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# FAA BCAS CONCEPT

## EXECUTIVE SUMMARY

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16. Abstract

A unique airborne aircraft collision avoidance system concept is presented which assures safe separation from the largest possible percentage of potential collision threats. The concept is designed to operate in all airspace as a compatible backup to the present and evolving ATC system, and to be acceptable to the pilot and the user community. The system concept capitalizes on the aviation community's large existing investment in ATCRBS transponders and on the ground based beacon surveillance system network for the basic sources of the collision avoidance information.

The report is contained in three volumes; an Executive Summary (I), Concept Description (II) and Appendices (III).

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FAA-EM-78-5

# THE FAA CONCEPT FOR A BEACON COLLISION ADVOIDANCE SYSTEM (BCAS)

## VOL I

## EXECUTIVE SUMMARY

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ACKNOWLEDGEMENTS

An effort of the scope of this BCAS design, performed within the rigid constraints of a ninety-day schedule, requires the intense devotion of a competent team of professionals. The members of the design team appreciate the cooperation and outstanding quality of work provided by everyone who contributed to this document. In particular, the team extends its thanks to the following individuals: Peter Hwoschinsky, Keith McDonald, and Del Weathers of FAA/OSEM; Frank Callio, Edward Glowacki, and Edward Quish of FAA/NAFEC; Dick Orr, Tom Savarino, and Aaron Weinberg of Stanford Telecommunications, Inc; Bob Stern of H. H. Aerospace Design Co., Inc.; and Al MacFarland, Andrew Zeitlin, Richard Bryant, and Charles Swett of MITRE Corporation.

For his profound insight into every facet of the problem--from the broadest technical and operational implications of system design characteristics to the details of hardware and software implementation--the team is indebted to Neal Blake. His interest and inspiration have made the development of this BCAS concept a goal well worth achieving.

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# EXECUTIVE SUMMARY

## 1. Objective

This report contains the results of a 90-day study performed by a design team established by the FAA's Associate Administrator for Engineering and Development to define the Beacon-Based Collision Avoidance System (BCAS). The team was led by Dr. E. Koenke of OSEM and consisted of the following members: Dr. L. Kleiman (H. H. Aerospace Design Company, Inc.); Mr. E. Lucier (SRDS); Mr. L. Schuchman (Stanford Telecommunications, Inc.); and Dr. W. Thedford (NAFEC). Each of the team members was supported by others within his own organization.

The design team was given three objectives to meet. The first was to formulate and document a BCAS concept that would work in all airspace and in all traffic environments, provide some level of protection for a wide variety of users, and minimize interference with the ground surveillance and air traffic control system. Such interference takes two different forms: reduction in accuracy and round reliability of the surveillance system, and disruption of the air traffic control process in the form of uncoordinated aircraft separation maneuvers generated by the BCAS. This report is the result of achievement of this first objective.

The second objective was to develop an engineering requirement (ER) which defined the performance specifications for the BCAS concept. The ER specifically identifies the requirement for inclusion of mode selection logic which is needed to select the best set of inputs on each threat to the BCAS-equipped aircraft and to provide the best and most accurate computation for both detection and resolution of collision situations. The third objective was to provide a realistic statement of work that fully supported the concept and the engineering requirement. The engineering requirement and statement of work are to be distributed separately.

## 2. Statement of the Problem

Mid-air collisions, near mid-air collisions, and system errors are extremely rare events in today's ATC system. They occur somewhat randomly throughout the airspace and affect commercial, general aviation, and military users operating under both Instrument Flight Rules (IFR) and Visual Flight Rules (VFR).

An effective, independent collision avoidance system must operate in all airspace and in all environments. Air traffic density ranges from near zero in some areas to 0.3 aircraft per square nautical mile in high-density areas. The surveillance coverage provided by the ATC system also varies greatly,

ranging from multiple radar and beacon coverage in the high traffic areas of domestic airspace to no coverage in oceanic and sparsely populated areas of the world. The operational ATC environment spans the range from positive control airspace services to uncontrolled airspace. Aircraft transponder equipage will also vary greatly including aircraft with a DABS transponder, ATCRBS transponder with altitude encoder (Modes A and C), ATCRBS transponder with identity transmissions only (Mode A only) and no transponder.

The environment includes a range of aircraft types, representing wide variations in performance, which conducting operations varying from the low acceleration maneuvers characteristic of commercial passenger flights to the high "g" maneuvers characteristic of military missions. The radio frequency interference (RFI) resulting from operation in the various environments ranges from high synchronous garble and fruit problems to little or no garble or fruit problem. Even stationary aircraft waiting to depart an airport with their transponders energized have an impact on the environment.

BCAS must function effectively throughout this complex environment, remain compatible with the ATC system, and provide traffic advisory and collision resolution services that are acceptable to the pilot. To operate effectively under all

conditions, it is evident that a complex BCAS is required. No simple solution exists.

## 3. Background

Four important developments in the evolution of BCAS will be discussed:

1. a passive, dual-radar concept using North reference data;
2. an active mode of operation;
3. a single-site passive concept; and
4. an all-DABS active mode.

A description of each development is followed by a discussion of its limitations and deficiencies as well as the measures taken to correct some of these deficiencies.

BCAS efforts were initiated in 1968 (Reference 1) based on the use of a "passive" mode concept. A BCAS-equipped aircraft received the ATCRBS replies to ground interrogations of other aircraft operating in its vicinity. It processed the received data, formed historical target track records, and informed the pilot in a timely manner of possible hazardous conditions.

The concept required that a BCAS aircraft receive interrogations from at least two ATCRBS sites located such that

a geometric solution existed and that each site provide North reference data. Target positions were then computed using the following inputs: relative positions of the ATCRBS main beam from North then it passed the threat target and the BCAS aircraft; PRF, as determined from main beam interrogations of BCAS aircraft; measurement by the BCAS aircraft of the difference in arrival times between ATCRBS interrogations and target replies; and decoding of altitude and identity information contained in the target replies.

Using this information, the BCAS algorithms determine the ellipsoidal surface containing the target for each radar used in the solution. The intersection of the ellipsoids determines the position of the target.

This concept was a significant step in the development of BCAS but was limited in the following ways:

- the multi-site passive solution would not work reliably in high-density airspace due to garble;
- the active and semi-active modes (involving airborne interrogation) were not sophisticated enough to treat the resulting active garble problem effectively;
- the concept was not compatible with the FAA's planned transition from ATCRBS to DABS;

- the active mode could not provide PWI (with target bearing) in areas of no surveillance coverage; and
- information on aircraft without encoding altimeters was not provided.

Some elements of the concept have been retained to provide an accurate solution when two or more radars are available and when a North reference can be obtained by means other than the modification of an ATCRBS interrogator site. The simple active mode proposed in this concept was expanded significantly to enable it to become a part of the full capability BCAS.

In 1974 the FAA began the development of an active BCAS (Reference 2) that could operate in most medium- and low-density traffic areas. This all-active system employed omnidirectional interrogations on both top and bottom aircraft antennas and a sophisticated tracker to degarble replies from aircraft in its vicinity. A "whisper/shout" technique was included in this concept as a means of employing multi-level interrogations to help reduce active-mode garble.

This all-active system was limited in the following ways:

- PWI was not provided;
- information on aircraft without encoding altimeters was not provided;
- the system could not operate in all airspace;

- serious false track problems existed; and
- provision could be made only for vertical maneuver commands.

This all-active concept has been extended, primarily through incorporation of an airborne directional antenna (Reference 3), and incorporated into the BCAS concept. The directional antenna also helps overcome some of the deficiencies of other modes of operation.

Soon after the start of active BCAS development, the concept of using a ground-based transponder (RBX) to provide an azimuth reference and range-to-target information (Reference 4), as well as a ground-to-BCAS data link, was introduced. Such a system permitted a passive mode of operation with just one ground-based interrogator. About the same time, a single interrogator site DABS CAS concept (Reference 5) which provided a passive, garble-free, target position solution employing time synchronization of DABS interrogations was postulated. These two single-site techniques were later integrated to form the single-site passive (SS-CAS) concept (Reference 6).

The SS-CAS mode contained the following deficiencies:

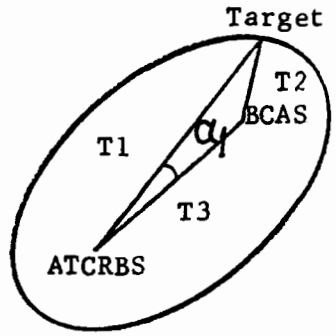
- the concept did not provide for resolution of single-site geometric singularities;
- optimum use was not made of information available in a two-site solution;

- no track information was provided on Mode A only targets; and
- the system did not operate in all airspace.

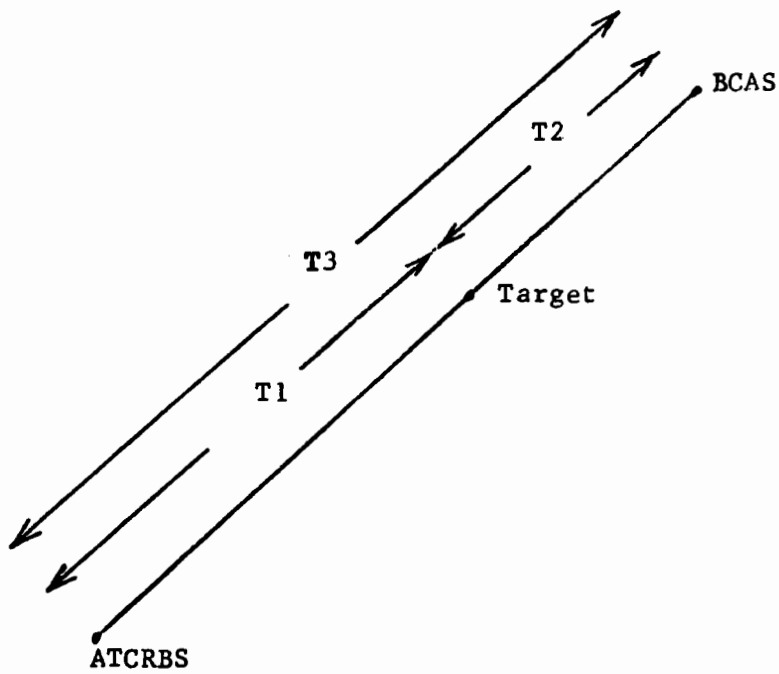
The SS-CAS mode has been expanded and retained in the BCAS concept described in this report. The directional antenna allows active mode operation to provide a solution where the SS-CAS mode results in geometric singularities. Integration of the dual-site mode and the active mode into a total system concept allows the other shortcomings to be resolved.

The term geometric singularity is important in BCAS, since all passive BCAS concepts must account for this phenomena. A geometric singularity occurs when the relative positions between the ATCRBS site(s), the BCAS aircraft, and the target aircraft are such that the target position cannot be computed accurately, if at all. Singularities, for example, exist when the threat aircraft is located between the BCAS aircraft and the radar site. Figure 1 illustrates such a geometric singularity with respect to one ATCRBS site equipped with a radar beacon transponder (RBX).

Figure 1A describes a good two dimensional BCAS geometry. The difference in time of arrival between the ATCRBS transmission and the corresponding target reply will be greater than zero ( $\Delta T_1 + \Delta T_2 - \Delta T_3 > 0$) as measured at the BCAS




1A. Good BCAS Geometry




1B. Poor BCAS Geometry

Figure 1. BCAS Geometrical Considerations

aircraft. Since the range to the ATCRBS site is known ( $\Delta T_3$), the target can be located anywhere on the surface of an ellipse as described in Figure 1A (the set of solutions for which $\Delta T_1 + \Delta T_2 - \Delta T_3$ = Constant). The angle $\alpha_1$ specifies where on the ellipse the target actually is.

Figure 1B describes a poor BCAS geometry. The target aircraft is between the ATCRBS site and the BCAS aircraft and on the line joining them. The angle $\alpha_1$ is zero, as is the difference in time of arrival of the ATCRBS transmission and the corresponding target reply (neglecting transponder delay). This information is sufficient to establish that the target is on the line and between the ATCRBS site and the BCAS aircraft, but it is not sufficient to specify exactly where on the line the target aircraft lies. Thus, the range-to-target cannot be determined.

Another concept, an all DABS active mode-system concept (Reference 7) was developed which is garble-free and utilizes DABS squitters (unsolicited replies) to obtain target ID and altitude. The DABS-CAS aircraft receives and processes the information in the unsolicited replies and then actively interrogates the DABS targets, utilizing the received DABS ID to elicit a response from only the addressed target. The

principal limitation of DABS-CAS is that it cannot provide PWI services or protection against aircraft equipped only with ATCRBS transponders.

The DABS CAS contributes significantly to the full-capability BCAS when integrated with the other modes of BCAS operation. In the transition period between ATCRBS and DABS operation, the DABS CAS supplements the active ATCRBS mode and the system provides protection against aircraft equipped with either type of transponder. Thus, it forms an integral part of the BCAS concept described in this report.

## 4. Approach to the Problem

In performing the work needed to define the BCAS concept, the design team found that it was necessary to undertake a number of analysis and simulation activities which had not been performed previously. These included a detailed study of the garble and fruit environment as they exist today in the major terminal areas in the United States, and forecasts of these environments as they may be in the 1980-2000 time period. This also included a study of the areas in which ATCRBS coverage is currently available and an examination of the geometry of the existing interrogators to determine the airspace where it would be possible to use multi-site passive solutions.

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The team then defined the performance requirements for a BCAS system. This included determinations of the minimum separation distances which would be acceptable to pilots and which must be achieved by the BCAS detection and resolution logic. It was also necessary to establish the accuracy required by the detection and resolution logic in order to minimize the number of false alarms that would be generated and, to the extent possible, to eliminate the problem of missed alarms. Solutions were found to all encounter geometries that provided the specified separations except for one maneuvering case. The exception relates to the case where two aircraft are flying parallel courses and one turns (or maneuvers vertically) into the other. In this case collision warnings are issued too late to allow safe separation.

A number of detection and resolution modes were examined to determine which ones were capable of meeting the accuracy requirements. Some modes are range-sensitive in that the required accuracy can only be met for a limited range from a radar site, while others meet the accuracy requirements at all distances from the radar site, but suffered other restrictions such as generation of RF interference to the ground system or susceptibility to garble saturation. The solution of the proper detection and resolution mode for each threat situation will be discussed later.

Following the completion of the analysis work, the team began the design of the system concept which would meet the performance requirements and provide the mode selection control that forms the basis of the future BCAS system. The BCAS system resulting from that design activity includes an antenna, receiver/transmitter, signal and reply processors, radar and target trackers, mode selection logic, and detection and resolution logic.

The group also produced the required documentation which included the BCAS concept description provided in this report, the engineering requirement, and the statement of work.

## 5. Findings of the Design Team

Obtaining acceptable performance of the aircraft separation assurance function in all airspace, done totally in an airborne unit, is a very complex task. To accomplish this task in all environments, particularly those which represent high density traffic areas, the team concluded that a directional antenna was required. This determination was supported both by the simulation efforts which were conducted for various traffic densities and in different geographical areas, and by flight tests which were conducted on a BCAS system operating within the current Los Angeles environment. These latter tests showed that even the current densities are sufficient to saturate an

active BCAS system. This saturation showed up as intermittent tracking of threat targets in the high-density portions of the simulated Los Angeles airspace.

The team examined some 100 detection algorithms and found that no one detection algorithm produced the best results in all environments. However, they did find that a family of solutions does exist that will provide accuracies that are equivalent to, or in many cases better than, those provided by the Automated Traffic Advisory and Resolution Service system (ATARS). The standard for comparison was the accuracy of the ATARS system at 50 nautical miles from the radar site. This is the maximum range at which the accuracy of the surveillance system is adequate to support the full range of ATARS services.

For BCAS to operate compatibility with ATC, it was apparent that BCAS must be interfaced with ATARS, and through ATARS with the conflict alert function, at the ATC ground site. It was also established that BCAS can be interfaced with the air traffic control system even in an all ATCRBS environment if a DABS transponder which incorporates the DABS data link is provided at the radar site. This permits the BCAS system to communicate with the radar and thereby provide data for the ATC conflict alert function. Additionally this data link provides some control of BCAS by the ground-based ATC system even in the pre-ATARS era.

The team assessed the effectiveness of various BCAS configurations ranging from the simple active system to the full BCAS by estimating their performance in detecting and preventing recorded mid-air and near mid-air collision situations.

Table 1 presents a safety performance comparison of several systems evaluated for collisions which involved at least one air carrier for the time period from 1964 to 1972. The data for this comparison were taken from the NTSB data file and include 15 collisions, each involving at least one air carrier, which produced a total of 271 fatalities.

Two of the collisions represent cases that perhaps no separation assurance system could have been totally effective in preventing. One of these occured over Carmel, N. Y., where one aircraft pulled up into another. The aircraft were operating above a sloping cloud deck at the time, and the optical illusion created the impression to one of the pilots that he was on a collision course with the other aircraft, when in fact a 1000 foot vertical separation existed. The other case involved an air carrier aircraft on a straight-in approach at Harlingen, Texas, that ran into a small general aviation aircraft as it turned from base leg to final. The collision

TABLE 1 SAFETY PERFORMANCE COMPARISON FOR INCIDENTS INVOLVING AT LEAST ONE AIR CARRIER

(NTSB DATA, 1964-1972)

| | COLLISIONS | FATALITIES | NMACS |
|---|---|---|---|
| TOTAL | 15 (100%) | 271 (100%) | 52 (100%) |
| PREVENTABLE WITH | | | |
| ATARS | 13 (87%) | 267 (99%) | 47 (90%) |
| FULL BCAS | 13 (87%) | 267 (99%) | 52 (100%) |
| OMNI BCAS (1975) | 9 (60%) | 179 (66%) | 41 (79%) |
| ACTIVE BCAS (1975) | 8 (53%) | 177 (65%) | 41 (79%) |
| OMNI BCAS (1995) | 7 (47%) | 153 (57%) | 34 (65%) |
| ACTIVE BCAS (1995) | 6 (40%) | 151 (56%) | 34 (65%) |

NOTE: ALL AIR CARRIERS ARE ASSUMED TO BE BCAS-EQUIPPED.

occurred at 250 feet above the ground, which is probably too low for effective operation of any separation assurance system.

Table 1 shows that ATARS would have been effective in the remaining 13 of the 15 collisions, which would have prevented 267 of the 271 fatalities. It is believed that the full BCAS shown on the next line would have been effective in the same cases. The omnidirectional BCAS system, that is, one not equipped with a directional antenna and which therefore cannot operate successfully in high-density airspace, appears to be effective for about 60 percent of the collisions and would reduce fatalities by about 2/3 when dealing with 1975 traffic levels. That same system, looking at 1995 traffic levels, would be only about 50% effective. By comparison, an active BCAS system in the 1975 environment is effective in about 53% of the collisions, and could possibly prevent about 65% of the fatalities. However, its performance becomes worse as traffic levels increase. In 1995 it could only be expected to prevent about 40% of the collisions and about 56% of the fatalities.

Shown in the far right column of Table 1 are near midair collision data for the year 1975. During that year there were 52 near midair collisions involving air carrier aircraft. It is believed that ATARS could have prevented 47 or 90% of these;

the remainder appear to have been below radar coverage. The full BCAS, on the other hand, would have been effective in preventing all 52, since it would operate even in the region below radar coverage. The assumption, of course, is made here that all air carriers would carry BCAS equipment, and that all other aircraft would be equipped with at least an ATCRBS transponder. The numbers at the lower right hand part of Table 1 indicate that use of the omni or active BCAS concept would have been effective in about 41 near mid-airs, or 79% of the cases in 1975, with this number dropping to about 34, or 65% of the cases in 1995. Hence, it seems clear that the full BCAS capability is required if a system is to provide independent protection in all airspace to the end of this century.

## 6. The Operational Environment of BCAS

One of the fundamental requirements in the design of the BCAS system is the ability to operate in the high density terminal areas with their high fruit and garble environments which have been forecast for the next 25 years. This section addresses the question of garble and fruit levels as they are forcast, particularly in the Los Angeles Basin. With this perspective we can address the need for the directional antenna system which appears required to provide successful BCAS operation in much of the high-density airspace during this time period.

Figure 2 portrays 743 aircraft in the locations where it is believed they might be operating in the 1982-1985 model of the Los Angeles airspace (Reference 8). The figure covers a geographical area which is approximately 120 nautical miles on a side. In order to determine the garble problem as a BCAS-equipped aircraft of the 1980's might encounter it, a circular flight path was defined in a high-density part of the basin. The cross in the middle of the circle represents the location of a threat aircraft. An examination of the garble situation was then conducted as the BCAS aircraft flew around the circular path.

Table 2 summarizes the garble as it would be seen by the BCAS aircraft at a point on the circle northwest of the threat aircraft for the full traffic model density, and also for 1/2 and 1/4 of this density. The garble situation is shown for each of the nine FAA interrogators located within the Los Angeles Basin.

Some of the team's analytical studies have shown that a BCAS system is capable of operating in garble levels where three reply trains are simultaneously overlapped as an average condition. It has also been shown that BCAS can operate through peak garble conditions of seven or even eight overlapped pulse trains if that condition does not persist for any appreciable length of time. From Table 2, it is apparent that the only

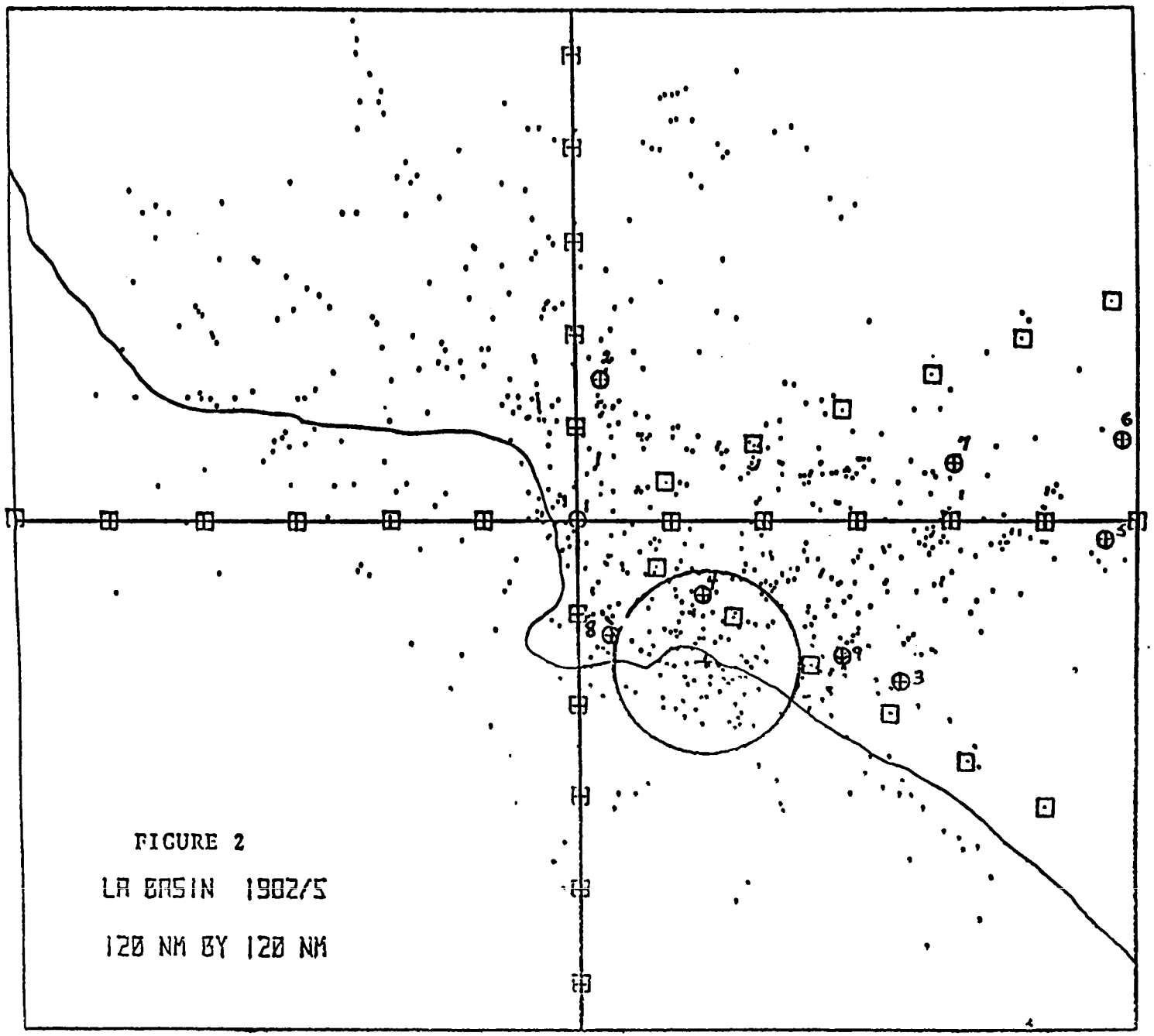



FIGURE 2

TABLE 2 STATIC PASSIVE GARBLE ANALYSIS SUMMARY

| DENSITY | INTERROGATOR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | LAX | MAR | BUR | LGB | ONT | ELT | NOR | SP | SA |
| FULL | 20 | 34 | 36 | 6 | 22 | 21 | 45 | 13 | 13 |
| HALF | 13 | 17 | 20 | 3 | 11 | 8 | 27 | 8 | 8 |
| QUARTER | 7 | 6 | 11 | 1 | 5 | 5 | 11 | 5 | 4 |

radar which falls below the seven to eight threshold for all of the traffic models is the Long Beach radar, which is also the radar closest to the BCAS aircraft. This point is significant, as it is the basis for selection of the detection modes to be used in the high-density airspace regions.

Examination of the bottom line of Table 2, which represents the traffic density equal to 1/4 of the Los Angeles Basin model, indicates that at this reduced traffic level a number of the other radars could be used, as the peak garble levels are below the maximum threshold. This factor is significant, since it indicates that multiple radar passive solutions may be used at locations with this density of traffic.

Table 3 depicts the performance that one might expect from an active BCAS system again operating at the maximum, half-density and quarter-density models of the Los Angeles Basin traffic. The two bottom lines on the figure represent the garble levels that could be expected if an omni antenna were used. Clearly, the garble situation is considerably worse in the case of an active system, since the active interrogation from the aircraft is soliciting responses from all aircraft within reach of its interrogation. The top line under omni antenna indicates that the garble level would be 77 overlapped

TABLE 3 STATIC ACTIVE GARBLE ANALYSIS SUMMARY

| | | 1982 MODEL DENSITY | | | | HALF DENSITY | | | | QUARTER DENSITY | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MAX | MIN | AVG | DEV | MAX | MIN | AVG | DEV | MAX | MIN | AVG | DEV |
| DIRECTIONAL ANTENNA WEDGE ANGLE* | $15^{o}$ | 13 | 0 | 3.2 | 2.5 | 9 | 0 | 1.6 | 1.6 | 3 | 0 | 0.7 | 0.7 |
| | $22.5^{o}$ | 16 | 0 | 4.9 | 3.3 | 10 | 0 | 2.4 | 2.1 | 3 | 0 | 1.0 | 1.0 |
| | $30^{o}$ | 18 | 1 | 6.4 | 4.0 | 11 | 0 | 3.2 | 2.5 | 4 | 0 | 1.3 | 1.1 |
| OMNI ANTENNA* | | 77 | - | - | - | 38 | - | - | - | 16 | - | - | - |
| OMNI ANTENNA** | | 83 | - | - | - | 46 | - | - | - | 17 | - | - | - |

* VALUES AT A PARTICULAR LOCATION WITHIN THE LOS ANGELES BASIN

** MAXIMUM VALUES FOR THE LOS ANGELES BASIN

replies. This represents the condition as it would been seen by a BCAS-equipped aircraft located on the circle northwest of the threat aircraft. The higher value of 83 also occurs at a position within the circle, but in a northeasterly direction from the threat aircraft. These values are approximatly ten times the estimated maximum value at which a BCAS system could successfully detect and protect against a threat aircraft.

At the top of Table 3, the garble condition is shown as it would be improved through the use of a directional antenna. Antenna wedges or look angles of 15 degrees, 22 1/2 degrees and 30 degrees were considered. The significant numbers are the maximum and the average values. Again, values above three in the average column and eight in the maximum column exceed the acceptable thresholds. Thus, an active BCAS system would not be usable either at the full model density or the half model density. However, the active mode BCAS can provide a useful service to terminals which have traffic equivalent to the quarter-density Los Angeles model. In these areas, where the active mode of BCAS may be called upon in some situations (e.g. resolution of singularities), the active mode actually represents the best solution.

The garble situation along a horizontal line extending in an easterly direction from the Los Angeles radar was examined.

Figure 2 shows boxes along that line spaced at ten-nautical-mile intervals. Figure 3 has similar boxes which represent the average and peak garble situations as they would be viewed by a BCAS aircraft at each location. There are nine squares within each box which represent the values for each of the nine radars shown in the figure.

For example, at the 10-mile box farthest to the left, the average garble for the Los Angeles radar would be 1.3 and the peak garble would be 7. This represents an acceptable level for system operation. At the second (20-mile) box, the average garble of 2.1 for the Los Angeles radar is still acceptable, but the peak garble has now reached the value of 9, which is above the threshold. By examining other numbers in the 20-mile box, one will note average garbles as high as 5.6 and peak garbles as high as 22 from other radars. These values are well above the threshold required for successful system operation. Another significant thing to note is that generally in each box there is only one or occasionally two radars which can provide average and peak values of garble which are below the acceptable threshold. This becomes an important point later on in selecting the mode of operation for the BCAS system in the high-density environment.

FIGURE 3 DYNAMIC GARBLE SIMULATION — 090° RADIAL

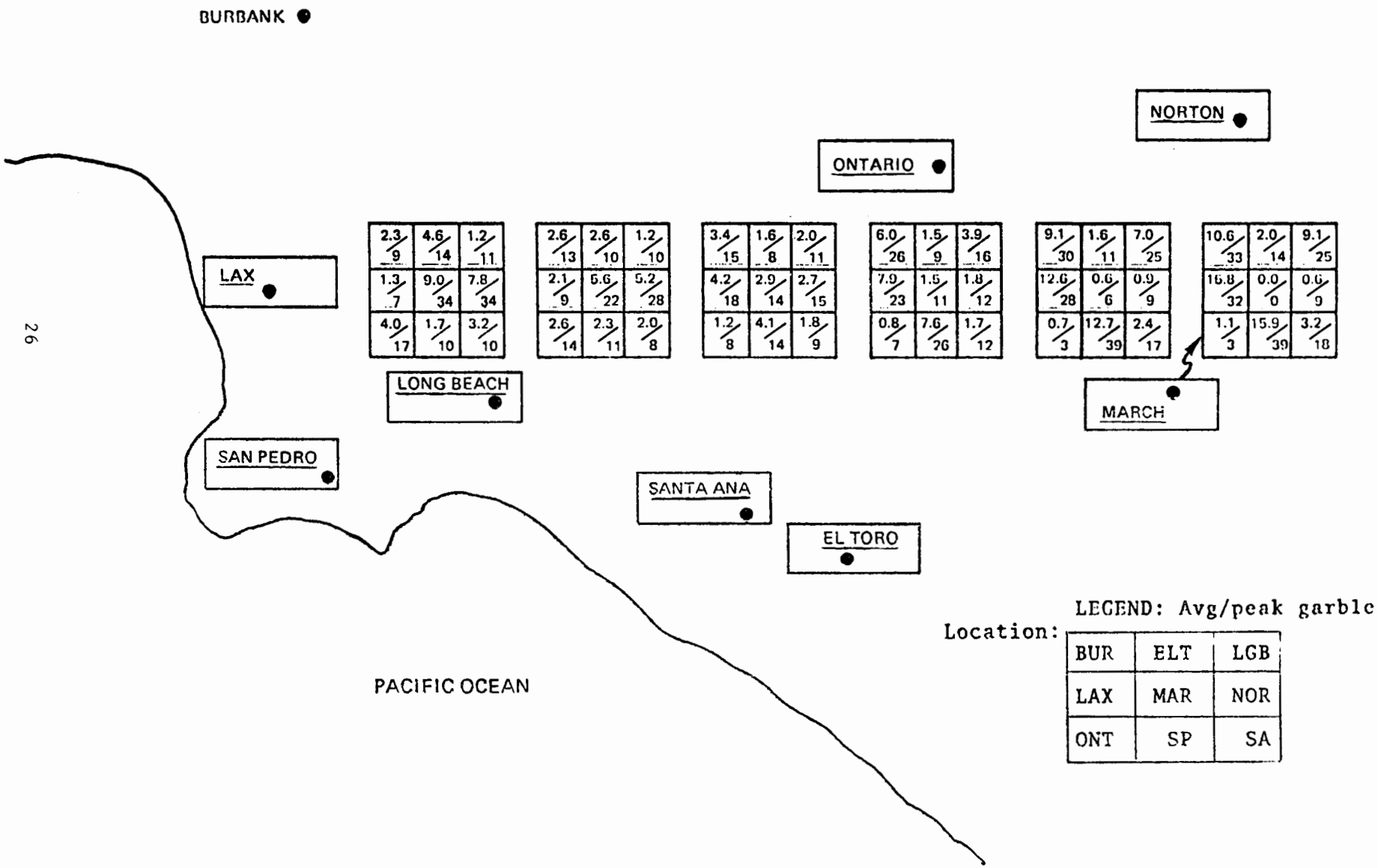


Figure 4 shows the fruit environment for several of the major airports. Along the top margin the environment is shown either as it existed in the Boston, New York, Washington and Los Angeles areas. Also depicted are some of the actual measurements taken at Boston and Washington; these are plotted along the theoretical or calculated curve which relates received fruit rate to traffic density.

The significant point to note in conjunction with Figure 4 is that generally fruit levels below about 8,000-10,000 fruit per second represent levels that can be fairly easily dealt with by both ground-based and airborne systems. Fruit levels above this value begin to degrade seriously the quality of both the ground ATC system and the airborne BCAS system. Also, since the received fruit replies are superimposed on the garbled replies shown previously, the problem compounds rapidly as traffic density increases. Since the scale is not linear, as the traffic density increases the problem of providing successful detection and resolution rapidly degrades. There is a very sharp transition at the threshold values which correspond to an average garble level of 3 overlapped pulse trains with a peak level of 8, and a peak fruit level of 10,000 fruit per second.

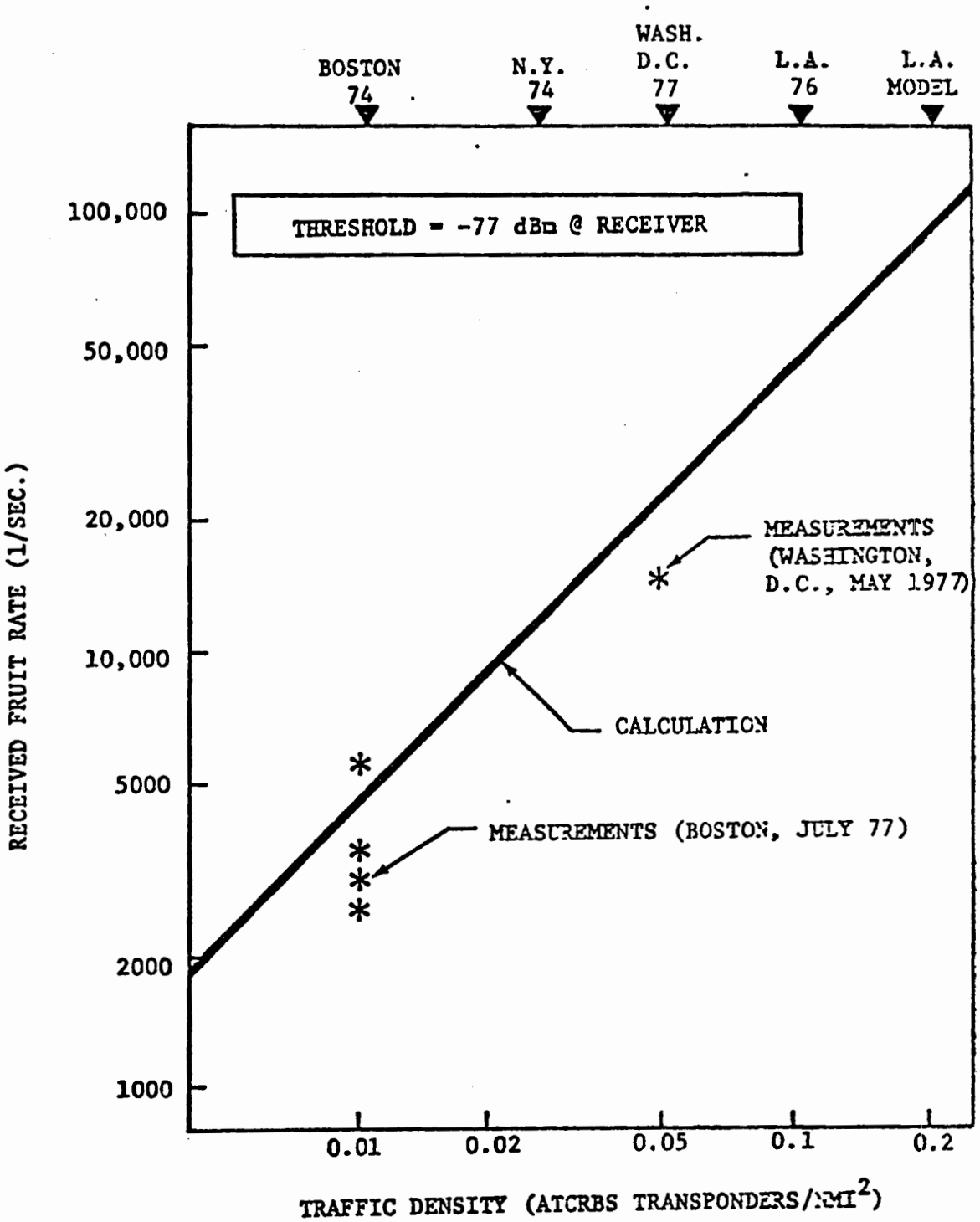



FIGURE 4
AIRBORNE FRUIT RATE

Tables 4 and 5 show the relationship of garble and fruit levels to the complexity of the BCAS equipment required. These two figures indicate the traffic density in aircraft per square nautical mile as it will exist in the top 60 terminals in the U. S. at various times from 1975 through 1995. The bottom segment on each figure represents those terminals and time periods in which a BCAS system with an omni antenna system would operate successfully. The middle segment represents the terminals and the time periods in which successful operation of the BCAS can only be achieved through the use of a directional antenna. In 1990 in Los Angeles and in 1995 in a total of five terminals, the fruit and garble environment will exceed the capabilities of even the full BCAS system. Hence, it is necessary to introduce some synchronization into the ground environment to limit the garble and fruit generated into the high-density terminals. It is proposed to achieve this synchronization through the use of a synchro-DABS mode of operation. The addition of this mode to the system adds a small amount of processing to the BCAS system.

Figure 5 is another way of portraying the same information. The circles represent the same 60 terminals that were shown in the previous two figures. The area which surrounds them represents a lower traffic density area, in which an active-only BCAS could be used. Caution, however, is required in

TABLE 4

BCAS COMPLEXITY VS. DENSITY AT THE
37 MEDIUM DENSITY HUBS (30-nm radius)

| HUB | 1975 | 1980 | 1985 | 1990 | 1995 | REQUIREMENT |
|---|---|---|---|---|---|---|
| OKC | 0.029 | 0.041 | 0.057 | 0.081 | 0.113 | |
| SAN | 0.027 | 0.039 | 0.054 | 0.076 | 0.107 | SYNCHRO-DABS |
| TUL | 0.026 | 0.036 | 0.051 | 0.071 | 0.100 | |
| RIV | 0.025 | 0.036 | 0.050 | 0.071 | 0.099 | |
| SJC | 0.025 | 0.035 | 0.049 | 0.069 | 0.096 | |
| PDX | 0.024 | 0.034 | 0.047 | 0.067 | 0.093 | |
| IND | 0.024 | 0.033 | 0.046 | 0.065 | 0.091 | |
| TPA | 0.023 | 0.032 | 0.045 | 0.063 | 0.088 | |
| MKE | 0.022 | 0.031 | 0.043 | 0.060 | 0.084 | |
| PHX | 0.021 | 0.029 | 0.041 | 0.057 | 0.080 | |
| SAC | 0.018 | 0.028 | 0.036 | 0.051 | 0.072 | |
| CMH | 0.018 | 0.026 | 0.036 | 0.050 | 0.070 | |
| LOU | 0.018 | 0.025 | 0.035 | 0.049 | 0.068 | |
| MEM | 0.016 | 0.022 | 0.031 | 0.044 | 0.061 | |
| BDL | 0.015 | 0.020 | 0.029 | 0.040 | 0.056 | |
| BUF | 0.014 | 0.020 | 0.028 | 0.040 | 0.056 | |
| OMA | 0.014 | 0.019 | 0.027 | 0.038 | 0.053 | |
| ABQ | 0.013 | 0.018 | 0.025 | 0.036 | 0.050 | DIRECTIONAL ANTENNA |
| CIN | 0.012 | 0.017 | 0.024 | 0.034 | 0.047 | |
| JAX | 0.012 | 0.017 | 0.024 | 0.034 | 0.047 | |
| ORL | 0.011 | 0.015 | 0.021 | 0.030 | 0.042 | |
| TUS | 0.010 | 0.014 | 0.020 | 0.028 | 0.040 | |
| SAT | 0.010 | 0.014 | 0.020 | 0.028 | 0.039 | |
| GSO | 0.010 | 0.014 | 0.019 | 0.027 | 0.038 | |
| DAY | 0.009 | 0.013 | 0.018 | 0.026 | 0.036 | |
| PBI | 0.009 | 0.013 | 0.018 | 0.025 | 0.036 | |
| GEG | 0.008 | 0.012 | 0.017 | 0.023 | 0.033 | |
| SLC | 0.008 | 0.011 | 0.015 | 0.021 | 0.030 | |
| ORF | 0.008 | 0.011 | 0.015 | 0.021 | 0.030 | |
| ROC | 0.007 | 0.009 | 0.013 | 0.018 | 0.026 | |
| ELP | 0.006 | 0.008 | 0.012 | 0.016 | 0.023 | |
| RIC | 0.006 | 0.008 | 0.012 | 0.016 | 0.023 | |
| RNO | 0.005 | 0.008 | 0.011 | 0.015 | 0.021 | |
| BNA | 0.005 | 0.007 | 0.010 | 0.014 | 0.020 | |
| SYR | 0.005 | 0.007 | 0.010 | 0.014 | 0.020 | |
| CLT | 0.005 | 0.007 | 0.010 | 0.013 | 0.019 | OMNI ONLY |
| RDU | 0.004 | 0.006 | 0.009 | 0.012 | 0.017 | |

See Glossary page for Hub names after tables

TABLE 5

BCAS COMPLEXITY VS. DENSITY AT THE

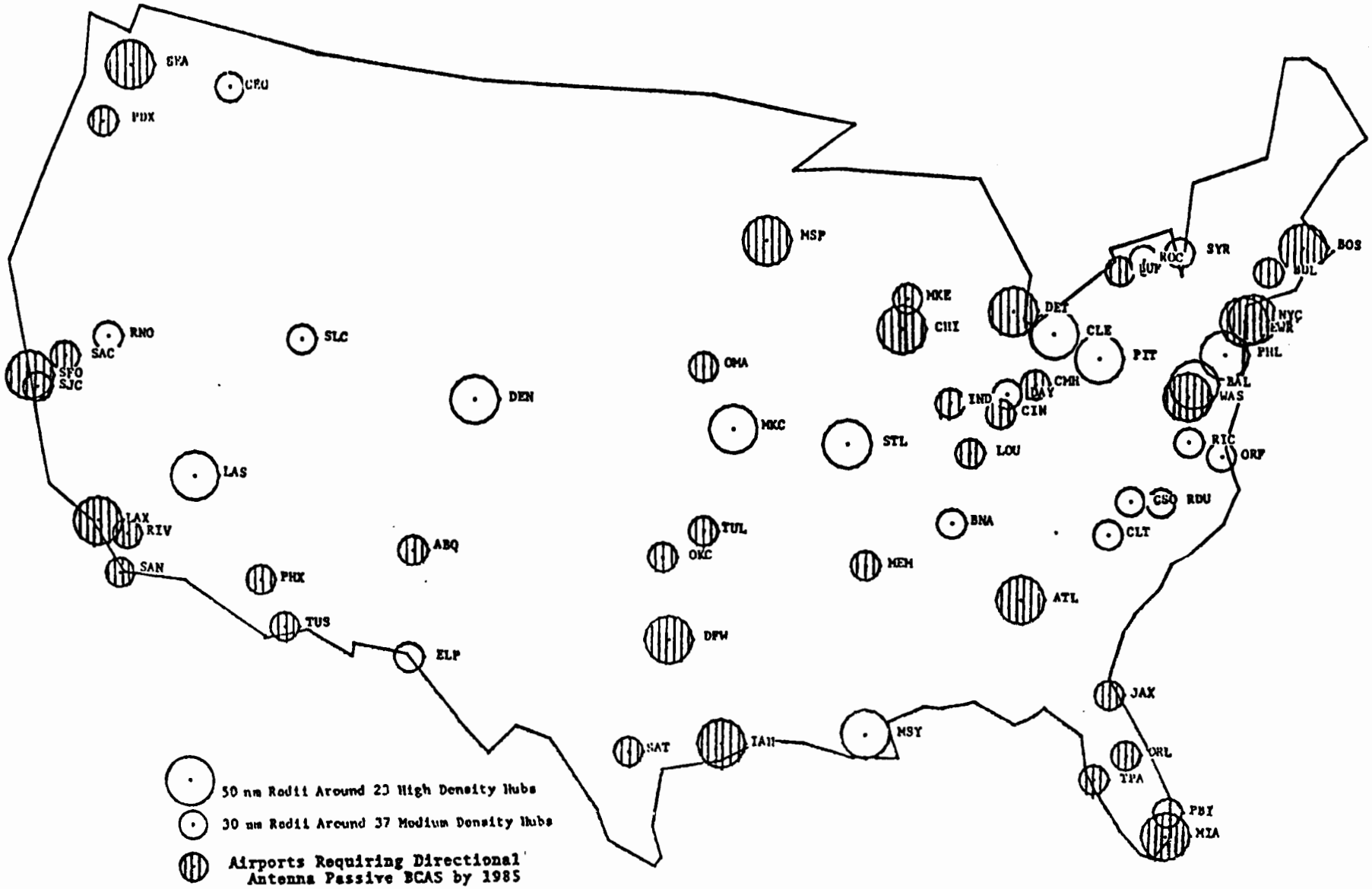
23 HIGH DENSITY HUBS (50-nm radius)

| HUB | 1975 | 1980 | 1985 | 1990 | 1995 | REQUIREMENT |
|---|---|---|---|---|---|---|
| LAX | 0.048 | 0.068 | 0.095 | 0.133 | 0.128 | SYNCHRO-DABS |
| CHI | 0.028 | 0.040 | 0.056 | 0.079 | 0.110 | |
| MIA | 0.025 | 0.038 | 0.050 | 0.070 | 0.098 | DIRECTIONAL ANTENNA |
| SFO | 0.022 | 0.031 | 0.043 | 0.061 | 0.085 | |
| NYC | 0.020 | 0.029 | 0.040 | 0.057 | 0.079 | |
| DFW | 0.020 | 0.028 | 0.039 | 0.055 | 0.078 | |
| WAS | 0.017 | 0.023 | 0.033 | 0.046 | 0.064 | |
| DET | 0.018 | 0.023 | 0.032 | 0.046 | 0.064 | |
| MSP | 0.016 | 0.022 | 0.031 | 0.044 | 0.061 | |
| EWR | 0.014 | 0.019 | 0.027 | 0.038 | 0.053 | |
| IAH | 0.013 | 0.019 | 0.026 | 0.037 | 0.051 | |
| SEA | 0.013 | 0.018 | 0.025 | 0.036 | 0.049 | |
| ATL | 0.012 | 0.017 | 0.024 | 0.034 | 0.048 | |
| BOS | 0.011 | 0.016 | 0.022 | 0.031 | 0.044 | |
| MKC | 0.009 | 0.013 | 0.018 | 0.026 | 0.036 | |
| PHL | 0.009 | 0.013 | 0.018 | 0.025 | 0.035 | |
| DEN | 0.009 | 0.013 | 0.018 | 0.025 | 0.035 | |
| CLE | 0.009 | 0.012 | 0.017 | 0.024 | 0.034 | |
| PIT | 0.009 | 0.012 | 0.017 | 0.024 | 0.034 | |
| STL | 0.007 | 0.010 | 0.014 | 0.020 | 0.028 | |
| MSY | 0.006 | 0.008 | 0.011 | 0.016 | 0.022 | |
| LAS | 0.004 | 0.006 | 0.008 | 0.011 | 0.016 | OMNI ONLY |
| BAL | 0.003 | 0.004 | 0.006 | 0.009 | 0.012 | |

See Glossary for Eub names on next page

| | | | |
|---|---|---|---|
| ABQ | Albuquerque | MSP | Minneapolis-St. Paul |
| ATL | Atlanta | MSY | New Orleans |
| BAL | Baltimore | OKC | Oklahoma City |
| BDL | Hartford | OMA | Omaha |
| BNA | Nashville | ORD | Chicago |
| BOS | Boston | ORF | Norfolk |
| BUF | Buffalo | ORL | Orlando |
| CIN | Cincinnati | PBI | West Palm Beach |
| CLE | Cleveland | PDX | Portland |
| CLT | Charlotte | PHL | Philadelphia |
| CMH | Columbus | PHX | Phoenix |
| DAY | Dayton | PIT | Pittsburgh |
| DCA | (WAS) National | RDU | Raleigh-Durham |
| DEN | Denver | RIC | Richmond |
| DFW | Dallas-Ft. Worth | RIV | Riverside |
| DTW | Detroit | RNO | Reno |
| ELP | El Paso | ROC | Rochester |
| EWR | Newark | SAC | Sacramento |
| GEG | Spokane | SAN | San Diego |
| GSO | Greensboro | SAT | San Antonio |
| IAH | Houston | SDF | Louisville |
| IND | Indianapolis | SEA | Seattle |
| JAX | Jacksonville | SFO | San Francisco |
| JFK | New York | SJC | San Jose |
| LAS | Las Vegas | SLC | Salt Lake City |
| LAX | Los Angeles | STL | St. Louis |
| MEM | Memphis | SYR | Syracuse |
| MIA | Miami | TPA | Tampa |
| MKC | Kansas City | TUL | Tulsa |
| MKE | Milwaukee | TUS | Tucson |

FIGURE 5 1985 REQUIREMENTS



interpreting the figure, as high density areas are shown limited to 30-mile and 50-mile radii from the radars. The density in the entire northeast part of the United States and much of California probably requires the use of a directional antenna, even in the 1985 time period portrayed here.

Figure 6 represents the same situation five years later in 1990. A directional antenna is now required for operation in much of the airspace east of the Mississippi River and along the West Coast. The Los Angeles air traffic has increased to the point where interrogation synchronization (synchro-DABS) operation is required.

Figure 7 shows the location and approximate coverage of the airport surveillance radars that are currently installed. These radar coverage contours overlie all of the high-density areas requiring BCAS operation with a directional antenna as shown in Figure 6. The significance of presenting this is to show that ATARS service can be provided in all of the areas where a directional antenna would be required. Thus, there is an alternative to a full BCAS system in the form of an integrated system which uses ATARS in the high-density airspace covered by radar, and BCAS in the medium and low density airspace where ATARS service may not be available.

FIGURE 6 1990 REQUIREMENTS

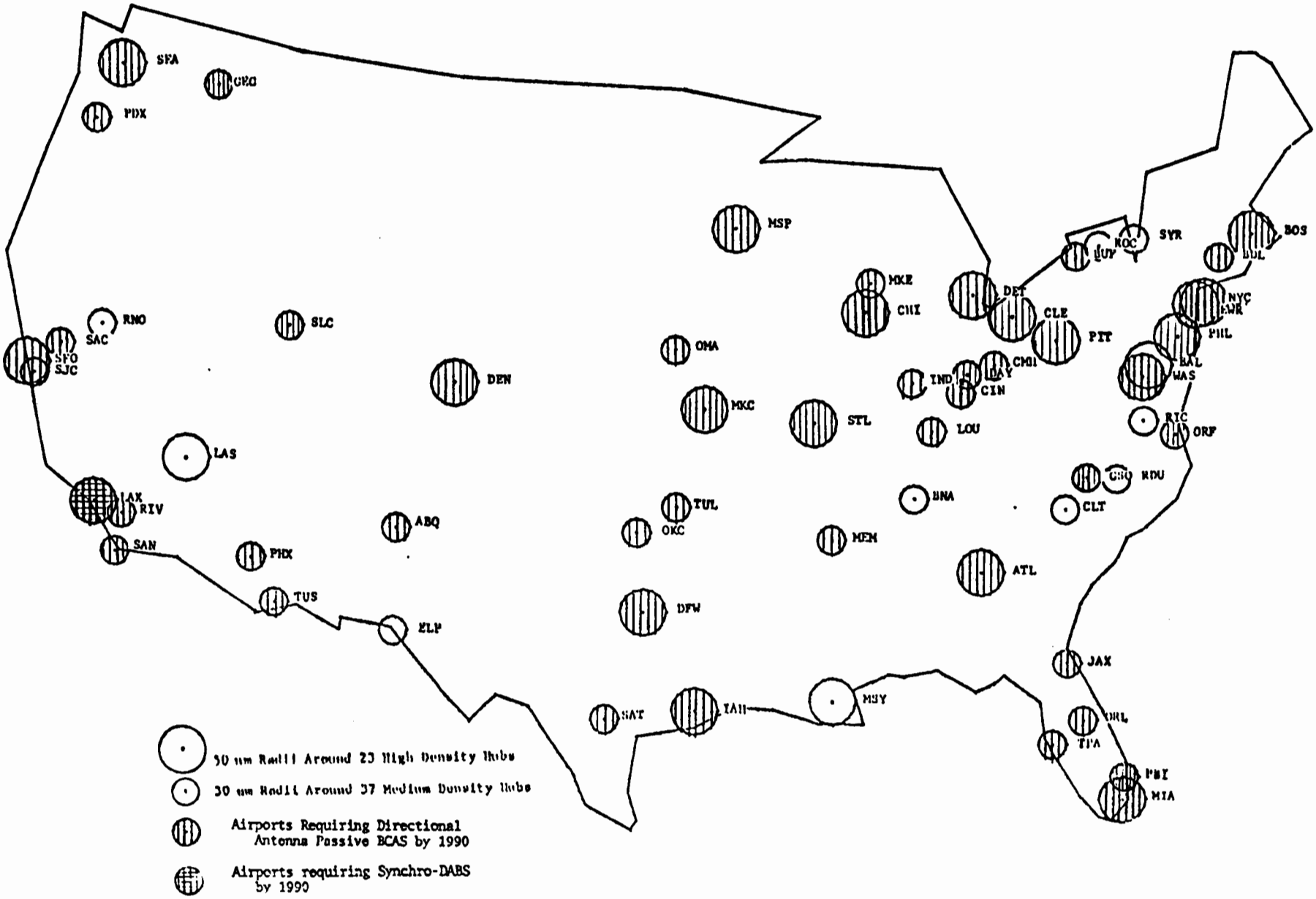


FIGURE 7

FAA AIRPORT SURVEILLANCE RADARS
(162 sites)
with 50 nm range rings
(1,250 foot equivalent altitude)

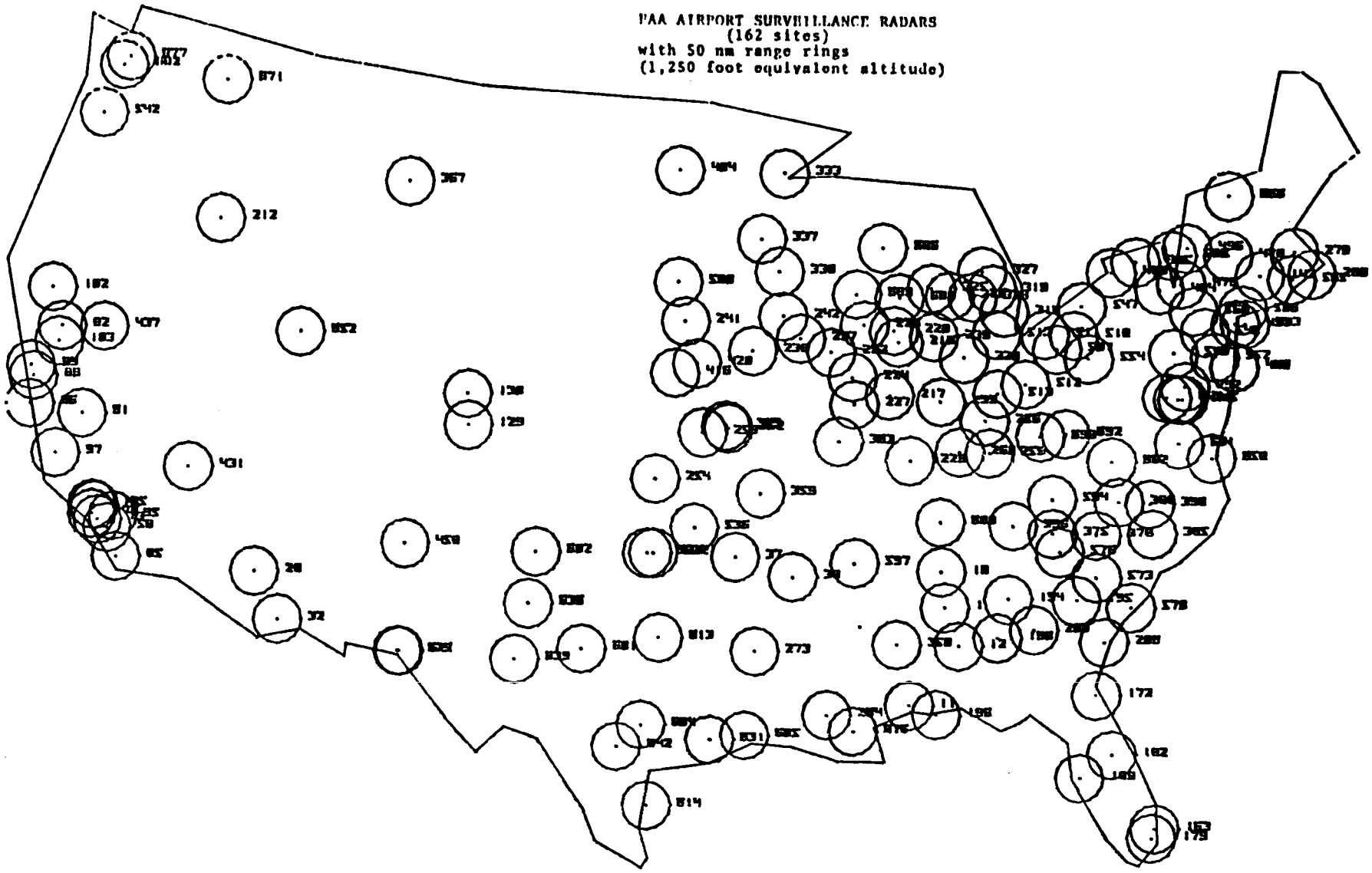


Figure 8 shows the basic elements of the active BCAS. All of these are elements of the total BCAS system. The 1090 MHz transmitter and 1030 MHz receiver shown at the bottom of the figure and the omni antenna are a part of the normal ATCRBS transponder as it is currently installed in aircraft. The other transmitter, receiver, signal processor, computer, and display elements represent new items specifically related to the BCAS function. The active system is limited to operation in low-density airspace, which corresponds generally to the open regions shown in Figure 5. This system is limited in that it can only provide commands for resolution in the vertical dimension. The display at the right is able to present to the pilot either a limit descent-rate/climb-rate command, or a climb/dive command.

Figure 9 shows the components of the active system and includes the additional components required for the passive mode of operation. The 1030 receiver receives interrogations from the ground which are used by the signal processor and computer to track the locations of the radars and to locate the BCAS-equipped aircraft and threat aircraft in relationship to these radars. A different type of display has also been added which can provide the pilot with traffic advisory information on <u>some</u> aircraft vertical resolution maneuver advisories on all transponder equipped aircraft, and horizontal as well as vertical

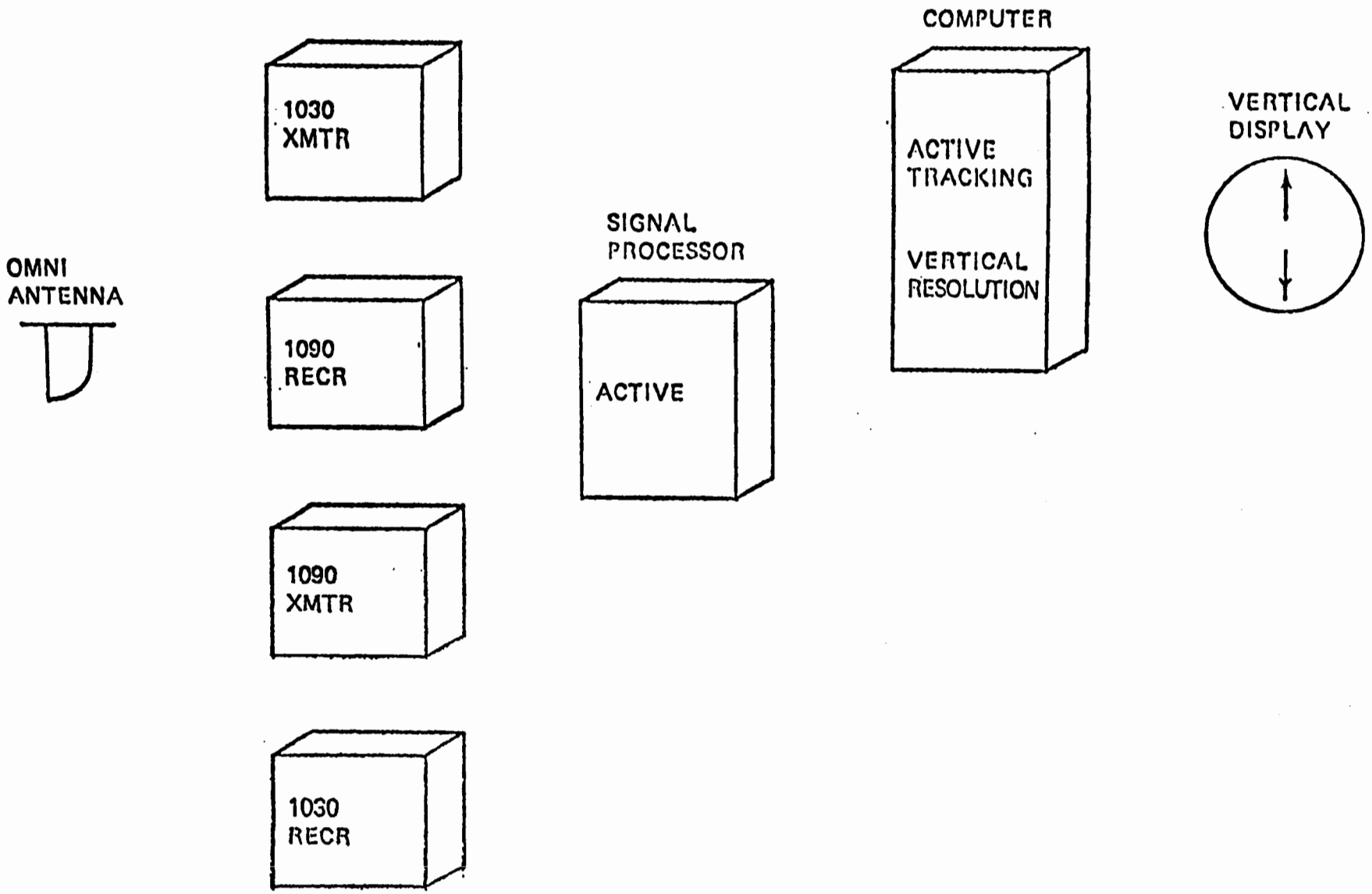



FIGURE 8 BASIC ELEMENTS OF ACTIVE BCAS

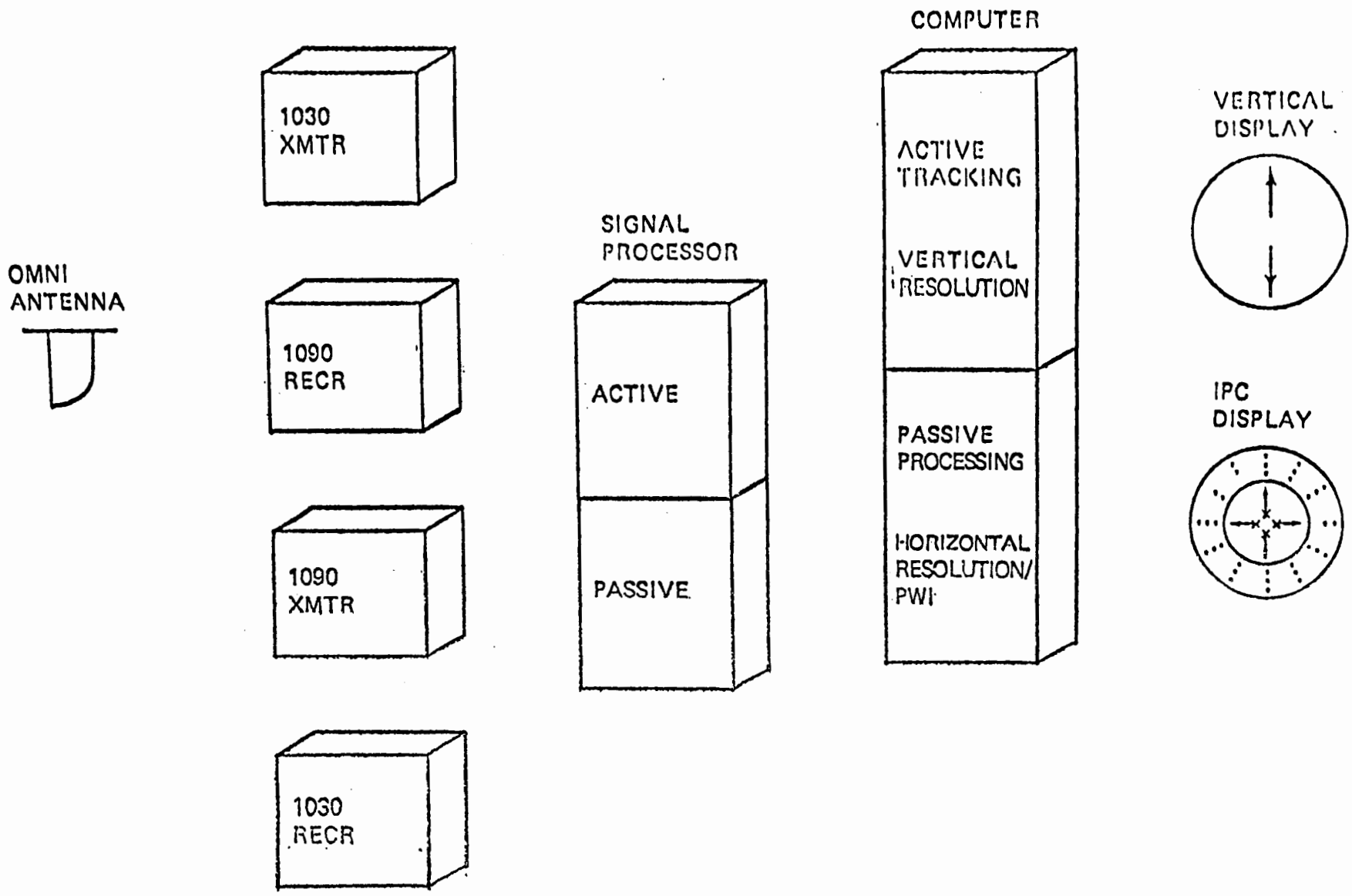



FIGURE 9 BCAS ACTIVE AND PASSIVE ELEMENTS

resolution on some aircraft. Traffic advisories and horizontal commands can only be provided on aircraft when the detection and resolution system has been able to use a passive solution. This requires that the replies received from the threat aircraft include information from at least two radars which have the proper geometry for an acceptable solution.

Figure 10 shows the active and passive elements as before, and shows the additional elements which are associated with the use and operation of the directional antenna. This system can operate in all areas of the United States in 1995 except at the top five terminals, where the synchro-DABS mode is also required. The equipment provides traffic advisories on all aircraft equipped with transponders and is able to select either horizontal or vertical resolution maneuvers in any potential collision situation involving another aircraft equipped with a transponder and encoding altimeter.

The quality of the traffic advisory information has also improved; it is possible to provide a traffic situation display to the pilot using a small cathrode-ray tube in the cockpit. This type of display is under investigation in a joint FAA/NASA program to determine what functions the pilot might be able to assume if traffic information were available in the cockpit. The addition of the directional antenna represents a significant improvement in that pilots can be given traffic advisory

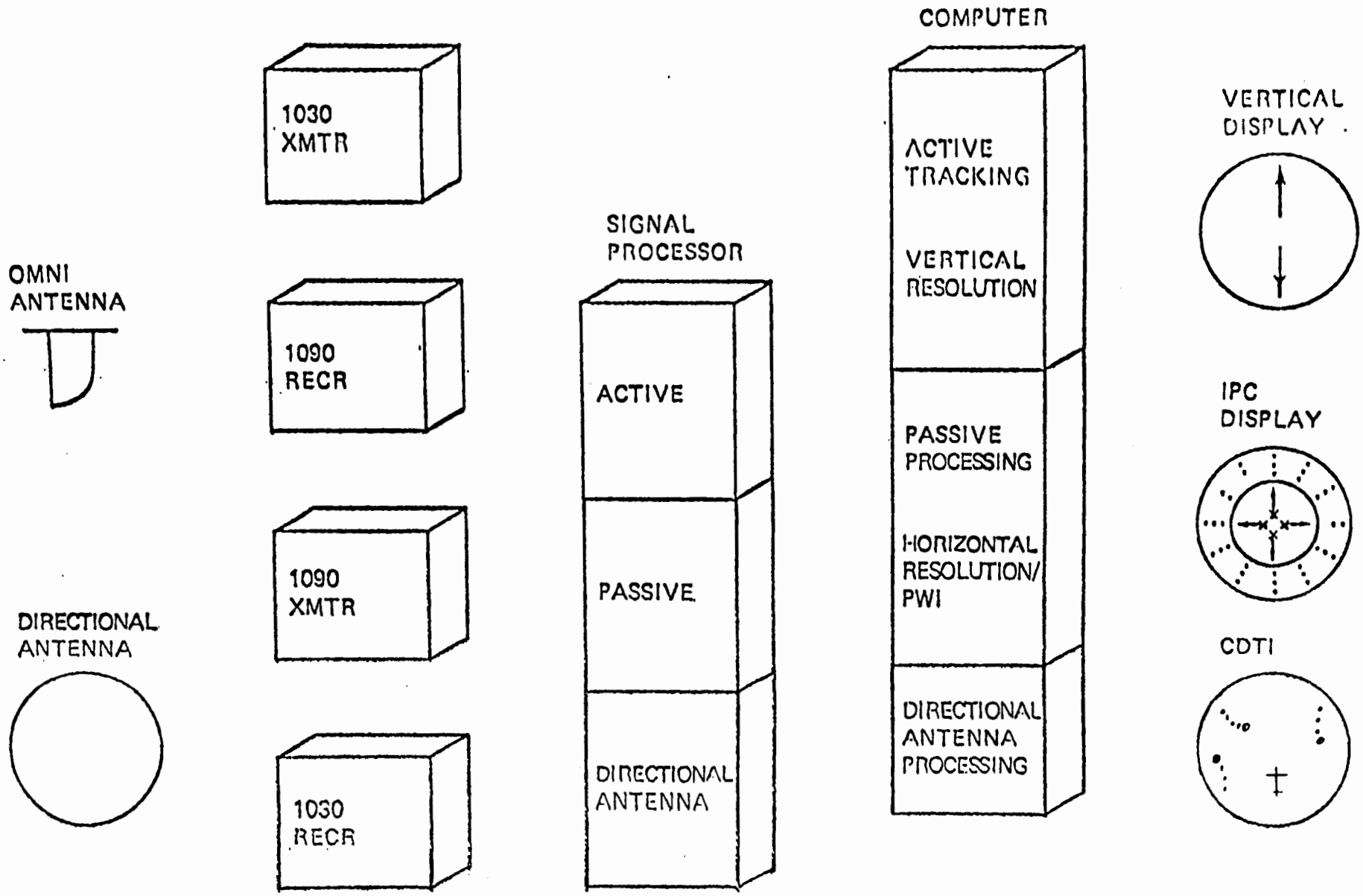



FIGURE 10 BCAS ELEMENTS WITH DIRECTIONAL ANTENNA AND TRAFFIC DISPLAY

information on threats which airborne separation assurance systems in the past have been unable to resolve. This class of threats will be presented later, but it is similar to the type of situation that occurred in the air carrier mid-air collision over Carmel, N. Y.

Figure 11 shows the final addition to the system: supplementary computer logic which provides for the processing of the synchro-DABS reply information. This information represents a transmission by the synchro-DABS equipped aircraft which is time-synchronized by the ground interrogation and includes the aircraft azimuth relative to the radar. The synchronized mode of operation provides a very good solution, and enhances all of the modes described previously. So far as the pilot is concerned, he sees no difference in his display.

## 7. Performance Requirements

This section addresses the performance requirements for the various elements of the BCAS which are required to provide successful operation in all airspace with a minimum of false and missed alarms. Starting at the left hand side of Figure 12, the minimum acceptable horizontal and vertical missed distances were ± 1000 feet and ± 200 feet respectively. These figures are based on a great deal of prior work, including results of the flight tests that were run recently at the DABS Experimental

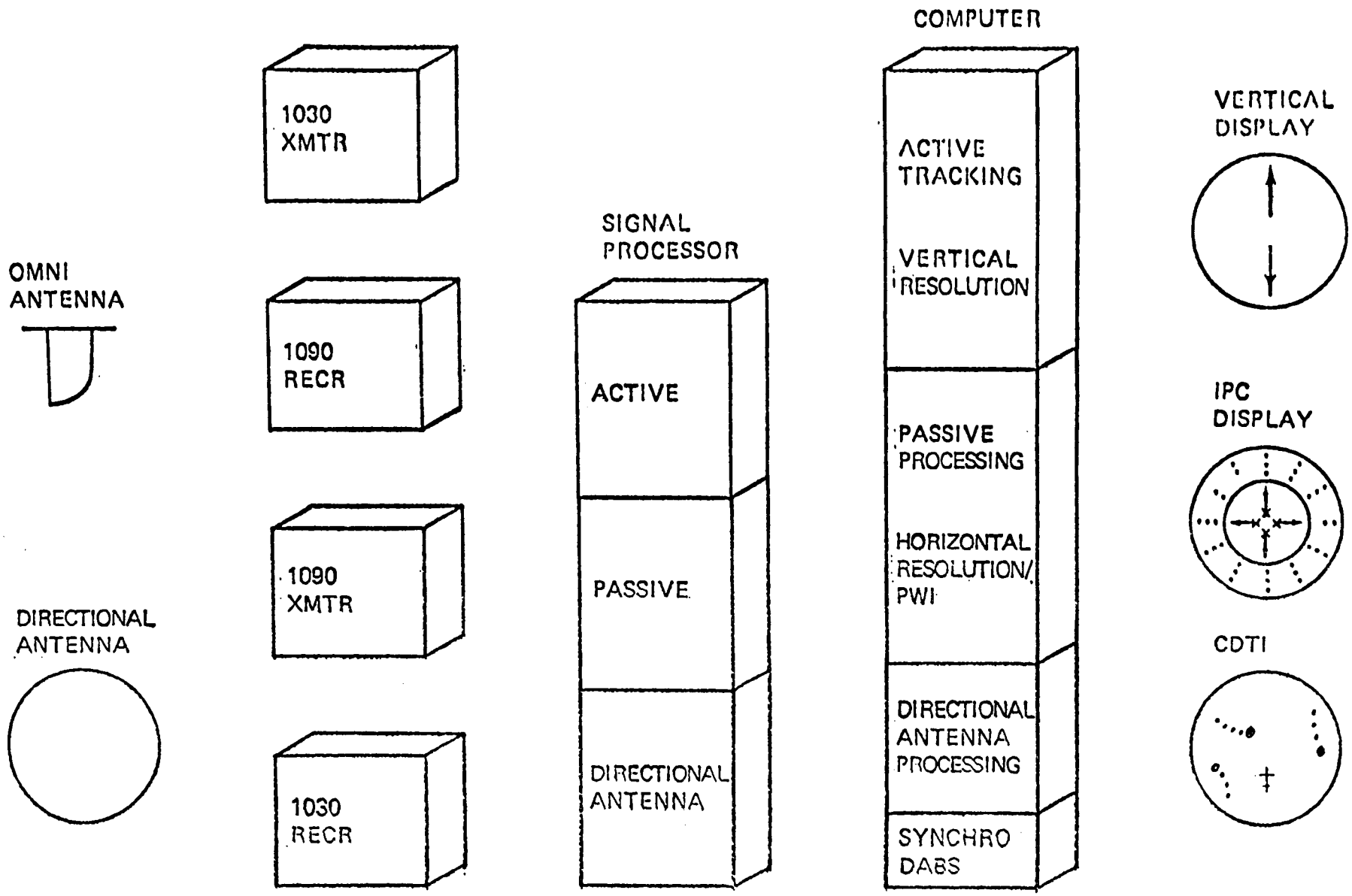
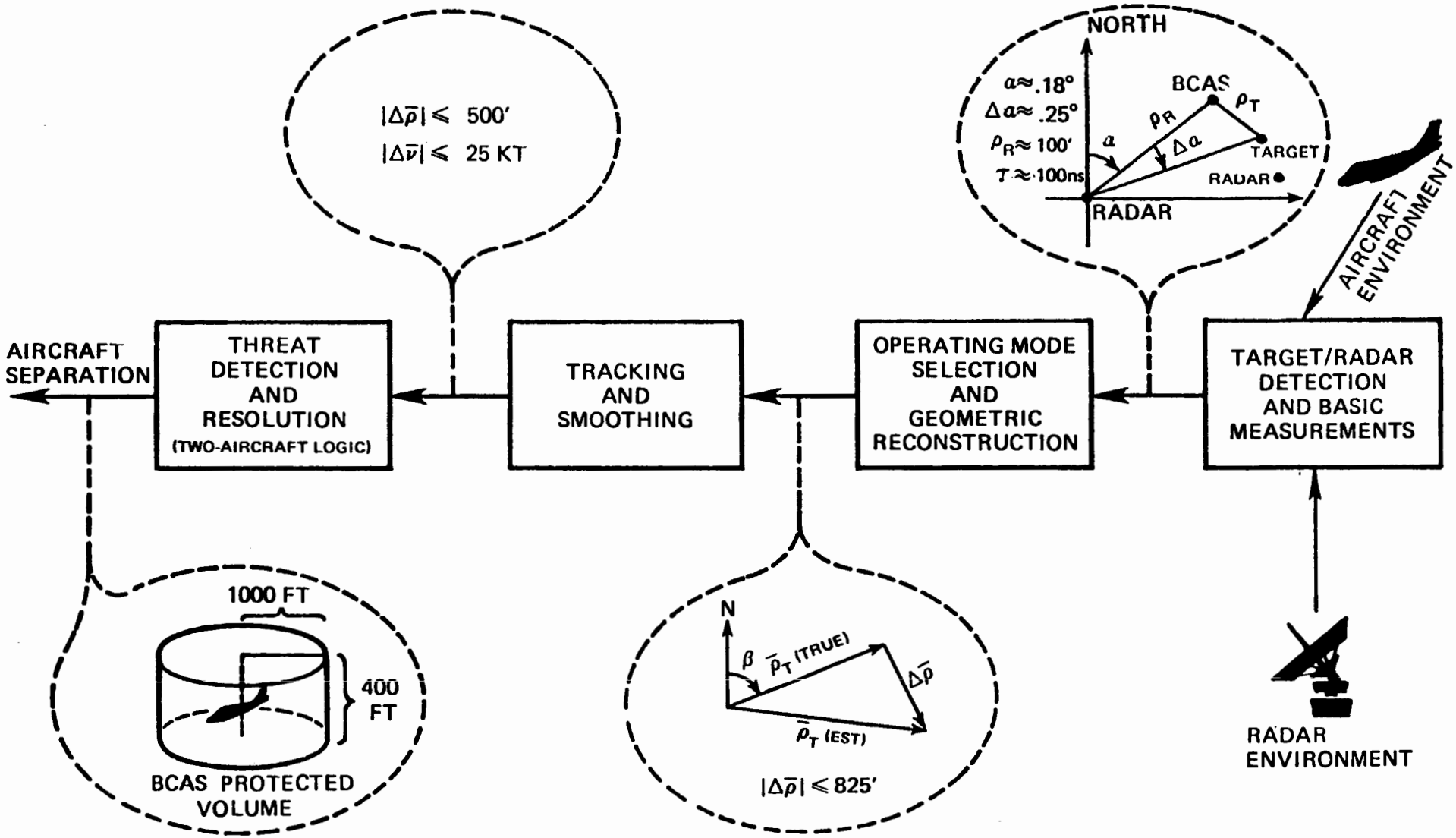



FIGURE 11 BCAS ELEMENTS WITH SYNCHRO-DABS

FIGURE 12 DETERMINATION OF PERFORMANCE REQUIREMENTS



Facility. This minimum separation had to be achieved by all detection and resolution modes under all error conditions as they would exist within the system.

The minimum separation values were examined in conjunction with the threat detection and resolution logic to determine the acceptable limits on the measurement of range and velocity values. A 500-foot error limit on range accuracy and a 25-knot maximum error allowable on relative velocity between the two aircraft were established. These values were then worked backwards through the tracking and smoothing equations and converted to a circular error of position of 825 feet as the maximum value that would be accepted for any solution. The errors that would be permitted in the measurement of the parameters relative to the ground radar system were determined by exercising the operating mode selection and geometric reconstruction logic. These values are shown at the top right of Figure 12. The derivation of several of these values is discussed in the following paragraphs.

Figure 13 is a plot of the probability of false alarms and missed alarms occurring as a function of the reconstructed position uncertainty. Three cases are shown: the false alarm probability given a turn to a one nautical mile miss distance, the false alarm probability given a straight-flight miss at one

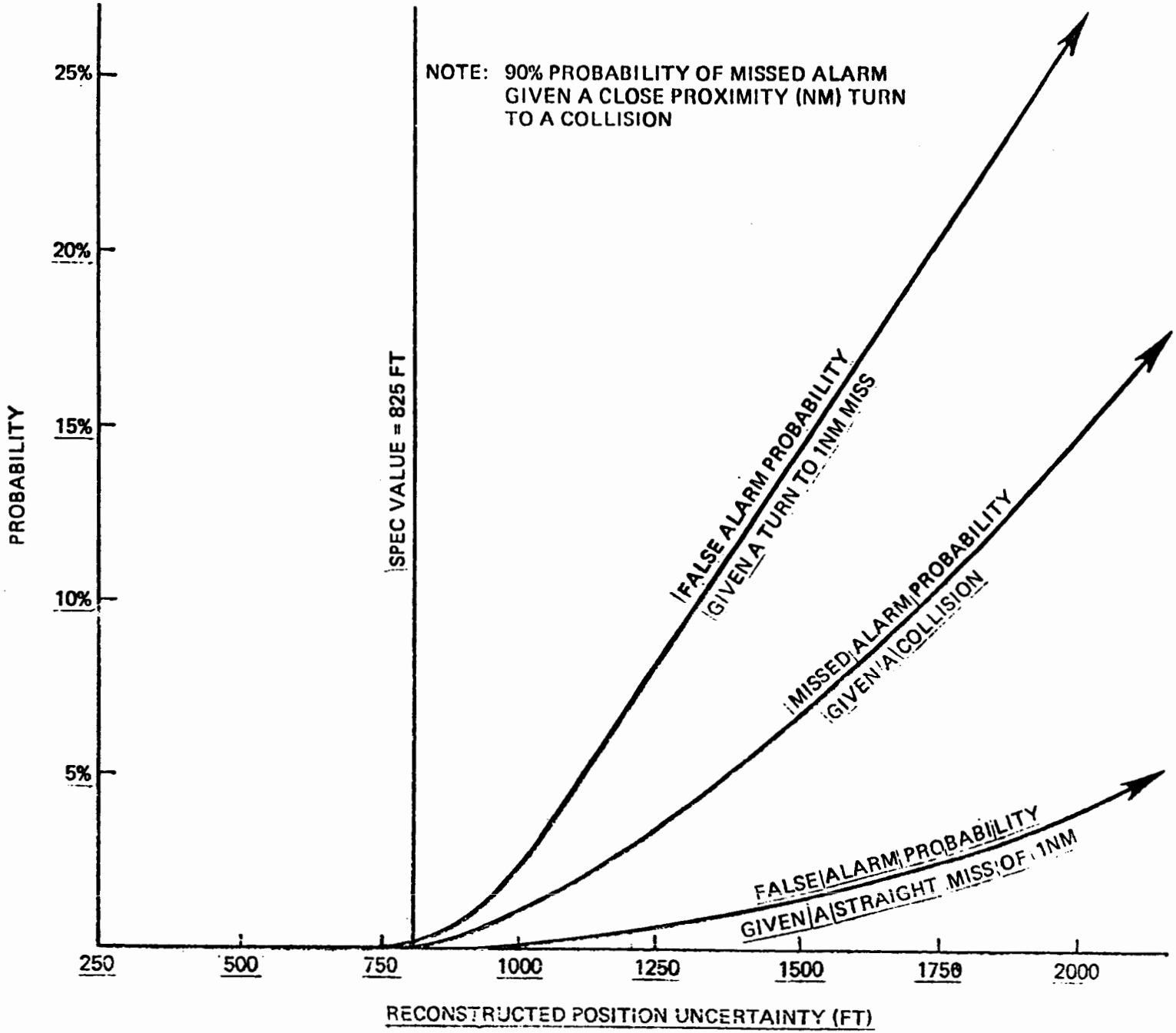


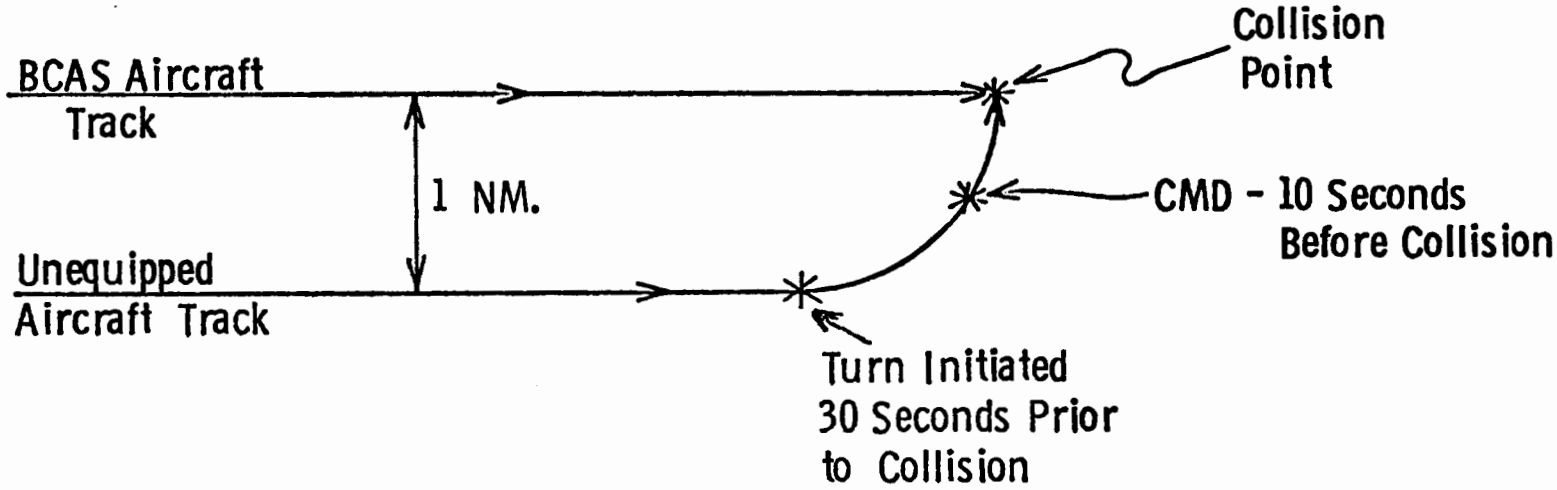

FIGURE 13 BCAS PERFORMANCE

nautical mile, and the missed alarm probability given that there was a collision situation existing. All of these have acceptably small values for data accuracies (better than 825 feet). Hence, this value was selected as the maximim permissible error in measured position. It corresponds closely to the 800-foot value which represents the accuracy achievable by the DABS portion of the ATARS at a range of 50 miles from the radar.

The note at the top of the figure points out, however, that there is one condition against which no aircraft separation assurance system can adequately protect. That situation is shown in Figure 14.

The turning encounter shown is one in which a BCAS aircraft is flying parallel to an unequipped aircraft with a separation distance of the order of one nautical mile. The unequipped aircraft suddenly starts a standard-rate turn onto a course which will cause a collision with the BCAS-equipped aircraft. As the aircraft turns, the value of tau (range/range rate) slowly changes from nearly infinite to one required to trip the detection and resolution logic. At the time it trips, however, there are only about ten seconds left before the collision occurs, instead of the desired value of 30 seconds. This is entirely due to the fact that the tracking of the aircraft is based on linear extrapolation and thus always lags somewhat behind the turn.

FIGURE 14 TURNING ENCOUNTER

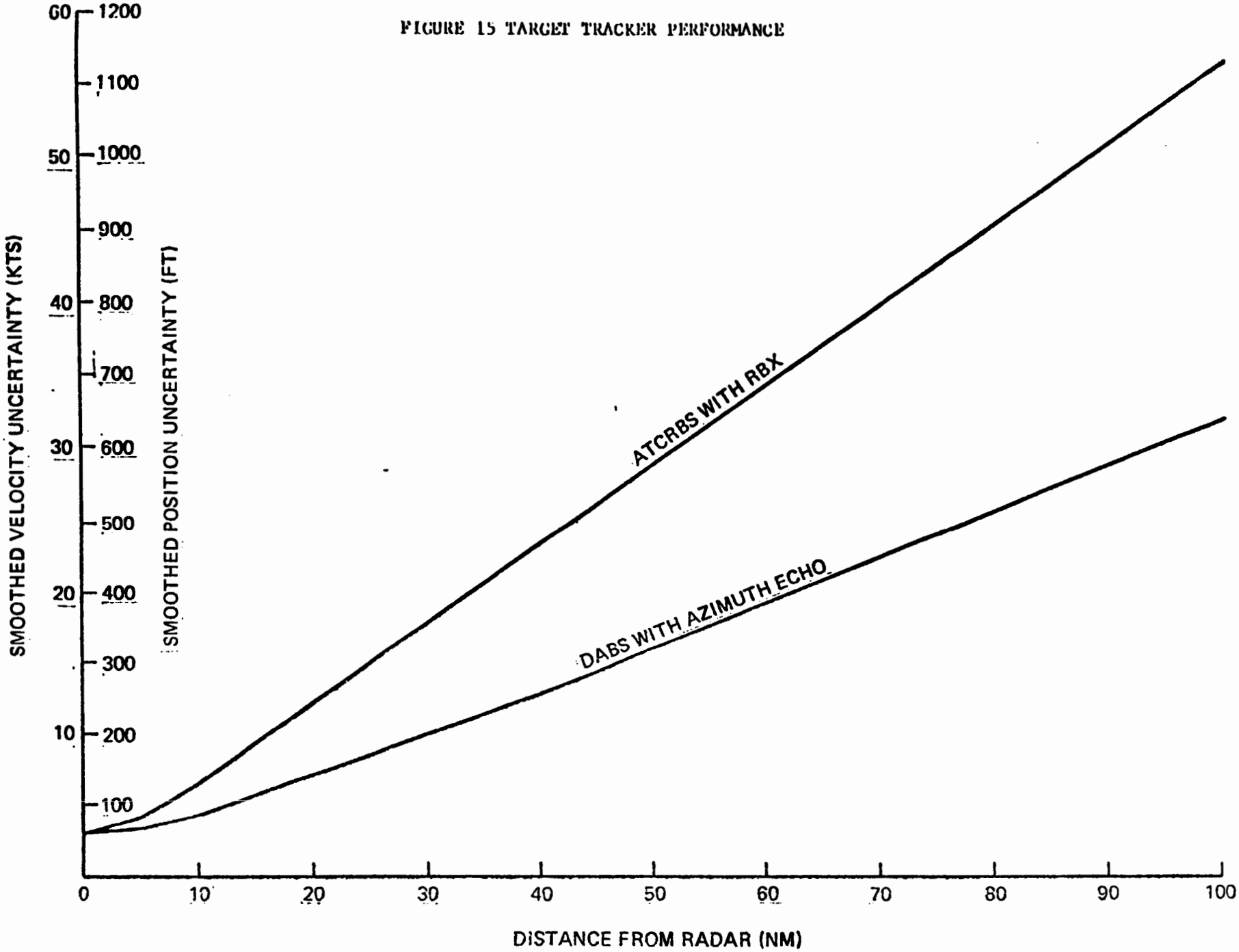


It is not possible for the logic to predict the extent of the turn. The same situation exists in the vertical plane where aircraft may be flying one above the other with separations of 1000 to 2000 feet. If the unequipped aircraft suddenly maneuvers vertically, a collision situation may occur with warnings that are substantially less than the desired 30 seconds and quite possibly in the order of 10 seconds. The collision which occurred over Carmel, N. Y. took exactly 11 seconds from the start of maneuver until the collision occurred.

Figure 15 shows the conversion from the reconstructed position uncertainty, which was set at 825 feet for the reasons given previously, into the acceptable velocity uncertainty and track position uncertainty.

In order to determine the required track capacity for a BCAS, the 1982 Los Angeles Basin traffic model was used. Figure 16 shows the traffic located in the Los Angeles Basin with the location of the radars within the basin identified. The traffic shown within the basin is the same 743 aircraft that were shown previously. For the purpose of the discussion that follows, the assumption is made that each one of these aircraft has a BCAS system installed. The situation as seen by the BCAS in each of these aircraft will be examined to

FIGURE 15 TARGET TRACKER PERFORMANCE



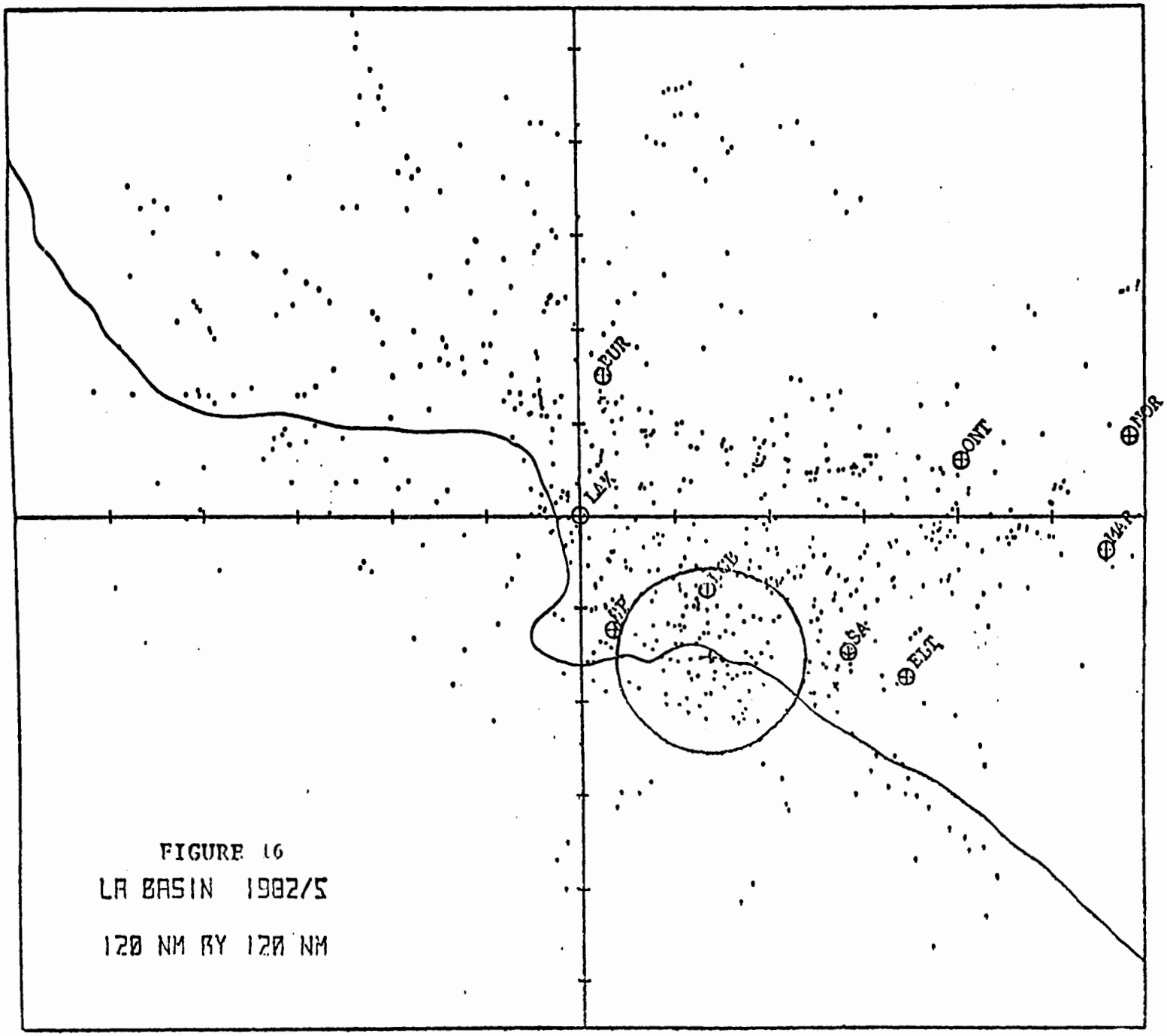



FIGURE 16
LA BASIN 1982/5
120 NM BY 120 NM

determine how many other aircraft that particular BCAS would need to track in order to provide the required level of protection.

Figure 17 presents a plot which shows a summary of the number of aircraft tracks that each aircraft would have to carry. For example, there would be 39 aircraft required to track 2 other aircraft, 33 aircraft required to track 28 targets, and 1 aircraft that would have to track in excess of 40 other aircraft. Because it is necessary to start tracks, drop tracks, and track phantom targets for a while, a safety factor must be provided beyond the active track capacity shown here. The safety factor set by the design team which also accommodates traffic growth through at least 1995 requires BCAS to have a track capacity of 250. The 1985 traffic model of the Los Angeles Basin when extrapolated to the 1995 time period indicated an increase in the number of aircraft from 743 to about 1463. This, in turn, more than doubles the number of targets that would have to be tracked within the system. It is believed, however, that the 250 aircraft tracks specified is adequate to handle the higher traffic levels.

## 8. The Concept

This section describes the concept and the logic used to detect, evaluate, and resolve each conflict situation. The design of this logic is such that it will always utilize the

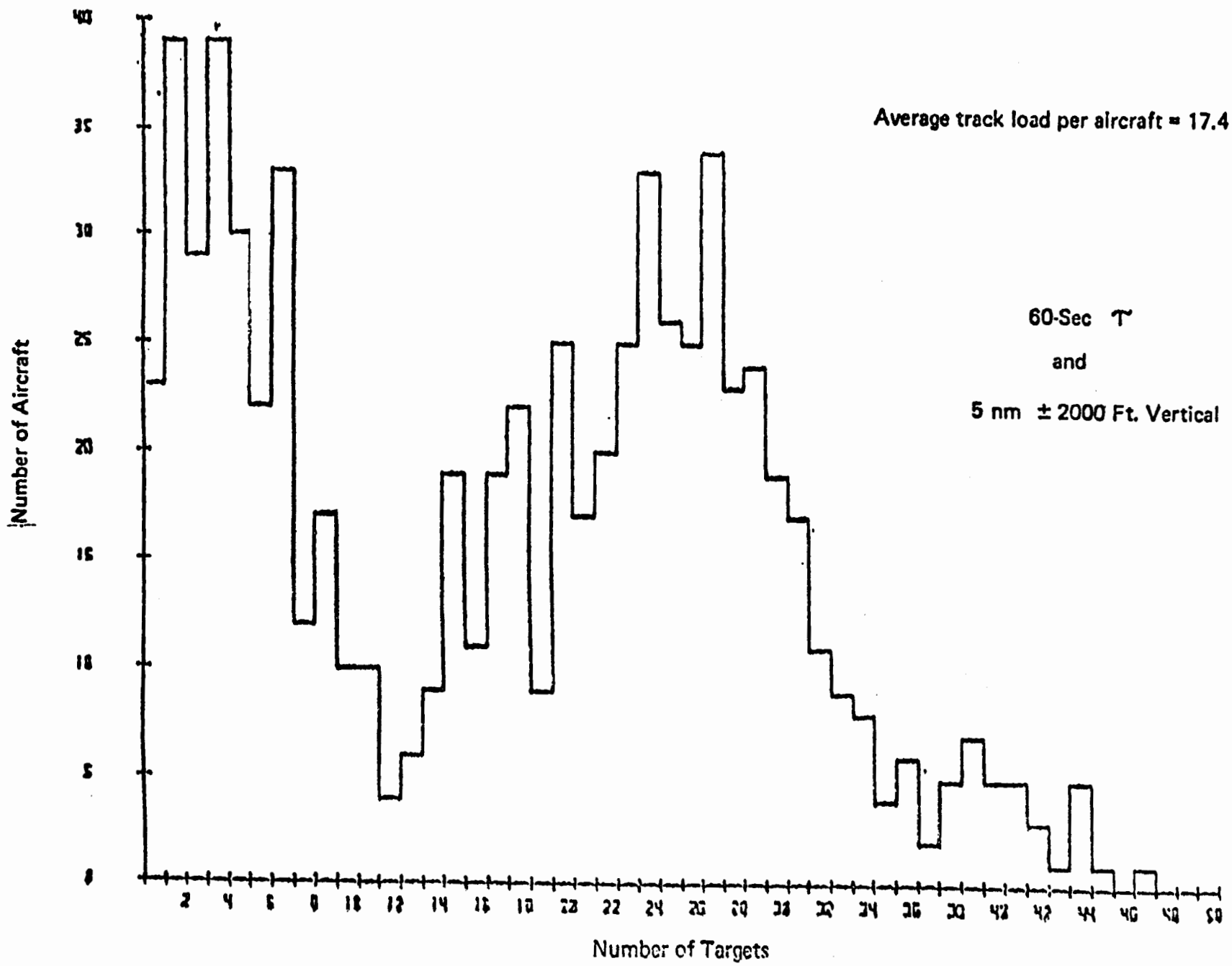



Figure 17 Target Track Requirements

best data available on each target threat. Studies have shown that there is a definite priority order that should be followed in selecting the data for detection and resolution. That order is as follows. Highest priority will always be given to a synchro-DABS solution. This will be followed in order by a DABS solution, and one using 2 ATCRBS sites which have a range and bearing reference or DABS transponder. (This transponder upon interrogation will give the interrogating aircraft both its azimuth and its range to the interrogated DABS site.) Next in preference would be a single ATCRBS site with a range-bearing reference. The next lower priority is given to a mixed site solution where one site would be ATCRBS and one DABS or ATCRBS with a range-bearing reference. Lowest priority is given to two ATCRBS sites without range-bearing reference, and, of course, to a no-radar solution.

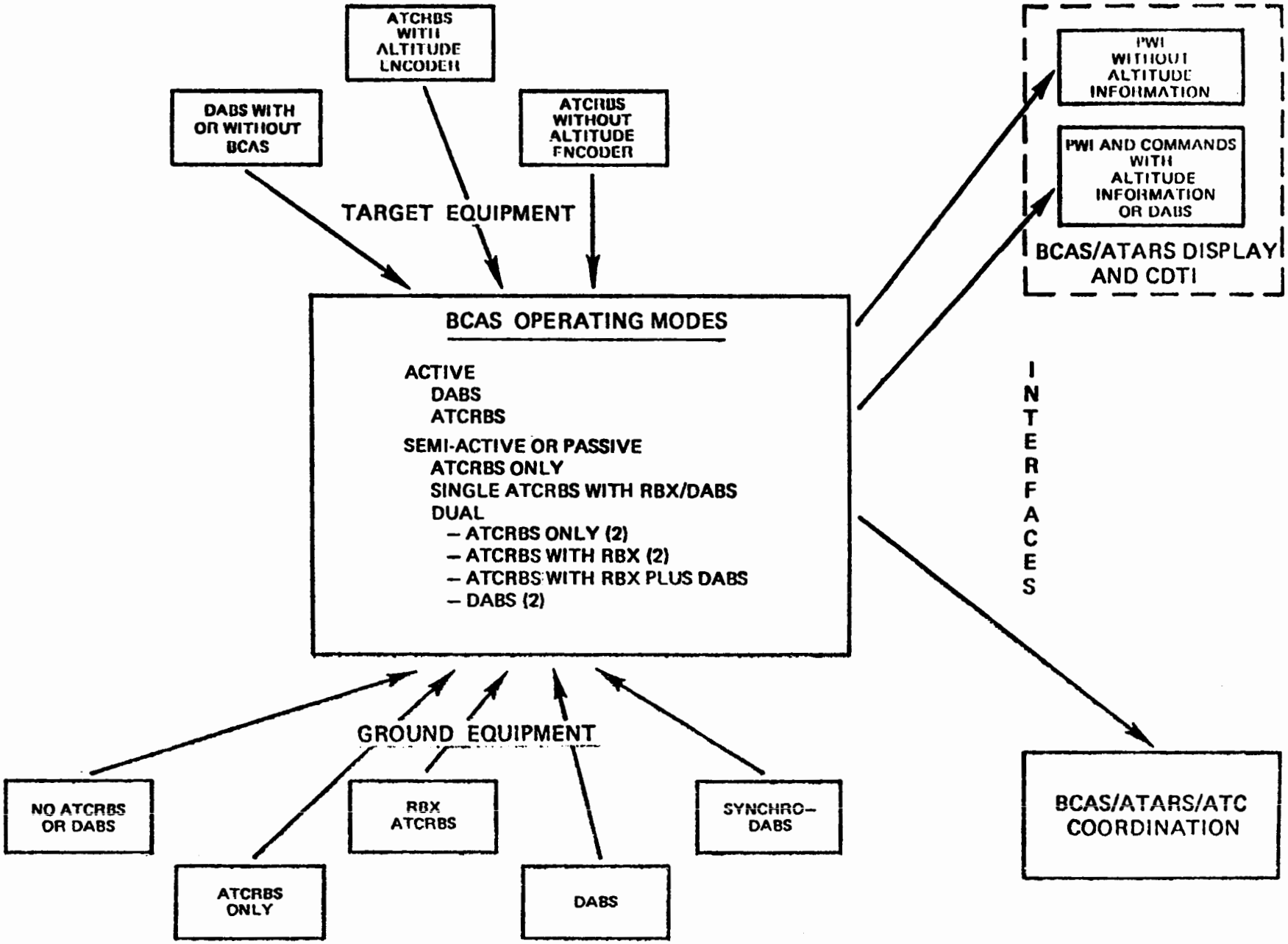
Once the input data have been selected, the logic will then provide the proper operating mode for each target threat. Preference is always given to a fully passive solution using the directional antenna. This is done deliberatly to reduce the amount of RF interference to the ground surveillance system which is generated by the BCAS equipment. Next in preference is a passive solution with a range-bearing reference where the airborne BCAS interrogates the DABS transponder on the ground to determine its range and azimuth to the site. Next in line

would be a semi-active solution where a single radar is used and combined with the results of an active mode of interrogation. Lowest priority is always given to the active mode due to its introduction into the system of additional fruit and garble which, in turn, can diminish the accuracy of the ground surveillance system.

Selection of the modes is always based on the best utilization of the directional antenna. This antenna permits the system to operate in dense traffic and interrogator environments. It produces the minimum interference with the ground system, and it provides the only protection possible from close aircraft when they suddenly turn into the BCAS-equipped aircraft. This protection, of course, it limited to proximity warning indication or traffic advisory followed in all cases by a late resolution command.

Figure 18 shows the recommended concept. In the center the BCAS operating modes are summarized (not in priority order). The BCAS must operate with the airborne environment shown at the top. This includes aircraft equipped with ATCRBS transponders with no altitude encoder, those equipped with ATCRBS with an altitude encoder, and aircraft equipped with DABS with or without BCAS equipment. The system must also operate in a variety of ground environments, varying from no ATCRBS or DABS,

FIGURE 18 THE RECOMMENDED CONCEPT



to ATCRBS only, to ATCRBS with a DABS transponder, to a DABS site, and finally to synchro-DABS. The BCAS system provides ouputs to the display shown at the top right. It provides traffic advisory information on all ATCRBS-equipped aircraft and, in addition, provides resolution commands on all ATCRBS or DABS-equipped aircraft which have altitude encoding equipment.

BCAS also provides an interface with the ground as shown at the lower right. This is required to provide for compatibility between the several aircraft separation assurance systems including ATARS and ground-based conflict alert. The BCAS system is designed so that whenever it is operating within an ATARS service area and detects a threat aircraft which is also receiving ATARS service, it self-suppresses any collision resolution commands generated by the BCAS logic. Priority in this case is always given to the ground system, which consists of ATARS and conflict alert. However, if the BCAS system discovers a "pop-up" threat not seen by the radar, the resolution commands will be transmitted to the ground ATARS and also posted to the pilot to resolve that threat. The ground system will store these commands and use them as constraints in the resolution of any other collisions involving this aircraft with aircraft seen by ATARS.

Figure 19 shows a high-level block diagram of the elements of the BCAS. It includes transmitters on both 1030 and 1090 MHz as well as receivers and signal processors on both these frequencies. It includes the directional antenna system and the control circuitry necessary to operate it. In the upper left, it provides logic which tracks the ground radar systems. In the right center, it provides target tracking logic as well as threat detection and resolution logic. In the center is the heart of the whole system, the mode control logic, which selects the best data and the best operating mode for each threat according to the priority scheme which was shown earlier. On the right side of the diagram is the logic required to interface with the ground system and to suppress BCAS commands on aircraft receiving ATARS service and also the logic required to present the information on potential collision traffic and resolution commands to the pilot.

Figure 20 depicts the actual logic tree which achieves the priority selection discussed previously. This is presented to show that the actual selection logic required is really quite simple; it is reproduced in its entirety on this diagram. Again, this logic selects the best data available in accordance with the priority scheme and then selects the best operating mode for the detection and resolution of each threat.

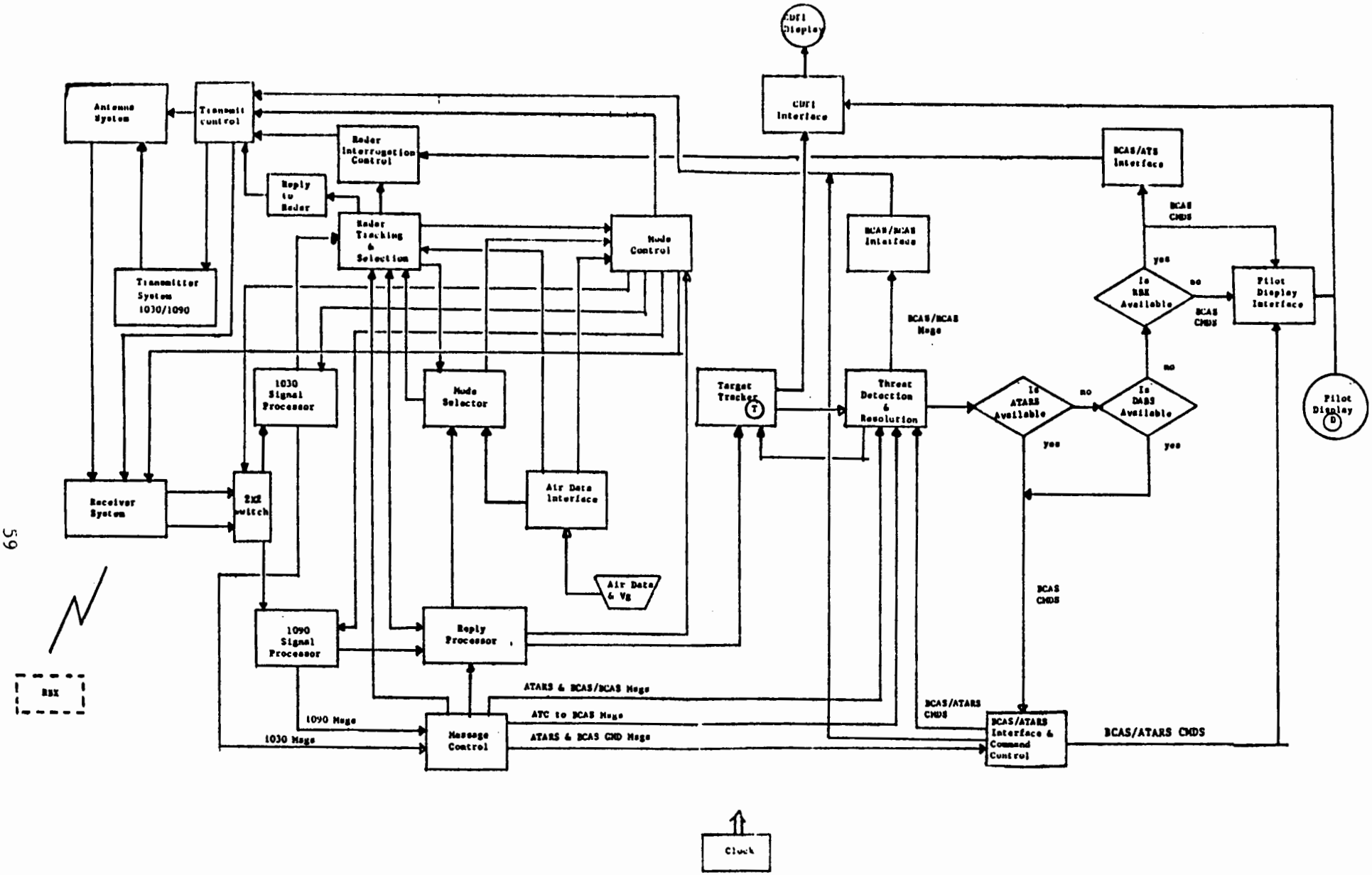



FIGURE 19 BCAS BLOCK DIAGRAM

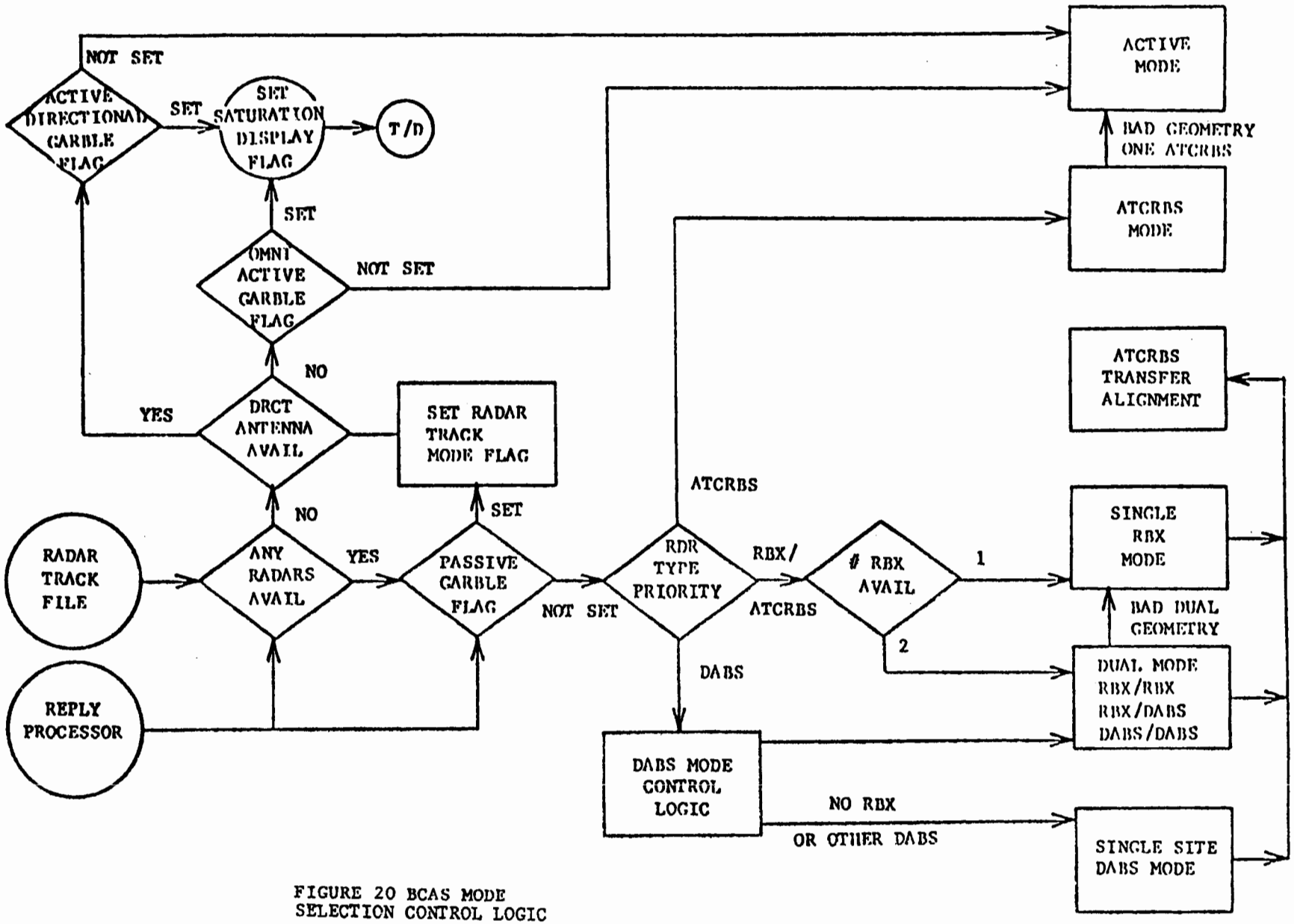



FIGURE 20 BCAS MODE SELECTION CONTROL LOGIC

Figure 21 shows the dual-radar BCAS modes. These represent detection and resolution modes which can be used whenever aircraft are operating in the vicinity of two radars that provide good geometry for the solution. There are a number of modes available, some using only ATCRBS information, some totally passive, some semi-active, and some using the ground-based DABS transponder in the solution. The bottom portion of the diagram represents the acceptable area for each solution. Some solutions are acceptable over the entire range of 100 nautical miles from the radar site, whereas others are only usable over a portion of the range. Some solutions are not usable at all; that is, they do not meet the accuracy requirement at any range.

There are several significant things to note with regard to dual-radar solutions. First, there is no ATCRBS mode that will operate successfully everywhere. Second, the dual radar modes are generally not usable in the high-density environment because of the garble problem discussed earlier. In order to operate in the higher-density environments, it is necessary to switch to single radar modes.

Figure 22 shows the single-radar BCAS modes. The DABS passive solution provides the best possible results under all conditions. The ATCRBS mode labeled RBX Passive Single Number 7 is a significant one in that it is the only ATCRBS mode which

FIGURE 21 DUAL RADAR BCAS MODES

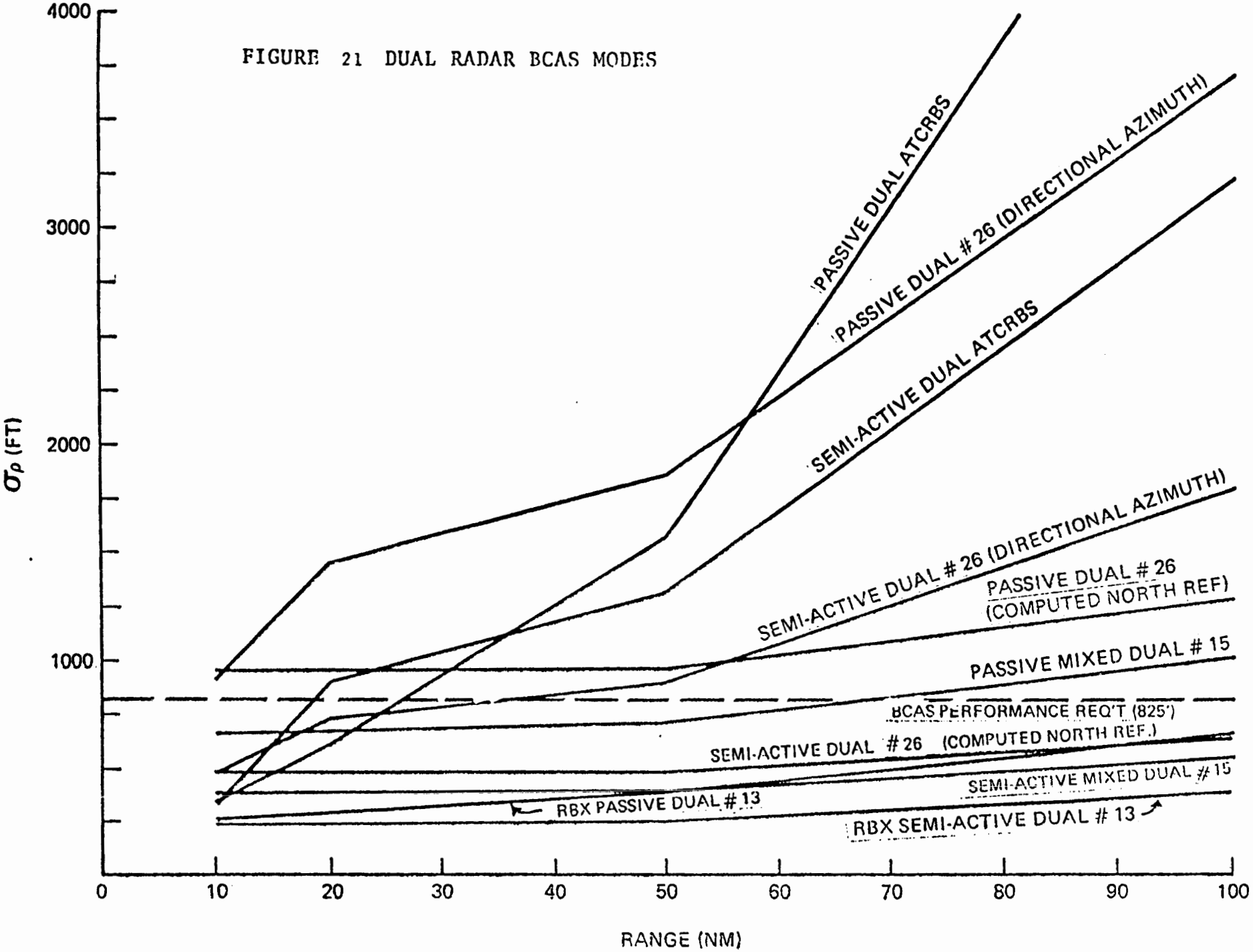
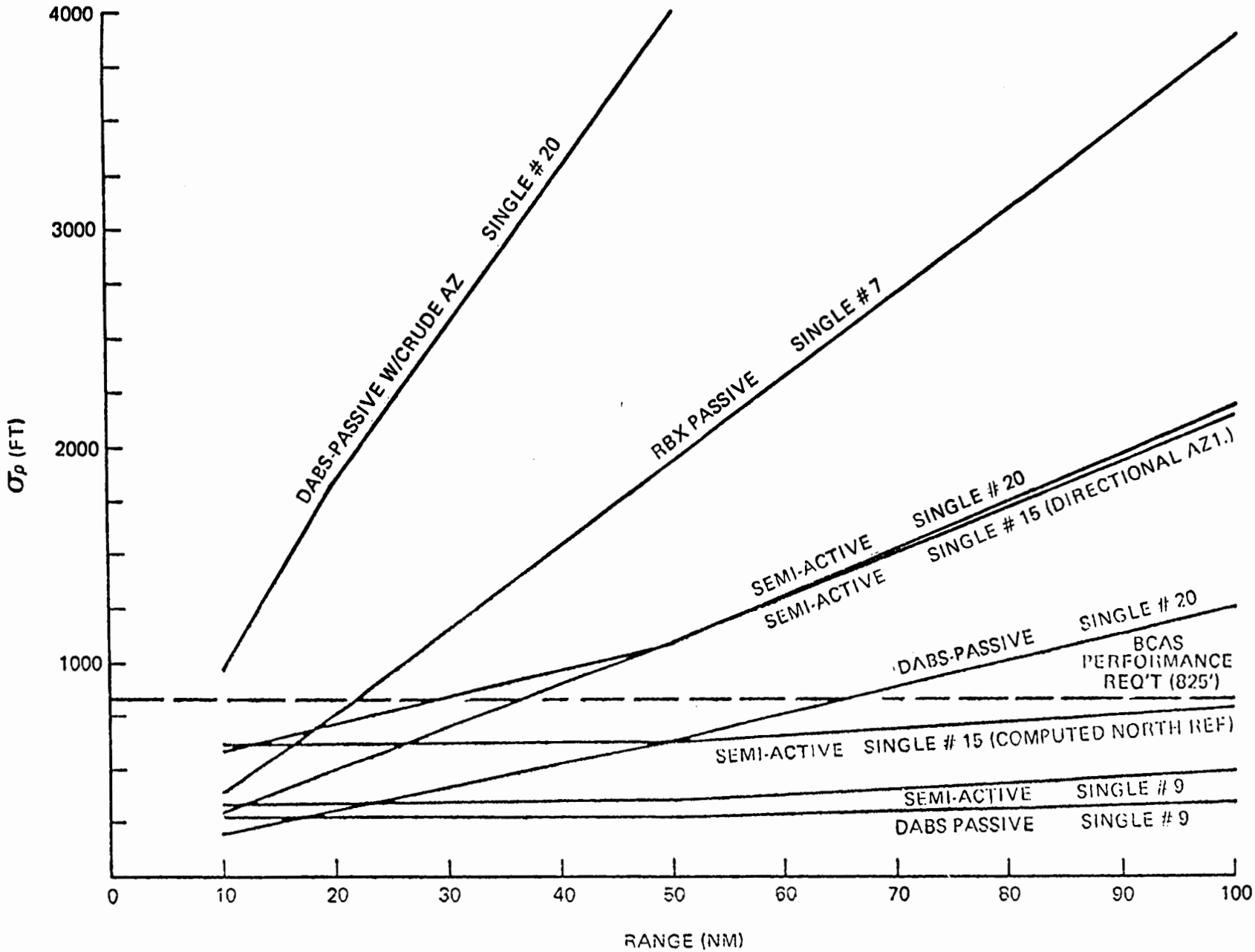


FIGURE 22 SINGLE RADAR BCAS MODES

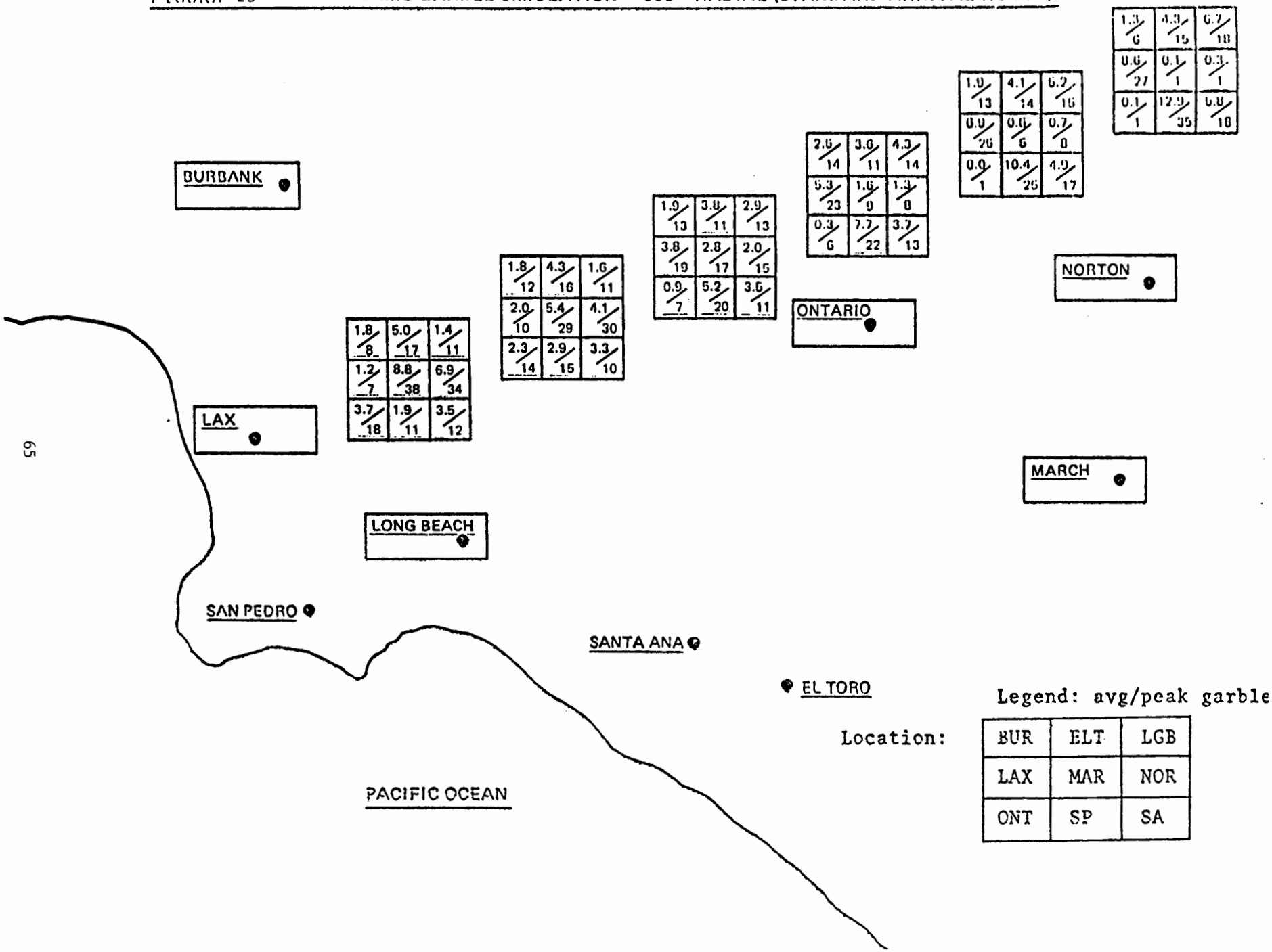


will operate successfully in the very high density environment that would exist in the Los Angeles Basin in the 1985 time period. Figure 23 shows the operation of this mode and how the logic tree of Figure 20 would operate using this mode in the Los Angeles Basin environment of 1985.

The situation of Figure 23 represents a normal arrival into Los Angeles International Airport. The aircraft follows a track which starts in the upper right hand portion of the figure and then proceeds diagonally down to the Los Angeles radar and into the airport. Each box represents 10 miles in additional range from the Los Angeles radar. The content of the boxes is indicated by the upper number, which is the average, and the lower number, the peak garble rate for the radar to which it relates.

The flight begins at the upper right hand corner. As the BCAS aircraft enters the Los Angeles Basin, the mode control logic selects the Norton radar (the closest one). The average garble is .3 and the peak is 1; both values are quite acceptable. As the flight continues along to the second block, mode control changes to the Ontario radar for three blocks. During that period the average garble increases from 0 to .9, and the peak garble from 1 to 7; these values are still within the desired range.

FIGURE 23 DYNAMIC GARBLE SIMULATION – 068° RADIAL (STANDARD ARRIVAL ROUTE)



As the flight continues to the next two blocks, mode control changes to the Los Angeles radar, for average garble values of 2 and 1.2 for the two boxes shown, but peak garble values of 10 and 7. While the 7 appears to be acceptable, the 10 is above the threshold. Thus, one could expect some interruption to the threat detection and tracking of the aircraft operating in that area. It also points out that the limit has been reached, as far as traffic is concerned, where the BCAS can operate entirely on its own. This is also the reason why it will be necessary to implement the synchro-DABS concept in the basin if full BCAS service is to be continued into the 1990 time period and beyond.

In the flight through the basin, the BCAS logic selected radars that were within 20 miles, since, as shown in Figure 22, the single-site ATCRBS RBX solution provides the required accuracy only out to that range. This matches up very well with the range at which the garble situation in the Los Angeles Basin is acceptable. Thus, this particular solution represents the solution selected by mode control for the detection and resolution of a situation involving a threat aircraft equipped with only a Mode A and C transponder in the high-density area.

Dual-radar passive solutions do not exist universally in high-density traffic areas because of high garble levels. For example, in the block immediately to the right of the

Los Angeles radar, there is only one two-radar solution which would meet both the average and peak garble thresholds. The one that exists would use data based on the Burbank and Los Angeles radars. This solution could be used from 10 miles to touchdown. No two-radar solution exists for the 20-mile box. Hence, dual-radar solutions do not appear to be usable once an aircraft enters high density airspace.

## 9. SUMMARY

In summary, a concept for BCAS has been developed which is compatible not only with the present ATCRBS system, but also with DABS, ATARS and the ATC system. The BCAS concept is designed to operate with whatever environment exists, but is not dependent upon it. At any particular time, it will select the best solution based on the data available from external portions of the system. Should one of those elements fail, such as the ground ATCRBS or DABS site, the system will immediately switch to the next best solution and continue to provide threat detection and resolution information.

The concept utilizes a directional antenna to permit operation in high-density airspace. System performance is equivalent to or better than ATARS performance at 50 nautical miles from the radar. The concept would provide a system that would

operate in all airspace and provide traffic advisories on transponder equipped aircraft. It would also give resolution commands on all aircraft equipped with both transponders and altitude encoders. Additionally, it can furnish the data base for a PPI type of display of all transponder equipped traffic in the airspace.

The BCAS system minimizes ground interference by operating in a passive mode wherever possible, and by utilizing the directional antenna in both active and passive modes. Since the high-density traffic areas normally coincide with the location of the greatest number of radars, the passive solution may be used to reduce interference. An active mode of BCAS could seriously degrade the performance of the ground surveillance system.

10. Special Considerations

During development, the team discussed the concept with a number of individuals who identified some important considerations. One of the items of concern related to the directional antenna, its performance characteristics, the problems associated with "burying" the antenna within the aircraft structure to reduce drag, and the expense of the antenna installation.

Analysis, design and costing of the BCAS directional antenna was posed to Sensor Systems Incorporated, which designs a number of aircraft antenna installations, and to NASA. In addition, in-house computations of drag and associated fuel penalties were performed by the design team. The results of these consultations and analyses indicated that a directional antenna, approximately 18 inches in diameter and 3 to 4 inches high, properly installed within an antenna blister, could be mounted on the surface of an aircraft with a drag penalty of only 3 to 6 pounds compared with the total drag of 24,000 pounds for an aircraft such as a Boeing 727. Since the antenna is mounted on the external surface of the aircraft, the installation should be no more difficult and no more expensive than the installation of any other type of surface-mounted antenna. Hence, it is believed that the use of a directional antenna would not impose a significant fuel penalty.

Another consideration related to the reduction in DABS data link capacity that would result from the use of the synchro-DABS mode of operation. Synchro-DABS requires two interrogations per aircraft on each rotation of the radar antenna in order to provide the highly accurate synchronized reply needed to perform the airborne collision avoidance function. In examining this problem, the team used the Los Angeles Basin traffic model extrapolated to 1995, in which there are

nine FAA interrogators. Traffic is expected to grow to an instantaneous airborne count of about 1500 aircraft by the year 1995. The DABS system operating in the synchro-DABS mode is capable of handling 400 aircraft per site initially, and with suitable expansion, 700 aircraft. Therefore, with nine interrogators a capacity of approximately 6300 aircraft is feasible which is at least a four-fold excess of that required for the forecast traffic.

The next concern related to dependence on the ground system. As indicated earlier, the system design utilizes the best data available to it on any target threat. If the source of the data is suddenly removed, the system will merely select the next best solution. So while there may be some slight degradation in performance, threat detection and resolution will continue regardless of the environment in which the aircraft is flying.

Another consideration relates to the need to install a radar-based transponder, specifically the DABS transponder, at a number of ground radar sites. Analysis has shown that the major need for and benefits from the installation of such a transponder relate to the performance of BCAS in the 60 high traffic density regions of the United States. If an average of four RBX units were required at each site, only 240 would be

needed for nationwide implementation. It is not neccessary to install this equipment at every radar site within the U. S. The system will work in a slightly degraded mode if ground transponders are not installed at all. The capabilities of the BCAS system allow the pilot of an aircraft equipped with a BCAS to obtain service throughout the world, even if DABS transponders were not installed at the radar sites of major international terminals. In summary, the system will operate regardless of whether the transponder is there or not, but better performance is provided in the high-density areas if the ground transponder is installed.

The last consideration concerns the possible degradation in BCAS operation with the worsening garble and fruit environment as the number of aircraft using the system increases. This will be somewhat alleviated as the ground surveillance system transitions to DABS with its monopulse operation. This type of operation reduces the number of interrogations per scan per aircraft.

BCAS saturation conditions are still expected to occur, however, in some regions of the high-density airspace in the 1995 time period. When the saturation occurs, the synchronized mode of operation can be employed, since it requires only a small software change in the ground facility, and no change in the airborne equipment.

## 11. Conclusions

The concept developed by the design team offers for the first time a technical method which appears viable for achieving a backup separation assurance capability in all airspace well into the 1990 time period. The proposed design results in a system that can be interfaced with ATARS and the air traffic control system, and which gives priority to the resolutions generated within the ATARS and air traffic control systems. On the other hand, it also provides an immediate backup in the event of failures in those systems. It is believed that ATARS will be a primary system in much of the domestic airspace when it is implemented. The ATARS display equipment costs less than BCAS; hence, much of the general aviation fleet is expected to receive primary protection from the ATARS rather than the BCAS system.

Although additional analysis work is needed on the BCAS system, the team has carried the work to the point that a procurement of BCAS can now proceed. The team can conduct the remaining analytical studies in parallel with that procurement and development.

The text of the concept paper includes all of the items discussed in this executive summary, including details of BCAS operation, design of the avionics, design of the ground

transponder, the performance required for the system, and outstanding issues. The separate engineering requirement is written to include all of the accuracy and performance requirements presented herein. It also includes a requirement for the mode selection logic and for the priority system discussed earlier.

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