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Technical Development Plan for a Discrete Address Beacon System Volume 1

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TECHNICAL DEVELOPMENT PLAN FOR A DISCRETE ADDRESS BEACON SYSTEM VOLUME I of II

PROJECT REPORT ATC-4
(Air Traffic Control)

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CONTENTS

VOLUME I

VOLUME II (Appendix)

ABSTRACT

The requirement for a Discrete Address Beacon System (DABS) was highlighted by the Department of Transportation Air Traffic Control Advisory Committee to provide improved surveillance and ground-air communications in support of air traffic control automation. This document presents a technical development plan for such a system; this plan was developed in close colaboration with FAA personnel in the Office of System Engineering Management and the Systems Research and Development Service. The DABS Technical Development Plan identifies the critical issues and technical options, presents a program for their resolution, followed by the development and test of a feasibility model of the system, and suggests a management structure to coordinate and carry out the many tasks involved in the implementation of the plan.

I. INTRODUCTION

A. Background

1. The Evolving Air Traffic Control System

The present Air Traffic Control (ATC) System is primarily a manual system with regard to the control and separation of air traffic; this manual system is in the process of transition to the semi-automatic Third Generation System recommended by the Project Beacon Task Force in 1961. The major improvements of the Third Generation system center around the use of computers to reduce the controller's workload and increase his efficiency. The controller is presented with improved displays, with targets automatically identified and tracked by data received from the Air Traffic Control Radar Beacon System (ATCRBS), and this surveillance data is checked automatically against stored flight plans. These improvements are embodied in the NAS Stage A program for enroute ATC centers, and the ARTS II and ARTS III programs for terminal ATC facilities.*

As a consequence of the mounting crisis in air traffic control during the late 1960's, especially the summer of 1968, the Department of Transportation formed the Air Traffic Control Advisory Committee (ATCAC) for the purpose of developing recommendations for an ATC system adequate for the 1980's and beyond. This crisis in ATC was primarily due to the failure of airport and ATC capacity to maintain a growth rate comparable to that of the aviation industry. Moreover, this demand from all categories of aviation can be expected to continue at a high rate of growth unless constrained by an inadequate airport and ATC system. The ATCAC task was to provide specific recommendations which would lead to an increase in system capacity, especially in terminal areas, to maintain or improve safety despite the increases in traffic density, and to provide a substantial increase in the traffic handling ability of controllers through extensive system automation.

Based upon its preliminary studies, the Committee determined that the Third Generation system now being implemented could not be expected to accommodate the forecast traffic loads of the 1970's without significant sys tern improvements. The Committee concluded that an evolutionary system plan should be developed to upgrade the Third Generation system and provide:% base to extend its useful life into the 1990's. In this regard several major recommendations were made by ATCAC, namely:

a. Terminal capacity should be increased by the use of close-spaced parallel runways, improved navigational aids, and the development of a scanning-beam microwave landing guidance system.

b. Air traffic control capacity should be increased by the extension of NAS and ARTS to higher levels of control automation, supported by the use of a digital data-link between aircraft and the ground for the transfer of control information.

c. The concept of intermittent positive control (IPC) should be developed and applied in mixed airspace. IPC is a concept for an automatic ground-based collision avoidance system which issues commands to normally-uncontrolled aircraft only when it is necessary to avoid a hazardous midair situation.

d. A new surveillance system should be developed, employing discretely-addressible airborne transponders and incorporating a ground-air-ground data-link; such a system is required to meet the needs of ATC automation for improved surveillance data quality and reliability, and for a digital communications channel.

2. ATC Surveillance

The capability of the surveillance and ground-air communication systems pace the performance of air traffic control. In the early days of ATC,controllers maintained an orderly flow of traffic and safe separation using data on aircraft position obtained through radio reports from the aircraft along with flight plan information contained on flight strips. As the numbers of aircraft and the air traffic density increased in the years following the Second World War, the use of voice position reporting was gradually replaced by radar surveillance. However, the aircraft population continued to increase dramatically, and it again became necessary to improve surveillance capabilities and reduce controller workload. Following the recommendations of Project Beacon (1961), the Air Traffic Control Radar Beacon System (ATCRBS) was implemented and has steadily supplanted radar as the primary ATC Surveillance System. ATCRBS is a cooperative radar- beacon system, with interrogators collocated with FAA enroute and terminal radars. It provides position, altitude and identity information on properly equipped aircraft, supplying the necessary inputs for the automation of ATC functions in the NAS and ARTS programs.

ATCRBS has a number of deficiencies which limit its ability to meet the demands presented by the increasing automation of ATC, particularly in an environment of increasing traffic density. These short-comings are well known, and have been discussed in the literature[(1)] as well as the ATCAC report.[(2)] Some of the problems of ATCRBS, for example those resulting from interrogator antenna lobing and over-interrogation, can be alleviated by appropriate system improvements. Such action can extend the useful life of ATCRBS and is required to meet the ATC surveillance needs of the next few years. However, there exist inherent limitations on the target capacity, resolution, and ranging accuracy of ATCRBS because of the nature of the system and its signal structure. An ATCRBS transponder replies to essentially all received interrogations, both those from the few interrogators "interested" in that aircraft plus those from the many other

(1) Shaw, N. K. and Simolunas, A.A., "System Capability of Air Traffic Control Beacon System", Proc. IEEE, Vol. 58, No. 1, March 1970, pp. 399-408.

(2) Report on DOT Air Traffic Control Advisory Committee Vols. I & II, Dec. 1969.

interrogator; within line-of-sight. In a typical high density terminal area there are many aircraft responding to many interrogators; a high level of interference occurs both at the transponder input and at the interrogator receiver, resulting in lost or garbled replies. Also, replies from aircraft closely spaced in azimuth or slant range overlap, and thus garble, each other.

The data acquisition requirements for a highly automated ATC system will exceed that which can be achieved by ATCRBS, particularly when aircraft traffic-densities reach the levels predicted for the 1980's and 1990's. To meet these requirements, the ATCAC committee recommended the development of a Discrete Address Beacon System (DABS) to provide garble-free replies: superior data quality, and the means for implementing a digital data-link.

B. The DABS Concept

The DABS surveillance system may be thought of as a modified ATCRBS. It is a network of sensors, each measuring range and azimuth on targets within its coverage limits, and obtaining air craft identity and altitude from coded replies. The chief difference lies in the fact that each interrogation is addressed to a specific aircraft which recognizes its own discrete address and only then replies to the ground.(1) Interrogations may be scheduled in such a way as to prevent garbling of the replies, since target position can be predicted from track data. Provision must of course be made to include new targets in the discrete address roll call.

Since aircraft are addressed individually in DABS, the surveillance system automatically provides a natural vehicle for a data-link between ground and aircraft which can be used for control purposes such as IPC.

(1) A similar concept is briefly described by C. Ullyatt, of the British Royal Radar Establishment: "Sensors for the ATC Environment with Special Reference to S. S. R.", U. K. Symposium on Electronic for Civil Aviation, September 1969.

The DABS design must recognize this double function, especially in the selection of modulation and coding techniques.

C. The Transition Period

DABS will be introduced and implemented during a time period when the Third Generation NAS/ARTS ATC system will be in full operation. It is expected that by this time ATCRBS transponders will be required for all air craft using controlled air space, hence ATCRBS will represent a huge capital investment in both ground and airborne equipment, The transition period and implementation strategy must therefore permit a reasonable amortization of the equipment then in use.

During the decade or so between the introduction of DABS and its essentially complete implementation, the demands on the ATC system will continue to increase. Aircraft will sometimes operate in areas with ATCRBS-only surveillance, sometimes with DABS-only surveillance, and sometimes with both. Therefore even as aircraft become DABS-equipped, they must maintain the capability of responding to ATCRBS interrogators; only during the latter phases of the transition period will aircraft operating over wide areas be able to depend on continuous DABS surveillance. Likewise DABS interrogators must retain the capability of interrogating ATCRBS-equipped aircraft, as it will be a number of years after the initial implementation of DABS before any airspace is closed to aircraft not DABS-equipped. Throughout this transition DABS should not cause any deterioration in the performance or safety of the existing ATC system, and it should interface smoothly with the various existing and on-going elements of the system.

The next section of this Chapter presents an overview of the DABS development plan, including a discussion of the DABS implementation phase during which the transition takes place. It should be emphasized that the change will be gradual, with DABS surveillance capability introduced in stages, first in high density terminal areas and then, progressively, enroute and in the remaining terminals. In each area where DABS interrogators are introduced, DABS surveillance and IPC service will be provided immediately to aircraft equipped with DABS transponders; however, a dual mode of operation will be maintained so that ATCRBS-equipped aircraft will continue to be accommodated for many years. It is expected that the interval between introduction of DABS in a given portion of airspace and rulemaking requiring DABS transponders in that airspace will exceed the useful life of an ATCRBS transponder.

D. Overview and Summary of the TDP

The concept of a discrete address beacon system is well understood. However, there remain significant areas of operational, technical, and economic uncertainty which must be resolved before a viable DABS design can be realized. The DABS Technical Development Plan identifies the critical issues and technical options, presents a program for their resolution, followed by the development and test of a feasibility model of the system, and suggests a management structure to coordinate and carry out the many tasks involved in the implementation of the plan.

Chapter 11 - Issues

The major issues which relate to the development of a DABS system: are presented. The discussion covers the technical requirements on DABS needed to support a variety of ATC functions and concludes that these requirements are not well understood at the present time. Projections of air traffic through 1995 are presented along with the planned growth of the ATCRBS interrogator environment. A number of issues which tend to constrain the design of DABS 'are also analyzed, such as

a. the need to coexist with ATCRBS during a long and gradual transition period,

b. the need to be compatible with military operations and requirements, and,

c. the need to interface with the NAS and ARTS display and control systems.

Chapter III - Design Options

The technical options available for the de sign of major subsystems of DABS are discussed. Several system trade-offs and technical uncertainties related to possible DABS configurations are emphasized. The following topics are treated.

a. Operating Frequency

The relative merits of remaining on the ATCRBS frequencies are compared with the use of other frequency bands, or other frequencies within the TACAN band.

b. Modulation and Coding

Various modulation and coding schemes are reviewed, including PAM, with ATCRBS- type parameters, PSK and FSK. Problems related to transponder cost, mutual interference and multi-path are emphasized.

c. Me s sage Structure

Questions of message length and format, the options in aircraft addressing schemes, and the nature of IPC commands and time-critical ATC data-link messages are discussed.

d. Interrogator Antenna

A discussion of the range of antenna performance parameters of interest for DABS and the problems related to realizing these parameters with mechanical rotators, phased arrays, or hybrid antennas is presented.

e. Azimuth Angle Measurement

Angle measurement techniques are briefly reviewed, with emphasis placed on off-boresight or rapid-nulling monopulse as a means of obtaining sufficiently accurate azimuth determination with a minimum nurnber of hits per scan.

f. Antenna Diversity

The importance of a reliable ground-air RF link is emphasized in this section, concluding that antenna diversity on aircraft is probably the most desirable means for achieving it.

g. Interrogation Management

Various scheduling algorithms for discrete-address are discussed, along with an analysis of several DABS-ATCRBS mode interlace options and their resultant system tradeoffs.

h. Sensor Coordination

Target assignment, coordination of sensors, the use of redundant surveillance coverage, enroute-terminal area coordination, and failure modes are topics treated in this section. The discussion emphasizes the methods by which proper utilization of sensors can reduce interference, improve data reliability, increase traffic handling capacity, and reduce system susceptibility to failure.

i. Data Processing

A brief treatment of surveillance data processing, i.e., target detection, location, and tracking as well as a qualitative discussion of the organization of the overall data processing task in a DABS-based surveillance system are given in this section.

Chapter IV - DABS Development Plan

The recommended development plan which leads from ATC surveillance requirements to design and implementation of the DABS system is presented. The DABS program will consist of three major phases:

a. Phase 1: System Definition and Feasibility Demonstration

This section of the plan is concerned with defining DABS requirements, evaluating a wide range of critical techniques relevant to various DABS subsystems, developing an overall DABS system design, and validating this design by experiment and analyses. To this end, a detailed set of task descriptions, schedules, management recommendations, and cost estimates are presented. This phase has been scheduled to last approximately four years and requires a total funding of $23 million. The major outputs of this phase are detailed plans and schedules for the two subsequent phases and a provisional

National Standard and MOC for DABS. This will permit the industrial production of prototype transponders for use in Phase 2. Negotiations for international agreement on DABS standards and operational practices should begin at or before this time.

b. Phase 2: Prototype Engineering, Test and Evaluation

This section is presented in terms of long-range schedules and general task guidelines. The goal of this phase is to develop and construct a fully-engineered DABS demonstration system and to obtain operational and technical experience in a live ATC environment prior to system implementation. The duration of this phase of the program is three and one half years. Because of the present uncertainty in system de sign, it is not possible to estimate the cost of Phase 2.

An output of Phase 2 should be a final MOC for DABS transponders and a firm National Standard for the DABS system.

c. Phase 3: Sys tern Implementation

This section is also presented in terms of long-term schedules and general considerations concerning procurement of DABS ground equipment. Consideration is given to FAA and user economics as well as to the production capabilities of the avionics industry. This phase is expected to begin approximately one year prior to the completion of prototype phase and be essentially completed within ten to fifteen years.

Interaction between DABS implementation and on-going ATCRBS improvement is treated. An implementation plan is developed which provides a gradual transition from an all-ATCRBS to an all-DABS surveillance environment. Large- scale commercial transponder production should begin with the installation of the first DABS interrogator/receivers at the start of Phase 3. These ground installations will begin with high density terminals, and the first rule requiring DABS transponders will apply to these terminal areas. As the number of terminal areas equipped'with DABS interrogators increases, the air carriers will become fully equipped with DABS. Later steps in rulemaking will require DABS transponders in Positive Control airspace (when enroute DABS implementation is complete enough to justify it), DABS equipment in all new aircraft, and eventually, DABS transponders for all aircraft using controlled airspace.

This chapter also discusses the assumptions on which costing and scheduling are based, the coordination of DABS with other ATC development <programs, such as ATCRBS improvement, IPC and ATC datalink programs, and contingency planning in order to handle funding delays and technical difficulties .

Chapter V - Program Management

A proposed management structure is presented and the roles of the various elements of the management structure are discussed, with emphasis on the areas of technical responsibility, administrative and agency coordination, and funding responsibility. The management structure is designed for the ambitious development program which has been recommended. Provision is made for extensive coordination with other concerned agencies within the FAA, and with the many interested outside agencies including the DOD and domestic and international user groups.

II. ISSUES

A. Introduction

The issues which define the ground-rules under which DABS must be designed are presented in this section. Topics are considered under the following three general headings:

Performance Requirements - A summary of the ATC functions which DABS is expected to support and, to the extent known, the performance required by each function.

Environment - A discussion of the traffic densities and distributions with which DABS must cope, together with the projected ATCRBS interrogator population; these relate directly to the required system capacity and the ATCRBS interference environment.

Constraints - A review of the constraints imposed upon DABS design and implementation by the need for compatibility with civil and military use of ATCRBS during an extended transition phase, and with the NAS/ARTS systems which it must interface.

B. Performance Requirements

DABS will inherit the basic air traffic surveillance function of ATCRBS, but will be expected to perform this function in a manner suitable for higher levels of automation of the control process. In addition, it must provide a communication channel between the ground environment and the aircraft. Because the recipient of the surveillance data and source of messages will frequently be a computer algorithm rather than a highly adaptive and relatively tolerant controller, much greater attention must be given to the quality of the surveillance data and communication channel than has been the case heretofore. Thus,it is necessary to examine the several automated ATC functions which DABS must support, and to attempt to quantitatively specify the requirements each places upon DABS in the areas of:

- air space coverage;
- surveillance data accuracy, reliability and refresh rate; and
- communication capacity, reliability, permissible delay.

DABS must be capable of satisfying these requirements under the air traffic conditions projected for its operational lifetime.

The remainder of this section discusses the particular ATC functions which DABS must support, primarily as identified by ATCAC. For each such function 'an attempt is made to summarize the present understanding of the requirements that function places on the performance of the surveillance system, and to point out where further effort is required to define these requirements more precisely. In most cases the performance requirements are drawn from the ATCAC report, supplemented where appropriate by later studies. It is recognized that economic or other constraints may preclude satisfying all of the requirements developed from an analysis of these various ATC functions. However, only by understanding in detail the relationship between ATC system performance and surveillance /communication capability can the design trade-offs between DABS performance and cost be intelligently resolved.

1: Reauirements bv ATC Function

The primary ATC functions which place particular demands on DABS are:'

- IPC (Intermittent Positive Control),
- lateral deviation monitoring,
- final approach sequencing and spacing,
- parallel approach monitoring, and
- ATC data-link.

Two other functions which may be supported by, and place special requirements on, DABS are:

- surveillance and control of V/STOL operations,
- and airport surface surveillance.

a. IPC

A central element of the ATCAC plan for ATC development is Intermittent Positive Control (IPC), providing automatic ground-based sensing of hazardous air traffic situations and the generation and transmission of appropriate collision avoidance commands to the involved air craft. While primarily designed to prevent collisions, IPC will also function to direct intruders away from positive control airspace.

IPC requires the tracking of aircraft, the prediction of future position to determine potential collision hazards, and the transmission of collision warning and avoidance information to aircraft via a DABS IPC data-link. Thus IPC imposes requirements on surveillance data reliability, accuracy, and refresh rate. Transmission of correct IPC commands to aircraft imposes requirements on communication capacity, reliability, and delay.

Key performance parameters of IPC are the probabilities of hazardous situation detection and false alarm, the required warning time, and the probability of delivery of the correct command. The environment is described by presumed traffic density and maneuver uncertainty of the aircraft involved (expressed perhaps as limitations on accelerations, or on turn and climb/descend rates). To understand the requirements IPC places on DABS one must relate IPC performance under various traffic situations to data accuracy, reliability and refresh rate, track quality, and communications capacity, reliability, and delay. This requires a precise definition of the IPC function and services, the definition of measures of IPC performance and determination of suitable values for these measures, together with a detailed mathematical model and analysis of the IPC process to permit the extraction of the requirements imposed on DABS. No analysis of this kind is available to guide the specification of DABS data requirements. For example, a highly reliable IPC system could be based on data of very poor quality at a low data rate provided one is willing to accept the penalty of excessive airspace allocated to each aircraft. Similarly, the communications requirements are very sensitive to the assumed traffic models, as is illustrated by the work performed for the ATCAC report, based on the random gas model for traffic. At this point it cannot be proved that data of the quality and refresh rate of the present-day enroute ATCRBS system is incapable of supporting a useful IPC service. Since IPC provides one of the fundamental motivations for DABS, efforts to establish quantitative requirements must proceed as an integral part of the DABS design.

b. Lateral Deviation Monitoring

The ability to monitor and detect lateral deviations from course-by controlled aircraft flying along assigned airways directly influences the allowable spacing between airways, and thus the efficiency of air space utilization. It is necessary to relate both the false alarm probability and the probability of detecting deviation from an assigned course to the airway width, spacing and the DABS surveillance reliability, accuracy and data rate.

The treatment of this problem to date has been one of estimating minimum safe airway separation achievable given nominal assumed DABS sensor accuracy and data rates. No definitive statement has been given as to the airway width and spacing required for future ATC, and therefore no DABS requirements have been imposed by the lateral deviation monitoring function.

c. Final Approach Spacing

In order to obtain a significant increase in runway utilization, studies[1] have shown that time-of-arrival at the approach gate

(1) DOT/ATCAC Report, Vol. II, p. 95

(outer marker) should be precisely controlled and held to a dispersion of 5 seconds (1σ). The approach sequencing and spacing problem involves prediction of air craft position, or time-of-arrival at a waypoint, as well as transmission of control information to aircraft via the DABS (or an alternative) data-link. A simulation study[1] of a computer-controlled final approach spacing algorithm suggested that aircraft position accuracy requirements were not especially stringent (0.1 mile accuracy appeared adequate); however, reconsideration of certain assumptions in the model may lead to requirements for more precise data. It will be necessary to verify the model parameters used for pilotage and wind errors in the study of approach spacing algorithms, and to include a class of spacing algorithms suitable for use with curved approaches.

d. Parallel Approach Monitoring

In order to achieve more efficient utilization of existing airport real estate, the use of closely spaced parallel runways (1/2 mile apart) was recommended by ATCAC. It was further recommended that a DABS interrogator on the airport surface be used to monitor independent IFR approaches to such close-spaced parallel runways for deviations from nominal approach paths which could result in a collision hazard.

The parallel appr oach monitoring function involves estimating air craft crosstrack (normal to the extended runway centerline) position, velocity, and acceleration, and the transmission of an emergency command whenever it appears that an aircraft might penetrate a buffer zone between the two extended runway centerlines. The decision algorithm must identify hazards quickly and reliably while permitting normal aircraft deviations from the localizer cour se. Transmission of an emergency command must be made in time to allow reaction time and airspace for the recovery maneuver.

Accurate estimation of crosstrack position and velocity of aircraft on final approach imposes stringent requirements on the azimuth estimation

(1) DOT/ATCAC Report, Vol. II, p. 95

accuracy, data rate, and low angle coverage (at least in the approach direction) provided by the DABS sensor. The performance of the parallel approach monitoring function can be characterized by the probability of detection of hazardous deviations from the normal approach course (i. e., those which would penetrate the buffer zone if uncorrected) and the probability of false alarms (i. e. , eliciting emergency maneuvers when none were necessary). A key issue in keeping the false alarm rate low is the characterization of aircraft deviations from the expected localizer course in a variety of wind conditions.

An analysis of final approach monitoring has concluded that safe operation of parallel runways 2500 feet apart could be achieved with a monitoring system that provided 100 to 200 foot crosstrack position accuracy, 5 to 10 knot crosstrack velocity accuracy, and a 1 second data update rate.[(1)] The model used in this analysis did not calculate false alarm probabilities, and is sensitive to assumed reaction times. This would indicate that verification of model assumptions is necessary.

In view of the stringent requirements on DABS data accuracy, rate, and airspace coverage imposed by the parallel approach monitoring function, it is reasonable to consider alternate approaches to performing this function in order to relieve these requirements. The ATCAC suggested a monitoring system based on obtaining accurate crosstrack velocity measurements from auxiliary passive receivers used in conjunction with a DABS interrogator. Use of the new microwave landing system to provide coverage of runway approaches was also suggested. The entire range of options for an approach monitoring system deserves further study to provide data for a minimum cost choice.

e. AT C Data-Link

In addition to accommodating message traffic due to IPC, positive controlled aircraft may receive certain ATC co-and information (e. g. vectors, altitude changes, etc.) via the DABS data-link. The

(1) DOT/ATCAC Report, Vol. I, p. 56

required message handling capacity of the DABS will depend on the number of DABS-equipped aircraft and the choice as to what range of ATC information will use this channel.

A previous analysis of DABS peak channel capacity requirements concluded that ATC data-link service requires on the average one message (of approximately 50 bits) every 10 seconds to each equipped aircraft.[1] Traffic projections for the Los Angeles area for the post-1990 period were then used in conjunction with an assumed mix of ATC data-link, IPC, and ATCRBS equipped aircraft, to arrive at peak message rates for enroute and terminal area DABS interrogators. It was concluded that for 50μ sec up- and downlink DABS messages, the message traffic could be accommodated in the same up and down channels used by the ATCRBS. However, the effects of interference between the ATCRBS and DABS transmissions in this model were not discussed and cannot be easily inferred. Since interference effects can affect the conclusions regarding peak DABS message rates (by necessitating repeats) and therefore the feasibility of using the ATCRBS frequencies, the interference between ATCRBS and DABS requires further study.

The recently completed FAA Staff Study on Data-Link[2] concluded that DABS was the most logical vehicle for the transmission of time-critical ATC commands (messages which must be delivered within 15 seconds). Non-time-critical messages can be sent via the ARINC VHF/UHF Universal Data-Link,[3] although it was considered desirable for DABS to provide a long-

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(1) DOT/ATCAC Report, Vol. I, p. 70.

(2) "Recommendations for Federal Aviation Administration Data-Link Development Program", July 1971, DOT, FAA, SRDS Staff Study.

(3) "Universal Air-Ground Digital Communications System Standards", RTCA SC 110/111 Final Report, 7 March 1968.

message capability for this purpose at low priority. No new quantitative data-link requirements are provided in the FAA Data-Link Report (except for message delays and error rates), and the Data-Link committee based its recommendations primarily on estimates of data-link requirements prepared as background material for the ATCAC Study (Appendix FI and unpublished support work for Appendix D). Message lengths used in these studies were 72 bits on the up-link and 85 bits on the down-link. Message rates projected for 1995 were roughly 12 per second for an entire ARTCC and 20 per second for a metroplex terminal area in this model. The RTCA report includes a message format and code (8 bits per character), developed for airline use on the Universal Data-Link which, if applied to ATC messages, would result in lengths of 174 bits on the up-link and 204 bits on the down-link, and the use of this message structure was also considered in the FAA Data-Link report. Thus, as pointed out in this report, quantitative requirements for ATC Data-Link await a "comprehensive treatment of ATC system characteristics and requirements for the 1980 decade".

f. V/STOL Operations

Although it is questionable whether the total number of V/STOL operations may ever significantly increase the load on DABS, the special mode' of operation of these air craft could result in difficult airspace coverage and data accuracy requirements. V/STOL operations in downtown areas will require special navigation and landing aids. As long as such traffic is light, there may be no need for ATC surveillance of V/STOL operations in these areas. However , as the density of V/STOL traffic increases, independent surveillance of V/STOL airways and landing areas may be required to maintain safety.

One important problem in monitoring urban V/STOL operations is sensor shielding and multipath due to tall buildings contiguous to the air-space. Thus coverage of V/STOL operations will require special attention to siting of DABS interrogators, and perhaps even the use of auxiliary receiving sites to locate aircraft by trilateration. Such discrete-address trilateration techniques are currently under test for use in locating ground vehicles in downtown areas of large cities.

g. Airport Surface Surveillance

The problem of precisely locating air craft and ground vehicles on the surface of an airport has characteristics similar to that of monitoring urban V/STOL operations, in particular, relatively short range, high precision, and the presence of nearby reflecting objects. The discrete-address feature of DABS, the increased range accuracy of a new transponder, and the use of auxiliary receivers to cover all areas of the airport may be able to provide sufficiently precise surface surveillance data for automation of ground control. The principle implications of airport surface monitoring to the design of DABS are siting constraints, the multipath environment, and the use of auxiliary passive receiving sites.

2. Summary

The preceding section has summarized the DABS requirements as presented by the ATCAC, as well as further extensions by the FAA, Hazeltine, RCA, MITRE, and MIT Lincoln Laboratory. The information available is incomplete from the point of view of providing a quantitative statement of the performance required of DABS to satisfy various automated AT C functions. Further efforts to clarify these issues must proceed in parallel with initial DABS development, recognizing that they may result in more stringent demands on DABS performance than initially assumed and/or the elimination of certain desired functions,

As presently understood, DABS requirements may be summarized as follows:

a. Air space Coverage

Ultimately complete coverage of all positive-controlled and mixed airspace will be required. In certain airspace, such as high density terminal control areas, approach paths to parallel runways, and special V/STOL operations areas, the need for greater accuracy and/or reliability may imply special techniques, for example, fully redundant coverage and auxiliary ranging receivers.

b. Surveillance Data Accuracy

Studies of the terminal area accuracy requirements for approach spacing algorithms and'the monitoring of close-spaced parallel approaches suggest that 100 to 200 feet position accuracies out to approximately 20 miles would be adequate. This implies a range accuracy of 100 to 200 feet and an azimuth accuracy of 0.1°. Estimates of required data rate in the terminal area range from 1 second to 4 second refresh intervals. The studies on which these conclusions were based require further refinement, especially with regard to verification of critical model assumptions.

The en-route accuracy requirements have not been studied in detail. The quality of IPC service must be related to surveillance data accuracy and refresh rate.

The requirements on surveillance data reliability (i.e., the probabilities of obtaining data samples at particular times) have not been treated for any of the terminal or enroute surveillance functions.,

c. Communication Capacity

For the assumed post-1990 air traffic in the Los Angeles basin, the ATCAC Report suggested communication capacity requirements of one IPC message per minute per IPC aircraft and one ATC data-link message (50 bits) per 10 seconds to data-link equipped aircraft. Other estimates range to over 200 bits in message length and down to one message per 30 seconds to each aircraft in the terminal area. These results are highly tentative; further refinement of traffic models, IPC algorithms, and plans for data-link utilization are required to generate requirements of sufficient validity to be useful in the de sign process.

C. Environment

The implementation of DABS is viable only if its projected service life is commensurate with the substantial investment which will be required. The system must therefore have an inherent capacity adequate to perform its air traffic surveillance and communication functions through the 1990-95 time period. Thus the DABS design must take into account the projected growth of air traffic demand for at least the next twenty-five years. Further, DABS must coexist with ATCRBS during an extended transition period. Projections of ATCRBS- and DABS-equipped air traffic as a function of time throughout this period, and of the interrogator population and its composition as well, are necessary to define the electromagnetic interference environment in which DABS will operate if implemented on ATCRBS frequencie s.

Air traffic activity projections many years into the future are clearly tenuous, especially with regard to the growth of general aviation. For example, the introduction of new technology, such as a low cost jet engine, or a protracted change in the national economy, could have a profound effect on current projections. Nevertheless, with these limitations in mind, a model against which DABS designs may be tested must be developed. It should be realized that the sensitivity (or insensitivity) of a design to changes in the model may be as important a criterion as the design's level of performance under the model assumptions.

1. Air Traffic

The following air traffic projections are presented first on a national basis (CONUS), and then subdivided by region. This information

Table II. 1

Fleet Size and Peak Instantaneous Airborne Aircraft(IAC) for CONUS (as of Jan. 1)

	1968		1980		1995	
User;	Fleet Size	Peak IAC	Fleet Size	Peak IAC	Fleet Size	Peak IAC
Air Carrier (AC)	2,457	1,300	3,600	2,100	6,700	4,600
General Aviation (GA)	122,200	8,500	260,000	20,800	600,000	54,600
Military (MIL)	20,000	3,500	20,000	3,300	20,000	3,500'
Total	144,657	13,300	283,600	26,200	626,700	62,700'

The growth in aircraft numbers and activity for CONUS are useful for developing peak IAC estimates on a regional basis. Los Angeles, New York and Chicago are given below for enroute and terminal airspace.

Table II. 2

Estimated Peak IAC for LA, NY, Chicago Centers

	Los Angeles			New York			Chicago		
User	1968	1980	1995	1968	1980	1995	1968	1980	1995
AC	100	200	350	260	520	920	250	520	925.
GA	1,020	3,300	6,500	190	570	1,100	400	1,460	2,950
MIL	350	350	350	180	180	180	175	175	175
Total	1,470	3,850	7,100	630	1,270	2,200	825	2,155	4,050

Table II. 3

Estimated Peak IAC for LA, NY, Chicago Terminal Areas

	Los Angeles			New York			Chicago		
User	1968	1980	1995	1968	1980	1995	1968	1980	1995
AC	30	50	70	50	110	200	50	105	185
GA	75	935	1,900	65	190	365	135	485	975
MIL	30	30	30	20	20	20	20	20	20
Total	335	1,015	2,000	135	320	585	205	610	1,180

has been drawn from the ATCAC Report[1] and supplemented by other sources.[2,3,4]

These figures represent a best estimate based on the, current socio-economic condition. There has been no attempt to develop figures for a possible large scale introduction of V/STOL aircraft into the airspace. In addition, the statistics for general aviation aircraft are not as well known as those for the air carriers. It would be most useful to include in the continuing FAA forecast series: (a) projected activity estimates for V/STOL, (b) more detailed data on the rate of growth of IFR general aviation aircraft flying in and around high density airspace, and (c) data on the nurnber of transponders in use. This information could then update the air traffic activity model and the effect on DABS could be determined. For example, there have been estimates that by 1985 there could be an additional 30 percent more air carrier aircraft due to V/STOL. There have also been estimates that general aviation could experience an explosion in growth which could result in overall increases in peak instantaneous airborne count (IAC) by a factor of two or three over the current FAA forecasts. While it is not wise to predicate a system development based on such "ifs", one must continue to look for the existence of such trends. The air traffic activity estimates for high density enroute and terminal environments provide the data necessary for determining the message rate load and interference environment for an interrogator embedded in the system. This information will permit a proposed DABS design to be evaluated and aid in the determination of the "best" approach.

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(1) "Report of the Department of Transportation Air Traffic Control Advisory Committee," Vols. 1, 2., December 1969.

(2) "Analysis of Future Use of National Airspace System", R. Dixon Speas Assoc., October 1970.

(3) The National Aviation System Plan - Ten Year Plan 1972-1981, DOT, March 1971.

(4) "The Magnitude and Impact of General Aviation, 1968-1980," R. Dixon Speas Assoc., AeroHouse, Manhasset, New York, 1970.

2. <u>ATCRBS Interrogator Population</u>

The beacon interrogator environment is made up of: (a) ATCRBS interrogators collocated with enroute surveillance radars and with terminal radars at civil and military airfields, and (b) special purpose interrogators located at NIKE sites, navy ships, and mobile units used in military training exercises. The special purpose interrogators are not generally in full time operation, and are not considered further in this section.

Table II-4 lists the, current and projected 1980 numbers of continuous-duty interrogators, i.e., those used for enroute plus civil and military terminal surveillance. The locations of the current and projected 1980 interrogator population for CONUS are shown in Figs. II-l, 11-2.*

D. -Constraints

DABS will be introduced into an operating ATC system, one involving huge capital investment both on the ground and in the air, and already strained to near capacity in many critical areas. During the decade or more between the introduction of DABS and its essentially universal implementation, the demands on the ATC system will steadily increase. Throughout this transition phase DABS must compliment and support the performance-of the system in being, must interface smoothly with on-going elements of the system, and must allow for the amortization of the equipment it replaces.

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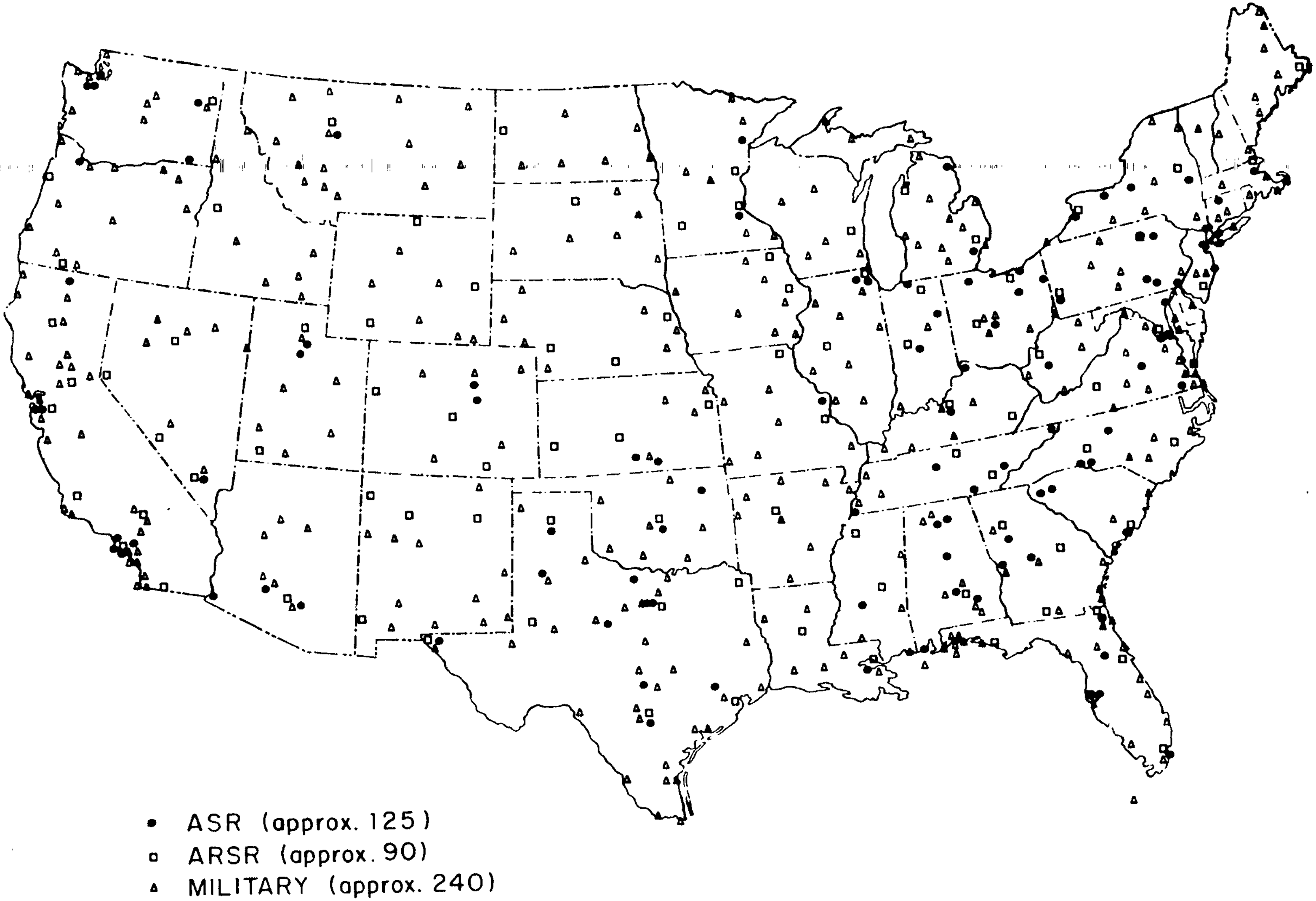
* Sources :

(1) "Report of the DOT ATC Advisory Committee", Vols. 1, 2, Dec. 1969
(2) "The National Aviation System Plan-Ten Year Plan, 1972-1981", DOT,, March 71.
(3) "Beacon System Interference Problem Subgroup; Minutes of Meeting, Nov. 17, 1971.
(4) "Problems Confronting the Federal Aviation Administration in the Development of an Air Traffic Control System for the 1970's", Twenty-Ninth Report by Committee on Government Operations House Report No. 91-1308, July 16, 1970.

Table II-4

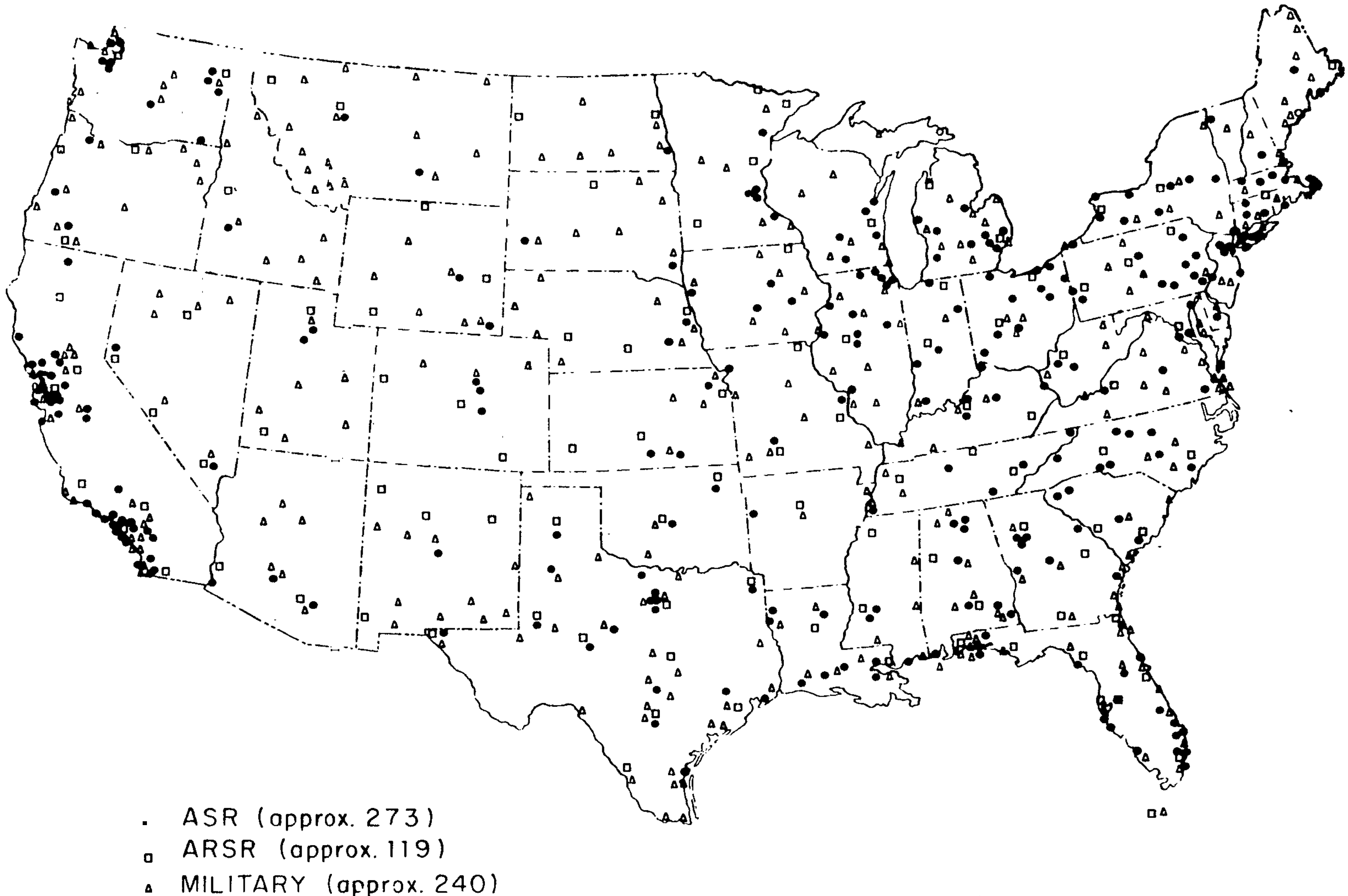
ATCRBS Continuous Duty Interrogator Environment for 1970 and 1980 (CONUS)

Interrogator Type	1970 Number	1980 Number
Enroute	90	119
Terminal	125	273
Military (approx.)	240	240
Total	4.55	632



Current ATCRBS Interrogator Locations (1970)
(FAA and Military Airfields Only)

Fig. II-1



Future ATCRBS Interrogator Locations (1980)
(FAA and Military Airfields Only)

Fig. II-2

This se-ction discusses three key aspects of the transition, with special regard to the constraints placed upon DABS design: coexistence with ATCRBS; the present and future military use of ATCRBS for ATC and IFF; and the need for interfacing with the NAS and ARTS systems.

1. Coexistence with AT CRBS

As delineated in the previous section, the CONUS ATC environment in the late 1970's, into which DABS will be introduced, will include the order of 600 ATCRBS interrogators and more than 200,000 ATCRBS transponder-equipped aircraft (assuming essentially all aircraft are transponder -equipped by that time). The transition to a s ys tern in which DABS&as supplanted ATCRBS will occur gradually over an extended period, probably in excess of a decade. During this transition period aircraft will be operating sometimes in areas into which DABS interrogators have been introduced, sometimes in areas using only ATCRBS. Similarly the aircraft operating in the surveillance volume of a DABS interrogator will be partly DABS equipped, partly ATCRBS equipped. Only during the latter phases- of the transition will it be possible to require DABS transponders for entry into certain airspace, and will aircraft operating over wide areas be able to depend on continuous DABS surveillance.

Coexistence thus requires that as DABS interrogators are introduced, ATCRBS surveillance of the same airspace must be maintained; and correspondingly, as aircraft are equipped with DABS transponders, they must still be able to respond to ATCRBS interrogations. There clearly exists the possibility of implementing DABS as a completely separate system, with functionallyand perhaps physically separate ground facilities and separate airborne boxes. Such an approach has the advantage that the existing system places a minimum of constraints on the design of DABS. However the requirement for interoperability points out strongly away from this approach for reasons of logistics and economics. A completely separate, comprehensive

ATCRBS system would have to be maintained until the implementation of DABS, both ground and air, was complete, at which time ATCRBS would no longer serve a useful purpose and could be abruptly decommissioned. A preferable approach, but one implying many constraints on DABS design, has DABS interrogators replacing ATCRBS interrogators, and thus of necessity serving ATCRBS-equipped as well as DABS-equipped aircraft, with DABS transponders capable of replying also to ATCRBS interrogations. As DABS becomes universal, ATCRBS, like an old soldier, will just fade away, with a minimum of residue. For this approach to represent a true saving over that of an independent system requires a high degree of hardware compatibility between DABS and ATCRBS, such that the cost of including ATCRBS capability in DABS interrogators and transponders represents a small fractional increment, appreciably less than the cost of procuring (and maintaining) separate parallel units.

Note that emphasis has not been given to the modification of existing ATCRBS transponders to DABS operation. Attractive as such a possibility seems at first glance, it is unlikely that the cost of modifying existing equipment, a large fraction of which would be five or more years old and nearing the end of its useful service life, will in general be attractive in comparison with that of replacement with new equipment. The substantial constraints placed on DABS by such an approach seem hardly worthwhile in view of the limited, if any, economic benefit.

The desire for DABS equipment to include an ATCRBS mode places a premium on the use of signal formats and operating frequencies for DABS similar, or if possible identical, to those already in use for ATCRBS. The most critical appears to be operating frequency; economic considerations bias the choice heavily towards the use of the ATCRBS frequencies, with a fallback position of other frequencies within the TACAN band, capable of using the same antennas and within the easy tuning range of transmitters and receivers.

The use of the ATCRBS frequencies for DABS, while highly desirable from the hardware compatibility standpoint, introduces the problem of RF interference between systems. Consideration must be given to the interference both of DABS to ATCRBS as well as ATCRBS to DABS, both on the up-and down-iink.

Uplink interference of ATCRBS to DABS is probably not a severe problem because of low channel occupancy time of ATCRBS interrogations. The main concern would be garbling of DABS interrogations by sidelobes of ATCRBS interrogators much closer to an aircraft than the DABS interrogator, e.g., enroute (Center controlled) aircraft transiting an area containing several ATCRBS interrogators. ATCRBS interrogations will not elicit false replies from DABS transponders.

Uplink interference of DABS to ATCRBS is a problem mainly because of the possibility of falsely triggering ATCRBS transponders. Without careful design of the DABS signal format, DABS interrogations will elicit false replies from ATCRBS transponders, in interrogator sidelobes as well as the main beam. To prevent this, the DABS interrogation format can be designed to suppress ATCRBS transponders by simulating an ATCRBS sidelobe interrogation, then complete the interrogation within the ATCRBS transponder suppression time of approximately 35 microsec. Alternately, a modulationformat can be used for DABS which continuously suppresses ATCRBS responses. With either approach the resultant suppression will have some effect on ATCRBS round-reliability, probably similar to that of an additional ATCRBS interrogator with Improved SLS.

Downlink interference of DABS to ATCRBS appears unimportant. Since the total interrogation/reply rate of a DABS transponder will be relatively low (once or twice every few seconds by one or two interrogator sites), the downlink channel occupancy time of a DABS transponder will be very low compared to that of an ATCRBS transponder; the interference to ATCRBS will thus be negligible.

Downlink interference of ATCRBS to DABS is potentially the most severe interference problem; in fact, the high level of downlink interference inherent in ATCRBS represents one of the motivating factors in developing DABS. This interference will diminish as an ever-increasing fraction of aircraft become DABS-equipped (and thus stop contributing ATCRBS interference), but could substantially impact the operation of DABS in the early stages of a transition period. While recognizing the potential seriousness of this problem, however, it must be realized that the ATCRBS interference environment is self-limiting in that whatever steps are necessary will have to be taken so that ATCRBS itself continues to provide satisfactory surveillance data on ATCRBS-equipped aircraft prior to and during the transition period. Thus only if the sensitivity of DABS to interference is much greater than that of ATCRBS (as may be the case, for example, with the use of monopulse techniques for azimuth angle measurement) will DABS be unworkable in an environment satisfactory for ATCRBS.

The problems of cross-interference between ATCRBS and DABS clearly disappear if different frequencies are used. This option must be left open, on the up- and/or downlink, until the questions of mutual interference are conclusively resolved.

One issue with regard to interoperability, the use of lock-out, arises whether or not the present ATCRBS frequencies are used for DABS. Lock-out refers to the suppression of responses by a DABS transponder to ATCRBS interrogations when the aircraft is under surveillance by a DABS interrogator. The capability for lock-out is required so that the implementation of DABS can reduce, or at least prevent the increase of, the interference on the ATCRBS downlink as the total air traffic increases.

Concern has been voiced relative to the impact of lock-out on the ability of ATCRBS interrogators to see targets of interest which are the coverage area of a DABS interrogator. The problem arises when two separate control facilities are concerned with the same airspace. In civil operations, this situation-occurs primarily at the interface between Centers, or between Center and Terminal Control; more substantial overlaps occur where military facilities desire to track military aircraft operating within the civil air space.

While the problem indeed exists, so does a relatively simple solution. Transponder lock-out can be controlled by the DABS interrogator, permitting suppression of the lock-out function whenever it is desired that certain designated aircraft or all aircraft in certain airspace respond to ATCRBS transponders. Further protection could be given to military operations, if required, by'suppressing lock-out completely on Mode 1, Mode 2, and Mode 4 interrogations. The additional ATCRBS interference caused by this selective suppression of lock-out is a small price to pay for the general reduction in unnecessary replies which lock-out provides.

2. Military Use of ATCRBS

The civilian ATCRBS is an outgrowth of the military IFF (identification friend or foe) systems of World War II and the post-war period. The National Standard for ATCRBS[1] accommodates continued use of this system for particular military functions as well as for control of military aircraft within the civil airspace. Within or contiguous to CONUS, military interrogators are employed for ATC functions at military airfields as well as on ships and at anti-aircraft batteries (primarily NIKE sites) to assist in target identification; they are also used for tactical aircraft control as part of training maneuvers. To support these military functions a number of special interrogation modes are employed in addition to the civil Modes A(4096 code reporting) and C (altitude reporting). A brief description of these modes and their utilization follows:

(1) FAA Advisory Circular 00-27; U.S. National Standard for the IFF Mark X (SIF) Air Traffic Control Radar Beacon System Characteristics (ATCRBS).

Mode 1 employs a two-pulse interrogation, and provides for 32 pilot-selectable response codes. It appears to be used on a limited basis for tactical combat surveillance in conjunction with military tactical data systems, e. g. , NTDS, MTDS; it is seldom used in CONUS except in training exercises.

Mode 2 employs a two-pulse interrogation, and provides for 4096 response codes; code selection is a maintainance operation, providing a semi-permanent aircraft identification. Mode 2 is interrogated on a regular (interleaved) basis by all joint-use interrogators in the CONUS (in the joint-use sites the Mode 2 returns are used only by the military). All military command and control functions operate on Mode 2 surveillance data. It is identical in technical function to Mode 3.

Mode 3 employs a two-pulse interrogation, and provides for 4096 pilot- selectable responses (pre-AIMS military transponders provided 64 reply codes). It is identical to the civil Mode A, and is used for civil ATC of military air craft.

Mode 4, employing special interrogation and response formats, provides a secure IFF capability. There are at present only a few interrogators capable of interrogating Mode.4 in the CONUS, and these are either research or training site s. At an operational Mode 4 site, the Mode 4 interrogations are not periodically interlaced with Modes 1, 2, and 3 interrogations, but are called for only on demand. If the use of Mode 4 in CONUS is not extended significantly, there will be no serious interference problem between military activity on this mode and DABS or ATCRBS.

The use of these modes at interrogator sites varies depending on the function of the particular site. In general more than one mode is used at a time, in an interlaced sequence controllable at the site. It is not possible to generalize about the relative utilization of various combinations further than to say that the most commonly used sequences are probably: l-2-3 for military sites; and 3-3-C for FAA sites. The 2-3-C and 2-3-C-3 sequences will be used with the common digitizer at joint-use sites.

The Department of Defense has undertaken an extensive development and implementation program, AIMS, with the goal of equipping all military aircraft with transponders meeting the requirements of the civil ATC system (Modes A and C), as well as accomplishing a general updating and improvement of military IFF capabilitie s . Together with the development and production of the TPX-42, a terminal beacon/radar processor providing decoding and alphanumeric display of the ATCRBS replies, the DOD investment in new ATCRBS-related equipment will exceed $700M. There is the clearly stated, and under standable, desire to amortize this investment over a reasonable period,(1) at least a substantial fraction of the useful service life of the' equipment, before requiring it to be replaced. Thus there is the clear requirement for the DABS program to proceed in such a manner to accommodate both the special military functional requirements and the need to obtainuseful service from the extensive investment in ATCRBS.

Ultimately it seems reasonable to expect that all military aircraft will have transponders including DABS capability, and, perhaps on a longer time-scale, that military interrogators, at least those concerned with air traffic control functions within CONUS, will incorporate a DABS mode. It is not possible to predict with any certainty what course such a transition will take. The DABS development effort clearly must be coordinated with the DOD, since military planning could have a significant impact on decisions relating to the-design on implementation of DABS.

3. NAS/ARTS Interfaces

NAS and ARTS may be envisioned as large data processing systems which accept raw surveillance data, flight plan data, and controller commands as inputs. The chief outputs of these systems are displays, both PPI and tabular, for the controllers, flight progress strips (NAS), and flight plan data. These sys terns should be widely implemented by the start of the time frame envisioned for the transition to DABS. The major impact of DABS

(1) In a recent presentation to the FAA 3rd Annual Planning Review Conference, Mr. John W. Klotz, Assistant Director (Combat Support), Office of the Director of Defense Research and Engineering, suggested a 5 to 7 year period as a minimum,

on NAS and ARTS will be a change in the character of the surveillance data provided to those systems, plus the introduction of a data flow from the control center to the interrogator site for target assignment, interrogation mode control, and transmission of ATC instructions to DABS-equipped air craft. To first order, no change will be required in the flight plan and display processing aspects of NAS and ARTS.

By the time DABS is introduced presumably all aircraft operating in controlled (mixed or positive- control) air space will be ATCRBS-equipped, many with altitude reporting. Radar will continue to be used as a back-up in the event of transponder failure, to detect unequipped intruders, and to display regions of heavy precipitation. Thus NAS and ARTS will continue to process-search radar targets and non-discretely addressed beacon targets, while requiring the expanded capability of processing DABS targets. The extent to which the surveillance data processing must be modified in NAS and ARTS reduces to two main considerations: (a) the way in which the new DABS interrogators deal with ATCRBS-equipped targets, and (b) the nature of the DABS system itself, primarily with respect to azimuth angle measurement and interrogation management. These two points will be discussed briefly here, in terms of NAS/ARTS interfaces. More de tail will be found in Chapter III, parts I and J.

The DABS interrogator will necessarily operate in two modes, an ATCRBS mode to handle targets equipped only with ATCRBS transponders, and a DABS mode, or discrete-address mode, for DABS transponders. Although the ATCRBS mode could simulate exactly the characteristics of present-day interrogators, there exists an opportunity to improve system performance, with respect to data rate, reliability, and angular accuracy and resolution above that achieved today. Improved angular accuracy may be obtained by the use of some form of monopulse, requiring a change in the angle measurement processing (hardwired in the Common Digitizer, software in ARTS-III). An increase in data rate would not force a change in the character of the NAS/ARTS surveillance data processing, but only an increase in the frequency of this processing. Depending on available excess computer capacity, this might be costly to attain.

Operation in the DABS mode requires scheduling of interrogations and azimuth angle measurement on one or a small number of replies. At sites equipped withlelectronically-scanned antennas, the option exists for varying the data refresh rate on DABS targets depending on the flight regime and air traffic environment.

During the transition period it is likely that NAS-equipped Centers will be required to accept data simultaneously from unmodified ATCRBS interrogators-as well as from new DABS/ATCRBS interrogators. ARTS, on the other hand, typically receives data only from a single interrogator site, and will'thus not have to accept data from both types of facility simultaneously.

A new requirement placed upon NAS and ARTS will be for target assignment, including hand-off from one interrogator site to another, and for use of a back-up site to provide data if unavailable from the primary site. This is one of several functions which will entail a flow of data from NAS/ARTS to the interrogator site, a flow not present in today's environment, and thus require a new interface between the control facility and the interrogator site.

III. DESIGN OPTIONS

A. Introduction

The purpose of this chapter is to outline the range of options which emerge from a preliminary analysis as reasonable candidates for elements of a discrete-address beacon system. It summarizes important parametric, hardware, and system options which influence the design of DABS. Included as parametric options are the choice of operating frequencies, modulation waveforms, coding format and message content. It reviews alternative methods for target angle detection, interrogator antenna scanning, and methods for realizing effectively omnidirectional coverage from airborne transponder antennas. It also considers the salient system choices associated with interrogation management, sensor data processing, and overall surveillance system organization. The pros and cons of each option are summarized to be used as a point of departure in making baseline decisions.

The frequency option is unique in that it directly influences all the other design choices. Specifically, if DABS is designed to operate in a separate frequency band from ATCRBS, interference problems are reduced and new hardware and system options are opened up. However, economic considerations strongly favor the use of the ATCRBS frequencies for DABS. For this reason most of the remaining options enumerated in Chapter III reflect a bias in favor of the use of the ATCRBS frequencies.

Except for the selection of operating frequencies, there is no attempt in this chapter to choose one option over another. However, critical or forcing options are identified in those cases where a series of system decisions are interrelated.

B. Operating Frequency

The choice of operating frequency for DABS influences all the remaining system options. The main issue is whether or not to use the present ATCRBS band at 1030 and 1090 MHz. From preliminary considerations, 1030/1090 MHz appears to be the most economical choice,

There are, however, advantages to alternative choices. This section considers the relative advantage of the present ATCRBS bands as opposed to another band or pair of bands, either within the TACAN band or near 1600 MHz, and summarizes the technical, economic, and political factors which will influence the final choice of operating frequencies for DABS.

1. 1030/1090 MHz

The main reason for utilizing the ATCRBS frequencies for DABS is to allow the use of common antennas, transmitters, and receivers in ground and airborne equipment. This results in a significant cost savings in the development of interrogators and transponders capable of operating in both ATCRBS and DABS modes. Use of the present bands also clears the way for the development of the new system without incurring the delays and uncertainties of obtaining new frequency allocations.

However, operation of DABS on ATCRBS frequencies introduces potential interference and channel loading problems. The possible forms of mutual interference include false triggering of replies, garbling, mutual suppression, fruit generation and overinterrogation. To avoid or minimize these problems, the designer must consider measures such as the use of alternative modulation and coding techniques, intentional suppression of ATCRBS transponders, careful scheduling of ATCRBS and DABS interrogations from a single site; and synchronization of interrogations from adjacent sites.

2. Other Frequencies

The primary advantage of implementing DABS outside of the ATCRBS bands is the elimination of RF interference between the old and new beacon modes. An additional advantage accrues by allowing DABS to operate independently of ATCRBS, eliminating the need for interleaving or time-sharing the DABS and ATCRBS interrogations. The capacity of the DABS system is increased while the ATCRBS channel loading is simultaneously reduced (assuming lock-out is employed).

Possible frequencies for DABS other than the ATCRBS frequencies fall into two categories: frequencies within the TACAN band (96 2- 1213 MHz), and others; in the latter category, principal consideration has been given to frequencies around 1600 MHz.

Several advantages accrue from the use of frequencies within the TACAN band. A high degree of hardware compatibility is achievable, almost equivalent to that on 1030/1090; the availability of low-cost general aviation distance measuring equipments (DME) demonstrates the capability to produce low-cost RF hardware tunable over this band. A transponder could be designed to operate at two frequencies in this band at a relatively small cost increment. Equally important, the interrogator antennas, a major cost item, could accommodate the new frequencies as well as ATCRBS.

Examination of the TACAN channel assignments, Fig. III- 1, suggests some interesting possibilities. In general, TACAN channels are paired with ILS and VOR frequencies to provide the common-use VORTAC system, in which the DME function of the TACAN serves also to provide a DME function in conjunction with civil VOR's. However, certain TACAN channels in the vicinity of 1030 and 1090 MHz have no paired VOR frequency. These channels have limited utilization, especially in CONUS, in order to minimize interference to ATCRBS. However, each of these “special use" channels comprise a pair of frequencies, with the result that within the TACAN band there are two additional sub-bands, 962-977 MHz and 1151-1156 MHz, which are not used either up- or downlink in the common-use VORTAC system. The frequencies in these bands share the same protection as those in the vicinity of 1030 and 1090 MHz. (It should be noted that an experimental military aircraft communication/navigation sys tern, PLRACTA, is using 970 MHz for its feasibility tests.)

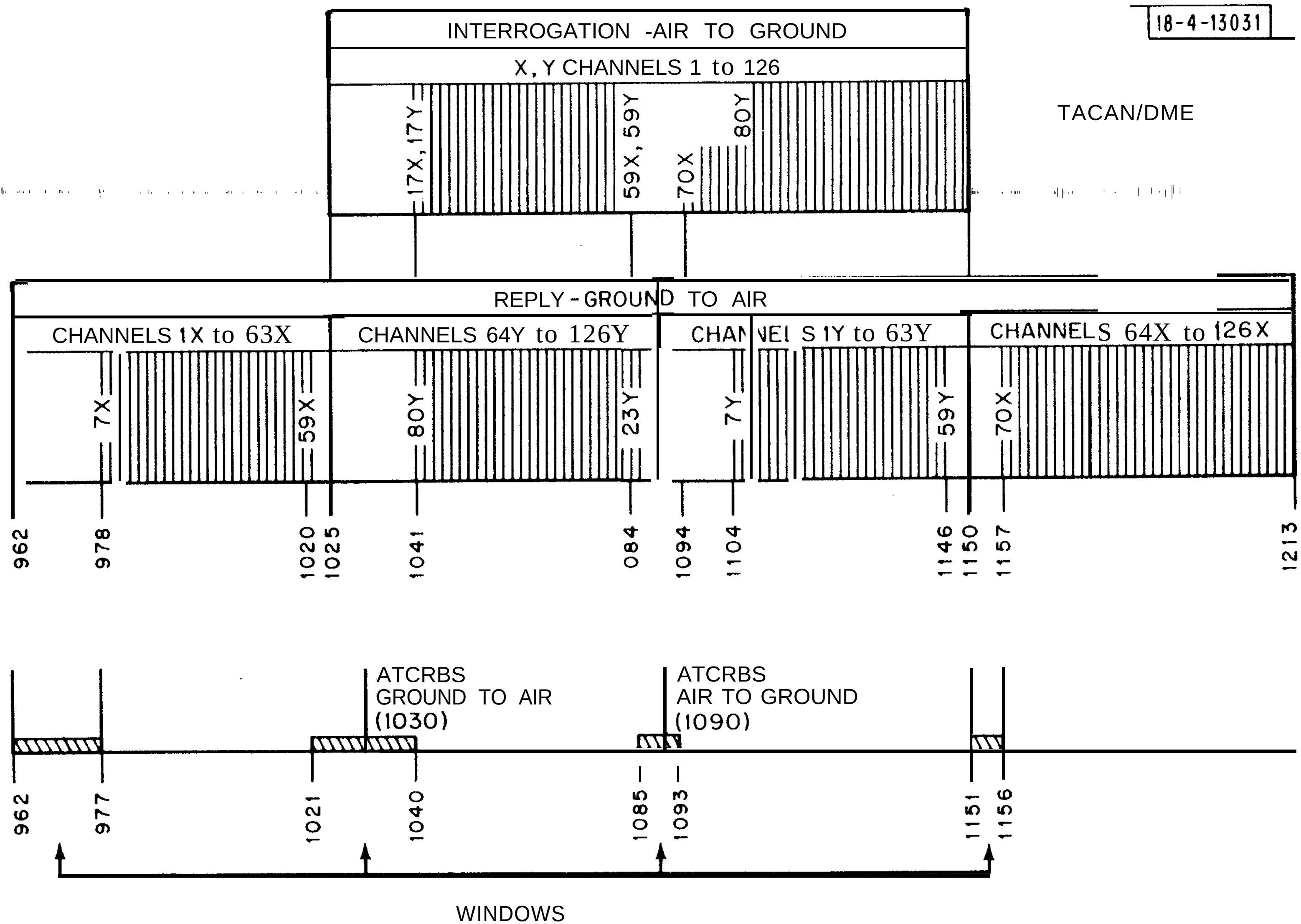


Fig. 111-l. TACAN/DME and ATCRBS channels.

If, as appears likely, the major interference problems between DABS and ATCRBS occur on the downlink, a possible scheme uses 1030 MHz for the DABS up-link, time-shared with ATCRBS, but places the DABS downlink around 970 or 1153 MHz. The choice between these two is not clear: 970 MHz offers a wider protected bandwidth, but is less desirable in that it forces the transponder transmitter to operate on frequencies 120 MHz apart, one above and one below the receive frequency, and requires the receive mono-pulse system to operate over a 120 MHz bandwidth if it is going to accommodate ATCRBS as well as DABS; the available protected bandwidth at 1153 MHz is only 6 MHz wide, possibly requiring crystal control of the transponder output, but the two downlink frequencies are then separated by only 63 MHz, both above the up-link frequency, thereby simplifying the transponder transmitter and the interrogator receiver and monopulse design. A detailed study of these design issues, plus an investigation of the present utilization of these frequencies for unforeseen sources of interference, is required to resolve the choice between 970 and 1153 MHz.

If the ATCRBS/DABS up-link interference is more serious than projected, requiring separate up-link frequencies, then both 970 and 1153 MHz could be used for DABS; the choice as to which is used for up-link, and which downlink, depends on considerations of relative transmitter and receiver frequency stability, and interference to and from TACAN.

If operation of DABS within the TACAN band proves impossible, either on the present ATCRBS frequencies or elsewhere, the aeronautical navigation band around 1600 MHz has been suggested as an alternative. The frequency availability picture within this band is confused at present, largely due to its proposed use for links to and from aeronautical satellites. Also, there is little chance of achieving appreciable hardware compatibility with ATCRBS; it is questionable whether even interrogator antennas could be shared. Therefore, if operation outside the TACAN band is necessary, consideration should be given to even higher frequencies, for example in the band around 2.8 GHZ presently used for ATC approach radar. With the increasing emphasis on the use of beacons, and the decreasing emphasis on radar, it might be possible to make some frequencies available in this band. An advantage of this approach is the ability to achieve the required angular accuracy and resolution with physically smaller antennas. The disadvantage, which also applies at least in part to operation at 1600 MHz, is that the lack of compatibility suggests an almost independent DABS system overlaying, and eventually supplanting, ATCRBS.

C. Modulation and Coding

The choice of modulation and coding for the discrete-address beacon system-will affect message duration, reliability of message delivery and, through these factors, the number of hits required per scan for surveillance and message transmission. The choice of signal format also affects the cost of the discrete-address transponder, a key element in the acceptability of DABS to general aviation. The type of modulation and coding for DABS, in turn, depends on several other design options, such as DABS operating frequencies, required communication capability (message length, frequency, delivery probability, and delay), and the use of monopulse on the downlink.

The choice of DABS operating frequency determines the channel interference environment of the up-link and downlink. As indicated above, ATCRBS compatibility considerations suggest the use of 1030/1090 MHz for DABS. In Chapter II mutual interference between ATCRBS and DABS on 1030/1090 is discussed in detail. The important interference considerations will be briefly reviewed here.

ATCRBS interrogation will result in some garbling of discrete-address interrogations and up-link messages. On the downlink, ATCRBS replies will provide the principal interference background. High ATCRBS reply rates will make it difficult for DABS to operate with one or two hits per scan.

DABS up-link transmissions on 1030 MHz may either trigger, suppress, or not affect ATCRBS transponders. The range of characteristics exhibited by existing transponders makes it difficult to select DABS signal formats which do not affect ATCRBS transponders at all, If DABS interrogations are designed to intentionally suppress ATCRBS transponders to avoid triggering them, the effect of such suppression on ATCRBS must be investigated. DABS to ATCRBS downlink interference will be small if DABS can operate with a very few hits per scan.

Assuming that a DABS interrogation (on 1030 MHz) initially suppresses ATCRBS transponders by simulating a side-lobe situation, there remains the problem of later parts of the DABS interrogation triggering a false ATCRBS reply after the ATCRBS transponder comes out of suppression. Alternative solutions are to keep the length of DABS interrogations less than the minimum ATCRBS suppression interval (25 μsec), to lengthen the ATCRBS suppression interval (a modification of existing designs), to require ATCRBS transponders to be re-suppressible while suppressed (also a modification of most existing designs), or to use a DABS modulation format which generates re-suppression.

With regard to message delivery reliability and delay, the ATCRBS interference background on 1030/1090 MHz and the DABS self-interference are key issues; the signal-to-noise ratio is sufficiently high to counter errors due to channel noise, Considering first the ATCRBS interference, several different approaches can be taken, representing varying relative emphasis on modulation and coding. In one approach each message is transmitted more than once, with the aim of achieving one reception "in the clear", i.e., not affected by interfering signals. Garble sensing and/or error detection coding is required to determine when a message should be accepted as correct.

The emphasis- in this approach is on efficient modulation to keep messages short, thereby lessening the probability of hits by interference.

An alternative approach attempts to achieve a very high round reliability in the face of 'interference by using a modulation format which provides some degree of interference protection and/or by the use of error correction coding. Since the form of the interference is known(i. e., ATCRBS transmissions) the effects of the interference on various modulation and coding systems can be evaluated. In fact, certain relatively simple modulation formats provide a significant degree of protection against ATCRBS transmissions,

The problem of DABS self-interference (i.e., interference between interrogation from and responses to different DABS interrogators) has not as yet been considered in detail. At early stages in the DABS implementation it will be negligible due to the relatively low density of DABS-equipped traffic. Careful system planning will be required, however, to prevent it from becoming a limitation on ultimate system capacity. Coordination between interrogator sites should provide an effective means of dealing with the problem.

The use of monopulse indirectly influences the modulation and coding choices. If a signal format requires several interrogation/response cycles for error control, this may be used to advantage in the monopulse angle processing. Also, the monopulse processor can make better use of the information-bearing part of the reply if the energy in the signal is independent of the information, as is the case for example with frequency-shift keying (FSK) or phase-shift keying (PSK) but not with the on-off pulse modulation used in ATCRBS. However? the monopulse system requirements do not appear strong enough to be a determining factor in the choice of signal format.

Multipath has been mentioned frequently as an important factor in the choice of the DABS signal format. However, on closer examination it appears that the only multipath which occurs with significant amplitudes cannot be alleviated by any reasonable modulation system. In particular, only reflections from objects in the main beam of the interrogator antenna will result in signals with an amplitude comparable to that of the direct path. For narrow antenna beams, the resulting path geometry is such that the path-length differences are too small to be resolved by reasonable modulation bandwidths. (This neglects the rare case of multiple large-amplitude reflections from fortuitously-placed objects).

There are of course important effects due to reflections from objects in the main beam; ground reflections will result in a significant vertical lobing of the antenna pattern, while buildings and other obstructions will cause horizontal pattern distortions. These effects are most effectively overcome by antenna design and siting.

Reflection from objects in the beam can cause the same target to appear at more than one azimuth (a form of multipath, but not the one considered above which presumes simultaneously-excited paths). This has presented a problem for ATCRBS in some locations. Its effects are alleviated by "improved" interrogation side-lobe suppression (IISLS). With discrete code target identification, either in ATCRBS or DABS, such "ghost targets" can be removed by data processing. DABS lock-out should prevent their appearance entirely,, except perhaps fleetingly on initial acquisition of a pop-up target.

The discussion of modulation and coding will proceed under the assumption that no attempt will be made to design the modulation and coding to counter multipath garble.

1. ATCRBS-Compatible Modulation Format (on 1030/1090 MHz)

As discussed earlier, economic considerations dictate that preference be given to ATCRBS-compatible modulation formats. This includes two classes of waveforms: those which conform strictly to the ATCRBS National Standard, and those binary pulse amplitude modulated (PAM) waveforms which are consistent with the ATCRBS bandwidth limitations and which can be transmitted and received by ATCRBS RF components. These will be designated as "standard ATCRBS" and "ATCRBS-like" waveforms respectively. An example of an ATCRBS-like waveform would be binary PAM pulses 0.5μ sec wide with 1.5μ sec interpulse spacing. "ATCRBS-compatible" will be used to designate waveforms in either of these subclasses. The following discussion considers the advantages and disadvantages of ATCRBS-compatible modulation formats for DABS, as well as the relative merits of standard ATCRBS as opposed to ATCRBS-like waveforms.

The use of ATCRBS-compatible waveforms for DABS has numerous advantages. Pulse amplitude modulation is relatively simple and inexpensive to implement. Properly designed ATCRBS hardware has proved to have adequate reliability. Only a moderate bandwidth is required, and readily available transmitter power levels and receiver sensitivities are well matched to the link requirements. By tightening certain transponder specifications the achievable range accuracy can be made adequate for the upgraded third generation ATC requirements.

The most important advantage of the use of ATCRBS-compatible modulation for DABS is the resultant economy of interrogators and transponders required to operate in both DABS and ATCRBS modes. In addition to the savings in equipment development and production, maintenance of the new equipment is simplified if there are no radical changes in the modulation format or RF components. The avionics industry has extensive experience with PAM techniques in beacon systems and has a natural interest in maintaining maximum compatibility and similarity between the ATCRBS and DABS systems.

On the other hand, PAM has several disadvantages relative to other modulation formats. It is relatively inefficient in the use of signal power and bandwidth, and relatively susceptible to multiple and self-interference (e.g. garbling between transmissions from identical equipments). For a given bandwidth, other formats can provide higher data rate and ranging accuracy, with lower transmitter power. The central question, however, is not whether an ATCRBS-compatible format is "optimum" in a technical sense, but whether it provides an adequate base for meeting the system requirements.

Interference problems are aggravated by the use of an ATCRBS-compatible format for DABS. The primary effects of interference are false triggering of replies and suppression gates, and garbling of up-link and downlink transmissions, These interference effects can be minimized by careful design of the signal format.

On the DABS up-link, the use of the standard ATCRBS format with message lengths exceeding 12-15 bits results in a high probability of triggering false replies from any ATCRBS transponder in the DABS interrogator beam (or, if close enough, in a side-lobe). With an appropriate choice of parameters, the use of an ATCRBS-like format for the DABS up-link can substantially alleviate the interference to ATCRBS.

On the DABS downlink, the use of the standard ATCRBS format provides no protection against ATCRBS-generated interference. An ATCRBS-like waveform may be able to provide some protection; the need for a non-standard format in the DABS downlink depends on the magnitude of the interference environment.

2. Other Modulation Formats on 1030/1090 MHz

Modulation formats which are not ATCRBS-compatible will in general lead to greater complexity in transponders which must operate in both DABS and ATCRBS modes. The reasons for considering these alternatives include gains in efficiency, range accuracy, and resistance to ATCRBS interference. A gain in efficiency could be applied to shortening the transmission time for a single bit of information and/or lowering the transponder power significantly below 500 watts without degrading maximum range performance.

The most important alternatives to binary PAM are binary frequency-shift keying (FSK), binary phase-shift keying (PSK), and binary differential phase-shift keying (DPSK). For reasons of transponder complexity only binary modulation systems appear interesting. Of these, FSK is probably the easiest to implement and can be made most rugged, i.e., tolerant to frequency inaccuracies and hardware degradation. PSK and DPSK provide higher communication efficiency at the cost of somewhat greater complexity. The differences are small, however, and vary with different implementation techniques.

All three techniques offer important advantages over binary PAM. A given level of performance can be achieved at lower ratios of signal-to-noise and signal-to-interference. With a proper choice of parameters, substantial rejection of ATCRBS interference can be achieved. The signal power is constant during the transmission, and independent of the information content; this both simplifies the design of transmitters, especially solid-state transmitters, and makes more signal energy available for monopulse processing. Finally the existence of well-defined transitions between symmetrical states (i.e., between "1" and "0") results in more precise ranging for a given signal bandwidth than is achieved by observing the leading edge of a pulse.

An important variant of each of these formats is its pulsed version, i.e., pulsed-FSK or pulsed PSK. By proper selection of the pulse envelope and repetition frequency (the latter a multiple of 0.5 MHz), ATCRBS transponders will be continuously re-suppressed, thereby eliminating false triggering. The DABS information is contained in the frequency or phase of each pulse.

These advantages, however, are obtained at the price of greater transponder and system complexity, especially since ATCRBS, using binary PAM, must continue to exist in parallel. If the final frequency choice permits

RF hardware compatibility, binary PAM is preferred as long as it can provide adequate system performance. If, however, interference or other considerations dictate the use of frequencies outside the TACAN band, thereby precluding RF hardware compatibility, these modulation formats must be given serious consideration.

3. Modulation Off 1030/1090 MHz

On frequencies free of ATCRBS interference, the choice of a DABS signal format becomes simply an issue of transponder cost versus system performance and capacity. The same performance considerations discussed above for operation on 1030/1090 MHz still apply, with the exception of resistance to ATCRBS interference. For operation off 1030/1090 MHz but still within the TACAN band, the possible use of RF hardware DABS and ATCRBS modes biases the choice of modulation format towards one which is ATCRBS-compatible. At 1600 MHz, or other far removed frequencies, the choice is unconstrained by any hardware compatibility considerations.

4. Error Control

For many of the messages to be transmitted on the DABS up-link, it is critically important that the message be displayed correctly to the pilot, or not at all. With the downlink available to confirm message receipt, loss of a message can be quickly sensed and the message retransmitted: display of an incorrect message, however, can result in initiation of an action, for example an incorrect evasive maneuver, causing or worsening a dangerous situation.

On the downlink, the error control requirements are less critical. Receipt of an incorrect identity code or altitude report will be quickly sensed by comparison with replies to previous and subsequent interrogations; garbled or lost confirmations of up-link messages will result in retransmissions, somewhat reducing system capacity but not seriously as long as the incidence is relatively low.

and is easily applied to a burst type of communication system such as DABS. This special case, as well as the broader class of error detection codes; deserves consideration for reliably recognizing erroneously decoded messages before they are displayed.

The need for redundancy in the transmission of the address code part of the interrogation requires further study. Clearly one does not wish the "right" message displayed in the wrong aircraft; however, with relatively long (12 to 20 bit) address codes, the probability is extremely small that the transmitted address code will be transposed into one corresponding exactly to that of another aircraft in the antenna beam.

Another approach to error detection can be based on garble sensing which attempts to detect the presence of interference by checking the detailed structure of the received signal. Garble sensing is presently used in the signal processing of ATCRBS replies by NAS and ARTS. For a PAM signal format the amplitude, spacing, and width of successive pulses of the received signal can be checked electronically, leading to the detection of interfering pulses with high probability. Similarly the envelope and switching times of PSK and FSK signals can be checked as a means of garble sensing. The effectiveness of simple garble sensing schemes for each of the types of modulation being considered for DABS should be investigated based on the known structure of the interfering ATCRBS signals.

Garble sensing can be used either alone or in conjunction with other forms of error detection. Because of the increased receiver complexity required for its implementation, its use may be more appropriate on the downlink rather than in airborne transponders. However, a relatively simple form may provide a useful adjunct to error detection on the up-link.

D. Message Content

DABS serves the dual functions of airspace surveillance and transmission of certain ATC-related messages between the ATC ground facility and air craft. The message characteristics required to support both these functions are important aspects of the DABS design. The major questions to be resolved relate to the form of aircraft address code to be employed, and the message length to be accommodated as part of a single transmission. Other questions include the details of message structure and the means of achieving the desired message delivery probability.

More consideration has been given to the up-link message requirements than to the downlink; the main identified uses of the latter are altitude reporting and up-link message confirmation. Any extensive additional uses of the downlink, such as the reporting of other aircraft sensor data, should be identified early enough to permit inclusion in the DABS design.

1. Aircraft Address Code

The length of the aircraft address code depends on whether each aircraft is assigned a unique code, permanently associated with that aircraft, or whether aircraft are assigned codes by ATC for each flight, or a part of al-flight, as is planned for discrete code assignment using ATCRBS.

a. Unique Codes

If every aircraft is given its own unique digital identity code, to be "hardwired" into its transponder, enough identity codes will have to be provided to accommodate the 600, 000 plus aircraft projected for the 1990-95 time period. This would imply a minimum address length of 20 bits. If for convenience the identity codes were made identical to the aircraft's registration "number" (tail number), at least 36 bits would be needed to accommodate the alphanumeric characters used under the present international convention.

The main disadvantage of unique codes is the requirement for long addresses to accommodate the projected aircraft population. Some advantages are (a) the avoidance of ambiguities due to two aircraft having the same identity code, and (b) the use of a "hardwired" code may result in a lower cost transponder.

b. As signable Codes

If aircraft are assigned identity codes that are unique only within a particular control area, the peak regional traffic load projections determine the required address length. If the Los Angeles Center is considered as a typical high density region, one can expect a peak instantaneous airborne counts of the order of 7,000 in 1995. A 13-bit address code would thus accommodate the projected Los Angeles ARTCC traffic load. A 16-bit address code would accommodate the projected 63,000 instantaneously airborne aircraft over the entire CONUS in 1995.[(1)]

c. Hybrid (Fixed/Assignable) Address Codes

A number of variations in code assignment strategies de serve study, such as air carrier codes based on flight number, combined with partial tail numbers or arbitrary assignments for general aviation aircraft. The main advantage of assignable address codes is the shorter addresses. A disadvantage is the increased likelihood of an aircraft setting its address code incorrectly.

There are a number of ways to combine fixed and assignable addresses. However, considering the problem of inserting a DABS-equipped VFR aircraft into the system and the importance of the proper aircraft having the proper address, the following approach seems reasonable:

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(1) The National Bureau of Standards has studied ATCRBS code assignment plans using only 800 of the 4096 discrete codes to determine the number of code changes required by various strategies. The traffic model used in this study was based on FAA statistics of peak loads experienced at major terminals and enroute centers and would not be applicable to traffic in the post 1980 period. (The peak load within any center at any hour was less than 800). The number of aircraft required to change discrete codes upon handover to another center was 13% at minimum for the particular traffic model and code assignment strategies considered.

Fixed address for all general aviation aircraft;
Assignable address for all military aircraft;
Flight number address for all air carrier aircraft.

Since the general aviation aircraft population will outnumber both military and air carrier aircraft, the address length required for this scheme is essentially the same as required by unique codes.

An alternative scheme which retains the advantages of hardwired codes while still keeping addresses short is the following. A short, hard-wired address code (say 12 bits) is built into DABS transponders, with an assignable tag of a few more bits attached to the 12-bit code when replying to provide unique identity codes within a control area. This tag could be automatically'assigned by a DABS interrogator and included in replies without pilot intervention.

2. DABS Message Identifier

It will be necessary to identify at least the following types of DABS messages:

Surveillance request, with altitude reply;
IPC message or acknowledgement;
ATC message or acknowledgement.

At least one additional bit is required to set lock-out in the transponder. Even considering many more unanticipated types of DABS transmissions (e.g. to read out special sensors on board aircraft), a 6-bit message identifier appears adequate.

3. IPC Messages

If both "do" and "don't" IPC commands can be displayed simultaneously, and each can display "up, down, left, or right", then 6 bits can accommodate the range of commands. It appears then that 8 bits would be adequate for the IPC message, including "attention-getter" and "display-test" signals. Because of the short IPC message length, it is practical to consider transmitting the state of the IPC display to the ground whenever something is being displayed. This can be used as a valuable check to insure that no one is executing unnecessary or incorrect commands.

Pilot acknowledgement of displayed IPC commands appears to be desirable and would only require an extra bit on the downlink (which typically would be transmitted after the pilot has pushed an acknowledgement button on the display).

4. ATC Messages

Time-critical ATC communications (those which must be delivered to aircraft within 15 seconds) are candidates for transmission via a DABS data-link because of the response time of this system. These messages would probably be short and would provide instructions to change heading, altitude, and speed, to enter or leave a holding pattern, etc. Use of a shorthand language to specify a set of standardized commands would result in economical transmission of ATC command information. If there is sufficient system capacity to handle long ATC messages, it may be desirable to split them into short segments for transmission on successive scans. If this is done the question of maximum message length is of less interest than the average message length and number of messages per aircraft per unit time.

The use of data-link messages in an automated ATC system is a topic under study within the FAA.[1] This effort should be coordinated with the DABS program to ensure a resolution of the role of DABS as an ATC communication sys tern.

(1) "Recommendation for Federal Aviation Administration Data-Link Development Program", July 1971, DOT, FAA SRDS Staff Study.

E. Interrogator Antenna

The choice of the interrogator antenna subsystem is one of the more far-reaching design decisions involved in the DABS system definition. The interrogator antenna system represents a major hardware committment and at the same time directly constrains the basic options available to other design areas.- Some of the chief characteristics of the antenna such as scan rate, beam agility, and beamwidth relate directly to the DABS system parameters of data refresh rate, target capacity, and angular accuracy. A constraint is imposed on the DABS antenna design if it must be collocated with the search radars. Many of the existing sites will no doubt be used for DABS interrogators, but it is not clear at present whether the se new sensors should be structually integral with the radars.

1. Antenna Performance Bounds

To place the possible antenna options in context, one can bound the range of antenna system performance specifications appropriate to the DABS problem. These bounds are independent of the ultimate choice of hardware configuration and apply to operating frequency, data refresh rate, elevation coverage, azimuth pattern, and degree of beam agility.

a. Operating Frequency

The frequency options are relatively well defined. Preferably DABS will use the ATCRBS frequencies of 1030 and 1090 MHz. If either the up-link or downlink or downlink or both are placed elsewhere in the TACAN/DME band (962-1213 MHz) there will be little effect on the antenna de sign. A decision to operate DABS in the vicinity of 1600 MHz, or higher, would require separate antennas for ATCRBS and DABS targets because of the difficulty in designing a single antenna with 40% or greater bandwidth. For this reason such a choice is exceedingly unattractive. A decision between 1030/1090 MHz and some other allocation within the TACAN/ DME band has little effect on the relative merits of the various antenna options.

b. Data Refresh Rate

Data refresh rates of interest range between once per second and once per ten seconds. The required refresh rate is a critical parameter for a rotating antenna; however, allowing for the possibility of multisided configurations, any rate in the range could be met by a rotator. Of course, agile-beacon arrays can easily operate over the required range.

c. Elevation Coverage

The DABS system, like ATCRBS, will make use of reported altitude, hence the elevation problem is one of coverage rather than elevation measurement. The present upper limit of 45^{o} in elevation remains a reasonable compromise, since the range of operational altitudes of aircraft is not expected to increase greatly and 45^{o} provides an acceptable cone of silence no more than six or seven miles in radius,

The requirement for good low angle coverage strongly affects the antenna de sign, since it must be achieved with minimum illumination of the ground. Ground illumination is responsible for deep nulls in the present ATCRBS elevation pattern. It can be decreased only by providing a narrow intrinsic beam in elevation, requiring significant vertical aperture. An ability to lift the beam over obstacles is desirable, since many sites which will have to be used are far from ideal, especially in terminal areas.

The shape of the antenna pattern in elevation is also critical. Nearly constant gain from the peak of the intrinsic beam to 45^{o} elevation is desirable so that replies from all targets at a given slant range will arrive with nearly equal power. A large gain variation with elevation leads to a potentially large difference in received power from two close-in targets at the same slant range but at different elevations. If the receiver dynamic range were increased to handle both of these close-in targets, it would be difficult to distinguish between the attenuated replies from the high elevation target and reflected replies originating from the low elevation target and appearing in side-lobes of the high gain part of the beam.

It is difficult to form a beam which has nearly uniform coverage to high elevation angles as well as sharp cutoff at the ground. With reflector-type antennas, this calls for multiple feeds and/or considerably more vertical aperture-than is needed to obtain the sharp cutoff alone. Thus the specification on elevation coverage should permit the maximum value of gain fall-off at high elevation angles consistent with adequate performance, recognizing the relatively small number of targets at these elevations. A fall-off as large as 10dB at 45° may prove acceptable, and considerably simplify the antenna design problem.

d. Azimuth Pattern

The relation between angular accuracy and beamwidth depends primarily on the angle measurement technique employed. Since it is assumed that an accuracy in the range of 1/20 to 1/10 of a beamwidth can be attained (see Section III-F), and a nominal accuracy of 0.1° is needed, the angular accuracy and resolution requirements of DABS can probably be met with a 3dB beamwidth of 1° to 2° in azimuth.

Due to the use of side-lobe suppression in the ATCRBS mode and the ability to interrogate DABS targets only when they are in the main beam, the antenna side and backlobe requirements are fixed by other considerations, such as up-link interference and the desire to reject fruit on the downlink. No well defined requirements on side and backlobes exist at present for DABS, and they will only emerge as outputs from a detailed study or simulation of the DABS interference environment.

Since DABS, like ATCRBS, will operate at relatively high signal levels, there is no requirement for high antenna gain to make up for lack of transmitter power or sensitivity elesewhere in the link. The peak antenna gain will thus be determined primarily by the requirements on azimuth and elevation beam shaping.

e. Beam Agility

A potential need for an agile-beam antenna occurs if one encounters large variations in target density in azimuth. It has not been demonstrated that sufficient target peaking of this kind will occur in either enroute or terminal environments to force the choice of an agile-beam system, either phased-array or hybrid. An agile-beam may be required in the highest density terminals, but the lack of detailed forecasts makes this requirement difficult to justify quantitatively. Hence on this issue, as with data refresh rate, the rotator is still a viable candidate.

2. Basic Antenna Options

The basic antenna options may be grouped into three classes: rotating antennas, phased-arrays, and hybrid (or rotating phased-array) configurations.

a. Rotating Antenna

This class includes antennas which form a fixed beam (or monopulse set) which is scanned by rotating the entire radiator, thus it also includes rotating arrays with fixed excitation. This type of antenna has' the advantages of a mature technology and well-understood design principles. Rotators can meet the basic beam-shape requirements of the system, lend themselves readily to monopulse techniques, and provide stable patterns, independent of pointing angle. The relatively high precision of angle measurement techniques available with a rotator may make it possible to relax the azimuth aperture requirement relative to an array. The maximum scan rate is constrained by the practical limits on rotational speed of large diameter structures. For example, a 40 foot aperture cannot be rotated much faster than 15 rpm, which corresponds to a tip speed of about 20 mph. This rate could be obtained in the open, but the use of a radome would ease the requirements on the drive system. A radome would also increase the reliability of the system and by eliminating over-turning forces, simplify the bearing design. The radome is probably cost-effective on this point alone. By proper design, bearing life on the order of 20,000 hours is possible, failure can be anticipated, and replacement can be effected in a few hours. A back-to-back arrangement is an attractive possibility, which presents a balanced load and, at 15 rpm, can provide a data refresh rate of once per two seconds. A four-sided structure could achieve the maximum refresh rate postulated, although, if each reflector is 40 feet in width, the tip velocity is increased to almost 30 mph.

A rotating antenna cannot provide beam agility, hence in handling DABS targets a system using such an antenna would have a definite limit on the target capacity per azimuth cell. The overall capacity of such a system depends, of course, on many other factors, including interrogation scheduling algorithms, sensor coordination and actual target distributions. A determination of the suitability of rotating antennas can only be made in connection with a tentative design of the overall system.

b. Phased-Arrays

A phased-array has two advantages which make it attractive as a potential DABS interrogator antenna: it allows a larger physical aperture than is practical with a rotator; and it is capable of high-speed beam steering. Additionally a matrix-fed array has the ability to form multiple simultaneous beams. The inherently high-speed beam steering capability of an array can be exploited to provide either a rapid conventional scan or complete beam-steering agility.

Either planar or cylindrical(1) array geometries could be used for the DABS application; however the requirement to scan a fan beam through 360°

(1) In the term cylindrical we include other rotationally-symmetric configurations.

is best met by a cylindrical array. A planar array would need at least three, and probably four or more, vertical faces for 360° coverage. Although planar array technology is better understood than cylindrical array technology, planar arrays have problems which limit their applicability for the DABS application. For example, as a fan beam from a planar array is scanned off broadside, the azimuth angle at the peak of the beam varies with elevation angle. In addition the azimuthal beamwidth increases with scan angle off broadside. Finally, a relatively large number of elements is required to provide the specified elevation and azimuthal beam shape in a planar array. However, as there is no need for scanning in elevation, vertical beam shaping can be obtained with one or two feeds stacked vertically, illuminating a shaped reflector. This approach can also be applied to a circular array, which uses a single ring of feed elements illuminating a reflector shaped in the vertical direction (e. g., a parabola of revolution). The alternate, more conventional configuration for the cylindrical array employs a ring of vertical columns of elements backed by a cylindrical ground plane and fed with a fixed vertical phase and amplitude distribution in each column to achieve the desired elevation beam shape. This scheme would require roughly the same total number of elements as a four-faced planar array.

Although the cylindrical array is better matched to the DABS requirements than an n-faced planar array, it will require a longer and more expensive developmental effort because it is not as well understood. The theory of mutual coupling of elements has not been developed in detail for these arrays, and pattern synthesis techniques are not well understood, particularly in the case of an array with a shaped reflector. Techniques for phasing and feeding cylindrical arrays are also complicated by the need to commutate an attenuation taper as well as a phase taper when scanning a complete circle .

A major problem with circular arrays is the tendency for the azimuthal beamwidth to increase with elevation, along with a drop in peak gain.

The effect occurs in both types of circular arrays, shaped reflector and cylindrical ground plane. The variation in beamwidth typically exceeds a factor of two or three over the range of useful elevation angles and, if not corrected, can seriously effect the angle measurement accuracy of a monopulse sys tem. The feed compensation networks required to reduce this effect add significantly to the cost of large circular arrays.

If a shaped reflector array is used, the number of elements required is relatively *small. For example, an array 45 feet in diameter requires fewer than 300 elements in a single ring at half-wavelength spacing, and excitation of a 120° -sector could produce a 3dB beamwidth of less than 2°.

The major disadvantage of a phased-array is the cost. Depending on the de sign, an array can be expected to cost from two to ten times as much as a rotator with equivalent beam characteristics. Of course, it is not possible to compare the two directly, because they are not equivalent in other respects. The cost effectiveness of an array antenna for the DABS interrogator will depend on the importance to the DABS system of achieving a large aperture and agile beam steering.

c. Hybrid Antennas

This class is typified by a vertical, mechanically rotated rectangular planar array with limited beam agility. The agility of the array over a relatively narrow angle provides a more flexible scan than is possible with a simple rotator. Hence bunching of DABS targets in azimuth could be handled by this antenna with greater ease than with a rotator but with less flexibility than a full array. This scheme is limited in average scan rate just as a simple rotator; it has all of the mechanical disadvantages of a rotator, with the complexity of an array. However, if its cost is sufficiently lower, it might, be an effective compromise for some DABS applications. As with the other options, the utility of this antenna structure can only be judged in the context of an analysis of the total system of which it is a part.

F. Azimuth Angle Measurement

As is done currently in ATCRBS, DABS will measure target azimuth to a small fraction of the interrogator antenna azimuth beamwidth. However, whereas ATCRBS uses 10 to 20 replies from a target'to make the measurement, DABS cannot afford such luxury; the required number of replies costs directly in system capacity, so that in DABS one desires to make the measurement using a minimum number of replies, preferably only one. To accomplish this an azimuth angle measurement system employing some form of monopulse is required.

The complete angle measurement system comprises antenna and feed hardware augmented by appropriate data processing. This discussion concentrates on the basic angle measurement technique and the required antenna configurations; the associated data processing is not treated in detail as it is not likely to be a limiting factor affecting the choice among options.

1. Fundamental Angle Measurement Problems

Certain fundamental difficulties be set any technique which attempts a precise measurement of azimuth. The most serious of these are extraneous radiation and calibration difficulties.

a. Extraneous Radiation

Extraneous radiation includes interference from other sources on the same channel, such as fruit replies, and unwanted replicas of the desired reply due to multipath. In the present ATCRBS system these effects dominate internal system noise; the same will no doubt be true for DABS. In general, the more subtle the scheme for extracting angle information from the incident wave, the more seriously it is degraded by such spurious effects. Quantitative evaluation of the effects of interference and multipath can only be obtained by measurement and analysis of each particular technique . No general model of beacon-system multipath exists, and present interference models, such as those developed for ATCRBS[1], will require modifications to represent a mixed ATCRBS-DABS environment.

It should be noted that interference and multipath are subject to some control by other aspects of the DABS system design. For example, the antenna design, together with careful siting, can reduce the severity of the multipath problem, while the interrogation scheduling algorithm and coordination between different sensors can help limit the interference on the channel.

b. Antenna Calibration

The problem of antenna calibration occurs in one form or another in nearly all angle measurement system.

In NAS and ARTS the received pulses are immediately quantized into ones and zeros, so that none of the details of the antenna beam pattern remain to affect the processing except its symmetry at those points on the pattern at which the threshold was exceeded. Retaining received signal amplitude information in the beam-splitting process requires a more detailed knowledge of the pattern, while single-hit (off-boresight) monopulse requires still more precise knowledge of both left and right (or sum and difference) beam patterns. These techniques are discussed below, but it is appropriate to remark here that azimuth beam patterns depend on target elevation and may be affected by reflections from surrounding terrain, making them functions of the boresight direction as well. Moreover, in a phased-array, each individual beam, or beam pair, must be separately calibrated due to variations in the feed networks.

Related to the calibration problem is the problem of stability. The system will require recalibration or adjustment each time components such

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(1) "The Mark X (SIF) ATCRBS Performance Prediction Model," Electromagnetic Compatibility Analysis Center, ESD-TR-69-247, 80D ECAC, September 1969.

as amplifiers or phase shifters experience significant changes in relative gain or insertion phase. Environmental alterations (e.g., grading of the terrain or new construction) in the vicinity of an interrogator site will also require recalibration in some systems,

It is impossible to make quantitative statements of any general validity, but the size of the required calibration data base and the degree of required component stability suggest considerable caution in choosing schemes which depend heavily on precise calibration of beam patterns.

2. Classes of Angle Measurement Systems

Angle measurement techniques may be classified according to three main characteristics: the number of beams simultaneously employed, the degree of beam agility available, and the scheduling of interrogations (periodic interrogations as in ATCRBS or adaptively-scheduled interrogations as in DABS), Some of the possible options are discussed here, categorized by the number of simultaneous beams employed.

a. Single Beam Systems

Only the rotating-scan, periodic-interrogation case is considered here for the simple antenna configuration which produces a single beam. Standard beamsplitting techniques are then available for measuring angle, assuming that pulse amplitude information is retained and a reasonable runlength is available (e.g., 8 or more hits between 10dB points on the antenna pattern). The te chnique amounts to the application of a matched filter to the received replies and is capable of achieving an angle measurement whose standard deviation, σ_θ, is given by

$$\sigma_\theta = K \frac{\theta}{(E/N_o)^{1/2}}$$

where

θ = 3dB antenna beamwidth,

E/N_o = reply energy to noise power density ratio,

K = constant the order of unity.

This formula is rigorously applicable when the measurement is perturbed only by white noise in the system, but it provides a general guide in a wide range of situations. Angular accuracies of the order of one-tenth the antenna beamwidth have been obtained with 20dB E/N_o, in conformity with this formula. However, an angle measurement of this quality cannot usually be obtained with an amplitude-quantizing system which uses a sliding-window operating on quantized data to establish leading and trailing edges of the return.

Because of the serious loss in system capacity which results from its use, the single-beam technique should be considered as a fall-back position for DABS only if for some reason satisfactory monopulse performance cannot be achieved.

b. Two Beam Systems

This case includes the various monopulse schemes which have been used in other applications. With regard to amplitude monopulse (i. e., gum-and-difference or pure amplitude schemes), the great bulk of practical experience relates to tracking systems in which the two antenna outputs are combined to provide an error signal (with a null on boresight) which is used in a servo loop to point the antenna at the target. Unfortunately, the scanning requirements of the ATC problem render this experience of only indirect value.

Three classes of monopulse techniques will be discussed here: rotating scan, rapid nulling, and single hit.

Consider first the rotating scan case. The use of a monopulse system with a rotating or regularly scanning antenna is similar to the beam-splitting technique used with a single beam. A sequence of hits is obtained at regular intervals on the monopulse error characteristic, and the target azimuth is determined by a process analogous to matched filtering. This technique provides some improvement in accuracy over the single beam, approach, and appears attractive for handling ATCRBS targets.

If the antenna system has the ability to switch a monopulse beam pair very rapidly over a limited angular range, nulling is possible during the time the target is being illuminated. This method is applicable to a phased-array or hybrid antenna system (see Section III-E). Nulling can be accomplished-during a single DABS target reply, if the reply presents sufficient energy over a time long compared to the beam switching time. Essentially, the system tracks during the course of one reply, swinging the beams back and forth to establish the null. This rapid nulling option remains a possibility, given the requisite beam agility, since switching times of the order of one or a few microseconds are possible and DABS replies are expected to last at least as long as 25usec. The use of rapid nulling imposes a constraint on the reply waveform so that sufficient energy be available for the measurement. Thus, this technique is not promising for use with AT CRBS replies, where one can depend on only the presence of the bracket pulses.

If the monopulse error curve is known with sufficient precision over a region around boresight, target azimuth can be determined from a single measurement within this region. While the most efficient, this technique is highly sensitive to the calibration difficulties mentioned above. Its successful implementation involves a delicate interplay between tracking accuracy, interrogation scheduling, and antenna calibration, and will require experiment and further analysis to determine its feasibility.

A compromise is possible between the rapid nulling and single-hit monopulse methods, using two or at most three hits per scan. The first hit is placed as near the null as prediction accuracy and scheduling constraints permit. Angle is measured on this hit by using an approximately calibrated error curve. This measurement is used to direct a second, and perhaps third hit (in rapid succession) as close as possible to the null. A variation of this scheme could be used with a rotator, by scheduling the first interrogation to fall on one side of the null and the second to fall on the other side, The two measurements, so placed should provide reasonable accuracy toge'ther with some degree of resistance to calibration errors. The rotator , -achieving monopulse beams by separate feeds to a common reflector, is inherently less difficult to calibrate than an array, making this option an attractive one.

c. Systems Using Three or More Beam Systems

Many techniques are possible if a number of simultaneous beams can be formed. A single hit with a set of M highly overlapping beams is equivalent to M hits with one scanning beam. Equivalently, a set of beams can be processed as a collection of monopulse pairs, each yielding a measurement on a different part of the typical error curves, hopefully with one-near null. Such techniques appear attractive in concept, but relatively little is known about their accuracy or implementation complexity.

G. Antenna Diversity

One of the limitations of the ATCRBS system is the high incidence of lost replies due to nulls in the aircraft antenna patterns. A conventional aircraft antenna cannot provide true omnidirectional coverage. When the aircraft banks, the antenna may be blocked by a wing or some other part of the airframe, or in the case of military aircraft, by externally-carried stores.

Automated surveillance requires a high channel reliability. The DABS round reliability will depend critically on a solution to the airborne antenna shielding problem. To achieve reliable coverage for essentially all aircraft attitudes, redundant antennas are needed either on the aircraft or on the ground.

1. <u>Air craft Antenna Diversity</u>

Three types of aircraft antenna diversity schemes have been investigated: duplicate independent transponder installations, periodic switching of a single transponder between two separate antennas, and a diversity transponder connected to two (or more) antennas, with each reply transmitted from the antenna which received the strongest up-link signal on that interrogation. Although complete transponder, redundancy is easily implemented, it is relatively expensive and can result in lobing effects between simultaneous transmissions from the two transponders mounted on the same aircraft. Periodic antenna switching is the least expensive form of antenna diversity to implement, but when one antenna is shielded (i. e. , when diversity is needed), half of the transponder replies are lost. When properly implemented, the diversity transponder with two antennas has been found to be very effective in eliminating dropouts due to airborne antenna nulls while costing less than the complete duplication of transponders.

2. <u>Ground Antenna Diversity</u>

When an aircraft maneuver interrupts the link between the transponder antenna and a particular interrogator, interrogators in other locations may continue to have unobstructed coverage of that aircraft. Recalling Figs . II-I and II- 2 of Section II, a large amount of the airspace, with the exception of quite low altitudes, will have multiple coverage. If provision is made for using data from all interrogators which provide coverage of an area, the problem of target dropouts due to maneuver s should be substantially reduced. In addition, such redundant coverage clearly enhances system reliability in the event of an interrogator site failure.

The use of redundant coverage enroute for backup is already being implemented in the NAS system, and is being considered for terminal areas as part of the ARTS-III enhancement program. The degree to which its planned use as part of DABS can reduce or eliminate the need for diversity transponders should be well understood before committing the design to the more complex airborne units. In addition to the already planned network of interrogators, consideration must be given to site relocation and/or the use of extra sites to provide adequate redundancy of coverage.

3. Relative Advantages of Airborne and Ground Diversity

Ground diversity is desirable in that it tends to reduce the incidence of target dropouts regardless of whether the dropouts occur because of interrogator or transponder antenna nulls. Furthermore, diversity can be realized selectively in those areas which have the greatest need for round reliability improvement.

In most situations airborne antenna diversity will result in more accurate surveillance data than ground diversity; because of the greater target range, data from an adjacent sensor is likely to be less accurate than data obtained from a sensor's primary coverage area. Further, airborne diversity has the economic advantage that it can be implemented gradually and selectively-according to user requirements. The cost is borne directly by the benefitting users. This is important since the need for diversity varies according to the characteristics of the aircraft. In particular, there is some evidence that small general aviation aircraft experience considerably less antenna shielding than air transport and military aircraft.

The need for diversity in an automated surveillance system is evident. At this time, it seems that the implementation of airborne diversity is the more cetain answer to this need. However, a final decision must rest on an economic and performance comparison of the two approaches.

H. Interrogation Management

ATCRBS interrogators operate open-loop, in a completely pre-programmed fashion, with the observed traffic having no effect on the operation of the interrogator. All targets within range are interrogated, whether or not they are of interest to the facility the interrogator serves. A DABS-equipped site, on the other hand, interrogates only those targets of interest to it, and successful operation requires knowing approximately' where to look for a target, as well as which targets to interrogate. To as sure continuous, efficient coverage of the airspace requires a considerable amount of interrogation management, both on a single sensor basis and on a system basis.

This section discusses those aspects of the interrogation management question which relate to a single sensor. The closely related topic of the assignment of targets to sensors in the multiple-sensor case is discussed in Section III-I, Sensor Coordination. For convenience, the discussion of interrogation management is divided into two parts: Interrogation Modes, and Interrogation Scheduling.

1. Interrogation Modes

The present ATCRBS system employs three modes (2, 3/A, and C), at enroute sensor sites and two modes (3/A and C) in terminal areas; however target detection and beamsplitting are based only on Mode 3/A returns (ARTS-III will have the capability of using Mode C returns also, when present). Therefore, the relation between beam dwell time, interrogation rate, and run length required for detection is dependent upon the interlace pattern in use. We make the explicit assumption that all ATCRBS transponders in the system at the start of the DABS implementation incorporate Mode C capability, so that the replies on both Modes A and C can be used for detection processing. One hopes, of course, that all these transponders include altitude encoders, so that the tracking system has automatic access to altitude data. However, the transponder will return bracket pairs when interrogated& Mode C in any case, and this is sufficient for our present purpose. At enroute sites, an interlace pattern such as 3/A, C, 3/A, 2 can be used. Thus all replies in the terminal area, and most of the replies enr oute , can be used for detection and beamsplitting; this allows angular resolution to be improved by beam narrowing, while keeping runlengths unchanged.

Added to these modes at a DABS interrogator will be a DABS roll-call insertion mode (discussed in detail below) and the discrete-address interrogation itself. The latter will have a number of sub-modes, hopefully all of the same basic format, for its various functions such as surveillance, data request, IPC message, and ATC data-link message. All replies will be processed for surveillance information.

The DABS roll-call insertion mode deserves special comment. It should be noted that in normal circumstances the address and track position of a DABS target will be handed off from departure point, through the Centers, to destination by interfacility data transfer. (interfacility data transfer of this type is already planned for NAS Stage A). However, to ac comrnodate'pop-up VFR targets , as well as to reestablish lost tracks, a search for DABS transponders not already in the roll-call must be carried out continuously. Because of the similarity of this search to normal ATCRBS interrogations, it is natural to consider linking the two. A possibility is to modify the ATCRBS Mode 3/A interrogation from a DABS interrogator, possibly by the addition of a third pulse, in such a way that to an ATCRBS transponder it appears a normal Mode 3/A interrogation, while a DABS transponder recognizes it as coming from a DABS interrogator, and responds with its discrete address.

The lock-out question is related to the question of DABS interrogation modes. The lock-out options, discussed in Section II, are: (1) DABS targets always locked-out by DABS interrogators, with position reports on these targets sent to other facilities such as military airfields and adjacent non-DABS sites during transition; (2) dynamic lock-out by DABS interrogators, permitting response to ATCRBS interrogations in certain geographical areas and during hand-off to coverage areas of non-DABS sites; (3) fixed lock-out without data remoting, but with pilot-controlled override to permit selective response to ATCRBS interrogations. It seems undesirable to allow lock-out to deny overlapping coverage by a pair of enroute sensors when only one is DABS-equipped, and hence it will be assumed that dynamic lock-out is employed. In fact, if it should prove desirable, techniques can be devised which permit a DABS interrogator to lock-out a DABS target from its own ATCRBS interrogations, while allowing the transponder to reply to any other ATCRBS interrogator, This arrangement, which is a special form of dynamic lock-out, will be referred to as "discrete lock-out".

2. Interrogation Scheduling

The DABS interrogator must schedule interrogations for a mixture of ATCRBS and DABS transponders; the way in which these two classes of interrogations are interleaved is the most fundamental design is sue in this area. The specific scheduling algorithms employed within these classes are also of major importance, along with the general question of data rates. For clarity these points will be discussed in turn, considering first scheduling within the individual classes, although they interact so strongly that in the actual design they must be treated only as different aspects of the same problem.

First, consider the scheduling of ATCRBS interrogations. One possibility is clearly to simulate exactly the behavior of the present interrogators.

However, many of the parameters of these systems were originally dictated by the characteristics of the search radars with which they are collocated. The introduction of DABS affords the opportunity for an upgrading of ATCRBS performance, including some combination of higher refresh rate, better azimuth accuracy and resolution and lower interrogation rate. The possibilities in this direction are strongly influenced by the monopulse capability of the antenna system. Monopulse azimuth measurement, combined with higher round reliability, could reduce the required run length, permitting the use of narrower beams and higher scan rates than those used at present. Alternately the need for fewer replies could be used to reduce the interrogation rate, reducing the ATCRBS interference level and allowing more time for DABS interrogations.

A number of options are available for scheduling DABS interrogations; the choice among these will depend strongly on the kind of "interlace" used between DABS and ATCRBS modes and whether or not the interrogator has simultaneous transmit and receive capability. To begin with, for high target densities the necessity to address each target individually costs DABS much more up-link time per target than is required in ATCRBS. The scheduling algorithm must therefore be capable of packing the replies efficiently on the downlink to overcome this while achieving high capacity. The capability of simultaneous transmission and reception antenna (diplexing) would substantially reduce this problem, providing a factor of two increase in channel efficiency. However, the amount of isolation required for diplexing is rather formidable (at least 130dB).

Scheduling algorithms can be divided roughly into two categories, depending on the degree to which they adapt the roll-call order for each scan to the current detailed range distribution of targets. One category, the "highly adaptive" algorithms, includes those which attempt to achieve maximum channel efficiency by preventing the appearance of gaps during which the system is neither transmitting nor receiving. One such scheme addresses targets in order of increasing range, leaving gaps in the interrogation schedule just when replies from previous interrogations are expected to be received. The second category includes "moderately adaptive" algorithms; an example is a range-ring algorithm in which targets are addressedin groups, here defined by range intervals, in a simple increasing range order within the group. An interval of time is devoted to each ring, the first portion containing interrogations and the second portion the corresponding replie s. The range intervals themselves are then interrogated enough times to accommodate all targets in that range interval. The algorithm is non-adaptive (and slightly inefficient) within groups, but the repeated interrogation of range intervals can be made to approximately conform to the actual distribution of the targets. With antenna diplexing a completely non-adaptive scheme is also possible, using simple increasing-range ordering.

Adaptibility is costly in terms of computation load, and this must be weighed against the higher channel efficiency attained. One must be especially wary of highly adaptive schemes which depend for their high capacity on fortuitous target range distributions; the capacity of ATCRBS itself is quite formidable for a sufficiently cooperative distribution of aircraft in range and azimuth. Also, the usefulness of some schemes is compromised if the channel must be rapidly time-shared with the ATCRBS mode.

The accommodation of both ATCRBS and DABS interrogations separates into two cases, depending upon whether both modes must be time-shared on a single beam, or whether they can be assigned to different beams. Multiple beams can be provided in phased-array systems, and in rotating antennas if two or more reflectors are mounted on the same pedestal. The back-to-back configuration is particularly attractive as a means of combining ATCRBS, on one beam, with DABS, on the other (if sufficient isolation can be achieved to permit fully independent operation of the two channels). With separate beams ATCRBS and DABS interrogation scheduling can be handled separately, and the continuous time available for DABS allows the full range of scheduling options.

In order to time-share DABS and ATCRBS on the same beam, one must find unused time in the ATCRBS cycle for at least the discrete-address interrogations. In the scheme described by ATCAC, the ATCRBS and DABS replies are made to occur during a common listening period. Other schemes alternately devote blocks of time exclusively to ATCRBS and DABS modes. In either case, the operating range of the system is restricted to a value less than the maximum unambiguous range corresponding to the ATCRBS interrogation rate, so that either range or interrogation rate will be sacrificed. In the ATCAC scheme the ATCRBS interrogation rate, which normally provides a maximum range of 200 nautical miles, is retained, but the operating range is dropped to about 120 nm in order to provide one-millisecond time blocks for DABS interrogations. Such an approach may be acceptable if the resultant 120-mile sensors are installed on a sufficiently dense grid to provide the desired degree of overlapping coverage on all targets .

If the single. beam being shared by DABS and ATCRBS has a high degree of agility, another class of schemes is possible in which large blocks of time are alternately devoted to each mode. Suppose, for example, that we interrogate each ATCRBS target at a nominal 400 pps rate, but use the system at a maximum range of only 100 miles. Then an agile beam could step through the same angular positions occupied by a rotator at the 400 Hz rate, but interleave an equal number of positions in another sector, say 180° away. In this way a full ATCRBS scan is accomplished in half the usual time without affecting run length or apparent PRF at a given transponder. The remaining ‘half-scan time would be used for DABS. The result is similar to the ATCAC scheme, but without the need for the 1 ms delay. Many Variations can be imagined and a wide range of DABS-ATCRBS switching rates is possible.

A third and perhaps the simplest alternative presents itself if the use of monopulse on ATCRBS permits a reduction in the ATCRBS interrogation rate. Enough time is then available in the interrogation cycle to permit the insertion of DABS interrogations without the requirement for beam agility or a delay in the transponder, and without additional constraints on maximum range. Clearly this approach is preferred if satisfactory ATCRBS performance can be maintained at the lower interrogation rate.

Finally, we mention the question of data refresh rate. Since ATC functions which require high refresh rate, such as conflict detection and approach monitoring, are exercised only intermittently, it would be convenient (computationally) to have the capability of dynamically setting this rate on individual targets. This could be done with a rotator only if its rotation rate coincided with the highest refresh rate to be used; the interrogation of DABS targets not requiring special service would then be spread out over several rotation periods, A multiple-sided rotator could also provide variable rate capability. A more natural setting for variable data would be an agile-beam phased array. It seems unlikely that variable data rate will prove important enough to force the use of an array, but if an agile-beam array is justified for other reasons, then the variable data rate feature could easily be incorporated into the interrogation scheduling procedure.

I. Sensor Coordination

A number of problems appear in the overall surveillance system which can be alleviated by varying degrees of coordination among sensors. Coordination of sensors can be used to reduce interference, increase data reliability, increase traffic-handling capacity, and to reduce the system susceptibility to failure. The types of potential sensor coordination considered in this article include coordinated target assignment, synchronized interrogations, redundant area coverage, and sharing of sensor data in a failure situation.

1. Assignment of Discrete-Address Targets

When DABS interrogators are widely implemented, overlapping coverage by more than two DABS sites (including both terminal and enroute sites) will be common. Redundant data is very useful, at least to the extent that each site can depend on a single backup site, but it is also desirable to minimize up-link interference and interrogation schedule coordination requirements by limiting the number of interrogators which may address a given target; system capacity will be greater if each site need not interrogate every DABS target within its range. Thus, coordinated target assignment is required; a target assignment algorithm based on geographical location can be quite simple, as demonstrated in the radar mosaic produced by NAS.

The question of DABS target assignment, lock-out, and roll-call insertion mode are closely related. One can imagine arrangements such as discrete lock-out combined with an ATCRBS insertion mode, or non-discrete lock-out with a new insertion mode, which would permit DABS interrogators: to acquire and track DABS targets independently, with no assignment of targets by a central facility. Central target assignment is a necessity in other cases (e.g., fixed lock-out with ATCRBS-mode insertion).

2. Discrete-Address Interrogator Synchronization

When two DABS sites overlap in their coverage, the up-link interference problem will potentially be more severe than in the equivalent ATCRBS situation for several reasons. First, the DABS up-link transmissions will be longer and will contain more energy than ATCRBS interrogations. They also require a separate message for each target addressed, resulting in a large number of interrogations at times of high traffic density.

Thus, the DABS up-link duty factor can be higher than ATCRBS, resulting in a higher probability of overlapping messages. A DABS interrogator will likewise provide- interference to an ATCRBS interrogator trying to reach an ATCRBS transponder. The magnitude of the se problems has not been studied in detail, but it seems probable that some form of schedule coordination or interrogator synchronization will be required to prevent simultaneous main beam illumination of a target by two or more DABS interrogators.

One particularly interesting scheme for interrogator synchronization deserving of detailed consideration, is based on precise synchronization of the time base at all interrogators. DABS interrogations are then timed such that all transponder replies occur on a specified time grid. Downlink interference between DABS responses can be effectively eliminated by this technique . The effects of interleaving ATCRBS interrogations requires further study, together with a trade-off of the advantages of this approach vs. the cost and system constraints imposed by the tight time synchronization of interrogator sites.

3. Utilization of Redundant Enroute Coverage

Around each sensor in a network is a region which consists of those points which are closer to this sensor than to any other. This region is defined as the "primary coverage area" of the sensor. The entire region covered by the network is a mosaic of these primary coverage areas. A ground rule in the DABS system design is that each sensor must alone provide data of adequate reliability and accuracy within its primary coverage area, although these accuracy and reliability requirements have not yet been specified in detail. It is clear that in general the useful range of each sensor will extend significantly beyond its primary coverage area, providing the network with some degree of data redundancy.

A factor influencing the usefulness of this redundancy is the degree to which each sensor meets the requirements of data reliability and positional accuracy (in x and y) beyond its primary coverage area. Since the data from several sites Will be available to a Center, in digital form and including reported altitude, a number of possibilities exist for exploiting this redundancy. One set of possibilities, aimed primarily at improving data reliability, assigns priorities to each sensor as a data source, depending on target position. Data from the single highest-priority available source for each target is then used as in NAS. The sensors are simply used as back-up sources beyond their primary coverage areas.

Another-set of possibilities, which assumes a high degree of reliability for'each sensor and aims at maximum accuracy, merges the data from all available sources onto the track. Since different sensors will in general report position on a given target at different times, each can be smoothed onto the track-separately, using smoothing constants which reflect the relative accuracy of the predicted track position and the position measurement in question. It must be assumed, for such merging to be useful, that biases due to non-random errors can be effectively removed.

Anotherform of redundancy is provided by primary radar, which backs up the beacon system. If, DABS interrogators are not collocated with search radars', the search radar data will be correlated with beacon data (i. e., merged with it or used as backup) in the control center (enroute or terminal area) processor, not at the site.

4. Enroute-Terminal Area Coordination

In the past no use has been made of data redundancy between terminal and enroute sensors; a primary factor has been the difficulty involved in merging analog data, compounded by the lack of altitude data needed for slant-range correction. The reasons no longer hold in the NAS/ARTS era, although the initial versions of these systems still make no use of redundancy. Terminal area interrogators could provide useful supplementary coverage to Centers, especially on low-altitude targets; and as discussed earlier, enroute sensors can provide valuable redundancy in terminal areas. Enroute sensor data would be more valuable if there were less disparity between enroute and terminal refresh rates than at present. Certainly, enroute sensor backup to terminals is a more attractive way of obtaining redundancy in terminal data than the use of multiple terminal interrogators, unless the latter are required by other considerations, such as approach monitoring for several sets of close parallel runways.

As discussed in the preceding section for enroute coverage, one can use enroute sensor data in the terminal either for backup purposes only, or it can be merged onto terminal-area tracks. In addition, there are the options of sending data from each appropriate enroute sensor directly to the terminal, or alternately, sending only the track data to the terminal, as derived at the Center from one or more sensors.

5. Failure Modes

A DABS site will require considerable on-site computational capability, mainly in connection with interrogation scheduling and the associated tracking. Hence, it is natural to think of designing into the site considerably more independence than present sites possess. This, in turn, would be useful in protecting against certain failure modes.

The loss of a single enroute sensor would normally be accommodated by the use of redundant coverage by other sensors of the same Center. However, some of the required overlapping coverage might be provided by a sensor in an adjacent Center. The ability to obtain data from the sensors of another Center, or track data directly from another Center, would obviously enhance the resistance of a Center to failure from sensor los s. The data transfer implied here is essentially the same as that required to implement enroute backup of the terminal.

The ability to cope with partial failures within a Center (other than sensor losses) belongs properly to the area of central processing system design, as in the restructuring capabilities of the NAS Central Computer Complex. However, in the unlikely event of a total loss of the Center, a transfer of sensor data to adjacent Centers could be considered. The capability to take over processing and control adjacent Centers would require a major extension of the NAS system concept. However, the availability of tracked and identified targets from the sites makes this a possibility, at least in the time period when most aircraft are equipped with a DABS transponders.

J. Data Processing

Data Processing is obviously involved in most of the design options already discussed in this chapter, although in general the processing loads do not seriously constrain the design choices. In this section we discuss the data processing requirements of the target reply processing and tracking functions, which are rather straightforward, and also give a brief analysis of the options for organizing the processing of data in a DABS-based surveillance system as a whole.

1. Target Detection and Location

Detection and angle measurement of ATCRBS targets may be handled in several ways at DABS sites depending on the type of antenna employed. With a single-beam rotator, one has the choice of using the simple algorithms of the Common Digitizer for detection and beamsplitting or a more complex technique such as that used in ARTS-Ill. The use of an agile-beam capability on ATCRBS targets would call for a new algorithm, such as a sequential detector. The largest change from present ATCRBS processing techniques would be brought about by the implementation of monopulse, in some form, for angle measurement. Since certain otherwise desirable changes in ATCRBS interrogation scheduling would lead to a reduced run-length (see Section H), all means should be considered which can preserve or enhance ATCRBS performance with a reduced run-length.

The processing of replies from DABS transponders will be heavily conditioned by the desire to achieve target detection, message readout, and azimuth measurement on a minimum number of replies, preferably one. Since the need for additional replies costs directly in system capacity, considerable signal processing complexity may be justified. A major influence on DABS processing will be the choice of technique for angle measurement. A rapid-nulling technique implies complex, highspeed processing. Single-hit off-boresight monopulse requires a moderate amount of rather straightforward computation (e. g. target elevation may have to be considered in determining the deviation from boresight), while regular scanning with multiple beams would be the simplest s cheme to implement.

2. Tracking

Much of the complexity of the tracking programs in NAS and ARTS results from the lack of discrete target identity. While these tracking algorithms may have to be preserved to work in conjunction with radar as a backup for targets without (working) transponders, the computational load should be negligible because of the small number of such targets. For those targets having a unique code (DABS or 4096-code ATCRBS), the tracking task is much simplified, and it should be possible to use more sophisticated algorithms for following maneuvers accurately and promptly. In a manual control environment improved tracking would enhance controller confidence in the display, and at higher levels of automation one could use track-derived velocity and acceleration components effectively in conflict detection and close-parallel approach monitoring.

If the tracker can be made more sensitive to maneuvers, it can provide more accurate estimates of present position and velocity than the simple CY - ß trackers in use today. Combined with higher data rate this accuracy might be made to exceed that of the most recently reported target position. The benefits, with regard to IPC and approach monitoring, could be significant.

3. Organization of the Data Processing Function

The distribution of the processing load, in particular the way in which it is divided between the sensors and the control centers, arises primarily in the context of enroute ATC; a terminal presents similar problems only if it is directly supported by a number of sensors. Hence the present discussion will be focussed on the enroute case,

The 3rd Generation System (i.e., ATCRBS and NAS) is characterized by an exclusively inward flow of data from autonomous sensors to the control center. This data is partially processed, by the Common Digitizer, at the sensor site before being transmitted to the Center. A new surveillance system, based on DABS sensors, will require a more extensive exchange of information between sensors and Center for two main reasons. First, the sensor is not "free-running", but interrogates targets on a dynamically evolving schedule based on the past history of the entire target environment. Second, the DABS sensor includes a two-way data-link between the aircraft and the agency of control on the ground. For both these reasons there will be a considerable flow of data, commands, and messages outward, from the control center to the sensors, with data processing at both ends. This data processing includes surveillance data processing, discussed in the first part of this Section, the coordination of data from several sites' and the interrogation management tasks discussed in Sections H and I, and the message processing required for IPC and the ATC data-link.

There are clearly several options for the organization of this overall data processing task. At one extreme is a highly centralized system, with all of the tracking and interrogation management tasks performed at the control center, along with those tasks involving multiple sensors. In this option the sensors are slaved to the center, being told where to point, which target to interrogate and when, and so forth. Obviously, a great deal of detailed information flows outward in such a configuration. At the other extreme is a system with considerable on-site computational capability. Each sensor could track all the targets assigned to it and manage its own interrogation scheduling in detail, while target assignment and other sensor coordination tasks are carried out at the control center. In an extreme form, some of the control function, such as IPC, could be performed by the sites.

Each variation of these configurations has its merits and weaknesses, and some compromise or intermediate scheme will probably prove to be the most reasonable. For example, to do its own detailed interrogation scheduling, an on-site computer needs to perform only crude tracking in order to predict the propagation delay of a given target on the next scan to a small fraction of the message length. Hence this kind of tracking could be performed on-site, while final tracking, making some use of redundant coverage, is carried out at the Centers.

At least conceptually, it is useful to introduce the idea of "processing centers", not necessarily as separate physical locations, but to illustrate the division of function and flow of data in the overall system, The arrangement is show schematically in Fig. III-Z, which indicates a large number of sensors interchanging data with a smaller number of processing centers. The processing centers, in turn, interchange data with a still smaller number of control centers. Information, data, commands, and mes sages may flow in both directions on all lines of communication shown. The processing centers carry out tracking and merging of multiple-sensor surveillance data (target detection and angle measurementare performed at the sensors), target assignment and lock-out control, interrogation scheduling and schedule coordination between sensors. Such automatic control functions are intruder detection and IPC may be considered part of the processing center function, or alternately assigned to the control center.

It should be noted that this arrangement provides alternate paths for the flow of data between sensors and control centers, and that surveillance

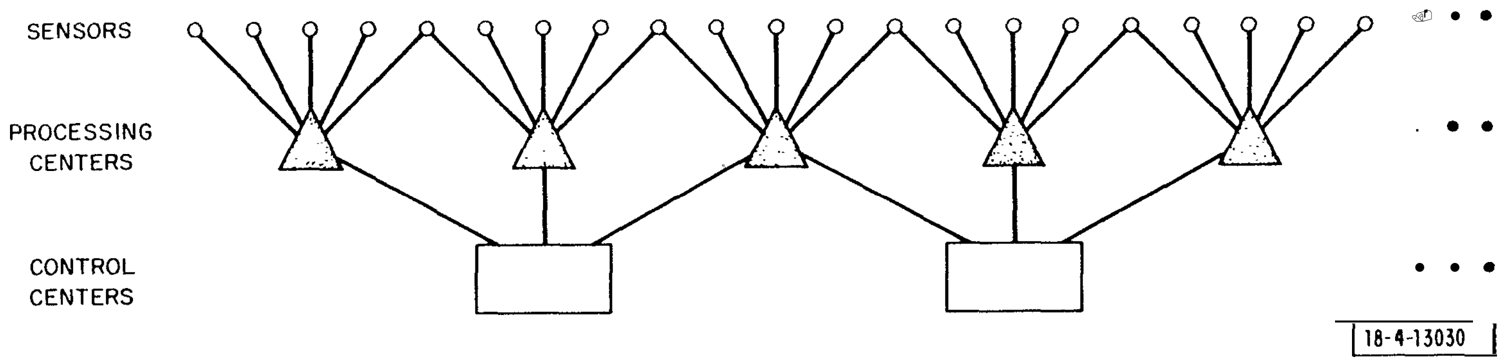

Fig. III-2. A system organization utilizing data processing centers.

data from one sensor is generally available at more than one control center. The overall network provides sufficient flexibility to support a de sign resistant to the failure of sensors, processing centers and, to some extent, control centers, From the point of view of reliability, one would strive for a configuration providing redundant paths of communication which carry highly processed, condensed information. The final choice will be made on the basis of a combination of considerations of cost, reliability and performance.

IV. DABS DEVELOPMENT PLAN

A. Introduction

The discussion in Chapter II points out that the current understanding of the requirements and constraints imposed on DABS is inadequate to proceed immediately with a system design. There are also a number of technical, economic, and operational questions mentioned in Chapter III which must be resolved in order to select a DABS design from among the variety of system and sub-system design options. The DABS development program begins with an effort to resolve these 'uncertainties in operational requirements, constraints, and technical issues in order to allow system definition. The work tasks to resolve these uncertainties, design the system, and validate the design comprise the first phase of the DABS development program.

Uncertainty in projections of air traffic growth and in the demand for ATC services, plus the lack of a well-defined saturation point for ATCRBS, make if difficult to support on that basis a precise time requirement for the implementation of DABS. However, two other factors contribute to the urgency of DABS development. First, improvement in ATC surveillance capability beyond that provided by ATCRBS, and the availability of a data-link for ATC communications, are essential ingredients for the automation of ATC functions (e. g. IPC) programmed for the early 1980's. And second, the early development of DABS and agreement on standards is essential to permit the aviation community a maximum time to make the transition before the demands on the system require that all users of controlled air-space have this capability; the longer it takes to define DABS, the less time will be available for its implementation. The DABS Development Plan has therefore been based on an intensive effort during the early phases, leading to system definition, field evaluation', and the generation of system stand-ards in the minimum reasonable time. With such an effort it appears poss-ible to have a fully evaluated DABS design, ready to begin widespread implementation, in approximately six years from program initation

To meet this schedule will require a dedicated commitment to the development of DABS on the part of the FAA, DOT, and DOD, and the support of the civil aviation community. A heavy effort is required from the outset of the program. A management plan has been outlined which should permit such an effort within the staffing constraints of the involved government agencies. However, any delay in making available the required resources, both money and manpower, will impact directly on the program schedule. Of particularly critical importance is adequate support in the contracting process, as the fairly large number of individual contracts makes the time for-placement of these contracts a significant element in the overall program schedule.

B. Overview of the DABS Program

1. Program Summary

The DABS program will consist of three major phases (See Fig. IV-1):

Phase 1: System Definition and Feasibility Demonstration

Phase 2: Prototype Engineering, Test, and Evaluation

Phase 3: System Implementation

Detailed data on work tasks, schedules, and cost estimates are presented for Phase 1. Only long range schedules and general outlines are presented at this time for Phases 2 and 3 because the detailed plans for these phases will depend on the DABS system configuration selected during Phase 1, and also because it is unrealistic to generate detailed program plans more than a few years in advance. The detailed plans for Phases 2 and 3 will be generated during Phase 1.

Phase 1 (System Definition and Feasibility Demonstration) includes the

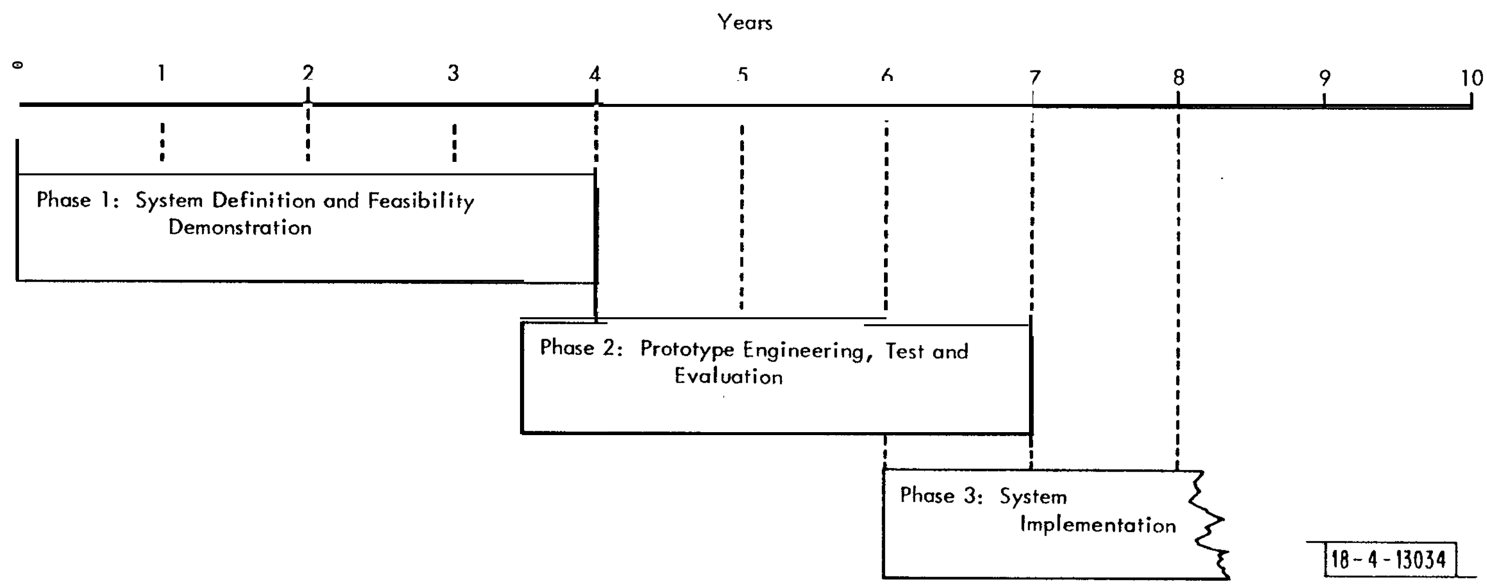

Fig. IV-1. Discrete-address beacon system (DABS) development program.

definition of required DABS performance, a broad program of critical technique evaluations, the overall system de sign, and validation of the system design by experiment and analysis. Feasibility testing will be done using NAFEC facilities with experimental DABS sensors and some number of aircraft equipped with experimental DABS transponders. A proven DABS design (proven in the sense of technical and economic feasibility) is the major objective of this phase of the program. Outputs of Phase 1 will include prototype DABS sensor and transponder specifications, provisional versions of a DABS National Standard and transponder Minimum Operating Characteristic, and detailed program plans for Phases 2 and 3.

Phase 2 (Prototype Engineering, Test and Evaluation) has as its objectives the development and test of fully-engineered DABS equipment and the accumulation of operational experience with DABS before a full-scale implementation program begins. Prototype system test and evaluation will'take place in an operational ATC environment with live air traffic, using the prototype DABS equipment with NAS and ARTS equipped control facilities and aircraft equipped with experimental and prototype DABS transponders.. The prototype ground equipment will meet all technical, operational and environmental specifications and should be fully interchangeable with production equipment to be built during the implementation phase. The major output of this phase will be a complete set of production specifications for DABS ground equipment and transponders, a refined version of a DABS National Standard and Minimum Operating Characteristic, and a refined System Implementation Plan.

Phase 3 (System Implementation) addresses the task of transitioning from an ATCRBS-based to a DABS-based ATC surveillance system. Its major objective is to carry out the DABS Implementation Plan generated in Phases 1 and 2, aimed at implementation of DABS on a schedule which avoids ATCRBS saturation and supports further advances in automation of the control junction. This phase of the program will be faced with the operational problems of the transition period which may require management of the interrogation environment during this critical phase of the program by various control measures. While exact schedules and milestones of Phase 3 are not possible to predict at this time, widespread implementation of DABS cannot be expected before 10 years from the start of the DABS development program.

2. Coordination and Interaction with other Programs and Agencies

The definition of DABS operational performance requirements, the major design choices, and implementation schedules cannot be formulated without considering many other aspects of ATC and the over-all ATC system evolution. Thus coordination and sometimes direct interaction will be necessary between the DABS program and other on-going as well as new ATC development programs, government agencies, and user organizations. For example, it is clear that the DABS program must be coordinated with the ATCRBS improvement program, the ATC data link development program, and the IPC development program because of the many areas of overlapping interest. Should such independent, parallel development programs as IPC and data link be initiated promptly, they may provide useful inputs prior to the design of DABS, especially in the area of required performance. In this case, the DABS program would be modified to have some of its work tasks transferred to and performed by these other programs. However, the present DABS program has been formulated to be completely independent of such external inputs from programs which may not come to fruition in time to meet DABS development schedules.

a. ATCRBS Improvement Program

While the primary goal of the ATCRBS Improvement Program now being planned by the FAA will be the upgrading of ATCRBS to better support NAS and ARTS prior to the implementation of

DABS, this p&gram must also set the stage for DABS implementation. This may require the development and implementation of procedures to control the ATCRBS interrogation environment during the transition period. It may also include the development of improved ATCRBS equipment incorporating the capability of being easily upgraded for DABS operation, thus extending its useful Lifetime. Specific examples of work tasks with strong ties to both the DABS and ATCRBS programs are:

(i) Upgrading and evaluation of the ATCRBS E-scan antenna for use in DABS.

(ii) ATCRBS interference environment measurement, modeling, and projection, The results of this effort is of critical importance to DABS design as well as ATCRBS performance,

Coordination of the ATCRBS and DABS programs are clearly necessary to avoid redundant efforts in the many areas of mutual interest.

b. IPC Development Program

In addition to providing surveillance data, DABS is expected to-provide a digital communication capability between aircraft and ground which can be used for transmission of IPC messages. Thus, it will be necessary to determine the DABS surveillance and communication capability that would be necessary to support an IPC system, and this task is included within the DABS program. However, the plan does not address the design and evaluation of IPC systems, or the development of hardware and software specifically associated with IPC systems. Should an IPC development program be started, it should logically be coordinated with the DABS program to avoid redundant efforts.

c. ATC Data Link Development Program

A similar situation exists with regard to the ATC data link capability provided by DABS. It will be necessary to determine the communication capability necessary to support data link applications to ATC, and this task is included within the DABS program. The plan does not include the development of RTC procedures and ground and airborne hardware for entering, controlling,and displaying ATC messages. Should an ATC data-link development program be undertaken, it would necessarily have to be closely coordinated with the DABS program.

d. Coordination with the Military

The issue of compatibility of DABS with military use of ATCRBS modes has been discussed in Chapter II. In addition, there is another basic issue that arises with regard to the military, namely the possible military use of the DABS data-link. Only a small fraction of military aircraft are now equipped with data-link. The widespread implementation of a universal data-link capability as provided by DABS will certainly be of potential usefulness in a number of strategic and tactical applications. The DABS program must therefore consider the possibility of performance requirements imposed on DABS by military applications, and the program must be structured to accommodate such a possibility. This conclusion is in agreement with that of the FAA Data-Link Committee[1]

e. Microwave Landing System Development Program

The DABS program must be coordinated with the Microwave Landing System (MLS) program in order to establish any special operational requirements that the MLS might impose on the DABS in the terminal area. Use of the DABS to relay aircraft-measured MLS data to the ground is one such potential requirement.

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[1] "Recommendations for FAA Data-Link Development Program" by the Data Link Committee, Systems Research and Development Service, FAA (July 1971).

f. NAFEC

The use of NAFEC test facilities and staff for the DABS feasibility tests requires coordination with other test programs within the FAA. An example is the use of the NAS and ARTS equipment at NAFEC, which would have to be modified and checked out prior to its use in DABS experiments.

g. ATC Developments in Foreign Countries

The development of new ATC data acquisition systems is presently underway in some foreign countries. Close cooperation with such efforts should be maintained not only to be aware of any technical developments that might be applicable to DABS, but also to be certain to incorporate adequate capability within DABS to accommodate the international community of users. Such cooperation would be desirable in setting the stage for later international agreements concerning DABS implementation.

h. International Standards

The pursuit of international agreements affecting the use of ATCRBS and DABS should begin as soon as possible in order to avoid later delays in implementation due to extended negotiations for international standards. In particular, an amendment to the International Standards and Recommended Practices on Aeronautical Telecommunications (Annex 10) of the International Civil Aviation Organization will be required for any substantial modifications to the present beacon system.

3. Contingency Planning

As mentioned earlier, funding or staffing constraints, or unexpected difficulty in resolving technical problems, would all tend to insert delays in various parts of the program leading to a stretching of the overall program schedule. If the program must be adjusted for such contingencies the order in which tasks are carried out should remain essentially as shown to provide the necessary inputs to later tasks. It would still be desirable to start in parallel the those tasks which address the critical uncertainties in DABS definition. These those tasks are:

(i) Analysis of DABS- supported ATC functions and definition of DABS performance specifications (included in Task Group A);

(ii) Interference environment measurement, modeling, and projection (included in Task Group B);

(iii) Modulation and coding design studies and experiments (included in Task Group C);

(iv) Antenna and monopulse design studies and experiments (included in Task Group D);

Other tasks either affect later decisions and can thus be stretched with the plan, or cannot begin without inputs from earlier tasks, implying they should be automatically rescheduled in a stretched plan.

C. System Definition and Feasibility Demonstration (Phase 1)

1. General

The objective of the first phase of the DABS Development Program is the formulation of a DABS design whose feasibility and economics have been proven by analysis and experiments. The realization of this objective requires a program of broad scope which must:

- define the operational requirements, constraints, and RF environment of DABS;
- provide the technical and economic basis for system design by performing technical evaluations and design/costing studies;
- select a DABS design consistent with the established operational requirements, compatibility constraints,

channel environment, and cost;

- prove out the chosen DABS design by operation of experimental equipment to demonstrate feasibility, and simulation studies.

The System Definition and Feasibility Demonstration Phase of the DABS Development Program is designed to achieve these goals within the first four years of the program. The program plan of this first phase, shown in Fig. IV-2, begins with a number of parallel efforts which focus on defining the operational requirements and interference environment of DABS, and on design studies which include technique evaluations, transponder cost studies, etc. The design studies together with the requirements and interference studies will provide the necessary data to allow system design to be completed during the second year of the program.

Following the system design phase, specification and contracting for experimental equipment is begun in order to carry out system feasibility tests duringthe fourth year. In parallel with the equipment procurement and tests, design validation studies and analyses are conducted to evaluate those aspects of system performance that are not practical to investigate experimentally, such as combined DABS/ATCRBS operation during all phases of the transition period, and to analyze the experimental data gathered in the feasibility test. If there are no major problems uncovered during the design validation studies and feasibility tests, and if results of the experimental and analytical studies are in agreement, then this phase will be completed with the generation of:

- prototype equipment specifications;
- Phase 2 program plan;
- provisional DABS National Standard and Transponder Minimum Operating Characteristic;
- DABS Implementation Plan (Phase 3 Program Plan).

The estimated annual costs for Phase 1 are shown in Fig. IV-2. The total cost of this phase is estimated to be $23 million, of which $8.8 million (approximately 40%) is spent on industrial contracts.

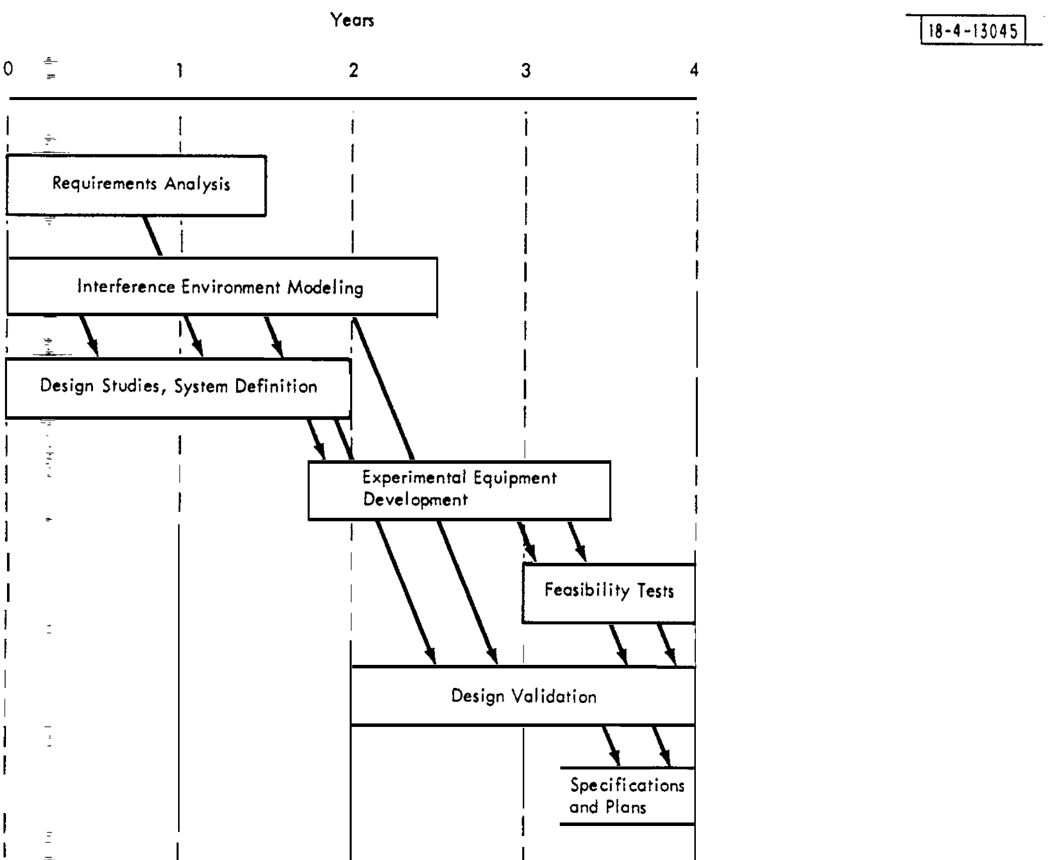
The work of Phase 1 has been organized into eight Task Groups, each of which consists of a number of highly interrelated work tasks. The first task of each group is a lead task which forms a part of the over-all system engineering effort. The task Groups are listed below and are discussed in the next section. A detailed description of each task is included in Appendix A.

- Task Group A: Definition of Performance Specification
- Task Group B: Interference Environment Modeling
- Task Group C: Modulation and Coding
- Task Group D: Antenna and Monopul se
- Task Group E: Data Processing and Interfaces
- Task Group F: Feasibility Test
- Task Group G: De sign Validation
- T-ask Group H: System Engineering

2 Phase 1 Task Groups

The scheduling of the eight Task Groups of the first phase, including schedules of the supporting studies and experiments of each. is shown in Fig IV-3. The objective and activities of each task group are discussed in this section. Figs IV-4 through IV-11 are detailed schedule charts for each task group showing times of key outputs and required inputs from other task groups. Tables IV-1 through IV-7 summarize the estimated level of effort and cost of the individual tasks within each task group.

Task Group A: Definition of Performance Specification - The main objective of this task group is the definition of DABS performance specifications. This task group is regarded as one of the basic ones because of the necessity to define required DABS performance specifications before



Sponsor	Year 1	Year 2	Year 3	Year 4	Total Dollars (m)	Percent of Total
Government and Nonprofit Support Agencies	$3.4	$3.4	$2.4	$5.0	$14.2	62
Industry	1.9	4.2	1.7	0	8.8	38
Totals (m)	$5.3	$8.6	$4.1	$5.0	$23.0	100

Fig. IV-2. DABS development program, Phase 1 system definition and feasibility demonstration (millions of dollars).

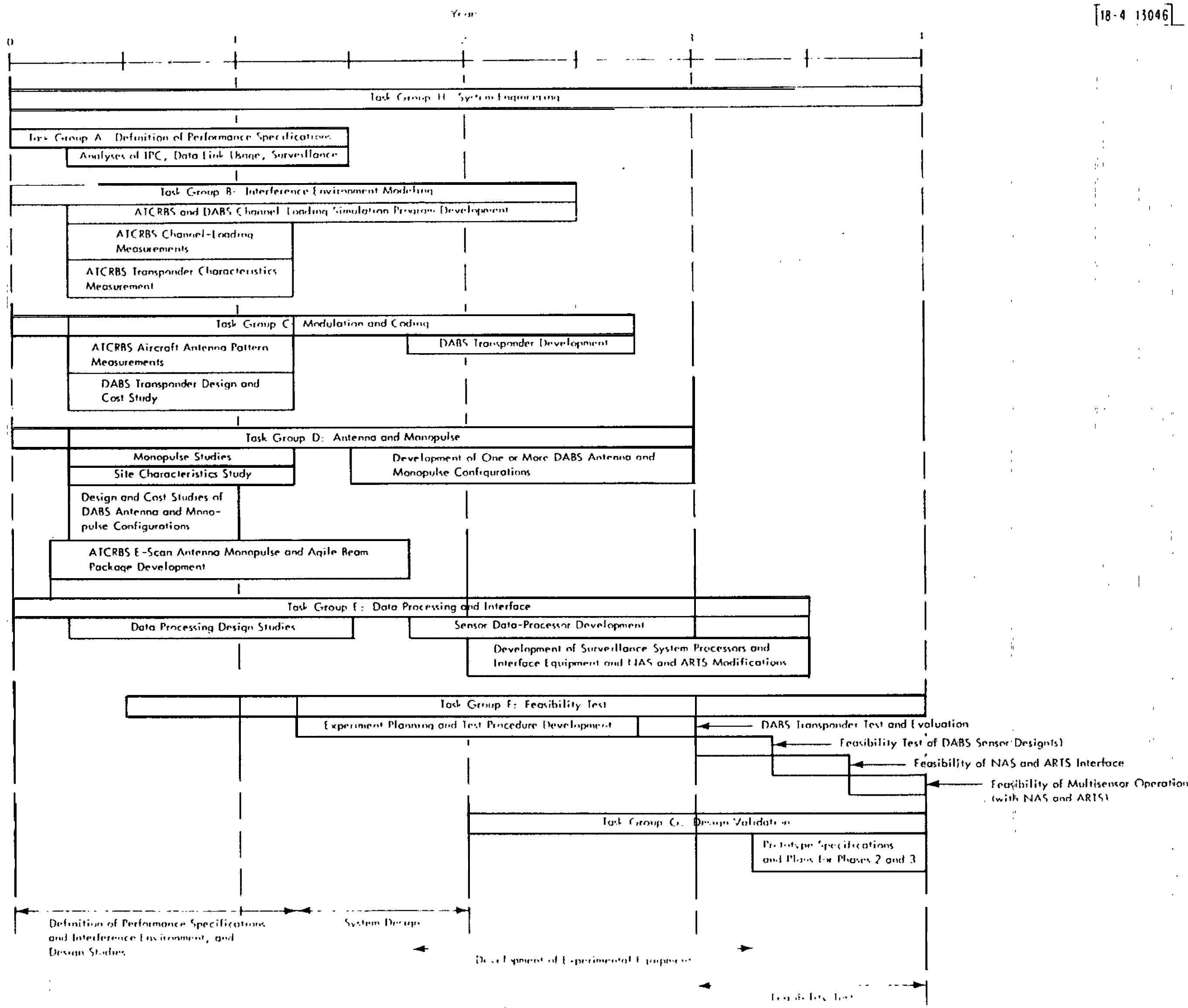


Fig. IV-3. DABS development program, Phase 1 task groups.

selection of techniques and hardware configurations can be made. The initial effort is to define the scope of the study in terms of anticipated DABS- supported ATC functions. The work tasks then address the analysis of these ATC functions to permit trade-off studies of the performance of each function in terms of DABS characteristics. The individual work tasks in this groupare:

A-1: DABS Performance Definition and Task Coordination
A-2: IPC Analysis
A-3: Analysis of ATC Datalink Usage
A-4: Analysis of DABS Surveillance Function

The Lead Task includes the key responsibility of defining the set of ATC functions on which the DABS performance specifications will be based. Once the set of ATC functions which will drive the DABS design have been identified, DABS required performance can be specified using the results of the trade-off analyses. The schedule of this task group must allow DABS definition to begin early in the second program year, if experimental hardware is to be specified and developed in time for feasibility testing to commence in the fourth program year.

Task Group B: Interference Environment Modeling - The objective of this task group is the realization of models of ATCRBS and DABS channel loading for use in analysis of self and mutual interference effects. The central technical problem to be faced in selecting a DABS signal format and monopulse technique is the interference environment due to ATCRBS and to DABS itself. Since the use of the ATCRBS frequencies by DABS has strong economic and compatibility advantages, it is necessary to understand in detail the effects of ATCRBS interference to a DABS operating on 1030 and 1090 MHz. The work tasks in this group include measurements of ATCRBS interrogation and reply channel utilization and ATCRBS transponder characteristics, simulation of ATCRBS channel utilization, and, once DABS has been sufficiently well defined, the simulation of DABS channel

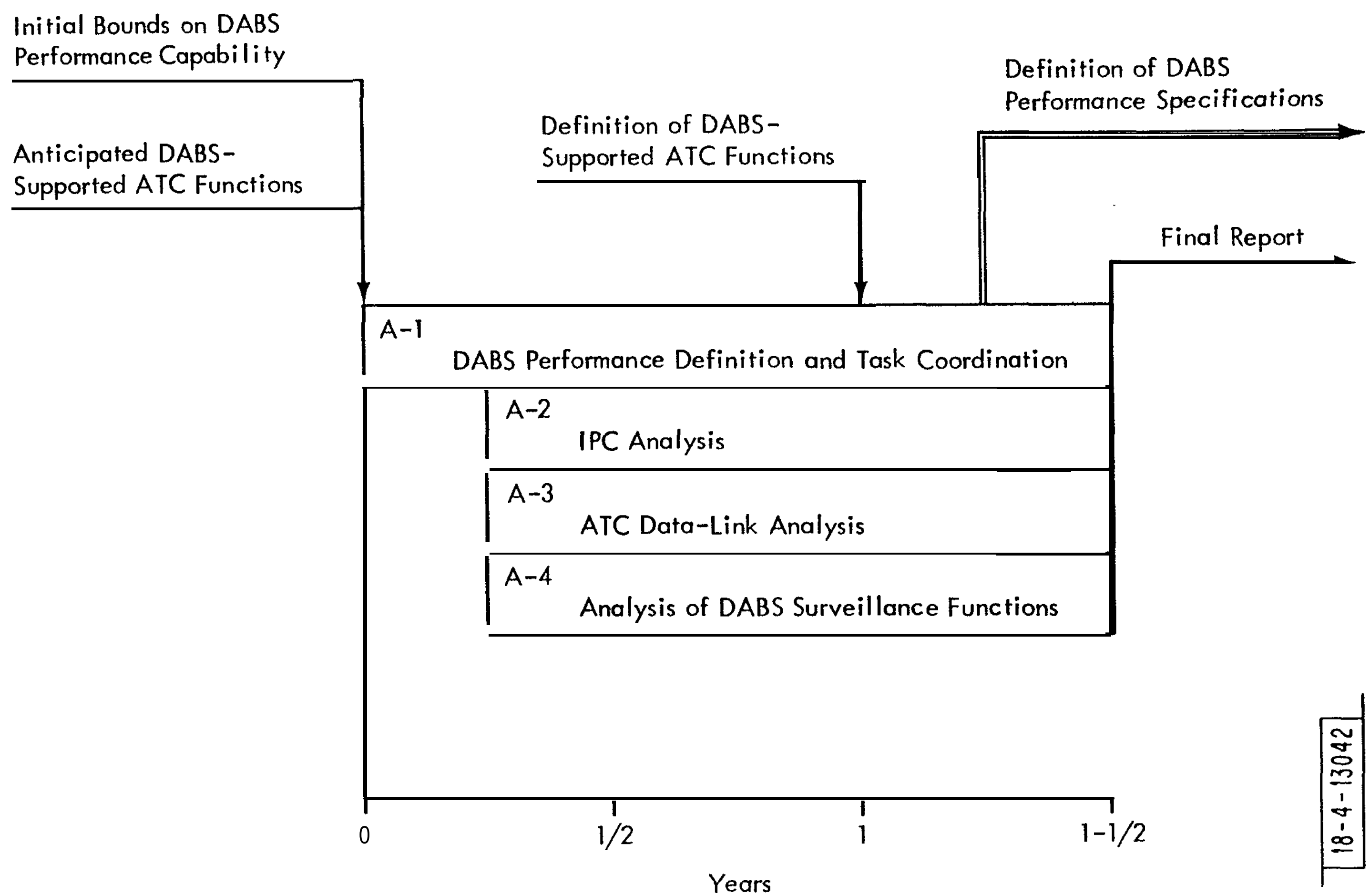


Fig. IV-4. Schedule chart of Task Group A: definition of performance specifications.

TABLE IV-l

COSTING SUMMARY, DEFINITION OF PERFORMANCE SPECIFICATIONS

TASK GROUP A

TASK NO.	TASK DESCRIPTION	AGENCY	YEAR 1 MEN	YEAR 1 COST	YEAR 2 MEN	YEAR 2 COST	YEAR 3 MEN	YEAR 3 COST	YEAR 4 MEN	YEAR 4 COST	TOTAL COST
A-1	DABS Performance Definition and Task Coordination	SEG	6	360K	4	240K					600K
A-2	IPC Analysis	G/NPA	4	240K	2	120K					360K
A-3	ATC Datalink Analysis	G/NPA	2	120K	1	60K					180K
A-4	Analysis of DABS Surveillance Functions	G/NPA	3	180K	8 1/2	90K					270K
	TOTAL GOVERNMENT AND NON-PROFIT		15	900K	8 1/2	510K					1410K
	TOTAL INDUSTRY										
	TOTAL		15	900K	8 1/2	510K					1410K

NOTES:

utilization. The individual work tasks in this group are:

- B-1: DABS/ATCRBS Interference Model Development and Task Coordination
- B-2: ATCRBS Transponder Characteristics Measurement
- B-3: ATCRBS Channel Loading Measurements
- B-4: ATCRBS Channel Loading Simulation Program Development
- B-5: DABS Channel Loading Simulation Program Development

This task group begins its work with an initial specification of the structure of the ATCRBS interference model; this is later refined during the course of modulation and monopulse design studies. Interim results based largely on analytical models will be required early in the second program year for selection of DABS modulation and monopulse. Computer models of the interference generated by both ATCRBS and DABS will be required for the design validation studies beginning in the third program year.

Task Group C: Modulation and Coding - The objective of this task group is the selection of DABS modulation and coding techniques and signal processing algorithms, and the development of experimental DABS transponders for use in the feasibility tests. This task group includes analysis of the performance of various candidate modulation systems in a postulated interference environment, DABS transponder design/costing studies for candidate modulation/coding systems, and measurement of ATCRBS transponder responses to candidate DABS interrogations.[1] Also included in this group is the measurement of ATCRBS aircraft antenna patterns to assess the need for aircraft antenna diversity on light aircraft, transport aircraft, and military aircraft carrying external stores. The selection of DABS modulation and coding formats is the responsibility of the Lead Task of this group. This selection will be made on the basis of the

[1] This is closely related to and hence included in Task B-2.

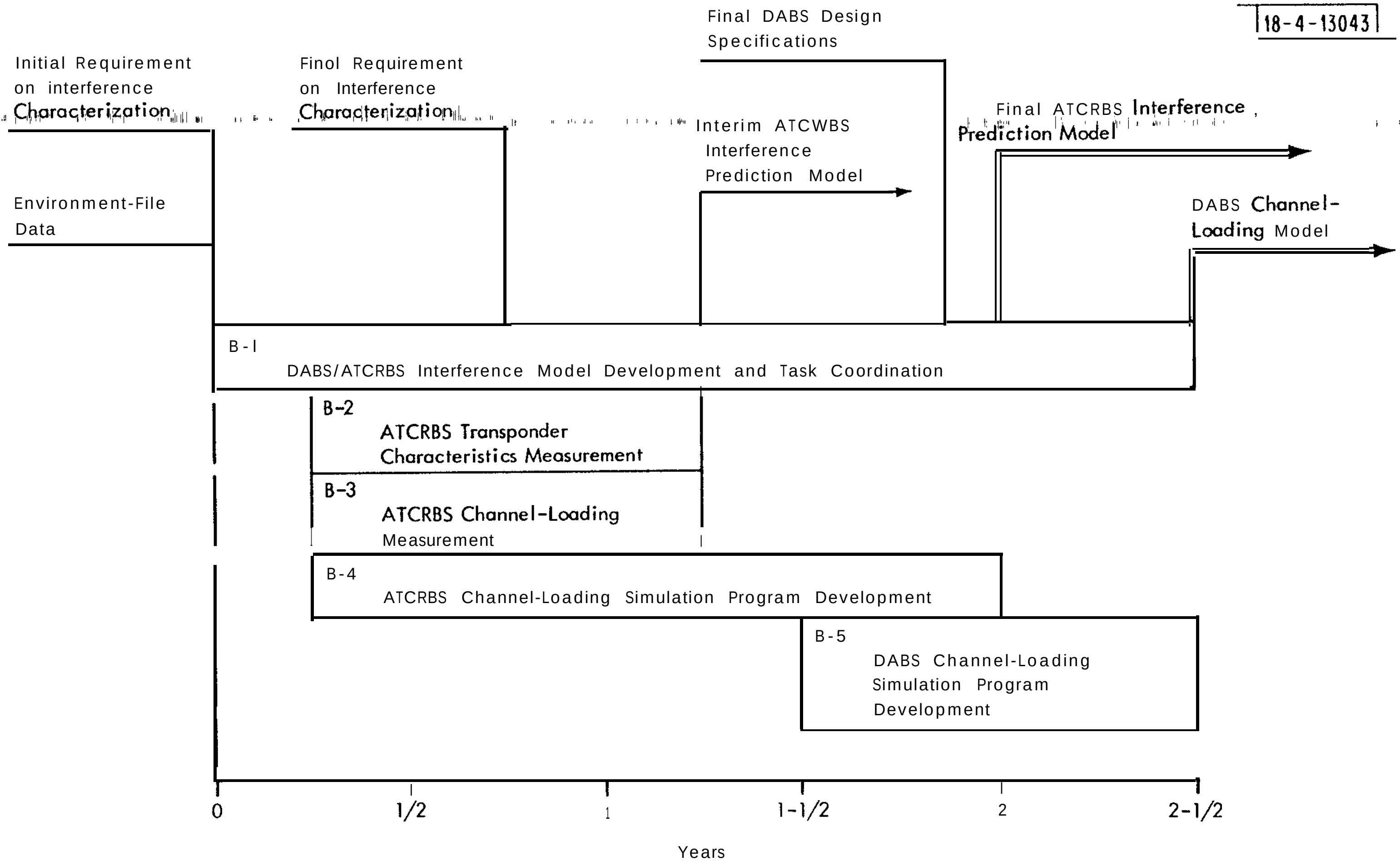


Fig. IV-5. Schedule chart of Task Group B: interference environment modeling.

TABLE IV-2

COSTING SUMMARY, INTERFERENCE ENVIRONMENT MODELLING

TASK GROUP B

ASK NO.	TASK DESCRIPTION	AGENCY	YEAR 1		YEAR 2		YEAR 3		YEAR 4		TOTAL COST
			MEN	COST	MEN	COST	MEN	COST	MEN	COST	
B-1	DABS/ATCRBS Interference Model Development and Task Coordination	SEG	2	120K	2	120K	2	120K			360K
B-2	ATCRBS Transponder Characteristic Measurement	G/NPA	1	100K							100K
B-3	ATCRBS Channel Loading Measurements	INDUSTRY or G/NPA	4	400K							400K
B-4	ATCRBS Channel Loading Simulation Program Development	INDUSTRY or G/NPA	3	240K	2	160K					400K
B-5	DABS Channel Loading Simulation Program Development	INDUSTRY or G/NPA			2	160K	2	160K			320K
	TOTAL GOVERNMENT AND NON-PROFIT		3	240K	2	120K	2	120K			460K
	TOTAL INDUSTRY		7	640K	4	320K	2	160K			1120K
	TOTAL		10	860K	6	440K	4	280K			1580K

NOTES:

performance specifications defined by Task Group A, the projected interference environment defined by Task Group B, the technique evaluations and DABS transponder design/coding studies performed within this group, and the format requirements imposed by the selected monopulse technique (Task Group D).

The tasks included in this group are:

C-l: -Modulation and Coding Design and Transponder Specification
c-2: Transponder Design and Cost Study
c-3: ATCRBS Aircraft Antenna Pattern Measurements
c-4: Transponder Development

Selection of DABS modulation and coding formats is clearly dependent on the generation of key results in Task Group A through D. This selection will have to be made by the midpoint of the second program year if the experimental DABS transponders are to be specified, contracted for, fabricated, and flight tested prior to the fourth program year when these transponders will be used in system feasibility tests.

Task Group D: Antenna and Monopulse - The main objective of this task group is the design and development of receive monopulse and antennas for DABS. The activities include the analytical and experimental evaluation of realizable monopulse performance in multipath and interference environments, measurements to determine the range of site characteristics that must be accommodated by the DABS antenna designs, and cost/performance trade-off studies of a number of antenna configurations by industrial contractors . The candidate antenna configurations include a new rotating antenna (possibly with back-to-back reflectors), a DABS array (of greater capability than the ATCRBS E-scan array), and modifications of varying degrees to the basic ATCRBS boom antenna and the ASR and ARSR antennas. Selection ofbne or more DABS antenna configurations to be fabricated for feasibility testing will depend on key inputs from Task Group A (required

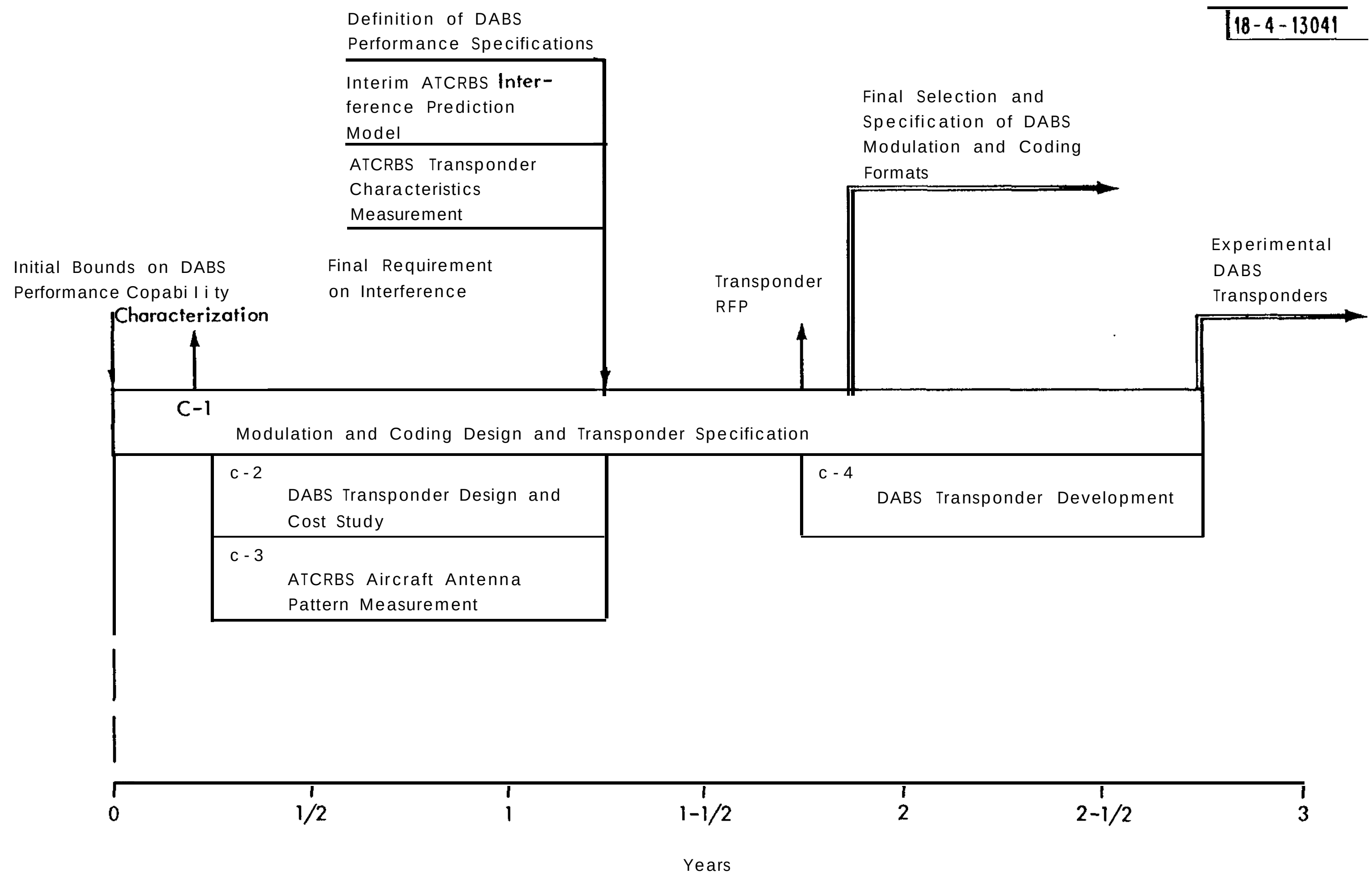


Fig. IV-6. Schedule chart of Task Group C: modulation and coding.

TABLE IV-3

COSTING SUMMARY, MODULATION AND CODING

TASK GROUP C

TASK NO.	TASK DESCRIPTION	AGENCY	YEAR 1		YEAR 2		YEAR 3		YEAR 4		TOTAL COST
			MEN	COST	MEN	COST	MEN	COST	MEN	COST	
C-1	Modulation and Coding Design and Transponder Specification	SEG	3	180K	3	180K	1	60K			420K
C-2	Transponder Design and Cost Study	INDUSTRY	NA [1]	300K							300K
C-3	ATCRBS Aircraft Antenna Pattern Measurements	G/NPA or INDUSTRY	3	240K							240K
C-4	Transponder Development	INDUSTRY			NA [1]	400K	- [2]	-			400K
	TOTAL GOVERNMENT AND NON-PROFIT		6	420K	3	180K	1	60K			660K
	TOTAL INDUSTRY		NA	300K	NA	400K					700K
	TOTAL		6	720K	3	580K	1	60K			1360K

NOTES: 1. Not applicable, major costs are not staff-related.

2. Work continues in year 3, commitment in year 2.

data refresh rates and azimuth accuracy), Task Group B (projected interference environment for monopulse operation), and the monopulse technique evaluations and site characterization of this task group.

Provision of the ATCRBS E-scan antenna with monopulse and beam agility and its evaluation as a DABS sensor are also included in this group, together with-procurement of the transmitter and receiver equipment for each experimental antenna.

Selection of antenna and monopulse designs must be completed by midpoint of the second program year to allow sufficient time for equipment fabrication, delivery, and checkout prior to system feasibility tests beginning in the fourth program year. The time available to initiate the antenna design/costing studies to provide critical inputs to the selection process is very short. The time from antenna/monopulse selection to the start of equipment fabrication is also tight because of the scheduling constraints imposed by system feasibility tests.

The individual tasks included in this group are:

- D-1: Antenna and Monopulse Design and Task Coordination
- D-2: Monopulse Studies
- D-3: Study of Sensor Characteristics
- D-4: DABS Rotating Antenna Design and Cost Study
- D-5: DABS Array Antenna Design and Cost Study
- D-6: Design and Cost Study of Modified ATCRBS Boom Antenna
- D-7: Design and Cost Study of ASR Antenna Modifications for DABS
- D-8: Design and Cost Study of ARSR Antenna Modifications for DABS
- D-9: Fabrication of Monopulse and Agile Beam Capacity for ATCRBS E-scan
- D-10: Fabrication of Experimental DABS Rotating Antenna
- D-11: Fabrication of Experimental DABS Array Antenna
- D-12: Fabrication of Modified ATCRBS Boom Antenna

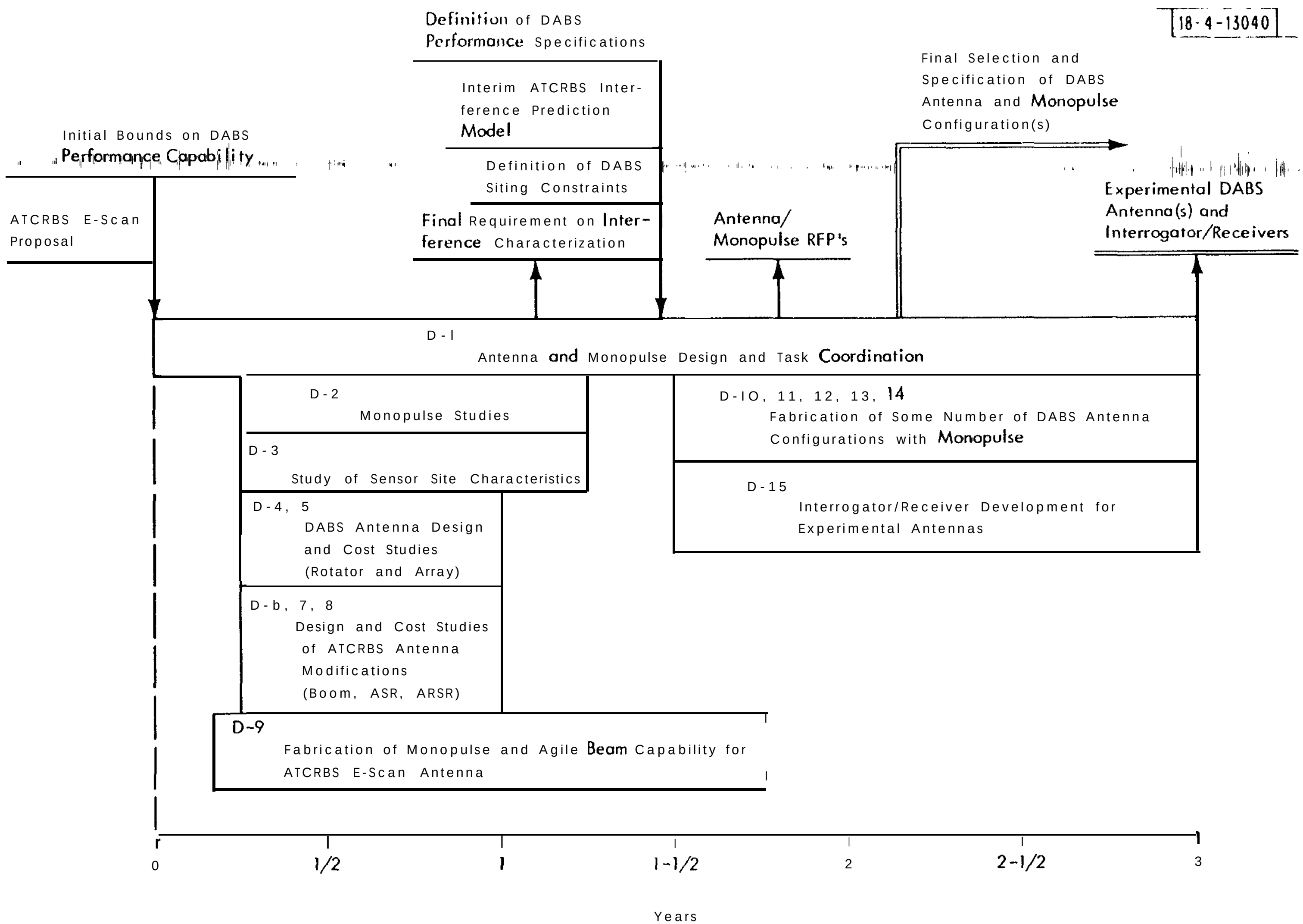


Fig. IV-7. Schedule chart of Task Group D: antenna and monopulse.

TABLE IV-4a

COSTING SUMMARY, ANTENNA AND MONOPULSE

TASK GROUP D

TASK NO.	TASK DESCRIPTION	AGENCY	YEAR 1		YEAR 2		YEAR 3		YEAR 4		TOTAL COST
			MEN	COST	MEN	COST	MEN	COST	MEN	COST	
D-1	Antenna and Monopulse Design and Task Coordination	SEG	4	240K	4	240K	2	120K			600K
D-2	Monopulse Studies	G/NPA	5	500K	5	500K					1000K
D-3	Study of Sensor Site Characteristics	G/NPA	2	120K	2	120K					240K
D-4	DABS Rotating Antenna Design and Cost Study	INDUSTRY	4(1)	200K(1)							200K
D-5	DABS Array Antenna Design and Cost Study	INDUSTRY	5(1)	250K(1)							250K
D-6	Design and Cost Study of Modified ATCRBS Boom Antenna	INDUSTRY	3(1)	150K(1)							150K
	TOTAL GOVERNMENT AND NON-PROFIT		11	860K	11	860K	2	120K			1840K
	TOTAL INDUSTRY		12	600K							600K
	TOTAL		23	1460K	11	860K	2	120K			2440K

NOTES: 1. Staffing and cost are totals for 2 contracts.

TABLE IV-4b

COSTING SUMMARY, ANTENNA AND MONOPULSE

TASK GROUP D (CONT.)

TASK NO.	TASK DESCRIPTION	AGENCY	YEAR 1		YEAR 2		YEAR 3		YEAR 4		TOTAL COST
			MEN	COST	MEN	COST	MEN	COST	MEN	COST	
D-7	Design and Cost Study of ASR Antenna Modification for DABS	INDUSTRY	3[1]	150K[1]							150K
D-8	Design and Cost Study of ARSR Antenna Modification for DABS	INDUSTRY	3[1]	150K[1]							150K
D-9	Fabrication of Monopulse and Agile Beams Capability for ATCRBS E-scan	INDUSTRY	NA[2]	50K	-[3]	-[3]					50K
D-10	Fabrication of Experimental DABS Rotating Antenna	INDUSTRY			NA[2]	600K	-[4]	-[4]			600K
D-11	Fabrication of Experimental DABS Array Antenna	INDUSTRY			NA[2]	1500K	-[4]	-[4]			1500K
D-12	Fabrication of Modified ATCRBS Boom Antenna	INDUSTRY			NA[2]	100K	-[4]	-[4]			100K
	TOTAL GOVERNMENT AND NON-PROFIT										
	TOTAL INDUSTRY		NA	350K	NA	2200K					2550K
	TOTAL		NA	350K	NA	2200K					2550K

NOTES:
1. Staffing and cost are totals for 2 contracts.
2. Not applicable, major costs are not staff related.
3. Work continues in Year 2, committment in year 1.
4. Work continues in Year 3, committment in year 2.
5. This task is optional, dependent on system decision as to required DABS Antenna types.

TABLE IV -4c

COSTING SUMMARY, ANTENNA AND MONOPULSE

TASK GROUP D (CONT.)

TASK NO.	TASK DESCRIPTION	AGENCY	YEAR 1		YEAR 2		YEAR 3		YEAR 4		TOTAL COST
			MEN	COST	MEN	COST	MEN	COST	MEN	COST	
D-13	Fabrication of Modified ASR Antenna	INDUSTRY			NA[1]	200K	-[2]				200K
D-14	Fabrication of Modified ARSR Antenna	INDUSTRY			NA[1]	300K	-[2]				300K
D-15	Interrogator/Receiver Development	INDUSTRY			NA[1]	500K	-[2]				500K
	TOTAL GOVERNMENT AND NON-PROFIT		11	860K	11	860K	2	120K			1840K
	TOTAL INDUSTRY		NA	950K	NA	3200K					4150K
	TOTAL		11	1710K	11	3960K	2	120K			5960K

NOTES:
1. Not applicable, major costs are not staff related
2. Work Continues in Year 3, committment in year 2
3. Work continues in Year 4, committment in year 3
4. This task is optional, dependent on system decision as to required DABS Antenna Types.

D-13: Fabrication of Modified ASR Antenna

D-14: Fabrication of Modified ARSR Antenna

D-15: Interrogator/Receiver Development

Task Group E: Data Processing and Interfaces - The objectives of this group are:

(a) Definition of the division of processing and control between on-site and central facilities;

(b) Selection of on-site and central data processing equipment configurations and algorithms;

(c) Development of on-site and central data processing equipment and interfaces for the feasibility tests.

An early output of this group must be the definition of the final interface between the DABS surveillance system and the enroute or terminal processing, display and control system. The question of which DABS processing tasks should be performed on-site and which at the control centers can then be addressed. These decisions will be made with the aid of supporting analyses of the specific data processing tasks to be performed, such as interrogation management, DABS reply processing, target assignment, etc. , together with an analysis of the merits of various ways of organizing the overall DABS data processing task with respect to economy, reliability, and technical capability.

Following the choice of techniques and algorithms to perform each basic processing task, and of a system configuration for the organization of the whole processing load, the development and fabrication of specific equipment must be carried out in order to provide at least two fully operable DABS sensors for feasibility testing. Similarly, the central data processing equipment, including modifications to NAS and ARTS (as well as interface equipment to these systems) must be developed and fabricated for operational testing of the entire system.

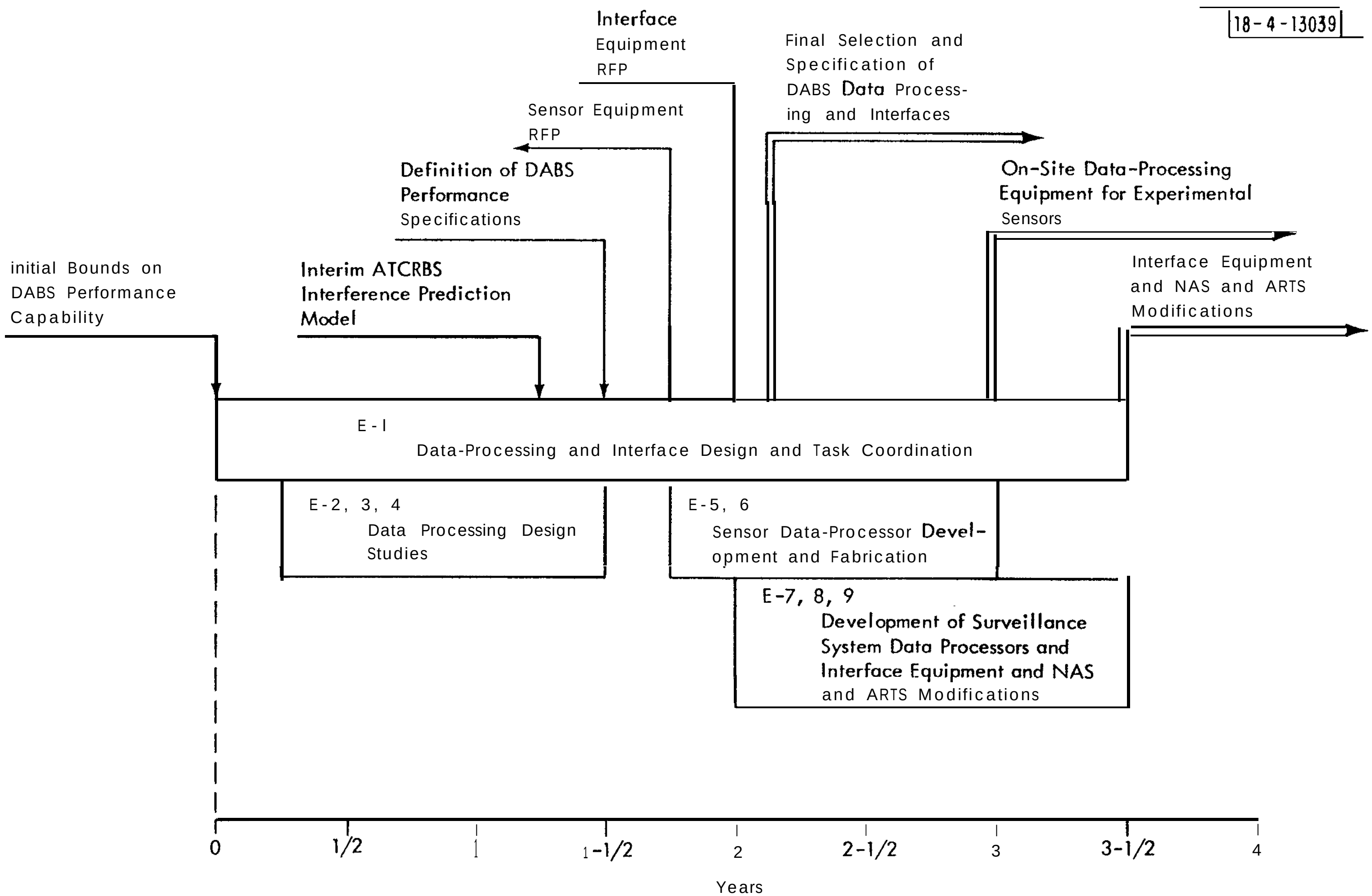


Fig. IV-8. Schedule chart of Task Group E: data processing and interfaces.

TABLE IV-5a

COSTING SUMMARY, DATA PROCESSING AND INTERFACES

TASK GROUP E

TASK NO.	TASK DESCRIPTION	AGENCY	YEAR 1		YEAR 2		YEAR 3		4		TOTAL COST
			MEN	COST	MEN	COST	MEN	COST	MEN	COST	
E-1	Data Processing and Interface Design and Task Coordination	SEG	3	180K	3	180K	2	120K	2	120K	600K
E-2	Interrogation Management Design Study	G/NPA or INDUSTRY	3	180K	2	120K					300K
E-3	Sensor Data Processing Design Study	G/NPA or INDUSTRY	2	120K	2	120K					240K
E-4	Surveillance System Data Processing Design Study	G/NPA or INDUSTRY	3	180K	2	120K					300K
E-5	Interrogation Management Processor Development and Fabrication	INDUSTRY or G/NPA			NA[1]	800K	-[2]	-			800K
E-6	Sensor Data Processor Development and Fabrication	INDUSTRY or G/NPA			NA	500K	-[2]	-			500K
	TOTAL GOVERNMENT AND NON-PROFIT		11	660K	9	540K	2	120K	2	120K	1440K
	TOTAL INDUSTRY				NA	1300K	-	-[2]			1300K
	TOTAL		11	660K	9	1840K	2	120K	2	120K	2740K

NOTES: 1. Not applicable, major costs are not staff-related

2. Work continues in year 3, committment in year 2.

TABLE IV-5b

COSTING SUMMARY, DATA PROCESSING AND INTERFACES

TASK GROUP E (CONT.)

TASK NO.	TASK DESCRIPTION	AGENCY	YEAR 1		YEAR 2		YEAR 3		YEAR 4		TOTAL COST
			MEN	COST	MEN	COST	MEN	COST	MEN	COST	
E-7	Surveillance System Data Processor Development and Fabrication	INDUSTRY or G/NPA					NA(1)	700K	-(2)	-	700K
E-8	NAS Modification and Interface Equipment Development and Fabrication	INDUSTRY or G/NPA					NA	400K	-(2)	-	400K
E-9	ARTS Modification and Interface Equipment Development and Fabrication	INDUSTRY or G/NPA					NA	400K	-(2)	-	400K
TOTAL GOVERNMENT AND NON-PROFIT			11	660K	9	540K	2	120K	2	120K	1440K
TOTAL INDUSTRY					NA	1300K	NA	1500K			2800K
TOTAL			11	660K	9	1840K	2	1620K	2	120K	4240K

NOTES: 1. Not applicable, major costs are not staff-related.
2. Work continues in Year 4, committment in year 3.

The individual tasks of this group are:

E-1: Data Processing and Interface Design and Task Coordination

E-2: Interrogation Management Design Study

E-3: Sensor Data Processing Design Study

E-4: Surveillance System Data Processing Design Study

E-5: Interrogation Management Processor Development and Fabrication

E-6: Sensor Data Processor Development and Fabrication

E-7: Surveillance System Data Processor Development and Fabrication

E-8: NAS Modifications and Interface Equipment Development and Fabrication

E-9: ARTS Modification and Interface Equipment Development and Fabrication

Task Group F: Feasibility Test - The objective of this task group is the demonstration of feasibility of DABS equipment design and experimental verificationof DABS characteristics. These feasibility tests are essential to the realization of the Phase 1 objective of achieving a proven DABS design ready for prototype engineering. The test series begins with evaluation of DABS transponder and aircraft antenna system design and continues to involve more DABS equipment in each test until a demonstration of operation of NAS and ARTS (suitable modified) with multiple DABS and ATCRBS sensors can be carried out. This task group will be carried out primarily by NAFEC, and will involve extensive utilization of existing NAFEC facilities such as the prototype NAS and ARTS installations.

The individual tasks listed in this group are:

F-1: Experiment Planning and Test Procedure Development

F-2: Test Facility Preparation

F-3: DABS Transponder Test and Evaluation

F-4: Experimental Feasibility Demonstration of DABS Sensor Design

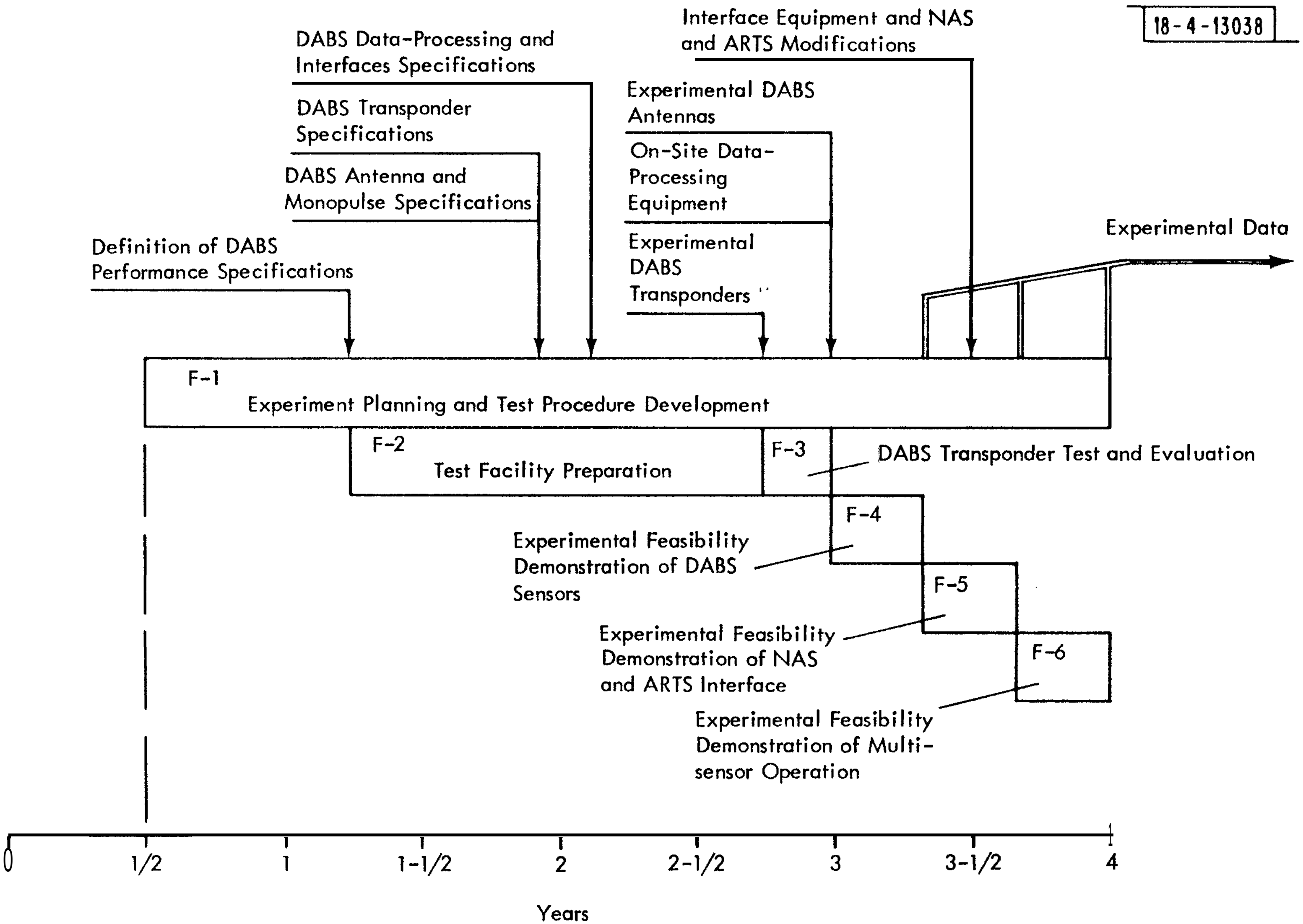


Fig. IV-9. Schedule chart of Task Group F: feasibility test.

TABLE IV-6

COSTING SUMMARY, FEASIBILITY TEST

TASK GROUP F

TASK NO.	TASK DESCRIPTION	AGENCY	YEAR 1		YEAR 2		YEAR 3		4		TOTAL COST
			MEN	COST	MEN	COST	MEN	COST	MEN	COST	
F-1	Experiment Planning and Test Procedure Development	NAFEC	1	50K	2	100K	2	100K	2	100K	350K
F-2	Test Facility Preparation	NAFEC			NA[1]	700K	NA[1]	800K			1500K
F-3	DABS Transponder Test and Evaluation	NAFEC					2	100K			100K
F-4	Experimental Feasibility Demonstration of DABS Sensor Design	NAFEC							4	1000K	1000K
F-5	Experimental Feasibility Demonstration of NAS and ARTS Interface	NAFEC							3	1000K	1000K
F-6	Experimental Feasibility Demonstration of Multi-Sensor Operation	NAFEC							3	1400K	1400K
	TOTAL GOVERNMENT AND NON-PROFIT		1	150K	NA	800K	NA	1000K	12	3500K	5350K
	TOTAL INDUSTRY										
	TOTAL		1	50K	NA	800K	NA	1000K	12	3500K	5350K

NOTES: 1. Not applicable, major costs are not staff-related.

F-5: Experimental Feasibility Demonstration of NAS and ARTS Interface

F-6: Experimental Feasibility Demonstration of Multi-Sensor Operation

Task Group G: Design Validation - The objective of this task group is the evaluation of the predicted performance of the chosen DABS design over its expected operational lifetime, leading to design validation and generation of a System Implementation Plan for Phase 3. Interference environment models are a key input to the construction of a performance prediction model for combined DABS/ATCRBS operation. Evaluation of experimental data from the feasibility tests will be done to verify the accuracy of the performance prediction model. Analytical and/or simulation studies of combined DABS/ATCRBS operation will be carried out with models of projected traffic and in various phases of the transition period. Of critical interest in this series of investigations will be interference effects between DABS and ATCRBS and testing various approaches to the implementation of DABS.

Satisfactory demonstration of DABS design feasibility and performance (i.e. system capacity, communication reliability, and data accuracy) during the expected operational lifetime of DABS then leads to the generation of:

(i) a program plan and prototype equipment specifications for Phase 2;

(ii) provisional DABS National Standard and Transponder Minimum Operation Characteristic;

(iii) a System Implementation Plan for Phase 3.

The tasks included in this group are (both considered equivalent to Lead Tasks):

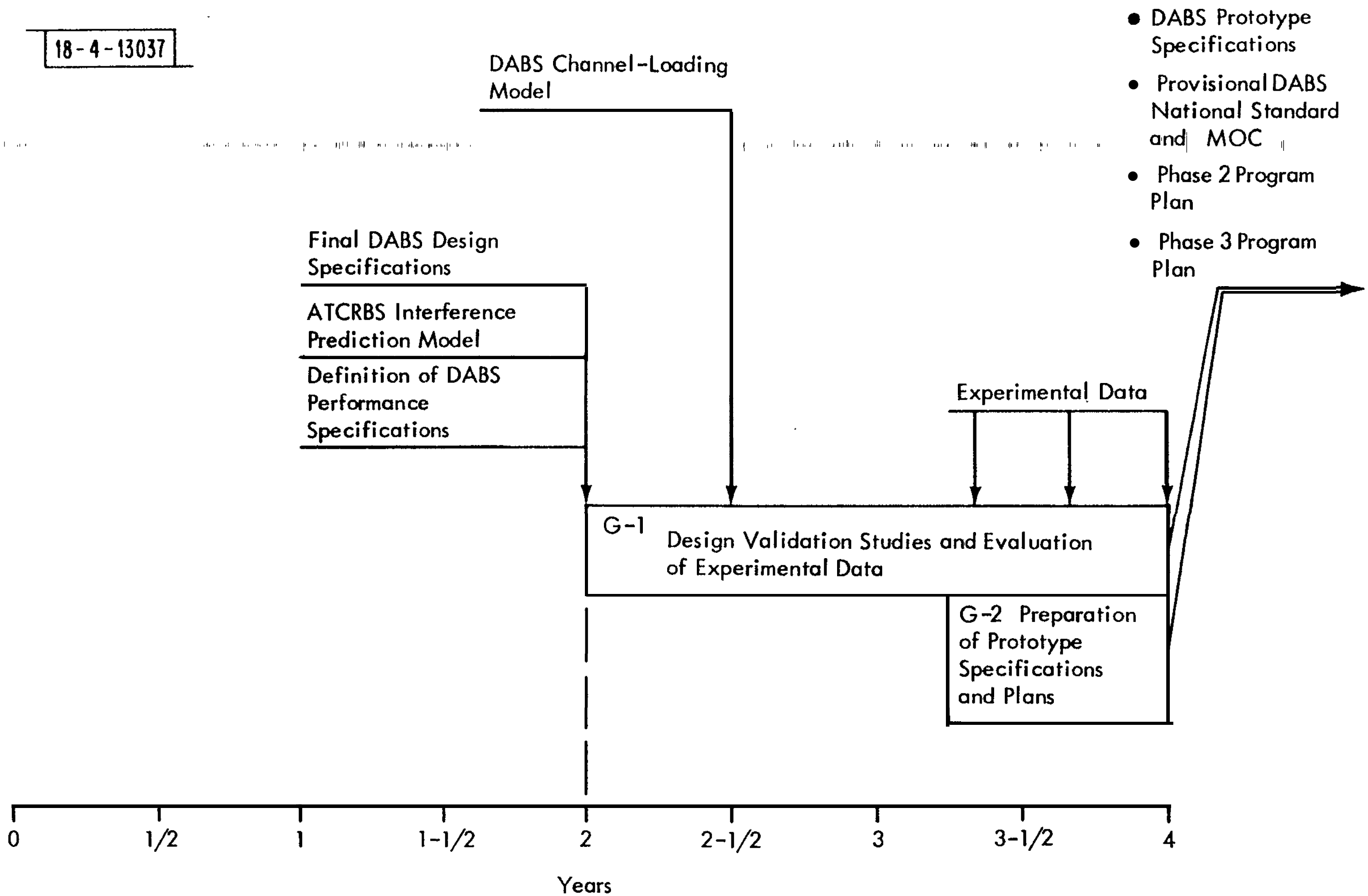


Fig. IV-10. Schedule chart of Task Group G: design validation.

TABLE IV-7

COSTING SUMMARY, DESIGN VALIDATION AND SYSTEM ENGINEERING

TASK GROUPS G AND H

ASK NO.	TASK DESCRIPTION	AGENCY	YEAR 1		YEAR 2		YEAR 3		YEAR 4		TOTAL COST
			MEN	COST	MEN	COST	MEN	COST	MEN	COST	
G-1	Design Validation Studies and Evaluation of Experimental Data	SEG					8	560K	8	500K	1060K
G-2	Preparation of DABS Specifications and Plans	SEG							6	300K	300K
H-1	DABS System Design	SEG	5	280K	7	390K	8	450K	9	600K	1720K
	TOTAL GOVERNMENT AND NON-PROFIT		5	280K	7	390K	16	1010K	23	1400K	3080K
	TOTAL INDUSTRY										
	TOTAL		5	280K	7	390K	16	1010K	23	1400K	3080K

NOTES:

G-1: Design Validation Studies and Evaluation of Experimental Data

G-2: Preparation of DABS Specifications and Plans

Task Group H: System Engineering - This task has as its main objective the DABS system definition, design, and design validation. A key activity necessary to carry out this objective is the consideration of all other tasks to assure that necessary technical, economic, and operational data is available at the proper times to provide a sound basis for design decisions. Although the majority of the system engineering activity is included in the Lead Tasks of each Task Group, there will be system engineering staff not directly associated with these Lead Tasks who will be involved in overall program planning and coordination, with responsibility to assure that all aspects of the system design are considered and with responsibility for final design decisions.

3. Summary of Phase 1 Funding

Table IV-8 shows the estimated annual funding required for each Task Group to carry out the four year System Definition and Feasibility Demonstration Phase. Funding sub-totals are shown for three types of agencies that would participate in Phase 1:

1. Government and Non-Profit Agencies (G/NPA's) - - a mixed group of agencies consisting possibly of TSC, DOD Technical Agencies, NASA Laboratories, FCRC's, and non-profit research companies;
2. NAFEC;
3. Private Industry.

The G/NPA participation is heaviest in work critically related to DABS design decisions which must be made objectively with regard to choice of techniques. Industry participation is quite heavy throughout the first three years of this phase, involving design/costing studies and equipment design

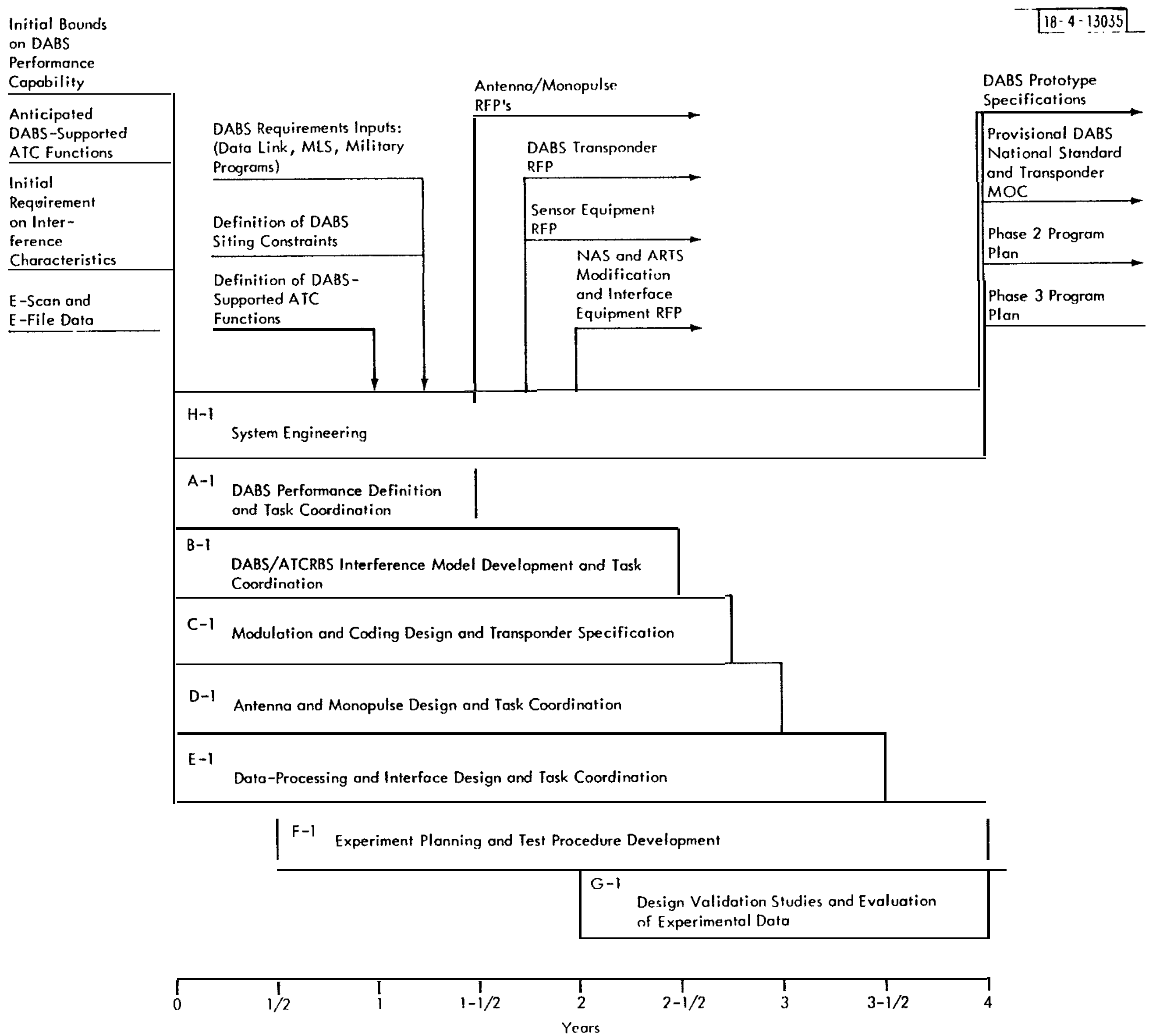


Fig. IV-11. Schedule chart of Task Group H: system engineering.

TABLE IV-8 PHASE 1 COST ESTIMATES (Thousands of Dollars)

GROUP	DESCRIPTION	AGENCY	YEAR-1	YEAR-2	YEAR-3	YEAR-4	4-YR TOTAL
A	Definition of Performance Specifications	SEG	360	240			1410
		G/NPA	540	270			
		IND					
B	Interference Environment Modeling	SEG	120	120	120		1580
		G/NPA	100				
		IND	640	320	160		
C	Modulation and Coding	SEG	180	180	60		1360
		G/NPA	240				
		IND	300	400			
D	Antenna and Monopulse	SEG	240	240	120		5990
		G/NPA	620	620			
		IND	950	3200			
E	Data Processing and Interfaces	SEG	180	180	120	120	4240
		G/NPA	480	360			
		IND		1300	1500		
F	Feasibility Test	NAFEC	50	800	1000	3500	5350
G	Design Validation	SEG			560	800	1360
F	System Engineering	SEG	280	330	450	600	1720
ANNUAL	SUB-TOTAL	SEG	1360	1350	1430	1520	
ANNUAL	SUB-TOTAL	G/NPA	1980	1250			
ANNUAL	SUB-TOTAL	NAFEC	50	800	1000	3500	
ANNUAL	SUB-TOTAL	IND	1890	4220	1660		
ANNUAL TOTAL (ALL AGENCIES)			5280	8620	4090	5020	
GRAND TOTAL							23010

and fabrication. NAFEC funding and responsibility grows during the program, peaking during the DABS feasibility tests in the fourth year. It is premature to cost Task Group F, the NAFEC responsibility, in any detail but it is quite clear that some fraction of the funding of this task group will be spent on industrial contracts, adding to the industry totals for Phase 1. The data for Table IV-l was derived from the Task Group Summary Tables of the previous section.

D. Prototype Engineering, Test, and Evaluation (Phase 2)

Phase 2 of the Development Plan encompasses the development of fully-engineered DABS hardware, both ground and airborne, and its installation and evaluation in an operational ATC environment. This Phase can commence as soon as the Phase 1 testing has progressed sufficiently to permit the specification of and contracting for prototype hardware.

While the detailed planning of Phase 2 will be accomplished during Phase 1, it is anticipated that Phase 2 will include the equipping of a major high-density terminal area and at least some part of the surrounding Center with DABS capability. Emphasis in the test and evaluation will be on the operation of DABS as a system and its integration with existing ATC facilities, particularly NAS and ARTS; it is assumed that the problems relating to a single sensor, and the sensor-aircraft link, have been resolved during Phase 1. The Phase 2 installation therefore must be sufficiently extensive to address the system problems of sensor coordination and control, including target assignment and hand-off, message routing, selective ATCRBS lock-out, etc.

Successful completion of Phase 2 testing will require the equipping of a substantial number of aircraft with DABS transponders, built to the provisional National Standard developed during Phase 1. The extent to which the FAA will subsidize the development, purchase, and installationof the transponders used for these tests will be a subject for negot:iation between the FAA. avionics manufacturers, and the user community.

The primary outputs of Phase 2 comprise:

1. a fully tested design for DABS, and a plan for its orderly implementation.
2. a National Standard for DABS, plus a TSO and/or MOC for transponders.
3. complete engineering/production specifications for all hardware and software elements of DABS
4. a schedule of proposed rulemaking actions for requiring DABS transponders on aircraft.

While international acceptance and standardization is not a prerequisite for the domestic implementation of DABS, effort should be made to achieve this agreement at an early date, preferably by the conclusion of the Phase 2 evaluation.

E. System Implementation (Phase 3)

Of critical importance to the acceptability of DABS to the aviation community is an implementation plan which provides for a gradual transition from ATCRBS to DABS, permitting the user to "get his money's worth" out of his ATCRBS equipment before forcing him to re-equip. Although as has been pointed out previously the exact nature of DABS can not be defined at this time, it is possible to describe in general terms an implementation plan which meets the above criterion and is applicable to a wide variety of potential system designs. The purpose of outlining such a plan at this time is to provide a perspective on how the system might be implemented, and highlight some of the key events in that process; it is not intended to suggest that this is the only or even the best way to-bring the system into operational use. Only much further along in the development cycle, when both the operational pressures and

and the system design are clearer, can a detailed implementation plan be meaningfully prepared.

Fig. IV- 12 outlines such a preliminary DABS implementation plan, illustrating the relationship of key events in Phase 3 (Implementation).

Certain dates and time intervals shown for Phase 3 have been selected to agree with the proposed time schedules set for Phase 1 and 2 and the planned NAS/ARTS implementation.(1) The remaining dates and intervals, especially those related to requirements to be DABS equipped, represent an approximate time ordering of events. It will not be possible to set realistic schedules for implementation until completion of the prototype phase.

The first event shown as part of the implementation schedule is the availability of transponder specifications approximately three years after the start of Phase 1; this will provide avionics manufacturers with time to develop pre-production DABS transponders for use in the DABS prototype testing phase. A preliminary DABS system definition is expected during the fourth year as an output from Phase 1. As a consequence of the prototype testing and evaluation during Phase 2, a DABS National Standard and transponder MOC, and ground equipment specifications, should be forthcoming during the sixth year, It would be useful to both the manufacturer and the user if at the same time the FAA were to release proposed rul'e-making actions on the requirement to have DABS capability. These rules would set the circumstances and the dates when the requirements would become effective. It is anticipated that these requirements would result in a gradual implementation of DABS airborne equipment and would

(1 he National Aviation System Plan, Ten Year Plan · 1971 - 1981 DOT/FAA March 1971.

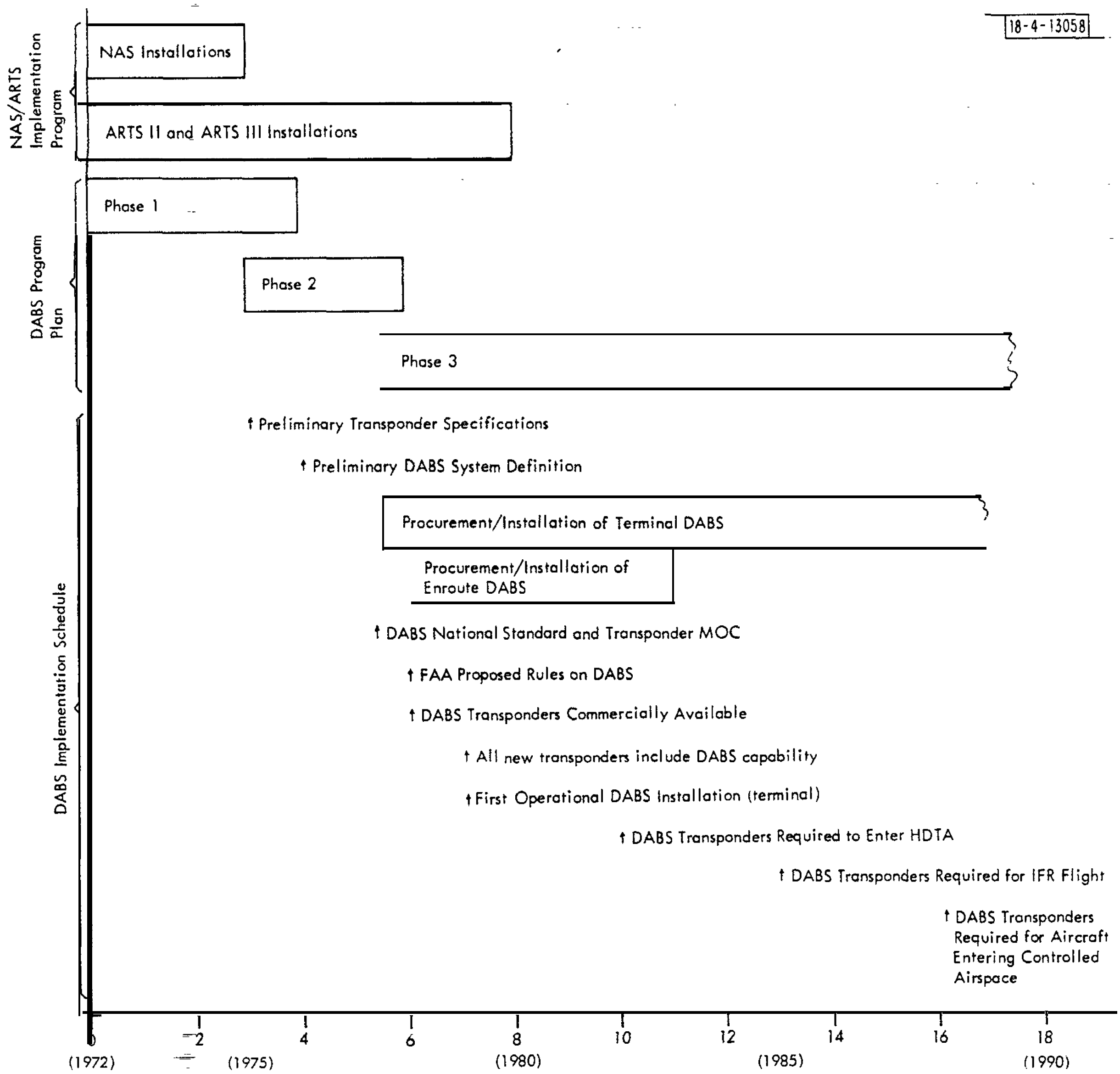


Fig. IV-12. A tentative DABS implementation schedule.

recognize the economic impact on the individual user.

System implementation will commence with the initial procurement of production equipment around the sixth year. The first DABS installation, probably in a high-density terminal environment, is expected to become operational about 18 months later. The initial procurement would probably emphasize equipping most high density terminal areas (HDTA) so as to provide an early alleviation of the ATCRBS synchronous garble problem. In this regard, it would seem likely that aircraft flying in a HDTA be required to have DABS capability within a relatively short time, perhaps four years after DABS transponders become commercially available; by this time all critical HDTA's would be DABS-equipped, Enroute DABS installations would also commence during the sixth year, with all enroute centers and sensors equipped with DABS in approximately five years. Around seven years after the availability of DABS transponders, all aircraft conducting IFR operations would be required to be DABS equipped, with such capability required for all operations within controlled airspace a few years later.

As stated above, such a schedule allows for an orderly transition to DABS with a minimum burden on the user. It is possible that the outlined schedule is too leisurely, in that it may not rapidly enough meet the requirements of ATC for improved surveillance quality and for a data-link capability. A key element of the early phase of the program must be to quantitatively assess these requirements and develop a transition schedule which meets the real needs of ATC while placing a minimum economic burden on the airspace user.

V. PROGRAM MANAGEMENT

A. General

Today DABS exists only as a concept, not a system specification or design. The initial-phase of the development effort must focus on developing a set of performance specifications for the system, an interactive process involving trade-offs between the needs of ATC and the costs of various levels of DABS capability. Ideally such a process would be carried out by a government design team which can interact freely with overall ATC planning activities, with related activities within the DOD, and with a wide range of industrial organization and user groups. It would be difficult, however, to bring together within the government a sufficiently large team of full-time professionals, and who have available the technical facilities needed to carry out the system design effectively. Therefore an alternative program management structure has been sought which retains the flexibility and objectivity of a government design team, but does not require as heavy an involvement of government personnel. Such a management structure is outlined in this Chapter.

For a variety of reasons already discussed, the DABS Development Plan has been formulated to minimize the time to system implementation. The realization of such a program requires a serious government commitment to the DABS program, including a willingness to compress normal administrative processes, especially those concerned with personnel allocation and with procurement. To accomplish Phase 1 in the scheduled time will require a number of parallel efforts at the outset of the program; this, in turn, will call for a substantial administrative effort in quickly initiating work on DABS at a number of different agencies. The proposed management structure and work breakdown are strongly influenced by the need for such an intensive effort early in the program.

One other factor relating to overall program management deserves comment at the outset. At present separate divisions within the FAA are responsible for the development of the sensors and for the development of the surveillance data processing functions such as digitization, tracking, and combination of data from different sensors. The realization of a successful DABS depends on its development as a surveillance system; the designer must view his task as that of providing a certain quality of air space surveillance, not of providing a new sensor to replace an existing sensor. Only with this broader charter can he carry out the various trade-offs necessary to realize an efficient, economical design, and one incorporating a planned use of redundant coverage to minimize the effects of the loss of any element.

B. Proposed Management Structure

As discussed above, the design of DABS is an activity in which many government programs will have to be dealt with objectively, with the needs of the user community kept foremost in mind. An FAA design team would be a logical choice to carry out the DABS design if it were not for internal staffing constraints. However, the FAA staffing available for the program at the start will be small and will probably be constrained to grow gradually. It is thus mismatched to the intensive effort required at the outset of the program.

The recommended alternative is a relatively small FAA DABS Program Management Office (PMO), staffed with four to six professional personnel, and supported on contract by a System Engineering Group (SEC) of approximately 25 technical staff. The quasi-governmental nature of the SEG, involving participation in FAA and DOD planning activities and the review, coordination, and guidance of numerous industrial efforts, suggests the use of one of the government-sponsored non-profit technical organizations for this function. Such a group can deal objectively with technical and operational issues; and can provide the technical capability necessary for the system design process without the potential conflict of interest which would arise if the system design function were carried out by a potential hardware contractor,

Figure V-l outlines the proposed DABS program management structure. The PMO is responsible overall program direction, and for all contracting; in these activities it is supported by the SEG. Coordination of the design tasks, including the execution of certain key design and trade-off studies, and the overall system design is carried out by the SEG. A formal mechanism for coordination with other concerned government departments and agencies is provided by a Government Advisory Group. Communication and coordination with user groups is provided by the formation of a User Advisor Group working directly with the PMO.

The functions of each of these elements, and their interrelationship, are discussed in further detail in the following section.

C. Group Activities and Responsibilities

1. <u>The FAA Program Management Office</u>

The FAA will be the primary agency of the government responsible for the implementation of the DABS Development Plan. The responsibilities of the PMO include:

a. Organization and management of the overall DABS design and development effort, including FAA facilities and resources as well as those of the SEG;

b. Planning and coordination with other FAA and DOT programs on ATC, and with the DOD (including the DOD user groups);

c. Communication and coordination with non-military user groups, both domestic and international and the pursuit of ATCRBS and DABS-related international agreements;

d. Establishment of the management structure to carry out the prototype engineering, test and evaluation and the system implementation, as the system definition and feasibility demonstration phase nears completion.

e. Funding and contracting of all participating agencies engaged in the development effort.

2. Government Advisory Group

The Government Advisory Group will provide a focal point for coordination with other government programs and activities. It will include representation from at least the following agencies:

a. Each major division of the FAA, and each branch within SRDS;

b. The DOT R&D management branch;

c. The DOD R&D management branch.

As one-of its early functions, this advisory group should provide the necessary medium of communication in enlisting the active involvement of concerned government agencies, including military user groups, in arriving at a definition of DABS operational requirements and performance specifications.

3. User Advisory Group

Representation of user interests in the DABS Development Program will require participation of many user organizations. A practical means of communication with all user groups may be realized by the formation of a special RTCA committee to periodically review the program with the PMO, communicate with its member organizations, and present recommendations to the FAA. The necessary communication with ARINC, which will probably assume the responsibility of developing the final airline equipment specifications , should be provided through this group. Similarly, the international coordination activities required for eventual ICAO standardization of the DABS may be pursued, at least initially, through this group.

4. System Engineering Group

The SEG will provide direct support to the PMO in many of the latter's functions such as coordination with other agencies, preparation of RFP's, review and evaluation of proposals, and monitoring and guidance of contractors; it will act as the agent of the PMO in the day-to-day execution of many of these functions. In addition, as indicated in detail in Chapter 4, the SEG will be the focal point for the system design effort. It will coordinate the efforts of all of the technical agencies and contractors supporting the program, and will itself carry out some of the critical analytic and experimental studies involved in arriving at a final system design. The responsibility of the SEG also includes the support of the PMO in its interaction with the advisory groups.

5. Industrial Contractors

The experience and expertise of industry in designing, fabricating, and costing equipment relating to DABS is essential if the development program is to result in realizable and economic equipment designs. While retaining the basic technical decision process within the government, the PMO and SEG will solicit extensive participation in the program by industry, both formally through study and fabrication contracts, and informally through technical meetings and exchanges. The DABS transponder and antenna/monopulse design/costing studies early in the program will weigh heavily in the selection of a DABS design. The later fabrication, installation, and operation of experimental DABS equipment is essential to the early demonstration of feasibility of the selected DABS design.

6. Government and Non-Profit Agencies (G/NPA)

A number of government or government-related agencies have special facilities and areas of competence which will provide a valuable source of support for the DABS program. The role of NAFEC in carrying out the test program has already been identified in Chapter IV. There are DABS-related-efforts already underway at the Transportation Systems Center (TSC), the Electromagnetic Compatibility Analysis Center (ECAC), Lincoln Laboratory, and the Mitre Corporation, among others; these efforts can be readily continued and expanded. DOD technical agencies will be involved in the military aspects of the program. The relative ease of initiating or expanding efforts with the G/NPA's make this source of support well matched to the program's early need for extensive analyses and experiments on which key DABS design decisions will be based.

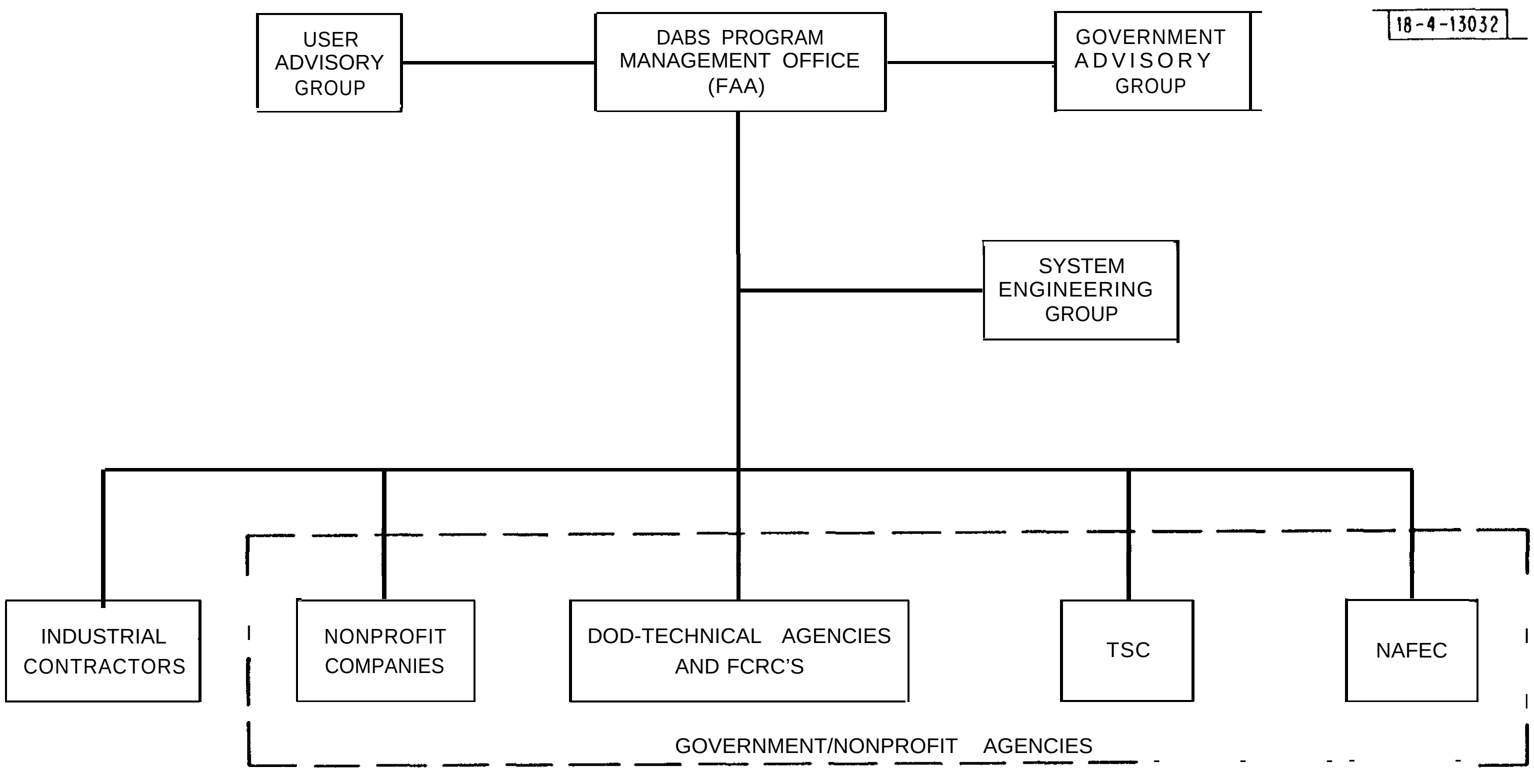


Fig. V-l. Proposed DABS program organizational structure.