

AD-A017 102

AN ACTIVE BEACON-BASED COLLISION AVOIDANCE SYSTEM  
CONCEPT (BCAS)

L. Schuchman

Mitre Corporation

Prepared for:

Federal Aviation Administration

October 1975

DISTRIBUTED BY:

**NTIS**

**National Technical Information Service  
U. S. DEPARTMENT OF COMMERCE**

322072

REPORT FAA-EM-75-7

ADA017102

# AN ACTIVE BEACON-BASED COLLISION AVOIDANCE SYSTEM CONCEPT (BCAS)



DDC  
RECEIVED  
NOV 11 1975  
C

OCTOBER 1975

DOCUMENT IS AVAILABLE TO THE  
PUBLIC THROUGH THE NATIONAL TECHNICAL  
INFORMATION SERVICE, SPRINGFIELD, VA. 22151

U.S. DEPARTMENT OF TRANSPORTATION  
FEDERAL AVIATION ADMINISTRATION  
OFFICE OF SYSTEMS ENGINEERING MANAGEMENT  
WASHINGTON, D.C. 20591

Reproduced by  
NATIONAL TECHNICAL  
INFORMATION SERVICE  
U.S. Department of Commerce  
Springfield, VA. 22151

|   |  |  |   |  |                       |
|---|--|--|---|--|-----------------------|
| 1. Report No.<br>FAA-EM-75-7<br>██████████  |  | 2. Government Accession No.                              |   | 3. Recipient's Catalog No.                         |                       |
| 4. Title and Subtitle<br><br>AN ACTIVE BEACON-BASED COLLISION<br>AVOIDANCE SYSTEM CONCEPT (BCAS)  |  |  |   | 5. Report Date<br>October 1975                     |                       |
|   |  |  |   | 6. Performing Organization Code<br>W-43            |                       |
| 7. Author's<br>L. Schuchman   |  |  |   | 8. Performing Organization Report No.<br>MTR-7036  |                       |
| 9. Performing Organization Name and Address<br><br>The MITRE Corporation<br>1820 Dolley Madison Blvd.<br>McLean, Virginia 22101   |  |  |   | 10. Work Unit No. (TRAIS)                          |                       |
|   |  |  |   | 11. Contract or Grant No.<br>DOT-FA70WA-2448       |                       |
|   |  |  |   | 13. Type of Report and Period Covered<br><br>Final |                       |
| 12. Sponsoring Agency Name and Address<br><br>Office of Systems Engineering Management<br>Department of Transportation<br>Federal Aviation Administration<br>Washington, D.C. 20591   |  |  |   | 14. Sponsoring Agency Code<br>DOT/FAA              |                       |
|   |  |  |   | 15. Supplementary Notes                            |                       |
| 16. Abstract<br><br>The concept of an active Beacon Collision Avoidance System (BCAS) is described in this paper. The design constraints of this air-to-air collision avoidance system are given, together with the system design which enables BCAS to minimize the critical problem of garble. Results from a dynamic aircraft traffic model simulation are presented and finally the possible extensions of BCAS to high density airspace and to a DABS/IPC environment are discussed. |  |  |   |  |                       |
| 17. Key Words<br><br>Air-to-Air Collision Avoidance System,<br>Beacon Collision Avoidance System,<br>Garble, Detector/Tracker,<br>Transponder   |  |  | 18. Distribution Statement<br><br>Unlimited availability. Document may be released to the National Technical Information Service, Springfield, Virginia, 22151, for sale to the public. |  |                       |
| 19. Security Classif. (of this report)<br><br>Unclassified  |  | 20. Security Classif. (of this page)<br><br>Unclassified |   | 21. No. of Pages<br><br>37                         | 22. Price<br><br>4.00 |

**NOTICE**

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

|  |   |
|--|---|
| CLASSIFICATION                             |   |
| TOP SECRET                                 | White Section <input checked="" type="checkbox"/> |
| SECRET                                     | off Section <input type="checkbox"/>              |
| CONFIDENTIAL                               | <input type="checkbox"/>                          |
| RESTRICTIONS                               |   |
| BY<br>SENTR. DIVISION / AVAILABILITY CODES |   |
| Dist. AVAIL. and/or SPECIAL                |   |
| A  |   |

## ACKNOWLEDGEMENT

The author is indebted to Dr. Paul Ebert for creating the unique design of the BCAS cracker and to Mr. Ned Spencer for his many valuable comments on this paper.



## TABLE OF CONTENTS

|   | <u>Page</u> |
|---|-------------|
| 1. INTRODUCTION                               | 1-1         |
| 2. BASIC APPROACH                             | 2-1         |
| 3. SYSTEM DESCRIPTION                         | 3-1         |
| 3.1 Overview                                  | 3-1         |
| 3.2 Transmitter/Receiver                      | 3-1         |
| 3.3 Detector/Tracker                          | 3-3         |
| 3.3.1 Track Acquisition                       | 3-3         |
| 3.3.2 Track Extensions                        | 3-5         |
| 3.3.3 Track Elimination                       | 3-10        |
| 3.3.3.1 Garble Free Multiple Tracks           | 3-10        |
| 3.3.3.2 False "1"s                            | 3-10        |
| 3.3.3.3 False "0"s                            | 3-11        |
| 3.3.3.4 Miscellaneous Track Elimination Rules | 3-11        |
| 3.3.4 Track Establishment                     | 3-11        |
| 3.4 Threat Detector                           | 3-12        |
| 3.5 Display                                   | 3-12        |
| 3.6 Data Link                                 | 3-14        |
| 4. PRELIMINARY PERFORMANCE RESULTS            | 4-1         |
| 4.1 Tracker Simulation                        | 4-1         |
| 4.2 Threat Detector and Resolution Logic      | 4-2         |
| 4.3 ATRCBS Impact                             | 4-5         |
| 5. GROWTH CAPABILITY                          | 5-1         |
| 5.1 Extensions to High Density Airspace       | 5-1         |
| 5.2 DABS/IPC Environment                      | 5-3         |
| APPENDIX A: ENGINEERING MODEL OF ACTIVE BCAS  | A-1         |
| APPENDIX B: DISTRIBUTION LIST                 | B-1         |

## LIST OF ILLUSTRATIONS

|  | <u>Page</u> |
|--|-------------|
| FIGURE 2-1: BCAS INTERROGATION AND REPLY MESSAGE SEQUENCE                        | 2-2         |
| FIGURE 3-1: THE BCAS SYSTEM BLOCK DIAGRAM  | 3-2         |
| FIGURE 3-2: TRACK ACQUISITION  | 3-4         |
| FIGURE 3-3: TRACK EXTENSIONS IN RANGE  | 3-6         |
| FIGURE 3-4: TRACK EXTENSIONS IN ALTITUDE WITH NO CORRECTION                      | 3-7         |
| FIGURE 3-5: TRACK EXTENSIONS IN ALTITUDE WITH CORRECTION<br>DUE TO UNCOVERED "O" | 3-9         |
| FIGURE 3-6: CAS DISPLAY  | 3-13        |
| FIGURE 4-1: ARTS TRACKER (REFERENCED TO BCAS INTERROGATOR)                       | 4-3         |
| FIGURE 4-2: BCAS TRACKER   | 4-4         |
| FIGURE 5-1: 1985 L.A. BASIN MODEL AIRCRAFT DISTRIBUTION                          | 5-2         |
| FIGURE A-1 BCAS SYSTEM   | A-2         |
| FIGURE A-2: TEST MODEL BCAS TRANSMITTER/RECEIVER                                 | A-3         |
| FIGURE A-3: TEST MODEL BCAS SIGNAL PROCESSOR AND<br>INTERFACE UNIT (SPIU)        | A-4         |
| FIGURE A-4: HALF OF TEST MODEL BCAS COMPUTER                                     | A-5         |
| FIGURE A-5: TEST MODEL BCAS INTERROGATOR TRANSPONDER<br>(MODE D CAPABILITY)      | A-6         |
| TABLE 4-1: A SUMMARY COMPARISON OF THE ANTC-117 AND<br>BCAS REMITTER LOGICS      | 4-6         |

## 1. INTRODUCTION

This report describes a concept for an airborne Collision Avoidance System (CAS) based on replies obtained from ATCRBS transponders.\* Being based on the Beacon system, it has been termed BCAS.

In this particular application, BCAS is independent of the ground system, but it utilizes the very widely deployed ATCRBS avionics to sense the range and altitude of nearby aircraft. It is designed for aircraft who wish to have a CAS capability in airspace where the ATC system does not provide surveillance based separation services. In addition, the system will provide some backup to the ground system in airspace within surveillance coverage.

BCAS, as will be described in this report, is an active system consisting of an airborne interrogator, interrogating omnidirectionally with ATCRBS Mode C (altitude). Replies are received from all aircraft within a range of roughly 20 nmi which are equipped with an ATCRBS transponder and a reporting altimeter. The replies are then sorted to obtain range and altitude, and they are tracked to determine whether or not they are a threat. When the BCAS threat detection and resolution logic projects a time to collision of 30 seconds, evasive action is displayed to the pilot.

The system thus assumes widespread deployment of altitude reporting ATCRBS which the BCAS-equipped aircraft can sense and avoid. The ATCRBS-only aircraft which does not have BCAS equipment would not receive collision avoidance warnings; it is assumed that this aircraft continues on its present course. This class of aircraft is said to be carrying a remitter. BCAS also provides protection for two BCAS-equipped aircraft, ensuring complementary maneuvers.

Section 2 presents the basic approach to the design of the system while Section 3 describes the system. Preliminary performance results are presented in Section 4. The growth capability of BCAS is the topic discussed in the final section of this paper.

---

\* A BCAS system which has a passive mode is being developed by Mr. George Litchford. In the Litchford system the equipped user, when under surveillance coverage, listens to ATCRBS ground interrogators and airborne replies to determine the range, altitude and bearing of target aircraft. This paper deals only with an all active BCAS concept.



## 2. BASIC APPROACH

The attractiveness of the concept is that the cost of BCAS is only to the equipped user desiring an independent collision avoidance capability which protects him from all aircraft which are transponder equipped with a mode C (altitude reporting) capability. However, the co-sharing of the channel with ATRBS imposes two requirements on the design of BCAS which had to be met if the concept were to be feasible.

The first requirement is that BCAS should not significantly impact the ATRBS performance. The second is that BCAS would have to work in spite of the fact that replies from many interrogated aircraft might be received simultaneously—this is known as synchronous garble.

To minimize the impact on ATRBS the rate of interrogations has to be kept low. The design calls for a rate of only 2 interrogations per second. The results of an analysis is presented in Section 4 from which it is concluded that even with substantial deployment in a dense environment, BCAS will have a small impact on ATRBS.

The key problem to resolve in BCAS is garble. The garble problem is illustrated in Figure 2-1. An equipped aircraft is shown transmitting a mode C interrogation and receiving replies from five aircraft. Because he uses an omni antenna and since mode C replies are 20.3  $\mu$ s long, aircraft within a slant range of 3.2 nmi of each other, as seen from the interrogator, will have their replies overlapped. In the example given, target replies R2, R3 and R4 will overlap resulting in their altitude codes being garbled.

Two items of information are in each reply; the time at which it occurs, or range, and the altitude code. The method used by BCAS to read through the garble is first to establish a track on range and then to augment it by adding the altitude information. The basis for this approach is described in the following.

The ATRBS signal is a pulse amplitude modulation. That is, energy is transmitted for the "1" bits and no energy is transmitted for the "0" bits. A characteristic of this signal is that interfering pulses rarely destroy the "1"'s but they do cause an error on "0"'s. Since the "1"'s are virtually certain to occur, BCAS will detect them—in particular, the bracket pulses—, digitize the range, and form a tentative track.

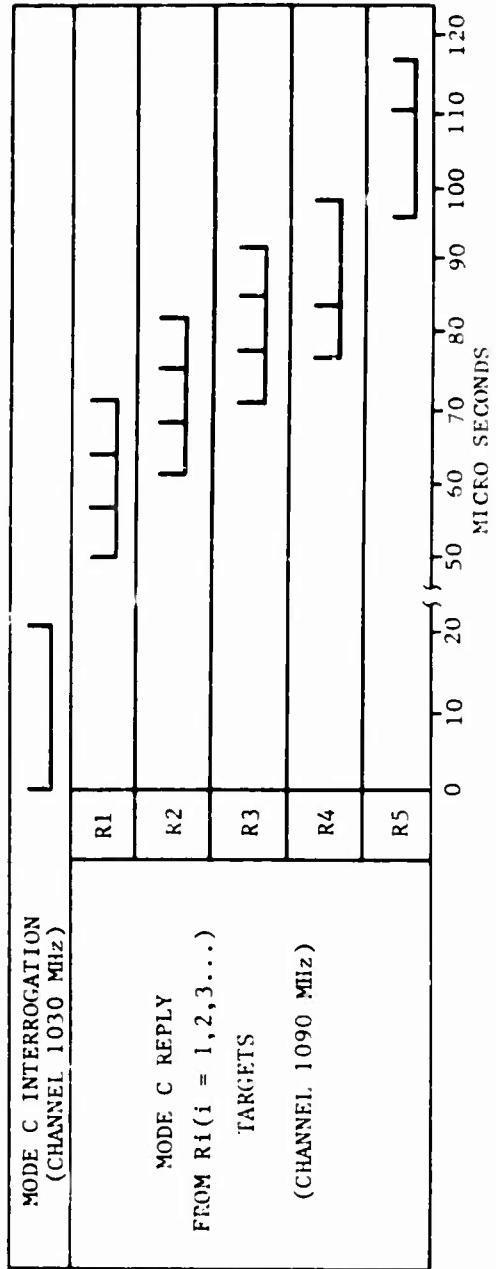
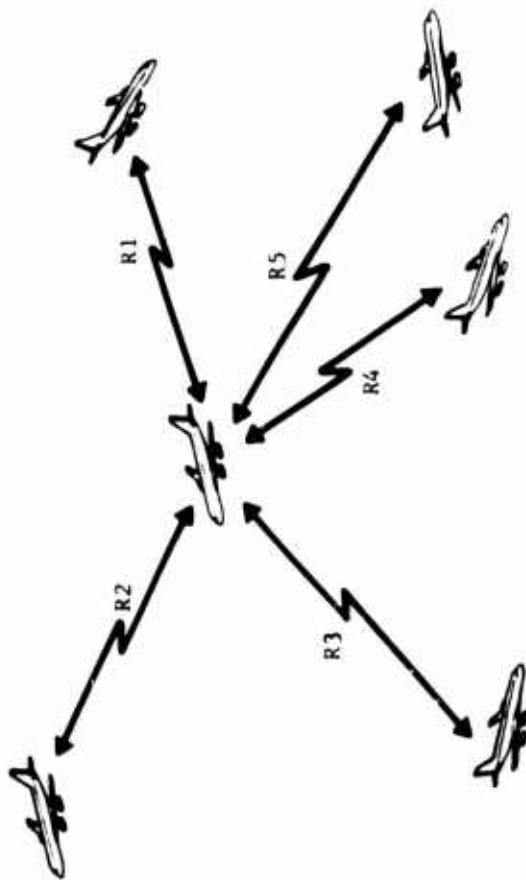


FIGURE 2-1  
BCAS INTERROGATION AND REPLY MESSAGE SEQUENCE

On the other hand, with high probability, the "0" bits will often look like "1" bits in a garble environment. However, as aircraft motion shifts the overlapped replies relative to each other by as little as 1/2 microsecond (500 feet), the garble nearly always becomes independent. Therefore, correlating many successive samples of a track will enable the true code to be read. Thus, given enough time, one can resolve ambiguities, eliminate all phantom tracks, and determine all true tracks.

The BCAS tracker acquires aircraft sufficiently far away so that at least 60 seconds is available before a collision hazard could occur—30 seconds is used to establish track reliability, and 30 seconds is for escape maneuvers. Thus, by allowing extra tracking time, BCAS is able to acquire aircraft in garble and to continue tracking through it.

### 3. SYSTEM DESCRIPTION

#### 3.1 Overview

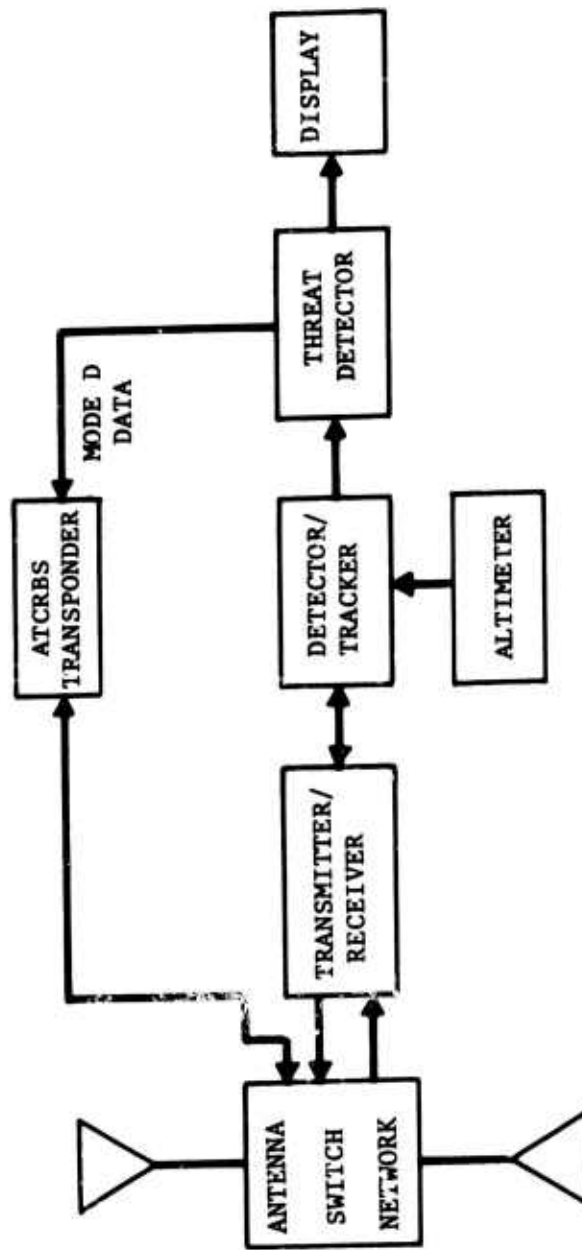
The BCAS functional block diagram is given in Figure 3-1. Mode C interrogations are transmitted sequentially via top and bottom antennas, and received replies are demodulated in the receiver and then passed to the Detector/Tracker. The Detector/Tracker determines if the received replies are from new targets, established target tracks or simply fruit. Tracks are formed and maintained in range and altitude. An altitude reference is provided by the aircraft's own encoding altimeter which enables the tracker to estimate the relative altitude of targets.

Newly formed tracks within a 10 mile range and established tracks whose range difference becomes 10 miles or less are flagged by the tracker and a determination of whether this target is BCAS equipped or not is made. To make this determination a mode D interrogation is sent. If the target replies (and it appears at the expected range and altitude), the tracker labels the target as BCAS equipped, otherwise it is labeled as unequipped since all equipped aircraft have a mode D reply capability.

Established tracks (tracks are declared established after being tracked for at least 30 seconds or after 4 successive ungarbled reports) are passed on to the Threat Detector to determine if a target is a threat. Separate algorithms are used for equipped and unequipped targets. When an unequipped target is determined to be a threat, a command is displayed to the pilot for him to maneuver his aircraft away from danger. If, on the other hand, an equipped target is determined to be a threat, a mode D interrogation is made to the target to assess the maneuver intent of the target. On the basis of the reply received a command is displayed to the pilot which makes him aware of the situation and which may direct him either to maneuver or not to maneuver his aircraft. When interrogated on mode D, the aircraft replies with a code that describes the command message sent to the display. This elementary data link provides the means for ensuring that the aircraft make complementary maneuvers.

#### 3.2 Transmitter/Receiver

The transmitter/receiver used by BCAS is a standard Air Force Identification, Friend or Foe (IFF) transmitter/receiver. The transmitter/receiver is coupled both to the bottom and to the top antennas, with interrogations transmitted alternately via each antenna at a combined rate of once every 1/2 second. Thus in areas where a null exists in either the top or bottom



**FIGURE 3-1**  
**THE BCAS SYSTEM BLOCK DIAGRAM**

antennas, aircraft will receive mode C requests at a one second update rate. The receiver takes the rf replies from the several aircraft in the vicinity, demodulates them and looks for pulse pairs separated 20.3  $\mu$ s apart. The window size for this bracket pair detection is made sufficiently wide to account for pulse position uncertainty due to such things as pulse jitter and pulse tolerance. All bracket detected pulse pairs and their associated framed binary sequences are sent to the Detector/Tracker.

### 3.3 Detector/Tracker

There are three major functions of the Detector/Tracker. These functions, discussed in this section, are track acquisition, track extension and track elimination.

#### 3.3.1 Track Acquisition

To acquire or form new tracks all replies (bracket detected pulse pairs) on four successive interrogations are used. Each second reply received, as illustrated in Figure 3-2, is connected by a straight line to all replies received on the third interrogation which could possibly relate to a given track and for which the range rate would be negative (aircraft closing on interrogator). This would mean the slope of the straight line should be negative. However, due to transponder jitter some straight lines will be formed with slightly positive slopes (note  $A_1$  in Figure 3-2). The maximum negative slope allowed is limited by the anticipated maximum closing rate of aircraft.

Once all reasonable pairs have been connected by straight lines each line is extended backwards and projected forward in time by one time interval. At each end of the straight line corresponding to the first and fourth interrogation replies a range window is placed. This window accounts both for aircraft motion and for expected transponder jitter. Any replies falling into the window are considered part of a track. If more than one point falls within a window, there will be more than one track formed. If at either end point no reply falls within a window, no track acquisition is declared. Thus, with respect to the illustration given in Figure 2-1 there are no tracks formed on line  $A_0$  while 1, 2 and 4 tracks are found respectively on lines  $A_1$ ,  $A_2$  and  $A_4$ .

After a new track is formed, an altitude is associated with this track by taking the altitude reports from each of the four replies associated with the track and passing them through an "AND" logic. Thus, if at least one of the reports is garble free, the correct altitude will be associated with the target.\*

\*Recall that "1"s are resistant to interference and "0"s appear when the interference disappears.

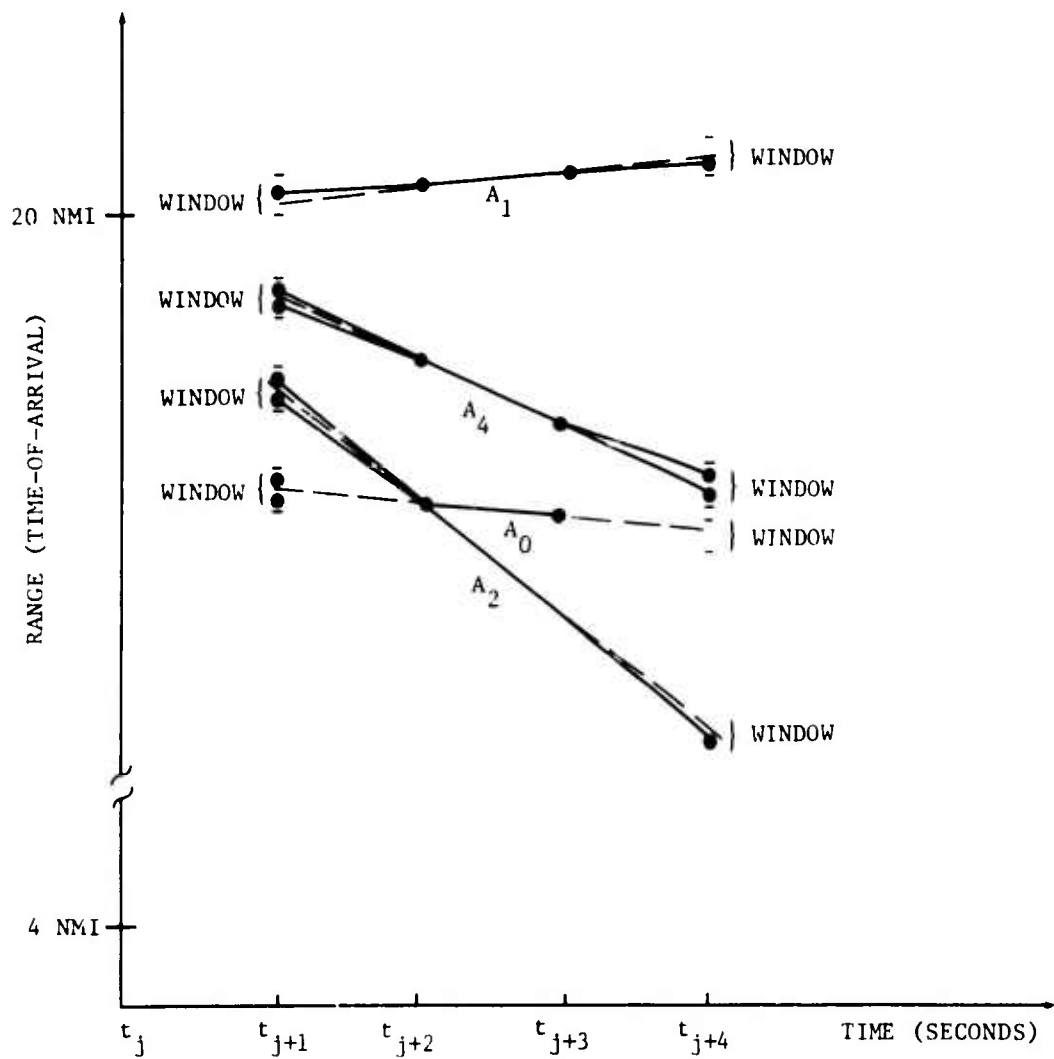


FIGURE 3-2  
TRACK ACQUISITION



### 3.3.2 Track Extensions

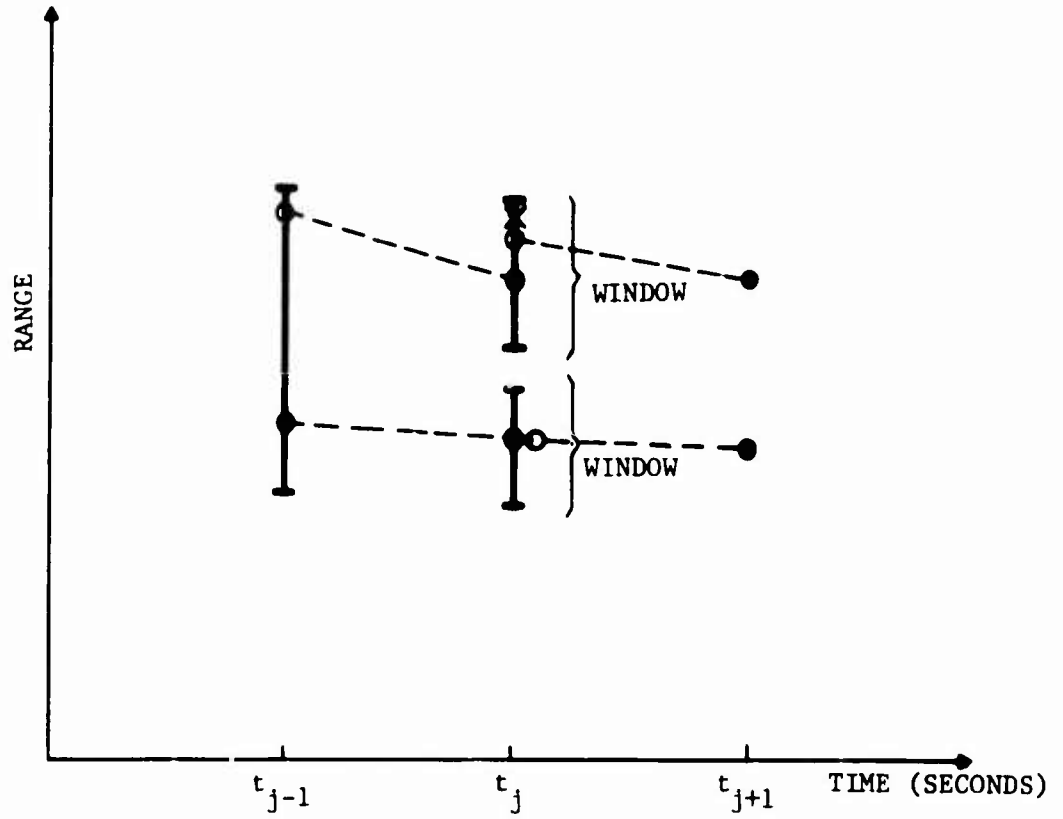
Once a track has been formed a straight line prediction is made of the range and altitude based on the previous estimate of the target's range, range rate, altitude and altitude rate. The range tracking is illustrated in Figure 3-3; each established track at time  $t_{j-1}$  is extended by prediction one second to time  $t_j$ . A window is then formed around the prediction whose size is determined by aircraft motion, transponder jitter and range. For each received reply found in the window a weighting of both the received reply and the prediction is made to obtain our best estimate as to where the target is at time  $t_j$ .\* If no reply is found in the window, the track is "coasted" and the prediction is used as the track estimate. In the illustration given in Figure 3-3 one track is seen to have a reply in the window at time  $t_j$  so that the track is extended by prediction from the estimate point. The second track has no reply at time  $t_j$  in its prediction window so that the track is extended from the prediction point.

Each aircraft is not only tracked in range, but also in altitude. Thus, for each track extended in range an associated track extension is made in altitude. The time-of-arrival of a mode C reply is used to form and extend tracks in range. The content of the reply is used to form and extend tracks in altitude. The content of the reply is the aircraft's altitude coded in "Gray Code." A "Gray Code" is a sequences of ones and zeros corresponding to unique altitude values as shown in Figure 3-4.

The extension of tracks occurs in the following way. Based on estimates of altitude and altitude rate each established altitude is extended one second. Thus, in the example given in Figure 3-4 the prediction is 14,794 feet. Since the Gray code is quantized to within 100 feet, the prediction is taken to be 14,800 feet. To account for aircraft maneuvers within the one second update interval and tracking errors, a  $\pm 100$  foot window is used around the nominal prediction value of 14,800 feet. The

---

\* If one could predict perfectly where a target will be just before the next update and if one could measure range perfectly, then the prediction point and the measurement point would be identical at time  $t_j$ . Unfortunately, one can neither predict nor measure range perfectly so that the measurement and prediction points will not be identical. Thus, one "weights" the measurement with a factor which is a function of the systems range accuracy and weights the prediction with a factor which is a function of the prediction accuracy to obtain a best estimate at the update time which will always lie somewhere between the prediction and measurement points.



LEGEND

- PREDICTION
- TRACK ESTIMATE
- × MEASURED REPLY

**FIGURE 3-3**  
**TRACK EXTENSIONS IN RANGE**

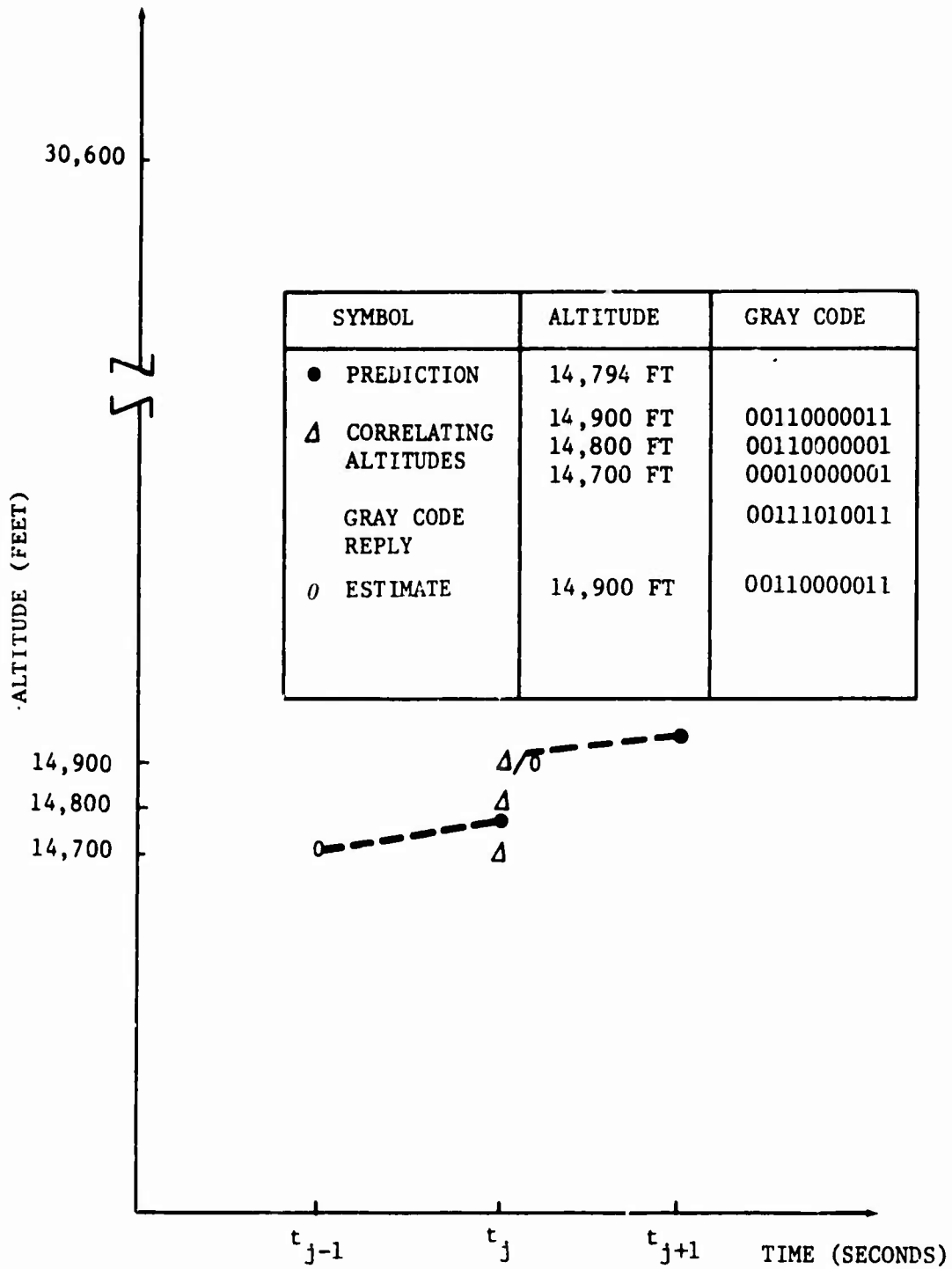


FIGURE 3-4  
TRACK EXTENSIONS IN ALTITUDE WITH NO CORRECTION

Gray code equivalent of 14,700, 14,800 and 14,900 feet are then correlated with the Gray code of a reply whose time-of-arrival has already been used to extend a range track. The altitude with the highest correlation is then taken as the initial altitude estimate of the track at time  $t_j$ . In the example given, the  $t_j$  estimate is seen to be 14,900 feet. The track is then extended in altitude from this value.

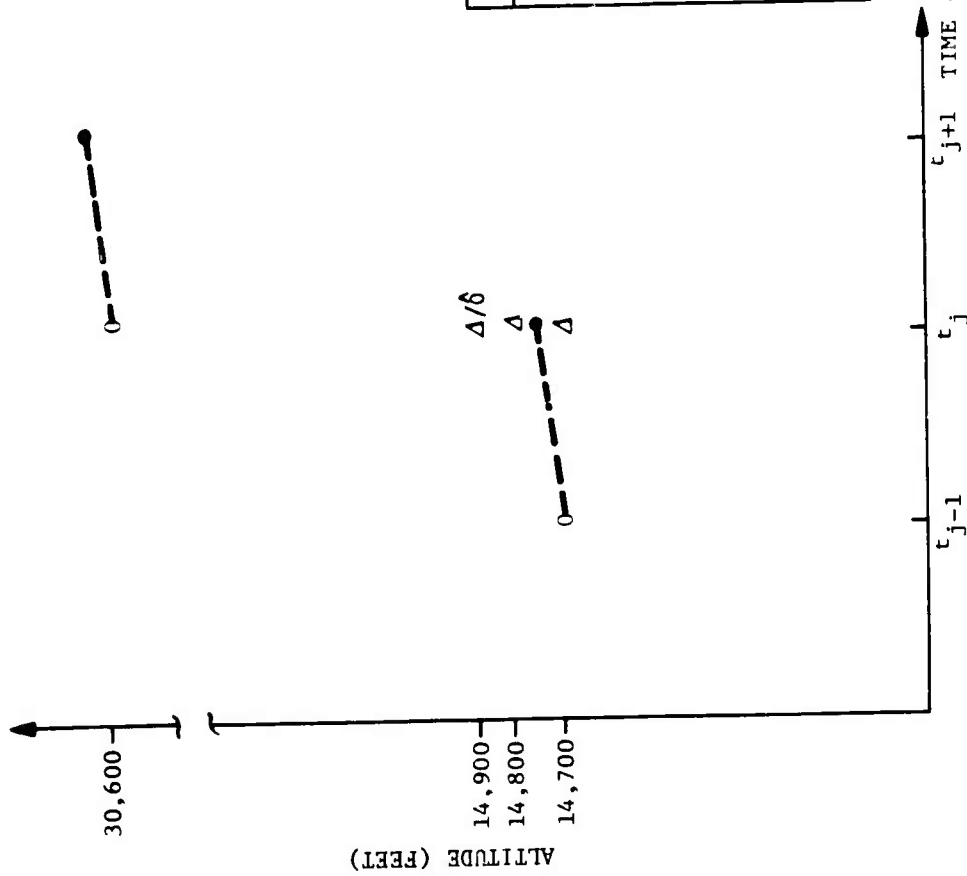
The procedure just described for track extension, although providing the correct answer for the example given, is not complete. An additional step has to be added to determine if a possible garbled zero has been uncovered. To illustrate this procedure Figure 3-5 is used. It can be seen in comparing Figure 3-4 with Figure 3-5 that the prediction point at time  $t_j$  is the same in both tracks but that the Gray code replies differ in that the fourth bit of the Gray code reply is a "1" in Figure 3-4 while it is a "0" in Figure 3-5. The procedure followed to obtain an estimate for this second example is identical to the procedure just described for the example in Figure 3-5 and again results in the estimate of 14,900 feet except in this second example it is termed the initial estimate. Once this initial estimate is made, it is compared with the Gray code reply, and where the Gray code has a "0" and the initial estimate has a "1" a correction to the estimate is made by changing the "1" bit to a zero.\* The rationale for this correction arises from the underlying bases of the tracker in that "1" bits are not destroyed. Thus, it is highly probable that a Gray code reply that shows a "0", where previously it has shown a "1", had been garbled up to that point and has as its true bit value a "0".\*\* In the illustration of Figure 3-5, the fourth bit in the Gray code of the reply is a "0" while the corresponding fourth bit of the initial estimate is a "1". Thus, the tracker has probably uncovered a garbled "0" and therefore at time  $t_j$  shifts the track from 14,900 feet to 30,600 feet.\*\*\*

---

\* Note that for the example given in Figure 3-4 the initial and final estimate would be the same.

\*\* A change from a "1" to a "0" can occur without garble when an aircraft's altitude report changes by 100 feet. This is accounted for by correlating with three different altitudes in the  $\pm 100$  foot window and is reflected in the value of the initial estimate. The uncovering of garbled "0"s in the final estimate relates to altitude change greater than 100 feet.

\*\*\* As discussed in Section 3.3.3, there is the possibility of false "0"s. Therefore, if both the initial and final estimates differ, two tracks will be stored by the BCAS tracker until the validity of the "0" is established.



| SYMBOL                  | ALTITUDE  | GRAY CODE   |
|-------------------------|-----------|-------------|
| ● PREDICTION            | 14,794 FT | 00110000011 |
| Δ CORRELATING ALTITUDES | 14,900 FT | 00110000001 |
| Δ                       | 14,800 FT | 00010000001 |
| Δ                       | 14,700 FT | 00110000011 |
| Δ INITIAL ESTIMATE      | 14,900 FT | 00110000011 |
| GRAY CODE REPLY         |           | 00101010011 |
| 0 ESTIMATE              | 30,600 FT | 00100000011 |

FIGURE 3-5 TRACK EXTENSIONS IN ALTITUDE WITH CORRECTION DUE TO UNCOVERED "0"

The process of looking for garbled zeros occurs at each update point but the probability that such a zero exists decreases as the age of the track increases so that by the time the track is declared established (30 seconds) all of the true zeros will have been determined.

### 3.3.3 Track Elimination

Many undesirable tracks are carried in BCAS which are either phantom (tracks of non-existent aircraft), multiple tracks of the same aircraft, valid aircraft tracked incorrectly, and tracks which are not potential threats to the BCAS aircraft.

In general the process of eliminating unwanted tracks is related to the process of comparing a confidence factor associated with each track and a given threshold. Thus, when the confidence factor falls below a given value, a track is eliminated. The confidence factor is a function of the number of interrogations and the number of replies. For a given reply rate confidence increases with time, and if the reply rate increases, confidence increases. A more detailed description of the process of track elimination is described below.

#### 3.3.3.1 Garble Free Multiple Tracks

The BCAS tracker is constantly forming new tracks. At the same time acquired aircraft are tracked in the process of track extension. Since tracks are extended by linear prediction while tracks are formed by linear estimation, the same aircraft may be acquired many times generating more than one track, even in a garble free environment. Such newly formed tracks will not differ greatly and with time will converge to a single track. To hasten the process, tracks which fall within the same "windows" in range, range rate and altitude are merged into one track. In this process, tracks are compared pair wise, with the track having the greater confidence factor (normally the oldest) surviving. The merging of a new track with an older track normally occurs within a few seconds.

#### 3.3.3.2 False "1"s

Garble will generate false "1"s which in turn leads to incorrect altitude tracks and phantom tracks. Incorrect tracks are corrected with time by the process of Track Extension. Phantom tracks are eliminated in time by the same process since the confidence factor associated with such tracks will normally fall below a given threshold within a short time.

#### 3.3.3.3 False "0"s

The principal of the BCAS tracker is predicated upon the fact that "0"s are more believable than "1"s in a garble environment with PAM modulation. However, the possibility of generating a false "0" in BCAS exists and must be accounted for. Mainly, the false "0" occurs when the transponder on the tracked aircraft fails to reply to an interrogation and a fruit return enters the expected window. A "0" bit on the fruit return, where a "1" exists on the true reply, would be falsely interpreted as a "0" bit. However, the transitory nature of such a combination of circumstances is treated by looking for the "0"s to occur more than once for improved confidence factor.

For example, in the section on track extension the process of "0" identification was illustrated in Figure 3-5. There it was shown that the final estimate of the track altitude differed from the initial estimate of the track altitude with the decision to change the altitude of the tracked aircraft. The BCAS tracker does not drop tracks as described in Figure 3-5, but when it uncovers a possible "0" carries both tracks. With time one of the tracks is eliminated.

#### 3.3.3.4 Miscellaneous Track Elimination Rules

There are several criteria in addition to those already discussed for eliminating tracks. Thus, tracks are eliminated when aircraft land or fly out of the range of interest (20 miles). Finally, tracks are eliminated when there has been no reply for seven successive seconds.

#### 3.3.4 Track Establishment

A track is declared established when the confidence factor is greater than a given threshold. This threshold is designed so that only 1 out of  $10^6$  phantom tracks will be declared established. All established targets are tracked both in the tracker and in the threat detector. The threat detector, however, is not concerned with unestablished tracks.

Although fruit and garble have greatest impact on the unestablished track file they also affect established tracks. As will be illustrated later, garble can cause loss of track and multiple tracks, but normally such phenomena only occur to those established tracks which are far from the interrogator. Close-in tracks do not experience as much garble and the impact of fruit and garble on close-in established tracks appears to be negligible.



### 3.4 Threat Detector

The threat detector receives as its input the relative range, relative range rate, altitude and altitude rate of established aircraft tracks. It determines whether a command is necessary, and if so, issues it until the conflict is resolved.

The threat detector is capable of solving conflicts with another BCAS-equipped aircraft, or with an ATRBS mode C aircraft. In some cases multiple aircraft conflicts can also be resolved.

Two different detection and resolution logics are used depending on the equipment of the intruder aircraft: if it is BCAS-equipped, the logic specified in the Air Navigation/Traffic Control (ANTC)\* Report No. 117 is employed; otherwise, a remitter logic is utilized which makes use of either a modified range-tau test and a vertical-tau test, if the relative range rate is negative, or an immediate range and altitude test, if it is positive. In both logics, a maneuver command is not displayed until it appears as a result of two consecutive interrogations.

When the ANTC-117 logic determines that a command should be displayed, it interrogates (mode D) to determine the maneuver intent issued by the ANTC-117 logic of the intruder aircraft. Based on the mode D reply a compatible collision avoidance command is displayed to the pilot.

### 3.5 Display

The display is shown in Figure 3-6. It is a standard CAS display which indicates to the pilot the following positive and negative commands.

- |   |   |          |
|---|---|----------|
| 1. Level off                            | } | Positive |
| 2. Climb                                |   |          |
| 3. Descend                              |   |          |
| 4. Don't climb                          |   |          |
| 5. Don't descend                        |   |          |
| 6. Don't climb more than 500 ft/sec     |   |          |
| 7. Don't climb more than 1000 ft/sec    |   |          |
| 8. Don't climb more than 2000 ft/sec    |   |          |
| 9. Don't descend more than 500 ft/sec   |   |          |
| 10. Don't descend more than 1000 ft/sec |   |          |
| 11. Don't descend more than 2000 ft/sec |   |          |
| 12. No command                          |   |          |

\* The Air Navigation/Traffic Control Report No. 117 issued by the Air Transportation Association of America, June 1967.

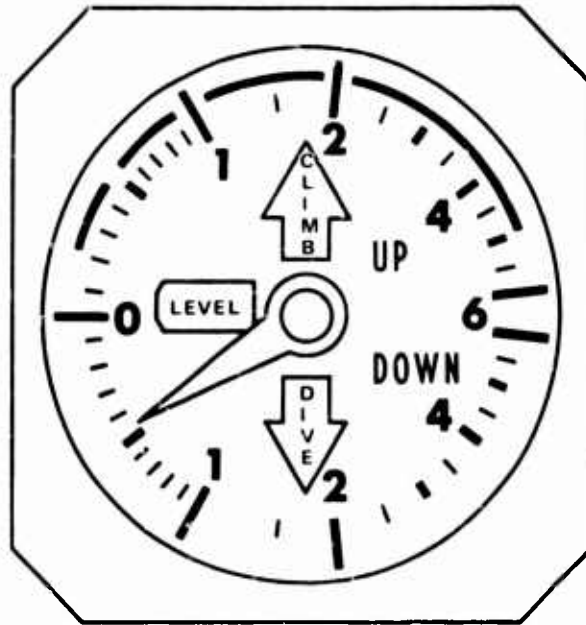


FIGURE 3-6  
CAS DISPLAY

### 3.6 Data Link

As indicated in preceding sections, communication between equipped aircraft is required to coordinate maneuvers. The mode D transponder reply is used in BCAS. This was chosen because it is easily implemented and will be relatively garble free. In addition, the identity of the target aircraft is not needed to affect the communication.

There are a total of 4 different intents (level off, climb, descend, or no positive command), that affect our action; therefore, 4 mode D code words are needed. The code words were chosen so that the message is decodable when up to 3 pulse positions are garbled. Further error protection against fruit is obtained by repeated interrogation, and periodic interrogation once a threat is detected.

The code word for the mode D response is supplied to the transponder immediately upon determination of the maneuver, so that any aircraft making a mode D interrogation after that instant will be informed of the aircraft's intent.

#### 4. PRELIMINARY PERFORMANCE RESULTS

The tracker design has been completed except for the optimization of the  $\alpha$ - $\beta$  parameters for the range and altitude trackers. These parameters will be adjusted during the flight test program which will begin October 1975.

To obtain confidence in the tracker design and in the threat detection and resolution logic, simulation studies were performed. To determine the impact of BCAS on the ground, an analysis was performed. A description of the simulation and analysis studies together with the results from these studies is presented in this section.

##### 4.1 Tracker Simulation

Three types of traffic scenarios were used as inputs in the tracker simulation program: the first had only two aircraft flying various collision and near-miss encounters; the second used the 1985 Los Angeles Traffic model; and the third used actual recordings of aircraft tracked by the terminal beacon (ARTS) at Washington, D.C.

The initial two-aircraft scenarios demonstrated that in a garble free environment, the tracker was performing properly. The Los Angeles Basin simulation model includes over 750 aircraft. The BCAS concept described in this paper is not designed to operate in such dense environments. However, by placing the interrogator aircraft on the outskirts of the Los Angeles Basin and allowing it to move in the direction of increased aircraft density, the impact of garble and the limits of the tracker could be assessed. The results of this simulation imply that the tracker could work in an environment in which the replies of up to 4 or 5 aircraft were overlapped, provided the interrogator aircraft and the target aircraft were flying level flights.

The most realistic simulation study utilized tapes obtained from the Washington D.C. National Airport terminal radar, which contained the tracks of all aircraft tracked during a peak hour of a day in the summer of 1974.\* During that hour there was an instantaneous aircraft count of 70 aircraft in a 60 nmi range, of which 20 were in the Terminal Control Area (TCA). In the simulation, one aircraft in the TCA was chosen as the BCAS equipped aircraft. Out of the 20 aircraft tracked only 9 to 10 aircraft were within

\* The simulation did not account for no target responses due to shielding effects. The impact of shielding (one antenna/receiver on the target) on performance will be evaluated in the BCAS flight test program.

a 20 mile range of the BCAS interrogator. A five minute description of such aircraft tracks, as seen on the ARTS tapes and referenced to the BCAS aircraft, is illustrated in Figure 4-1.

The results of the BCAS tracker simulation in which aircraft in the flight pattern were interrogated and to which a fruit intensity of 16,000 per second was added is described in Figure 4-2 for the same scenario as depicted in Figure 4-1. Figure 4-2 shows only the established tracks declared by BCAS.

Before comparing the two figures it is to be noted that the tracks are 30 seconds in age before they are entered into the BCAS established track file. Thus, tracks 1 and 2, shown in Figure 4-1 which are less than 30 seconds in their entirety should not appear in the BCAS established track file.

As can be seen in comparing the ARTS tracks (our referenced perfect data) with the BCAS tracks, tracks 1 and 2 do not appear in Figure 4-2 and in addition the tracks displayed by BCAS are seen to be shorter again reflecting the 30 second initialization period before tracks are declared established. More significantly it can be seen that there are no phantom or lost tracks in Figure 4-2 and that all aircraft are tracked accurately through the garble and fruit environment. A close examination of the track file showed that at times, returns were overlapped with as much as two fruit and two synchronous replies.

#### 4.2 Threat Detector and Resolution Logic

In the case of two equipped aircraft, BCAS and ACAS are considered as equivalent capabilities so that they both utilize the same logic. Thus, BCAS utilizes ANTC-117 conflict detection and resolution logic to assure separation between two equipped aircraft.\*

Since BCAS must deal with the problem of the remitter aircraft, special logic was developed to handle this case. Of importance here is that only one aircraft maneuvers to avoid a collision (as compared to the two equipped case where both maneuver), and that the remitter aircraft cannot be inhibited from making adverse maneuvers (since it is not BCAS equipped). In order to provide a solution which works in the face of these limitations, the new conflict detection and resolution logic developed for the remitter case increased the lead time at which positive collision avoidance commands are issued to the equipped aircraft. The

---

\* The FAA is currently considering possible revisions to ANTC-117 in order to solve certain ATC/interaction problems.

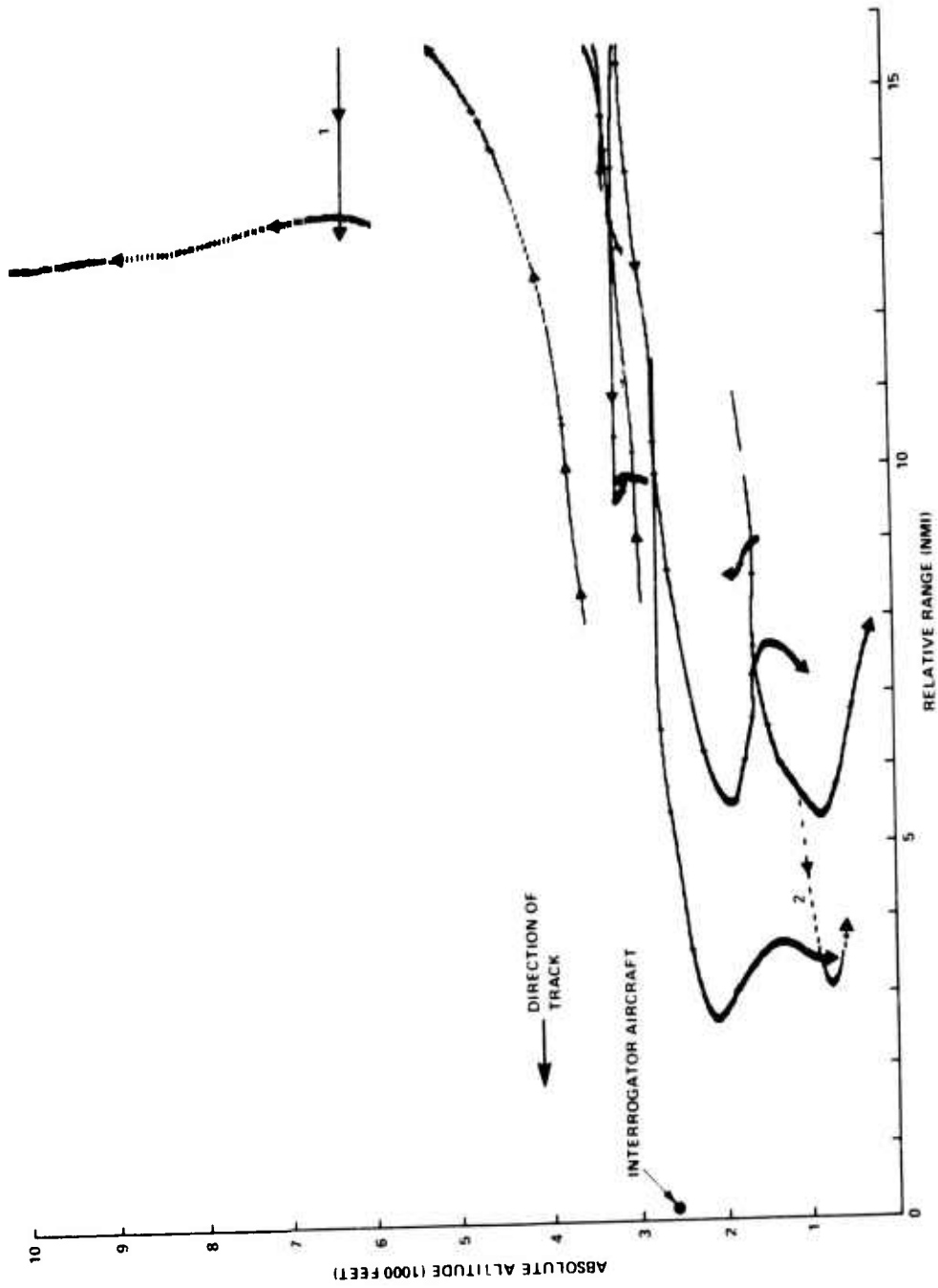


FIGURE 4-1  
ARTS TRACKER  
(REFERENCED TO BCAS INTERROGATOR)

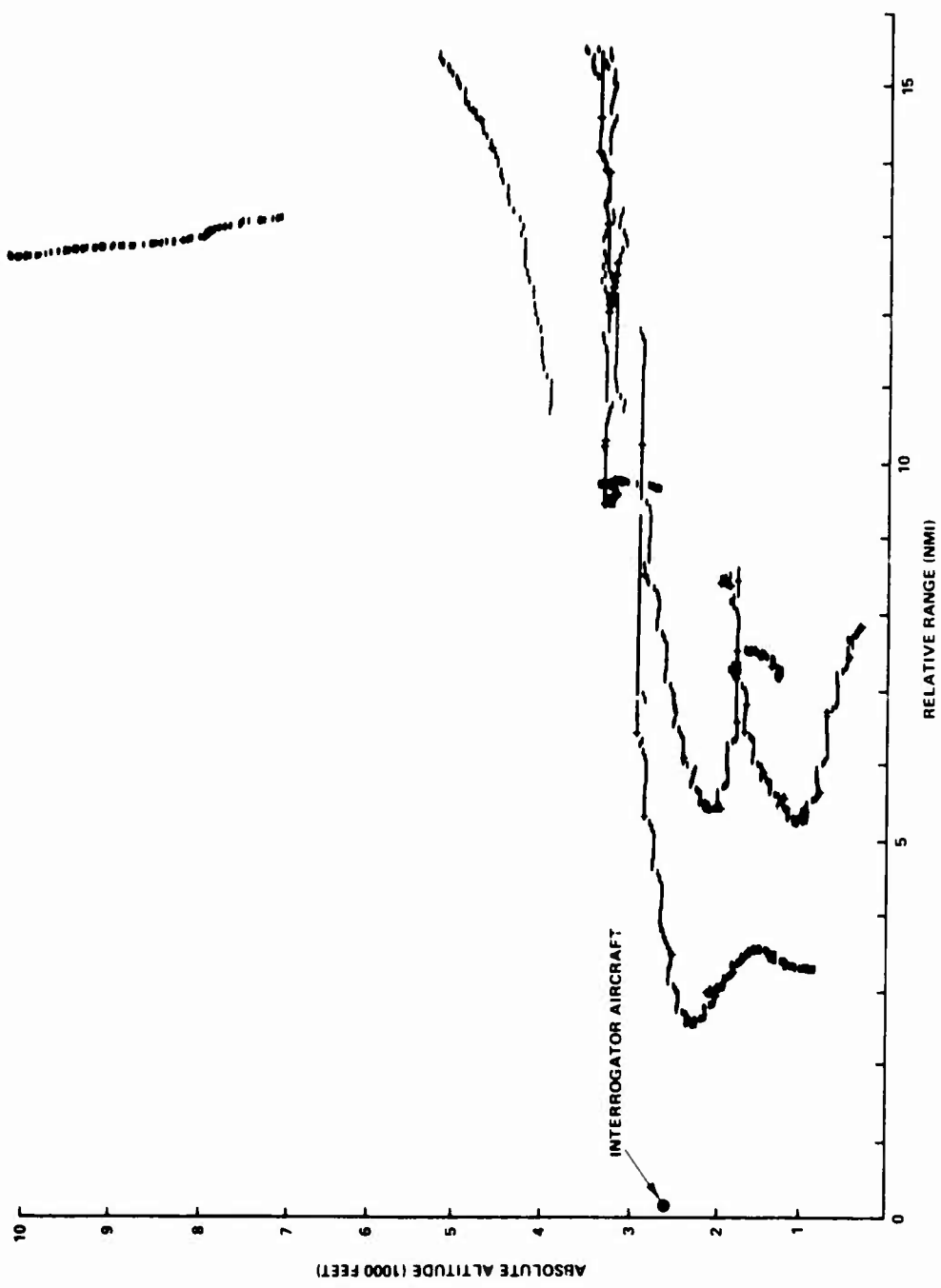


FIGURE 4-2  
BCAS TRACKER



impact of the increased lead time is to give more time for separation to occur since only one aircraft is instructed to maneuver, and to provide more escape capability from an accelerating remitter aircraft (note that ACAS does not have this latter problem since it inhibits maneuvers when necessary).

The changes to the positive command logic has also lead to modifications to the negative command logic since part of the air volume protected by negative commands in ANTC-117 is incorporated into the air volume protected by the new BCAS remitter positive command logic. A summary of the differences between the ANTC-117 logic and the new remitter logic is given in Table 4-1.

Certain performance evaluations have been made to validate the new remitter logic. Monte Carlo simulations were run in which two aircraft (one equipped, one a remitter) were put on collision courses and the BCAS was called on to separate the aircraft. The evaluation to date has been limited to straight flight encounters and has shown the system to be effective as long as the BCAS equipped aircraft is capable of either a 1000 foot per minute climb or descent rate or of outmaneuvering a climbing or descending remitter aircraft, whichever is greater. Since, in general, BCAS is intended for high performance aircraft these limitations are not of concern. The case of turning encounters, where the remitter aircraft turns into a BCAS equipped aircraft has only partially been evaluated. In the evaluation it was observed that since BCAS provides commands when aircraft achieve a lateral separation of 1 nmi and since the turn radius of low performance aircraft is significantly less than 1 nmi, the system inherently provides protection.

#### 4.3 ATCRBS Impact

From the Washington tapes a count of 70 transponder equipped aircraft was obtained. It was then assumed that 20 out of the 70 aircraft were BCAS equipped, where 20 represented an estimate of the number of aircraft with two or more engines. Thus 40 interrogations per second were assumed to occur; this would result in a degradation to ATCRBS uplink reliability of only 0.32%. In addition, BCAS would generate 2800 fruit per second which, if uniformly distributed, would result in a 100 fruit rate per second to ATCRBS (4° beam and side lobes which see 1/16 of fruit).

The analysis confirms the initial judgment that the low PRF of 2 per second has a completely negligible impact on the ATCRBS surveillance system. Future experimental data will also be obtained as a check on all assumptions.

TABLE 4-1

A SUMMARY COMPARISON OF THE ANTC-117  
AND BCAS REMITTER LOGICS

|  | <u>ANTC-117</u>   | <u>BCAS Remitter Logic</u>  |
|--|---|---|
| Protection Volume<br>for positive commands | If within 25 seconds two aircraft are projected to be within 1/4 nmi range of each other and less than 600 feet apart in altitude, positive commands are issued.  | If within 30 seconds two aircraft are projected to be within a 1 nmi range of each other and less than 600 feet apart in altitude, a positive command is issued.  |
| Protection Volume<br>for negative commands | If outside of the protection volume for positive commands but within 40 seconds two aircraft are projected to be within 1.8 nmi range of each other and less than 3300 feet apart in altitude, negative commands are issued.* | If within 30 seconds two aircraft are projected to be within a 1 nmi range of each other and greater than 600 feet apart in altitude but less than 1000 feet, if in level flight, a negative command is issued. |

\* Advisory commands have been included here.

## 5. GROWTH CAPABILITY

### 5.1 Extensions to High Density Airspace

The main thrust of BCAS is that it provides service in airspace that is not covered or surveyed by the ATC systems. Within radar surveillance, and especially within controlled airspace, separation services can be provided by the normal ATC system. Nevertheless, the possible extension of BCAS to a high density environment is explained utilizing a 1985 Los Angeles Basin traffic model (Figure 5-1).

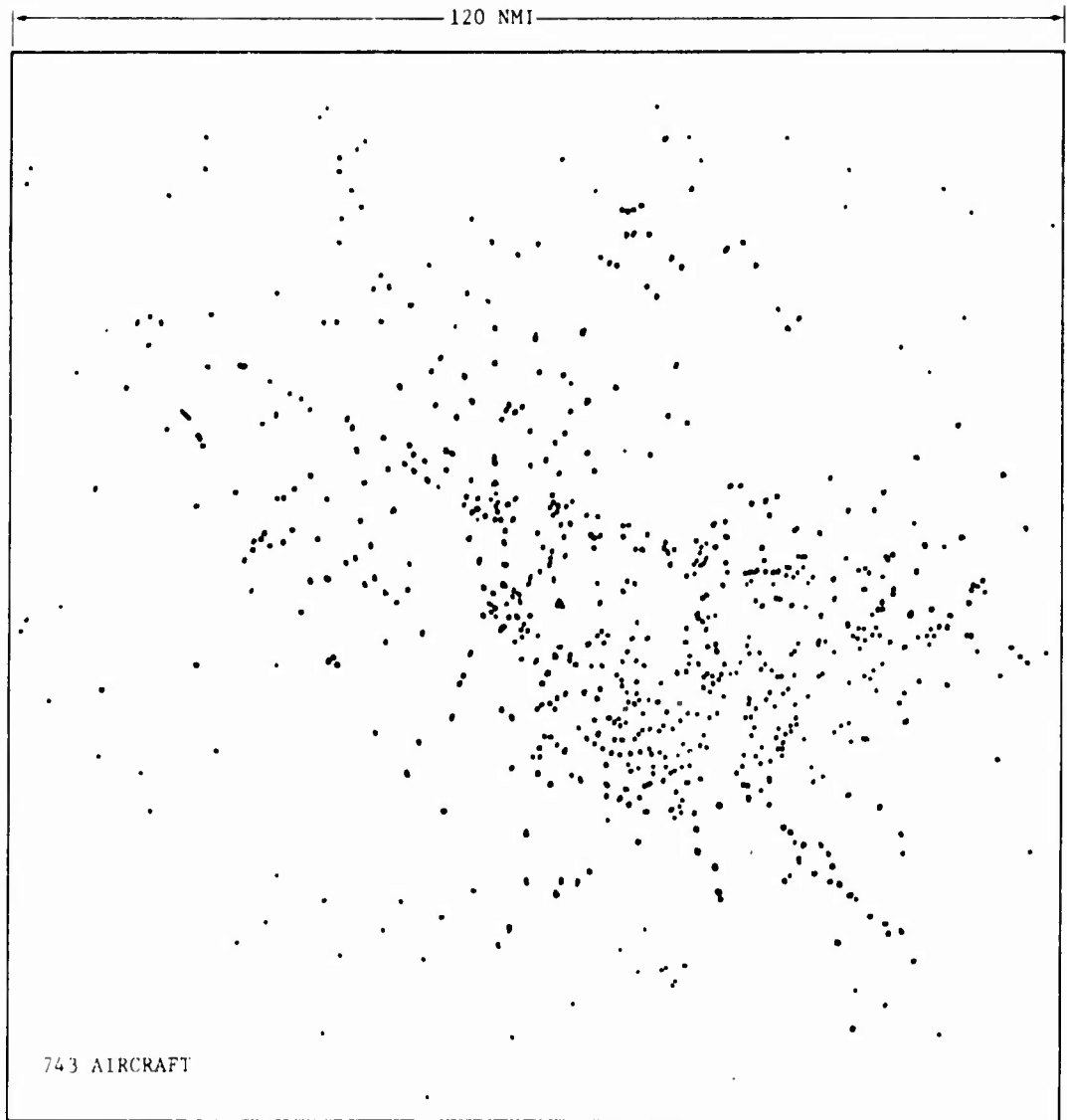
A study of the 1985 Los Angeles Basin model shows that if the BCAS system were to be supplied there, it would have to operate in environments where the number of overlapped replies would regularly exceed 3 or 4 and could be as high as 40. A preliminary analysis shows that BCAS could be extended to operate in such environments by modifying the equipment (detector/tracker, transmitter and the antenna) and restricting the number of users to about 100.\*

The detector/tracker can be improved by detecting on four "1"s of the mode C reply. Three of these "1"s must occur in all mode C replies of interest. A fourth "1" must exist in one of three positions. Therefore, returns could be processed in three altitude groups. The more "1"s the detector/tracker uses the faster it can eliminate phantom tracks. The detector/tracker described in Section 3 tracks only on two "1"s of the mode C reply.

The antennas used by BCAS are omnidirectional antennas. However, if a multibeam antenna were used, fewer overlaps would usually be found as the interrogator sequences through each of the beams.

Advantage can also be taken of the fact that aircraft have different electronic "hearing" capabilities due to different receiver sensitivities and different antenna patterns. The process may be described as follows. An interrogation is transmitted at a very low power level. Next, a suppression set of pulses ( $P_1$ ,  $P_2$ ) is sent at about the same power level. This suppresses all of those transponders that have just replied, so that a new interrogation at a higher power level will elicit replies from another group of aircraft. Successively repeating the procedure divides the aircraft into multiple reply groups. This procedure has been termed the "whisper/shout" technique.

\* The ATCRBS system would be severely impacted if all aircraft in the L. A. basin were equipped with BCAS.



**FIGURE 5-1**  
**1985 LA BASIN MODEL AIRCRAFT DISTRIBUTION**

These improvements--antenna directivity, whisper/shout, and extended processing--can greatly increase the ability of BCAS to work in high density environments. They also are techniques that may be applied selectively to those aircraft requiring such performance, and need not be developed early in the program.

## 5.2 DABS/IPC Environment

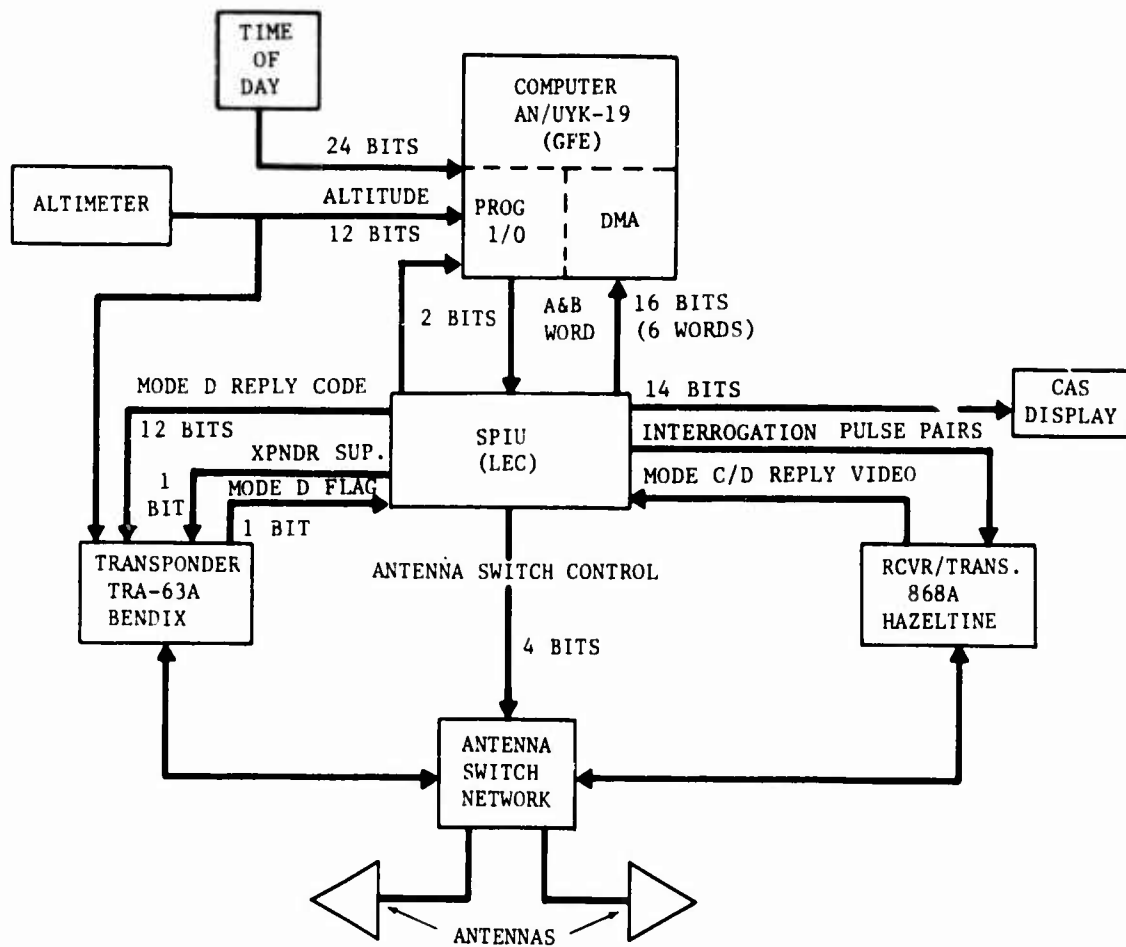
In DABS/IPC environment, IPC will be the backup to the ATC system in airspace where separation assurance is provided by the ground. The primary function of BCAS in this DABS world would then be to fill in the gaps in dense airspace not seen by the ground surveillance system and in addition to provide a CAS capability where no ground derived separation assurance is given.

Since the designs of both DABS/IPC and BCAS are in the early stages, an excellent opportunity exists to include minor modifications to each that would enhance the operation of both. For example, reducing the specified "dead time" of the DABS transponder following a BCAS interrogation could further reduce any impact on the ground system caused by BCAS, thereby removing restrictions on the number of aircraft that might wish to carry BCAS; the "lockout" control by DABS could be set so as to ensure BCAS operation at the boundaries or radar coverage, complementing IPC service; and mode D intent data could be sent to the ground. The point is that there is opportunity for coordinating these two systems to their mutual benefit.

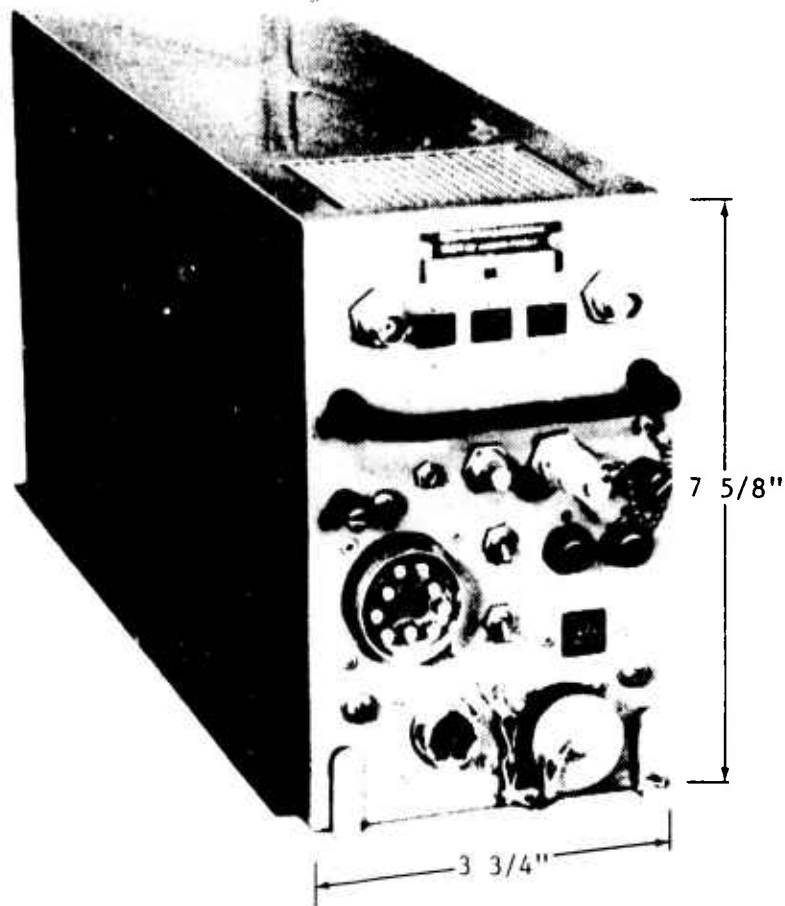
APPENDIX A

ENGINEERING MODEL OF ACTIVE BCAS

In this appendix the overall block diagram of the engineering model of the BCAS to be tested in October is presented together with pictures of several of the key components.

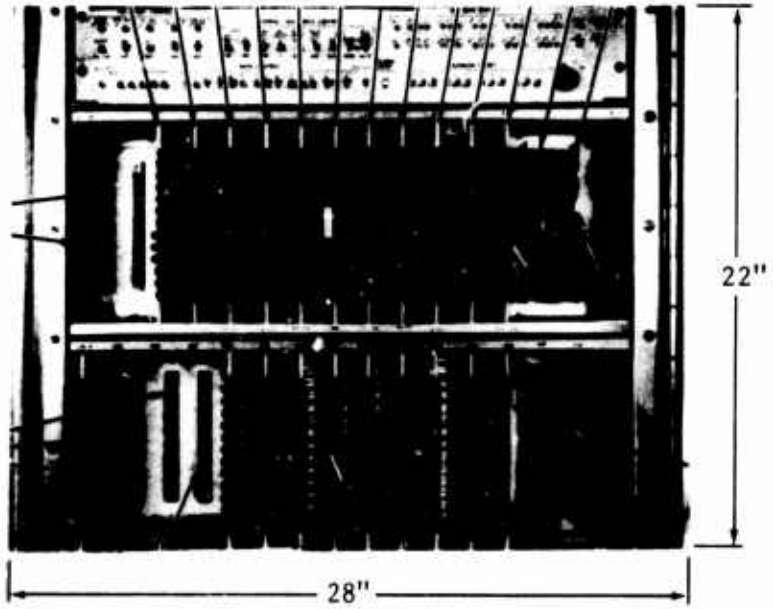


**FIGURE A-1  
BCAS SYSTEM**

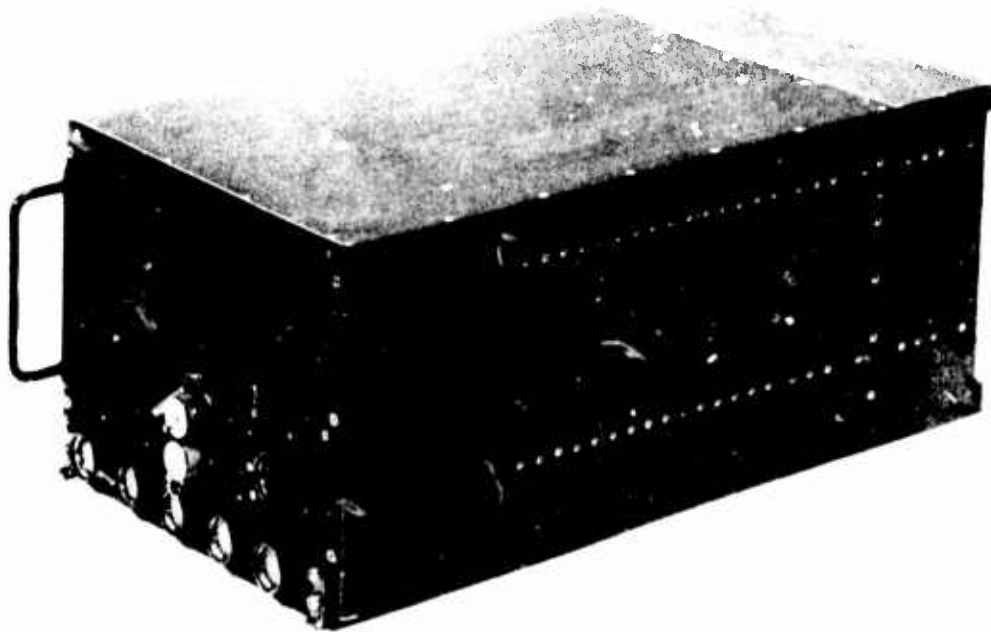
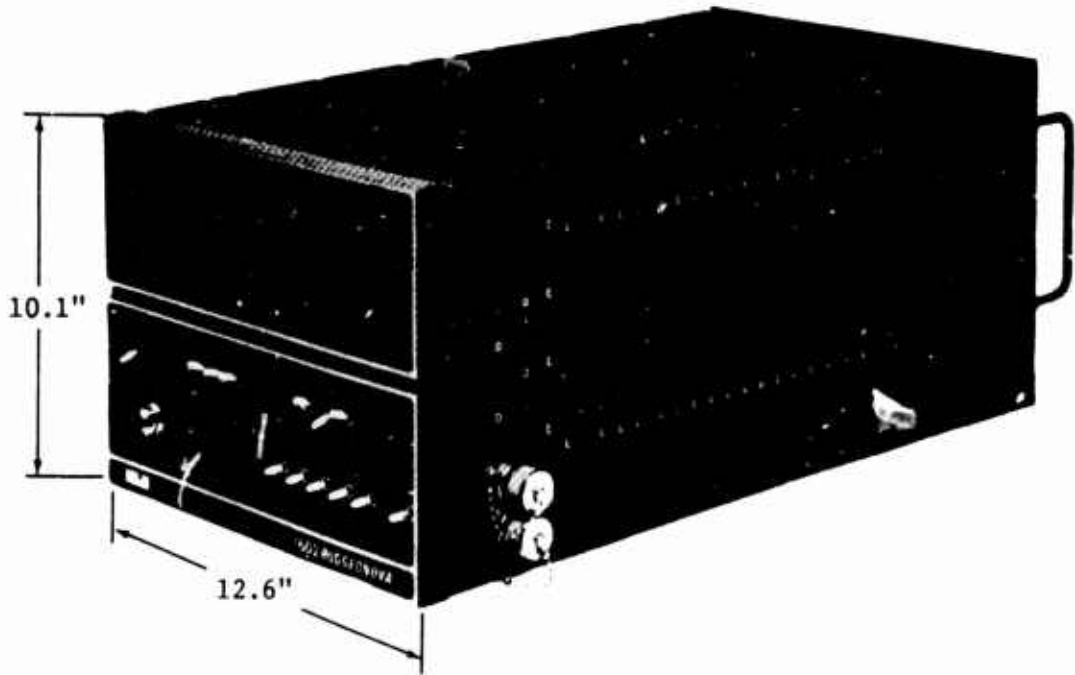


**FIGURE A-2**  
**TEST MODEL BCAS TRANSMITTER/RECEIVER**

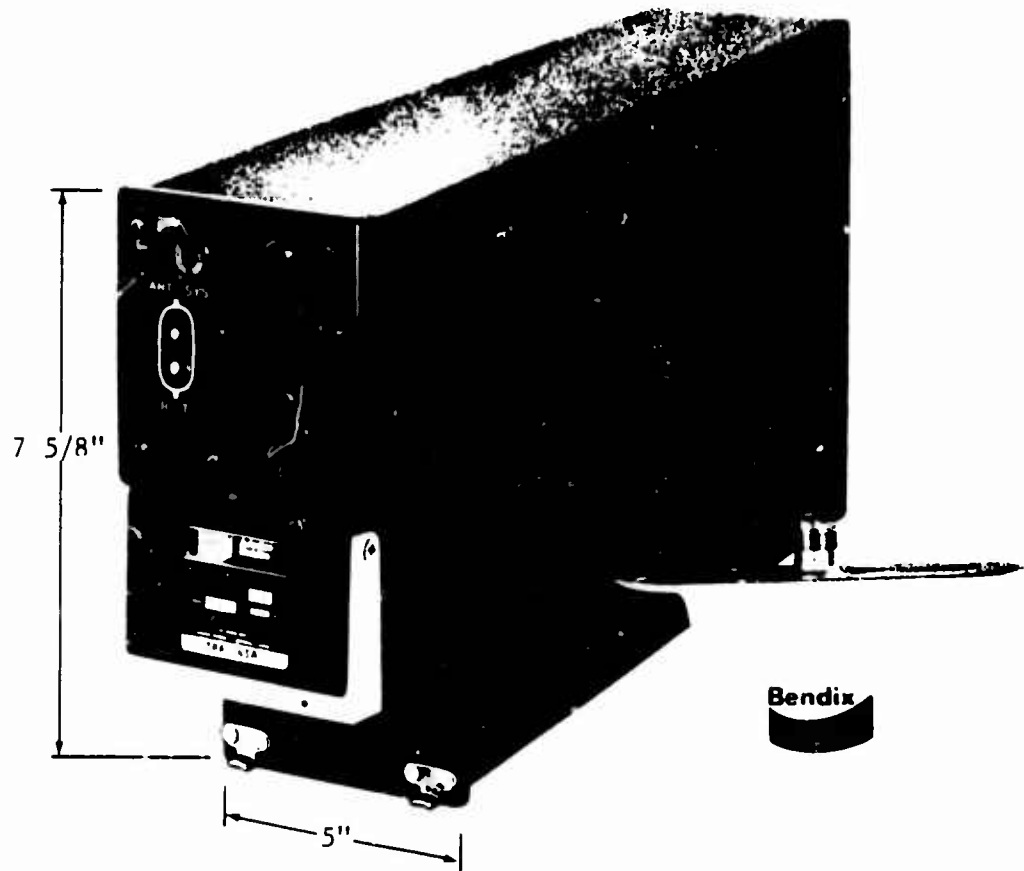




**FIGURE A-3**  
**TEST MODEL BCAS SIGNAL PROCESSOR AND INTERFACE UNIT (SPIU)**



**FIGURE A-4  
HALF OF TEST MODEL BCAS COMPUTER**



**FIGURE A-5  
TEST MODEL BCAS INTERROGATOR TRANSPONDER  
(MODE D CAPABILITY)**