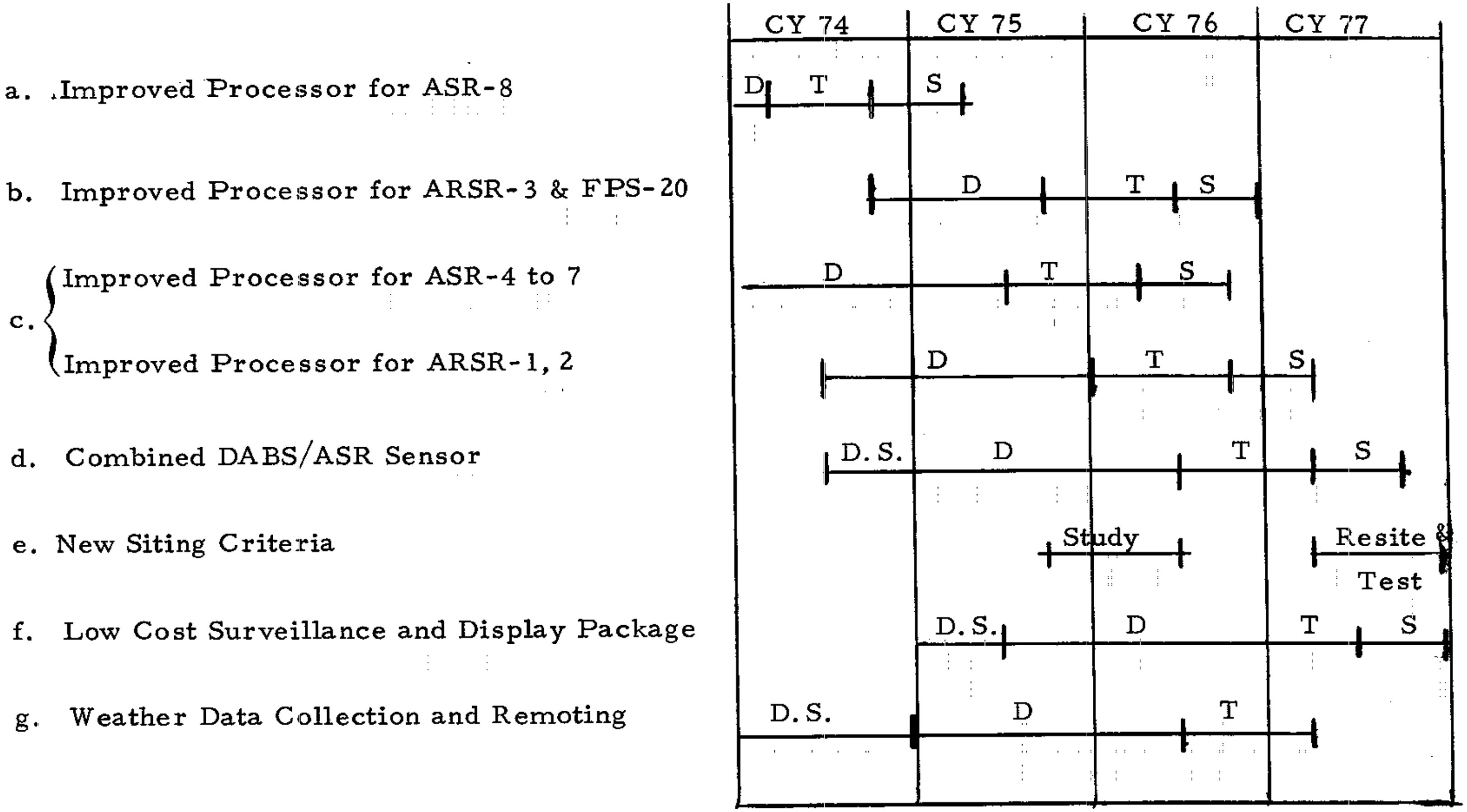
(f) It is recommended that an integrated, low-cost, surveillance and display package be designed specifically for use at general aviation airports.

On a longer term basis, as DABS becomes more fully deployed and the structure of the automated ATC system becomes clearer so too will the role of radar in the DABS era. At present, it is not clear. Intruder detection, back-up for transponder failure, and improved weather determination are defined possibilities. But the needs are not well enough defined to be able to suggest specific development areas.

Weather and turbulence surveillance is an evident need particularly emphasizing turbulence along the flight path of aircraft in flight. Currently, the controller depends to a large extent upon rain clutter returns on the ASR and ARSR for alerting the pilot and rerouting. Improvement of these radars to utilize coherent processing also makes available a more explicit delineation of ground and weather clutter as they are separated from the aircraft returns.

(g) It is recommended that a program of study and breadboarding be undertaken to develop techniques for accumulating weather information from the radars with MTD and remoting it to the control facilities.

Table III-1 is a projected research and development schedule for carrying out the above recommendations. These schedules provide for the design and test of prototype models of the MTD processors for the various radars - original equipment and retrofits. The specifications developed in the scheduled programs will be directly suitable for procuring units for operational deployment.



D = Development of Breadboard Hardware and Software

T = Test Program

D. S. = Design Study

S = Specify

Table III-1. Proposed Schedule for Radar Research and Development.

D. Digital Data Communications

The DABS provides a high capacity digital data channel for aircraft control and information. This channel will serve the automated control functions through the ARTS and En Route Stage A or Stage B systems. These automated control functions are in the early stages of development.

The DABS channel, however, contains significantly more data link capacity than is required by the aircraft control function alone. The quantity of data that must be passed over the channel to effect IPC and so called "tactical messages," such as metering and spacing, etc., is really rather small. A number of other kinds of messages--containing "strategic" information for longer term planning-- are visualized as being sent over this channel, including weather data, full text clearance, ATIS, information relating to area navigation, etc. These latter classes of data do not generally originate within either ARTS or NAS nor is ARTS or NAS the sole recipient for these data that come down from the aircraft. Consequently, in addition to the basic DABS system that services ARTS and NAS, provision must be made to accept data from other sources and to route data to the other sources.

The question arises as to whether the sensor or the control facility is the proper entry and exit port for these other data sources. That hinges upon the types of data and their destination. If the data sources on the ground (for instance, a flight service station) know which sensor is currently in contact with an aircraft, then it would be possible for that source to exchange data directly with that sensor; or, if the data were merely to be transmitted to all aircraft within hearing of a given sensor without respect to the aircraft's specific identity, then the communication could be made directly with the sensor. This is illustrated in Figure II-2 by an in/out port at the sensor.

On the other hand, if the data source does not know which sensor is in contact with which aircraft, then the control facility is the logical entry and exit port. In Figure II-2 there is also an in/out port at the control facility where the routing is done.

(a) Each data link application needs to be studied in detail to determine what form of ground routing mangement is required for non-tactical messages. Then inter-facility communication formats can be established and the direct impact on DABS hardware and software determined.

APPENDIX A

SUMMARY OF SURVEILLANCE AND COMMUNICATION REQUIREMENTS[1]

A. Environment

A detailed review of air traffic predictions for the next 20 year period was undertaken to provide a picture of the nature of the forecast growth in air traffic demands. This review included current FAA statistics and forecasts as well as the ATCAC projections. Figure A-1 reflects the result, based on current predictions of 14% fewer Air Carriers and 21% fewer General Aviation aircraft in the 1980's than was projected by ATCAC. Several conclusions may be drawn from the projections in Figure A-1. Air Carrier operations will increase 20% by FY'82 and at that time will be maintaining a growth rate of about 4 1/2% per annum. GA itinerant VFR traffic will have increased by a factor of 2.5 in FY'82. But most significant, GA IFR operations will have grown by a factor of more than 5, to predominate all IFR traffic. This will produce a drastic change in the nature of the air traffic environment for ATC in the 1980's. While operations at the major airports in terminal areas will only slightly increase, the total IFR traffic to be handled will almost double by the end of

[1] This Appendix is a short summary of requirements taken largely from Ref. [8, 9, 10].

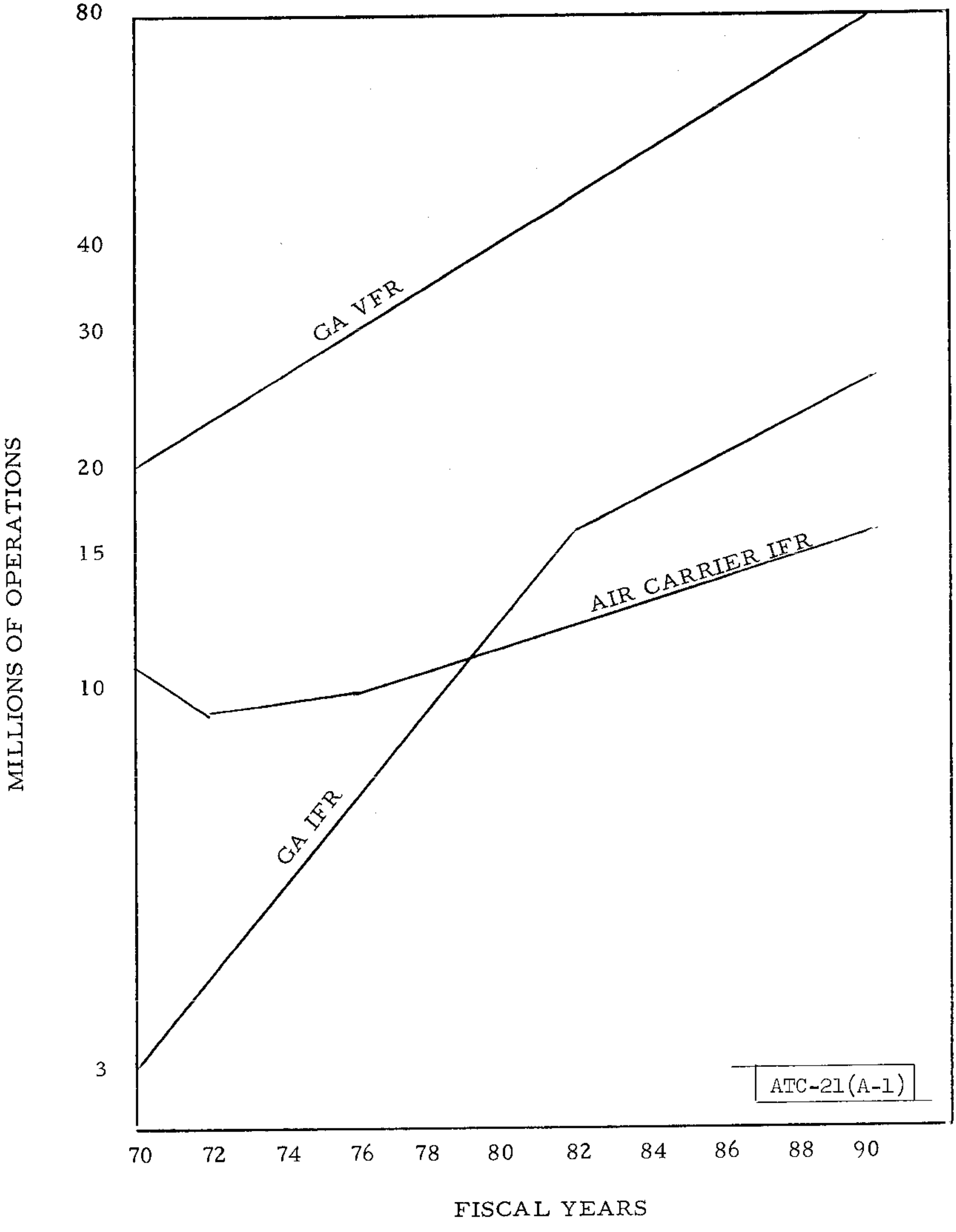


Fig. A-1. Itinerant Operations Forecast-FY 1970 - FY 1990.

the 1980's in currently dense terminal areas, complicated by GA IFR traffic operating in and out of a multiplicity of satellite airports. Mixed airspace--both en route and adjacent to controlled terminal airspace--will have a three-fold increase in air traffic density by FY 82. The air traffic control problem will become more complex by virtue of there being 3 VFR aircraft for each IFR aircraft in this airspace.

This burgeoning of IFR operations and the attendant increase in complexity of airspace environment present a direct and major increase in burden upon the FAA. This increased demand for service must be met by some combination of increase in number of controllers and increase in efficiency. It is not clear that simply increasing the number of controllers could cope with the increased demand. It would appear that significant, increasing automation of Air Traffic Control functions will be required by the early 80's if the FAA is to support those demands economically and safely.

This automation must start by relieving the controller of routine overhead tasks such as frequency assignment, altitude requests, and hand-overs. It must then expand to include real control functions such as Metering and Spacing, Conflict Detection and Resolution, etc. Initially, this automation will most likely occur at the densest (commercial) terminals - TCA's and TA's. However, if it is to cope with the projected General Aviation demand it must rapidly expand to include the growth in service demand of the associated satellite airports. At the same time, the combination of rapid growth in IFR operations by GA and the general increase in GA activity especially in the vicinity of active commercial terminals will result in a greatly increased complexity of control which will necessitate introduction of IPC to maintain safety levels.

B. Requirements

Increasing the degree of automation in the ATC System has a significant impact on the nature of the requirements on equipment supporting the System. Thus far, automation as represented by NAS En route Stage A and ARTS III involves essentially clerical functions such as automated tagging of beacon targets displayed for controllers. This level of automation was predicated upon the introduction of digital computation into the ATC System. In NAS Stage A, only with digital processing did the storage and distribution of flight plan data become feasible. Likewise, with both the NAS Stage A and the ARTS Systems, digital computation was a pre-requisite to the automatic presentation of data blocks associated with aircraft blips on the controllers display scope. The introduction of digital processing into the ATC system has provided the capability for far more efficient, flexible, and broader utility of the ATC System.

The next, up-coming level of automation based upon digital processing is the automatic tracking of (all) targets, automatic generation of commands to control aircraft flight and the automatic delivery of these commands to the pilot. This new level of automation has a direct impact upon the surveillance and communications requirements necessary to support this automatic system. To this end, we have reviewed in some detail the surveillance and communications requirements associated with the implementation of automatic control functions such as M&S, IPC, and

Close-spaced Parallel Approach Monitoring. This has provided a better understanding of the intended performance of the automated system as a framework for our examination of the transition plan.

1. Surveillance - Acquisition and Tracking

One of the first requirements of the surveillance system is a highly reliable, automatic acquisition and tracking of targets with strong discrimination against non-real targets. Development of quantitative requirements for this reliability are quite difficult. The probability of detecting a real target is controlled essentially by the power budget. In beacon systems such as ATCRBS and DABS, the detection is generally not limited by noise. There are RF link problems such as vertical lobing, blockage of interrogator, transponder antenna shielding, transponder sensitivity, and transponder suppression which do limit detection. Vertical lobing and blockages are deterministic effects, very specific to a site, not subject to "averaging out," and therefore must be accommodated by the system. Transponder suppression is a random effect subject to "averaging out." If suppression probabilities are in the few percent area or lower, it need not seriously degrade the performance of an automatic acquisition system.

Transponder antenna shielding can range over more than 10 dB or 20 dB and is very dependent upon the specific aircraft and antenna location. The uplink and downlink power budgets cannot be made to accommodate such a loss over all situations. Shielding of the transponder antenna does occur especially in maneuvers and may extend over several scans causing a loss of track. It most certainly means a loss of good position data on the target when position is changing most rapidly. This can be critical.

In addition to detection losses, false targets can present a problem to automatic acquisition and tracking systems. The false targets seen in beacon systems are deterministic reflections from nearby structures. To an automatic system these can appear to be legitimate targets and could pose a major problem for an automatic IPC or Conflict Resolution system. Such false targets represent unexpected, pop-up targets, deep within the coverage volume of the system and not conforming to established traffic patterns. If these targets are confined to isolated regions of the coverage, they may have little impact on the control functions. If they appear in complex traffic areas, they could severely impact the system. Keep in mind that these false targets are deterministic and do appear repeatedly in the same areas. Hence, false targets must be kept to a low level. How low is hard to say and depends on where they appear. Certainly, in critical areas such as approach patterns and departure patterns, false targets should be limited to a few per day or less.

2. Surveillance-Accuracy

Once track is established, the surveillance system must produce target track position of sufficient accuracy to support the specific automated control function implemented. Studies have been made of M&S,

IPC, and Parallel Approach Monitoring to determine the surveillance accuracy required to support these control functions.

The function of the M&S program is to deliver approaching aircraft to a specified point (called the gate) in the final approach with a time error less than 5 sec. The control program effects this delivery by estimating aircraft ground position and velocity and adjusting the path length by timing turns so as to deliver the aircraft to the gate at the proper time. The key problem for the surveillance system is the estimation of ground velocity [11]. From this reference, it is necessary to estimate ground speed to about 5 knots to attain the desired delivery time accuracy. Since the aircraft is under control and the flight pattern is a sequence of straight line segments, the velocity can be estimated from position measurements over a constant velocity path. The velocity estimate goes roughly as

$$\sigma_V = \frac{\sigma_P}{\Delta T} .$$

With surveillance position accuracy of about 300 ft, the velocity can be estimated to the desired accuracy in about 35 sec. At a range of 10 nmi, this position accuracy corresponds to an azimuth accuracy of about 5 mrad or 0.3 degrees. The data rate for this velocity measurement is not critical. The nominal 4 sec rate of ASR's is quite adequate.

A study has also been made of IPC requirements on the surveillance system. In the IPC environment, aircraft motions are not as in that of M&S; indeed, the pilot is generally free to maneuver until the system recognizes a potential conflict and moves to resolve it. This freedom of maneuver defines a fairly significant volume within which each aircraft might be at some time in the near future. The IPC system must protect essentially this total volume. Surveillance data on past positions can only define present position and velocity. Typically for an IPC system, tracks must be extrapolated for 30 sec or more. In that period of time, an aircraft turning at 3^{o}/sec would change heading by 90^{o} and his cross-track position would have changed by 33 V ft (where V is his speed in knots). The surveillance system must provide position data only with an accuracy small compared to this cross-track maneuver capability. A position error of a few hundred feet is quite adequate. This is borne out in a much more careful study of the dependence of IPC performance on surveillance parameters [8]. Figure A-2 illustrates this point. The negative command cross-section plotted on the ordinate represents roughly the radius of the protected area around the aircraft such that penetration of this area will result in a negative command (Don't Turn Left). The figure shows the dependence of this cross-section on sensor error and sensor update interval. As can be seen, the dependence on both is moderately weak. A factor of 3 reduction in sensor error from 1000 ft brings only a 50% reduction in negative commands [D(-)] at a 4 sec update rate and even less for the 1-sec update rate. Again, the reason is that the ability of the pilot to maneuver the aircraft is the major determinant of the command cross section. Surveillance errors have only a secondary effect.

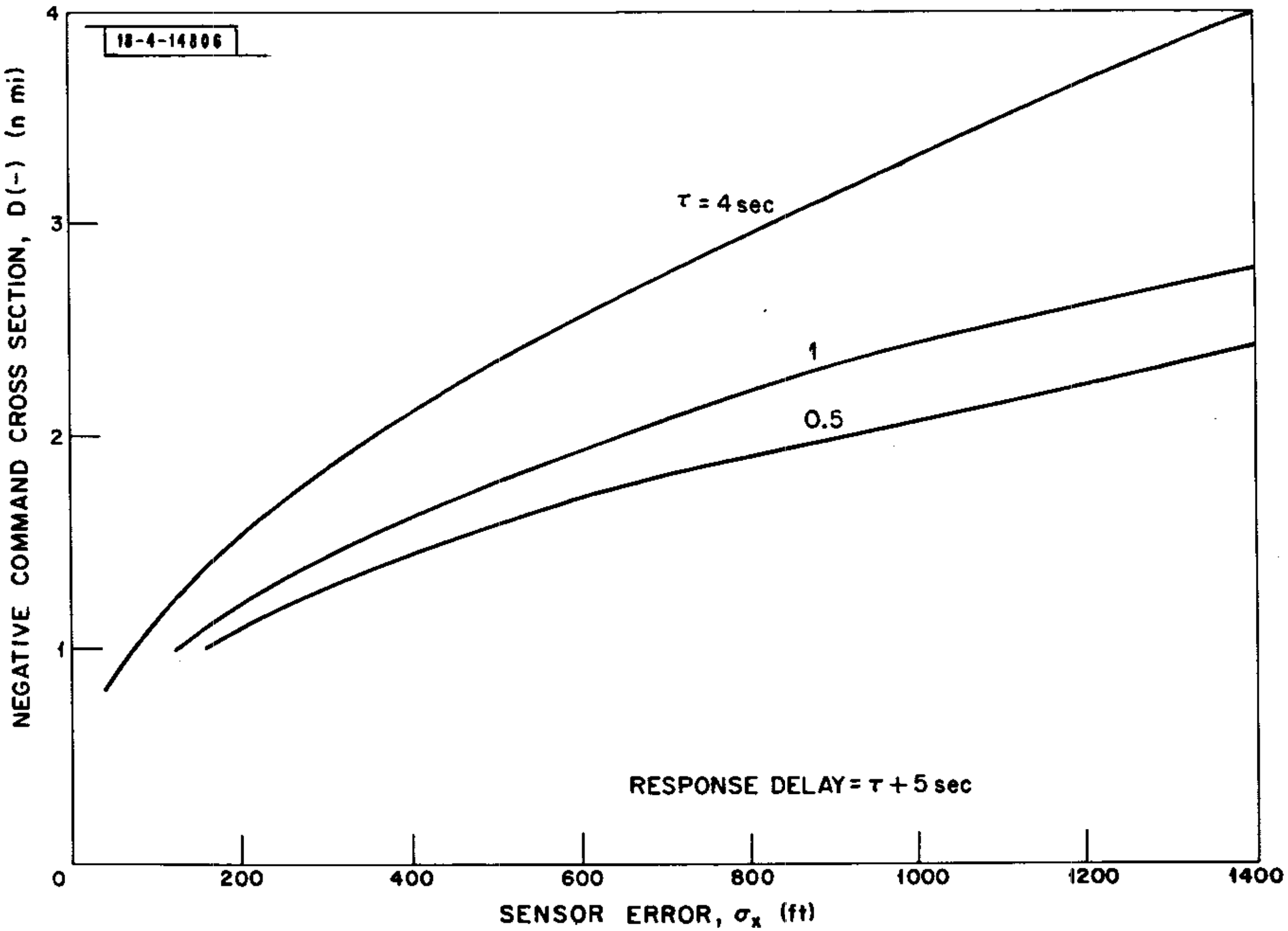
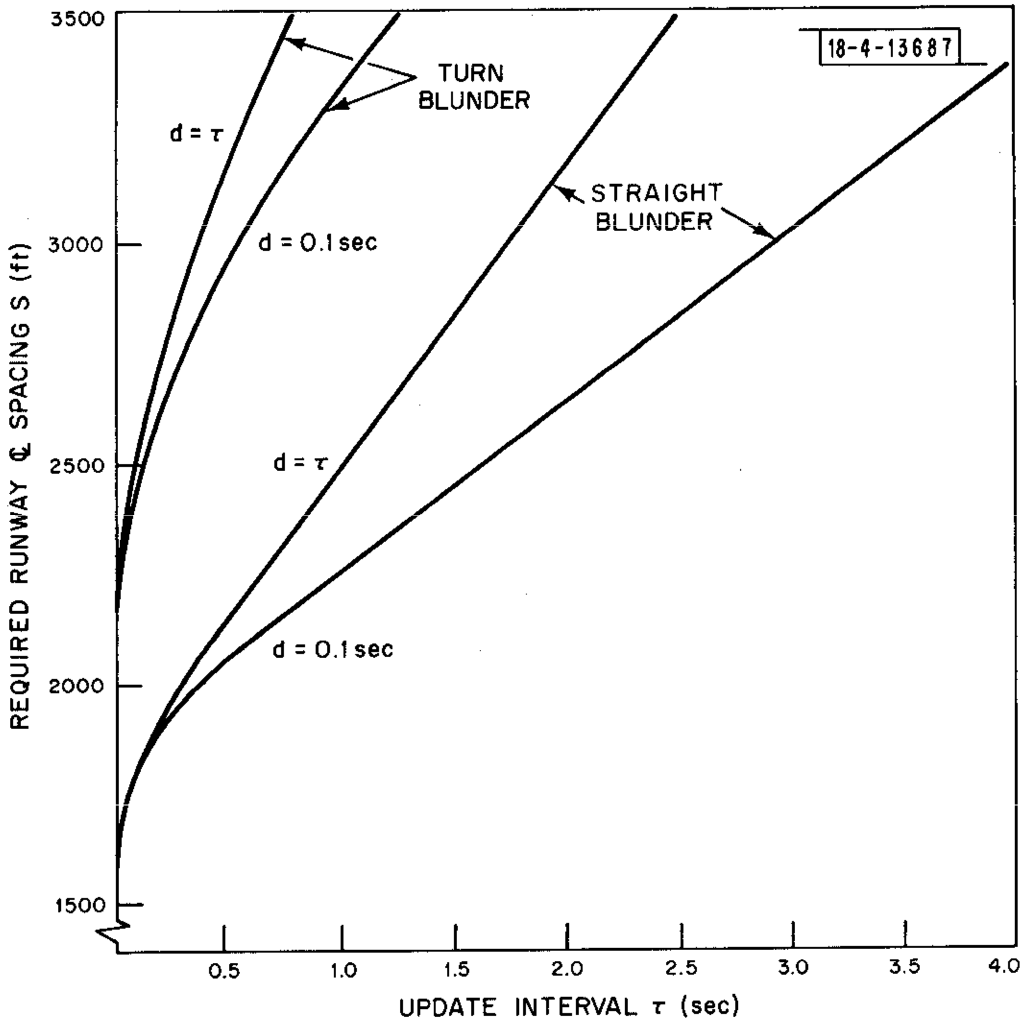


Fig. A-2. Effect of Surveillance Parameters on Negative Command Cross Section.

As a result, we conclude that surveillance errors of about 300 ft and a data interval of 4 sec is adequate to serve IPC intypical environments. Large decreases in position errors and/or sample interval would result in only modest reduction in command cross-section. The basic question for the surveillance system is at what range must this position accuracy be achieved? At a range of 20 nmi, a position error of 300 ft corresponds to an azimuth error of 0.15 deg. From this, it is evident that the range at which a sensor must provide surveillance data for an IPC function is an important factor. The type of IPC analyzed relates to regions of high aircraft density, regions near to large clusters of busy airports. Hence, it is anticipated that the critical regions for IPC and surveillance will be within 10's of miles of sensors and azimuth accuracies better than 0.3 degrees will be required.

Surveillance requirements for parallel approach monitoring have also been investigated. The problem is to monitor pilot-controlled approaches to close-spaced parallel runways so as to detect blunders and provide corrective instructions to the pilot. The analysis estimated the dependence of minimum runway separations on aircraft maneuver characteristics and surveillance parameters. As in the situation with IPC above, the maneuverability of the aircraft dominates - even with perfect surveillance and communication the minimum runway separation required is something over 2000 ft. As surveillance parameters are introduced, the strongest dependence is on update interval. This dependence is shown in Figure A-3. The dependence on position accuracy is shown in Figure A-4. From these figures it is evident that normal surveillance data rates (4 sec per sample) are completely inadequate for runway separations approaching the desired 2500 ft. Extrapolation of the



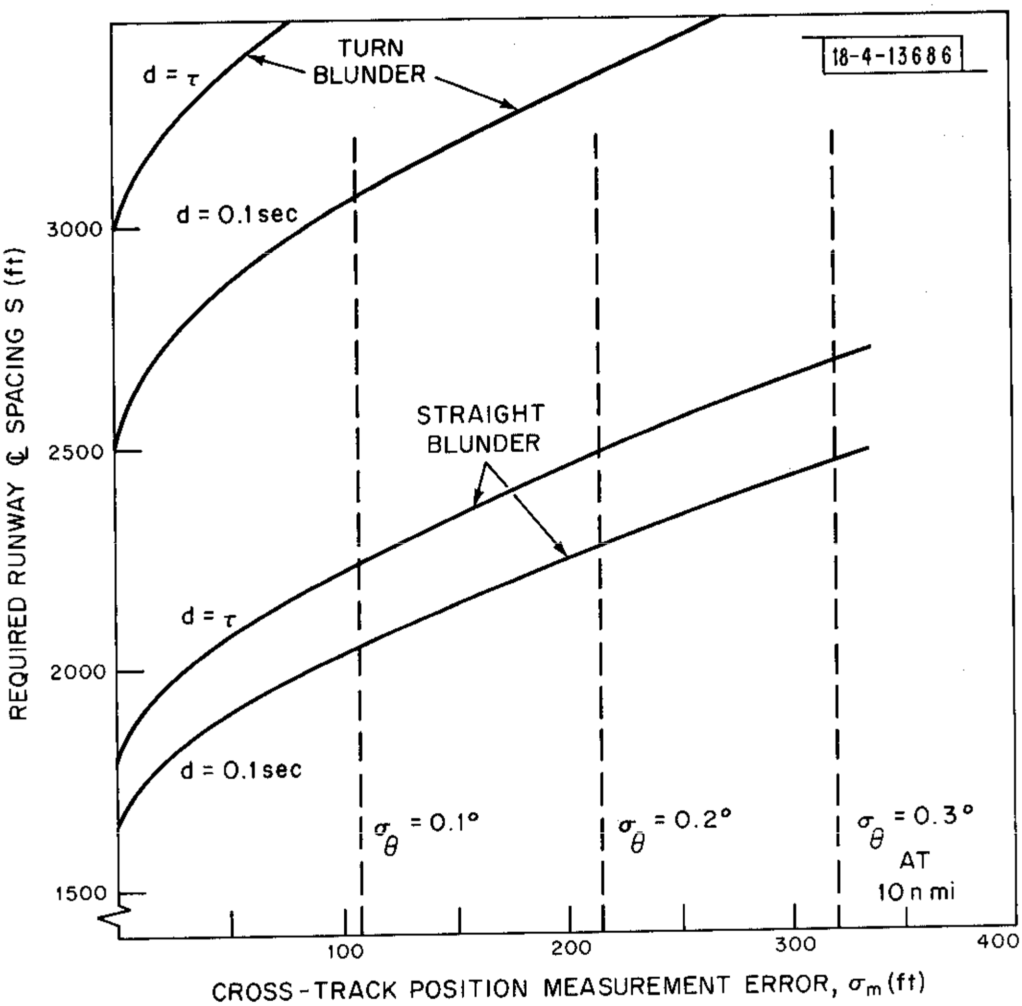
NOMINAL SENSOR ERROR

$\sigma_\theta = 0.2°$
($\Rightarrow \sigma_m = 213$ ft AT 10 nmi)

FIXED PARAMETERS

NOZ = 800 ft BZ = 500 ft
$m_1 = 1.0$ $m_2 = 0.0$
$\omega_1 = 1.5$ °/sec $\omega_2 = 3.0$ °/sec
$C_\gamma = 10$ °/sec V = 180 KNOTS
$T_p = 2.0$ sec

Fig. A-3. Required Runway Spacing vs Update Interval.



NOMINAL UPDATE TIME

τ = 1.0 sec

FIXED PARAMETERS

NOZ = 800 ft BZ = 500 ft
m_1 = 1.0 m_2 = 0.0
ω_1 = 1.5°/sec ω_2 = 3.0°/sec
C_γ = 10°/sec V = 180 KNOTS
T_P = 2.0 sec

Fig. A-4. Required Runway Spacing vs Position Measurement.

curve in Figure A-3 to an update interval of 4 sec indicates its applicability to 5000 ft separations. For parallel runways, separated by 2500 ft, the update interval must be significantly less than 1.0 sec.

From this, it is concluded that if parallel runway monitoring is to be done by a ground surveillance system for separations approaching 2500 ft, data rates higher than 1 per sec are required. This should be met by a special surveillance device. Imposing such a rate upon a general surveillance system would have a major impact (if it is at all feasible). The number of potential candidate terminals for such monitoring is small, probably less than a dozen, and it appears more reasonable to design special equipment for this particular surveillance task. It should be noted that this study of parallel approach monitoring concentrated on the ground surveillance aspect only. It is not clear whether some cooperative data from the aircraft (such as turn rate) on a down link in conjunction with a general (4 sec) surveillance might provide a viable system. Any further examination of close space parallel monitoring should include such possibilities since it is the unknown maneuver state of the aircraft that has such strong influence on minimum separations.

From these studies it is clear that the surveillance requirements of IPC (Conflict Prediction and Avoidance) are somewhat more stringent than those for M&S but similar enough that they could be satisfied by a single similar general surveillance system. The following will satisfy the requirements of both.

Azimuth Error	0.15 deg	1σ
Range Error	300 ft	1σ
Update Interval	4 sec	1σ

These accuracies are not much greater than accomplished presently by the ATCRBS system. Parallel approach monitoring requires similar accuracies but a data rate more than 4 times as fast.

Note that altitude reporting is essential to the operation of all these automatic control systems. Aircraft altitude is not available from any ground measurement and must be reported from the aircraft on the downlink. Altitude separation is a major element in the safe structuring of the air space for free operation of aircraft.

3. Communications

The requirements of a digital data link to serve an automated control system are intimately related to the demands of the control system. There are two aspects to the data link requirements associated with an automated ATC system - access time and capacity requirements. Access time is the time it takes to deliver a message to the ultimate user. Access time considerations were actually included in the surveillance requirements studies mentioned above. These studies indicate that the access time requirements are similar to the surveillance update intervals. Again, this is largely a consequence of the fact that aircraft maneuverability tends to dominate the prediction problem and the sampling interval represents a characteristic time for the system which must also apply to the access time. Note that this access time does not indicate the average time between data contacts - they are not related. The access time represents the delay between the time a command is formulated and its delivery to the aircraft. This delay may be a queueing delay or the delay associated the period of a rotating antenna. Here, its consistency with the updata interval implies that the surveillance system can serve as a carrier of the command data.

The second aspect of the data link requirements involve capacity, specifically, the rate of the transmission of bits from a ground station (or stations) necessary to provide communications services to all the aircraft under its control. An estimate has been made of the capacity requirements of the Los Angeles Basin of 1995 for all FAA traffic. The estimate was based upon a typical profile of communications between each aircraft and the ground and some 2700 aircraft under control in the whole basin. This profile included extended messages such as Flight Plan Clearances and Weather as well as maneuver commands for M&S and IPC. From this data, plus estimates of the number of aircraft with various data link capacities, the average data rate required to support the entire FAA aircraft load for the whole Los Angeles basin for each flight segment can be computed. The results are shown in Table A-1. Note that this average rate pertains to the peak airborne count and so represents a maximum demand. Furthermore, the estimate of peak count taken represents the highest values of estimates of the total airborne count for 1995. Fluctuations among demands of individual aircraft probably do not influence strongly the total load since so many aircraft (2700) are involved that the sample mean is always close to the average. Hence, these data rate estimates are considered to represent maximum demands. These data rates of the order of 5000 bits/sec are quite modest. A few channels of VHF would have sufficient bandwidth to handle all the FAA communications in the Los Angeles basin of 1995.

Table A-1. FAA Data Link Capacity Requirements.

Average Data Rate	Char/Sec Up	Char/Sec Down	Bits/Sec* Up	Bits/Sec* Down
Ground	31	23	460	340
Terminal	68	68	1020	1020
En route	225	294	3400	4400
Total	324	385	4880	5760

* Assumes 15 bits/char to account for overhead.

APPENDIX B

SUMMARY OF ATCRBS/ARTS III PERFORMANCE

A. Introduction

The basic element in the review of the transition role of the present semi-automatic Air Traffic Control System is, of course, the ATCRBS-based surveillance system. This system currently provides the principal surveillance information to the controller necessary for his exercising control of all aircraft under his responsibility. This system will continue in the transition period to provide the basic surveillance function. Hence, its current performance and performance in the transition period in the face of changes in the environment are vital elements of this re-examination of the transition. The current ATCRBS system operates at both en route and terminal levels. Each incorporates a degree of semi-automation represented by automatic or manual acquisition of targets, computer retention of track files on all targets of interest, computer association of these track files with identity, and computer display of data blocks associated with each of these targets indicating the aircraft altitude, velocity, and identity to the controller. The ARTS-III program in the the terminal area, is more widely deployed than the comparable program in NAS En route Stage A system. Understanding and evaluation of both these systems is necessary to proper evaluation of their role in the next transition period. To this end, review of the literature available and extensive discussions with interested and involved parties were conducted. In addition, magnetic tapes were obtained at several ARTS-III terminals of detailed data under actual operating conditions and a detailed analysis made. A comparable analysis of field data from the Stage A system was not performed because of time limitations within the program. The NAS Stage A system does not have data as readily available for determining hit-by-hit response of targets for and evaluation of the general system performance. Hence, our efforts were concentrated on the ARTS-III program in anticipation that the types of problems revealed there would be similar to those problems that were associated with the NAS Stage A system.

Our general findings were that the ATCRBS ARTS-III system in the terminal areas works quite well in the present environment. The track file establishment and continuity are quite good. The data block display is extremely useful to the controller. This convenient display of both targets and data reduces the controller's workload significantly in associating identity, altitude, and velocity with targets, freeing him to pay more attention to the detailed task of controlling the aircraft under his responsibility. There are strong indications that these displays have increased significantly the number of aircraft a controller can handle, perhaps by as much as 50%, over and above the strictly manual mode of a raw video display with "shrimp boat" identity of targets.

Since we were looking for problem areas, we found them. These problem areas appear to be sources of annoyance to a controller, but he very successfully accommodates them and mentally corrects for their failings. The problem areas reviewed include false targets, missing targets and hits, synchronous garble and fruit. These will be discussed in more detail, below.

In addition to the identification of problems, a very important result of this exercise was the recognition of the great importance of the accessibility of data that is now available through the ARTS program. This data is readily available at the ARTS III and extremely valuable in determining, under operational conditions, the performance of the ATCRBS/ARTS III system. Great insight was gained into the way the system operates by detailed examination of this data. Problems of a very specific and local nature are identified, as well as general problems. The value of continuing such procedures to the FAA cannot be overstressed. Indeed, there ought to be serious consideration given to looking into the NAS Stage A system from the point of view of developing equipment or modifications to the system which would permit a similar extraction of this type of data from the en route system. Such data analysis reveals very clearly quantitative measures of performance as well as details of the nature of problems which perhaps cannot be evaluated any other way.

B. Problem Areas Studied

At this point we would like to examine in somewhat more detail problem areas associated with the ATCRBS/ARTS III system which we have observed either in the literature or in the data we analyzed. The data included some several minutes of data recorded from the ARTS III extractor program at Andrews Air Force Base in Maryland during the busy hour of a normal operational day. Additional data was obtained at Boston's Logan Airport in operational conditions but at several different times. The analysis of this data, plus that from some other airports, showed generally similar characteristics of problems. A listing of the problem areas determined from the data tapes and rough estimates of frequency of occurrence and possible solutions are included in Table B-1. It should be reiterated at this point that these problem areas were evident in the analysis of data but they were not major problems; they were not problems which crippled the system or prevented it from operating very well. Emphasis is placed upon them because they do represent the generalized problems which ATCRBS will experience and which will, in general, get worse as the number of aircraft under surveillance increases in the future. It should be noted that the listing in this Table is roughly in order of decreasing degree of intrusion upon the system.

1. False Targets

The most obtrusive problem evidenced in the data was that of false targets. The false targets which were observed both at Andrews and Logan Airport were all attributable to reflections from well-defined obstructions. The targets were all deterministically related to some known aircraft, representing a reflection on either or both the uplink and downlink. These targets had somewhat different characteristics in Boston and at Andrews AFB. At Andrews they were generally characterized by sudden appearances of significant segments of a track and then subsequent disappearances of that track. The extent of the track was generally a number of scans. The data from Andrews was examined in detail and, by correlating false targets with their true sources, the extent, orientation, and distance of the reflecting surface could be determined. Furthermore, an obstruction chart for Andrews AFB showed that the reflecting surfaces so determined could be identified with existing buildings, generally alongside the runways. In Figure B-1 is shown the association of derived reflecting surfaces with actual structures at Andrews AFB.

At Logan Airport the false target situation was somewhat different in character from that of Andrews AFB. In addition to some false targets

Table B-1. ATCRBS/ARTS III Performance.

Problem Area	Freq. of Occur. Now	Freq. of Occur. 1980s	Possible ATCRBS Fixes
<u>False Targets</u>	High	High	Software:
Reflections from Obstructions			Geometric Correlation Discrete Code Decoding Radar Augmentation
<u>Weak/Missed Targets</u>	Moderate	Moderate	
Blockage			Resiting Decreased Target Declaration Threshold
Low Altitude and/or Marginal Targets			Decreased Target Declaration Threshold
Aircraft Attitude			Radar Augmentation
Vertical Lobing (Strong Site Dependence)			Radar Augmentation Large Vertical Aperture
<u>Missing Hits</u>	Moderate	Moderate	
(For Declared Targets, 7.3% Hits Missing)			
BDAS (3.5%)			
Missing RF (1.8%)			Radar Augmentation
<u>Synchronous Garble</u>	Low	Moderate	Software: Scan-Scan Correlation More Decoding
Angular Resolution Target Loss	Low	Moderate	More Decoding
Fruit	Negligible	Moderate	
Defruiter Decode Errors	Low	Moderate	Replace/Remove

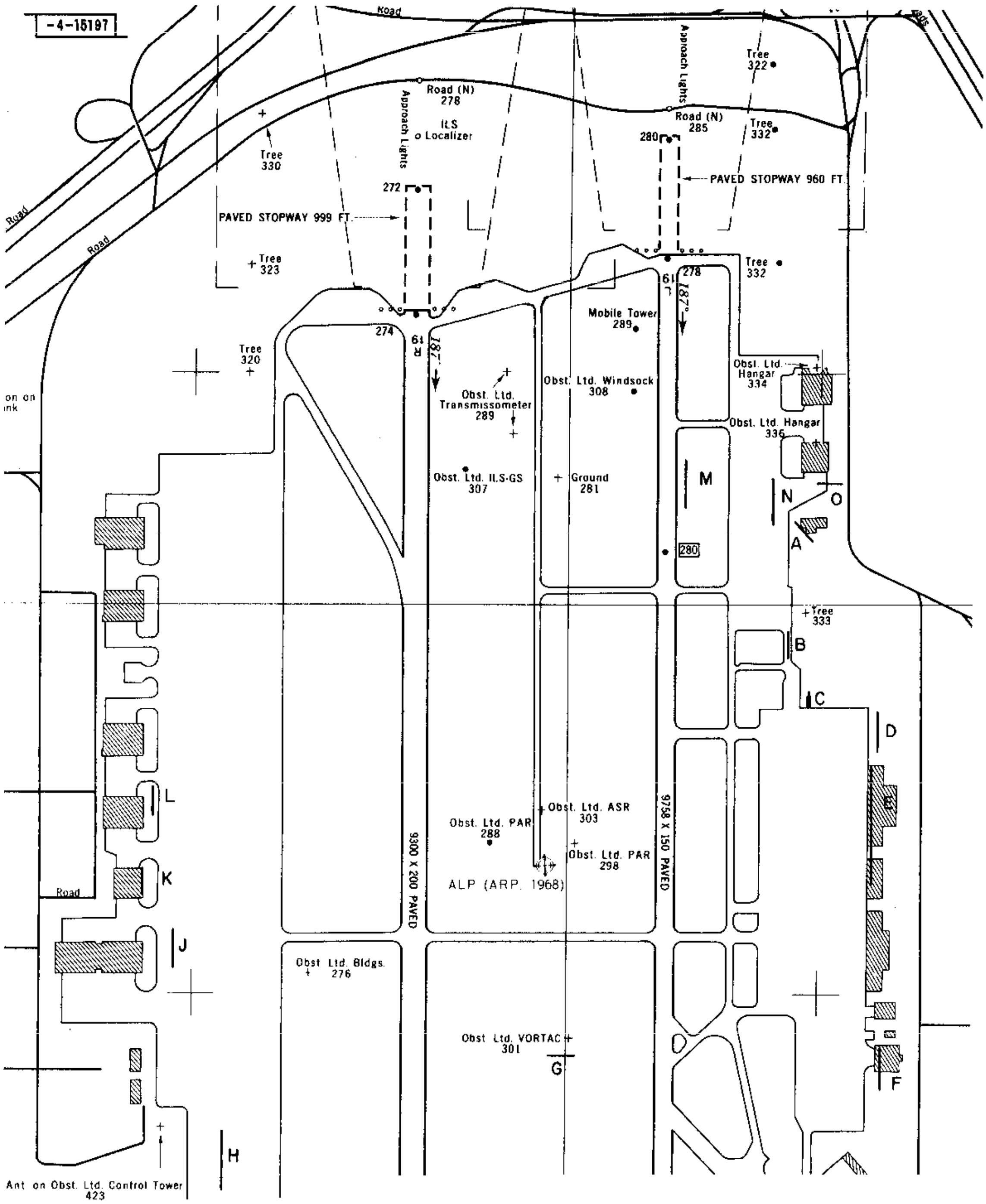


Fig. B-1. Reflecting surface Location and Orientation - Andrews AFB.

appearing as a single, well-defined track several scans long, there was at Logan a multiplicity of brief false targets appearing at many azimuths. Figure B-2 shows the sequence of false targets for one particular aircraft track. The source of this type of false target appearance is the combination of large RF margin of the Logan ASR coupled with a multiplicity of small and distant reflectors. The power budget at Logan is high (650 W transmitted, -92 dBm receiver sensitivity) to help overcome blockage by high buildings in downtown Boston which shadow an important approach route. As a consequence, small and distant reflectors can and do cause detectible reflections accounting for the multiplicity of short false targets observed as demonstrated in Figure B-2. It should be noted that these reflections are always associated with aircraft at low altitude and therefore, near the end of the runway.

As indicated in the middle column of Table B-1, the frequency of occurrence of these false reflector targets is considered to be high, i.e., they appear fairly frequently from scan-to-scan. The controllers generally have recognized the characteristics of these spurious targets and sucessfully function despite them. At least in the terminals which were examined, the false targets fell into areas where there was minimal actual traffic so that the controllers could easily ignore them. However, if reflections fell into areas where there was fairly heavy traffic it could pose a significant problem for the controllers. We understand that one site with this problem was not commissioned for several years because of it. Certainly, in any period of automatic acquisiton and tracking of all targets, the false target situation would represent at least an additional load on the tracking system. Even more serious would be the situation where these tracks appeared in regions of mod-

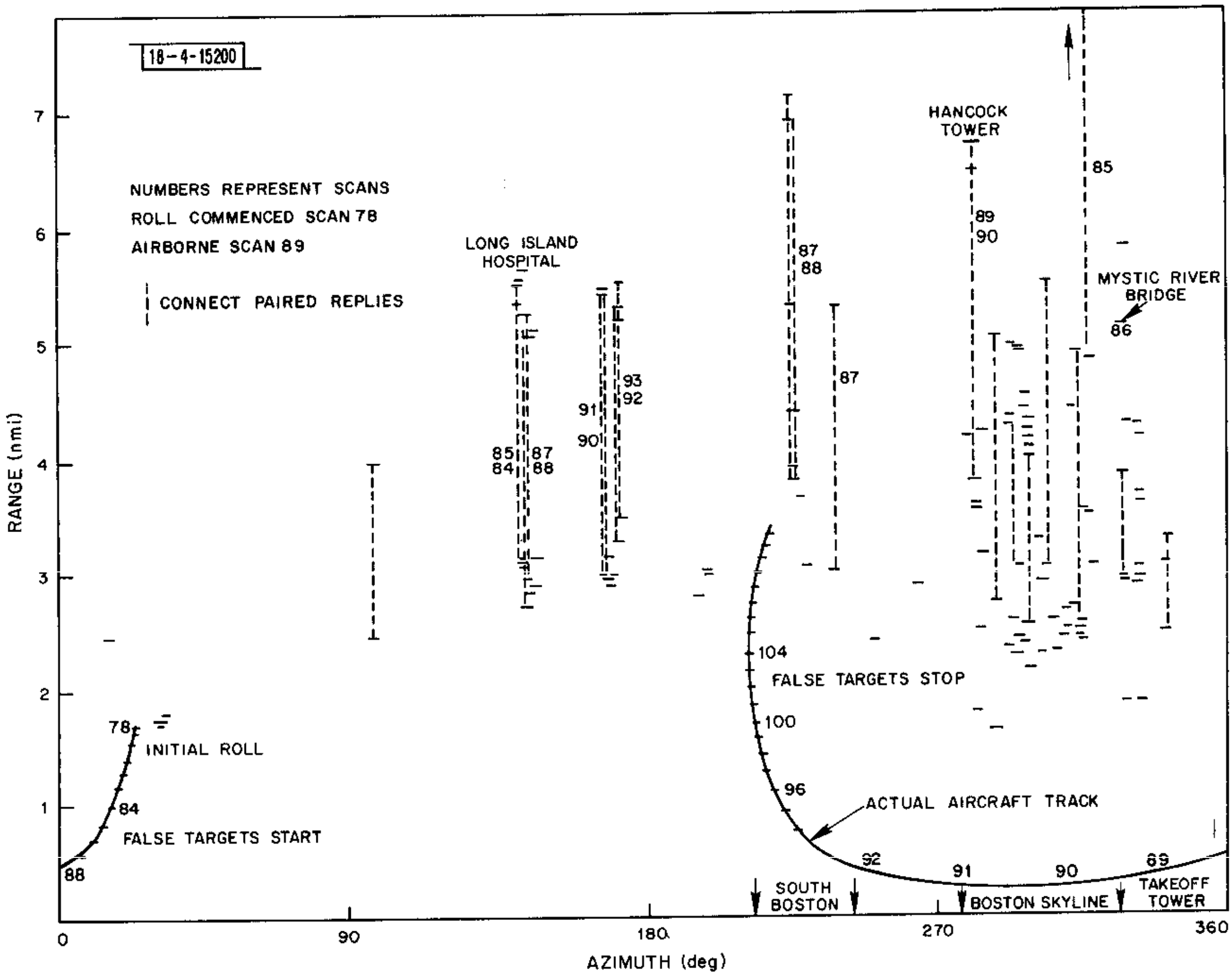


Fig. B-2. False Targets Caused by Aircraft on Takeoff - Boston.

erate track density and if an IPC or conflict resolution function were being generated automatically, then a great number of additional, unnecessary, commands would result.

There are several possible solutions to this false target problem for both the present system and the ATCRBS mode of DABS. The current approach to the false target problem as implemented in the ARTS III computer is based upon the assumtion (questionable), that their runlengths are shorter than those associated with real targets. Real targets have average runlengths in the neighborhood of 15 or 16 hits per scan, extending from 7 or 8 up to beyond 30. On the other hand, reflected targets often have runlengths below 7 or 8 hits per scan. As a consequence, the current mechanism for reducing the target declarations on these false targets is to establish a threshold at 8 or more hits before a target is declared, thus successfully discriminating against many of the false targets. In addition, the controller can correlate the radar return from the questioned area with the beacon return. The R^4 mechanism associated with primary radar and the additional reflection attenuation seem to prevent targets being seen through reflection. Hence, a target with no radar confirmation, particularly in certain areas, is probably false. This evaluation is currently made by controllers. Automatic correlation inside the computer would relieve him of performing this task and eliminate such false targets from the display altogether.

It would appear that a software fix of this problem is possible. The reflection areas, especially at a place like Andrews AFB, are very well defined and very limited in azimuth extent. Each reflecting surface which is a source of false targets defines an azimuth sector where false targets can originate and a corresponding region where the source of the reflection must be. Figure B-3 illustrates the geometry of the reflector, false target and real target. For a pop-up target at a measured range, the location of the potential real target can be calculated explicitly if the location and angle of the reflecting structure are known. Hence, it should be quite straightforward to provide a subroutine for pop-up targets in specified sectors which calculates the position of a potential real target causing a reflection and checks whether or not a real target exists there. If it does, then the pop-up target can be considered false and not processed further. Each reflecting surface would have to be defined in terms of its azimuth extent, distance, and orientation. These can be included in the computer in a sort of reflection map sequence and, whenever a target appears suddenly within a suspect azimuth area, a correlation would be made for targets in the associated real source area. Increased use of discrete codes would facilitate the checking since, if all aircraft in the area were known to have a discrete code, then simple code correlation would reveal that a pop-up target had the same discrete code as an existing target and the geometrical relationships were right for one to be the reflection of the other.

2. Weak and Missed Targets

The next area of problems associated with the ATCRBS surveillance system concerned weak and missed targets. In the category of missed targets, a number of tracks observed in the Andrews AFB data terminated suddenly and then reappeared after a number of scans. These tracks were charaterized by long run lengths indicating good, solid targets until they disappeared suddenly. Radial lines from the interrogator location to

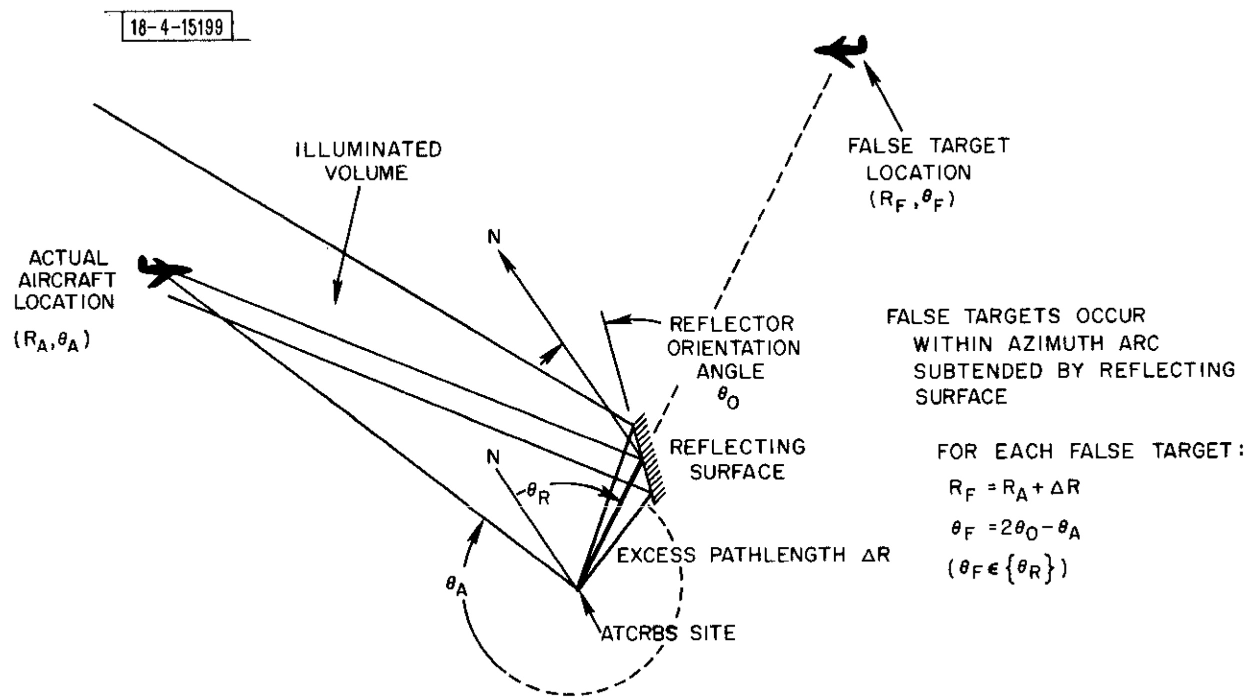


Fig. B-3. Reflected Target Geometry.

the edges of these missing segments defined azimuth sectors where several tracks dropped out. These azimuth sectors in general can be associated with buildings on the horizon blocking the line of sight. For one particular such sector, there were three tracks which traversed it at different times. Two of them showed breaks in the track with identical boundaries; the third showed no break at all. The coincidence of the loss in track segment for the two tracks confirms an RF link problem such as blockage. The continuous track was probably that aircraft flying high enough to be above the building blockage. Unfortunately, none of these targets were mode C equipped so their altitudes were unknown. This prevented computing target elevation angle which would have been useful in correlating with building blockage.

If a fix of this problem is called for (if coverage within these sectors is required) then a resiting of the antenna is the only good way of eliminating such blockage. This resiting may take the form of a different position at the same height above ground or at a high point so that there was no significant blockage by other structures.

The ARTS III data permits examining hit by hit results to determine the nature of targets (runlength) and declarations. An examination of the data showed that there were a number of targets not declared whose runlengths were moderately short but reliably present: targets with runlengths in the 2, 3, 4, and 5 range. These targets, again, were not mode C equipped, so their altitude was not known. However, we do have some indication that they are flying at low altitudes. At least one aircraft exhibited a type of behavior that would seem to be associated with touch-and-go at a nearby airport. The short runs indicate weak targets which could well be caused by their being below the minimum coverage angle of the interrogator. We have no indication that any of these weak, undeclared targets were in a region where they should be covered by the interrogator (high elevation angles). Hence, it is not clear that these weak targets are of immediate concern.

If it is desired to introduce these short run-length targets into the system, then the target declaration threshold could be reduced, these targets declared, and track files established for them. As indicated above, the selection of a threshold of more than 8 hits per scan for target declaration was predicated largely upon a minimization of the false targets that appeared. If a software or radar fix to the false target problem occurs then the threshold could be reduced without swamping the system with false targets.

Another source of weak or missing targets that has been discussed a great deal is associated with blockage of the airborne antenna by the aircraft, or parts thereof, when the aircraft is in a turn. In our data, a number of tracks were observed in turns and were examined carefully for evidence of dropouts associated with the turn. There was evidence that, in certain cases, there would be a loss of data on one or two scans during the period in which the target was turning away from the interrogator. Not all targets did this and of those targets that did, the degree of loss was significantly smaller than that which would have been anticipated from general considerations of antenna blockage. In this situation, of course, the target aircraft were completely unknown; nothing was available as to the type, nature, and location of either the aircraft or the beacon antenna. On the other hand, reports that we have from Atlanta operations seem to indicate that some 20% of the track files are dropped and this dropping is associated with aircraft being in turns, or the antenna blocked for some other reason. The basis for this association is that it is found that radar observation of the same target does not show a drop at at the same time and indeed when radar targets are correlated with beacon targets, the combined loss of targets drops from the aforementioned 20% to something of the order of 3-4%. As a result, the combination of radar data with the beacon interrogator data does result in a significant improvement in track reliability under certain circumstances. In addition, results of our study (Task C) of the effects of switched antennas on tracking are applicable to this question. In tese tests, with military aircraft on bottom antenna only, the number of scans lost while in turns was determined for several aircraft. While the average was 1-2 lost scans per complete turn, some aircraft consistently lost 6-10 scans in turns. Some consistently lost none.

The principal conclusion is that antenna blockage can cause scan loss in turns. The loss can range from 0 to 10 scans and appears strongly dependent upon the particular aircraft/antenna configuration. Loss of one or two scans in a turn probably should not be critical. Loss of 5-10 scans could cause a track drop as well as inject a large uncertainty in the position and heading of the aircraft. More detailed measurements of antenna patterns of representative aircraft-antenna configurations are needed to provide the missing data necessary to calculating scan loss characteristics.

The occurrence of replies missing among otherwise solid runs was also noted and a study of the data for their characteristics made. Eight targets were examined for approximately 50 scans for missing replies. These targets were all strong and all declared for every scan having runlengths on the average of 20 replies per scan. Hence, the number of replies in toto, associated with this group of targets is about 8,000. Of these some 7.3%

were missing. This number does not include those initial replies that are stripped off of the mode A and C reply sequences by the defruiter. Since these were considered to be normal operation of the defruiter, they were not included in the "lost" count. Of this 7,3%, some 3.5% of them were single misses; that is, misses occurring one at a time. This imples that RF pulses were received by the defruiter for these particular replies, but some additional process after the defruiter prevented them from being declared valid. This is evident from the fact that, had the reply not been received at the input to the defruiter, the defruiter action would have resulted in eliminating the following hit as well from the reported sequence. The explanation for the single missing hits is not clear. One reasonable explanation is associated with the Beacon. Data Acquisition System (BDAS) of the ARTS III system. After the defruiter passes a train of reply pulses to the BDAS, the BDAS tests the framing pulses for proper separation. The tolerance of acceptability about the 20.3 microsecond nominal value is quite small; hence, it is postulated that certain pulse trains were passed by the defruiter as being associated with a previous sweep pulse train and, therefore, not fruit, but were, however, outside tolerance in the framing pulse separation and thereby rejected by the BDAS.

Of the balance of the replies missing in this sequence, 3.6% were all double misses and therefore associated with replies missed at the input to the defruiter. These misses, then, are associated with the RF link and, generally, are the basis of system reply probability. The 3.6% of the missing double replies represent 1.8% actual losses giving a reply probability of 98.2% for this ground. These losses are commonly attributed to the aircraft transponder's being in suppression this fraction of the time by other interrogators in the area. This level of reply probability is certainly commensurate with that expected in the general environment.

3. Vertical Lobing

Another much-discussed phenomenon associated with missing targets is vertical lobing caused by multipath reflections from the ground. Spingler [12] has made RF measurements in aircraft at NAFEC and found a definite existence of severe lobing under certain circumstances. However, the circumstances were strongly dependent upon the nature of the terrain over which the reflections took place. In one case, nulls of the order 20 dB or more below the peak were observed in the area of $1/2^{\circ}$ or 1.0° elevation angles. On the other hand, another terrain revealed essentially no lobing effects; no variation of the RF power received at the aircraft over the same regime of elevation angles. Since this has been a much-discussed topic, our data was examined carefully in search of evidence of such lobing at Logan and at Andrews AFB. Targets were examined which were flying at constant altitudes and along radial paths, providing a variation of elevation angle as a function of time along the path. The targets were all fairly strong. Their runlengths were plotted as a function of time to determine if there was a periodicity in them. Even for strong targets, a variation of about 10 dB in the signal strength at the target due to multipath cancellation should result in a fluctuation in runlength. However, no such variation in the runlength in the several targets of opportunity that were suitable for this type of test were observed. It must be noted at this point that, because these were targets of opportunity, no control was available over the elevation angles over which they passing. Indeed, the elevation angles associated with the targets tended to be in the several-degree area. For elevation angles of this order, the lobing depth is not pronounced -- perhaps of the order of 10 dB for a stongly lobed situation. In addition, interrogators are operated at a relatively high power level. The level of power normally used is sufficient that even with fairly severe lobing the minimum detectible signal level is many dB below the antenna peak gain. As a result the runlength is determined along a steep slope of the antenna (azimuth) gain pattern lowering the sensitivity of runlength to gain variations. With these considerations it is estimated that for a deeply lobed situation the runlength might vary by from 4-8 hits due to 10 dB lobing. Since the generally observed runlength variation due to other phenomena was about this magnitude, it is not clear that the lobing would have been observed.

To illustrate this lobing structure, a rough computation has been made of the coverage limit associated with vertical lobing for a typically bad reflection aperture of about one wavelength and situated 30 ft above the ground. The ground was taken to be dry, sandy loam as representing the reflectivity situation. The uplink is the limiting element since the gound receiver has typically 15 dB more sensitivity than the transponder and transmitted powers are not very different between uplink and downlink. Transmitter power was taken to be 500 W with an antenna gain of 22.5 dB. The airborne transponder has an antenna gain of 0 dB and a receiver sensitivity of -73 dBm. With these parameters, and no ground reflectivity problem, the maximum range at which the transponder will respond is 550 nmi. With the dry, sandy loam ground as a reflector, the lobing becomes pronounced. The antenna gain shows a null of about 20 dB below that of free space at about 1° with successive, less-deep nulls every degree. The resultant coverage limits are shown in Figure B-4. Note that a 60 mile radar would have no significant reduction in coverage. Changes in height of the interrogator antenna would change the angular location

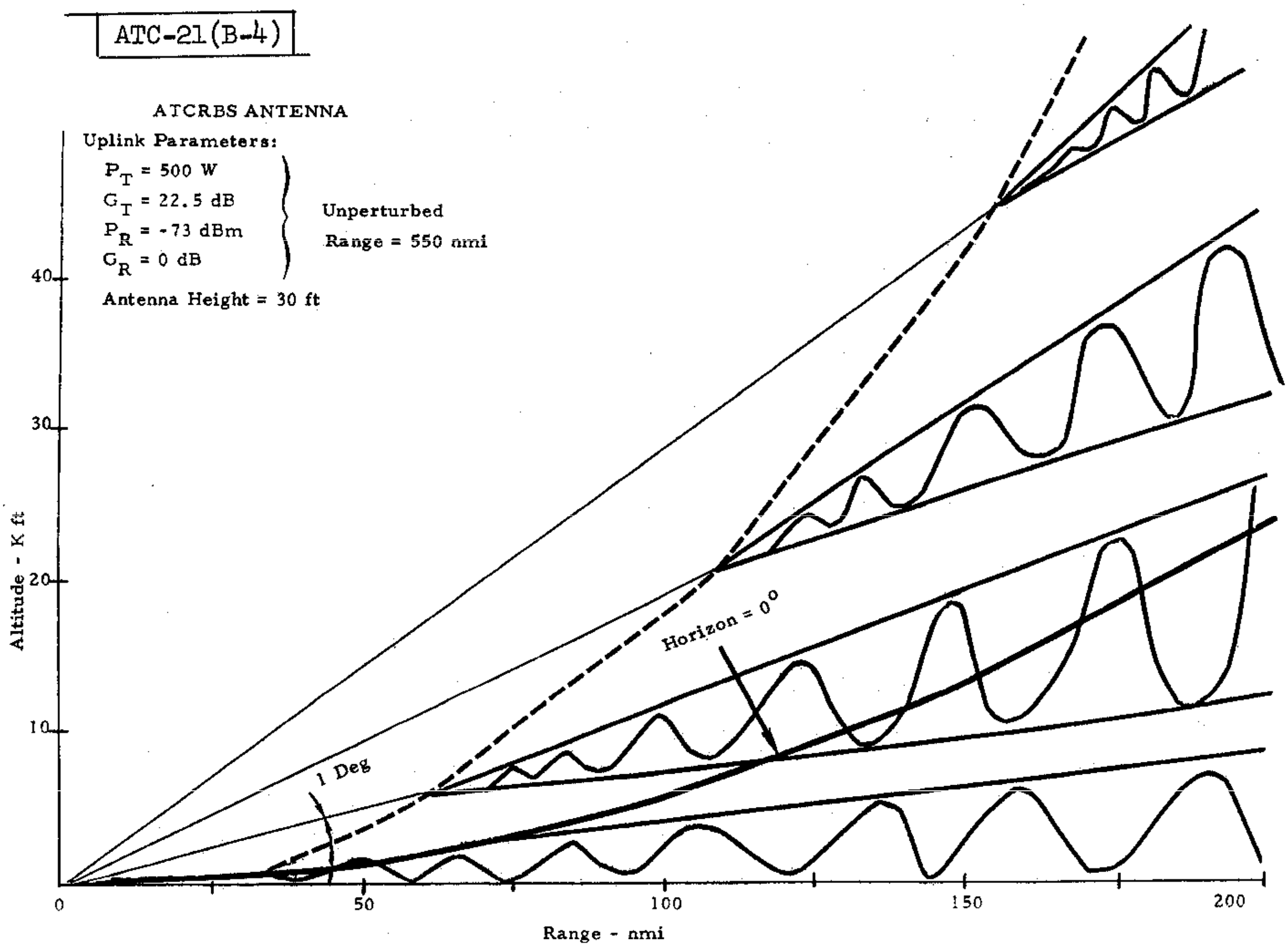


Fig. B-4. Vertical Lobing Limits on Coverage.
Airborne Antenna - Nominal Omni.

of the lobes - increased height, lower angle lobes. The bottoms of the nulls, however, would fall on the locus roughly defined by the indicated bottoms as shown. If the airborne antenna exhibited a null of 10 dB, each of the wedge-shaped boundaries would move in a factor of 3 in range along the constant elevation line. This has a significant affect on coverage as indicated in Figure B-5.

For those sites where severe lobing is determined to cause loss of important coverage, there are several possible fixes. One is through the use of radar augmentation. The radar, operating at a different frequency, will have a lobing structure that differs from that of the interrogator. Hence, the combined effect would be to provide coverage by the radar where beacon-interrogator coverage was lacking, and vice versa. A second approach is to increase the vertical aperture of the beacon interrogator. This would permit a sharper cutoff of RF energy radiated in the direction of the ground, reducing the reflected power along the multipath and resulting in a much less severe lobing of the antenna gain pattern. Another possibility is a clutter fence which prevents the ground rays from the antenna from reflecting off the ground and interfering with the direct ray. Such a fence located at about 1/3 mi from the interrogator and some 20 ft high could reduce significantly the vertical lobing. This might be a useful solution especially if the lobing were a problem only over certain azimuth sectors. Finally, resiting of the interrogator antenna may help. Implied just above is the fact that the reflection of the interfering ground rays occurs fairly close to the antenna -- about 1/3 mi. Hence, a shift in antenna location by such distances may result in sufficient change in the close-by terrain to modify considerably the lobing pattern.

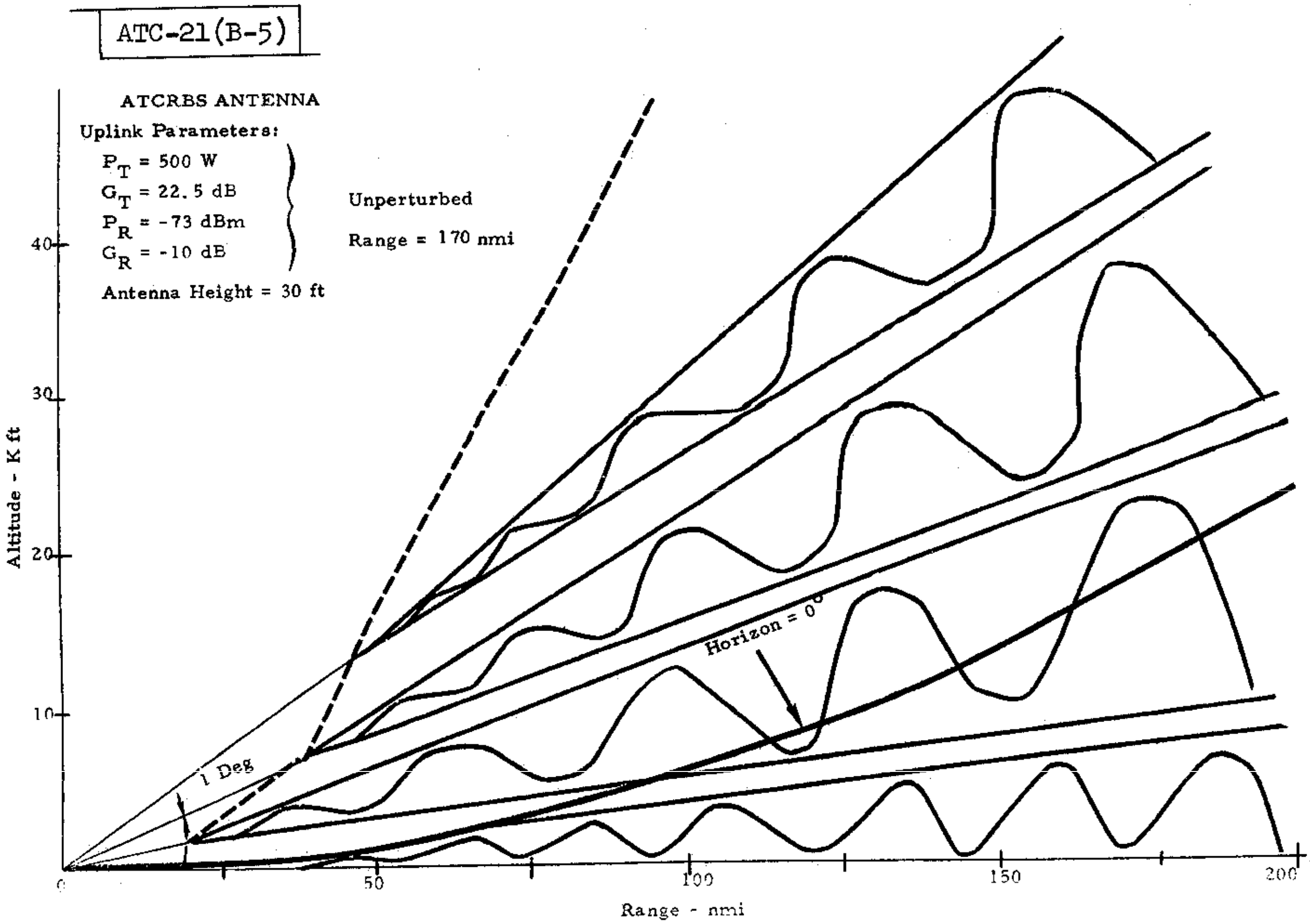


Fig. B-5. Vertical Lobing Limits on Coverage. Airborne Antenna - 10dB Loss.

Our conclusions concerning vertical lobing are diffuse. Vertical lobing is real but very site dependent. Its effect in severe multipath situations may become important only for conditions where the RF uplink suffers losses of the order of 10 dB or more beyond nominal values. Gross vertical lobing caused by widespread ground reflections should be determined by direct RF measurements. More localized phenomena probably must depend upon careful analysis of operational data. Selection of options to correct the problems must be based upon their detailed measurements.

4. Synchronous Garble

The response of the system to synchronous garble situtations was also investigated. In the data collected, some 88 instances of synchronous garble were noted. The ARTS III program labels as "garbled" two replies when the individual pulses from replies overlap one another. Pulses from two replies which interleave with one another are properly decoded by the system and are not so labelled.

First, in none of the cases of garbling was there a lack of a declaration of a target. All hit sequences were declared. The only potential problem was improper decoding of the reply, or improper association of a code with the target. Such coding errors occurred only in a very few, roughly 10%, of the garbling situations.

The ARTS III system operates such that, when two code replies in sequence from an aircraft agree, that code is associated with the target from then on, with further association being done through range correlation.

Hence, two targets which overlap, but which exhibit at least two hits either at the beginning of the run or the end of the run which do not overlap, are properly decoded. Figure B-6 shows the regions of space around a "victim" aircraft where the presence of one other replying aircraft will cause a garble. The garbling mechanism is also shown. One error was associated with a target which had two replies the in the clear; however, examination showed that the codes in the first two replies did not agree apparently because the first reply had a missing pulse presumably due to marginal signal level. Since the first two codes did not agree, the ARTS computer then chose to declare the garbled but consistent code.

In most cases of garbling, the garbled codes could be recognized as a subset of the true code as interfered with by the garbler. In other words, by recognizing the presence of a "one" from the garbling code, the victim code could be properly associated with its true value. Furthermore, in no case was there a situation where the garbling existed for more than one scan. If two aircraft garbled for one scan, the preceding and following scans were in the clear. As a general conclusion, the garbling turned out not be a severe problem as far as frequency of occurrence and the ability of the system to handle it. The ARTS III system is very successful in degarbling the interleaved pulse situation. It is very tolerant of garbling situations requiring only that two codes (either at the beginning or at the end of the run) be in the clear. Thus, the region of overlap within which garbling can occur seriously enough to cause a decoding error is very small. The addition to the software of decoding based upon the codes declared in the previous scan would alleviate most, if not all, of the decoding errors.

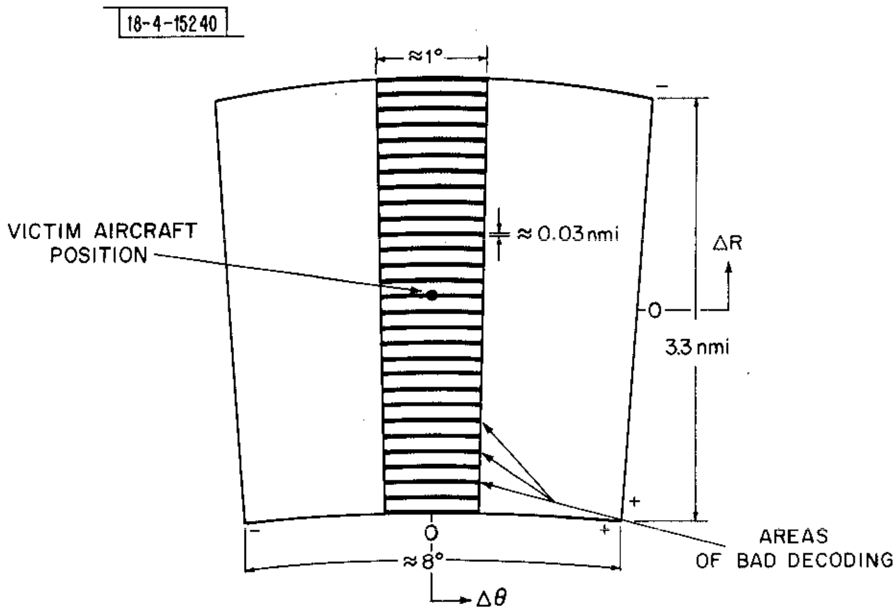


Fig. B-6(a). Garble Cell Geometry.

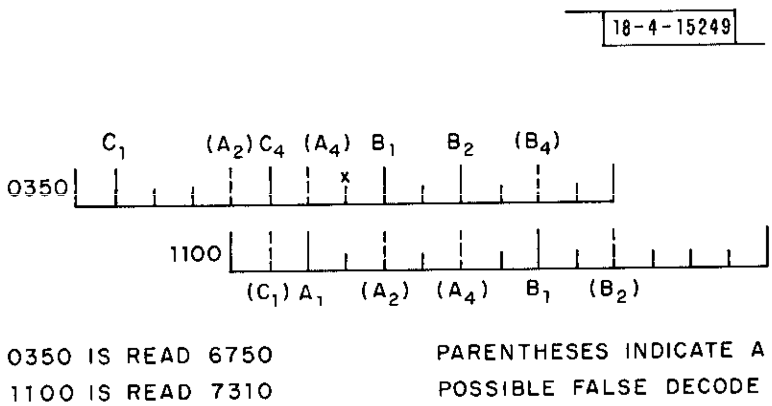


Fig. B-6(b). Typical Garble Pattern.

Estimates of synchronous garble due to overlapping pulses from the replies of two or more aircraft have been made. In order to do this, models of the garbling processes were formulated and the performance determined by both analysis and simulation. There are a number of simplifying assumptions in the model, such as: equal run length for all aircraft, uniform pulse widths, shapes, and spacing, etc. Because of these assumptions, the results of the analysis and simulation show qualititive trends and indicate only approximately the quantitative behaviour of the system for the synchronous garble problem.

In order to verify the model, where possible, an examination was made of the data from ARTS extractor tapes [4] mentioned above which contained a number of cases of one aircraft garbling another. The percentage of garble deduced from this data is consistent with the model. We also looked for two or more aircraft garbling another, and found only one case. Thus for the multiple aircraft garble situations, there is as yet not sufficient data to verify the model.

The problem can be formulated on several levels.

a. If only one aircraft is within $\pm 4^{\circ}$ and $\pm$ 1.65 nmi of the victim aircraft what is the probability of garble? The model and the test data agree that 5% or less is correct.

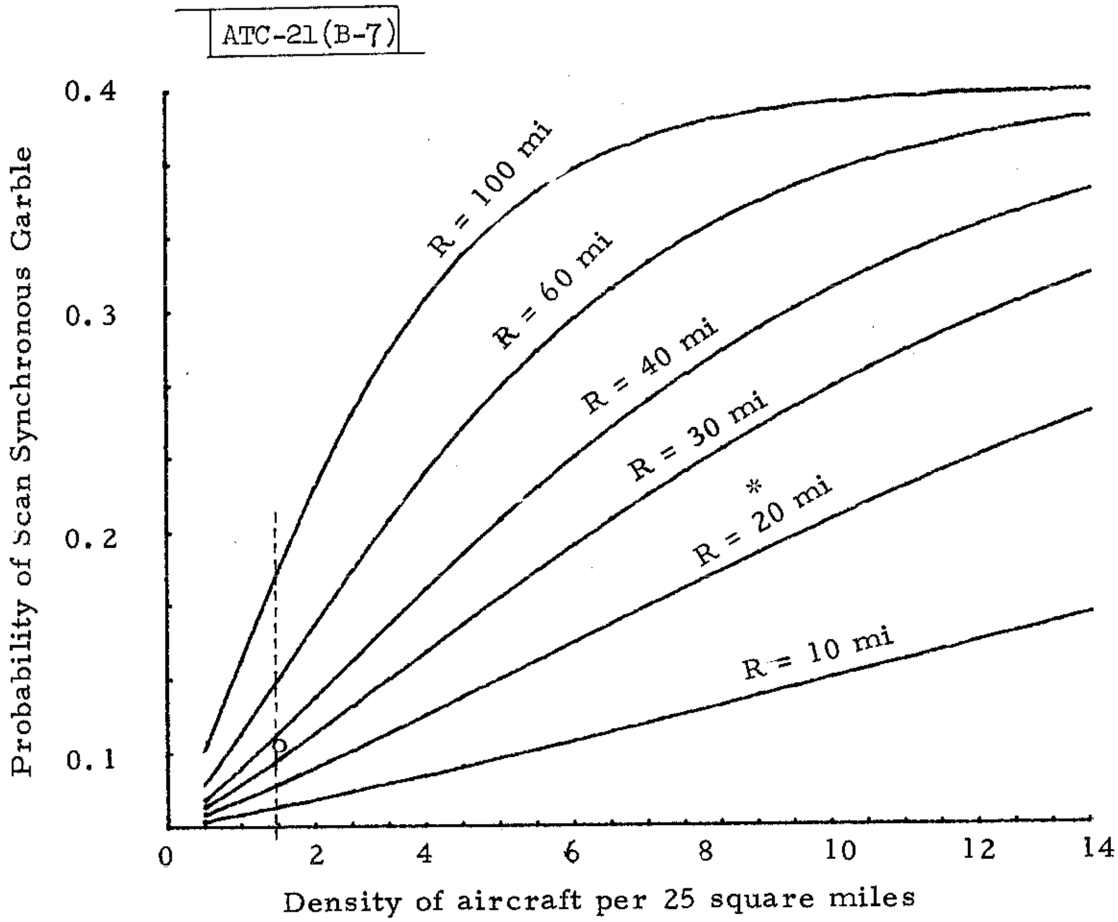
b. If several aircraft are within $\pm 4^{\circ}$ and $\pm$ 1.65 nmi of the victim, what is the probability of garble by one or more o of the aircraft individually? That is, at least one of the aircraft would have produced the garble by itself. The problem is relatively straightforward to analyze and can be related quite closely to the model for (a) above.

c. If several aircraft are within $\pm 4^{o}$ and $\pm$ 1.65 nmi of the victim, what is the probability of a garble caused by the combination of replies from two or more aircraft, but not from any one aircraft alone? This problem is considerably more complex than either a or b above so that confirmation of the model (assumption and simplifications) would be highly desireable.

Combining these cases one can plot the results as in Figure B-7. The probability of scan synchronous garble is the probability of a datum loss due to code garble for a scan. The aircraft density is shown referenced to 25 mi^2 areas. This is because many models for predicted traffic densities show the number of aircraft in each square of a five by five mile grid. For areas like Los Angeles in 1980-1990 the number of aircraft in these cells range from 0 to 20 or more in certain localities.

The seriousnesss of synchronous garble has sometimes been referenced to the amount of garble averaged over a large region. For instance, if one assumes a Poisson distribution of 500 aircraft within 50 miles of a sensor, then the average probability of garble is shown in Figure B-7 as about 8%. A more meaningful measure of the phenomenon is based on the observation that even though the average aircraft density is 1.6 a/c per 25 mi^2 there are local regions where 10 to 15 aircraft are in a 25 mi^2 area. In this case, if the area is some 25 mi from the radar each aircraft in that area will experience 30% garble.

There are two points to be made. First, the critical problem pertains to those local regions very high densities and its seriousness should not be diluted by averaging over large areas where garble is not a problem.



¦ Average density of 500 a/c within 50 mi of sensor

o Probability of synch garble for above case

* Probability of synch garble for dense sub region

Fig. B-7. Probability of Synchronous Garble.

Second, even these higher levels of garble, in isolated areas, are not necessarily a serious problem to the human controller managing IFR traffic. Chances are that he would have put those aircraft there, and would know generally what they were doing so the garble and loss of track would be an annoyance, but not a catastrophe. In an automated system containing mixed IFR and VFR aircraft, with IPC or other automatic control in effect, high levels of garble and resultant track loss, even in isolated areas may very well be quite serious.

Figure B-7 is representative of the synchronous garble as we would expect ARTS III to perform providing that additional registers are added to the BDAS so that 3 or more declarations can be accumulated simultaneously. There are modifications [4] that can be made to improve this performance somewhat, but it is not yet known quantitatively how much improvement should be expected.

Another situation which occurred in recorded data (very similar to synchronous garbling) relates to the presence of two targets separated by about a beamwidth at the same range. Under these circumstances, the ARTS sees a continuous, long string of hits with a break too small to indicate the trailing edge of one target and the leading edge of the other. By virtue of its only checking the code at the beginning for two identically coded replies, the ARTS system does not see the change in code in the middle and declares a single target of long runlength with an azimuth position somewhere in the middle of the two interfereing targets. A simple checking of code more frequently than just at the beginning could have, in every case, revealed the presence of a change in code and the indication that there were, indeed, two targets which could be separately declared and separately identified.

5. Fruit

Another problem area often discussed with respect to ATCRBS is fruit. There have been many studies and measurement of fruit resulting in a wide range of estimates of fruit levels. Over the past several years the level of fruit observed has been significantly reduced especially in the denser areas. This reduction has been largely accomplished by the successful efforts of the Beacon Management Team to educate the users of interrogators, to localize extraneous interrogators and to establish operating controls. As a result of these activities it would appear that fruit will not become a significant problem for many years.

Estimates have been made by Mitre [14], as well as by Lincoln Laboratory [14], on the impact of fruit on the performance of the ATCRBS surveillance system. It is generally agreed that until fruit levels exceed about 30,000 fruit replies per second the effect is not important. The specific effect of fruit investigated was the probability of receiving at least k replies in the clear for code declaration by the processor. As fruit rates increase above this level the impact grows resulting in a significant decrease in this probability of receiving k replies in the clear. At levels of 100,000 fruit per second, the effect is crippling.

As indicated above, current levels of fruit rate have been significantly reduced from that of a few years ago by activities of the Beacon Management Team regulating the general use of interrogators. Recent measurements have been made by the Mitre Corporation for Lincoln Laboratory of the fruit levels in the New York City area [15]. Fruit rates measured in this program averaged over 5 minute intervals ranged from 1000 to 2000 fruit per second near air traffic busy hours. Peak rates averaged over 7 seconds were about 50% higher. Some estimates of fruit levels have been made based on our collections of ARTS III data from several terminals. Indirect estimates based on defruited tapes indicate fruit levels in the neighborhood of 1000 fruit returns/sec. At these rates fruit would not impose any problems on operation of the system. Some undefruited tapes have also been obtained at Boston. These indicate that only about 15% of the fruit comes from the main beam; the balance from the sidelobes. Furthermore, the sidelobe fruit comes from aircraft within 8 nmi of the airport.

Estimates were made of the fruit level in the 1982 period in both New York and Los Angeles vicinities. These estimates were based upon the New York City fruit measurements mentioned above, estimates of PIAC, and extrapolations of traffic densities to this period. An implict assumption was made that there would be no significant increase in interrogator population. On this basis, the estimated fruit environment for these areas is

	Fruit Rate - 1982	
	5 Min Average	7 Sec Average
New York City	11,500 fruit/sec	18,700
Los Angeles	21,600	33,600

It should be noted that these estimates postulate not only a general increase in aircraft population but a stronger increase in the fraction of the GA population having transponders. At these levels, there would begin to be a significant impact on the performance of ATCRBS surveillance capabilities principally through reduced decoding capabilities and reduced round reliability. Hence, until the 1980's in the densest air traffic areas of CONUS, fruit should not materially reduce ATCRBS capabilities. Beginning in this period, fruit levels could increase in certain areas to the point where the ATCRBS ability to get a reply and to decode it would be significantly reduced.

There is one final area where problems were observed in the data: erroneous decoding of the transponder code. In all cases, this was attributable to a defruiter. The defruiter being used was a storage tube defruiter, and apparently there were spots on the tube face such that pulses from a reply occurring at specific ranges would be improperly recorded and read. Spots on the defruiter tube are known to occur. The obvious fix here is to use a different kind of defruiter such as the digital defruiter now under deployment. Consideration might also be given to the removal of a hardware defruiter and use of software to perform this function. Such an approach depends upon fruit levels encountered at the particular location. For fruit less than, say 1000 returns per second, software processing should not present a significant added load.

APPENDIX C

THE ROLE OF RADAR[1]

A. Introduction

The role of radar in ATC is in a state of change. In its initial introduction into the air traffic control system, radar provided the only independent source of data for presentation to the controllers. At that time, it represented a major improvement over the existent system. In the early 60's the beacon surveillance system (ATCRBS) was introduced as a secondary system to augment radar surveillance. In the ensuing decade, the ATCRBS system has become the primary source of surveillance for three principle reasons: First, active participation by the aircraft in the surveillance process provided an important increase in the reliability of detection of the target. Second, the beacon system introduced downlink digital data containing two vital pieces of information: altitude and identity. Thirdly, with the introduction of digital computation into the system in the ARTS III and En route Stage A programs, the data available to the system is displayed much more conveniently for the controller. As a result of these features, the ATCRBS system has gradually taken over the primary role of surveillance and the radar now is used to augment the beacon system. This augmentation is currently

[1]This Appendix summarizes work done not only under Task A but also under Task B of the Basic Interagency Agreement. References to Task B work are as follows: QTS's and ATC-14 Concepts for Improvement of Airport Surveil-Radar, E. Muehe, February 1973.

performed visually by the controller and will be done automatically in the Enhanced ARTS system.

Within this context therefore, it is appropriate to examine the roles of radar in this transition period and into the period when DABS becomes widely deployed. The roles of radar are changing; the real question is to what and how quickly. Furthermore, do these new roles impose new or added requirements upon the current system which must be met?

B. Roles

There are several areas where radar has a potential role in the transition period as well as into the DABS era. These areas are ATCRBS augmentation, service to unequipped aircraft, intrusion detection, and weather information.

1. ATCRBS Augmentation

As the ATCRBS system has progressed into the role of primary surveillance, there continues to be situations where radar data is needed to augment the beacon data for aircraft equipped with transponders. These generally have been discussed above in the section on ATCRBS. Specifically, radar has been useful to the controller/computer in eliminating false (reflected) targets and in providing data on aircraft when the transponder does not reply. This use of radar has been of significant benefit to controllers. The goal of the ARTS enhancement program is to bring this radar data into the computer and perform the correlation of the radar data with that of the beacon automatically presenting a correlated view of all targets to the controller.

Certainly, this role for radar will continue as long as there remain ATCRBS interrogators providing surveillance data for the system. This extends through the 1980's into the 90's and ultimately depends upon the philosophy of DABS deployment.

It should be noted that the DABS design has recognized these problems and will incorporate in its design those features necessary to increase the reliability of DABS target coverage to the point where such augmentation is not needed.

2. Unequipped Aircraft

In addition to performing an augmentation role for aircraft equipped with transponders, radar has a primary role for aircraft not so equipped. In the present air traffic environment, some 60% or 70% of the aircraft are not beacon equipped. For these aircraft, radar provides the only means of surveillance for the controllers. Controllers are interested in these aircraft for two general reasons. First, FAA regulations do not require that aircraft be transponder equipped in order to file IFR flight plans. Hence, the radar provides a vital surveillance function for these aircraft on IFR flight plans. Secondly, the FAA will provide to the IFR traffic under its control, advisories concerning the proximity of VFR aircraft. Such services are generally provided only as the controller has time, but it certainly depends directly upon radar data on the unequipped aircraft. Here again, radar is providing a valuable function for the air traffic control system environment of today. The number of transponder equipped aircraft is, of course, growing with time. More importantly, the fraction of the total fleet that is transponder equipped is increasing and is anticipated will be accelerated with the introduction of DABS. Hence, it is felt that the role of radar in providing service to unequipped aircraft while remaining significant for the next few years will diminish as the DABS implementation grows. However, it is not possible at this time to predict with a certainty that within the next 20 years there will cease to be a requirement for service to unequipped aircraft either broadly or in in a large fraction of the airspace.

In fact, an opposite argument can be made. As DABS is implemented and as the density of traffic increases around certain densely populated airports, there will be an increasing tendency to reserve airspace in these areas for beacon equipped aircraft. Rather than encouraging the installation of DABS transponders on the local general aviation aircraft, this may result in a movement to unrestricted areas, significantly increasing the traffic density at such airports. There are 350 airports in the country which have sufficient activity to qualify them for an FAA Tower. Of these approximately 125 have associated with them an ASR providing electronic surveillance to augment the local controller in his operations. Sixty-one of these are terminal areas with ARTS III installations. All of these ASR installations are at terminals with heavy carrier operations. The balance of the airports with towers serve, largely, general aviation and rely solely upon visual contact by the tower for local control of aircraft. Among these airports without the benefit of radar (or beacon) surveillance are a number with very high levels of general aviation activity. Current ASR's are simply too expensive to install at these airports; the general aviation activity, even though very dense, may not support the cost of such installation. At the same time, a very significant fraction of accidents involving near misses and mid-air collisions between general aviation aircraft occur very close to the airport where one or the other is in a transition region approaching the landing.

The conclusion of this argument is that radar coverage will not only continue to be essential but coverage should be expanded to GA airports. The lifetime of these needs will probably extend well into the DABS era. As a result, improvements in the radar system which will facilitate these services should be undertaken.

3. Intrusion Detection

As the deployment of DABS increases and as the fraction of general aviation aircraft equipped with transponders increases there is anticipated to be an additional role for radar in detecting the intrusion of unequipped aircraft into restricted areas or locating aircraft whose transponder has failed to operate. As the air traffic population increases it will be natural to find that there will be an ever increasing number and size of volumes of airspace restricted to aircraft which are transponder equipped. In these areas, general surveillance will be provided only to those aircraft so equipped. These restricted areas will tend to be some combination of high speed areas, of high density areas, of areas of transition - those areas where air traffic control problems proliferate. Continuous positive control will be exercised for all aircraft in the area. Because of the nature of the traffic situation within these areas, the intrusion of an aircraft with no transponder will impose a very serious problem. Such a problem may be serious enough to warrant continued support of a specialized radar for the purpose of detecting and locating such aircraft so that the air traffic control system can successfully prevent any serious mishap resulting from the intrusion. Such a function is, to some degree, currently being performed by ASR's and as anticipated will be equally necessary when DABS is fully deployed.

4 Weather

For all air operations, the question of weather is an important one. Weather advisories are provided by the controllers to aircraft under his control.

At present, the principal source of this weather information is obtained from his radar display. Current radars can show the controller the outlines of significant storm activity within his control zone. This information is used to alert the pilot of potentially hazardous weather ahead with recommendations for re-routing to avoid it. Presently, this function is most important to the general aviation pilot because of his limited ability to fly over heavy weather and to air carriers in terminal areas. Such specific and detailed information service will continue to be required into the DABS era.

Improvements to the surveillance radars can yield better sub-clutter visibility with respect to ground and rain clutter. This very process that pulls aircraft targets up out of the clutter, can also distinguish between ground and rain clutter. Thus, it is anticipated that the radar can provide two distinct outputs. One is the desired aircraft targets and the other is the rain return, largely separate from ground clutter. Provision to collect the rain return and from it form suitable displays, can give a higher quality weather map than is currently available.

C. Conclusions

From the foregoing it is evident that there will continue to be a need for radar in the period of transition to DABS and even beyond. The general characteristics required except for weather sensing are similar to those provided by ASR and ARSR radars. Improved capabilities in detecting smaller targets in the presence of various clutter sources is desired as is a good integration of the radar and DABS systems.

The current ten year plan includes a procurement of some 25 additional ARSR-3's and 100 ASR-8's to provide expanded coverage for FAA services.

These and the existing radars must provide the services discussed above in this transition period.

Application of current technology to these procurements can result in significantly improved performance with little on the cost. Introduction of such improved performance can take place in two stages. The first stage involves improved MTD processing utilizing a digital system of extended linear range performing Doppler processing on the data within the framework of the present design. Such processing is being examined in detail under Task B of this program and would indicate sub-clutter visibility improvements of 25 dB for ground clutter and some 15 dB for rain clutter over and above the ASR-8 designs.

In addition to this, the ARSR-3 and FES-20/60 would also be amenable to a retrofitting with the same type of processor for similar improvements. The balance of the radars--magnetion ASR's and ARSR's --could also be retrofitted with an improved MTD processing unit but it would not result in quite as greate an improvement in performance

The second stage of improvements is to initiate the development of a completely new ASR. The procurement period for the ASR's extends over a 10 year period. It is felt that within this time frame a new ASR can be developed and specified in time to apply to most of these systems. Such a development could, using current techniques, provide the best performance for money already anticipated to be invested in new radars. Such a new ASR development would include examining the applicability of step-scan arrays and lower operating frequencies as well as the improved MTD included above. Lower frequency operation would tend to reduce the return from birds, insects and rain clutter, without significantly affecting the return from aircraft of interest. This will tend to reduce the minimum detectable cross-section - closer to that of the small general aviation aircraft - permitting a simplified signal processing over that required in the first stage above. L-band radars are currently in operation and under further procurement by a number of foreign nations for air traffic control use.

At this point, such a radar will be operating primarily with DABS sensors and consequently the design should be closely integrated with DABS. Questions of co-location, siting, synchronization, range, data rate, target correlation, data formats, etc., must be addressed and resolved. It should be pointed out that a change of radar to a lower frequency may make it insensitive to precipitation thus eliminating the radar as a source of weather data for the controller. In such an event, some alternate source of data should be provided.

It is anticipated that for at least the next 10-15 years there will be many high density general aviation airports serving significant number of unequipped aircraft. Even with the deployment of 100 additional ASR's over the next 10 years, there will remain about 100-150 general aviation airports with towers but without radar (or beacon) coverage. Present ASR installations costs range from about $1.2M to $2.0M depending upon how much of the whole surveillance and communication package is included. This is simply too high a cost to be supported by general aviation. It is felt that a careful study should be made of the specific surveillance and communication requirements of a general aviation airport from the point of view of a minimum cost, integrated package. It would be possible with current technology to produce a low-cost short range radar, specifically designed for Tower Control use at general aviation airports, so as to provide these airports with added capability to serve their general aviation operations. With such a radar must be included an inexpensive but complete controller display and control station. The emphasis throughout must be minimum capital cost and minimum operating cost. As much as possible should be integrated into unitized packages for simple installation.

In the DABS era, there will be a further change in the role of radar. DABS surveillance will no longer require the support of radar for assistance with transponder-equipped targets. There may be, however, a definite requirement for detecting unequipped aircraft, the notion of intrusion detection mentioned above. At this time, it is not clear as to which directions the air traffic control situation will take, especially with respect to equipped and non-equipped aircraft, increasing restrictions on airspace, etc. As a result, the requirements for intrusion detection are not now very clear. However, it is felt that such a role will become evident as more experience is gained with the DABS system in the field. Hence, after initial deployment of DABS has been accomplished and some experience in the field is obtained, a re-examination of the problem of intrusion detection and back-up for failed transponders seems needed. The objective of the investigation would be to determine whether or not new requirements and/or new techniques would permit a departure from the general ASR approach which would result in lower installation and operating costs.

APPENDIX D[1]

DIGITAL DATA LINK

The digital data link is a vital element in the automated ATC System. Automatic generation of ATC commands must be accompanied by automatic delivery of these commands in order to realize the full advantages of automation. As indicated above, the capacity required of a digital data link to handle the projected ATC communications load at the most active region (Los Angeles) is quite modest as far as digital data transmission capabilities are concerned. There are, however, considerations beyond simple capacity which influence the parameters of candidate data link systems. These include effective capacity, channel management and polling, single vs multiple channel, simplex vs duplex systems, costs, reliability, etc. Some of these factors are explored here.

A. Effective Capacity

The capacity of a channel is often defined in terms of the channel alone without consideration of limitations of the channel. These limitations reduce the effective capacity of the channel. For systems pertinent to an ATC data link, the principal factors limiting channel capacity are transceiver turn-around time and message propagation time. The effective capacity for

[1] This Appendix summarizes work begun in defining the characteristics of an ATC Data Link as the basis for comparing DABS with a VHF multiple channel link. The work was not carried to full completion as a result of a redirection of effort.

simplex and duplex channels typical of a VHF system are shown in Figure D-1. As is evident from this figure from this figure, only as the mean turn-around time for simplex operation or as the variation in the mean for duplex operation drops to 10 msec or less does the channel approach full capacity. The channel capacity of 160 char/sec represents a bit rate (including over-head) of about 2400 bits/sec, typical of the capacity of a voice-quality tele-phone line.

It should be noted at this time that the choice of dual channel versus single channel depends upon this turn-around time question. If in the design of the airborne equipment it is difficult to achieve a short turn-around, small standard deviation, then a dual channel permits more efficient use of the channel capacity. On the other hand, the single channel configuration is more versatile in efficient handling of mixtures of message lengths in up- and/or downlink and in turn-around times or propagation times. Under similarly favorable turn-around time conditions, the single channel system has somewhat more capacity than the dual channel.

In the case of the DABS data link, the basic channel capacity is extremely wide; 4 Mb/sec up and 1 Mb/sec down. Likewise, the transponder turn-around time will be measured in tens of microseconds. As a result, the available, realizable capacity of the DABS channel is about 2 orders of magnitude greater than that of a VHF channel.

B. Polling

In addition to capacity requirements, there is a closely related polling requirement. Positive control over the data link must be exercised in order to ensure absence of internal interference and maximum efficiency.

ATC-21(D-1)

<u>Simplex</u> (Two way alternate)

$$C_{EFF} = \frac{N_M}{T_M + T_x + T_T}$$

<u>3/4 Duplex</u> (Ground: Two way simultaneous)
(Air: Two way alternate)

$$C_{EFF} = \frac{N_M}{(T_M + 2T_T) + 2\delta T_x}$$

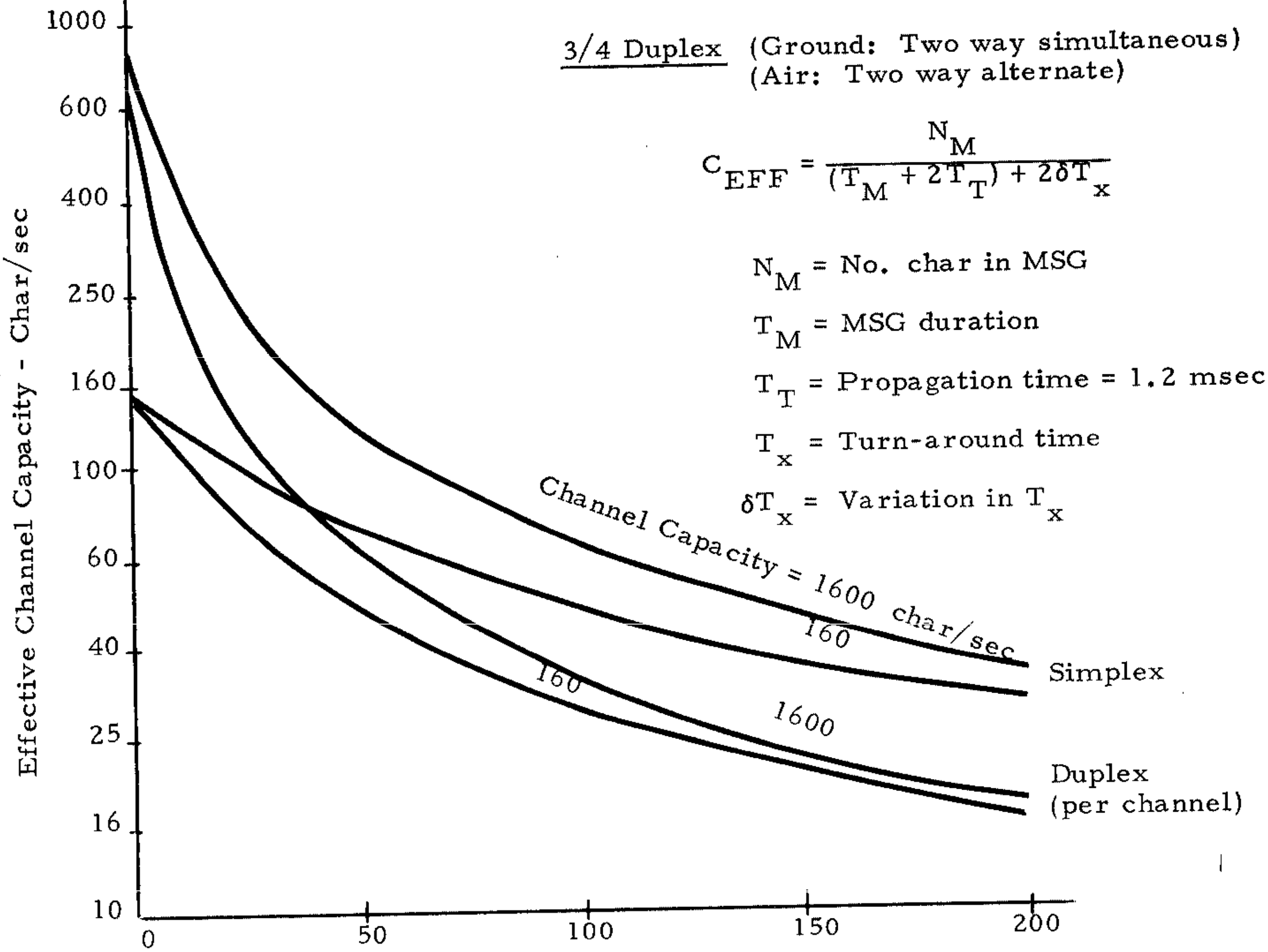
N_M = No. char in MSG

T_M = MSG duration

T_T = Propagation time = 1.2 msec

T_x = Turn-around time

δT_x = Variation in T_x



T_x = Turn-around Time
or δT_x = Variation in T_x
} msec

Fig. D-1. Effective Channel Capacity.

This control is most logically exercised by the ground since messages and aircraft data are concentrated there. The ground must then schedule uplink message delivery and provide polling for the downlink. With each uplink delivery, the aircraft would be polled for downlink. It is estimated that the average interval between uplink messages to each aircraft is about 1 minute. This is not sufficiently often for acceptable polling of pilot requests for downlink transmissions, especially responses to control commands. Hence, separate polling is required which would provide 5-10 second service to the pilot.

This level of polling has a major impact on the capacity of the link. The number of aircraft that can be handled by a single channel is dependent upon the polling requirements as well as the data capacity requirements. The dependency of the number of aircraft that a single channel can handle upon transaction time and probability of delay is:

$$N_{ac} = \frac{T_{mit}}{\tau} \quad e^{\frac{\ln P}{T_D}}$$

where

N_{ac} = Number of aircraft per channel.

T_{mit} = Average time between messages to each aircraft.

τ = Transaction time and equal to the sum of message duration (τ_m), turnaround time (τ_t) and propagation time (τ_p) for both the uplink and downlink.

T_D, P = Are the probability P that the message queueing results in a delay T_D in transmission of the message.

This function is plotted for $P = 0.001$ in Figure D-2.

This figure can be used to estimate the channel capacity with and without polling. Without polling, the average interval between messages is estimated at 60 sec. The transaction time is:

$$\tau = 2\,(\tau_m + \tau_p + \tau_t) \quad .$$

For a VHF system typical of a new transceiver specification (ARINC Spec. 566-A), the turnaround time τ_t is 50 msec $\pm$ 1 msec, single channel. The message duration τ_m for a 100 bit message at 2500 bits/sec is 40 msec. Hence, $\tau \sim 2(50 + 40) = 180$ msec and for a 0.1% probability of delay $T_D = 4$ sec, the channel could handle some 250 aircraft. On the other hand, if polling requires a contact to the aircraft for downlink accessibility every 4 sec, then the time between messages T_{mit} becomes identically 4 sec and the number of aircraft handled drops proportionately as indicated in the equation above. Hence, one channel could now handle $250 \times 4/60 = 16$ aircraft. Recalling from Appendix A that the number of aircraft in the Los Angeles basin model was taken to be 2700 aircraft, this implies 120 channels! If the transceiver turn-around time is reduced from 50 msec to 10 msec, the number of aircraft per channel becomes:

$$N = \frac{T_{mit}}{\tau} = \frac{4}{2(10 + 40) \times 10^{-3}} = 40$$

decreasing the number of channels to about 70, still a respectable number.

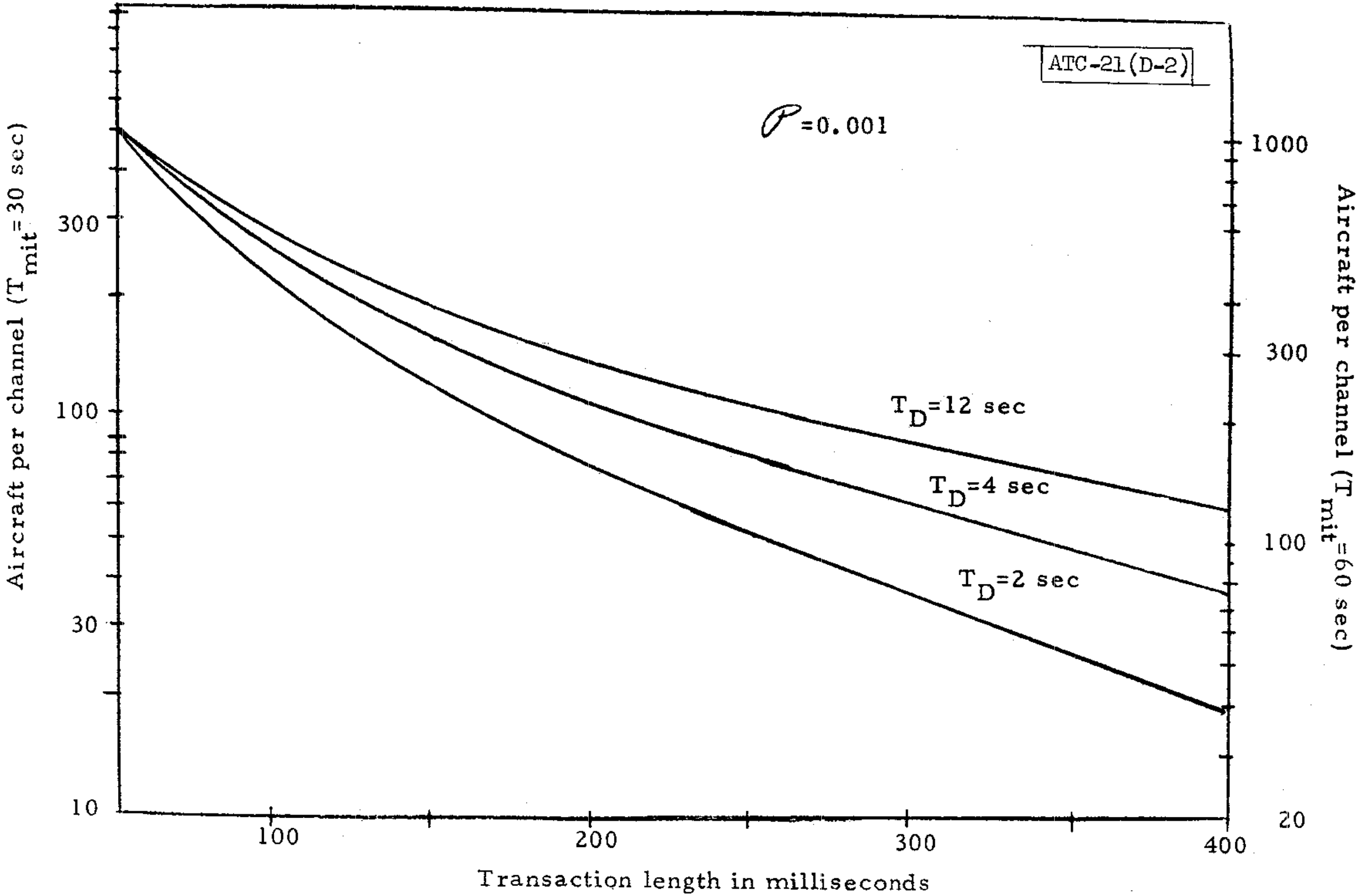


Fig. D-2. Aircraft per channel.

In the DABS surveillance mode, contact with the aircraft is made several times every 4 sec, automatically providing the 4-sec polling desired for downlink control.

C. Interim Data Link

Under the assumption upon which this study is based that there will be an early deployment of the DABS system - early 1980's - the question of an interim data link was reviewed. Data link usage includes both maneuver control and auxilliary data such as Clearances and Weather Forecast. Introduction of a data link for maneuver control purposes without computer generated commands or vice versa does not enhance the system. In either case, it can only burden the controller by requiring him to perform and added function in his control operation. Some small advantage might be realized with an interim data link if the computer were used to handle automatically some of the the routine functions such as frequency assignment, code assignment, altimeter settings, etc. In addition, some of the auxilliary data could be transmitted on the data link. However, this would not have any significant influence on controller efficiency.

In summary, there does not seem to be sufficient benefit to warrant an interim data link especially where it is anticipated that DABS deployment could begin in 1977.

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