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RESULTS OF AN ACTIVE BEACON COLLISION AVOIDANCE EXPERIMENT COND--ETC(U)
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Page 2 of 2

Report No. FAA-RD-80-7

LEVEL # (12)

Results of an Active Beacon Collision Avoidance Experiment Conducted in the Los Angeles Airspace

AD A 096285

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16. Abstract ✓ The Active BCAS test bed equipment, which had been tested both at NAFEC and at Washington, D.C., was upgraded to include the Whisper-Shout technique for garble reduction and the DABS mode for high integrity BCAS-to-BCAS operation. The test bed was then flown in the environment of the Los Angeles TCA and of the Orange County Airport. A comparison was then made under various levels of traffic, and with various system features. As a result of all of the tests on the feasibility equipment, general performance results are predicted and improvements for future designs are given.		14. Sponsoring Agency Code ARD-240	
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
<u>LENGTH</u>				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
<u>AREA</u>				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
ac	acres	0.4	hectares	ha
<u>MASS (weight)</u>				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
<u>VOLUME</u>				
teaspoon	teaspoons	5	milliliters	ml
tablespoon	tablespoons	15	milliliters	ml
fluid ounce	fluid ounces	30	milliliters	ml
cup	cups	0.24	liters	l
pint	pints	0.47	liters	l
quart	quarts	0.96	liters	l
gallon	gallons	3.8	liters	l
cubic foot	cubic feet	0.03	cubic meters	m ³
cubic yard	cubic yards	0.76	cubic meters	m ³
<u>TEMPERATURE (exact)</u>				
Fahrenheit temperature	Fahrenheit temperature	5/9 (after subtracting	Celsius temperature	°C

CONCLUSIONS

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	DTIC	TAB			
	Unannounced				
	Justification				
Pr.	Distribution/				
	Availability Codes				
	Avail and/or				
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The major characteristic that first appeared in the Washington tests--that the correlation of clear (not overlapped) replies is only 78%--was confirmed in the Los Angeles flights. This low reply probability appears to be present only for BCAS, not ARTS. It is not strongly influenced by the transmitter power level nor by the interrogation-suppression protocol.

As surmised at the end of the Washington tests this characteristic was attributed to a combination of multipath and the shielding of the ATCRBS target aircrafts' antenna by its fuselage. Further tests made with a combination of the BCAS aircraft and the M.I.T. Lincoln Laboratory's Airborne Measurements Facility (AMF) confirmed this theory and added a quantitative understanding of the phenomenon. From that, the suggestion of using Whisper/Shout to reduce the effects of multipath arose. This and other steps appear to offer fruitful potential for further improvements.

An important conclusion that can be drawn from the Los Angeles flight test data is that the performance of the DABS mode against diversity transponders is of high integrity and is not degraded by the large population of ATCRBS equipped aircraft that were present. Since DABS is garble free, any number of interrogators and transponders could be flown with no degradation of the DABS performance. However, the DABS fruit and ATCRBS suppressions caused by a large number of DABS interrogations could possibly interfere with the ground ATCRBS system. This problem was examined in Reference 8, where an interference limiting algorithm is described which precludes such possibility. Performing the error correction in software is wasteful of computer resources, and is not considered advisable.

Technical conditions under which the ATCRBS mode of the test-bed system is effective also were shown; namely, that the level of traffic be about as represented by the Washington, D.C. area or less, and that the other aircraft be within the altitude range of 2000 ft below to 5000 ft above the BCAS aircraft. The former condition is a characteristic of the ATCRBS mode's dependence on traffic density, the latter condition is a characteristic of the non-diversity antenna system that is deployed on the present transponder equipped fleet. Stressing the ATCRBS mode in the Los Angeles area, the measured effectiveness of the test-bed system for the set of one-on-one encounters flown was found to drop from about 100% to about 80%. At the same time a minor change in the algorithm was found which would preclude the generation of a large number of false alarms (alarms caused by phantom tracks). Specific improvements to the experimental equipment are noted for guidance to obtain a higher level of performance for future equipment.

RECOMMENDATIONS

The improvements, beyond the test-bed feasibility equipment, listed below are some of the measures that should next be explored both to improve the detection capability and to reduce the number of false alarms.

1. Improve the IF response.
2. Revise the application of Whisper/Shout to alleviate multipath rather than synchronous garble.
3. Require a track confidence level of at least 75% before using it in threat detection.
4. When a reply is in the clear, place a high degree of confidence in it and short-cut the track establishment and altitude correction procedures.
5. Reduce the track blooms by limiting the number of new tracks permitted to start simultaneously at approximately the same range.
6. Accommodate the possibility of a slightly non-periodic interrogation sequence to accommodate some degree of overloading.
7. Include an estimate of altitude rate when starting new tracks.

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1. INTRODUCTION

1.1 History

The omnidirectional, ATCRBS form of active BCAS system was first proposed by the MITRE Corporation in 1975 (Reference 1). It was decided that NAFEC would build and test such a system with MITRE furnishing technical assistance. This task was completed later that year, and it was tested and improved through 1977. The results of flights at NAFEC and in the Washington, D.C. area are described in subsequent reports by NAFEC and MITRE (References 2 and 3).

In 1977, a DABS capability was added to the Active BCAS, with MITRE and the M.I.T. Lincoln Laboratory furnishing the technical assistance on the ATCRBS and DABS modes respectively (References 4, 5 and 6). This system is the one that was flown during February and May 1978 in Los Angeles and whose performance is described in this report.

In 1978, M.I.T. Lincoln Laboratory was given the task of developing and constructing an improved version of the Active BCAS, packaged so that it could be flown under operational conditions, but functionally derived from the Active BCAS test bed. In other words, the Active BCAS that will be produced should perform at least as well as that given in this report.

1.2 Rationale for Testing in Los Angeles

The BCAS flight tests at NAFEC and in the Washington area (ATCRBS mode) showed that the Active BCAS had regions of weak coverage, but it never missed a simulated collision (one-on-one encounter with 400 ft altitude separation between aircraft). The areas of weak coverage were in regions that under many conditions would not prevent a 25 second alarm before collision. However, the traffic was not dense enough for the

Whisper/Shout degarbling technique (Reference 3) to show any meaningful improvement over the basic BCAS. Since Los Angeles has the highest density of aircraft in the world, it was felt that the limits of BCAS performance in synchronous garble could best be determined there.

The environment at Los Angeles is characterized by a mean density of 8 altitude reporting aircraft within 10 nmi, peaking up to 19. The fruit rate averaged at about 20,000 fruit/sec, but on occasion went above 30,000 fruit/sec. The average number of overlapping replies was 2.4 (peaking to 10) when all aircraft within 10 nmi were included. Within 5 nmi, the average number of overlaps was 1.8, with a peak of 10.

While it is not intended that active BCAS would operate unconstrained in a very high density environment, the tests in Washington and Los Angeles were run to ascertain the limits of technical performance. As contrasted to technical performance, operation as an element of the ATC system includes many other considerations that are not treated in this report.

1.3 Test Bed Configuration

1.3.1 DABS

The DABS portion of Active BCAS acquires and tracks DABS targets, and coordinates escape maneuvers. Squitters from the DABS transponders on the test aircraft permit acquisition; DABS interrogations via DPSK modulation permit both tracking and communication of intent. The algorithms used were an early form designed by M.I.T. Lincoln Laboratory and are described in Reference 5.

The DABS mode shared the airborne computer with the ATCRBS mode and occupied about half of the computer storage and computational capacity (a significant part of those resources were devoted to error correction in software, an expedient used in the test bed only).

1.3.2 ATCRBS

The ATCRBS mode tested in Los Angeles was essentially the same as that tested in Washington and NAFEC, except that it shared the computer with DABS for some of the flights. One operational mode, used in most of the May flights, was to interrogate only (no tracking) while in the air and to record the reply buffers. The tracking was performed later on the ground so that the amount of computer time required could be assessed independently of the inherent performance.

1.3.2.1 Targets

Two different types of tests were conducted while operating in the ATCRBS mode. In one series of tests one-on-one encounters were flown against an FAA test aircraft. That aircraft was tracked both by its ATCRBS returns and by its DABS returns.

In other tests targets of opportunity were tracked at all altitudes and ranges up to 12 nmi. These tracks were compared with ARTS tracks to obtain a quantitative measure of the ATCRBS performance.

1.3.2.2 Power Programming via Whisper/Shout

A technique to reduce synchronous garble, called Whisper/Shout was used in most of the tests. Data for Basic ATCRBS without Whisper/Shout, was also collected on all flights. In the February tests the accompanying electronically controllable attenuator

burned out, precluding the collection of any Whisper/Shout data. The design was subsequently altered somewhat and, in the May tests, data on Whisper/Shout was collected.

1.3.2.3 Interrogation Power

The interrogation power used in the February tests was more than 2 kW out of the BCAS interrogator, the same as used in the Washington flights. The power used in most of the May flights was reduced to what was considered a more reasonable level of 630 Watts at the transmitter. On May 10 data was taken at both 630 Watts and 315 Watts so that the effect of transmitter power could be studied.

1.3.2.4 Program Variations

The program variables studied were real-time operation vs. non-real-time, ATCRBS alone vs. ATCRBS/DABS combined, and ATCRBS track size.

The non-real-time operations were run with track file sizes of 75, 100, and 200 tracks to determine the effect of computer size. In all the non-real-time cases, the tracker was allowed to take as much time as needed between track updates, but the time needed was a strong function of the size of the track file.

1.3.2.5 Suppression On Top Antenna

During the Washington area flight tests a suppression was issued on the top antenna a few microseconds before the lower antenna interrogation. Some analysis indicated that this could possibly cause a lack of response by some aircraft below the BCAS aircraft. Therefore, the suppression was eliminated for most of the Los Angeles flights, but it was reinstalled for a few flights to study its effect.

1.4 Test Scenarios

1.4.1 Two Aircraft Tests

Two-aircraft one-on-one encounters were flown both directly over LAX, and in the general aviation environment of Orange County and were conducted in the February 1978 series. In these flights both aircraft had BCAS equipment on board and flew at each other head-on, or at right angles, with an altitude separation of 400 ft. The two aircraft flew at 7500 ft over LAX and about 3500 ft in Orange County. In most of these tests, both aircraft used DABS transponders so that they could be tracked via the DABS mode as well as ATCRBS. Due to a DABS transponder failure, some of the tests were flown with ATCRBS only, which fortuitously allowed a comparison between one system with DABS and ATCRBS modes sharing the computer, and one system with ATCRBS only.

1.4.2 Single Aircraft Tests

The single aircraft tests consisted of "figure-eights" over LAX, and were performed in May of 1978. It was during these tests that most of the parameter variations were conducted. Whisper/Shout was run, overall power variation was tried, and the suppression on the top antenna was varied. During most of these flights, only the reply buffers were recorded, with the tracking performed later. By doing this, we were able to evaluate the effect of track file size and Whisper/Shout, all on the same data.

1.4.3 Fruit Rate

The fruit rate, as seen by the BCAS receiver was recorded on each flight. This was accomplished by interrogating in Mode D, which practically no transponder answers with a code burst. The "replies" recorded during this interval thus represent an upper bound on fruit. Figure 1-1 is a plot of the fruit rate, averaged

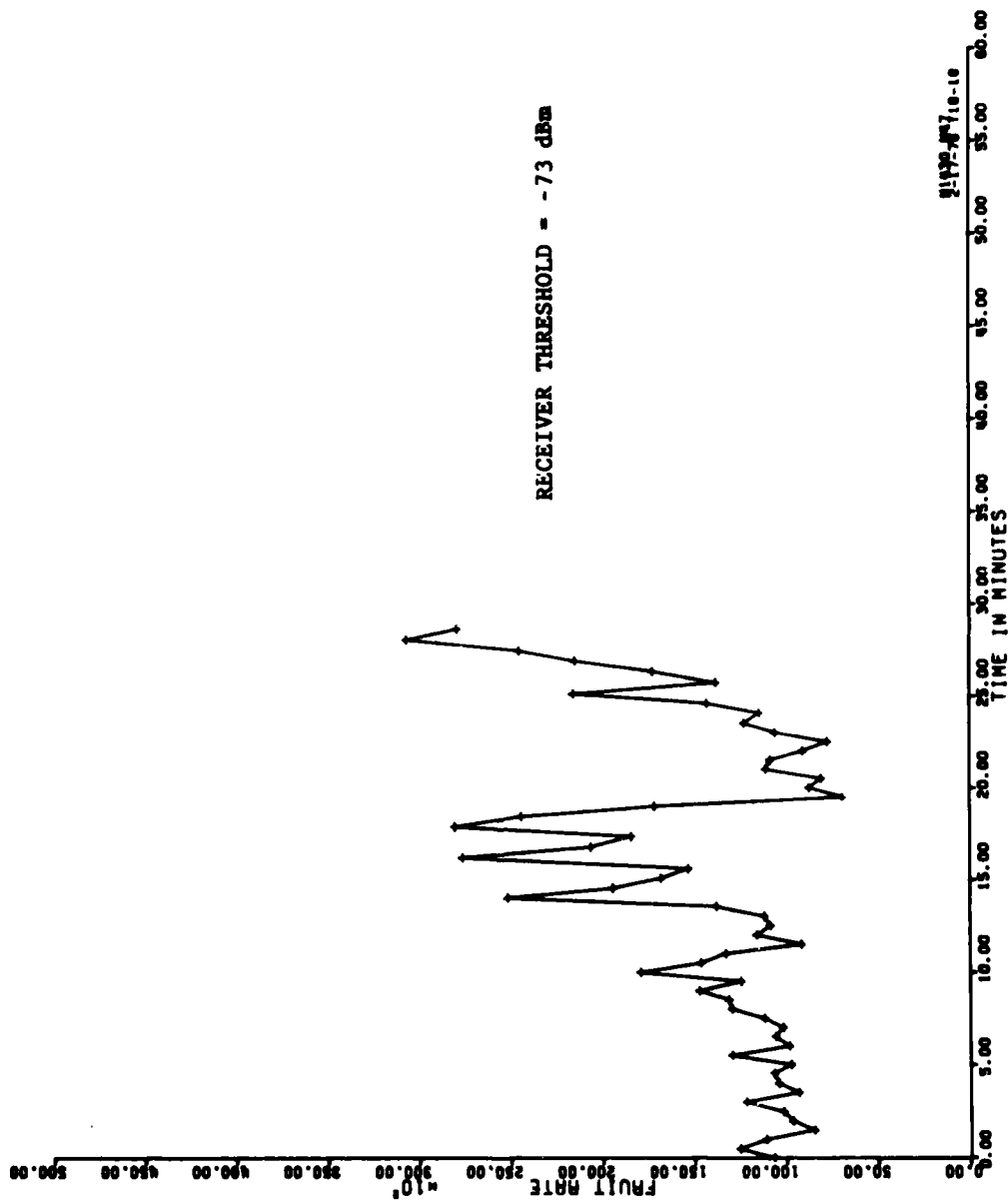


FIGURE 1-1
AIRBORNE ATCRBS FRUIT RATE AVERAGED OVER 30 SEC

over 30 seconds, for part of the February 17 flight. It can be seen that the fruit rate is quite variable, and is quite dependent on where in the Los Angeles basin the test aircraft is. Figure 1-1 includes two passes directly over LAX airport (at approximately 16 minutes and 25 minutes).

1.4.4 Receiver

The receiver used in these flight tests was an RT-868A/APX-76 with its sensitivity set to -73 or -76 dBm (depending on the flight). This receiver was followed by a slightly modified version of the video quantizer used in the DABS sensor, for extraction of range and reply code. This receiver performed both DABS and ATCRBS detection.

The major deficiency of the receiver was its slow rise and fall time of about .5 microseconds. This in itself is not bad, but the DABS sensor was designed to work with a receiver having a rise and fall time of less than .1 microsecond. As a consequence, the leading and trailing edge declarations of the sensor were not quite as intended. This should improve in future versions of the hardware.

The cabling losses between the interrogator and the antennas were 4.9 dB for the top antennas, and 3 dB for the lower antenna. These losses result in the following characteristics of the 630 Watt transmitter and the -73 dBm receiver, as seen at the antenna:

Antenna:	Top	Bottom
Power:	200 Watts	316 Watts
Sensitivity:	-68 dBm	-70 dBm

2. PERFORMANCE

2.1 DABS Performance

For the two-aircraft tests flown in February, in most cases DABS transponders were on both aircraft. One of the transponders performed poorly (that on board aircraft N49) and failed near the end of the tests. For this reason, the DABS performance in Figure 2-1, is displayed only for the properly operating unit. This figure shows the fraction of encounters for which the DABS mode had a track, at all ranges up to 12 nmi. Only closing encounters were used so that the time to establish track would be correctly discounted. The 12 nmi limit was arbitrarily chosen as the maximum range at which BCAS would track. Thus, the range limitation is not due to power limitations, since the interrogations were over 2 kW, but due to the algorithm cutoff at 12 nmi. In all cases, the aircraft had an airspeed of 175 knots. It can be seen that the DABS mode, when working against a properly operating DABS transponder, is 90% effective out to 10 nmi and at least 95% effective out to 8 nmi.

Figures 2-2 through 2-6 show some typical charts of the DABS operation. Figure 2-2 shows the number of DABS aircraft tracked as the test aircraft goes through its figure eight flight path. Two encounters are shown here; the target was tracked when within 12 nmi in both cases. Figure 2-3 shows the squitters received for the same time interval. Most of the squitters were false, caused by ATCRBS fruit combining to look like a DABS preamble, these squitters were removed from consideration because the confidence of the reply, as detected by the DABS sensor, was too low.

Figure 2-4 shows the squitters which were accepted by the system. When the two aircraft were far apart (from time 0 to 10 minutes) most of the squitters were from BCAS's own transponder,

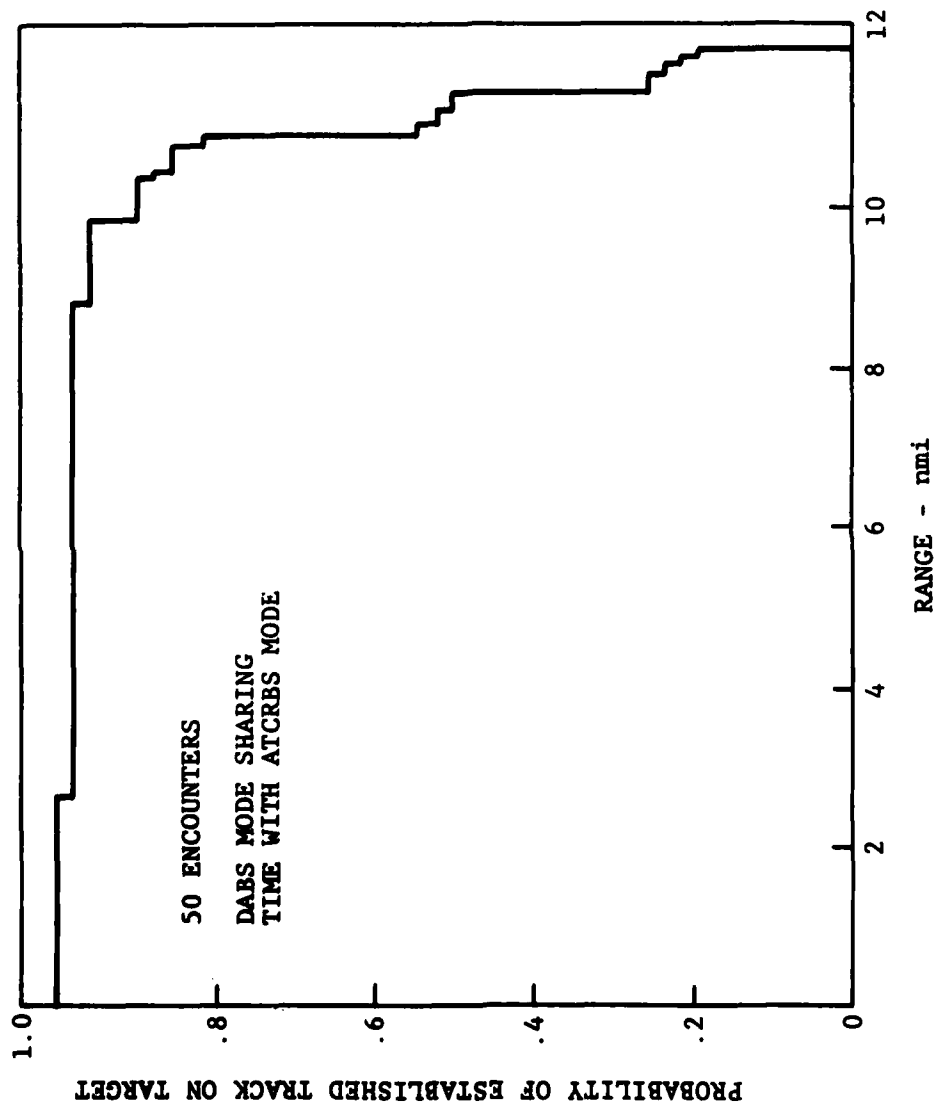


FIGURE 2-1
DABS PERFORMANCE FOR ONE-ON-ONE ENCOUNTERS
IN THE LOS ANGELES BASIN

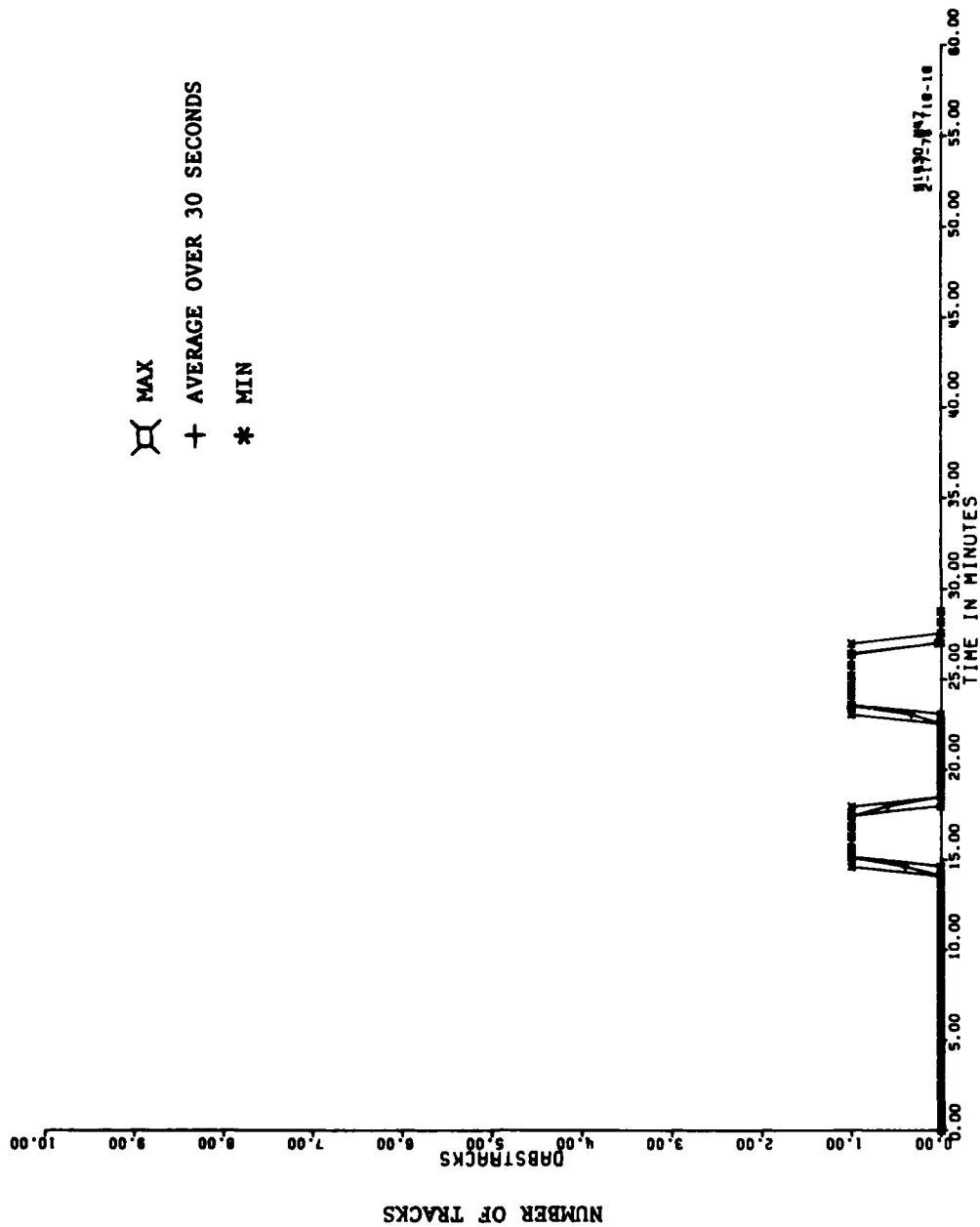


FIGURE 2-2
EXAMPLE OF NUMBER OF DABS TRACKS (FEBRUARY 17)

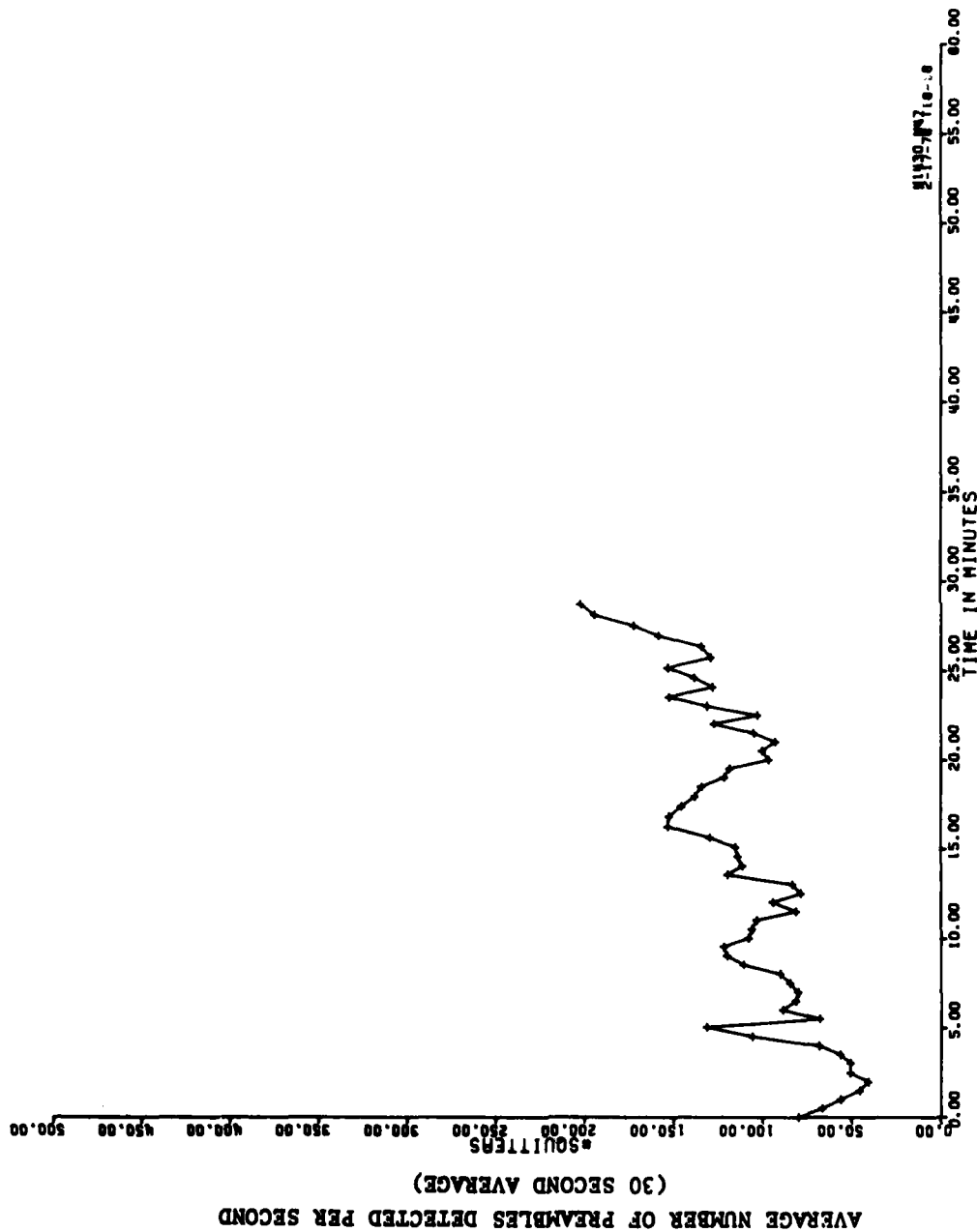


FIGURE 2-3
RATE OF PREAMBLE DETECTIONS IN TYPICAL FLIGHT (FEBRUARY 17)

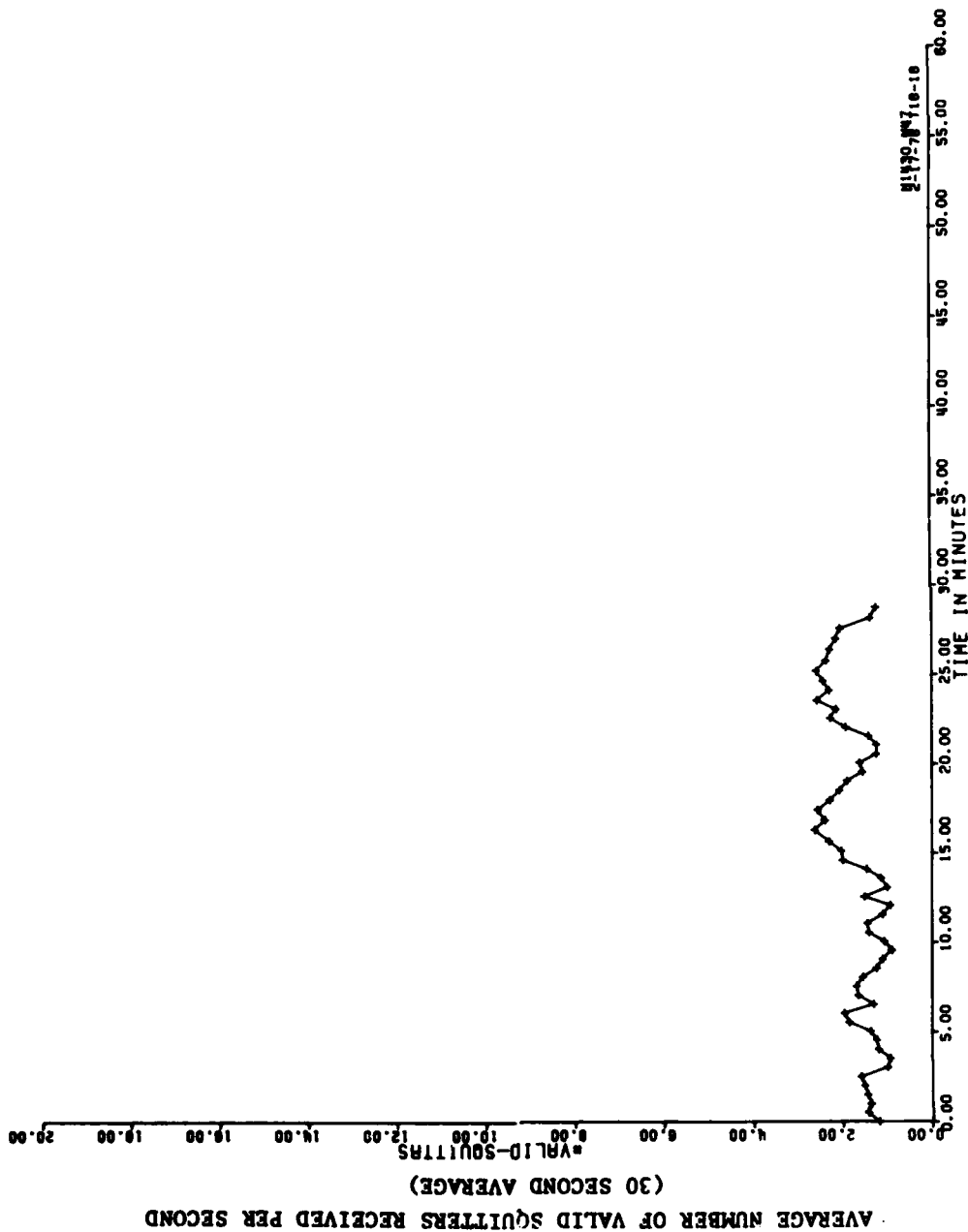


FIGURE 2-4
VALID SQUITTER RATE IN TYPICAL FLIGHT (FEBRUARY 17)

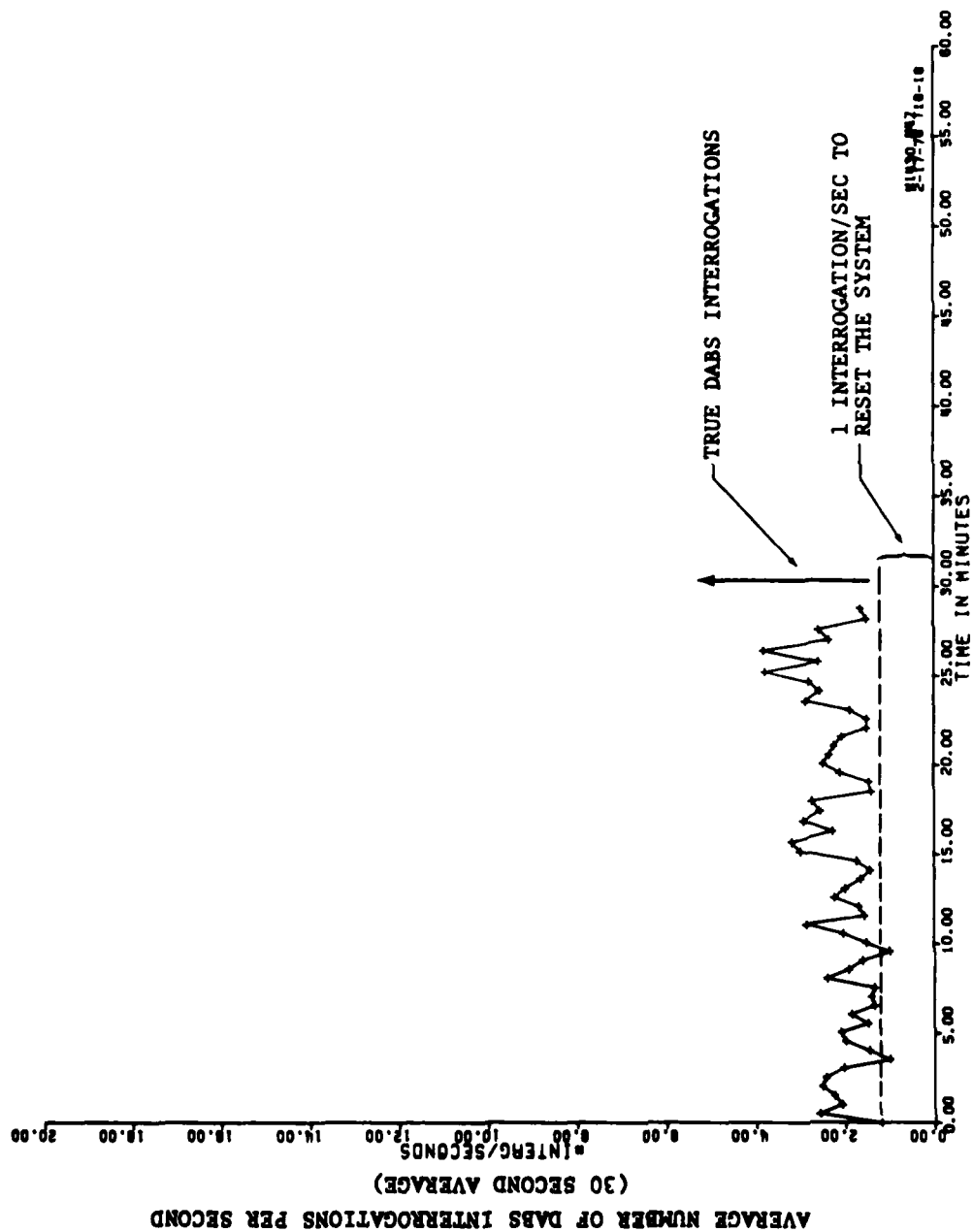


FIGURE 2-5
DABS INTERROGATION RATE IN TYPICAL FLIGHT (FEBRUARY 17)

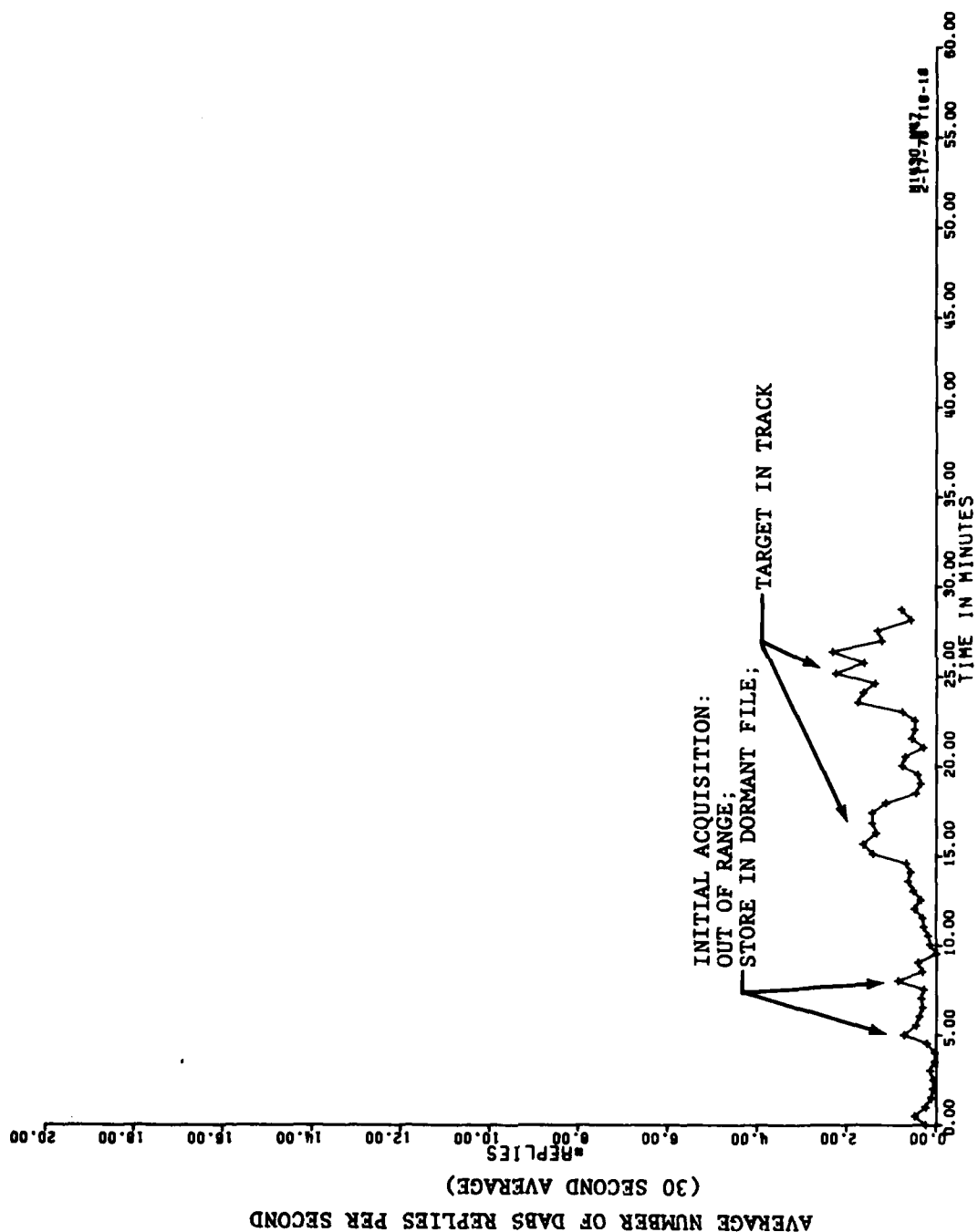


FIGURE 2-6
DABS REPLY RATE IN TYPICAL DABS FLIGHT (FEBRUARY 17)

but when they were near to each other, the number of squitters doubled.

The operation of the DABS link can be seen in Figures 2-5 and 2-6. Figure 2-5 shows the number of DABS interrogations per second. As an expedient in the test equipment, one zero address DABS interrogation was transmitted per second to clear the system, and therefore the number of interrogations to the target is one less than the curve. Whenever a target in track does not answer DABS reinterrogates, thus the number of interrogations can exceed two. Figure 2-6 shows the number of detected replies per second. This shows small peaks where the target is acquired and discovered to be out of range. Then, when it comes within range, the curve goes above one and stays there until the track is dropped at 12 nmi outbound. During this time the BCAS will reinterrogate if the error correcting code cannot correct the received errors, or if the reply is outside the predicted range window. The track is also reacquired every six seconds, which results in more than one reply per second on the average. All the points on the curves represent the per-second data averaged over a 30 second interval.

2.2 ATCRBS Performance

There are two primary measures of BCAS performance, the probability of missing an encounter, and the rate of false alarms. A false alarm is any alarm that is generated when in fact no aircraft is within the stated threat volume. We first discuss the probability of missing an encounter, or more specifically, the probability of not having a track on an intruder.

2.2.1 ATCRBS Effectiveness

For 16 intentional near-collision encounters in the Washington area and 84 in the vicinity of NAFEC, BCAS was found to be able

to track the test aircraft and to give a 25 second warning every time; and, for targets of opportunity, it was able to track about 73% of all ARTS-identified aircraft within 10 nmi and at all altitudes. In Los Angeles an essentially identical test of near-collision encounters was conducted. The same power (greater than 2 kW) was used, but a significantly higher density of interfering aircraft was present. Figure 2-7 shows that about 80% of these one-on-one encounters were tracked within 6 nmi, but there was a rapid decrease in effectiveness beyond 8 nmi, which was not observed in Washington. The data in Figure 2-7 is for basic BCAS (no Whisper/Shout). However, while the data in Figure 2-7 is for a real time operation system (tracking while flying) which includes any problems due to computer overload, the DABS portion had been shut down because of the previously noted DABS transponder failure. When the DABS portion was sharing the computer with ATCRBS, meaning that ATCRBS was only allotted 50 active tracks and about 1/2 of the computer time, the ATCRBS performance was severely degraded, but the 80% performance still occurs, at close range. This is shown in Figure 2-8. The impact of the system overload is thus to reduce the effective range and, quite likely, to delay an alarm. Such gradual degradation, as contrasted to a "system crash," is an important characteristic of BCAS to enable it to recover its full capability quickly after passing through an excessively dense condition. More will be said about computer sizing in Section 2.4.4.

Next, we look at Figure 2-9. This shows the effectiveness of the ATCRBS mode in tracking targets of opportunity at all relative altitudes. For the Los Angeles data, this represents 4.23 hours with a maximum power setting of 630 Watts. This figure shows that, for the Basic mode within 5 nmi, the performance in Los Angeles is somewhat worse than in Washington.

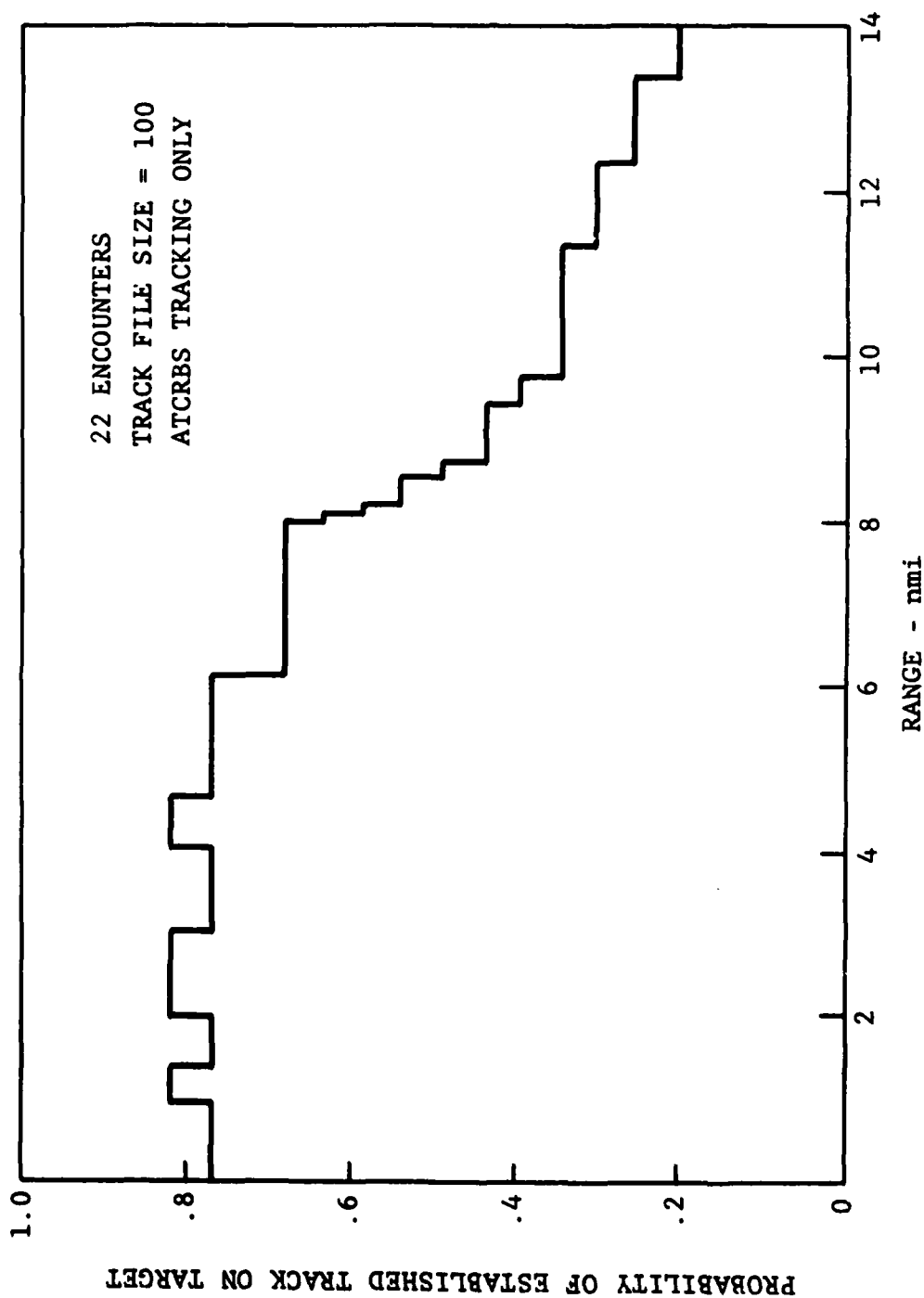


FIGURE 2-7
 ATCRBS PERFORMANCE FOR ONE-ON-ONE ENCOUNTERS
 IN THE LOS ANGELES BASIN

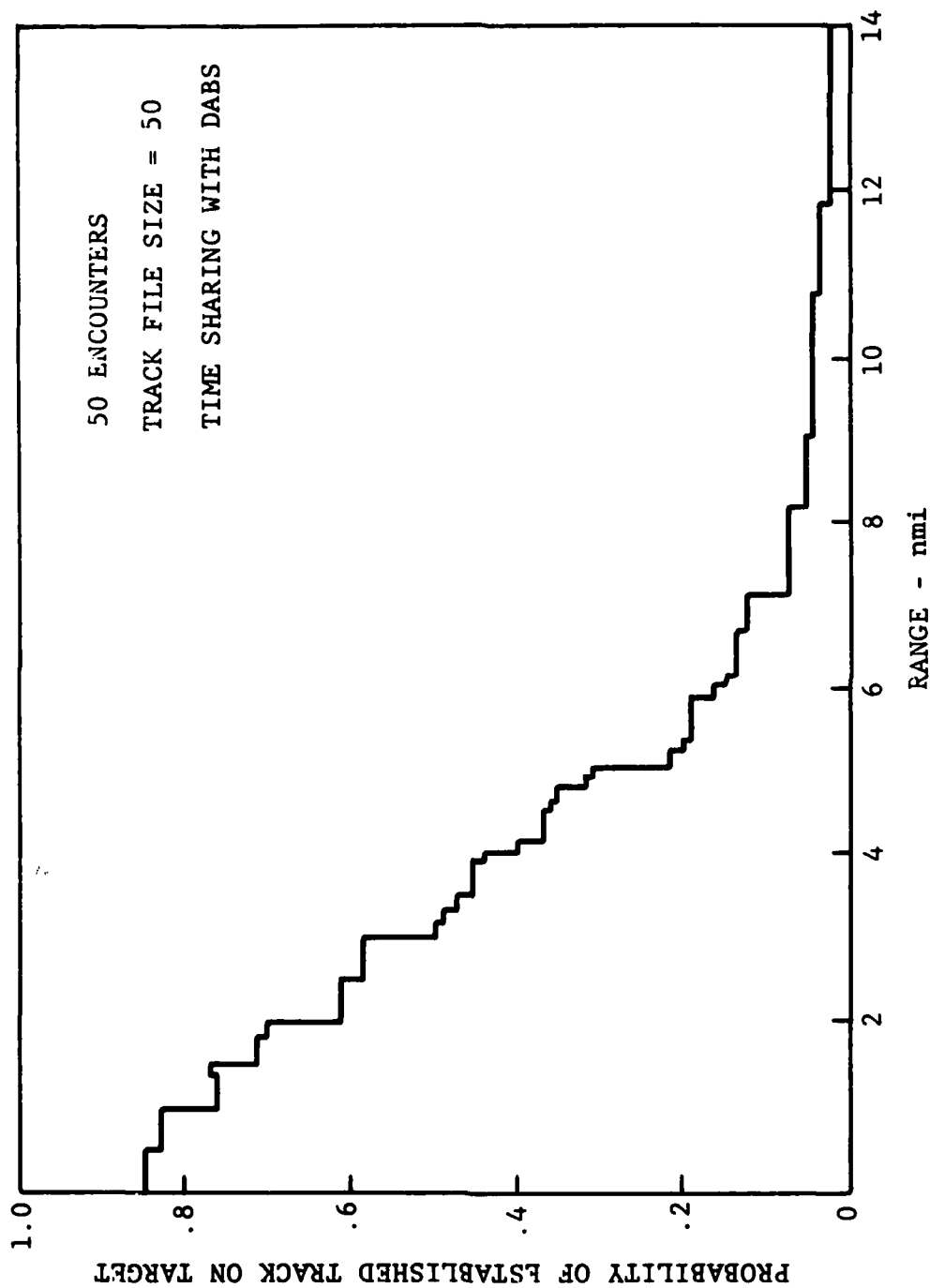


FIGURE 2-8
ATCRBS PERFORMANCE FOR ONE-ON-ONE ENCOUNTERS
WITH SEVERE OVERLOADING OF COMPUTER

RELATIVE ALTITUDE (k ft)

	RANGE (nmi)		RANGE (nmi)		RANGE (nmi)	
	0-5	6-10	0-5	6-10	0-5	6-10
(a) WASHINGTON; BASIC						
> 5	.87	.83	.86	.81	.79	.69
0 to 5	.97	.90	.88	.60	.78	.66
0 to -5	.72	.68	.66	.48	.66	.54
< -5	.65	.71	.48	.49	.56	.59
(b) LOS ANGELES; BASIC						
0 to 1	.98	.90	.89	.46	.86	.51
0 to -1	.90	.75	.89	.51	.87	.57
(c) LOS ANGELES; WHISPER/SHOUT						
(MAY 7, 8, 9)						

FIGURE 2-9
ASSOCIATION DATA

This is especially so in the region 0 to 5000 ft above the BCAS aircraft. There the performance dropped from 97% to 88%. At present, the cause of this reduction is not known.

Performance between 6 and 10 nmi is also worse, comparing Los Angeles to Washington. This is caused by a combination of more garble in Los Angeles and the reduction in overall power used in Los Angeles from 2 kW to 630 Watts. Some anomalies also appear in the Whisper/Shout data; this is discussed further in Section 2.4.1.

Further detailed data is shown for reference in Appendix A.

2.2.2. False Alarms

The tracker algorithm used in BCAS forms tentative tracks on any set of replies or fruit that looks anything like a track. Then, as time goes on, these tentative tracks are purged when they do not continue to behave as a reasonable aircraft track. Similarly, altitude "corrections" are made quite readily, and these corrections are purged after 10 seconds if they do not correlate better than the original track. The theory is that the "phantom" tracks will not live long enough to become established, which occurs after 25 to 30 seconds; or that phantom altitude corrections will not correlate better than the original altitude. Sometimes these expectations are not met and a phantom track is declared established and is sent on to the threat detector. Usually, the phantom is at the same range as a real track and is caused by difficulties in degarbling the altitude data. A phantom track is a BCAS track that had no corresponding ARTS track.

To obtain some assessment of the false alarm rate, we took each track that had a minimum TAU of less than 35 seconds and that was

within an altitude of 5000 ft (at that time) of the BCAS aircraft and displayed the count, Figure 2-10. Since the actual alarm volume (Reference 7) is considerably smaller than this, we proceeded to count the numbers of false alarms that would be generated. The result was 8 false alarms in Los Angeles (4 positive and 4 negative). One of these positive alarms was found to be caused by a "stuck bit" in that aircraft's altitude encoder. Not counting the false alarm from this defective encoder gives a rate of 7 alarms in 4.23 hours, or 1.7 alarms/hour for the test-bed BCAS in Los Angeles. The tracks giving rise to false alarms are indicated by an asterisk in Figure 2-10.

Similar data for the less dense Washington area showed 1 false alarm in 1-1/4 hours of data*. This phantom lasted 4 seconds. In fact, the alarm started when the track was on the 5th consecutive coast and stopped after the track was purged. Since there was only one rather shaky false alarm, a more accurate estimate of the false alarm rate can be made by counting the total number of phantoms in Figure 2-10(a) and comparing it to the Los Angeles data. Thus in Figure 2-10(b) there were 45 phantoms and 7 false alarms (not counting the aircraft with the "stuck bit"), therefore the 5 phantoms in Washington would imply .8 false alarms in the 1-1/4 hours of the test, or about .6 false alarms/hour. This is not too different from the estimate obtained by just counting the false alarms directly.

* This false alarm was discovered after going back through the Washington data; it had been missed when Reference 3 was written.

RELATIVE ALTITUDE (ft)

2-15

	0	5	10	15	20	25	30	35
4000								
2000								
0								
-2000	1							
-4000				1				

a) WASHINGTON DATA
TAU (SEC)

	0	5	10	15	20	25	30	35
4000								
2000			1					
0					2	1	3	
-2000					1*	1*	1	3
-4000	1⊕	1*			3*	3*	1	
	2						2	1
					1	1	3	1
							1	
				1				2

b) LOS ANGELES DATA (MAY 7, 8, 9)
TAU (SEC)

* FALSE ALARMS

⊕ BAD ENCODER

FIGURE 2-10
ALTITUDE AT MINIMUM TAU FOR PHANTOM TRACKS

In Figure 2-11 the false alarms are shown plotted against the average density of transponder equipped aircraft. The values of average density were developed from BCAS data, which provides the average density of aircraft having both transponders and encoders; this was modified by data produced by M.I.T. Lincoln Laboratory (Reference 10) to account for the fraction of transponders without altitude encoders. (These factors were as follows: in Los Angeles 48% of transponders had encoders; in Washington 72% of transponders had encoders.) Noting that the resultant curve has a large linear component may imply that multipath garble is the major cause of false alarms, rather than other forms of garble, which would be expected to cause a quadratic variation.

Looking more closely at the tracks that caused alarms, both real and false, a significant difference is apparent. At the onset of the alarm, the confidence level (the ratio of replies to interrogations) was found to be consistently higher for real tracks than for phantom tracks. Discounting the alarm caused by the faulty encoder in the Los Angeles data, all but one false alarm in Los Angeles and the only one in Washington were below 75% confidence. There were 4 real alarms in the Los Angeles data (an aircraft penetrated the threat volume); all of these had higher than 75% confidence. If the requirement of at least 75% confidence were imposed before a track would be used in the threat detector, then the curve of Figure 2-11 would more nearly resemble the dashed line, giving an estimated rate of about 1 alarm in 7 hours of flying in the Washington TCA environment, and about 1 alarm in 11 hours in a reference density of .02 aircraft per square nmi. As can be seen, the amount of data is quite small; more needs to be collected.

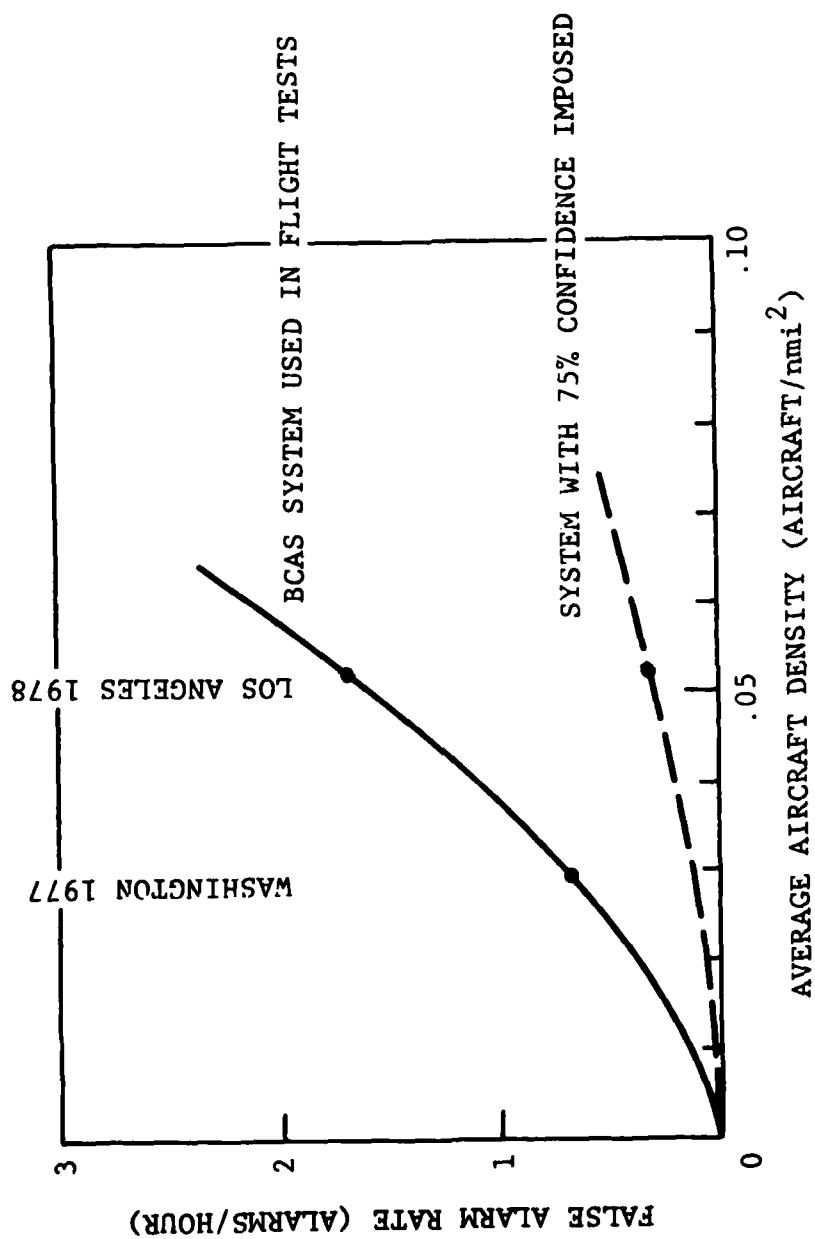


FIGURE 2-11
FALSE ALARM RATE VS. AIRCRAFT DENSITY

2.3 Factors Causing Degradation of BCAS Performance

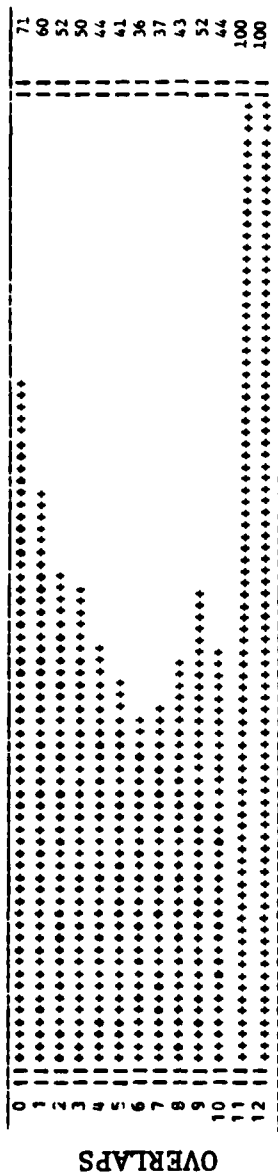
There are a number of unavoidable factors which are detrimental to BCAS performance. These are the givens of the system design. In this section we try to give specific information on how detrimental each factor is.

2.3.1 Garble

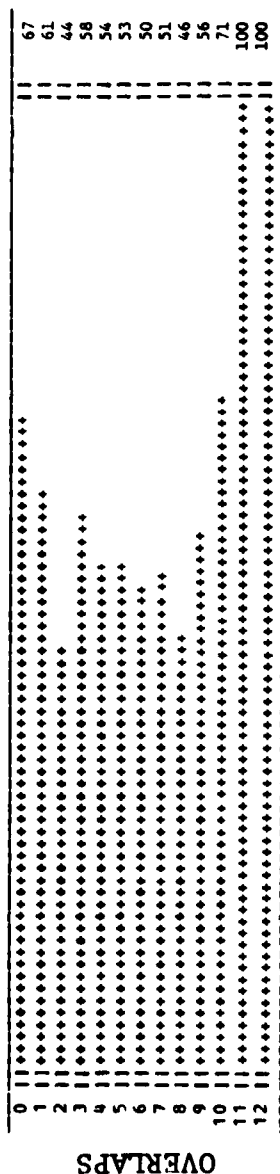
Garble is the primary enemy of the ATCRBS mode. A complicated tracking algorithm and the Whisper/Shout interrogation technique were developed just to fight garble. Therefore, a great deal of data was collected to see how well BCAS performs in various levels of garble. An accounting procedure was set up so that tracking with various levels of synchronous garble could be segregated. Figure 2-12 shows the fraction of aircraft seen by ARTS that were also tracked by BCAS, (called association) as a function of the number of overlapping tracks, as determined by the ARTS data. For the basic BCAS, the fraction starts at 71% for no overlaps (it is this low because it includes all aircraft as far out as 10 nmi and all altitudes), and rapidly falls off. The data for Whisper/Shout starts at 67% but degrades much less rapidly.

We also displayed the fraction of BCAS tracks which were correlated, as opposed to coasted, as a function of the number of overlaps, determined by ARTS data. These are shown in Figure 2-13, in this case we see that there is a negligible gain by Whisper/Shout, at most a few percentage points.

From these figures we see that garble does drive the performance down and that Whisper/Shout does help increase the percentage of aircraft tracked (but apparently not the correlation of individual tracks); however, garble is not the major problem in the region of interest. The same conclusion was drawn from the

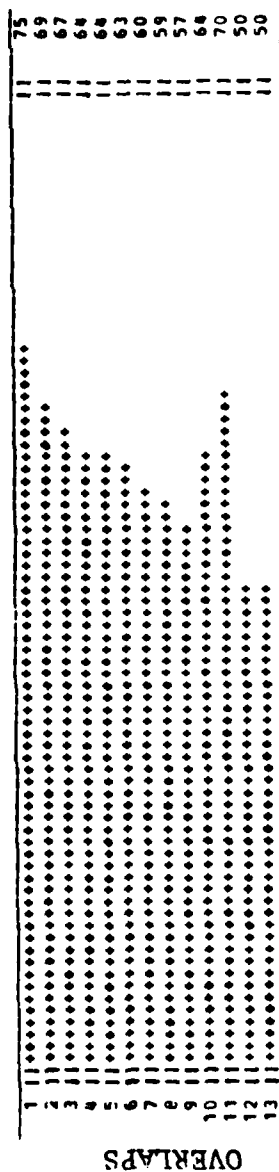


a) BASIC

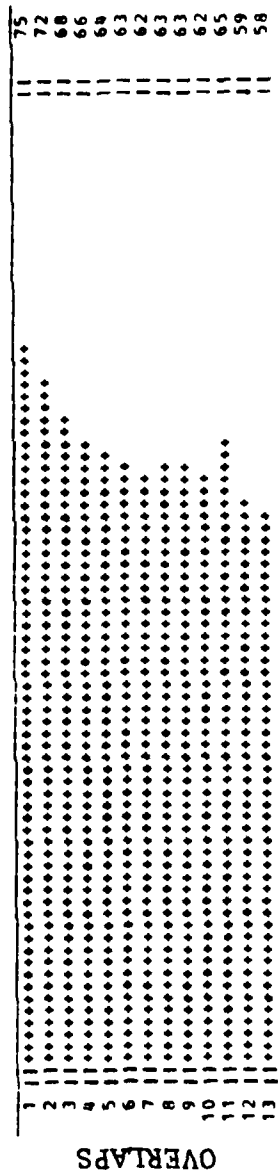


b) WHISPER/SHOUT

FIGURE 2-12
RATIO OF SAMPLES OF ARTS TRACKS
ASSOCIATED WITH BCAS TRACKS (MAY 7, 8, 9)



a) BASIC



b) WHISPER/SHOUT

FIGURE 2-13
CORRELATION CHARACTERISTICS OF ASSOCIATED BCAS
TRACKS (MAY 7, 8, 9)

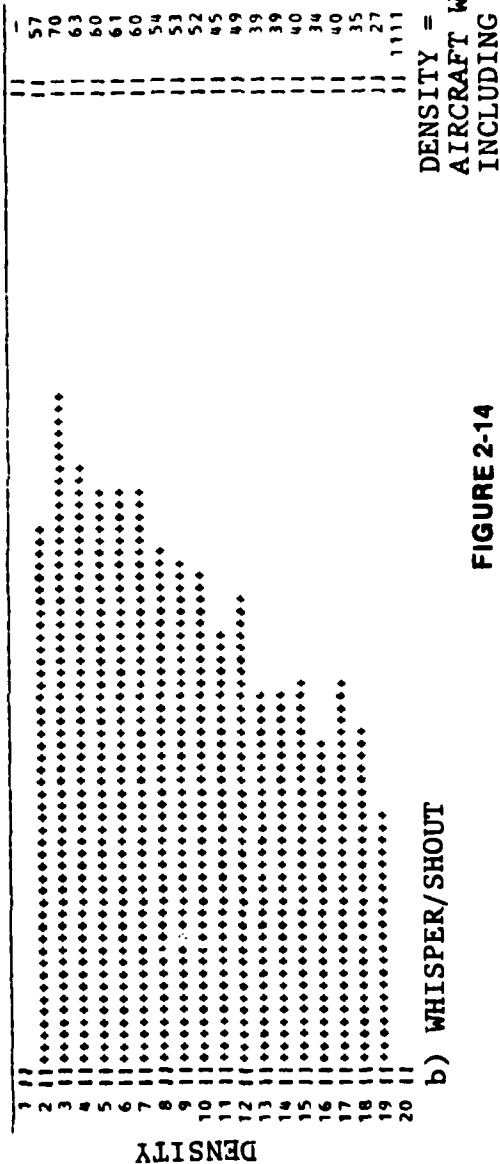
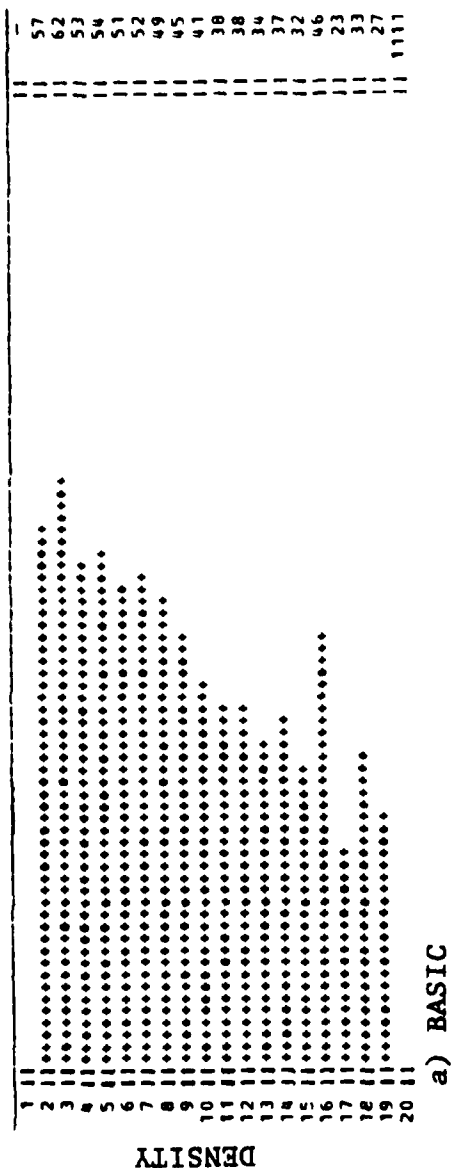
Washington data. This is apparent because the tracks with no overlaps do not correlate very well (75%), and when ARTS identifies such aircraft, BCAS tracks them only 71% of the time.

Reviewing the data in detail revealed two other factors. First, when a reply is in the clear this fact is known, and advantage could be taken of that fact. For example, the "stuck bit" phantom track was not garbled, yet all of the tentative tracks and start-up procedures were applied at each jump in apparent altitude. This obviously is an opportunity for improvement. A second observation is that utilizing the altitude rate data available when starting a new track would in many cases provide a quicker startup. The present algorithm assumes level flight until the tracker develops its own altitude rate estimate.

2.3.2 Density

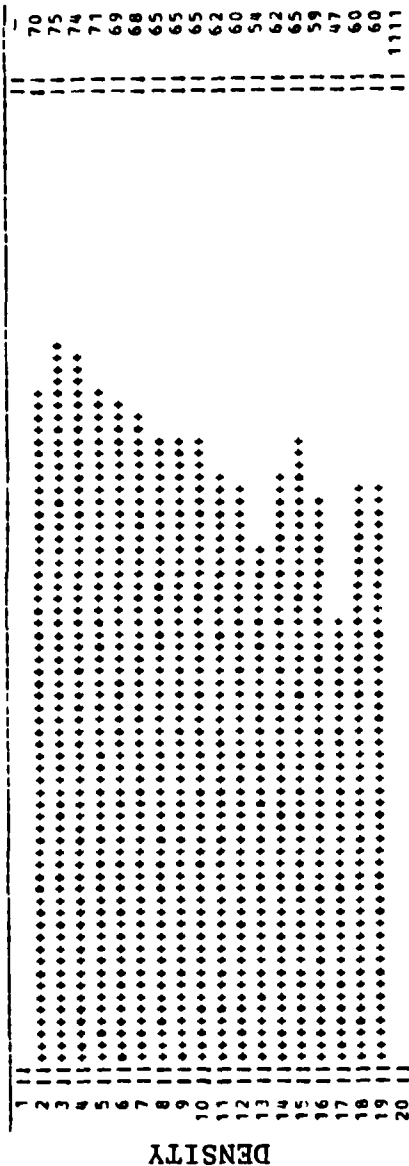
As was true for overlaps, the data was segregated for various aircraft densities, where the density was defined to be the number of Mode C replying aircraft within 10 nmi of the BCAS aircraft (including BCAS aircraft), as determined by the ARTS data. Figure 2-14 shows percent association as a function of density. We see that the best performance was at a density of 3, but the data is very sparse for density of 2. As the density increases the performance decreases, but not as sharply as with overlaps. Thus the decrease could be caused by the accompanying increase in overlaps with increasing density, but definitely not by limited processing time, because this data was processed in non-real time with the computer allowed to take as long as it needed.

Figure 2-15 shows the percent correlation vs. density, and this performance is even less affected by density.

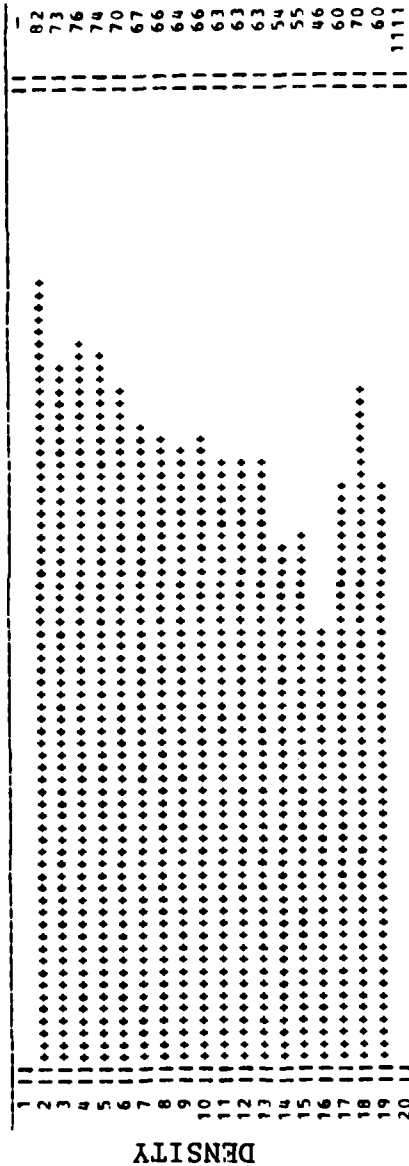


DENSITY = THE NUMBER OF
AIRCRAFT WITHIN 10 NMI,
INCLUDING BCAS

FIGURE 2-14
ARTS ASSOCIATION VS. AIRCRAFT DENSITY
(MAY 7, 8, 9)



a) BASIC



b) WHISPER/SHOUT

FIGURE 2-15
BCAS TRACK CORRELATION VS. DENSITY (MAY 7, 8, 9)

2.3.3 Shielding

During the flight tests at NAFEC and Washington it was recognized that there was a gap in coverage directly below the BCAS aircraft, caused by the use of bottom mounted transponder antennas on all ATRBS equipped aircraft. The BCAS equipped aircraft used both top and bottom antennas for interrogations so that the shielding by the BCAS aircraft itself is minimized, but nothing can be done about the shielding by the target aircraft. This shielding is offset when both aircraft are BCAS equipped, because the DABS transponder (either as part of the BCAS or in conjunction with it) includes diversity reception from top and bottom antennas (Reference 8), thereby eliminating shielding when seen from above. Even without diversity at least one of the two BCAS aircraft would have a good, unshielded link.

Flight tests previously run at NAFEC (Reference 3) showed that when aircraft are within 2000 ft of each other, the effects of shielding are minimal. Thus, allowing 10 seconds for track acquisition, 25 seconds of warning would be given for aircraft closing at 3400 ft/min.

A brief assessment was made of the contribution of the bottom antenna. For May 7, the data was reduced (after the flight) first using replies from both antennas and then using replies from the top antenna only. The association characteristics are shown in Figure 2-16. The principal result is that removing the bottom antenna greatly decreases the association for aircraft below the BCAS aircraft--70% decreases to 52%. From this it appears that the lower antenna produces an effective contribution.

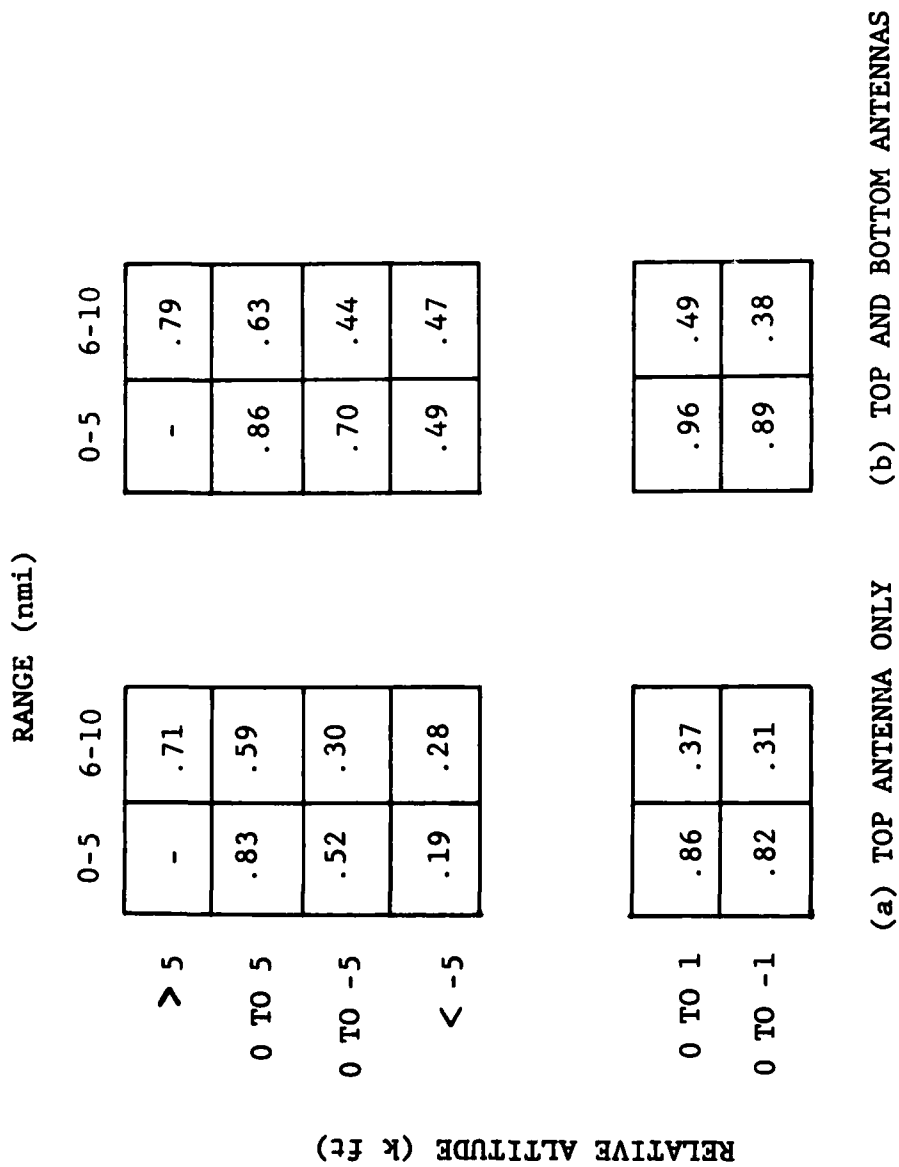


FIGURE 2-16
EFFECT OF BCAS ANTENNAS ON ASSOCIATION

Prior to going to Los Angeles a special set of flights were flown using the BCAS test bed in one aircraft and the Airborne Measurement Facility developed by M.I.T. Lincoln Laboratory in the other aircraft. This enabled reply-by-reply measurements to be made and the shielding/multipath question to be explored in depth. The results were presented in Reference 9 and gave a quantitative understanding to the phenomena of shielding and multipath.

2.3.4 Multipath

Multipath (reflections from the ground) affects BCAS in two ways. On the interrogation link, the BCAS Mode C interrogations may be converted to look like suppressions or like Mode A interrogations. In either of these cases the reply is not usable, although the tracker could have been modified to use the Mode A replies. On the reply path, multipath tends to generate extra garble. Both these problems are reduced by using the top antenna on the BCAS aircraft, which does not illuminate the ground as much as the lower, and (where possible) by using a top and bottom diversity on the target aircraft.

In its present configuration, the ATRBS portion of BCAS was found to drop tracks momentarily at appropriate ranges over reflective ground due to mode conversion, as discussed in Reference 3. The additional garble on the return, when the reflection is specular, produces extra target tracks at a longer range; this impacts the performance when very near an airport, as will be discussed in Section 2.3.6. On the other hand, when the reflection is diffuse, yet strong, the multipath signal is greatly spread out in time and could cause many false 1's to appear in the reply. This characteristic, together with the

effect of shielding, is a possible explanation for the poor correlation and association when aircraft are otherwise designated to be "in the clear."

2.3.5 FAA Transponders vs. Uncontrolled Transponders

All of the one-on-one data presented in this report was obtained by using FAA aircraft equipped with either DABS transponders, or calibrated ATCRBS transponders, while the target of opportunity data was taken with a sample of uncontrolled transponders. The difference is that the FAA transponders were tested regularly and therefore guaranteed to be in proper working order whenever data was collected.

In the case of the uncontrolled transponder population, there was no way to examine the transponders, and a certain number may not have met ATCRBS performance specifications even though they were tracked by ARTS III. As an example of this, in Section 2.2.2 we mentioned a particular false alarm that was determined, after carefully examining the ARTS data, to be the fault of a defective altitude encoder, which had one of the higher order bits "stuck" in one position.

The best direct comparison of performance of the controlled transponder vs. the uncontrolled transponders is a comparison of the basic ATCRBS performance against the target FAA aircraft and against all aircraft within 1000 ft altitude of the BCAS aircraft. For ranges less than 2 nmi or greater than 5 nmi, there was not much distinction between the two sets of aircraft. However between 2 and 5 nmi, tracking of the FAA aircraft was consistently better than for targets of opportunity. It is not clear why these differences exist and why they appear to be dependent on range.

2.3.6 Airports

Flying BCAS near airports tends to produce what is called a track bloom--a condition whereby many new phantom tracks are suddenly generated at nearly the same range. This occurs because stationary aircraft generate an unchanging garble pattern which allows the phantoms to become established. Several aircraft sitting on the ground can produce this effect, or a single aircraft and its reflection from a building can have the same effect. The phantom tracks caused by this garble do not die out as fast as those caused by moving aircraft because the only change in the garble pattern is that caused by the motion of the BCAS aircraft itself.

The ability of these track blooms to generate false alarms was discussed in Reference 3, and was found to be important only when the BCAS was within about one mile of the airport, such as when landing or when flying directly over it. An examination of the phantom tracks from the Los Angeles flight tests showed that track blooms existed about 10% of the time, were of short duration and did not destroy the other established tracks. The other aspect of track blooms that is of concern is the computer overloading that it may introduce. This was a factor in the design of the tracking algorithm. This algorithm provides the property of gradual degradation noted previously.

2.4 Parameters Affecting Performance

2.4.1 Whisper/Shout

Whisper/Shout was introduced to reduce the amount of garble by reducing the number of aircraft replying to each of the power levels. Table 2-1 shows how the replies were divided among the 8 levels over the 3 days of data, May 7, 8, 9. These numbers were fairly consistent throughout the three days. Only the

TABLE 2-1

PERCENT OF AIRCRAFT REPLYING TO WHISPER/SHOUT LEVELS

Top Antenna Only	100
Bottom Antenna	212.3
Level 1	0.0
Level 2	2.0
Level 3	3.8
Level 4	9.0
Level 5	12.4
Level 6	26.0
Level 7	23.9
Level 8	<u>45.2</u>
Sum of 1-8	122.2

- Notes:
1. Only replies between 5 nmi and 10 nmi were used.
 2. Fruit was measured and subtracted by using Mode D interrogations on the top and bottom antennas.
 3. Data represents totals from May 7, 8, 9 1978.

replies between 5 and 10 nmi were used in Table 2-1 because those were the aircraft that most needed garble improvement. It can be noted that some of the 8 levels are ineffective.

The objective of Whisper/Shout is to divide the population of responding aircraft into non-garbling sensitivity bands. The best that is possible is to have 1/8 of the aircraft reply in each band. Such a perfect splitting is not possible for two reasons. The sensitivity bands intentionally overlap by 1 dB to reduce the possibility that an aircraft falls in between bands and does not reply at all, and random variations in the target population sensitivity will cause the number of aircraft responding in each band to vary.

In the earlier tests in the Washington area we found that the best distribution that could be obtained by adjusting the 8 levels resulted in the most populous band containing 25% of the total population. Thus, some improvement could be obtained beyond that used in Los Angeles, but not a lot.

The overall changes brought about by the use of Whisper/Shout were shown in Figure 2-9 (page 2-12). It is seen that Whisper/Shout does nothing for performance within 5 nmi, in fact there is an unexplained loss, especially at higher altitudes. Beyond 5 nmi there is usually a small gain in Whisper/Shout performance as compared to the basic BCAS, but, again, there is an unexplained loss for the high altitudes.

A possible side benefit of Whisper/Shout is that it gives some targets more than one chance to reply, which could overcome low reply probability. Apparently this is not happening, because the percent correlation in the clear is no higher with Whisper/Shout, as was seen in Figure 2-13 (page 2-20).

The principal used in Whisper/Shout to break up garble has no effect on fruit received by BCAS, because fruit is the result of other interrogations. Consequently, the fruit rate in each of the sensitivity bands remains the same, and when the eight sets of replies are summed, the effective fruit rate is eight times that of Basic BCAS. This extra fruit for Whisper/Shout could have two effects; the performance in the presence of no garble may be worse for Whisper/Shout, and the phantom rate may be higher. From Figure 2-12 we saw that the performance in the absence of overlap is essentially unchanged. Therefore, the extra fruit has a negligible impact on the tracking capability. However, from Table 2-2, we see that the phantom track rate is increased by about 12% within 5 nmi.

The tradeoff on Whisper/Shout then is a questionable change in performance at the cost of a slight increase in phantom tracks. Thus, unless garble is a limiting factor (and it is not, for the Basic mode even in Los Angeles today) Whisper/Shout configured to reduced garble should be avoided.

There is a configuration of Whisper/Shout, however, which may reduce the effects of multipath--this format, proposed by M.I.T. Lincoln Laboratory, should be explored.

2.4.2 Power Level

On May 10 the data was collected for 4 runs with the normal power and 4 runs with the power decreased by 3 dB. One obvious result of the power decrease was a less even distribution of replies over the 8 Whisper/Shout interrogations. Figure 2-17 shows a summary of performance with a change of power of 3 dB.

TABLE 2-2

AVERAGE NUMBER OF PHANTOM TRACKS PER SCAN FOR
BASIC AND WHISPER/SHOUT (MAY 7, 8, 9)

	Basic	Whisper/Shout
Range		
0 - 5 nmi	.57	.64
0 - 10 nmi	2.21	2.78

Note: Only a small fraction of the phantom tracks become false alarms because most are outside the threat region.

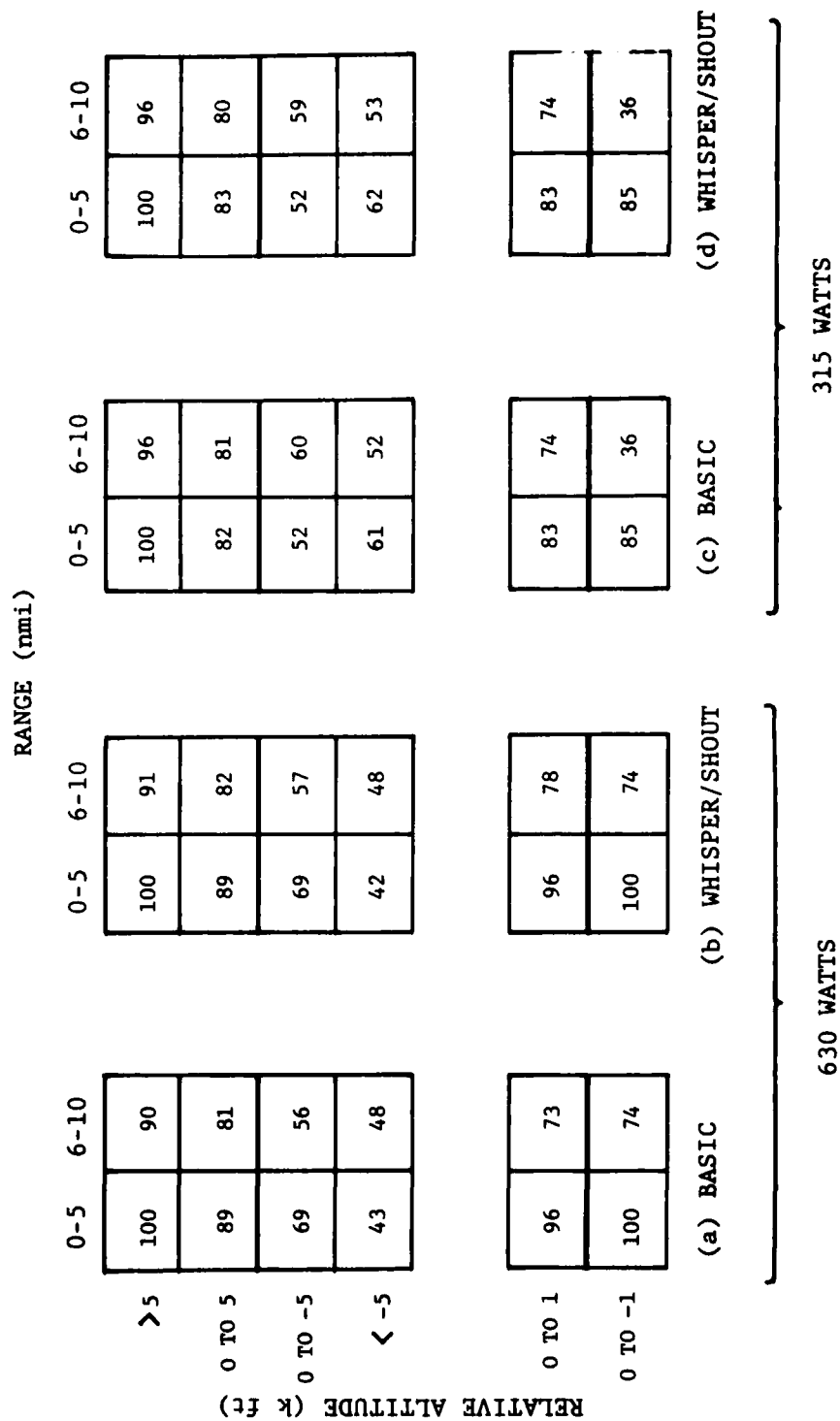


FIGURE 2-17
ASSOCIATION DATA VS. POWER LEVEL FOR 10 MAY 1978

We see that for both normal and Whisper/Shout there is usually an improvement in association within 5 nmi for the higher power. However, for moderate ranges (beyond 5 nmi), the increase in power actually appears to degrade the performance. It is difficult to blame this degradation on changes in the traffic between the two parts of the test, because the density and overlap distributions are comparable. One possible explanation is that the higher power elicits more replies at these moderate ranges, causing more synchronous garble, which in turn may overload the track file and degrade performance. The performance at close range, where the garble is much less and where an overloaded track file has less effect would improve somewhat because of the increased link reliability except possibly at low depression angles below the BCAS aircraft. It thus appears that a transmitter power of about 630 Watts, or in the range of 500 W to 1 kW is required.

It is interesting to note, also, that Whisper/Shout showed neither much benefit nor much degradation in this set of runs, confirming the conclusion of the preceding section.

2.4.3 Resuppression on Top Antenna

As shown in Reference 3, the suppression on the top antenna immediately before interrogation on the lower antenna may result in some targets not replying at all. For this reason, the suppression was removed for all Los Angeles flight tests except May 10 and 11. The effect of the suppression on performance was judged to be minimal. There was no improvement over the net of 75% of aircraft tracked in Washington even at very close ranges. Since the purpose of this suppression was to reduce the garble seen by the lower antenna, it should be retained.

2.4.4 Computer Loading

Up to this point we have seen the performance summary when the computer has sufficient time to complete its task. When it is forced to run in real time (one second to complete one second of tracking) the performance can degrade considerably in high density traffic. It was found on May 11 that a 15% to 20% loss in association occurred when run in real-time as compared to non-real-time. This is the result of trading off between computer resources and traffic load. Improvements are available, if needed, for increasing the efficiency of the operating code and for choosing the best memory size (next section).

The real time data obtained in the February flights, where only 1/2 of the computer was dedicated to ATCRBS would be expected to be even more degraded. Surprisingly it was better, even with approximately the same traffic density. This does not indicate that less computer is better, but that the 2 kW of power used in February more than made up for loss of computer resources. In comparing the February data with May 11 (not presented in this report) it was concluded that the 2 kW interrogations of February made some improvement in performance within 5 nmi, and beyond 10 nmi the additional computer power, plus Whisper/Shout, is more beneficial than large interrogator power (more than doubling the percentage of aircraft that were tracked).

2.4.5 Track File Size

Increasing the track file size for ATCRBS will generally improve the performance. On the other hand, an increased track file size will cause an increase in computer time required to make one update, and the possibility of an increase in the number of phantoms. The former effect is straight-forward and is not evaluated in this report. In fact, for the February flights,

the relationship was used to make more computer time available for the DABS mode by reducing the ATCRBS track file from 100 down to 50. Generally, the computer time required for an update grows linearly with track file size, when there is enough traffic to fully load the system. The question considered here is: how big a track file is needed to get a given level of performance in the Los Angeles environment.

The May 7 data was run using different sizes of track files; Figures 2-18 to 2-20 show the total number of active tracks for a maximum track file size of 75, 100, and 200. During the busy periods the track file is 80% full no matter how large it is, implying that tracks are being discarded because of overflow, even with a track file size of 200. Figures 2-21 to 2-23, which show the established tracks only, indicate that there is practically no difference in performance between 100 and 200 track files. The 75 track file curve shows that somewhat fewer tracks are established during busy periods than for the other cases.

The summary performance of the three cases is shown in Figure 2-24. We see that the performance is essentially the same, with perhaps a slight advantage for the 100 track system. Table 2-3 shows that the 75 track system will produce the fewest phantoms. Therefore the 75 track system seems to be the best overall performer.

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2.4.5 Track File Size

Increasing the track file size for ATCRBS will generally improve the performance. On the other hand, an increased track file size will cause an increase in computer time required to make one update, and the possibility of an increase in the number of phantoms. The former effect is straight-forward and is not evaluated in this report. In fact, for the February flights,

the relationship was used to make more computer time available for the DABS mode by reducing the ATRBS track file from 100 down to 50. Generally, the computer time required for an update grows linearly with track file size, when there is enough traffic to fully load the system. The question considered here is: how big a track file is needed to get a given level of performance in the Los Angeles environment.

The May 7 data was run using different sizes of track files; Figures 2-18 to 2-20 show the total number of active tracks for a maximum track file size of 75, 100, and 200. During the busy periods the track file is 80% full no matter how large it is, implying that tracks are being discarded because of overflow, even with a track file size of 200. Figures 2-21 to 2-23, which show the established tracks only, indicate that there is practically no difference in performance between 100 and 200 track files. The 75 track file curve shows that somewhat fewer tracks are established during busy periods than for the other cases.

The summary performance of the three cases is shown in Figure 2-24. We see that the performance is essentially the same, with perhaps a slight advantage for the 100 track system. Table 2-3 shows that the 75 track system will produce the fewest phantoms. Therefore the 75 track system seems to be the best overall performer.

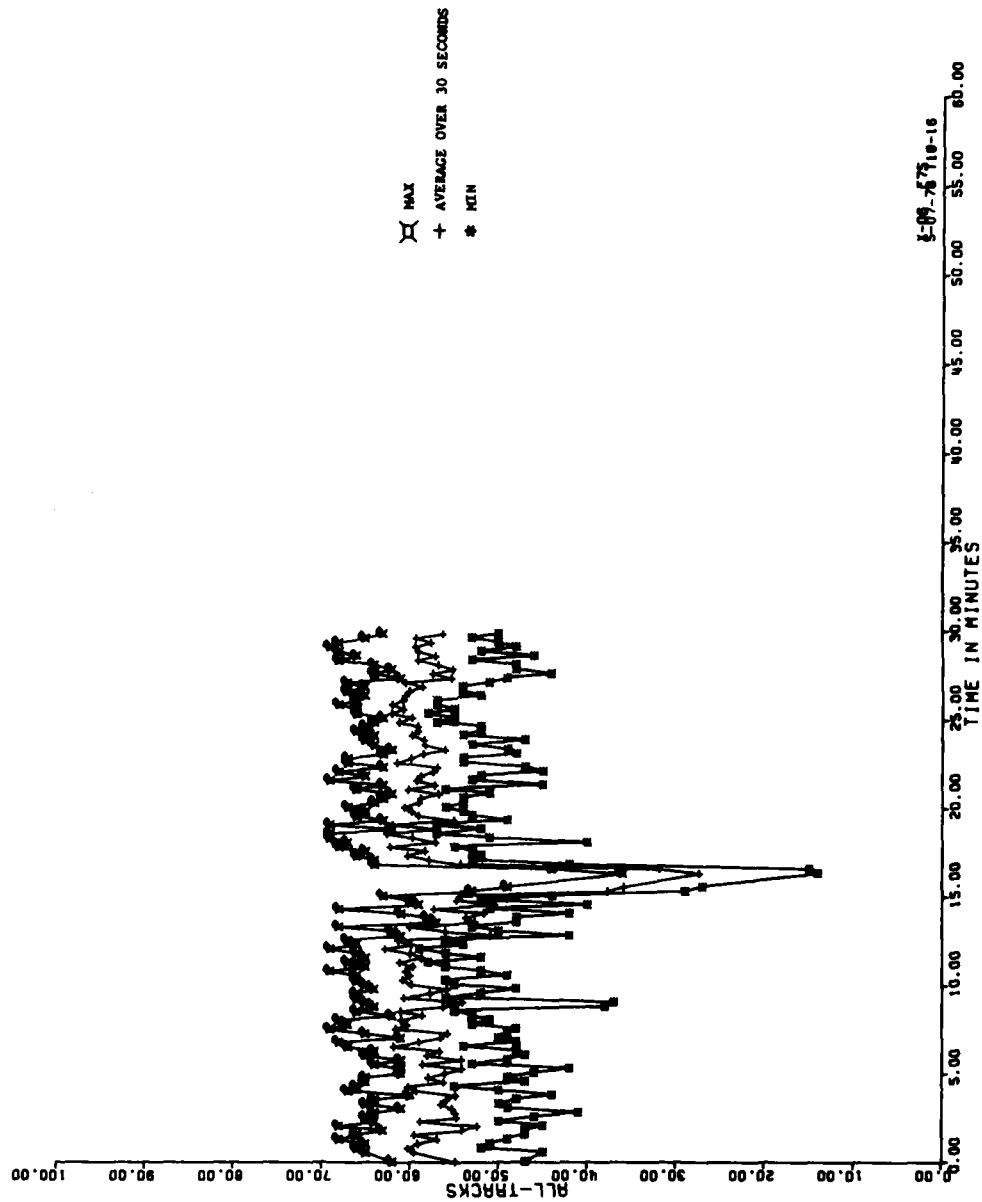


FIGURE 2-18
TRACK FILE VARIATIONS FOR A MAXIMUM TRACK
FILE SIZE OF 75 (MAY 7)

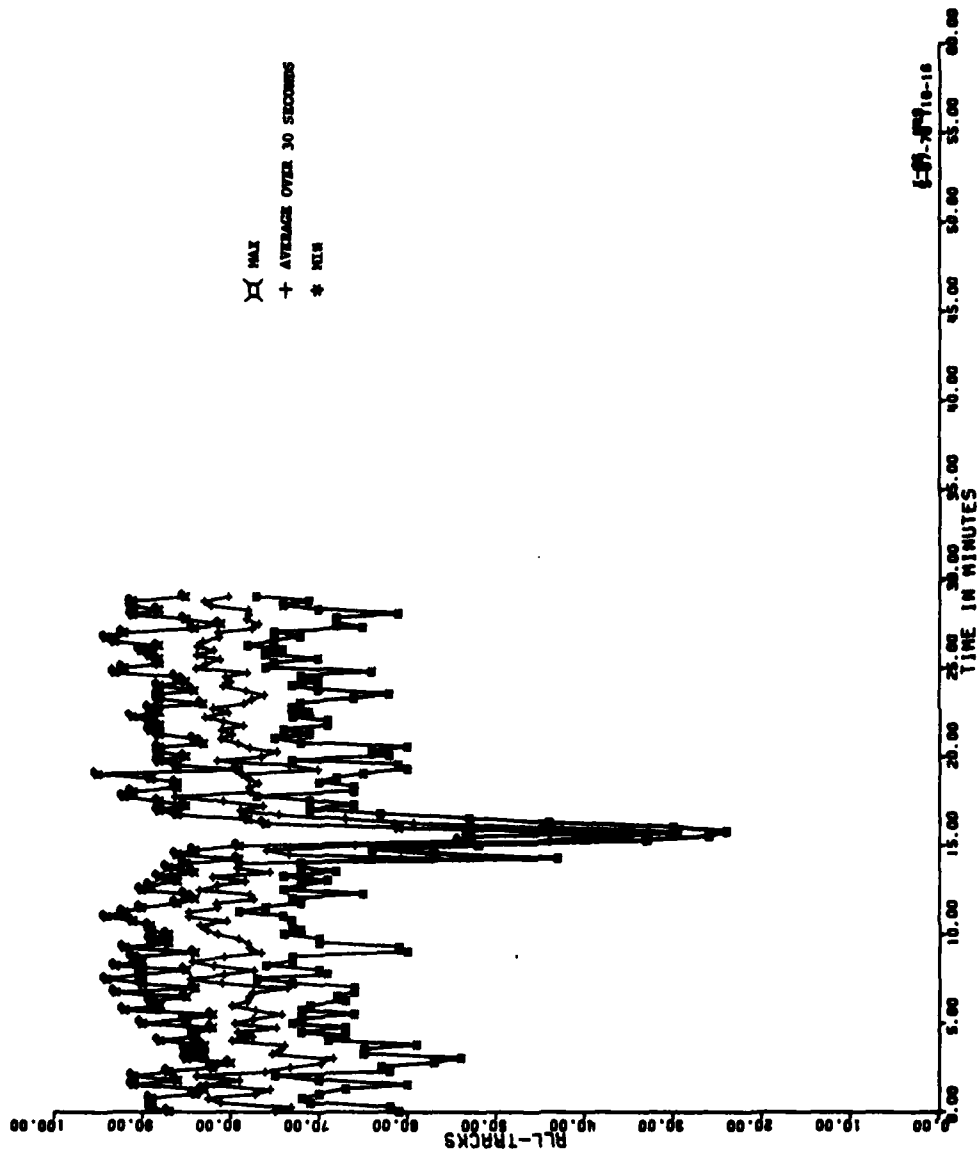


FIGURE 2-3
TRACE FILE MONITORING FOR A GROUND TRACK
(SEE OF MONITOR 2)

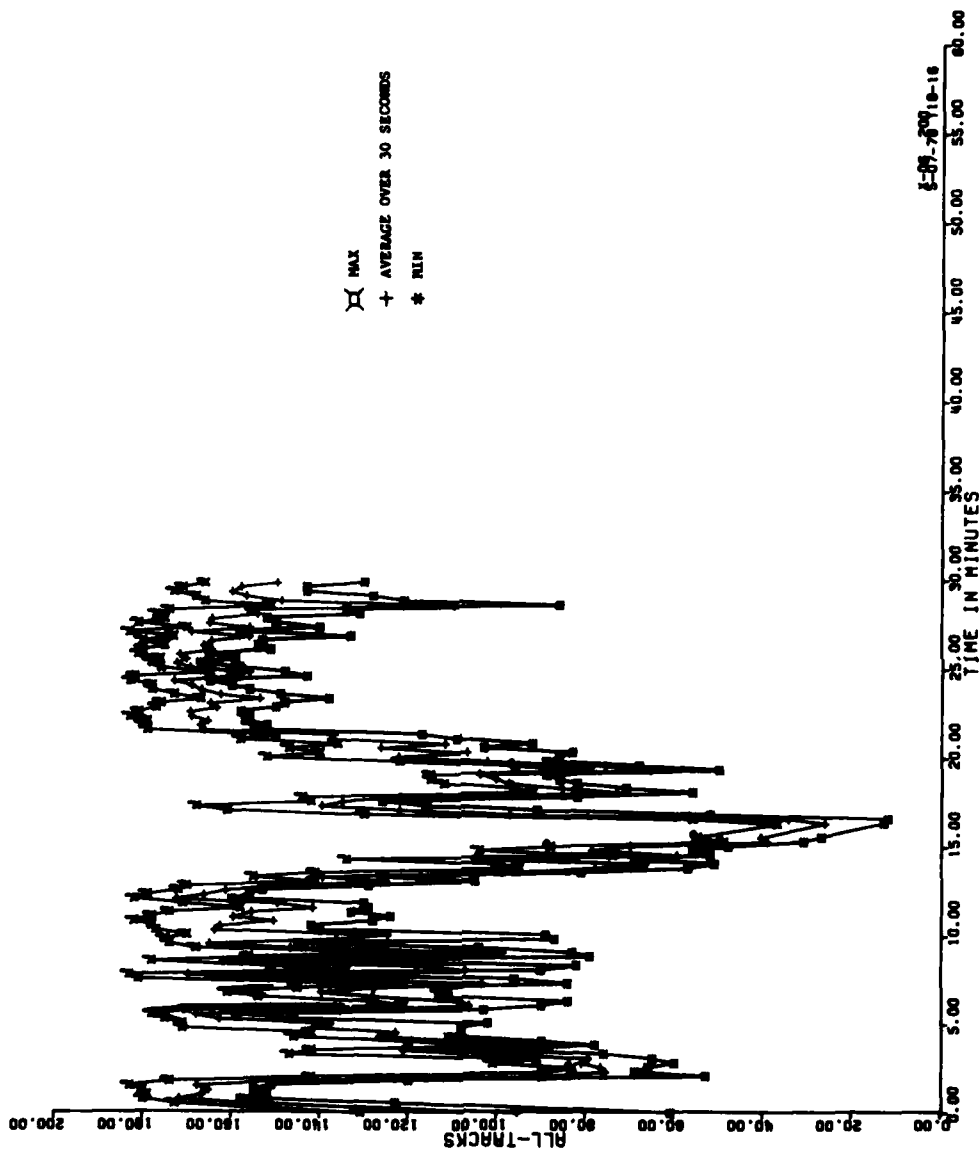


FIGURE 2-28
TRACK FILE VARIATIONS FOR A MAXIMUM TRACK
FILE SIZE OF 200 (MAY 7)

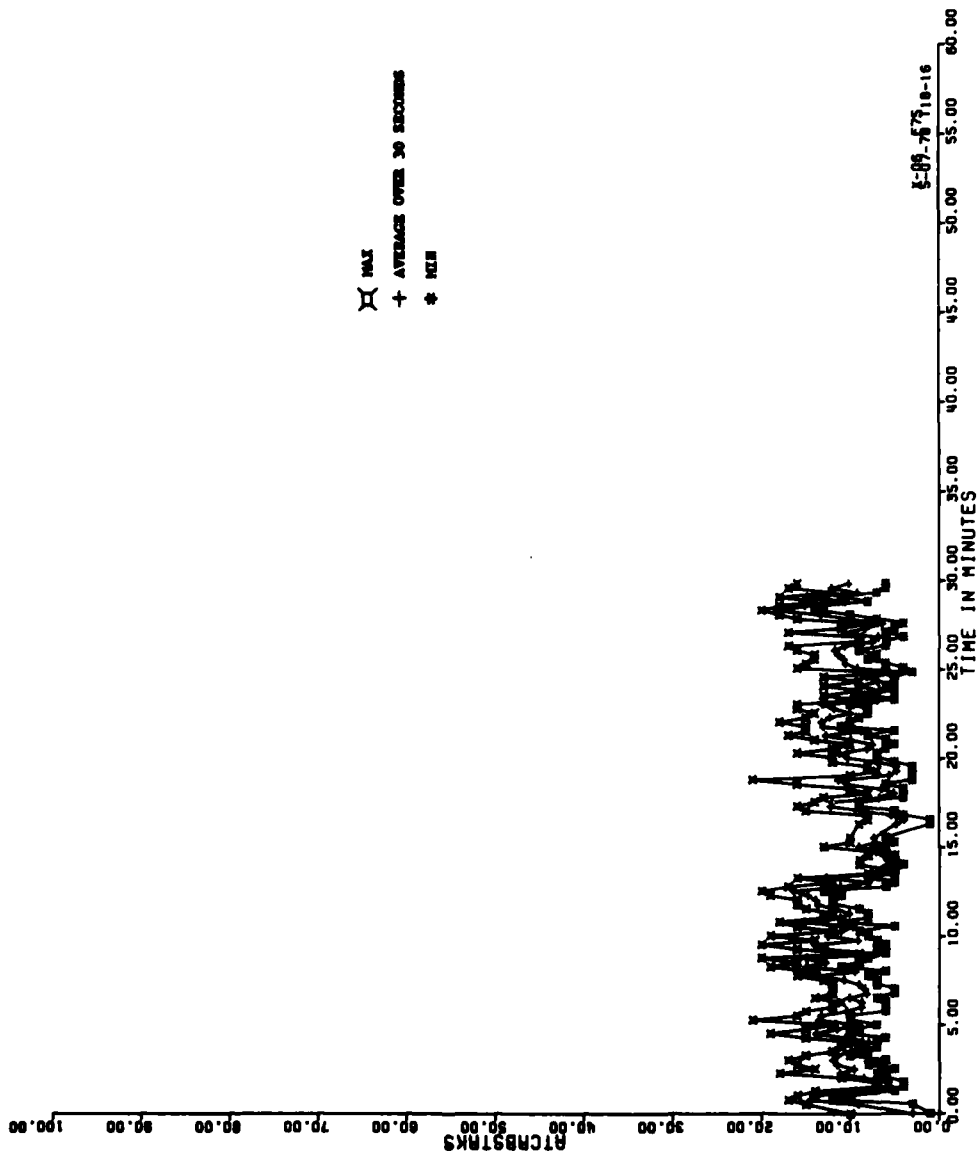


FIGURE 2-21
VARIATIONS IN NUMBER OF ESTABLISHED TRACKS
FOR A TRACK FILE SIZE OF 75

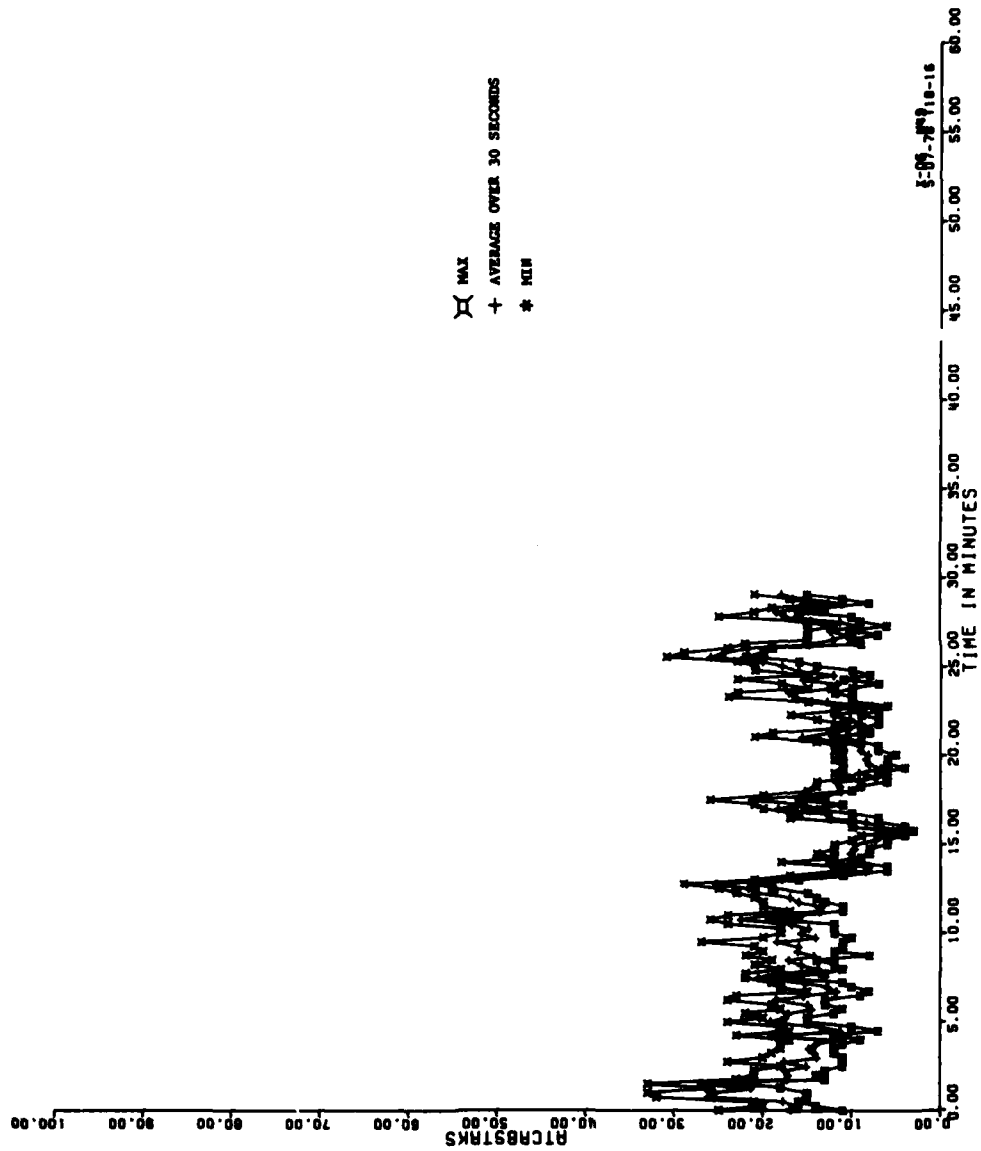


FIGURE 2-22
VARIATIONS IN NUMBER OF ESTABLISHED TRACKS
FOR A TRACK FILE SIZE OF 100

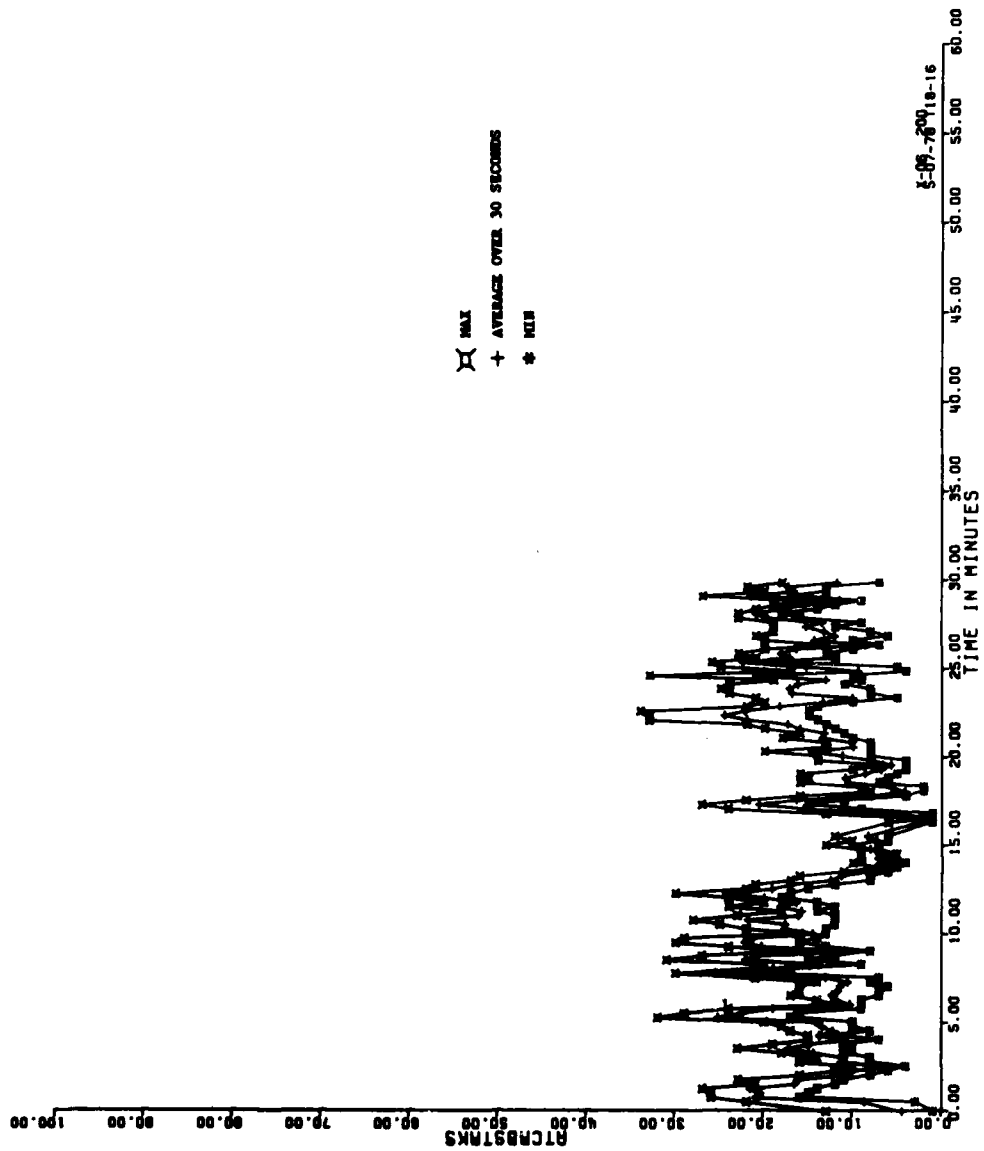


FIGURE 2-22
VARIATIONS IN NUMBER OF ESTABLISHED TRACKS
FOR A TRACK FILE SIZE OF 200

RELATIVE ALTITUDE (k ft)

2-43

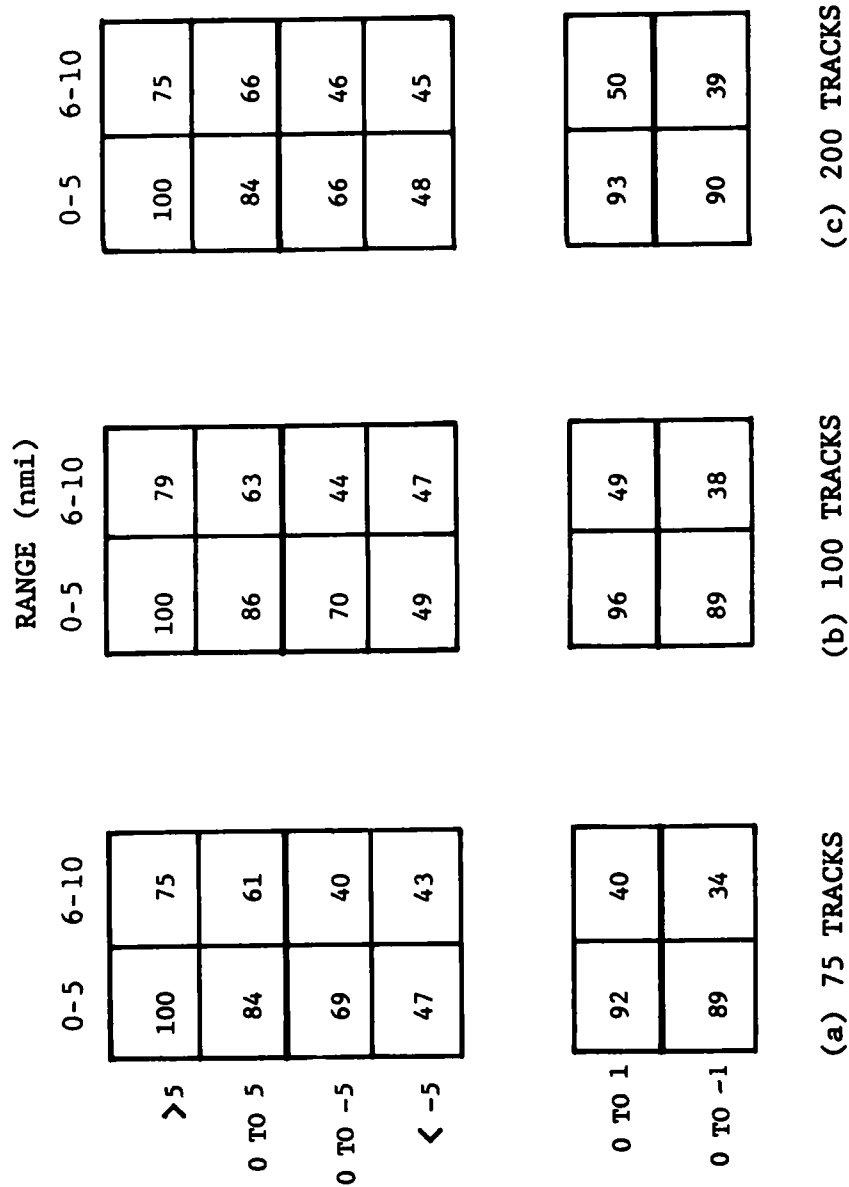


FIGURE 2-24
ASSOCIATION DATA VS. TRACK FILE SIZE (MAY 7)

TABLE 2-3

AVERAGE NUMBER OF PHANTOMS/SCAN
AS A FUNCTION OF TRACK FILE SIZE (MAY 7)

Range	Phantom Rate		
	Track File Size		
	75	100	200
0 - 5 nmi	.54	.63	.57
0 - 10 nmi	1.87	2.25	2.48

APPENDIX A

DATA COLLECTED IN THE LOS ANGELES AREA FOR 1978 MAY 7, 8, 9

The following data is presented in substantially the same format as that for the earlier Washington tests, as reported in Reference 3. For convenience, that data and its accompanying explanation are presented as Appendix B of this report.

The differences between the Washington data and the Los Angeles data are as follows:

1. In Washington, the data base included targets as far as 20 miles from the BCAS aircraft. In Los Angeles, this maximum range was reduced to 12 nmi, and statistics were gathered on targets only as far as 10 nmi.

2. In Washington, BCAS tracks were declared to be established (and therefore usable for the CAS logic) if they had a minimum age of 10 seconds, which increased linearly with range to a maximum of 30 seconds at 20 nmi. In the present Los Angeles tests this was revised to be a flat minimum of 25 seconds.

It should be recalled (as noted in Reference 3) that while phantom tracks were removed from the association matrix data (Figures A-1 through A-10 of this Appendix), this is not so for the overlap and density histograms (Figures A-13 through A-17). Thus, there may appear to be some slight discrepancies if comparisons do not account for this factor.

RELATIVE ALTITUDE (FEET)		RELATIVE RANGE (nm)																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ABOVE BCAS	10000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BCAS	5000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BELOW BCAS	-500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-2500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-3000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-3500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-4000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-4500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-5000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL AIRCRAFT TRACK MATRIX (R VS. Z)		131	629	1220	1770	2146	2451	2826	3075	3266	3535	1301	1236	0	0	0	0	0	0	0	0

FIGURE A-1
TOTAL AIRCRAFT TRACK MATRIX (R VS. Z)

RANGE RANGE (KNOTS)		RELATIVE RANGE (nm)																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
CLOSING	-600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-570	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-540	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-510	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-480	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-450	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-420	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-390	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-360	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-330	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SEPARATING	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	330	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	360	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	390	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	420	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	450	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	480	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	510	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	540	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	570	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

FIGURE A-2
TOTAL AIRCRAFT TRACK MATRIX (R VS. R)

		RELATIVE RANGE (nmi)																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
BCAS	BASIC MODE	89	326	730	1115	1329	1517	1594	1485	1519	1501	418	295	0	0	0	0	0	0	0	0
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-2500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-3000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-3500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-4000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-4500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-5000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-5500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-6000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-6500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-7000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-7500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-8000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-8500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-9000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-9500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-10000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

FIGURE A-3
TOTAL BCAS ASSOCIATED AIRCRAFT TRACK MATRIX (R VS. Z)

FIGURE A-4
TOTAL SCAS ASSOCIATED AIRCRAFT TRACK MATRIX (R VS. R)

[illegible]

FIGURE A-5
RATIO OF BCAS ASSOCIATED AIRCRAFT TRACKS TO
TOTAL AIRCRAFT TRACKS (R VS. Z)

(KNOTS) RATE RANGE

[illegible]

FIGURE A-3
RATIO OF BCAS ASSOCIATED AIRCRAFT TRACKS TO
TOTAL AIRCRAFT TRACKS (R VS. N)

RANGE	TOTAL	ASSOC.	% A	RANGE	TOTAL	ASSOC.	% A
1	131	89	67	1	106	57	53
2	629	326	51	2	626	313	50
3	1220	730	59	3	1224	727	59
4	1770	1115	62	4	1730	1119	64
5	2146	1329	61	5	2154	1436	66
6	2451	1517	61	6	2517	1739	69
7	2826	1594	56	7	2971	1930	64
8	3075	1485	48	8	3216	1822	56
9	3266	1519	46	9	3298	1734	52
10	3535	1501	42	10	3553	1719	48
11	1301	418	32	11	1107	519	46
12	1236	295	23	12	1140	461	40

(a) BASIC

(b) WHISPER/SHOUT

FIGURE A-7
AIRCRAFT ASSOCIATION, FOR EACH MILE, FOR ALL ALTITUDES

> 5 k ft	R	(0-5)	(6-10)
	T	149	410
	A	128	333
	%	85.9	81.2
0 TO 5 k ft ABOVE	R	(0-5)	(6-10)
	T	640	1470
	A	560	880
	%	87.5	59.9
0 TO 5 k ft BELOW	R	(0-5)	(6-10)
	T	2488	6737
	A	1642	3201
	%	66.0	47.5
< 5 k ft	R	(0-5)	(6-10)
	T	2617	6536
	A	1257	3202
	%	48.0	49.0
0 TO 1 k ft ABOVE	R	(0-5)	(6-10)
	T	215	365
	A	192	168
	%	89.3	46.0
0 TO 1 k ft BELOW	R	(0-5)	(6-10)
	T	456	753
	A	405	386
	%	88.8	51.3

FIGURE A-8
BCAS PERFORMANCE FOR VARIOUS ALTITUDE AND RANGE ZONES
(BASIC)

> 5 k ft	R	(0-5)	(6-10)
	T	123	382
	A	97	263
	%	78.9	68.8
0 TO 5 k ft ABOVE	R	(0-5)	(6-10)
	T	590	1448
	A	459	949
	%	77.8	65.5
0 to 5 k ft BELOW	R	(0-5)	(6-10)
	T	2460	6776
	A	1615	3632
	%	65.7	53.6
< 5 k ft	R	(0-5)	(6-10)
	T	2667	6949
	A	1481	4100
	%	55.5	59.0
0 TO 1 k ft ABOVE	R	(0-5)	(6-10)
	T	192	364
	A	165	185
	%	85.9	50.8
0 TO 1 k ft BELOW	R	(0-5)	(6-10)
	T	459	729
	A	398	414
	%	86.7	56.8

FIGURE A-9
BCAS PERFORMANCE FOR VARIOUS ALTITUDE AND RANGE ZONES
(WHISPER/SHOUT)

RANGE	TOTAL	ASSOC.	% A	RANGE	TOTAL	ASSOC.	% A
1	131	89	67.9	1	106	57	53.8
2	760	415	54.6	2	732	370	50.5
3	1980	1145	57.8	3	1956	1097	56.1
4	3750	2260	60.3	4	3686	2216	60.1
5	5896	3589	60.9	5	5840	3652	62.5
6	8347	5106	61.2	6	8357	5391	64.5
7	11173	6700	60.0	7	11328	7321	64.6
8	14248	8185	57.4	8	14544	9143	62.9
9	17514	9704	55.4	9	17842	10877	61.0
10	21049	11205	53.2	10	21395	12596	58.9
11	22350	11623	52.0	11	22502	13115	58.3
12	23586	11918	50.5	12	23642	13576	57.4

(a) BASIC

(b) WHISPER/SHOUT

FIGURE A-10
CUMULATIVE PERCENT OF AIRCRAFT ASSOCIATION

		PROBABILITY OF PHANTOM TRACKS										KNOTS VERSUS RANGE									
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
-600	0000	0000	0003	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
-570	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
-540	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
-510	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
-480	0006	0009	0003	0000	0009	0006	0006	0006	0009	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
-450	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
-420	0016	0009	0019	0044	0028	0025	0037	0031	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
-390	0000	0006	0053	0059	0078	0050	0050	0050	0087	0053	0022	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
-360	0000	0006	0019	0072	0112	0056	0059	0072	0059	0068	0003	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
-330	0000	0012	0025	0072	0090	0106	0072	0056	0034	0031	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
-300	0000	0016	0053	0093	0078	0124	0090	0121	0087	0075	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
-270	0003	0016	0056	0084	0104	0124	0103	0053	0056	0081	0016	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
-240	0000	0009	0031	0090	0118	0115	0115	0075	0100	0093	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
-210	0003	0012	0034	0065	0112	0134	0168	0109	0121	0096	0037	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
-180	0003	0022	0050	0087	0072	0128	0159	0149	0065	0121	0025	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
-150	0006	0012	0065	0096	0140	0156	0124	0112	0121	0137	0009	0022	0000	0000	0000	0000	0000	0000	0000	0000	0000
-120	0000	0028	0040	0100	0106	0168	0184	0202	0128	0171	0050	0019	0000	0000	0000	0000	0000	0000	0000	0000	0000
-90	0000	0016	0044	0106	0171	0162	0202	0162	0177	0146	0050	0050	0000	0000	0000	0000	0000	0000	0000	0000	0000
-60	0000	0006	0037	0121	0208	0208	0224	0184	0134	0131	0037	0056	0000	0000	0000	0000	0000	0000	0000	0000	0000
-30	0003	0016	0037	0084	0190	0196	0171	0109	0152	0199	0056	0084	0000	0000	0000	0000	0000	0000	0000	0000	0000
30	0003	0016	0093	0096	0152	0162	0149	0115	0131	0190	0075	0050	0000	0000	0000	0000	0000	0000	0000	0000	0000
60	0006	0000	0047	0103	0184	0221	0212	0140	0156	0193	0090	0152	0000	0000	0000	0000	0000	0000	0000	0000	0000
90	0000	0019	0028	0096	0115	0196	0205	0128	0128	0159	0062	0087	0000	0000	0000	0000	0000	0000	0000	0000	0000
120	0003	0022	0034	0068	0134	0149	0258	0193	0131	0240	0081	0050	0000	0000	0000	0000	0000	0000	0000	0000	0000
150	0003	0006	0012	0050	0112	0152	0221	0205	0146	0053	0053	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
180	0000	0009	0009	0050	0084	0093	0124	0180	0184	0096	0019	0044	0003	0000	0000	0000	0000	0000	0000	0000	0000
210	0000	0000	0016	0025	0068	0140	0165	0140	0137	0118	0028	0069	0000	0000	0000	0000	0000	0000	0000	0000	0000
240	0000	0009	0019	0034	0044	0128	0121	0087	0184	0137	0028	0050	0000	0000	0000	0000	0000	0000	0000	0000	0000
270	0000	0000	0003	0019	0053	0078	0078	0140	0189	0118	0047	0031	0000	0000	0000	0000	0000	0000	0000	0000	0000
300	0000	0000	0000	0019	0047	0031	0053	0078	0087	0156	0022	0040	0000	0000	0000	0000	0000	0000	0000	0000	0000
330	0000	0000	0003	0006	0019	0075	0050	0065	0062	0100	0047	0065	0000	0000	0000	0000	0000	0000	0000	0000	0000
360	0000	0000	0000	0000	0006	0034	0093	0065	0065	0068	0025	0006	0000	0000	0000	0000	0000	0000	0000	0000	0000
390	0000	0000	0000	0000	0003	0006	0034	0022	0062	0065	0050	0009	0006	0000	0000	0000	0000	0000	0000	0000	0000
420	0000	0000	0000	0000	0000	0003	0025	0037	0034	0037	0034	0006	0019	0000	0000	0000	0000	0000	0000	0000	0000
450	0000	0000	0000	0006	0016	0028	0034	0003	0025	0022	0040	0003	0006	0000	0000	0000	0000	0000	0000	0000	0000
480	0000	0000	0000	0003	0000	0003	0003	0009	0016	0012	0006	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
510	0000	0000	0000	0000	0000	0000	0012	0009	0003	0003	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
540	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0003	0003	0000	0000	0000	0000	0000	0000	0000	0000	0000
570	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
600	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
0056 0277 0834 1792 2694 3344 3639 3179 2992 3266 0880 0967 0003 0000 0000 0000 0000 0000 0000 0000 0000 0000		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

FIGURE A-12
PROBABILITY OF PHANTOM OCCURRENCES (R VS. R)

TABLE A-1

AVERAGE NUMBER OF PHANTOM TRACKS PER SCAN AT ANY ALTITUDE

	BASIC	WHISPER/SHOUT
0 - 5 nmi	.57	.64
0 - 10 nmi	2.21	2.78
0 - 12 nmi	2.39	3.08

OVERLAPS	0	1	2	3	4	5	6	7	8	9	10	11	12	1378	1/1
	1	1	1	1	1	1	1	1	1	1	1	1	1	2067	1/1
	2	1	1	1	1	1	1	1	1	1	1	1	1	2285	1/1
	3	1	1	1	1	1	1	1	1	1	1	1	1	1873	1/1
	4	1	1	1	1	1	1	1	1	1	1	1	1	1198	1/1
	5	1	1	1	1	1	1	1	1	1	1	1	1	723	1/1
	6	1	1	1	1	1	1	1	1	1	1	1	1	353	1/1
	7	1	1	1	1	1	1	1	1	1	1	1	1	184	1/1
	8	1	1	1	1	1	1	1	1	1	1	1	1	80	1/1
	9	1	1	1	1	1	1	1	1	1	1	1	1	24	1/1
	10	1	1	1	1	1	1	1	1	1	1	1	1	7	1/1
	11	1	1	1	1	1	1	1	1	1	1	1	1	2	1/1
	12	1	1	1	1	1	1	1	1	1	1	1	1	6	1/1

a) NUMBER OF SUCCESSFUL ASSOCIATIONS

OVERLAPS	0	1	2	3	4	5	6	7	8	9	10	11	12	566	1/1
	1	1	1	1	1	1	1	1	1	1	1	1	1	1373	1/1
	2	1	1	1	1	1	1	1	1	1	1	1	1	2134	1/1
	3	1	1	1	1	1	1	1	1	1	1	1	1	1894	1/1
	4	1	1	1	1	1	1	1	1	1	1	1	1	1540	1/1
	5	1	1	1	1	1	1	1	1	1	1	1	1	1060	1/1
	6	1	1	1	1	1	1	1	1	1	1	1	1	631	1/1
	7	1	1	1	1	1	1	1	1	1	1	1	1	307	1/1
	8	1	1	1	1	1	1	1	1	1	1	1	1	106	1/1
	9	1	1	1	1	1	1	1	1	1	1	1	1	22	1/1
	10	1	1	1	1	1	1	1	1	1	1	1	1	9	1/1
	11	1	1	1	1	1	1	1	1	1	1	1	1	0	1/1
	12	1	1	1	1	1	1	1	1	1	1	1	1	0	1/1

b) NUMBER OF MISSED ASSOCIATIONS

OVERLAPS	0	1	2	3	4	5	6	7	8	9	10	11	12	71	1/1
	1	1	1	1	1	1	1	1	1	1	1	1	1	60	1/1
	2	1	1	1	1	1	1	1	1	1	1	1	1	52	1/1
	3	1	1	1	1	1	1	1	1	1	1	1	1	50	1/1
	4	1	1	1	1	1	1	1	1	1	1	1	1	44	1/1
	5	1	1	1	1	1	1	1	1	1	1	1	1	41	1/1
	6	1	1	1	1	1	1	1	1	1	1	1	1	36	1/1
	7	1	1	1	1	1	1	1	1	1	1	1	1	37	1/1
	8	1	1	1	1	1	1	1	1	1	1	1	1	43	1/1
	9	1	1	1	1	1	1	1	1	1	1	1	1	52	1/1
	10	1	1	1	1	1	1	1	1	1	1	1	1	44	1/1
	11	1	1	1	1	1	1	1	1	1	1	1	1	100	1/1
	12	1	1	1	1	1	1	1	1	1	1	1	1	100	1/1

c) PERCENT ASSOCIATION

FIGURE A-13
ARTS ASSOCIATION VS. OVERLAPS (BASIC)

OVERLAPS	1/1	0	11	1244	1/1
	1/1	1	11	2044	1/1
	1/1	2	11	2342	1/1
	1/1	3	11	2127	1/1
	1/1	4	11	1337	1/1
	1/1	5	11	989	1/1
	1/1	6	11	570	1/1
	1/1	7	11	296	1/1
	1/1	8	11	104	1/1
	1/1	9	11	49	1/1
	1/1	10	11	24	1/1
	1/1	11	11	15	1/1
	1/1	12	11	42	1/1

a) NUMBER OF SUCCESSFUL ASSOCIATIONS

OVERLAPS	1/1	0	11	606	1/1
	1/1	1	11	1300	1/1
	1/1	2	11	1835	1/1
	1/1	3	11	1533	1/1
	1/1	4	11	1326	1/1
	1/1	5	11	894	1/1
	1/1	6	11	570	1/1
	1/1	7	11	284	1/1
	1/1	8	11	123	1/1
	1/1	9	11	39	1/1
	1/1	10	11	10	1/1
	1/1	11	11	0	1/1
	1/1	12	11	0	1/1

b) NUMBER OF MISSED ASSOCIATIONS

OVERLAPS	1/1	0	11	67	1/1
	1/1	1	11	61	1/1
	1/1	2	11	44	1/1
	1/1	3	11	58	1/1
	1/1	4	11	54	1/1
	1/1	5	11	53	1/1
	1/1	6	11	50	1/1
	1/1	7	11	51	1/1
	1/1	8	11	46	1/1
	1/1	9	11	56	1/1
	1/1	10	11	71	1/1
	1/1	11	11	100	1/1
	1/1	12	11	100	1/1

c) PERCENT ASSOCIATION

FIGURE A-14
ARTS ASSOCIATION VS. OVERLAPS (WHISPER/SHOUT)

[illegible]

●) SUCCESSFUL ASSOCIATIONS (BASIC)

[illegible]

	<u>RANGE</u>
b) MISSED ASSOCIATIONS (BASIC)	

1	62	63	69	71	80	60	71	73	61	62	40	21	1111	1111	1111	1111	1111	1111	1111
2	88	51	65	66	67	63	60	56	53	45	34	23	1111	1111	1111	1111	1111	1111	1111
3	46	26	49	62	56	61	53	52	47	41	28	22	1111	1111	1111	1111	1111	1111	1111
4	1111	28	48	58	55	57	57	46	47	40	29	27	1111	1111	1111	1111	1111	1111	1111
5	1111	0	30	39	52	55	50	40	39	37	34	26	1111	1111	1111	1111	1111	1111	1111
6	1111	50	23	28	54	49	45	35	36	39	31	22	1111	1111	1111	1111	1111	1111	1111
7	1111	1111	28	32	41	46	34	31	35	30	22	1111	1111	1111	1111	1111	1111	1111	1111
8	1111	100	30	30	42	45	33	33	41	29	17	100	111	111	111	111	111	111	111
9	1111	1111	1111	100	106	42	40	40	45	23	14	100	111	111	111	111	111	111	111
10	1111	1111	1111	111	100	110	60	40	52	30	17	100	111	111	111	111	111	111	111
11	1111	1111	1111	111	111	111	111	111	55	32	100	75	100	111	111	111	111	111	111
12	1111	1111	1111	111	111	111	111	111	111	111	100	100	111	111	111	111	111	111	111
13	111	111	111	111	100	111	100	111	100	100	100	100	111	111	111	111	111	111	111
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

FIGURE A-15
ASSOCIATION PERFORMANCE AS A FUNCTION OF RANGE AND OVERLAPS

OVERLAPS												
	0	1	2	3	4	5	6	7	8	9	10	11
1	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111
2	53	29	2	2	2	2	2	2	2	2	2	2
3	200	315	120	23	23	23	23	23	23	23	23	23
4	216	244	249	120	48	29	17	1111	1111	1111	1111	1111
5	180	301	311	211	81	40	11	7	1111	1111	1111	1111
6	175	402	432	291	148	55	15	4	1111	1111	1111	1111
7	132	287	323	329	389	48	23	5	1111	1111	1111	1111
8	79	195	221	249	349	114	60	37	4	1111	1111	1111
9	21	78	144	174	147	109	53	18	9	1111	1111	1111
10	10	30	48	60	94	70	25	28	11	1111	1111	1111
11	2	12	26	26	26	26	26	26	26	26	26	26
12	1	11	23	36	27	28	22	24	6	1111	1111	1111
13	1	1	13	11	12	10	5	3	2	1	1111	1111
14	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1
19	1	1	1	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	1	1	1	1
21	1	1	1	1	1	1	1	1	1	1	1	1
22	1	1	1	1	1	1	1	1	1	1	1	1
23	1	1	1	1	1	1	1	1	1	1	1	1
24	1	1	1	1	1	1	1	1	1	1	1	1
25	1	1	1	1	1	1	1	1	1	1	1	1
26	1	1	1	1	1	1	1	1	1	1	1	1
27	1	1	1	1	1	1	1	1	1	1	1	1
28	1	1	1	1	1	1	1	1	1	1	1	1
29	1	1	1	1	1	1	1	1	1	1	1	1
30	1	1	1	1	1	1	1	1	1	1	1	1
31	1	1	1	1	1	1	1	1	1	1	1	1
32	1	1	1	1	1	1	1	1	1	1	1	1
33	1	1	1	1	1	1	1	1	1	1	1	1
34	1	1	1	1	1	1	1	1	1	1	1	1
35	1	1	1	1	1	1	1	1	1	1	1	1
36	1	1	1	1	1	1	1	1	1	1	1	1
37	1	1	1	1	1	1	1	1	1	1	1	1
38	1	1	1	1	1	1	1	1	1	1	1	1
39	1	1	1	1	1	1	1	1	1	1	1	1
40	1	1	1	1	1	1	1	1	1	1	1	1
41	1	1	1	1	1	1	1	1	1	1	1	1
42	1	1	1	1	1	1	1	1	1	1	1	1
43	1	1	1	1	1	1	1	1	1	1	1	1
44	1	1	1	1	1	1	1	1	1	1	1	1
45	1	1	1	1	1	1	1	1	1	1	1	1
46	1	1	1	1	1	1	1	1	1	1	1	1
47	1	1	1	1	1	1	1	1	1	1	1	1
48	1	1	1	1	1	1	1	1	1	1	1	1
49	1	1	1	1	1	1	1	1	1	1	1	1
50	1	1	1	1	1	1	1	1	1	1	1	1
51	1	1	1	1	1	1	1	1	1	1	1	1
52	1	1	1	1	1	1	1	1	1	1	1	1
53	1	1	1	1	1	1	1	1	1	1	1	1
54	1	1	1	1	1	1	1	1	1	1	1	1
55	1	1	1	1	1	1	1	1	1	1	1	1
56	1	1	1	1	1	1	1	1	1	1	1	1
57	1	1	1	1	1	1	1	1	1	1	1	1
58	1	1	1	1	1	1	1	1	1	1	1	1
59	1	1	1	1	1	1	1	1	1	1	1	1
60	1	1	1	1	1	1	1	1	1	1	1	1
61	1	1	1	1	1	1	1	1	1	1	1	1
62	1	1	1	1	1	1	1	1	1	1	1	1
63	1	1	1	1	1	1	1	1	1	1	1	1
64	1	1	1	1	1	1	1	1	1	1	1	1
65	1	1	1	1	1	1	1	1	1	1	1	1
66	1	1	1	1	1	1	1	1	1	1	1	1
67	1	1	1	1	1	1	1	1	1	1	1	1
68	1	1	1	1	1	1	1	1	1	1	1	1
69	1	1	1	1	1	1	1	1	1	1	1	1
70	1	1	1	1	1	1	1	1	1	1	1	1
71	1	1	1	1	1	1	1	1	1	1	1	1
72	1	1	1	1	1	1	1	1	1	1	1	1
73	1	1	1	1	1	1	1	1	1	1	1	1
74	1	1	1	1	1	1	1	1	1	1	1	1
75	1	1	1	1	1	1	1	1	1	1	1	1
76	1	1	1	1	1	1	1	1	1	1	1	1
77	1	1	1	1	1	1	1	1	1	1	1	1
78	1	1	1	1	1	1	1	1	1	1	1	1
79	1	1	1	1	1	1	1	1	1	1	1	1
80	1	1	1	1	1	1	1	1	1	1	1	1
81	1	1	1	1	1	1	1	1	1	1	1	1
82	1	1	1	1	1	1	1	1	1	1	1	1
83	1	1	1	1	1	1	1	1	1	1	1	1
84	1	1	1	1	1	1	1	1	1	1	1	1
85	1	1	1	1	1	1	1	1	1	1	1	1
86	1	1	1	1	1	1	1	1	1	1	1	1
87	1	1	1	1	1	1	1	1	1	1	1	1
88	1	1	1	1	1	1	1	1	1	1	1	1
89	1	1	1	1	1	1	1	1	1	1	1	1
90	1	1	1	1	1	1	1	1	1	1	1	1
91	1	1	1	1	1	1	1	1	1	1	1	1
92	1	1	1	1	1	1	1	1	1	1	1	1
93	1	1	1	1	1	1	1	1	1	1	1	1
94	1	1	1	1	1	1	1	1	1	1	1	1
95	1	1	1	1	1	1	1	1	1	1	1	1
96	1	1	1	1	1	1	1	1	1	1	1	1
97	1	1	1	1	1	1	1	1	1	1	1	1
98	1	1	1	1	1	1	1	1	1	1	1	1
99	1	1	1	1	1	1	1	1	1	1	1	1
100	1	1	1	1	1	1	1	1	1	1	1	1

a) SUCCESSFUL ASSOCIATION (BASIC)

OVERLAPS												
	0	1	2	3	4	5	6	7	8	9	10	11
1	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111
2	24	60	0	48	32	19	6	1111	1111	1111	1111	1111
3	44	165	133	78	46	47	19	6	1111	1111	1111	1111
4	64	232	199	151	75	38	12	1	1111	1111	1111	1111
5	106	281	266	237	133	58	18	6	1111	1111	1111	1111
6	196	306	396	256	199	97	15	4	1111	1111	1111	1111
7	287	427	352	223	121	43	16	4	1111	1111	1111	1111
8	374	516	316	175	85	26	18	5	1111	1111	1111	1111
9	464	616	316	175	85	26	18	5	1111	1111	1111	1111
10	554	716	316	175	85	26	18	5	1111	1111	1111	1111
11	644	816	316	175	85	26	18	5	1111	1111	1111	1111
12	734	916	316	175	85	26	18	5	1111	1111	1111	1111
13	824	1016	316	175	85	26	18	5	1111	1111	1111	1111
14	914	1116	316	175	85	26	18	5	1111	1111	1111	1111
15	1004	1216	316	175	85	26	18	5	1111	1111	1111	1111
16	1094	1316	316	175	85	26	18	5	1111	1111	1111	1111
17	1184	1416	316	175	85	26	18	5	1111	1111	1111	1111
18	1274	1516	316	175	85	26	18	5	1111	1111	1111	1111
19	1364	1616	316	175	85	26	18	5	1111	1111	1111	1111
20	1454	1716	316	175	85	26	18	5	1111	1111	1111	1111
21	1544	1816	316	175	85	26	18	5	1111	1111	1111	1111
22	1634	1916	316	175	85	26	18	5	1111	1111	1111	1111
23	1724	2016	316	175	85	26	18	5	1111	1111	1111	1111
24	1814	2116	316	175	85	26	18	5	1111	1111	1111	1111
25	1904	2216	316	175	85	26	18	5	1111	1111	1111	1111
26	1994	2316	316	175	85	26	18	5	1111	1111	1111	1111
27	2084	2416	316	175	85	26	18	5	1111	1111	1111	1111
28	2174	2516	316	175	85	26	18	5	1111	1111	1111	1111
29	2264	2616	316	175	85	26	18	5	1111	1111	1111	1111
30	2354	2716	316	175	85	26	18	5	1111	1111	1111	1111
31	2444	2816	316	175	85	26	18	5	1111	1111	1111	1111
32	2534	2916	316	175	85	26	18	5	1111	1111	1111	1111
33	2624	3016	316	175	85	26	18	5	1111	1111	1111	1111
34	2714	3116	316	175	85	26	18	5	1111	1111	1111	1111
35	2804	3216	316	175	85	26	18	5	1111	1111	1111	1111
36	2894	3316	316	175	85	26	18	5	1111	1111	1111	1111
37	2984	3416	316	175	85	26	18	5	1111	1111	1111	1111
38	3074	3516	316	175	85	26	18	5	1111	1111	1111	1111
39	3164	3616	316	175	85	26	18	5	1111	1111	1111	1111
40	3254	3716	316	175	85	26	18	5	1111	1111	1111	1111
41	3344	3816	316	175	85	26	18	5	1111	1111	1111	1111
42	3434	3916	316	175	85	26	18	5	1111	1111	1111	1111
43	3524	4016	316	175	85	26	18	5	1111	1111	1111	1111
44	3614	4116	316	175	85	26	18	5	1111	1111	1111	1111
45	3704	4216	316	175	85	26	18	5	1111	1111	1111	1111
46	3794	4316	316	175	85	26	18	5	1111	1111	1111	1111
47	3884	4416	316	175	85	26	18	5	1111	1111	1111	1111
48	3974	4516	316	175	85	26	18	5	1111	1111	1111	1111
49	4064	4616	316	175	85	26	18	5	1111	1111	1111	1111
50	4154	4716	316	175	85	26	18	5	1111	1111	1111	1111
51	4244	4816	316	175	85	26	18	5	1111	1111	1111	1111
52	4334	4916	316	175	85	26	18	5	1111	1111	1111	1111
53	4424	5016	316	175	85	26	18	5	1111	1111	1111	1111
54	4514	5116	316	175	85	26	18	5	1111	1111	1111	1111
55	4604	5216	316	175	85	26	18	5	1111	1111	1111	1111
56	4694	5316	316	175	85	26	18	5	1111	1111	1111	1111
57	4784	5416	316	175	85	26	18	5	1111	1111	1111	1111
58	4874	5516	316	175	85	26	18	5	1111	1111	1111	1111
59	4964	5616	316	175	85	26	18	5	1111	1111	1111	1111
60	5054	5716	316	175	85	26	18	5	1111	1111	1111	1111
61	5144	5816	316	175	85	26	18	5	1111	1111	1111	1111
62	5234	5916	316	175	85	26	18	5	1111	1111	1111	1111
63	5324	6016	316	175	85	26	18	5	1111	1111	1111	1111
64	5414	6116	316	175	85	26	18	5	1111	1111	1111	1111
65	5504	6216	316	175	85	26	18	5	1111	1111	1111	1111
66	5594	6316	316	175	85	26	18	5	1111	1111	1111	1111
67	5684	6416	316	175	85	26	18	5	1111	1111	1111	1111
68	5774	6516	316	175	85	26	18	5	1111	1111	1111	1111
69	5864	6616	316	175	85	26	18	5	1111	1111	1111	1111
70	5954	6716	316	175	85	26	18	5	1111	1111	1111	1111
71	6044	6816	316	175	85	26	18	5	1111	1111	1111	1111
72	6134	6916	316	175	85	26	18	5	1111	1111	1111	1111
73	6224	7016	316	175	85	26	18	5	1111	1111	1111	1111
74	6314	7116	316	175	85	26	18	5	1111	1111	1111	1111
75	6404	7216	316	175	85	26	18	5	1111	1111	1111	1111
76	6494	7316	316	175	85	26	18	5	1111	1111	1111	1111
77	6584	7416	316	175	85	26	18	5	1111	1111	1111	1111
78	6674	7516	316	175	85	26	18	5	1111	1111	1111	1111
79	6764	7616	316	175	85	26	18	5	1111	1111	1111	1111
80	6854	7716	316	175	85	26	18	5	1111	1111	1111	1111
81	6944	7816	316	175	85	26	18	5	1111	1111	1111	1111
82	7034	7916	316	175	85	26	18	5	1111	1111	1111	1111
83	7124	8016	316	175	85	26	18	5	1111	1111	1111	1111
84	7214	8116	316	175	85	26	18	5	1111	1111	1111	1111
85	7304	8216	316	175	85	26	18	5	1111	1111	1111	1111
86	7394	8316	316	175	85	26	18	5	1111	1111	1111	1111
87	7484	8416	316	175	85	26	18	5	1111	1111	1111	1111
88	7574	8516	316	175	85	26	18	5	1111	1111	1111	1111
89	7664	8616	316	175	85	26	18	5	1111	1111	1111	1111
90	7754	8716	316	175	85	26	18	5	1111	1111	1111	1111
91	7844	8816	316	175	85	26	18	5	1111	1111	1111	1111
92	7934	8916	316	175	85	26	18	5	1111	1111	1111	1111
93	8024	9016	316	175	85	26	18	5	1111	1111	1111	1111
94	8114	9116	316	175	85	26	18	5	1111	1111	1111	1111
95	8204	9216	316	175	85	26	18	5	1111	1111	1111	1111
96	8294	9316	316	175	85	26	18	5	1111	1111	1111	1111
97	8384	9416	316	175	85	26	18	5	1111	1111	1111	1111
98	8474	9516	316	175	85	26	18	5	1111	1111	1111	1111
99	8564	9616	316	175	85	26	18	5	1111	1111	1111	1111
100	8654	9716	316	175	85	26	18	5	1111	1111	1111	1111
101	8744	9816	316	175	85	26	18	5	1111	1111	1111	1111
102	8834	9916	316	175	85	26	18	5	1111	1111	1111	1111
103	8924	10016	316	175	85	26	18	5	1111	1111	1111	1111
104	9014	10116	316	175	85	26	18	5	1111	1111	1111	1111
105	9104	10216	316	175	85	26	18	5	1111	1111	1111	1111
106	9194	10316	316	175	85	26	18	5	1111	1111	1111	1111
107	9284	10416	316	175	85	26	18	5	1111	1111	1111	1111
108	9374	10516	316	175	85	26	18	5	1111	1111	1111	1111
109	9464	10616	316	175	85	26	18	5	1111	1111	1111	1111
110	9554	10716	316	175	85	26	18	5	1111	1111	1111	1111
111	9644	10816	316	175	85	26	18	5	1111	1111	1111	1111
112	9734	10916	316	175	85	26	18	5	1111	1111	1111	1111
113	9824	11016	316	175	85	26	18	5	1111	1111	1111	1111
114	9914	11116	316	175	85	26	18	5	1111			

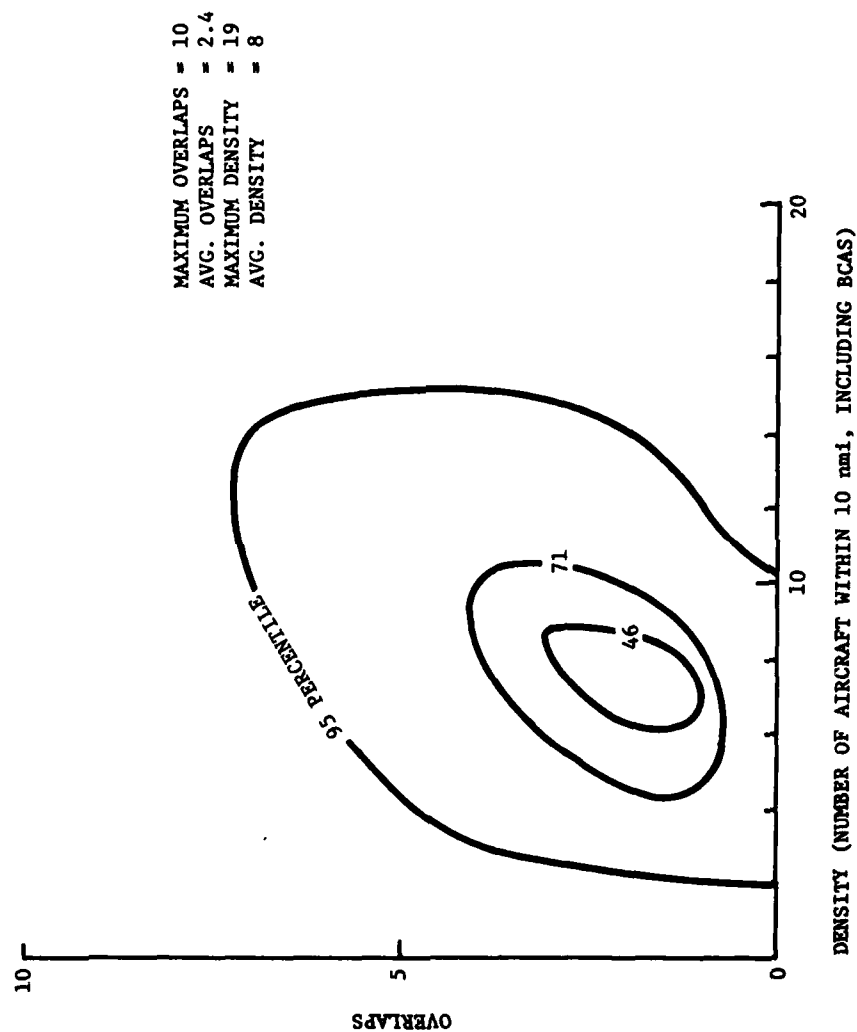


FIGURE A-17
 OVERLAPS VS DENSITY FOR LOS ANGELES DATA

APPENDIX B

DATA COLLECTED IN THE WASHINGTON AREA

The following Appendix from Reference 3 is repeated for convenience. To maintain consistency, section and figure numbers will remain as they were in Reference 3.

In the following Figures A-15, A-16, A-19, and A-20, which refer to density, the entry for a density of "1" has been omitted, since it refers to be BCAS aircraft itself and has no significance.

DATA COLLECTED IN WASHINGTON, D.C. AREA

A.1 Introduction

The data presented in this Appendix comes from the data reduction package mentioned in Section 2. It is principally a comparison of BCAS tracks with the tracks obtained by using the target reports from ARTS III data tapes in the Washington flights.

First, an overall view of the system is shown by a series of matrices for "real" BCAS tracks and for "phantom" BCAS tracks. This is followed by detailed tables and histograms of performance with such parameters as the number of overlapping replies and the density of aircraft in the airspace. The figures for this section will be found grouped together at the end of the section.

A.2 Overall Performance Characteristics

The Total Aircraft Track Matrix lists, for each scan and in each range-altitude bin, the number of tracked aircraft events obtained during the comparison interval. An aircraft track is determined principally by the presence of an ARTS track; however, if the ARTS track is lost and the corresponding BCAS track continues, the aircraft track is also continued. Thus an "aircraft track" implies a continuous process; whereas, an ARTS track is often a segmented process.

Total Aircraft Tracks are described by two matrices:

1. Range versus Altitude Matrix, denoted $A(r,z)$ (Figure A-1)

where $\bar{r}$ - is the integerized range of an ARTS* track:

$\bar{r} = \text{INTEGER}(r) + 1$; this implies that the range of a track is, at most, r nautical miles from BCAS aircraft.

$\bar{z}$ - is the relative altitude quantized into 500 foot bins.

$$\bar{z} = (\text{BCASALT MINUS THREAT ALT PLUS } 10,000)/500;$$

e.g., suppose an aircraft is 5.597 nautical miles away from our BCAS equipped aircraft and has an altitude of 12,000 feet. Let BCAS altitude = 7,300 feet.

Then $\bar{r} = 5.597 + 1 = 6$

$$\bar{z} = (7,300 - 12,000 + 10,000)/500 = 4800/500 = 9.6 \approx 10$$

So $(\bar{r}, \bar{z})$ is put in the $\bar{r}, \bar{z}$ slot of $A(r,z)$.

Any aircraft having relative altitude, greater than 10,000 feet is counted as relative 10,000 feet.

2. Range versus Range Rate Matrix, denoted as $JKR(r,k)$ (Figure A-2)

where $\bar{r}$ - is the integerized range of an ARTS track;

$\bar{k}$ - is the range rate in knots of an ARTS track quantized into 30 knot bins.

$$\bar{k} = (\text{Range rate of threat aircraft} * 3,600 + 600)/30;$$

* As previously noted, the BCAS range is used in certain instances, when an ARTS track is lost.

e.g., let 3.79 be the relative range of a threat aircraft and -0.056 be its range rate (nmi/sec).

Then $\bar{r} = \text{INTEGER}(3.79) + 1 = 4$

$\bar{k} = (-0.056 * 3,600 + 600)/30 = 13.28 = 13$

So $(\bar{r}, \bar{k})$ is put in the $\bar{r}, \bar{k}$ slot of $\text{JKR}(\bar{r}, \bar{k})$.

Criteria for Track Association of a BCAS track with an ARTS track are as follows:

1. $\text{ABS}(\rho_B - \rho_A) < R_{\text{WIN}}$ & $\text{ABS}(Z_B - Z_A) < H_{\text{WIN}}$
where ρ_B is relative range of aircraft being tracked by BCAS and ρ_A is relative range of ARTS aircraft;
 R_{WIN} is range window. H_{WIN} is altitude window. Z_B is altitude of aircraft being tracked by BCAS and Z_A is the altitude of an aircraft being tracked by the ARTS site (i.e., Washington National). R_{WIN} is set initially to 0.99 nmi and H_{WIN} is set initially to 299 feet.

2. Both ARTS tracks and BCAS tracks must be established.
An ARTS track is considered to be established when it reaches an age of 30 seconds, unless an established BCAS track associates with it, in which case two successive ARTS reports are required in order for the track to become established. BCAS tracks are established at an age of 10 seconds, increasing linearly with range to a maximum of 30 seconds at 20 nmi.

Total BCAS Associated Aircraft Track Matrices represent the total number of BCAS tracks* that were successfully associated with corresponding aircraft tracks during the course of the comparison interval. There are two associated BCAS track matrices. They are as follows:

1. Range vs. ALT matrix (Figure A-3) - denoted $ASC(r,z)$ where r,z represents the range and altitude of an ARTS track with which a BCAS track successfully associates. However, if the ARTS track is temporarily lost, the r and z of the associated BCAS track is used.

$$ASC(r,z) \subseteq A(r,z)$$

2. Range vs. Range Rate matrix (Figure A-4) - denoted $RATE(r,k)$ where r,k represents the range and speed of an ARTS track with which a BCAS track successfully associates.

$$RATE(r,k) \subseteq JKR(r,k)$$

Ratio of BCAS Associated Aircraft Tracks to Total Aircraft Tracks gives the ratios of the preceding matrices and indicate the overall capability of BCAS to track aircraft within a radius of 20 nmi. These appear as Figures A-5 and A-6.

ARTS - BCAS Track Association Summary Tables (on a per mile basis) can be defined in the following way:

$$R_n = \sum_{n=1}^{20} B_n / A_n$$

* Here, BCAS tracks are those which remain after removing phantom tracks (see Section 6).

where B_n is the number of times a BCAS track associated with an aircraft track whose range was n nmi, and A_n is the total number of aircraft tracks at n nmi (Figures A-7 through A-9).

Cumulative Summary Table of BCAS associated aircraft tracks to total aircraft tracks (Figure A-10) is defined as follows:

$$\text{Cumulative ratio} = \sum_{S=1}^{20} (B_S + B_K) / (A_S + A_K)$$

where B_S , number of times a BCAS track associated with an aircraft track whose range was S nmi.

$$B_K = \sum_{J=1}^{S-1} B_J, \text{ total number of times a BCAS track associated with an aircraft track from 1 to (S-1) nmi.}$$

A_S , total number of aircraft tracks at S nmi.

$$A_K = \sum_{J=1}^{S-1} A_J, \text{ total number of aircraft tracks from 1 to (S-1) nmi.}$$

Note: If $S-1 = 0$, then $B_K, A_K = 0$.

Phantom Probability Matrix (Figures A-11 and A-12) contains those BCAS tracks that have been defined as being phantoms.

1. Any BCAS track with no association history at all is considered to be a phantom.
2. Any BCAS track not having either three consecutive associations, or at least 50 percent association, is also labeled as being a phantom.

Each entry consists of the number of scans that phantom tracks were found to exist divided by the total number of scans. If a BCAS track is found to be a phantom track, its entire track history is put into the phantom matrix. In addition, the association matrix is also modified, thus removing phantoms from it.

A.3 Detailed Tables and Histograms

The preceding paragraphs provide the overall performance of BCAS. In order to understand some of the underlying relationships various other analyses were made. The following paragraphs examine the variation of performance with two major parameters, the number of overlapping replies and the number of aircraft in the airspace. These tables were compiled directly from ARTS and BCAS track data. No attempt was made here to distinguish between real and phantom tracks. In general, the results with the Basic system are presented first, followed by those for the Whisper-shout system.

The Track density table of ARTS peak traffic conditions

(table A-1) provides the following for established ARTS tracks:

1. The range within which the indicated maximum number of overlaps occurs, and the time at which it occurs.
2. The range within which the indicated maximum number of aircraft (ARTS tracks only) occurs, and the time at which it occurs.

TABLE A-1
PEAK TRAFFIC CONDITIONS

RANGE	MAX OVERLAPS	TIME	MAX AIRCRAFT	TIME
2.50	3	53463	4	54602
5.00	5	52512	5	52512
7.50	7	53877	10	52071
10.00	9	52559	14	52569
15.00	9	52559	21	52602
20.00	9	52559	23	53750

Overlaps within a given range interval, J, are computed as follows:

Given: A_k , where k denotes the number of tracks, A, in an ARTS environment,

$$O_i = \left\{ \left(R(A_i) - 1.65 \right) \leq N \leq \left(R(A_i) + 1.65 \right) \right\} ; \quad i = 2, k; R(A_i) \leq J$$

where N represents number of aircraft whose range falls within the overlap interval i.

$O_i = N-1$ since the aircraft for which the overlaps are computed is not counted.

$R(A_i)$ stands for Range of track A_i .

Therefore, maximum overlaps within given interval J (denoted MAXJ) is defined as follows:

$$\text{MAXJ} = \text{MAX}(O_1, O_2, \dots, O_h)$$

For example, suppose A_2, A_3, A_4, A_5 are BCAS tracks with range of 1.67, 2.47, 3.43, 5.19 nmi away from BCAS Equipped Aircraft (A_1).

Then to compute the Maximum Number of Overlaps within a given range interval (5 nmi) do as follows:

1. First count number of aircraft within overlap interval of A_2 . Clearly, $R(A_2)$ and $R(A_3)$ falls within overlap interval of A_2 since:

$$\{1.67 - 1.65 \leq R(A_2) \leq 1.67 + 1.65\} \text{ and} \\ \{1.67 - 1.65 \leq R(A_3) \leq 1.67 + 1.65\} \text{ and } R(A_2) \leq 5 \text{ nmi}$$

So there are two aircraft within overlap interval of A_2 .

$$\therefore N = 2$$

$O_2 = N - 1 = 1$ since the aircraft A_2 for which the overlaps are computed is not counted.

2. Now count the number of aircraft within overlap interval of A_3 .

Clearly, $R(A_2)$, $R(A_3)$, $R(A_4)$ falls within overlap interval of A_3 and $R(A_3) \leq 5$ nmi.

$$\therefore N = 3$$

$O_3 = N - 1 = 2$ OVERLAPS since the aircraft A_3 for which the overlaps are computed is not counted.

3. Count number of aircraft within overlap interval of A_4 .

Clearly, $R(A_2)$, $R(A_3)$, $R(A_4)$ falls within overlap interval of A_4 and $R(A_4) \leq 5$ nmi.

$$\therefore N = 3 \text{ aircraft}$$

$O_4 = N - 1 = 2$ OVERLAPS since the aircraft A_4 for which overlaps are computed is not counted.

4. Since $R(A_5) > 5$ nmi, its overlaps are not considered.

Therefore, $\text{MAX}(0_2, 0_3, 0_4) = \text{MAX}(1, 2, 2) = 2$ Overlaps.

So the maximum number of overlaps within 5 nmi is 2.

ARTS Association vs. the Number of Overlapping Replies is shown in Figure A-13 for the Basic mode; Figure A-14 is for Whisper-shout. ARTS tracks are listed as being associated with BCAS tracks or unassociated, as the case may be. The resulting histograms are shown.

Overlaps of ARTS traffic versus percent associations can be defined as follows:

$$R_{OVP} = \sum_{VP=0}^{12} A_{OVP} / (A_{OVP} + M_{OVP} + 0.01) * 100$$

where A_{OVP} is the total number of associated ARTS tracks with OVP overlaps and

M_{OVP} is the total number of unassociated ARTS tracks with OVP overlaps. $(A_{OVP} + M_{OVP})$ represents total ARTS tracks with OVP overlaps.

This data has been truncated so as to include only those tracks within 10 nmi and above 15 degrees depression angle.

ARTS association vs. density of aircraft is given in the next set of data, Figures A-15 and A-16. The data truncation beyond 10 nmi and below 15 degrees depression angle applies here. We define density here as the number of established ARTS tracks within 10 nmi of the BCAS aircraft. Therefore a "density" of 31

aircraft corresponds to 0.1 aircraft per nmi^2 . The percent association is determined by evaluating the fraction

$$A_K = NA_K / (NA_K + M_K)$$

where NA_K = number of associations in a density of K aircraft.

M_K = number of missed association in a density of K aircraft.

BCAS track correlation vs. overlaps is shown, for associated BCAS tracks, in Figures A-17 and A-18. Correlation describes the status of the BCAS track at every scan interval (about 4.7 seconds). If the BCAS track does not correlate with a BCAS report at that time, the track is tagged with a coast status flag. Correlation is therefore the fraction of time that a track is not in coast status. ARTS data is used to determine how many overlapping replies exist for each BCAS track sample. The data is truncated at 10 nmi and 15 degrees.

BCAS track correlation vs. density relates BCAS coasting to the density of aircraft within 10 nmi. Figures A-19 and A-20 shows this data, for the Basic and the Whisper-shout systems, respectively.

BCAS Consecutive cost characteristics for associated tracks are shown in Figure A-21.

This consecutive coast status is obtained directly from the BCAS data tapes with the 1-second interrogation rate.

Association performance as a function of the range and overlaps is presented in Figure A-22. The data is truncated at 10 nmi and 15 degree depression angle.

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RESULTS OF AN ACTIVE BEACON COLLISION AVOIDANCE EXPERIMENT COND--ETC(U)

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Association performance as a function of the density and overlaps
is presented in Figure A-23. Here, too, the data is truncated
as noted.

		BASIC MODE																				RELATIVE RANGE (NM)																						
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			
ABOVE BCAS	10000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BELOW BCAS	5000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

FIGURE A-1
TOTAL AIRCRAFT TRACK MATRIX (R VS Z)

RANGE RATE	BASIC MODE																				RELATIVE RANGE (NM)			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20				
-600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-570	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-540	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-510	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-480	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-450	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-420	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-390	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-360	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-330	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
-30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
330	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
360	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
390	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
420	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
450	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
480	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
510	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
540	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
570	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
CLOSING																								
66	240	400	422	528	686	743	663	792	796	992	319	604	609	974	375	1386	913	646	566					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20					

FIGURE A-2
TOTAL AIRCRAFT TRACK MATRIX (R VS R)

RELATIVE ALTITUDE (FEET)	BASIC NODE																				RELATIVE RANGE (NM)									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	1	2	3	4	5	6	7	8	9	10
10000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-2500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-3000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-3500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-4000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-4500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-5000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-5500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-6000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-6500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-7000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-7500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-8000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-8500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-9000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-9500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-10000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

FIGURE A-3
TOTAL BCAS ASSOCIATED AIRCRAFT TRACK MATRIX (R VS Z)

		BASIC MODE																				RELATIVE RANGE (MGT)									
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20										
CLOSING	-600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-570	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-540	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-510	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-480	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-450	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-420	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-390	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-360	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-330	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SEPARATING	-300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL		51	169	290	334	366	548	519	449	606	586	712	660	594	579	518	586	555	445	537	314										

FIGURE A-4
TOTAL BCAS ASSOCIATED AIRCRAFT TRACK MATRIX (R VS R)

[illegible]

FIGURE A-5
RATIO OF SCAS ASSOCIATED AIRCRAFT TRACKS
TO TOTAL AIRCRAFT TRACKS (R VS Z)

[illegible]

FIGURE A-8
RATIO OF ECAS ASSOCIATED AIRCRAFT TRACKS TO
TOTAL AIRCRAFT TRACKS (R VS R)

RANGE	TOTAL	ASSOC.	ZA
1	66	51	77
2	240	169	70
3	400	290	72
4	422	334	73
5	528	366	69
6	686	548	79
7	740	519	70
8	663	449	67
9	792	606	76
10	796	586	73
11	992	712	71
12	1019	660	64
13	964	594	61
14	969	579	59
15	974	518	53
16	1075	586	54
17	1086	553	50
18	913	445	48
19	646	307	47
20	586	314	53

FIGURE A-7
AIRCRAFT ASSOCIATION, FOR EACH MILE, FOR ALL ALTITUDES

a) RELATIVE ALT GREATER THAN 5K FT				b) RELATIVE ALT LESS THAN 5K FT			
RANGE	TOTAL	ASSOC.	ZA	RANGE	TOTAL	ASSOC.	ZA
1	0	0	0.	1	35	34	97.
2	0	0	0.	2	51	49	96.
3	8	8	100.	3	57	57	100.
4	22	19	86.	4	56	56	100.
5	22	18	82.	5	71	65	92.
6	44	38	86.	6	94	90	96.
7	37	27	73.	7	115	106	92.
8	23	18	78.	8	111	102	92.
9	69	62	90.	9	117	105	90.
10	65	53	82.	10	140	114	81.
11	54	35	65.	11	157	121	77.
12	56	51	91.	12	154	113	73.
13	63	59	94.	13	191	126	66.
14	97	83	86.	14	176	102	58.
15	112	93	83.	15	142	76	54.
16	110	100	91.	16	125	52	42.
17	111	63	57.	17	140	48	34.
18	116	69	59.	18	98	41	42.
19	91	67	74.	19	75	37	49.
20	63	55	87.	20	76	42	55.

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FIGURE A-8
AIRCRAFT ASSOCIATION, EACH MILE, FOR VARIOUS ALTITUDE ZONES

c) RELATIVE ALT GREATER THAN -5K FT				d) RELATIVE ALT LESS THAN -5K FT			
RANGE	TOTAL	ASSOC.	ZA	RANGE	TOTAL	ASSOC.	ZA
1	28	15	54.	1	3	3	100.
2	89	66	74.	2	100	54	54.
3	139	102	73.	3	196	123	53.
4	173	143	81.	4	171	120	70.
5	203	129	64.	5	232	154	66.
6	257	214	83.	6	291	236	71.
7	279	177	63.	7	309	209	68.
8	276	168	61.	8	253	161	64.
9	236	165	70.	9	370	274	74.
10	281	182	65.	10	313	235	76.
11	339	221	65.	11	442	334	76.
12	363	196	54.	12	446	301	67.
13	345	157	46.	13	365	251	69.
14	376	181	48.	14	320	213	67.
15	427	191	45.	15	293	158	54.
16	507	256	50.	16	333	177	53.
17	409	164	40.	17	426	280	66.
18	386	137	35.	18	313	196	63.
19	249	122	49.	19	231	81	35.
20	280	129	46.	20	167	91	54.

FIGURE A-8
AIRCRAFT ASSOCIATION, EACH MILE, FOR VARIOUS ALTITUDE ZONES (CONTINUED)

> 5K FT ABOVE	IR	(0-5)	(6-10)	(11-15)	(16-20)
	IT	52	238	362	491
	IA	45	198	321	354
	IZ	86.5	85.2	84.0	72.1
0 TO 5K FT ABOVE	IR	(0-5)	(6-10)	(11-15)	(16-20)
	IT	27	577	82	514
	IA	261	517	538	220
	IZ	96.7	85.6	65.6	42.8
0 TO 5K FT BELOW	IR	(0-5)	(6-10)	(11-15)	(16-20)
	IT	632	1329	1850	1831
	IA	452	906	946	808
	IZ	71.5	68.2	51.1	44.1
> 5K FT BELOW	IR	(0-5)	(6-10)	(11-15)	(16-20)
	IT	702	1533	1666	1470
	IA	454	1085	1257	825
	IZ	64.7	73.8	67.4	56.1

FIGURE A-9
BCAS PERFORMANCE FOR VARIOUS ALTITUDE AND RANGE ZONES

RANGE	TOTAL	ASSOC.	ZA
1	66	51	77.3
2	306	220	71.9
3	736	510	72.2
4	1128	844	74.8
5	1656	1210	73.1
6	2342	1758	75.1
7	3082	2277	73.9
8	3745	2726	72.8
9	4537	3332	73.4
10	5333	3918	73.5
11	6325	4630	73.2
12	7344	5290	72.3
13	8308	5884	70.8
14	9277	6463	69.7
15	10251	6981	68.1
16	11326	7567	66.8
17	12412	8120	65.4
18	13325	8565	64.3
19	13971	8872	63.5
20	14557	9186	63.1

FIGURE A-10
CUMULATIVE PERCENT OF AIRCRAFT ASSOCIATION

PHANTOM RATE WITHIN 5 NM= 0.37732
PHANTOM RATE WITHIN 10 NM= 3.96247
PHANTOM RATE WITHIN 15 NM= 1.47113
PHANTOM RATE WITHIN 20 NM= 1.88865

FIGURE A.11

[illegible]

FIGURE A.12
PROBABILITY OF PHANTOM OCCURRENCES (R VS R_i)

OVERLAPS	0	655
	1	728
	2	750
	3	560
	4	284
	5	134
	6	73
	7	34
	8	15
	9	0
	10	0
	11	0
	12	0

a) NUMBER OF SUCCESSFUL ASSOCIATIONS

OVERLAPS	0	237
	1	307
	2	354
	3	251
	4	128
	5	58
	6	44
	7	16
	8	5
	9	3
	10	0
	11	0
	12	0

b) NUMBER OF MISSED ASSOCIATIONS

OVERLAPS	0	73
	1	70
	2	68
	3	69
	4	69
	5	70
	6	62
	7	60
	8	75
	9	0
	10	1111
	11	1111
	12	1111

c) PERCENT ASSOCIATION

NOTE: DATA TRUNCATED AT 10 MW
AND 15° DEPRESSION ANGLE

FIGURE A-13
ARTS ASSOCIATION VS. OVERLAPS (BASIC)

OVERLAPS	0	.....	671
	1	.....	700
	2	.....	624
	3	.....	667
	4	.....	344
	5	.....	171
	6	.....	98
	7	.....	47
	8	.....	9
	9	.....	1
	10	.....	0
	11	.....	0
	12	.....	0

a) NUMBER OF SUCCESSFUL ASSOCIATIONS

OVERLAPS	0	.....	206
	1	.....	277
	2	.....	281
	3	.....	187
	4	.....	67
	5	.....	48
	6	.....	31
	7	.....	19
	8	.....	11
	9	.....	3
	10	.....	0
	11	.....	0
	12	.....	0

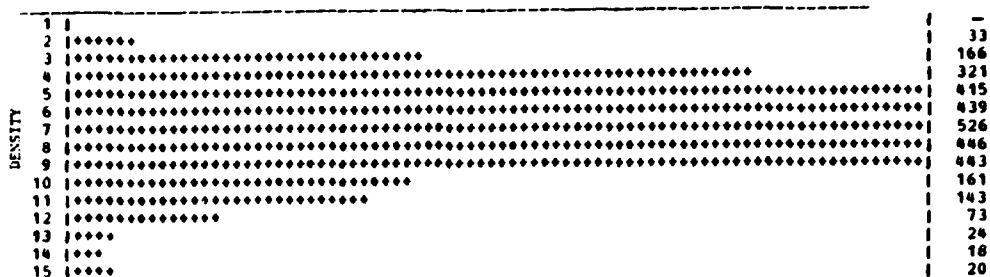
b) NUMBER OF MISSED ASSOCIATIONS

OVERLAPS	0	.....	76
	1	.....	74
	2	.....	74
	3	.....	78
	4	.....	84
	5	.....	78
	6	.....	76
	7	.....	71
	8	.....	45
	9	.....	25
	10	.....	1111
	11	.....	1111
	12	.....	1111

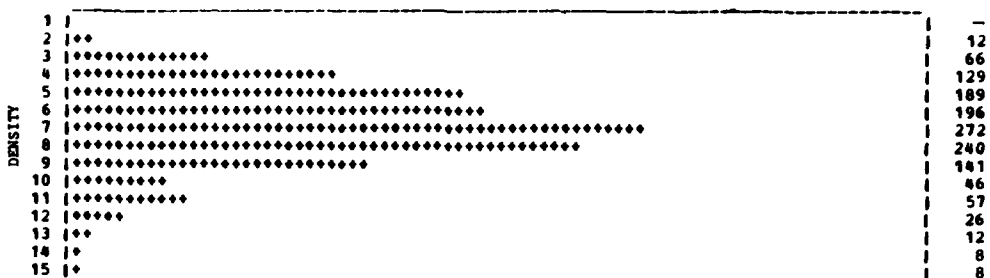
c) PERCENT ASSOCIATION

NOTE: DATA TRUNCATED AT 10 NMH
AND 15° DEPRESSION ANGLE

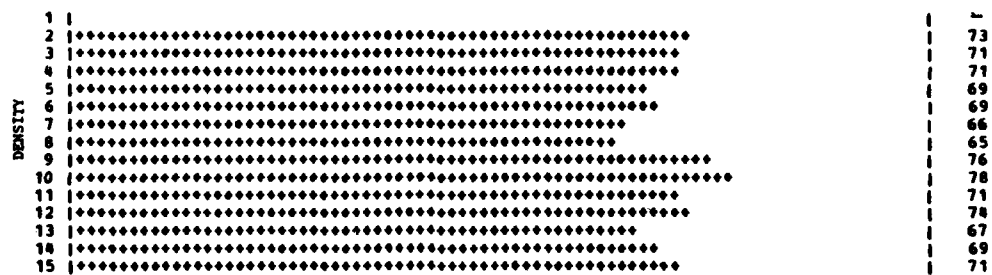
FIGURE A-14
ARTS ASSOCIATION VS. OVERLAPS (WHISPER-SHOUT)



a) NUMBER OF SUCCESSFUL ASSOCIATIONS



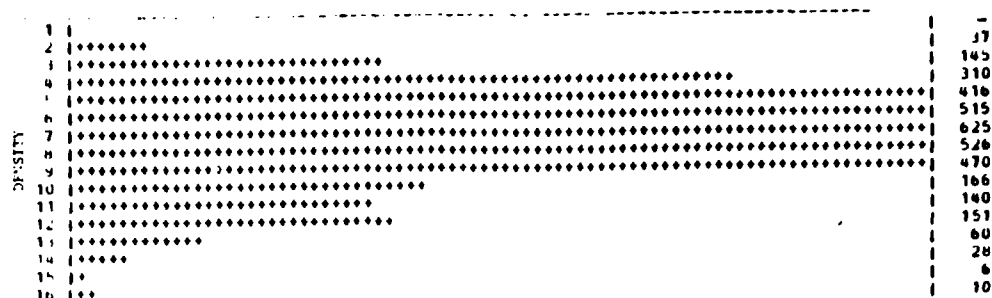
b) NUMBER OF MISSED ASSOCIATIONS



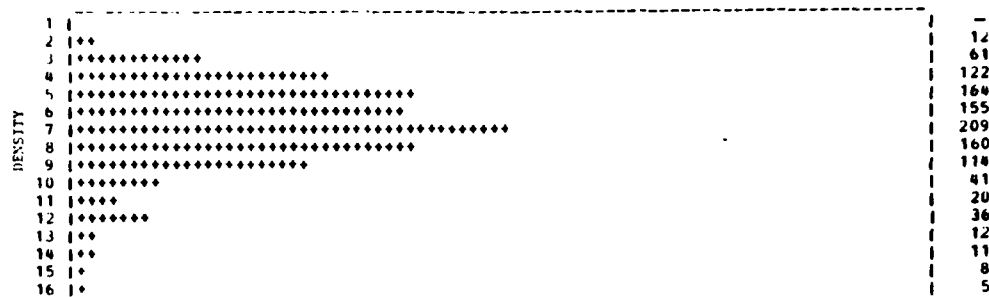
c) PERCENT ASSOCIATION

NOTE: 1. DATA TRUNCATED AT 10 NMI
AND 15° DEPRESSION ANGLE
2. DENSITY = THE NUMBER OF
AIRCRAFT WITHIN 10 NMI

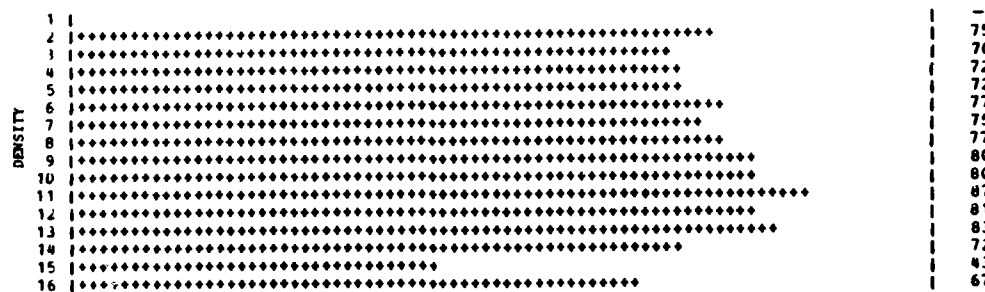
FIGURE A-15
ARTS ASSOCIATION VS. AIRCRAFT DENSITY (BASIC)



a) NUMBER OF SUCCESSFUL ASSOCIATIONS



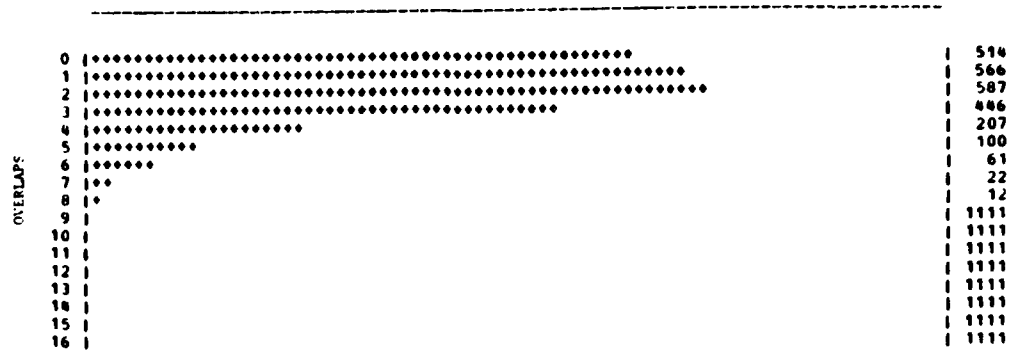
b) NUMBER OF MISSED ASSOCIATIONS



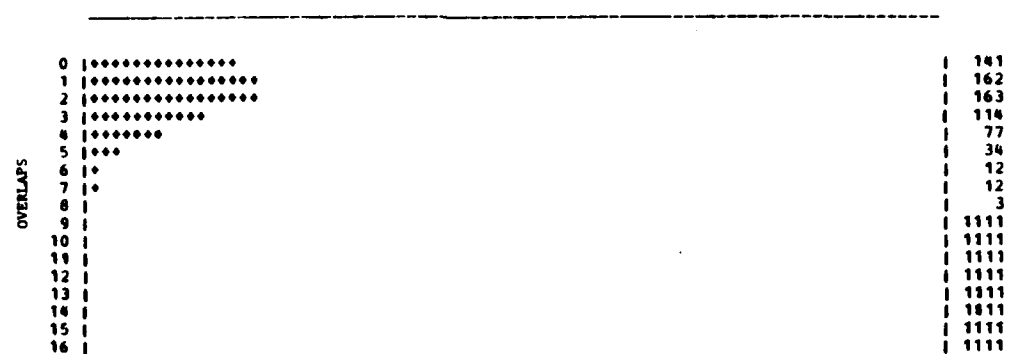
c) PERCENT ASSOCIATION

NOTE: 1. DATA TRUNCATED AT 10 NM
AND 15° DEPRESSION ANGLE
2. DENSITY = THE NUMBER OF
AIRCRAFT WITHIN 10 NM

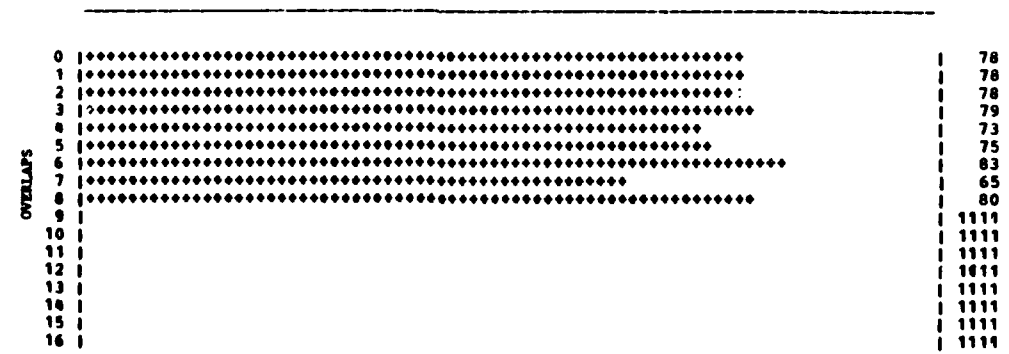
FIGURE A-18
ARTS ASSOCIATION VS. AIRCRAFT DENSITY (WHISPER-SHOUT)



a) NUMBER OF SUCCESSFUL CORRELATIONS



b) NUMBER OF COASTS



c) PERCENT CORRELATION

NOTE: DATA TRUNCATED AT 10 NMH
AND 15° DEPRESSION ANGLE

FIGURE A-17
BCAS TRACK CORRELATION VS. OVERLAPS (BASIC)

0	.....	512
1	.....	616
2	.....	675
3	.....	540
4	.....	279
5	.....	131
6	.....	78
7	.....	34
8	.....	7
9	.....	1
10		1111
11		1111
12		1111
13		1111
14		1111
15		1111
16		1111

a) NUMBER OF SUCCESSFUL CORRELATIONS

0	.....	159
1	.....	164
2	.....	149
3	.....	127
4	.....	65
5	.....	40
6	.....	20
7	.....	13
8	.....	2
9		1111
10		1111
11		1111
12		1111
13		1111
14		1111
15		1111
16		1111

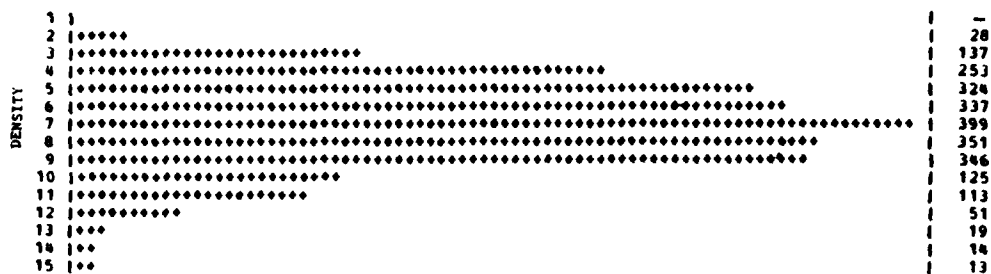
b) NUMBER OF COASTS

0	.....	76
1	.....	79
2	.....	82
3	.....	81
4	.....	81
5	.....	77
6	.....	79
7	.....	72
8	.....	78
9	.....	99
10		1111
11		1111
12		1111
13		1111
14		1111
15		1111
16		1111

c) PERCENT CORRELATION

NOTE: DATA TRUNCATED AT 10 NMH
AND 15° DEPRESSION ANGLE

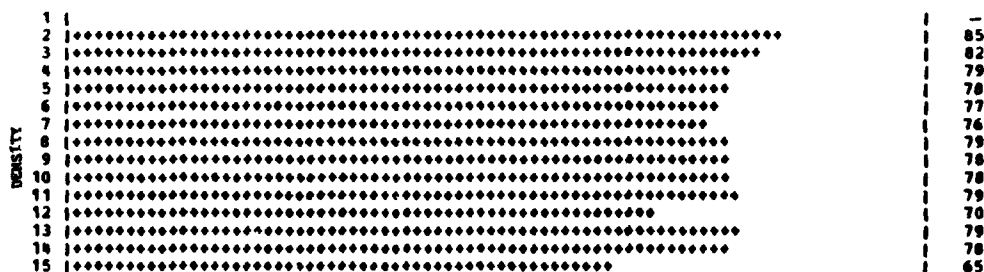
FIGURE A-18
BCAS TRACK CORRELATION VS. OVERLAPS (WHISPER-SHOUT)



a) NUMBER OF SUCCESSFUL CORRELATIONS



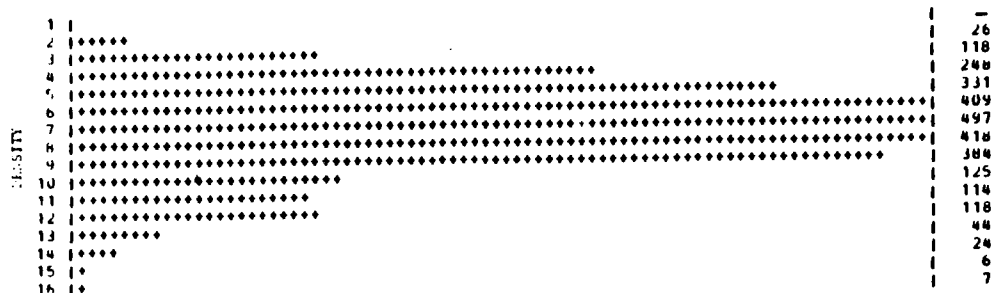
b) NUMBER OF COASTS



c) PERCENT CORRELATION

NOTE: DATA TRUNCATED AT 10 NMH
AND 15° DEPRESSION ANGLE

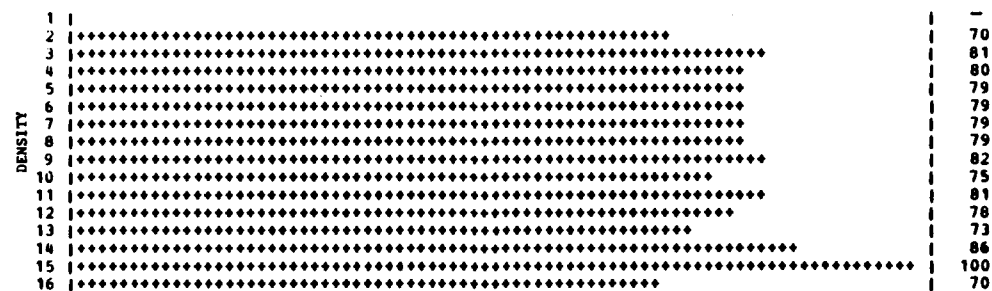
FIGURE A-18
SCAS TRACK CORRELATION VS. DENSITY (BASIC)



a) NUMBER OF SUCCESSFUL CORRELATIONS



b) NUMBER OF COASTS



c) PERCENT CORRELATION

DATA TRUNCATED AT 10 NMI
AND 15° DEPRESSION ANGLE

FIGURE A-20
BCAS TRACK CORRELATION VS. DENSITY (WHISPER-SHOUT)

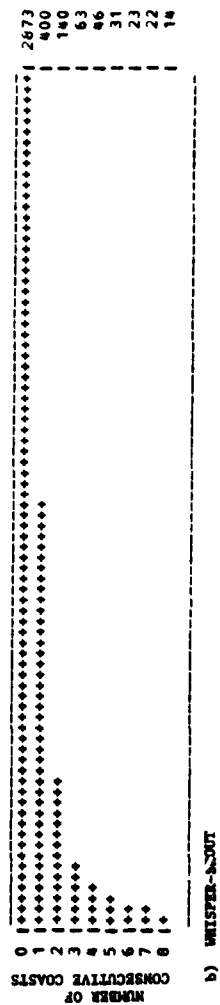
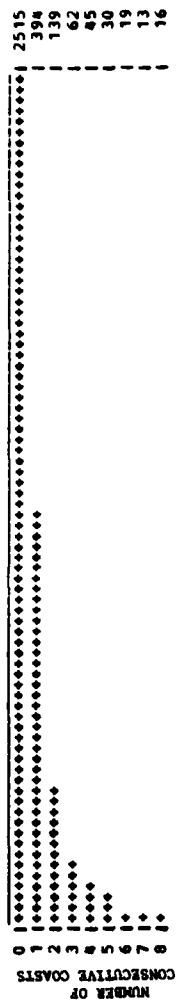
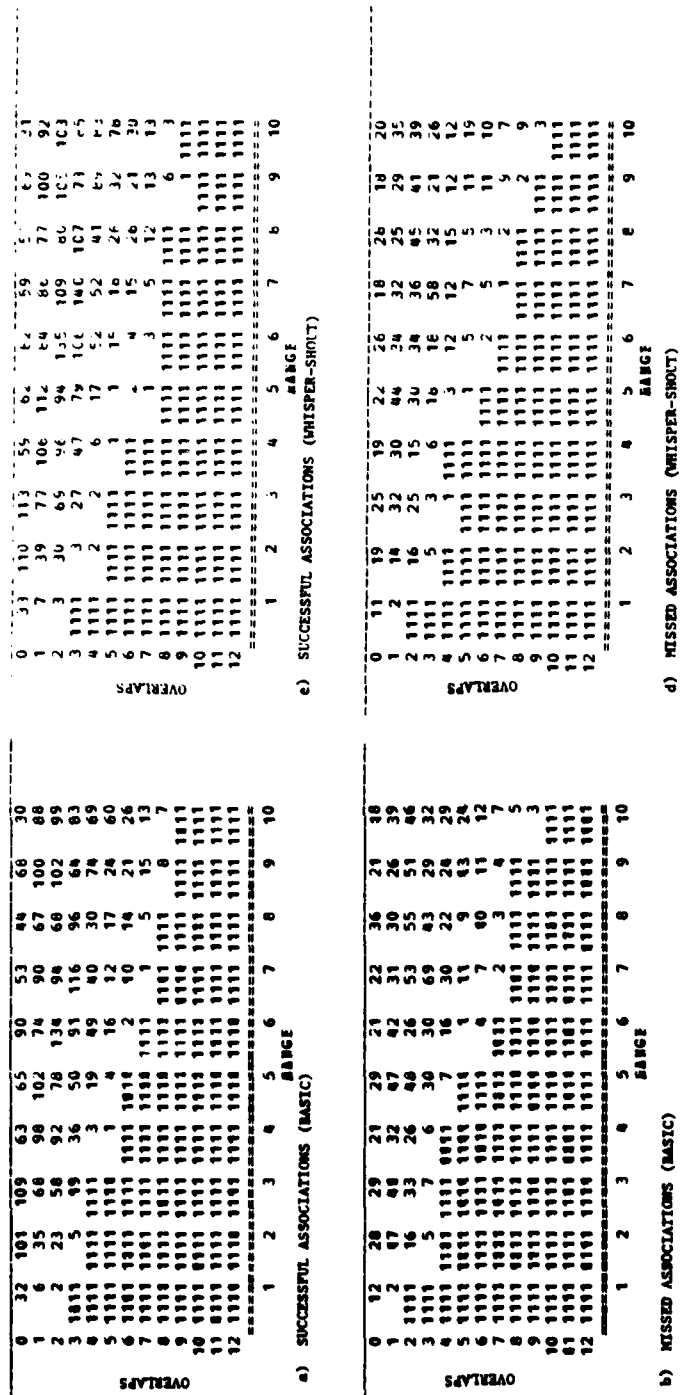


FIGURE A-21
BCAS CONSECUTIVE COAST STATUS FOR ASSOCIATED TRACKS



NOTE: DATA TRUNCATED AT 10 NRT
AND 15° DEPRESSION ANGLE

FIGURE A-32
ASSOCIATION PERFORMANCE AS A FUNCTION OF RANGE AND OVERLAPS

	1	2	3	4	5	6	7	8	9	10	11	12
1	3	1111	4	1111	1112	1111	1111	1111	1111	1111	1111	1111
2	36	1	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111
3	117	34	3	1	1112	1111	1111	1111	1111	1111	1111	1111
4	5	112	31	4	2	1111	1111	1111	1111	1111	1111	1111
5	116	112	1	4	2	1111	1111	1111	1111	1111	1111	1111
6	169	166	89	18	3	1111	1111	1111	1111	1111	1111	1111
7	66	161	177	141	37	33	8	2	1111	1111	1111	1111
8	40	79	116	167	89	42	4	7	1111	1111	1111	1111
9	29	54	116	123	84	33	18	4	1111	1111	1111	1111
10	1	16	20	35	41	22	16	5	1111	1111	1111	1111
11	4	37	35	24	6	22	6	1111	1111	1111	1111	1111
12	7	37	35	24	6	22	6	1111	1111	1111	1111	1111
13	4	7	16	7	18	9	2	2	1111	1111	1111	1111
14	1	5	4	3	1	4	5	1	1111	1111	1111	1111
15	1	1111	1	1	1113	1111	1	2	1111	1111	1111	1111
16	2	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
17	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
18	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
19	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
20	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
21	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
22	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
23	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
24	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
25	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
26	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
27	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
28	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
29	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
30	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
31	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
32	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
33	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
34	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
35	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
36	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
37	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111
38	1	1111	1111	1	3	1111	1111	1	2	1111	1111	1111

e) **SUCCESSFUL CORRELATIONS (WHISPER-SHOUT)**

9	6	0	3	2	1000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0
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a) **SUCCESSFUL CORRELATIONS (BASIC)**

[illegible]

4) MISSED CORRELATIONS (MISSING-ENTRY)

3	1100	1100	0	1111	0011	1101	1101	0011	1101	1101	1101	1101	0111	1
2	12	1111	0001	0011	1111	1111	1111	1111	1111	1111	1111	1111	0111	1
3	43	17	5	1	1111	1111	1111	1111	1111	1111	1111	1111	0111	12
0	61	05	16	2	3	2	1111	1111	1111	1111	1111	1111	0111	12
5	68	59	57	6	3	2	2	0011	1111	1111	0011	1111	0111	189
6	25	75	54	41	3	0	0101	1111	0011	0001	1111	1111	0111	189
7	22	54	69	75	26	15	5	2	1111	0100	1101	1111	0001	272
0	11	29	72	55	97	15	6	3	1111	0101	1101	1111	0111	260
9	3	12	46	38	25	6	0	3	1111	0111	1111	1111	1111	161
0	1111	6	14	6	3	4	0101	1111	1111	1111	1111	1111	1111	46
12	1111	2	8	13	5	0	10	2	1000	1111	1111	1111	1111	57
12	1111	1	8	2	3	0	1000	1111	1111	1111	1111	1111	0111	26
12	0111	1	3	3	3	1	0101	1111	1	2	1111	1111	1111	82
04	0111	1110	3	1	1000	1111	1111	1	2	1	1111	1111	1111	8
15	1111	0101	1	1	0	1	1111	1101	2	2	1111	1111	1111	8
237	307	354	251	128	58	46	16	5	3	0	0	0	1	1403

b) MIXED CORRELATIONS (ELASTIC)

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APPENDIX C

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