ATCRBS Reply Environment at Memphis International Airport

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16. Abstract

This report demonstrates, through data and analysis, how the airport environment can affect ATCRBS surveillance. The Lincoln Laboratory ATCRBS Monopulse Processing Subsystem was used to collect reply data at Memphis International Airport during March 1991. These data show a correlation between aircraft density, potential reflectors, and ATCRBS reply integrity. The number of replies has been shown to be directly related to multipath from reflecting surfaces, including taxiing aircraft. Additionally, it is shown that conditions can exist during which not all of the replies from ATCRBS equipped aircraft can be processed when forming target report measurements. Finally, it is shown that the bunching of replies in both time and space can introduce reply decoder overloading.

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EXECUTIVE SUMMARY

The Lincoln Laboratory Precision Runway Monitor (PRM) program was tasked in 1987 to evaluate how the improved surveillance data quality of a Mode S monopulse Air Traffic Control Radar Beacon System (ATCRBS) sensor may be used to enhance the monitoring of parallel runway approaches. The experimental Lincoln Laboratory real-time ATCRBS Monopulse Processing Subsystem (AMPS) of a Mode S sensor was modified for this program to collect data on the PRM performance.

The analysis of many flight tests and data collections of targets of opportunity has confirmed that the Mode S sensor can provide reliable surveillance of aircraft equipped with ATCRBS transponders during parallel approaches. However, analysis also indicated that an increase in the number of replies received by the sensor, associated with close-in surveillance of aircraft within 5 nmi of the sensor, could cause problems with ATCRBS reply detection and reply processing. Specifically, two phenomena can contribute to this signal degradation: multiple reply paths (multipath) and the close proximity of numbers of aircraft to one another.

This report presents the results of a study designed to describe the ATCRBS reply environment at Memphis International Airport (MEM) and its effect on reply integrity. ATCRBS reply data were collected at MEM during March, 1991, using the AMPS. Four azimuth quadrants were sampled separately: North, East, South, and West. Statistics were then gathered on the number of garbled replies and on the number of sweeps during which decoder overload occurred in each quadrant.

Except at close range, reply sequences from true aircraft were not degraded significantly by removal of garbled replies. Replies from aircraft on or near the airport surface exhibited a high degree of garble. This garbling of true replies was probably due to overlap with multipath replies as well as to synchronous garble with nearby aircraft. The variability in the degree of garbling was attributed to non-persistent reflectors such as surface vehicles.

In general, multipath replies were associated with aircraft on or near the airport surface and were caused by replies reflecting off of airport structures and objects along the adjacent roadways. For example, the nearby ASR/beacon radar caused severe multipath, with significant numbers of false replies out to 10 nmi from the sensor. Almost all the multipath replies were garbled.

The North quadrant exhibited the most severe environment with respect to total reply density, multipath, reply garbling, and decoder overload. In general, the ATCRBS reply garbling percentages decreased with increasing range from the sensor. The start of the roll-off in the percent of garble was variable, suggesting that transient factors such as surface traffic can affect the reply environment. The data suggest that the high reply density inside 5 nmi significantly increased the probability of overlap between two or more replies during the same sweep, and that this region of high garble probability extended into the region of low reply density.

The data from the North quadrant had examples of the effect of multipath on ATCRBS surveillance. First, many reply sequences had associated multipath replies at longer range and often at a different azimuth from the direct-path replies. In addition, the data showed how the true replies can be missing for an extended period, while reflected replies are present. Finally,

some reply sequences showed that it is possible for the direct-path reply to be garbled while the multipath reply from the same scan is not.

Decoder overload occurred mostly in the North quadrant. The azimuths with the greatest overload density covered the major airport structures as well as the North approach lanes. Comparison of the occurrence of decoder overload with activity around the airport surface suggests that the severity of decoder overload is dependent on the concentration of potential reflectors as well as on aircraft activity. Persistent decoder overload was greatest when the presence of active, stationary surface transponders overlapped periods of peak activity.

The problem at MEM with multipath in the North quadrant highlights a potential problem at many airports: the radar is located at the opposite end of the major runway(s) from the terminal(s). Therefore, the multipath sources are not evenly distributed in azimuth with respect to the sensor. The major structures, aircraft parked at the terminal(s), and taxiing aircraft are concentrated in an azimuth wedge of less than 180 deg. This concentration of reflectors significantly increases the reply population in the azimuth wedge. Thus, the sensor must process a large number of replies, both garbled and ungarbled.

Two ways to possibly alleviate these surveillance problems are to increase the antenna elevation and to find a more central location for the antenna. Increased elevation reduces the potential for multipath. A central location, or one to the side of a major runway, would distribute the multipath sources more evenly. This in turn would decrease the effects of reply bunching and help eliminate the decoder overload syndrome.

A more robust means to alleviate surveillance problems would be to improve the processing algorithm for the "close-in" surveillance region. The correlation and tracking algorithms can be improved with enhanced velocity reasonableness tests, track initiation algorithms that ensure the uniqueness of tracks starting, and similar techniques for track maintenance.

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1. INTRODUCTION

The Lincoln Laboratory Precision Runway Monitor (PRM) program evaluated how the improved surveillance data quality of a Mode S monopulse Air Traffic Control Radar Beacon System (ATCRBS) sensor may be used to enhance the monitoring of parallel runway approaches. In support of that effort, an experimental Lincoln Laboratory real time ATCRBS Monopulse Processing Subsystem (AMPS) was modified and installed at the Memphis International Airport (MEM), Memphis, Tennessee. A variety of flight data was collected during 1988-1991.

The analysis of many flight tests and data collections on targets of opportunity confirmed that the Mode S sensor can provide reliable surveillance of aircraft equipped with ATCRBS transponders during parallel approaches. However, analysis also indicated that an increase in the number of replies received by the sensor, associated with close-in surveillance of aircraft within 5 nmi of the sensor, could cause problems with ATCRBS reply detection and reply processing. Specifically, two phenomena can contribute to this surveillance degradation: multiple reply paths (multipath), and the close proximity of numbers of aircraft to one another.

Multipath occurs when there is more than one signal path between the sensor and a transponder. The false, reflected replies can interfere with and distort the direct-path, or true, reply signal. Multipath (or, reflected) replies are caused by a variety of objects. Long-term, stable sources can be nearby structures and other stationary objects with the proper reflective properties. Transitory sources can be mobile objects such as vehicular traffic or taxiing aircraft.

The effects of multipath on ATCRBS replies are as varied as the causes of multipath: cancellation between replies; split replies; reply azimuthal errors; and, reply code corruption. These effects can persist to the point that the scan-by-scan consistency of aircraft surveillance is compromised, and tracking of an individual target may be lost for an extended period of time.

The close proximity of aircraft to one another can create a situation in which mode A or C replies from more than one aircraft to a given interrogation overlap. The loss in signal integrity caused by mixed reply signals can result in errors similar to those listed for multipath.

This report presents the results of a study designed to describe the ATCRBS reply environment at MEM and its effect on reply integrity. The material is presented through a series of figures and discussions. A qualitative overview of the reply population is presented, followed by a quantitative assessment of reply garbling and decoder overload over all azimuths. Finally, the surveillance region with the greatest reply degradation is analyzed in greater detail.

The discussions concentrate on the two phenomena mentioned above: multipath and aircraft density. While it is recognized that false replies uncorrelated in time (fruit) also contribute to reply garbling, no attempt was made to quantify their effect, as that has been analyzed in a variety of other reports.

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2. METHODS

ATCRBS reply data were collected at Memphis International Airport during March, 1991, using the Lincoln Laboratory AMPS. Figure 1 shows the airport layout, including the AMPS site and major structures.

2.1 AMPS

AMPS is an experimental radar system developed and built by Lincoln Laboratory. The sensor configuration at MEM consisted of a pair of 5-by-26-ft open array antennas mounted on a 3-channel rotary joint. An equipment van held the transmitters, receivers, and a Digital Equipment Corporation PDP 11/55 computer. The computer hosted all surveillance software.

The antennas rotated at a nominal 4.6-s scan rate. Because of hardware limitations, modifications to allow back-to-back (BTB) surveillance with a 2.3-s update period limited BTB surveillance to a maximum azimuth wedge of 135 deg. No limitations existed when operating with a single antenna face (4.6-s update period).

2.1.1 Interrogation Scheme

The AMPS processing of ATCRBS replies is based on an interrogation and reply time interval, called a sweep. The number of sweeps per second defines the pulse repetition frequency, or PRF. During each sweep, a single interrogation is transmitted over a 3-deg azimuth wedge, or beamwidth. The remaining time is used to detect and process the replies generated by aircraft within the beamwidth. The reply detection is done using a design in compliance with the FAA ER 2716, the production Mode S sensor specification. The processed replies are assembled by the reply processing hardware, then passed to the surveillance computer for correlation, target report formation, and dissemination. Each of these steps is described in detail in [1].

At Memphis, the interrogations alternated between mode A (aircraft code) and mode C (altitude) at a 90 PRF. This resulted in a maximum of 4 replies per target per beam dwell. A beam dwell is the time it takes for the beam to rotate one antenna beamwidth through an azimuth point.

The ATCRBS reply messages contain data fields with position, mode A or C information, and control information. The mode A/C field is a 16-bit word containing the 12-bit reply and 4 bits of control information. A second data field holds bit confidence information, either high or low, for each of the reply and control bits in the identity or altitude code. The ATCRBS message format is described in [1].

2.2 DATA COLLECTION

To support 360-deg data collection in 135-deg azimuth wedges, four quadrant maps were defined: North, East, South, and West. Each quadrant was centered on the respective compass direction: 0 deg, 90 deg, 180 deg, or 270 deg (see Figure 1). Adjacent quadrants had a 42.5-deg overlap.

Data collection occurred during periods of peak aircraft activity: arrival and/or departure pushes. Two sampling schemes were used. Data used for a general overview of the reply

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environment were collected in all quadrants consecutively for 30-40 min each. Data used for detailed analysis of increased-multipath sectors were recorded in the North quadrant for 90-min periods.

Sweep header and ATCRBS reply information were recorded on a 9-track, 800 bpi tape drive.

2.3 DATA EXTRACTION

Statistics were gathered on the number of garbled replies and on the number of sweeps during which decoder overload occurred. A reply was considered garbled if at least one of the confidence bits associated with the 12-bit mode A/C reply was set to low. Reply decoder overload was determined by a bit in the sweep header, set by the sensor software. Decoder overload occurs when all four reply decoders are in use and an additional reply is received. This occurrence signals a potential loss of the additional reply.

21

15

9

3   33

27

18L

WINCHESTER ROAD

B

18R

0   1   2

FT (x 1000)

C

D

E

36R

SWINNEA ROAD

AIRWAYS ROAD

A	FEDERAL EXPRESS
B	ATCT
C	TERMINAL
D	FUEL TANKS
E	POST OFFICE
F	ASR/BEACON RADAR

N

W   E

F

36L

SHELBY
DRIVE

S

A

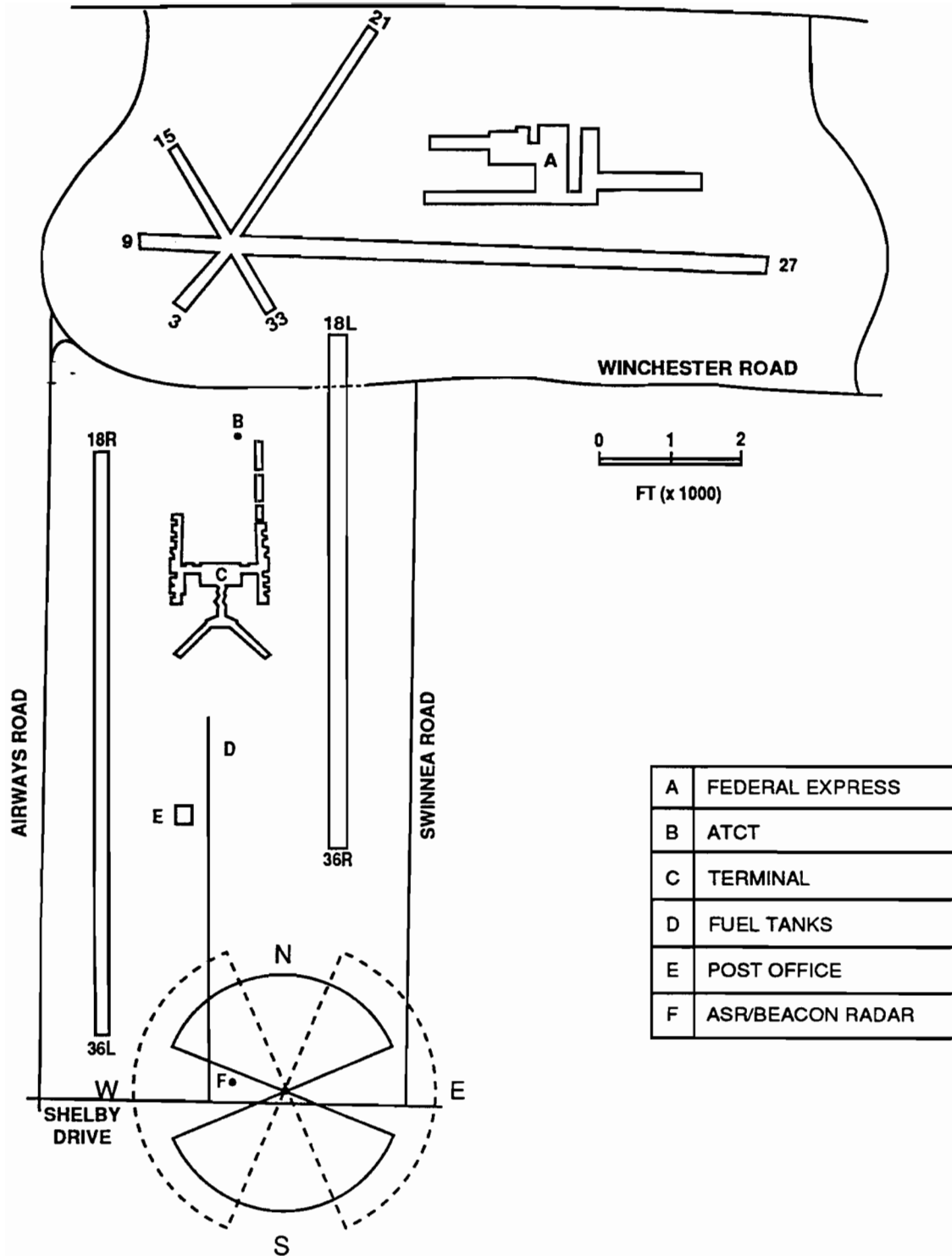*Figure 1.   MEM airport layout. The four surveillance quadrants are centered on the AMPS site.*

3. ATCRBS REPLY ENVIRONMENT

3.1 GENERAL COMMENTS

There was significant reply environment variability with respect to azimuth around the Memphis Airport. The greatest concentrations of reply traces from real aircraft were in the North and South quadrants, corresponding to the prevailing air traffic patterns. For this report, a reply trace consists of those replies that, with high probability, would be correlated into the target reports that become associated with a given aircraft track. Except at close range, the reply traces for all azimuths were not degraded significantly by removal of garbled replies. Replies from aircraft on or near the airport surface exhibited a high degree of garble. This was illustrated by the loss of reply trace information when garbled replies were removed. This garbling of true replies was probably due to overlap with multipath replies as well as to synchronous garble with nearby aircraft.

In general, multipath replies in the East, South and West quadrants were associated with aircraft on or near the airport surface, and were probably caused by replies reflecting off of objects along the adjacent roadways. In addition, the nearby ASR/beacon radar caused severe multipath, with significant numbers of false replies out to 10 nmi from the sensor. Almost all the multipath replies in these three quadrants were garbled.

Multipath replies in the North quadrant were mainly within 5 nmi of the sensor, and at azimuths between 300 deg and 40 deg. Most of the replies within this region, including the true (or direct-path) replies were garbled. This suggests synchronous garble, or some signal overlap, between true and/or multipath replies.

3.2 ANALYSIS BY QUADRANT

The following is a discussion of representative ATCRBS reply data for the four sample quadrants. One set of plots for each quadrant shows the (x, y) positions of all replies within 20 nmi of the sensor. Garbled replies are presented separately from the ungarbled replies. The other set of plots for each quadrant shows range, azimuth, mode A and mode C information versus scan number for the same data set. This second set of plots show the information for all replies in the left-hand column, and for ungarbled replies in the right-hand column.

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Figures 2 and 3 illustrate the reply environment in the East quadrant. The non-persistent, random replies in the plots are fruit and/or multipath replies. In general, there was insignificant garble to the east, except close to the sensor. The azimuth and range information in Figure 3a show bands of garbled replies within 1 nmi of the sensor around scans 300, 370, and 445. These bands suggest reflections from buildings and vehicles along Swinnea Road and Shelby Drive.

(a)   (b)
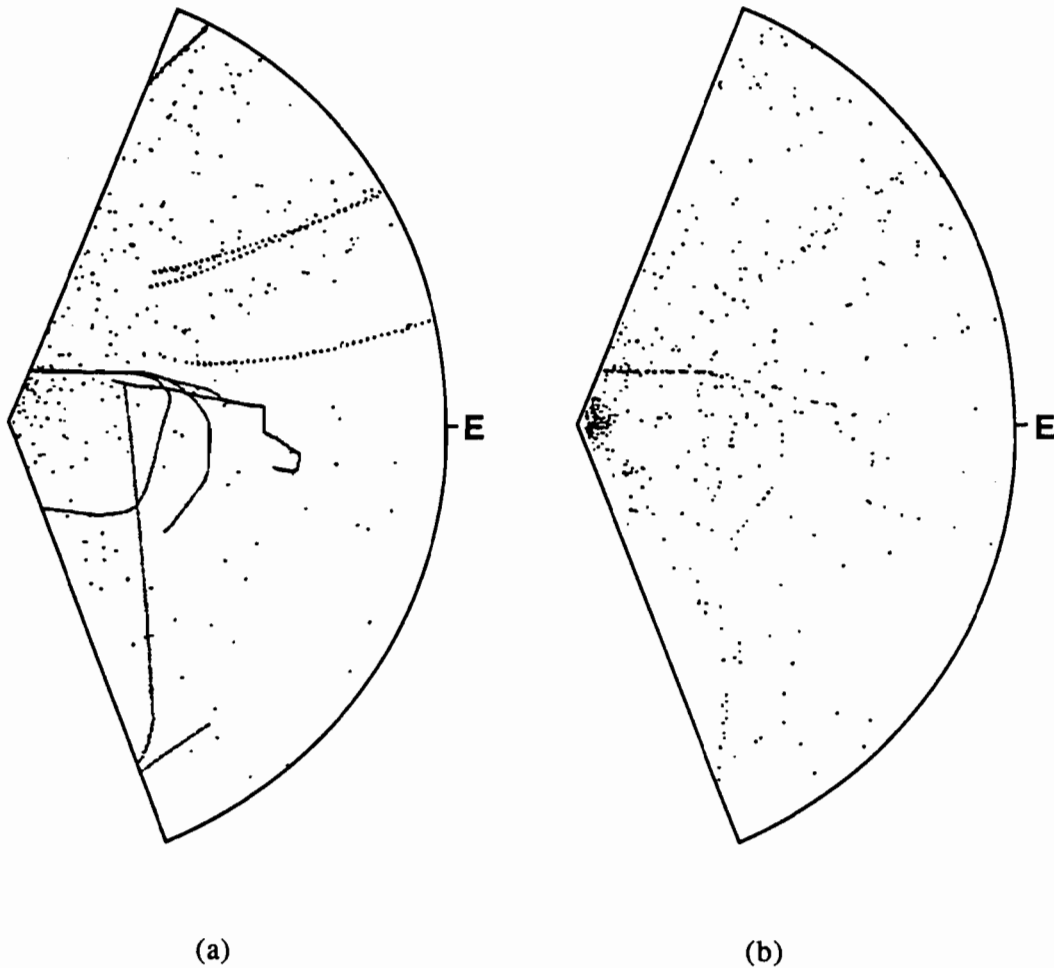
Figure 2.   Replies from the East (E) quadrant.   Maximum range is 20 nmi.   (a) ungarbled replies. (b) garbled replies.
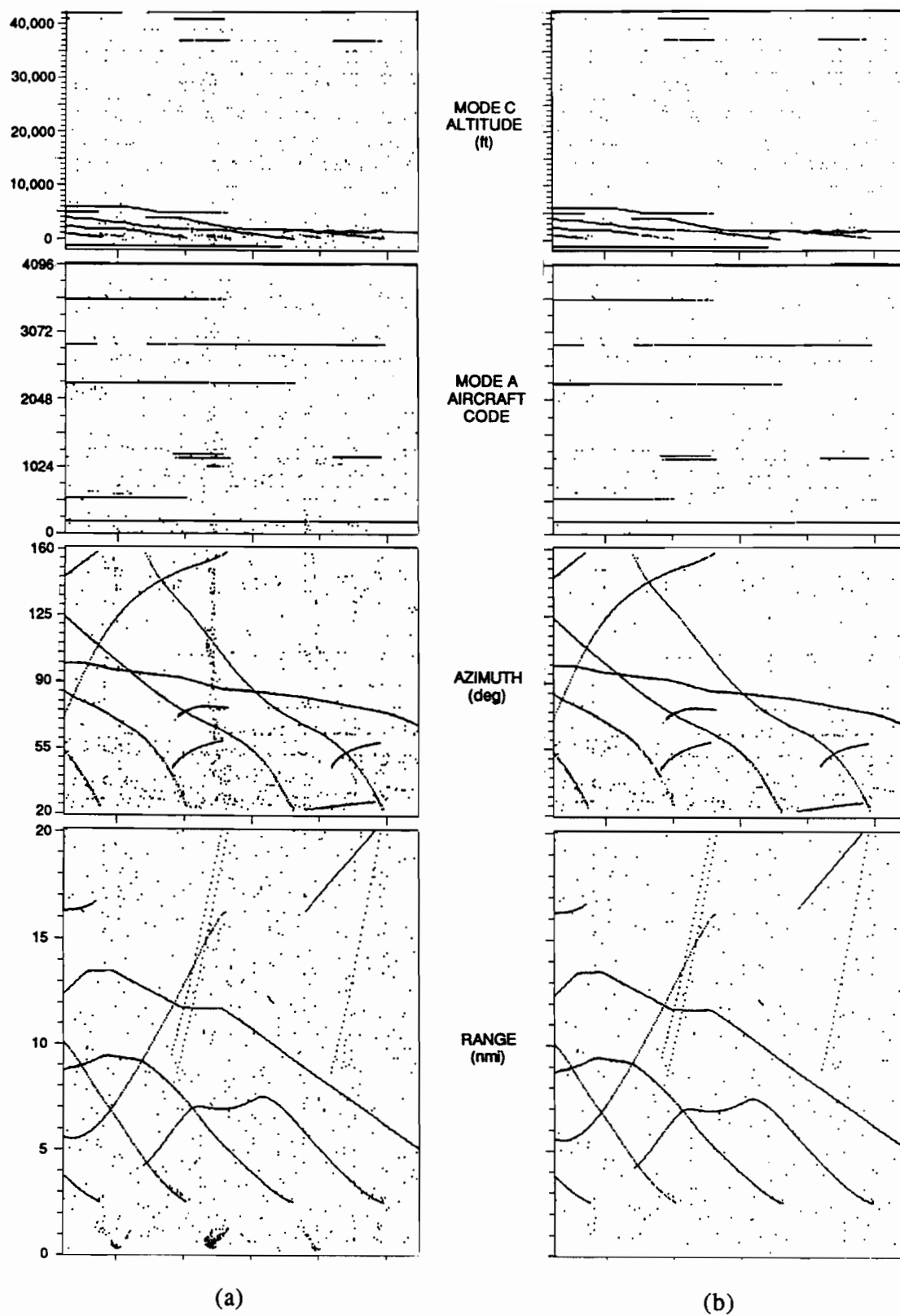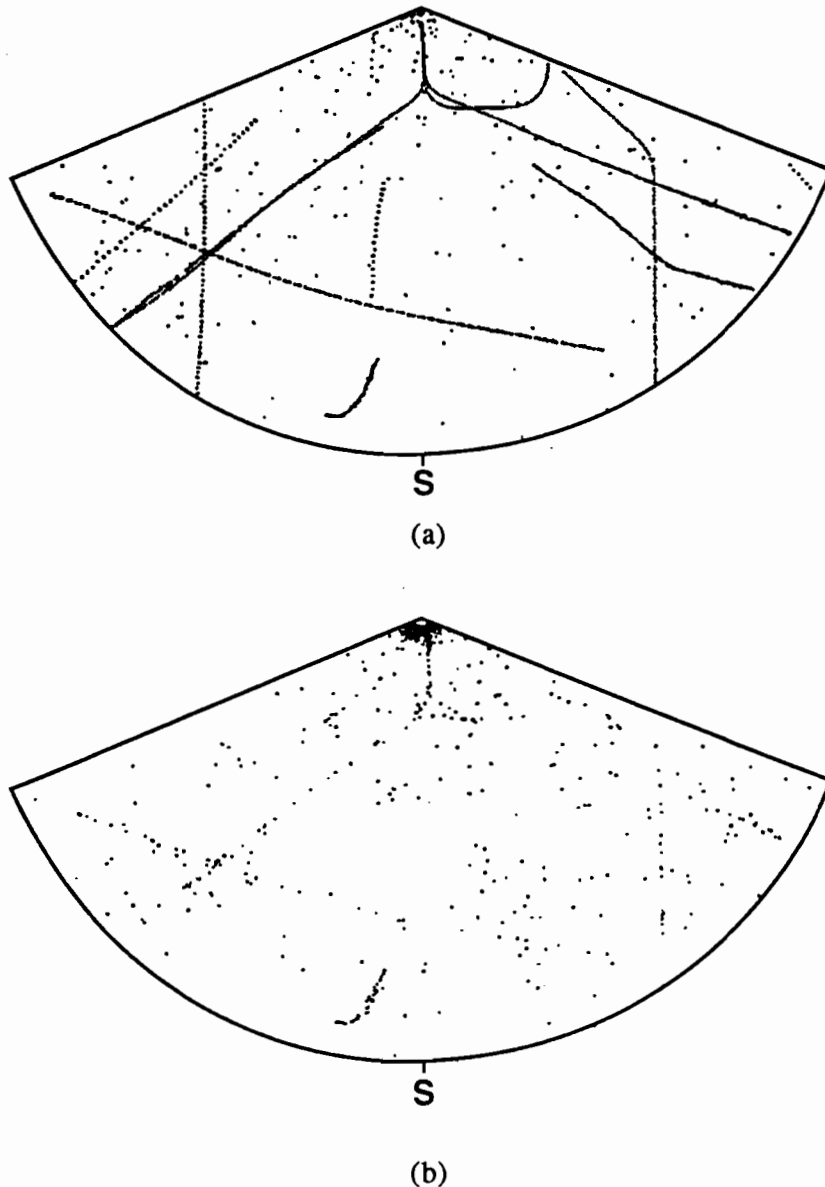
Figure 3. Representative reply information from the East quadrant. (a) all replies. (b) ungarbled replies.

Figures 4 and 5 illustrate the reply environment in the South quadrant. As in the East quadrant, there was insignificant garble and multipath except for close to the sensor. The band of garbled false replies within 1 nmi of the sensor in Figure 4b occurred for most reply traces and for operations to both parallel runways. The azimuth and range information in Figure 5a show that these multipath replies are associated with arrival aircraft, around scans 550, 640, and 725. The variability in the degree and persistence of the bands suggests reflections from vehicular traffic as well as from the chain link fencing along Shelby Drive.

(a)

(b)

*Figure 4.   Replies from the South (S) quadrant.   Maximum range is 20 nmi.   (a) ungarbled replies.
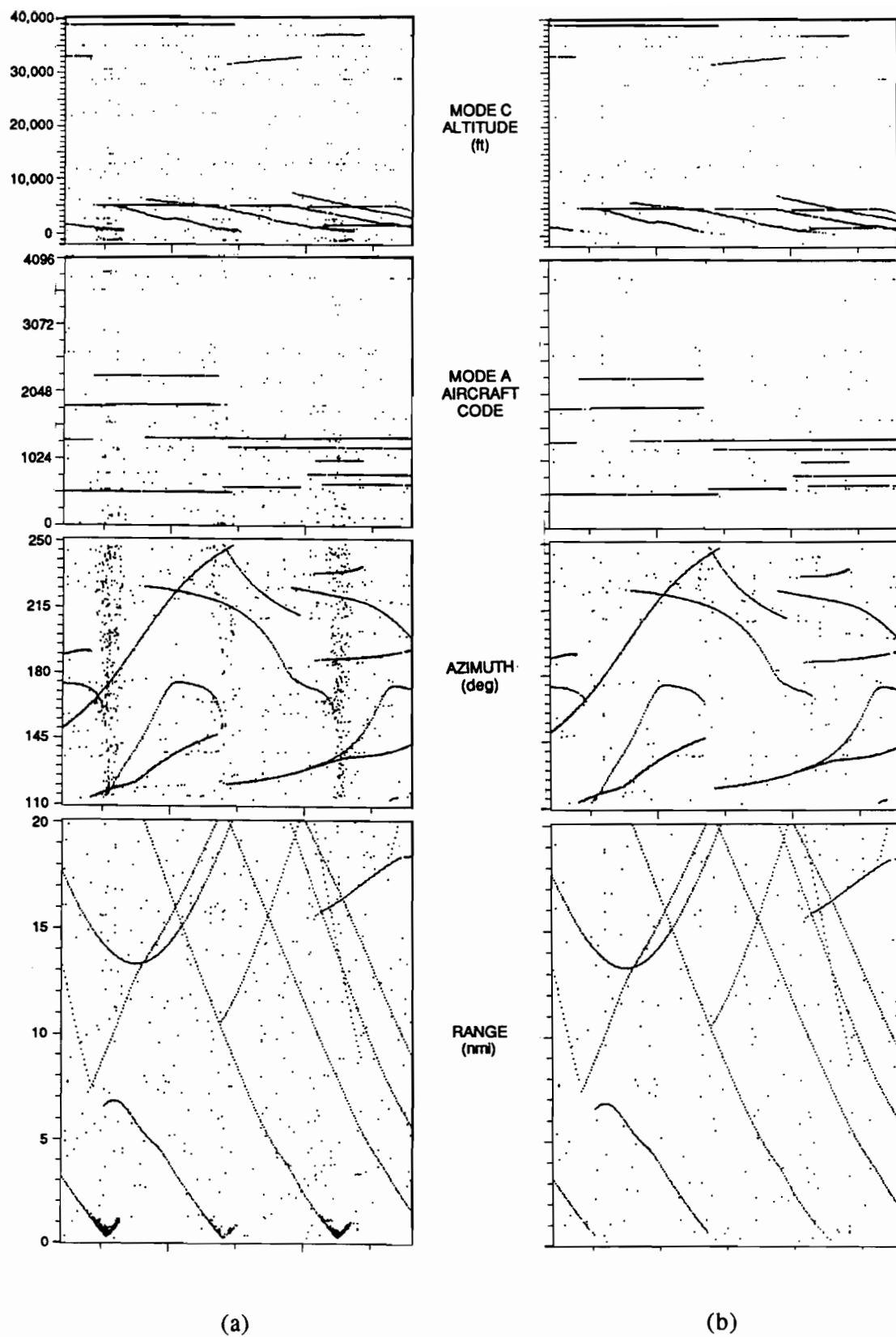(b) garbled replies.*

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Figure 5. *Representative reply information from the South quadrant.* (a) all replies. (b) ungarbled replies.

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Figures 6 and 7 show replies in the West quadrant, and illustrate two regions of severe garble and multipath. As shown in Figure 6b, there was a region of garble close to the sensor running north-south and parallel to runway 18R/36L. Figure 7 shows that these replies, around scans 290, 350, and 425, were associated with 1 departure and 2 arrival aircraft traces, labeled D1, A1 and A2 respectively. The replies paralleling the reply traces, at slightly larger ranges, were multipath replies caused by airport traffic as well as by road traffic or buildings along Airways Road.

The second region of false replies, at 275 - 280 deg, was caused by reflections from the ASR/beacon radar. The range plot in Figure 8 shows that if the replies in this azimuth wedge are isolated, the range data contain sequences of replies that mimic range sequences from real targets. The azimuth and mode A information for these false replies are erratic, however, suggesting that the replies would not be associated with a persistent track. These false sequences of range information are highlighted in Figure 7 by single-ended arrows.

Two false range sequences, marked by double-ended arrows in Figure 7, are associated with the true reply traces for A1 and A2. Figure 9 shows the true reply sequence for A2. The aircraft was tracked until it exited the surveillance quadrant at 202.5 deg, then re-acquired about 90 scans later as it re-entered the surveillance quadrant close to the sensor. The ASR tower was the major source of the multipath replies between these two points.

(a)   (b)

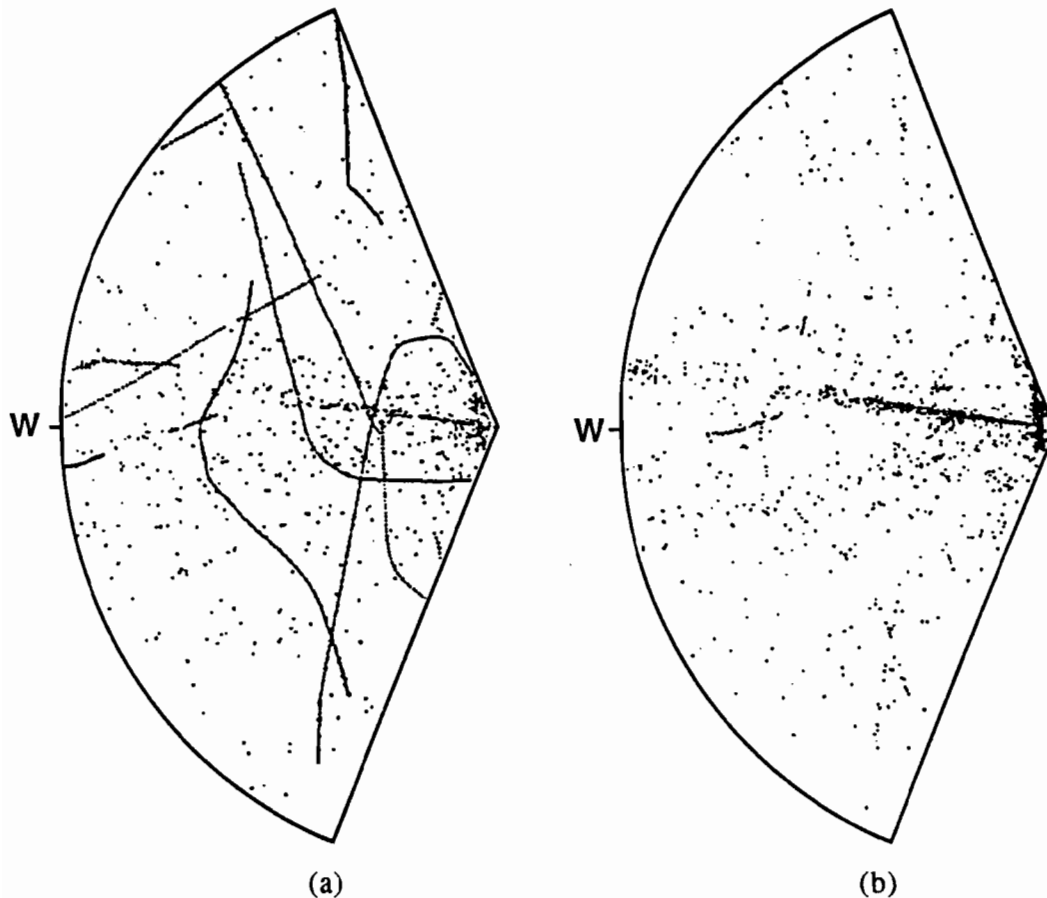Figure 6.   Replies from the West (W) quadrant. Maximum range is 20 nmi. (a) ungarbled replies.
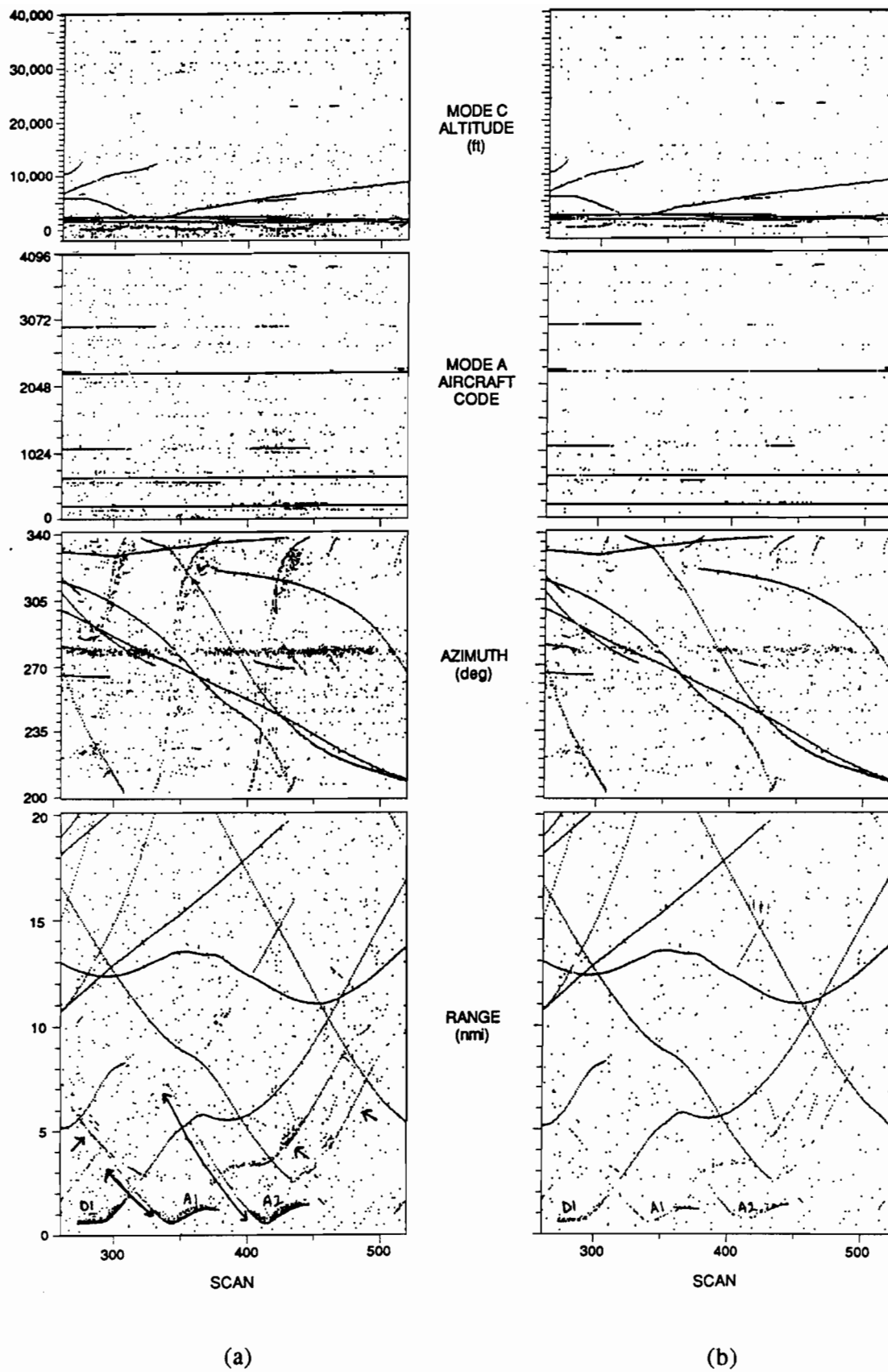   (b) garbled replies.

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Figure 7.   *Representative reply information from the West quadrant.   (a) all replies.   (b) ungarbled replies.*
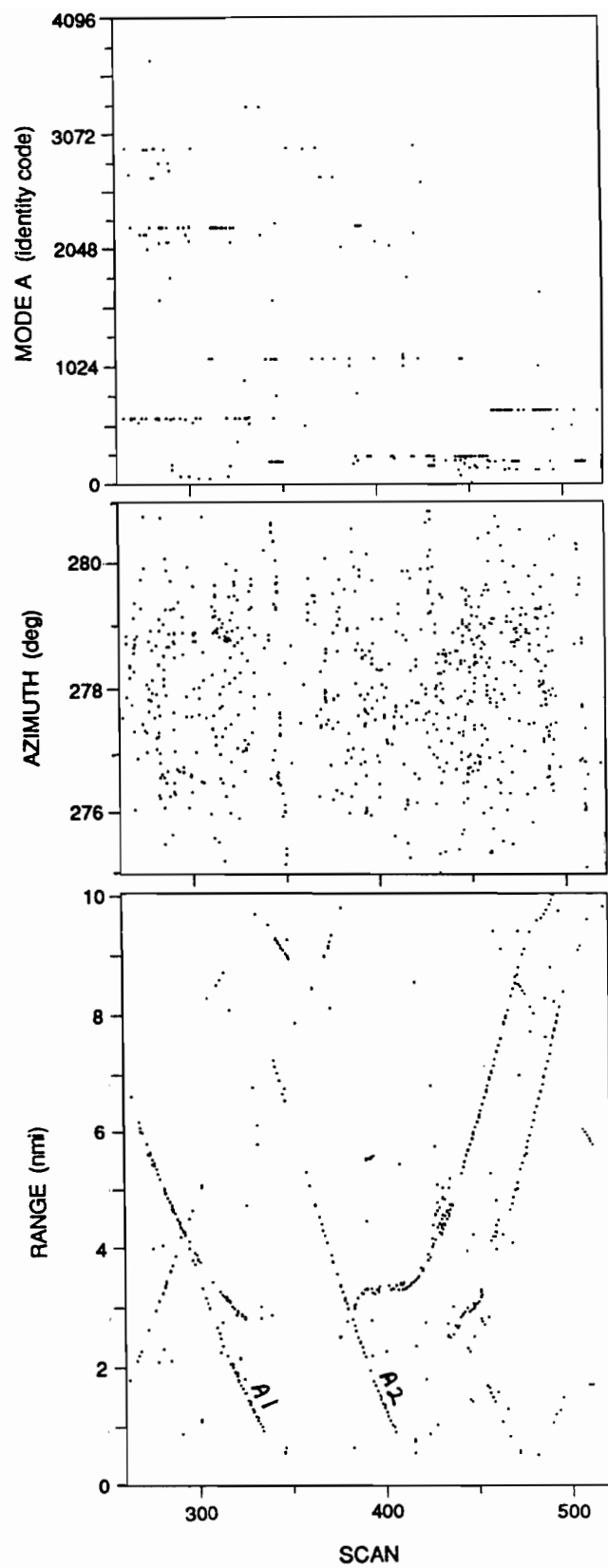
Figure 8.   False range sequences due to reflections from the ASR.

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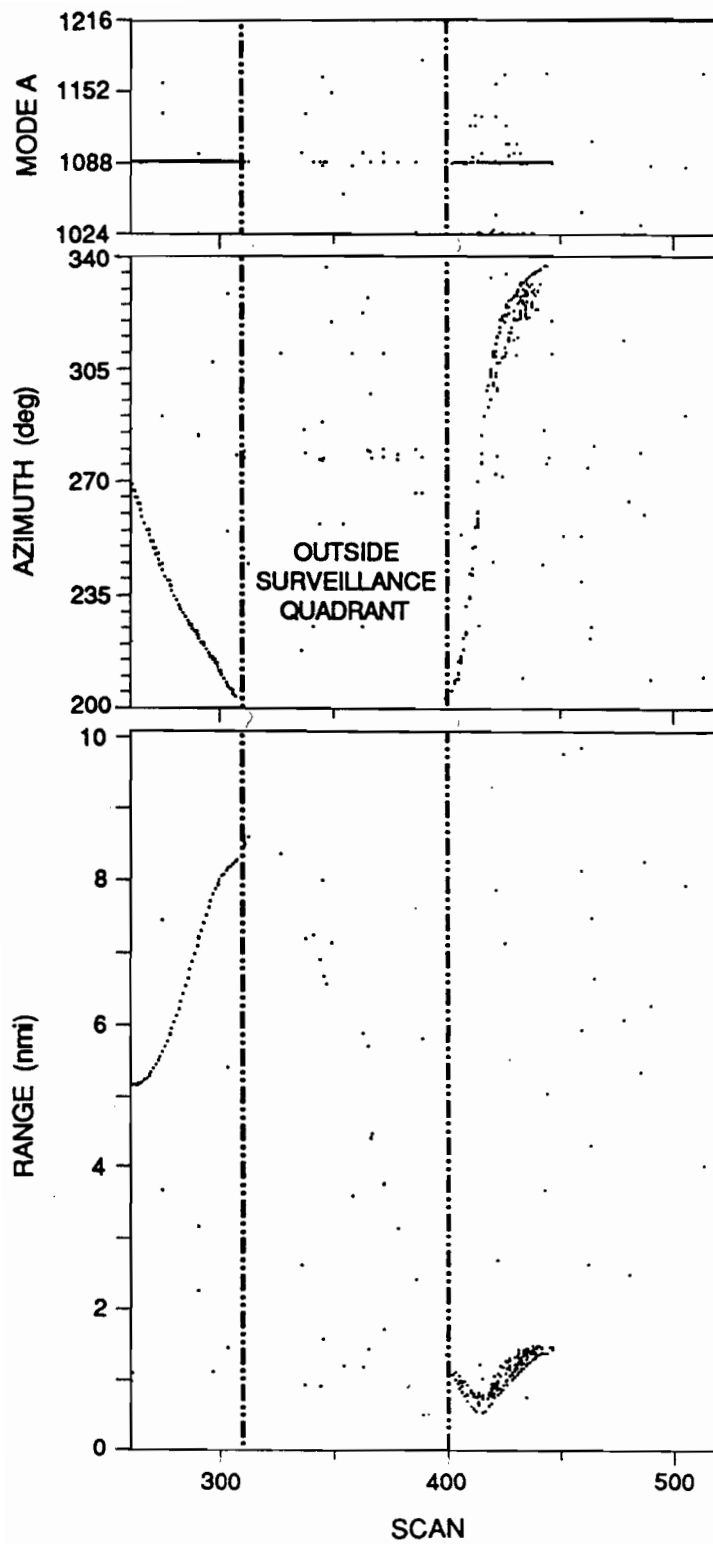
Figure 9.   Valid reply sequence for the arrival aircraft A2 from Figure 7.

Figures 10 and 11 show the reply environment in the North quadrant. Figures 10a and 11b illustrate how most of the reply traces in this region were corrupted: the ungarbled reply traces were incomplete near the airport. Figures 10b and 11a show the severity of multipath within 4 to 5 nmi of the sensor. An earlier study on multipath at Memphis [2] identified the passenger terminal, Federal Express building, the fuel farm, and buildings along the roads as persistent sources of multipath in this quadrant. Non-persistent sources of multipath would be surface aircraft and vehicles.

(a)

(b)
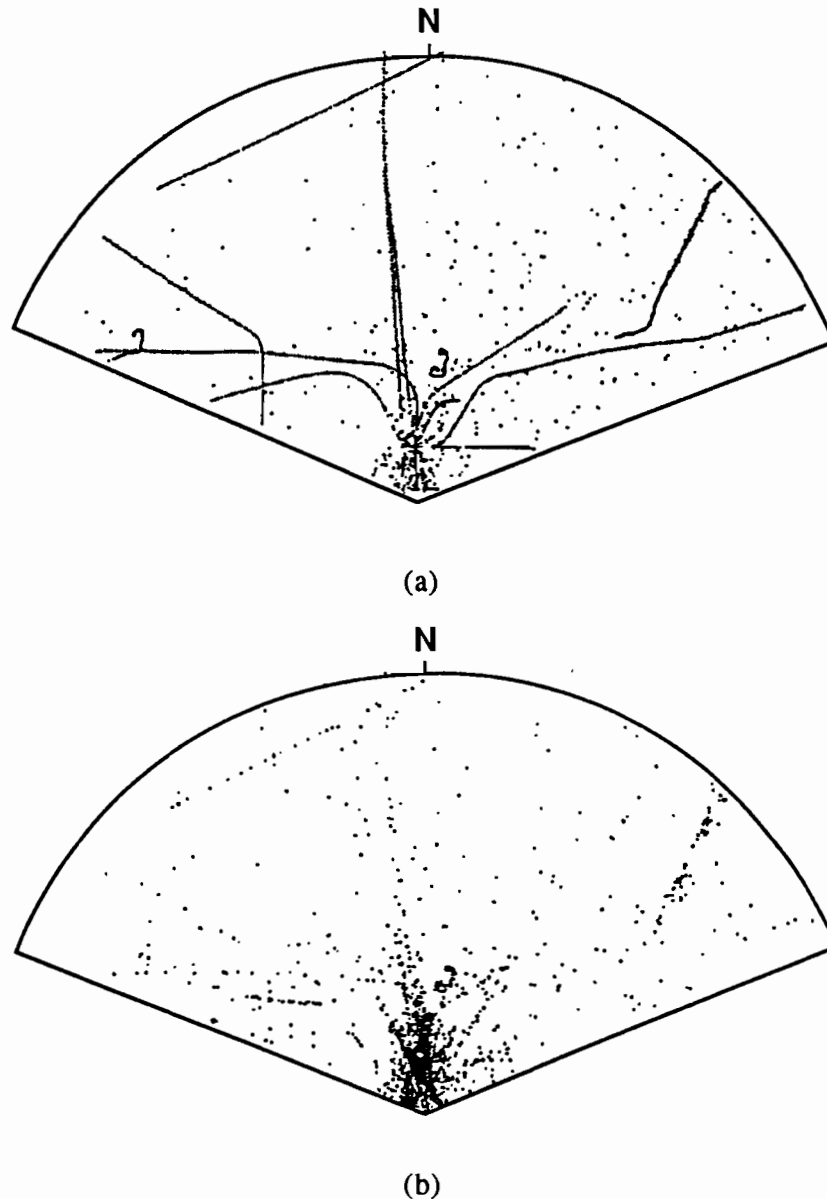
Figure 10. Replies from the North (N) quadrant. Maximum range is 20 nmi. (a) ungarbled replies. (b) garbled replies.

Figure 11. Representative reply information from the North quadrant. (a) all replies. (b) ungarbled replies.

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4. GARBLE AND DECODER OVERLOAD

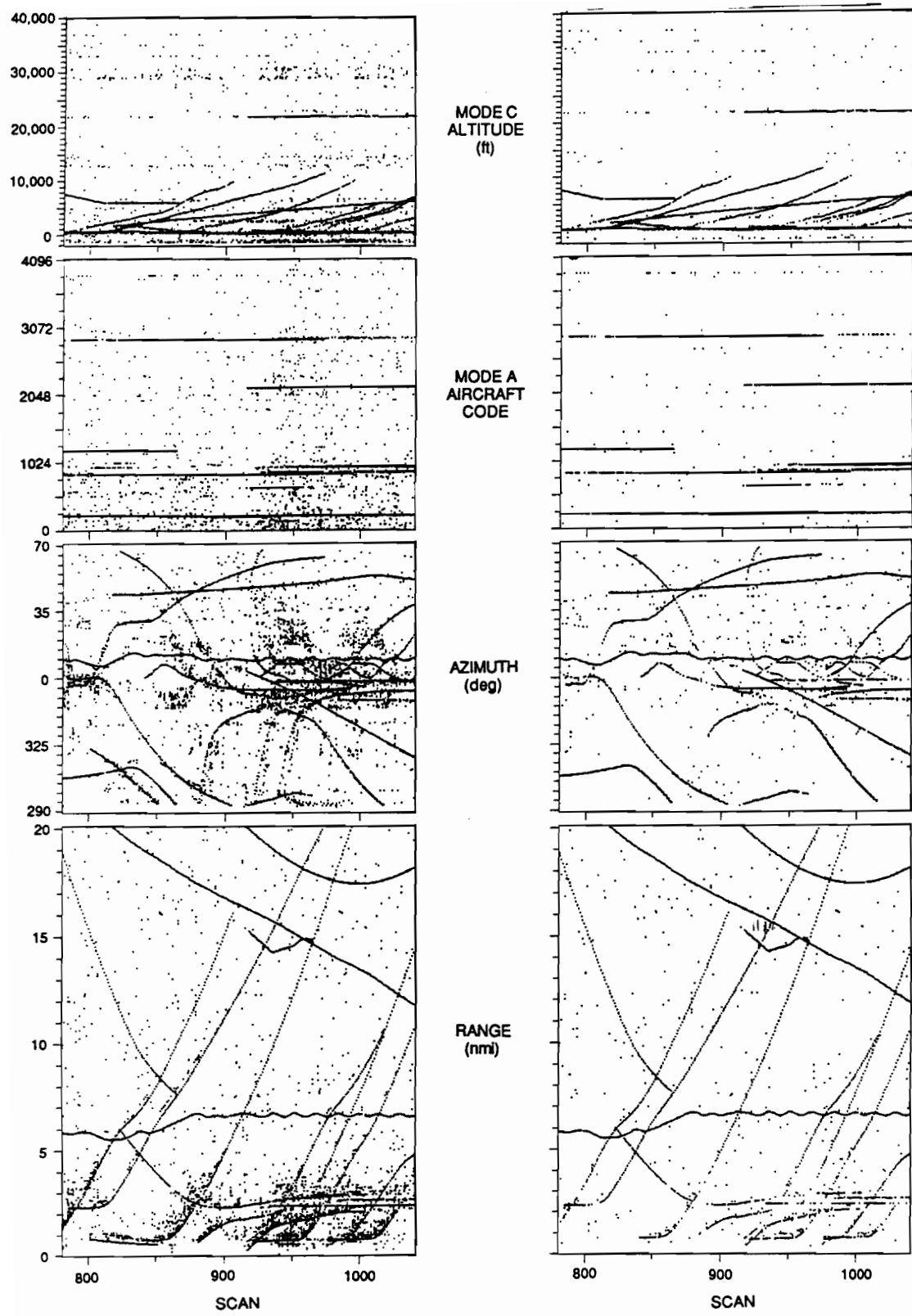Section 3 presented a qualitative overview of the ATCRBS reply environment at Memphis, including the known sources of multipath. This section provides a quantitative view of the garble and decoder overload environment. Data from the three days during which replies were recorded in all four quadrants were used for the analysis.

4.1 ATCRBS GARBLE

The relationship between the percentage of garble and the ATCRBS reply population is recorded in Figure 12. For each plot in Figure 12, one data point represents 10 minutes of data resolved over a 10-deg azimuth wedge. Figure 12a presents the percent of garbled replies over the entire reply population, while the next two plots present the garble percentage for replies with ranges less than 5 nmi (12b) and greater than 5 nmi (12c). Figures 12d and 12e present total reply counts and the percentages of replies within 5 nmi of the sensor, respectively.

The total reply population was fairly constant over all azimuths except around 360 deg, where most multipath occurred. The slight increase at 90 - 110 deg is associated with the airport activity in Olive Branch, TN. The increase at 270-280 deg is associated with multipath from the ASR/beacon structure.

The percentage of replies that were within 5 nmi of the sensor was significant to the north and south. These peaks in numbers are associated with the concentration of aircraft along the approach and departure paths, as well as with the potential for multipath in these regions. The percentage of close-in replies to the south was highly variable - consistent with non-persistent multipath sources such as road traffic.

Within 5 nmi of the sensor, the percentage of replies that were garbled was significant over all azimuths. As suggested in the previous section, this garble is associated mainly with air traffic on or near the airport surface.

In general, less than 50% of the replies at ranges greater than 5 nmi were garbled. The data points with elevated garble at azimuths between 130 and 240 deg in Figure 12c are artifacts caused by small sample sizes and low aircraft density. Analysis of some of these samples with significant garble percentages showed that all of the replies were random, indicating fruit or multipath replies. No consistent reply traces were found in the analyzed samples.

4.2 ATCRBS REPLY DECODER OVERLOAD

The ATCRBS garbled reply percentage plots illustrate the potential for reply processor decoder overloading in certain sectors where many replies may be received during a given sweep. As previously mentioned, decoders are hardware processors that detect the incoming replies, thus permitting the handling of overlapping ATCRBS replies during a high-density traffic period. If a reply is received while all decoders are in use, that reply is not saved and decoder overload is declared.

Figures 12f and 12g display the relationship between the percentage of non-empty sweeps in which reply decoder overloads occurred and the percentage of sweeps which contained replies. A non-empty sweep is a time interval during which an interrogation was sent and at least one reply was received. As shown in Figure 12f, decoder overload occurred mainly in the North quadrant.

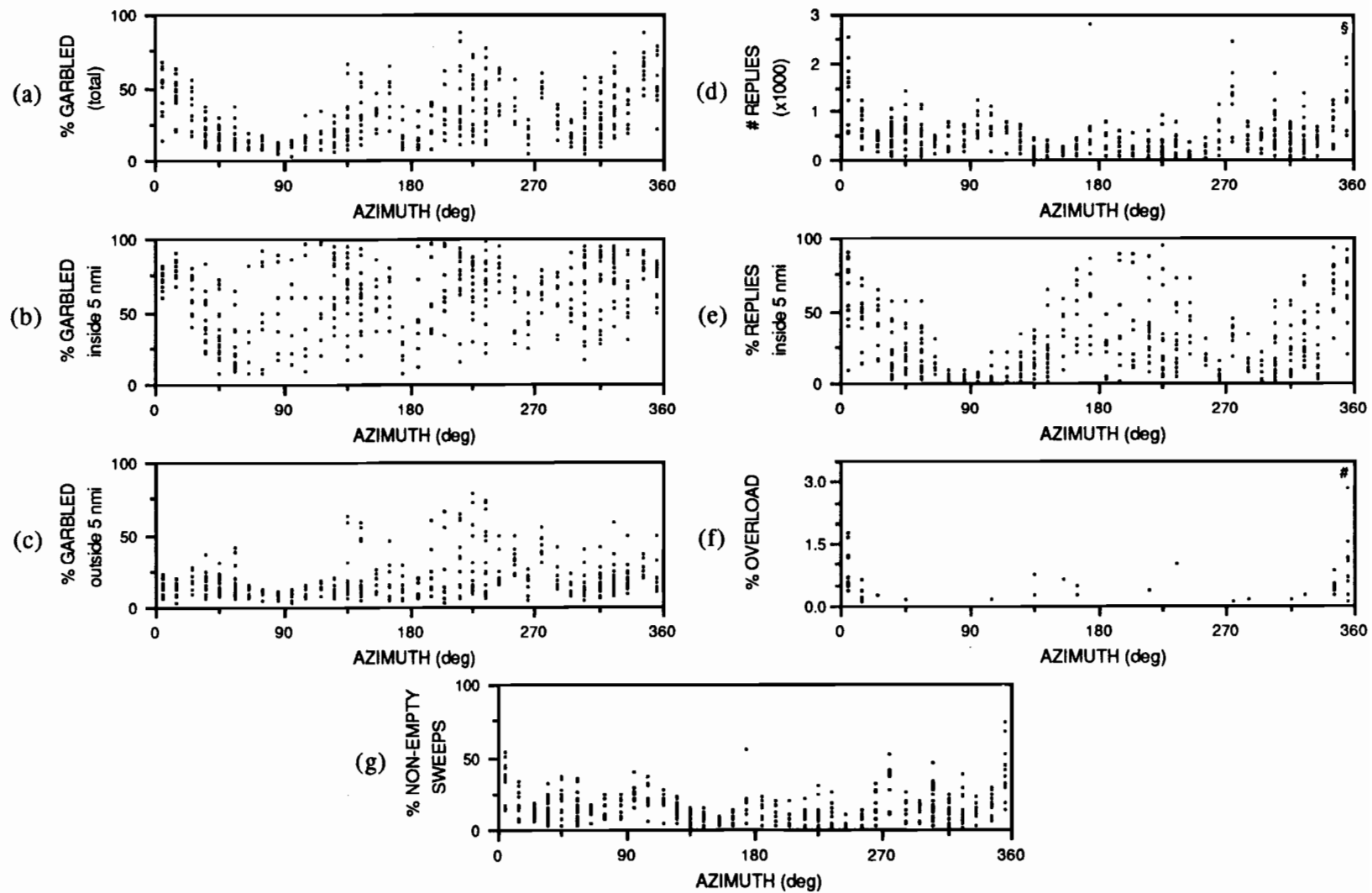*Figure 12. Overview of garble and overload. (a) % garbled replies. (b) % replies inside 5 nmi that were garbled. (c) % replies outside 5 nmi that were garbled. (d) reply count (§ 2 values outside the range: 4256 and 4924). (e) % replies inside 5 nmi. (f) % non-empty sweeps with decoder overload (# one value outside the range: 7.8%). (g) % sweeps with replies. Each data point represents a 10-deg wedge sampled for 10 min.*

5. ANALYSIS OF NORTH QUADRANT DATA

Section 3 showed that the ATCRBS reply environment caused minimal multipath over most azimuths except for ranges of less than 2 nmi. Section 4 showed that while most of the replies close to the sensor were garbled in all directions, the number of close-in replies to be processed was small, except to the north. In addition, the occurrence of decoder overload was persistent only from 340 deg to 30 deg azimuth.

This section examines the garble and decoder overload environment in the North quadrant. Three data sets lasting 90 min each were used: RPS003, RPS007, and RPS008. RPS007 and RPS008 were collected on the same day.

5.1 ATCRBS REPLY GARBLING

Figure 13a-c illustrates the degree of ATCRBS reply garbling as a function of range from the PRM sensor for replies over all azimuths in the North quadrant during the three data sets. The data were analyzed in 0.5-nmi range bins over 10-min intervals, for a total of nine sample intervals per data set. Figure 13d shows the average number of replies per 10-min interval for each 0.5-nmi range bin.

In general, the ATCRBS reply garbling percentages decreased with increasing range from the sensor. The start of the roll-off in the percent of garble was not the same during all three recording periods, suggesting that transient factors such as surface traffic can affect the reply environment. For RPS003, the garble percentage started decreasing at 2 - 3 nmi from the sensor. For RPS007 and RPS008, the decrease started at 4 - 5 nmi from the sensor. The main difference in environments between the two days was the presence of persistent active surface transponders in RPS007 and RPS008 at ranges between 2 - 3 nmi. There were no active surface transponders in RPS003. The other difference between recordings was that RPS003 was recorded while approaches were being conducted from the south while RPS007 and RPS008 were recorded while approaches were being conducted from the north.

The regions of high garbling percentages extended beyond the regions of high reply density by less than 2 nmi for all three recordings. This distance can be correlated with the length of an ATCRBS reply: 20.3 μs. Given the speed of light,[1] the length of a reply is equivalent to 1.64 nmi. Thus, if an aircraft responding to an interrogation is within 1.64 nmi of another responding aircraft or a multipath reply, the two replies overlap and garbling can occur. The data in Figure 13d suggest that the high reply density inside 5 nmi significantly increased the probability of overlap between two or more replies during the same sweep, and that this region of high garble probability extended into the region of low reply density.

Figures 14 and 15 illustrate the garble phenomenon in the North quadrant. These plots show all replies and ungarbled replies within 10.5 nmi of the sensor for a 10-min period. Reply traces of interest are marked by their associated identity codes, in octal form.

The effect of multipath is evident in Figure 14 for reply traces within 5 nmi of the sensor. The "squirrel tails" associated with the range traces for aircraft 2440 and 3072 were caused by reflected replies. The azimuth data for aircraft 2440 for scans 70 - 95 illustrate how these

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[1]   Speed of light in a vacuum (C) = 2.997925 $\cdot$ 10^8 m/s. Speed of light in air = 0.99972 $\cdot$ C.

multipath replies are often at a different azimuth than the true reply. The "squirrel tails" are not present in Figure 15, which shows only ungarbled replies. In Figure 14, the range traces between 2 and 5 nmi for aircraft 2440 and 3072 also illustrate how the true replies can be missing for an extended period, while reflected replies are present. Finally, the reply sequences for aircraft 2440 and 3072 show that it is possible for the direct-path reply to be garbled while the multipath reply from the same scan is not.

The reply traces at a constant range around 2.2 nmi are associated with ATCRBS replies emitted from a stationary aircraft. Some aircraft flight crews appeared to have kept the aircraft's ATCRBS transponders on after landing, or they turned the transponders on long before taking the active runway prior to takeoff. The degree to which the replies from these stationary aircraft affect the overall garble picture is unclear. These aircraft appear to contribute to the amount of garble, possibly by increasing the occurrence of overlapping replies, but the full effect has not been determined.

Figure 14 also illustrates two other effects of the airport environment on reply integrity: signal blockage and diffraction effects. Reply traces with gaps in the range information illustrate the problem with blockage of the direct path between the target and the sensor. The reply trace from scans 140 - 170 for aircraft 3072 is broken at ranges between 2 nmi and 5 nmi. For some scans, only reflected replies were received. Thus, the target track for this aircraft could coast for periods of several scans, or the report correlator could assign a report created from multipath replies to the track.

The reply traces with a consistent sequence in the range information but with variability in the azimuth information suggest incorrect monopulse estimates due to diffraction by objects along the direct signal path. In scans 45 - 70 in Figure 14, aircraft 4322 exhibited increased variability in the corrected azimuth for azimuths between 5 deg and 20 deg. For the same scans, the range information exhibited a continuous reply trace. Aircraft 4327 exhibited a similar trend in scans 150 - 170. Both aircraft were on or near the airport surface during these periods, so the buildings and other structures could have affected the reply signals.

5.2 ATCRBS REPLY DECODER OVERLOAD PERCENTAGES

Figure 16 shows the percentage of non-empty sweeps that had decoder overload in the azimuth wedge with the most overload: 330 deg to 30 deg. The data for each recording period are shown for successive 10-min intervals. Each data point in an interval represents the percent overload resolved over 1 deg of azimuth.

RPS003 consisted of an arrival push from the south, with some traffic to runway 9/27. There were no persistent, active surface transponders during this period. RPS007 and RPS008 consisted mainly of arrival pushes from the north. In addition to aircraft arriving at approximately 2-min intervals, these two recordings had extended periods with at least one active, stationary surface transponder.

The three sets of plots in Figure 16a-c highlight the variability in magnitude and location of decoder overload. Maximum overload for a 1-deg wedge sampled over 10 min was 5.17% for RPS003, 6.76% for RPS007, and 8.33% for RPS008. The variability in peak overload appears to correlate with reply density. There is also a loose association with the number of aircraft in a given 10-min interval.

Comparison of the occurrence of decoder overload with activity around the airport surface for all North quadrant data suggests that the severity of decoder overload is dependent on aircraft activity. Persistent decoder overload was greatest when the presence of active surface transponders overlapped periods of peak activity.

Figure 17 illustrates this phenomenon in the region of greatest overload: 345 deg to 15 deg azimuth. The top graph shows the azimuth of sweeps with overload vs. scan number for a period of 750 scans (about 29 min). The middle graph shows the estimated true azimuth for all replies, and the bottom graph shows the range for all replies. The greatest number of overload sweeps occurred between scans 0 - 350, when both active surface transponders and peak arrival activity occurred. Decoder overload was variable over the remaining scans, depending on the aircraft arrival density.

All of the data collected during the peak activity periods from the north also had active, stationary surface transponders, so the effect of high air traffic volume to the north on decoder overload in the absence of active stationary transponders could not be studied. The data from RPS003, which had arrivals from the south in the absence of active stationary transponders, suggest that surface activity in the same azimuths as multipath objects can cause moderate decoder overload.

Decoder overload rarely occurred when surface transponders were active during periods of low aircraft traffic.
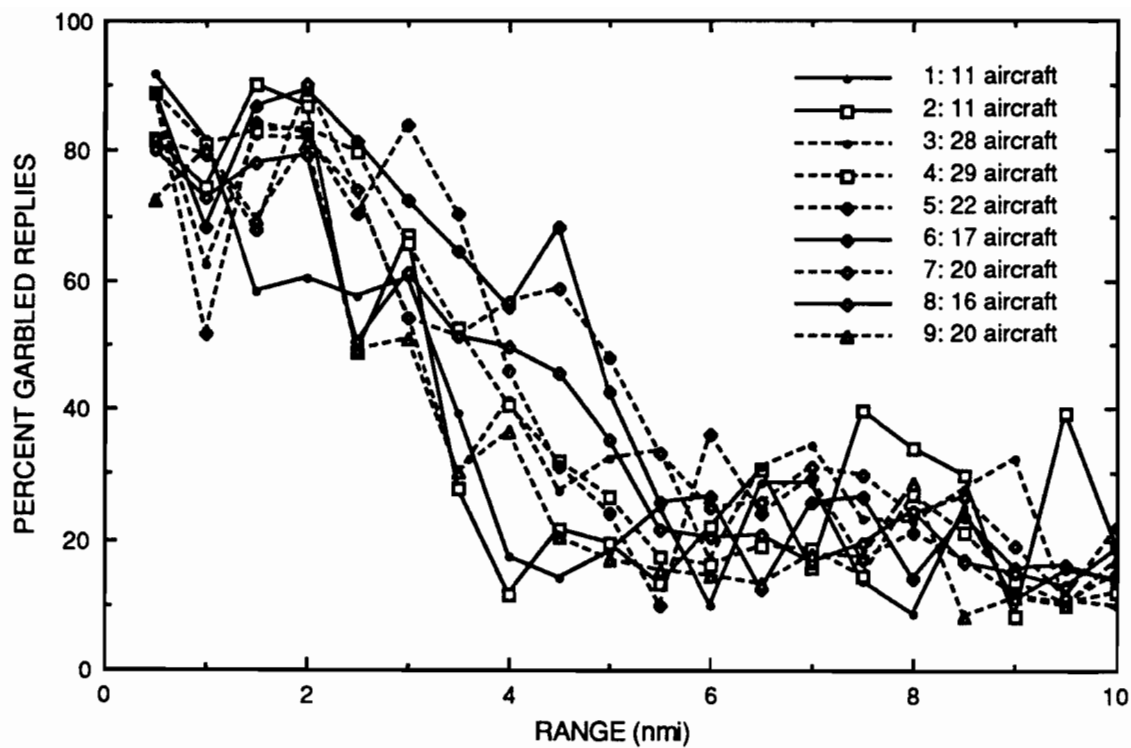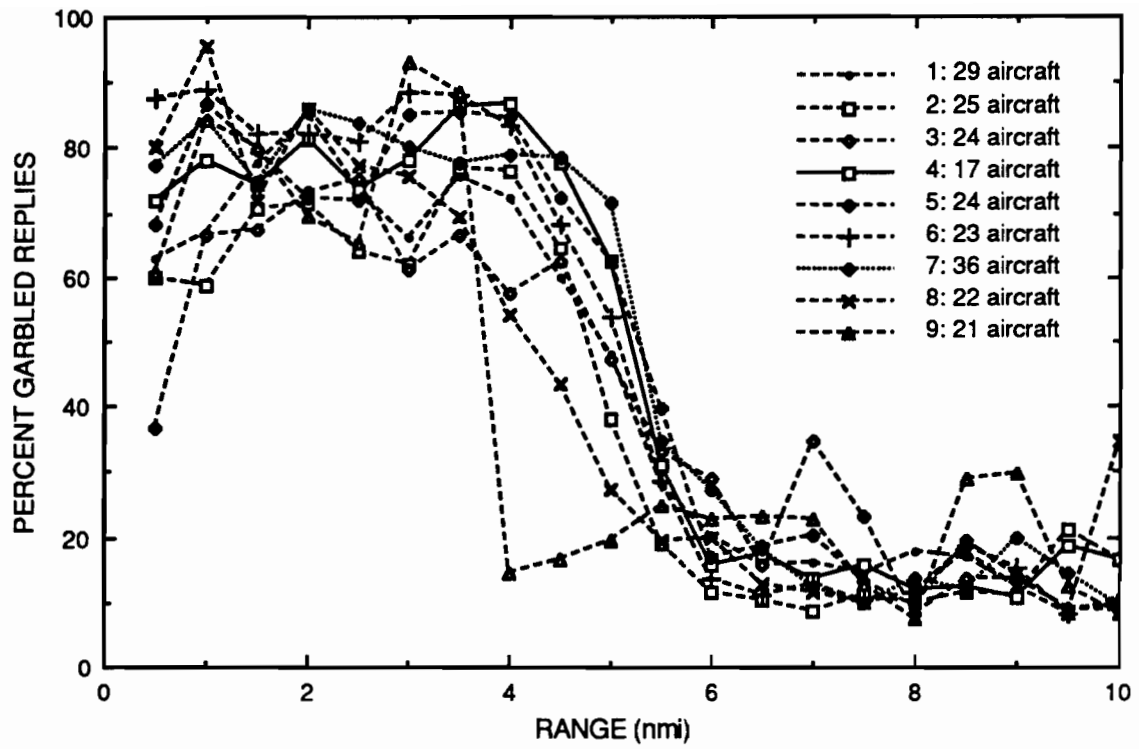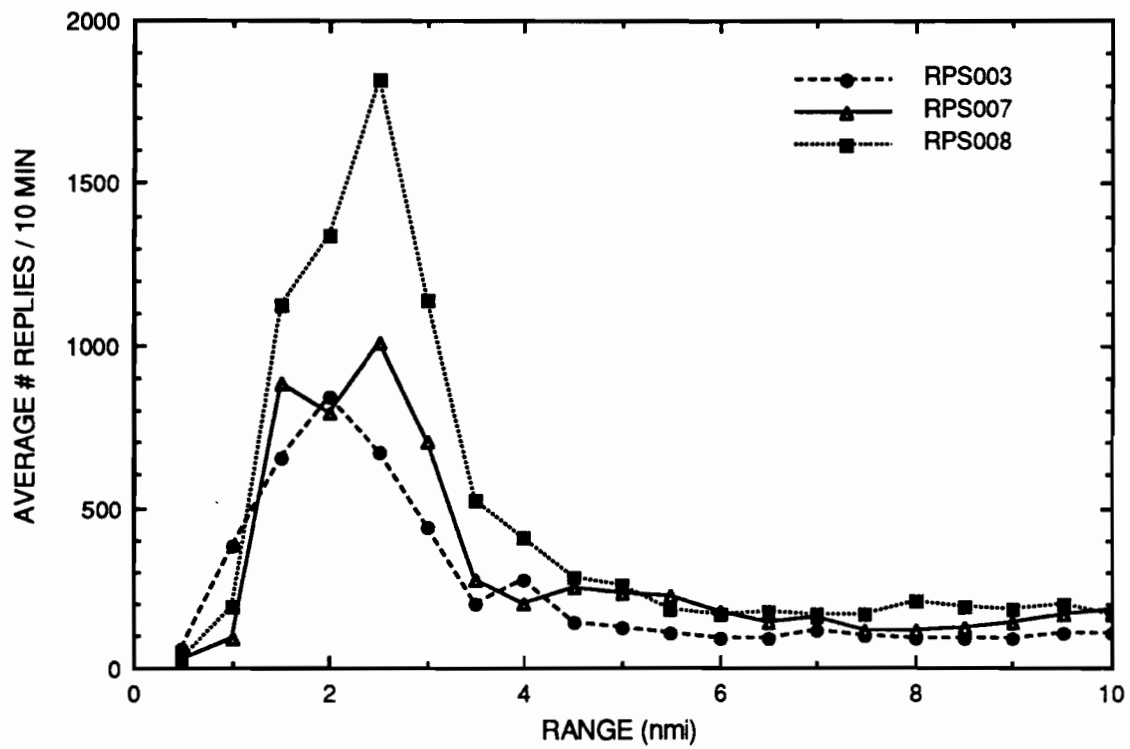
(a)
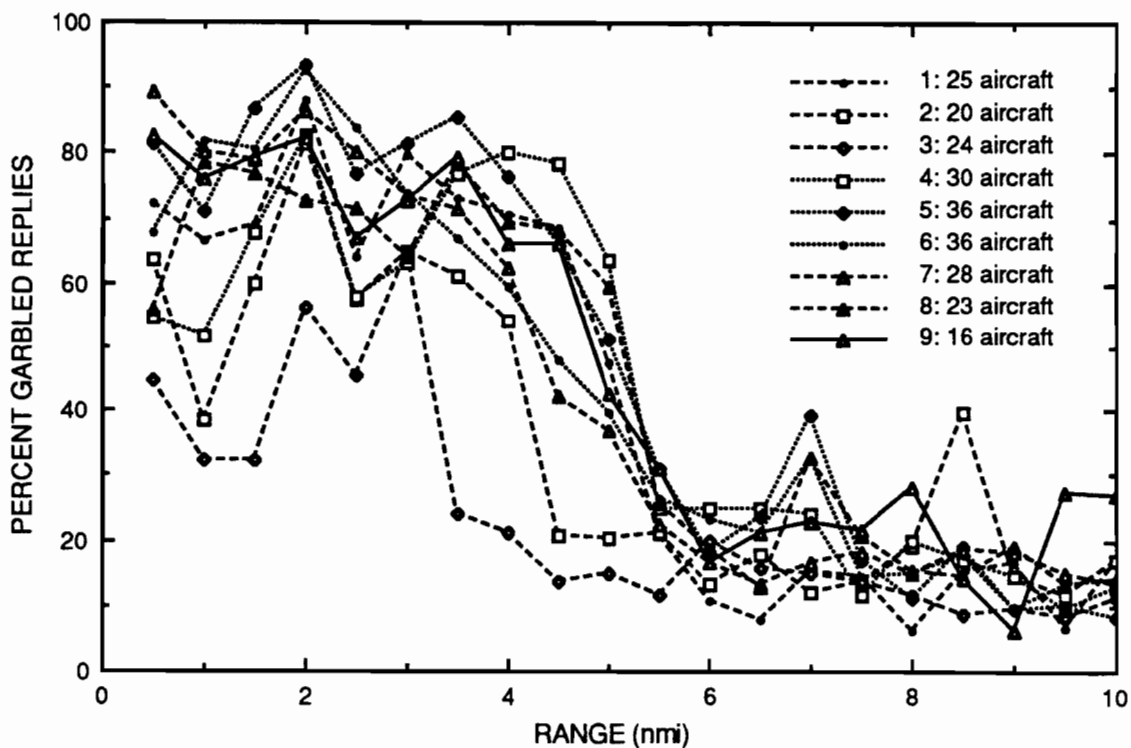
(b)

Figure 13. ATCRBS reply garbling in the North quadrant. (a) RPS003. (b) RPS007. (c) RPS008. (d) Average number of replies in a 10-min sample.

(c)
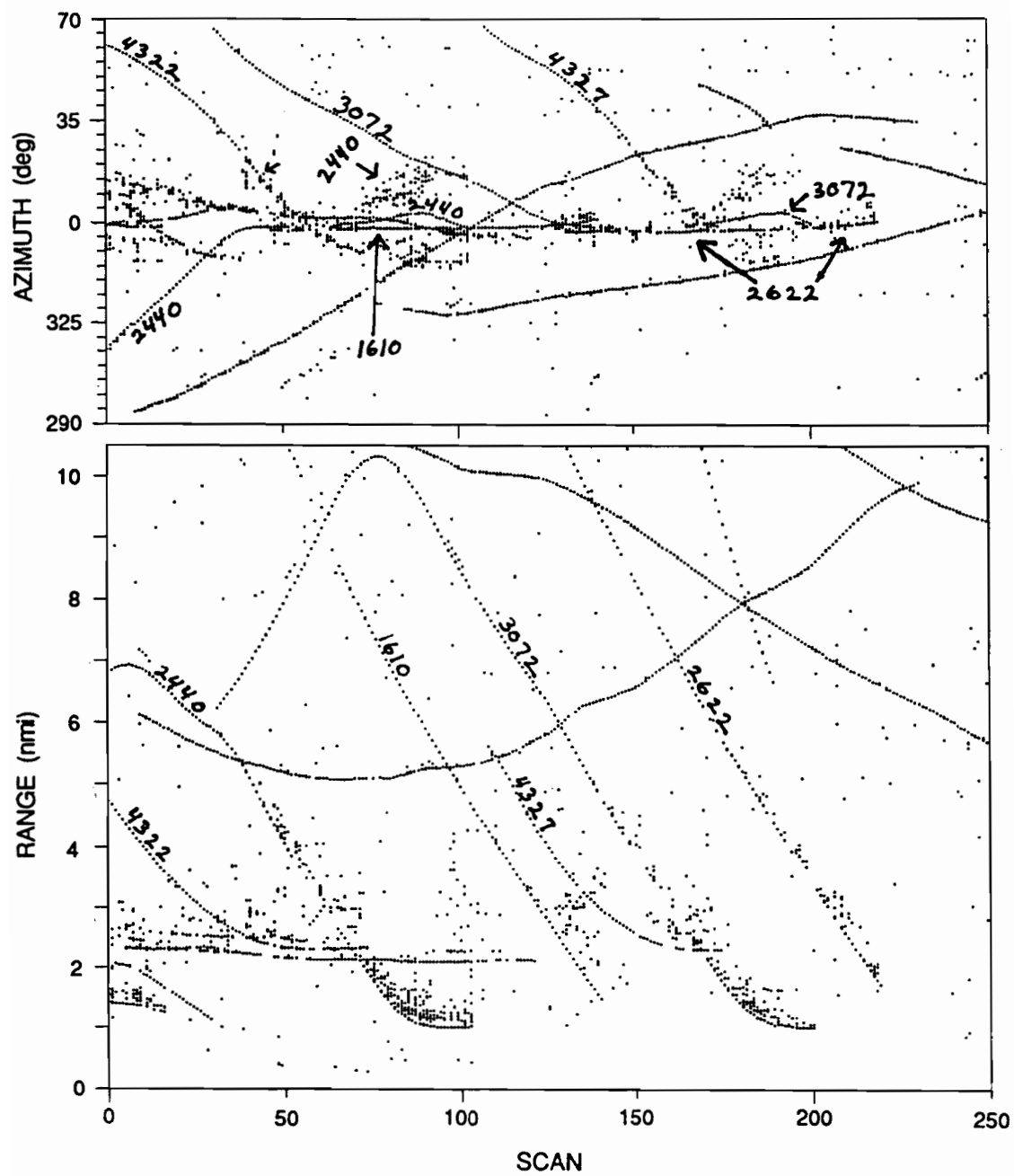

(d)

Figure 13. (continued)

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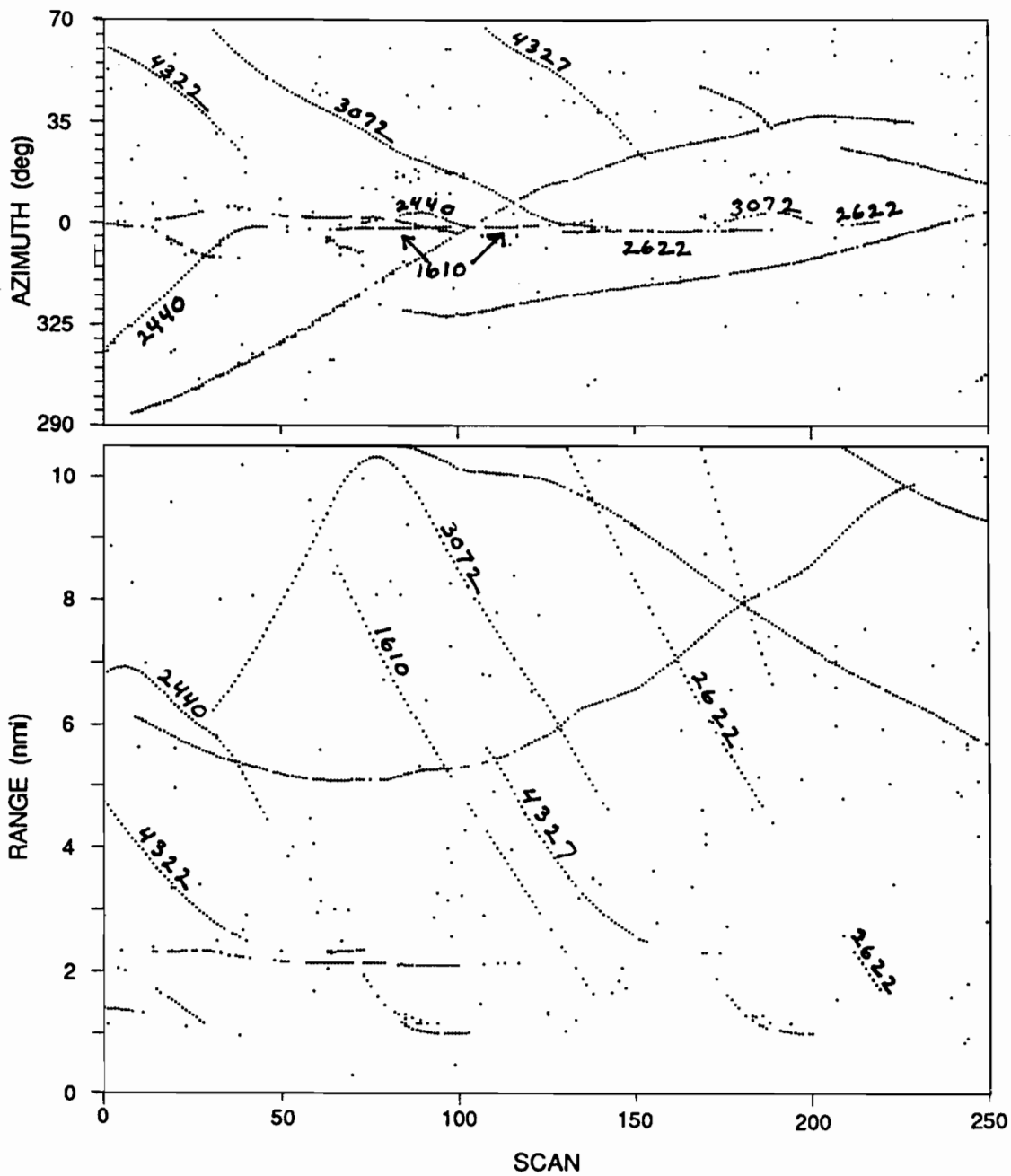*Figure 14.   All close-in replies in the North quadrant for a representative 10-min period.*

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Figure 15. Ungarbled close-in replies in the North quadrant for a representative 10-min period.
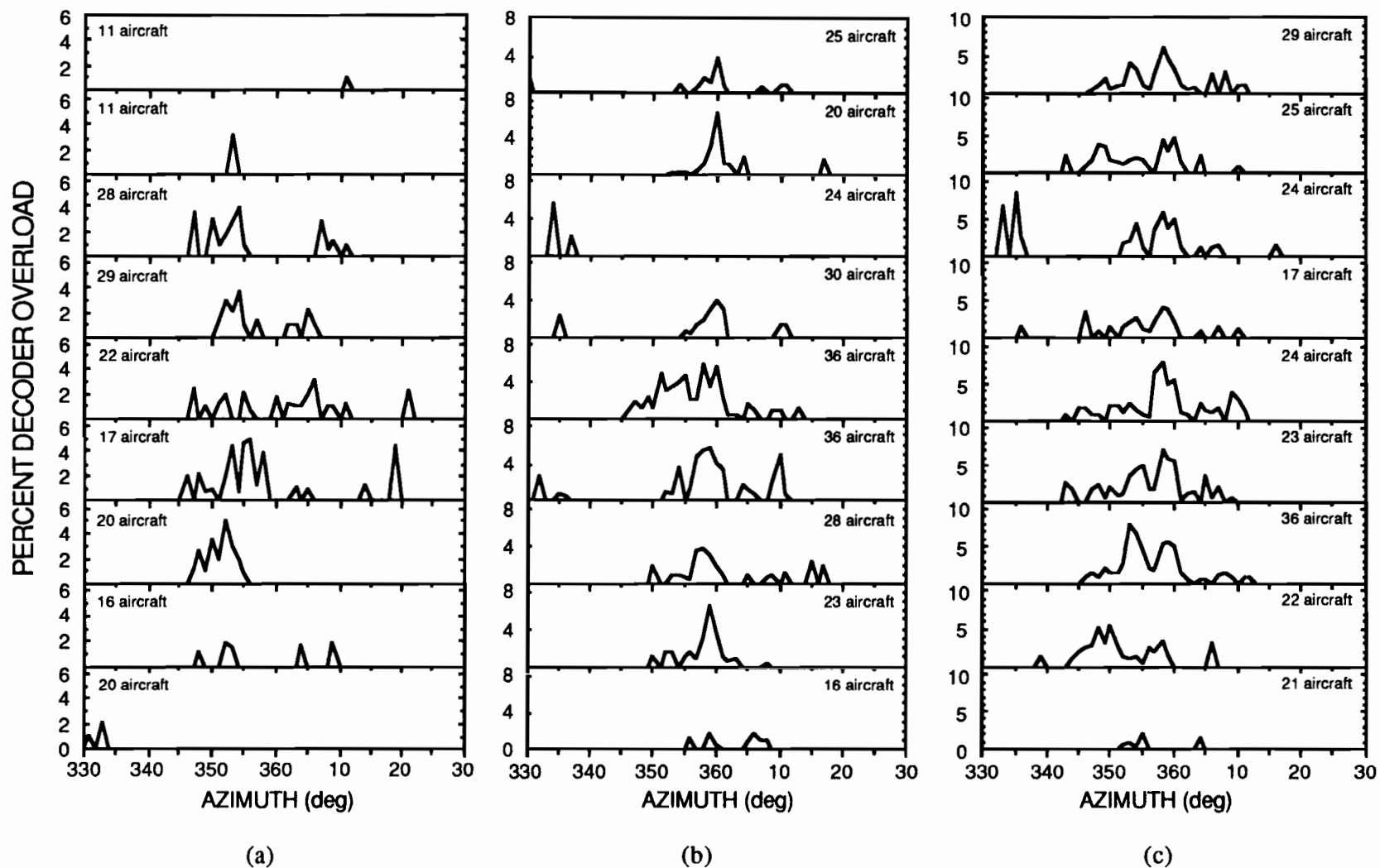
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Figure 16. Reply decoder overload in the North quadrant. (a) RPS003. (b) RPS007. (c) RPS008. The plots represent consecutive 10 min of data with 1-deg resolution.
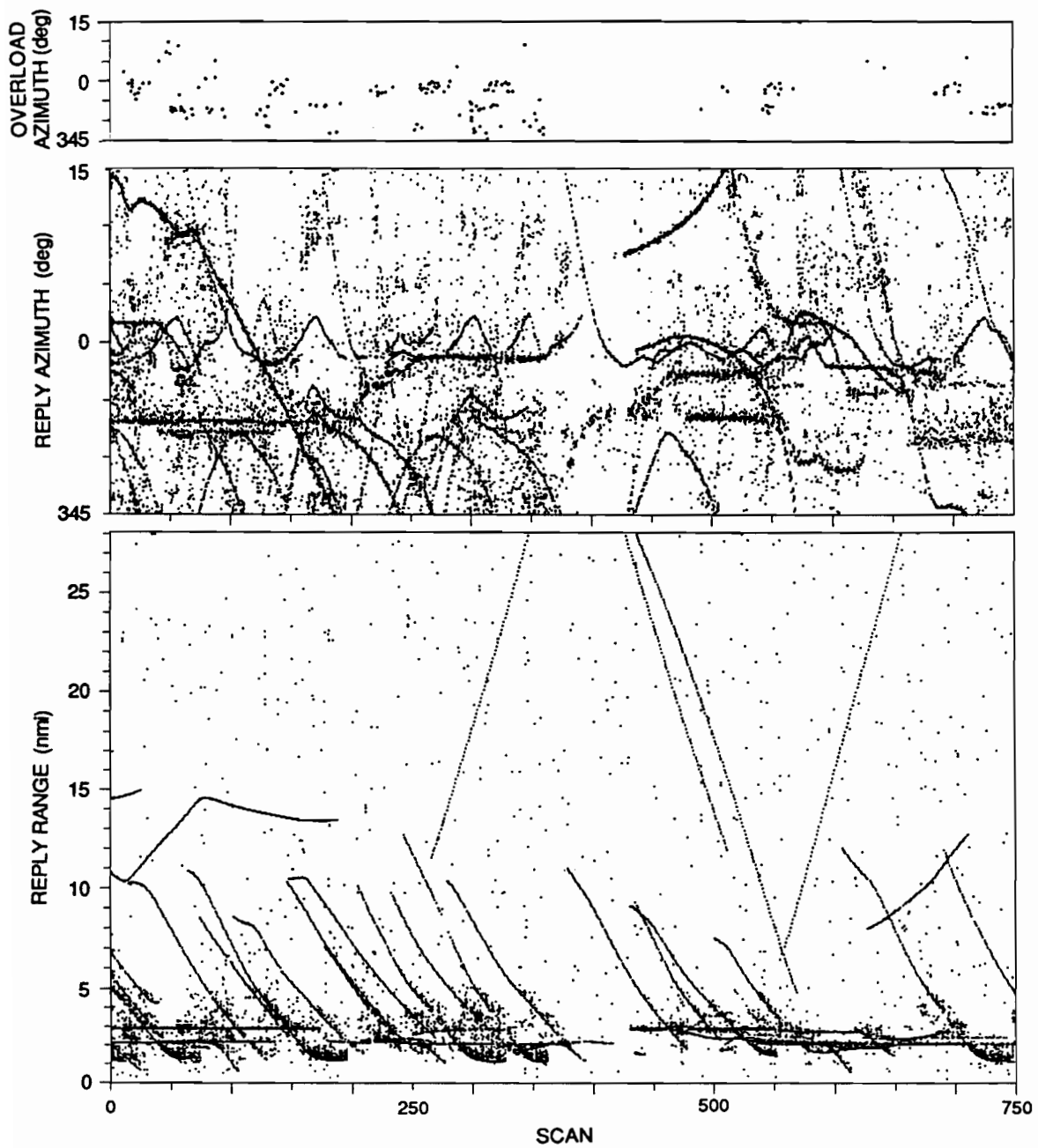
Figure 17. Occurrence of decoder overload relative to reply environment.

6. DISCUSSION

Except for the major multipath regions, most replies associated with reply traces were ungarbled, while most of the reflected replies were garbled. Ideally, the majority of these extraneous, false replies could be eliminated by discriminating with respect to code garbling. Unfortunately, the increase in the reply population near the airport also increases the number of true replies with garbled code information. Thus, a simple algorithm to remove all garbled replies would also remove replies which are necessary to form target reports for real targets close to the sensor.

Sources contributing to multipath appear to be buildings and other structures such as radar towers, vehicles, and surface aircraft. It was shown that the number of replies in a given sweep increased as the number of reflectors increased.

The problem at MEM with multipath in the North quadrant highlights a potential problem at many airports: the radar is located at the opposite end of the major runway(s) from the terminal(s). Therefore, the multipath sources are not evenly distributed in azimuth with respect to the sensor. The major structures, aircraft parked at the terminal(s), and taxiing aircraft are concentrated in an azimuth wedge of less than 180 deg. This concentration of reflectors drastically increases the reply population in the azimuth wedge. Thus, the sensor must process a large number of replies, both garbled and ungarbled.

As discussed in Section 5, the problems for reply processing can increase if a pilot leaves the transponder active while on the surface. First, the potential for synchronous garbling is increased. Second, if a stationary, active transponder were properly aligned with a reflector, then there could be persistent multipath at a given range and azimuth, leading to more overlap with true replies and more garbling.

The data presented in this report illustrate three problems associated with surveillance through the airport environment:

(1) As the number of replies in a given sweep increases, the potential for decoder overload increases. The decoder overload condition could result in loss of true, direct-path replies from aircraft, especially from those close to the sensor. Surveillance problems could occur as a result. First, surveillance reports may not be created for the aircraft. Second, a target report may be generated from multipath replies, but not from replies from the real aircraft. The target report produced may then become correlated with the real target track and introduce large tracking errors.

(2) With increased garbling of valid replies combined with multipath replies, it is possible to generate an ungarbled report from the multipath replies and a garbled report from the valid replies. If the report to track correlator places priority on ATCRBS code agreement, the wrong report could be associated with the aircraft's track. The correct information would be lost, and tracking errors would occur.

(3) Loss of valid replies also occurs when objects block the direct signal path between the sensor and the aircraft: the signal can be lost or distorted. As with the above, this could result in an incorrect surveillance report being associated with the target's real track, or in surveillance being lost.

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Two ways to possibly alleviate these surveillance problems are to increase the antenna elevation and to find a more central location for the antenna. Increased elevation reduces the potential for multipath. A central location, or one to the side of a major runway, would distribute the multipath sources more evenly. This in turn would decrease the effects of reply bunching and help eliminate the decoder overload syndrome.

A more robust means to alleviate surveillance problems would be to improve the processing algorithm for the "close-in" surveillance region. The correlation and tracking algorithms can be improved with enhanced velocity reasonableness tests, track initiation algorithms that ensure the uniqueness of tracks starting, and similar techniques for track maintenance.

7. SUMMARY

This report presented results that characterize the reply data that can be expected from ATCRBS transponder-equipped aircraft at or near a busy airport. The number of replies has been shown to be directly related to multipath from reflecting surfaces, including taxiing aircraft.

Additionally, this report has shown that conditions could exist where not all of the replies from ATCRBS equipped aircraft might be processed when forming target report measurements. The bunching of replies in a time and spatial manner introduces decoder overloading, and replies may be lost and unavailable for target formation.

The success of the Precision Runway Monitor system depends on providing the high resolution controller displays with accurate and reliable scan by scan target report measurements. These measurements should include those targets close to the sensor, on or near the airport surface, as well as those out to 30 nmi. The challenge exists in designing a PRM sensor which anticipates and recognizes that the ATCRBS reply data environment at active airports is less than a benign one.

A partial solution to the problem might be found in improved siting and location of the PRM sensor on or near an airport. Improved siting can minimize the amount of reflected replies, thereby lessening the probabilities that the direct replies from a real aircraft will be garbled or lost to the system for processing.

A general solution should place emphasis on surveillance processing: those tasks which make up the target formation, correlation, and dissemination functions. The development of algorithms which make the correct correlation choices, in spite of potential ambiguity brought on by multipath, is of the highest importance.

GLOSSARY

AMPS	ATCRB Monopulse Processing Subsystem
ASR	Airport Surveillance Radar
ATCRBS	Air Traffic Control Radar Beacon System
bpi	bits per inch
BTB	back-to-back
deg	degree(s)
fruit	false replies uncorrelated in time
MEM	Memphis International Airport
min	minute(s)
mode A	ATCRBS code request
mode C	ATCRBS altitude request
nmi	nautical mile(s)
PRF	Pulse Repetition Frequency
PRM	Precision Runway Monitor
s	second(s)

REFERENCES

[1] Gertz, J. L., "The ATCRBS Mode of DABS." MIT Lincoln Laboratory, ATC-65, January 1977.

[2] Wood, M. L., "Parallel Runway Monitor Tracking and Multipath Study." MIT Lincoln Laboratory, 42PM-PRM-0007, November 1991.