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Statistical Study of the Distance of Closest Approach of Aircraft to Ground-Based Emitters

April 1999

Final Report

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U.S. Department of Transportation
Federal Aviation Administration

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16. Abstract

A Technical Program was initiated by the Federal Aviation Administration (FAA) William J. Hughes Technical Center to determine the closest distances that aircraft fly to high-intensity radiation emitters. This program was launched as the FAA and the High-Intensity Radiated Fields (HIRF) advisory committees were defining HIRF regulatory rulemaking requirements. This study was conducted at the Denver International Airport to determine the actual closest distances that aircraft fly in proximity to high-intensity radiation emitters. Information on emitter location, frequency, power, etc., was obtained from the Government Master File. Aircraft flight information was obtained from the SAR (System Analysis Recordings) tapes at the Denver En Route Center. This program was used in conjunction with a research effort which located all high-powered emitters in the U.S. and Europe and established the actual HIRF environment.

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EXECUTIVE SUMMARY

The flight safety issues associated with the exposure of aircraft to High-Intensity Radiated Fields (HIRF) are being addressed by the Federal Aviation Administration (FAA). The current HIRF environment for aircraft is based on a worst-case evaluation of exposure leading to a concern that the required test levels may be excessive and unnecessarily burdensome. A clearer understanding of the interaction of HIRF with aircraft is desirable in order to understand both the likelihood of occurrences and the intensity of encounters. This report examines one of the main determinants of interaction, the closest approach of an aircraft to a HIRF emitter in the course of normal flight.

A square area (120 miles on a side) surrounding Denver International Airport (DIA) Denver, Colorado, was chosen as a study site. Information on emitter location, frequency, power, etc., was obtained from the U.S. Government Master File. Information on aircraft flight positions was obtained from the SAR (System Analysis Recordings) tapes at the Denver En Route Center using the National Traffic Analysis Program. Approximately 5500 flights over a three-day period were examined for proximity to emitters.

Based on the data collected, distributions of closest approach to any emitter were generated. Beacon codes were used to categorize different types of flight operations which were then examined for differences in the closest-approach distributions. Local flight operations were observed to have significantly different closest-approach characteristics as compared to other types of flights. It was also observed that the smallest values of closest-approach to emitters often occurred either at or very near airports.

Such information and other like it contained in this report are essential in understanding the distributions of aircraft-emitter separation distances as they occur in normal flight. Only after an informed selection of separation distances is made can a better understanding of the HIRF environment be achieved.

INTRODUCTION

BACKGROUND.

The flight safety hazards associated with the exposure of aircraft to High-Intensity Radiated Fields (HIRF) are constantly being assessed and addressed by the Federal Aviation Administration (FAA). The actual HIRF environment for aircraft is still not fully defined thus restricting the development of required testing levels for certification. A clearer understanding is needed of the interaction of HIRF with aircraft.

The HIRF levels currently used for certification of aircraft and avionics systems are based on a worst-case exposure. There is a real concern within the aviation community that these present test levels may be excessive and necessitate overtesting. In fact, the interaction of HIRF can be broken down into a number of components, each of which have a distribution of variables which determine both the likelihood and the strength of the HIRF-aircraft interactions. When distributions of variables associated with aircraft in actual use are examined, the likelihood of exposure as a function of the variables can be evaluated. The consideration of this additional detailed information permits better informed and better directed decisions about HIRF certification testing levels than does generic worst-case analysis.

This report describes an examination of one of the distributions involved in the interaction of HIRF and aircraft, the distance of closest approach of aircraft to ground based transmitters in a specified area. The project objective is to obtain closest-approach information for defining the emitter-aircraft separation distance which then can be used in specifying HIRF test certification levels.

APPROACH.

Some of the components of the interaction of HIRF with aircraft include

- emitter characteristics.

  - frequency
  - location
  - power
  - maximum antenna gain
  - antenna direction
  - antenna pattern
  - time dependence (on/off or pulse repetition pattern)

- aircraft characteristics.

  - type of aircraft (certification requirements)
  - shielding effectiveness of airframe
  - shielding effectiveness of cables and equipment

- operating frequencies of equipment
- susceptibility levels of equipment
- time dependence of equipment use (takeoff/landing, cruising etc.)

- aircraft flight characteristics.

  - class of aircraft
  - destination/flight purpose
  - altitude
  - location
  - time dependence of position (time of day/year, takeoff/landing/cruising etc.)

Unfortunately, many of these variables are correlated in ways which are not easy to isolate. It is obvious that variables within one of the three categories listed might be correlated, but there also can be correlations between categories. For example, a radar devoted to tracking specific targets in a certain air space may adapt power level, antenna characteristics, and dwell time on target based on the location and motion of a specific aircraft. Especially in cases such as this, but also more generally, caution must be exercised in trying to build up a general distribution from a product of individual distributions which are assumed to be independent.

After some consideration of the possibilities, the effort in this investigation focused on the distance of closest approach of aircraft to ground-based transmitters in a specified area. In essence, this makes use of the locations of emitters and the positions of aircraft while in flight. The geographical region used in the study is the Denver, Colorado, metropolitan area (roughly within 60 nm of Denver International Airport). Emitters were limited to those in the U.S. Government Master File (GMF) with frequency > 400 MHz with a nonnegligible electric field. The in-flight aircraft position information was obtained from the radar data recorded by the FAA for air traffic control purposes. Additional attention was given to types of flights and to the proximity of airport boundaries as they impact the observed closest approach distances.

EMITTERS

SOURCE OF EMITTER INFORMATION.

The emitter information from the FAA Washington Headquarters Government Master File database of electromagnetic emitters was supplied by Spectrum Engineering. The initial selection criteria for emitters were

- within approximately 60 nm of Denver International Airport, and
- had a power to transmitter > 10 Watts <u>or</u> antenna gain > 10 dB.

Over 3800 emitter entries met these requirements. It should be noted that some emitters had multiple entries, one for each of several operating frequencies. An ASCII record for included emitter entry provided:

- GMF identification
- city of location
- state of location
- emitter latitude to 1 second
- emitter longitude to 1 second
- frequency
- power
- antenna gain
- site elevation
- antenna height above ground
- pulse information
- system descriptor

PROCESSING OF EMITTER INFORMATION.

The information obtained from the Government Master File is not without errors or omissions. Some of the observed problems and the way these problems were solved are

- latitude/longitude information only to nearest minute, use 00 for seconds value.

- antenna gain missing, use 6 dB.

- site elevation missing or obviously in error, use information from U.S. Geological Survey Digital Elevation Model.

- antenna height missing, use 0 ft.

U.S. GEOLOGICAL SURVEY DIGITAL ELEVATION MODEL. Site elevation problems were resolved by making use of U.S. Geological Survey Digital Elevation Model (DEM) information. This standard resource is openly available and contains elevation information to the nearest meter at 3 arc-second spacing in the United States. The information is available in separate files, each of which span 1 degree of latitude and longitude. For this project, sixteen files covering 4 degrees in both longitude and latitude were used. When the DEM was used to calculate the site elevation for emitters with known values, the agreement was generally good to 50 ft or better with only a handful of discrepancies greater than 100 ft. This cross-check procedure also helped to identify GMF site elevation errors.

SELECTION OF CANDIDATE EMITTERS. The list of emitter entries was pared down to 1962 by requiring frequency > 400 MHz. The final selection cut was made on electric field level. For each emitter, an electric field, E, at 100 ft distance was calculated using

$$E = \sqrt{\frac{377PF_g}{4\pi R^2}} \tag{1}$$

where P = emitter power
F_g = antenna gain factor
R = 30.48 m (100 ft)

For frequencies > 400 MHz and at a distance of 100 ft, one is in the far field of each element of a transmitting antenna, but lack of phase coherence over the entire antenna may prevent the 1/R behavior assumed in equation 1. However, this effect on E is expected to be less than a factor of two. With this in mind, a relatively low level, E > 10 V/m, was used to select emitters for the final group to be used in further calculations; 216 GMF entries satisfied this cut. This final group of emitters is meant to represent the set of all emitters in the Denver area which could possibly be responsible for the largest E field which any aircraft may experience. In fact, the 10 V/m cut is fairly conservative and the selected group is surely a worst case. Figure 1 shows the geographical distribution of these emitters. Clearly, it is not difficult to extend this procedure to calculate the largest field that may be experienced in the Denver area for each frequency, modulo, the uncertainty factor in the E field calculation cited above.

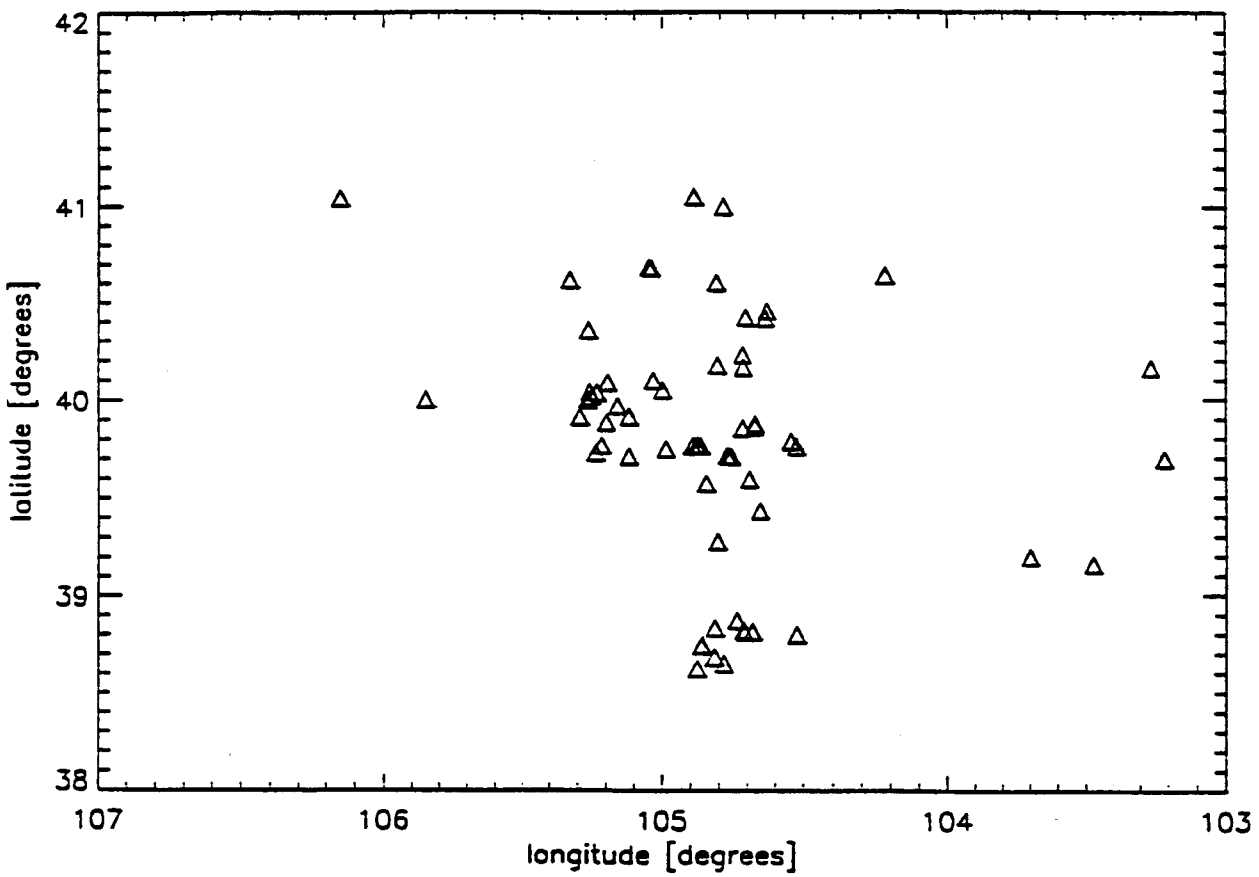

FIGURE 1. LOCATION OF EMITTERS CONSIDERED FOR CLOSEST APPROACH OF AIRCRAFT

AIRCRAFT FLIGHT POSITIONS

SOURCE OF AIRCRAFT FLIGHT DATA.

The aircraft flight positions were obtained from the FAA's Denver En Route Air Traffic Control Center. The data were extracted from three days of System Analysis Recordings (SAR) tapes recorded near the beginning of January 1997. The National Traffic Analysis Program (NTAP) was run by FAA personnel to select the aircraft position information as a function of time. The use of NTAP output to generate the desired information was outside the original design of the program and required intensive effort by FAA personnel. Although many voluminous data files were generated, it appeared that there were still gaps in SAR information obtained by this method. The basic set of radar information extracted for an aircraft at a given time included

- beacon code identifier number reported by the aircraft transponder,
- latitude to the nearest second from radar processing,
- longitude to the nearest second from radar processing,
- time of the radar report to the nearest second, and
- adjusted altitude reported by the aircraft to the nearest 100 ft with respect to mean sea level.

GENERAL PROCESSING OF AIRCRAFT POSITION INFORMATION.

The first step in processing the NTAP output was to remove all but the information just listed. The result was an unordered group of sets of flight information data, for about 550,000 space-time points. A preliminary operation calculated aircraft altitude above ground level (AGL) at each point. This was done using the altitude reported with respect to sea level and the same Digital Elevation Model described in the emitter section. This new information was added to the existing information set for each point. The next processing step ordered the information sets first by beacon code and then by time. Inspection of this data structure revealed that some beacon codes were used and reused several times throughout the day. In fact, data for beacon 1200 code (used by aircraft not filing a flight plan) sometimes had multiple aircraft and their positions associated with the same time value. This additional ambiguity in the 1200 code data made it desirable to treat it separately from the non-1200 code data.

NON-1200 CODE DATA.

SEPARATION INTO FLIGHT TRACKS. Since one of the aims was to differentiate by flight, it was essential to identify the beginning and end of data segments associated with distinct flight operations. These will subsequently be referred to as flight tracks. Several data characteristics were examined to aid in distinguishing the individual tracks; they include

- time interval between radar reports,

- distance between aircraft positions on successive radar reports,
- difference in aircraft altitude on successive radar reports,
- aircraft speed calculated using position and time differences on successive radar reports,
- aircraft ascent/descent rate using successive radar reports,
- accumulated observation time for a beacon code with respect to some defined beginning time,
- accumulated distance for a beacon code with respect to some defined beginning position, and
- total number of points accumulated for a beacon code with respect to some defined beginning.

Figure 2 shows a scattergram of the speed calculated for successive radar reports versus the time interval between the reports. There is a clear separation in the data representing a region associated with points belonging to the same flight from a region associated with noise points or points belonging to different flights. Figure 3 projects this same data into a relative frequency histogram versus aircraft speed. On both figures an acceptance cut at < 0.5 miles/second is indicated. This value allows for some radar measurement jitter but rejects clearly unphysical speed values.

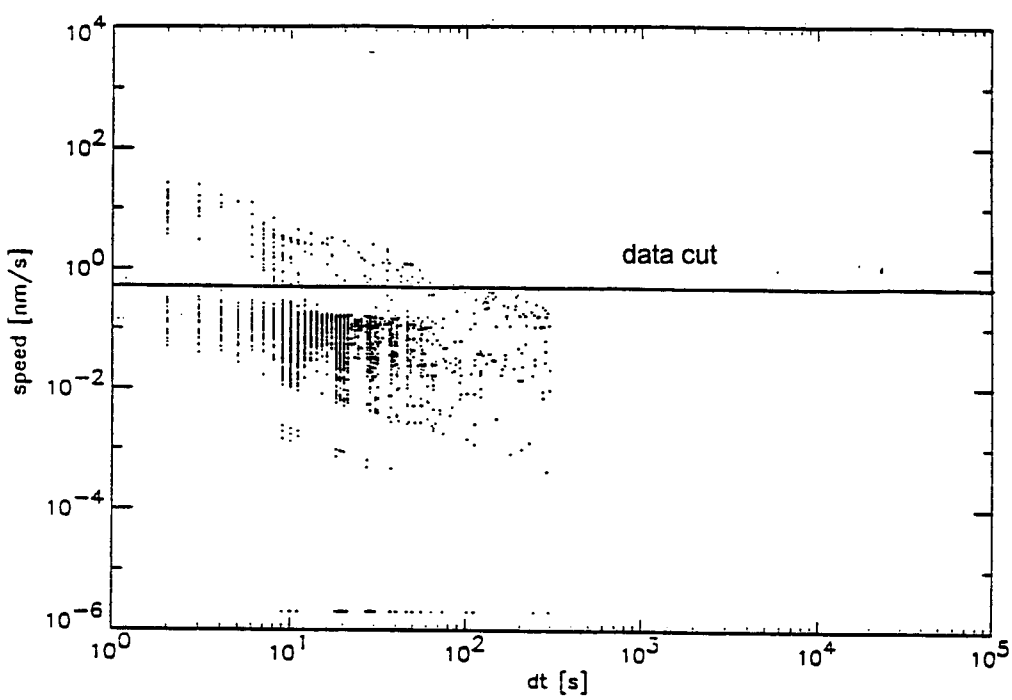

FIGURE 2. SCATTERGRAM OF SPEED VERSUS THE TIME INTERVAL FOR SUCCESSIVE POINTS RECORDED FOR NON-1200 CODE FLIGHTS

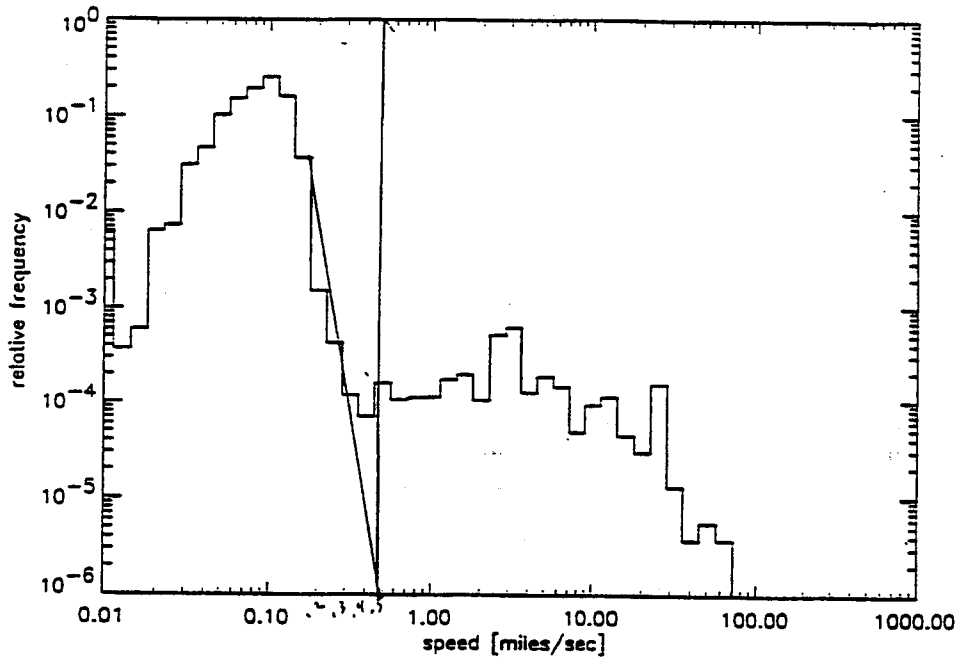

FIGURE 3. RELATIVE FREQUENCY HISTOGRAM FOR SPEED BETWEEN SUCCESSIVE POINTS RECORDED FOR NON-1200 CODE FLIGHTS

A similar consideration of altitude leads to the relative frequency histogram versus the absolute value of ascent/descent rate displayed in figure 4. In this plot, too, a cut on maximum rate (200 ft/sec) is indicated.

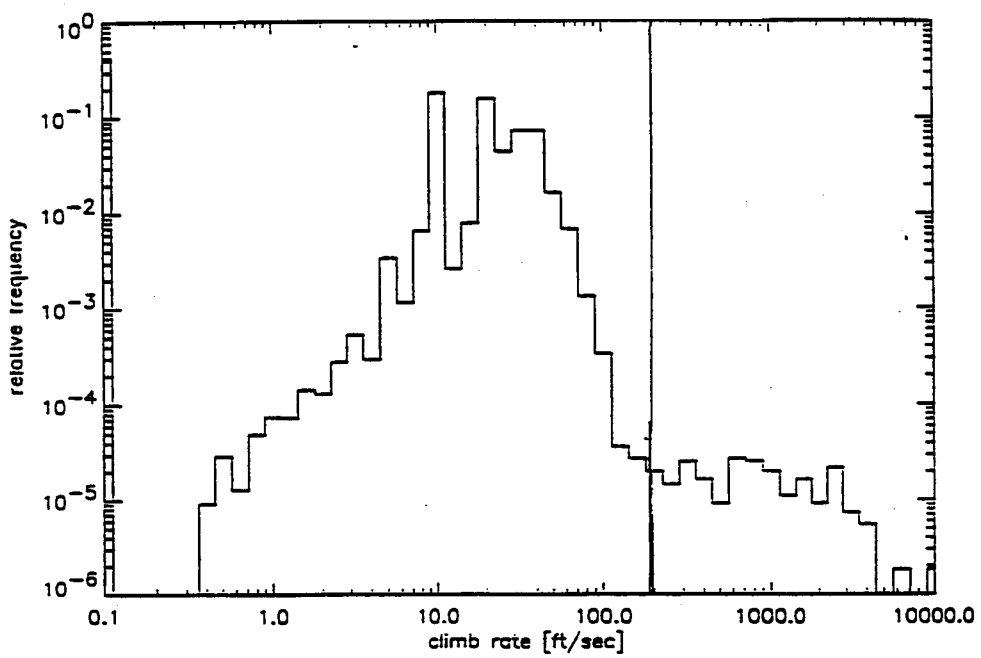

FIGURE 4. RELATIVE FREQUENCY HISTOGRAM FOR ASCENT/DESCENT RATE BETWEEN SUCCESSIVE POINTS RECORDED FOR NON-1200 CODE FLIGHTS

The third cut made required that there be 300 seconds or less separation between successive radar reports. This seems rather generous, but visual inspection of plotted points revealed clearly identifiable flights that contained gaps up to 300 seconds in duration.

QUALITY CONTROL AND ACCEPTANCE OF FLIGHT TRACKS. The resulting flight track selections were examined for reasonableness and to understand their general characteristics. Figure 5 shows the relative frequency histogram versus the entire time accumulated for a flight track. It was decided that tracks of duration less than 5 minutes were not useful for the study and probably represented incomplete or unreliable data. This data cut is shown on the histogram.

A similar consideration of the number of points recorded in the flight track leads to figure 6. This plot shows the relative frequency distribution for the total number of radar reported points in the track. Again, a cut level (number of points 19) is shown on the histogram. Making this cut excludes a few percent of the tracks but eliminates many of those with marginal information. If a radar scan period of 10 seconds is assumed, a 20-point minimum for a 5-minute minimum duration track corresponds to a data loss rate of no more than 25%.

With these additional requirements, processing yields ~ 5300 tracks averaging ~ 100 points/track for non-1200 codes. By checking the location and altitude of the first and last points of the flight tracks, the track data at Denver International Airport (DIA) can be associated with takeoffs or landings. Approximately 3500 tracks fit this category and figures 7 and 8 show sample DIA tracks. Takeoffs and landings at other Denver area airports as well as higher altitude overflights can be found in the remaining tracks.

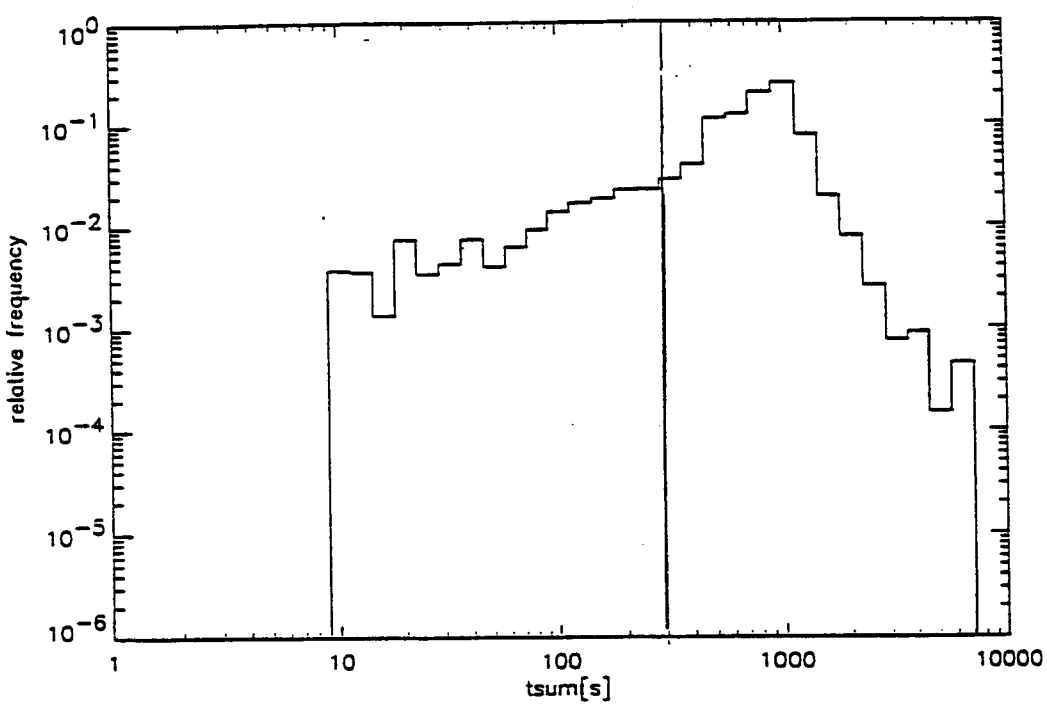

FIGURE 5. RELATIVE FREQUENCY HISTOGRAM FOR ENTIRE FLIGHT TIME FOR TRACKS SELECTED FOR NON-1200 CODE FLIGHTS

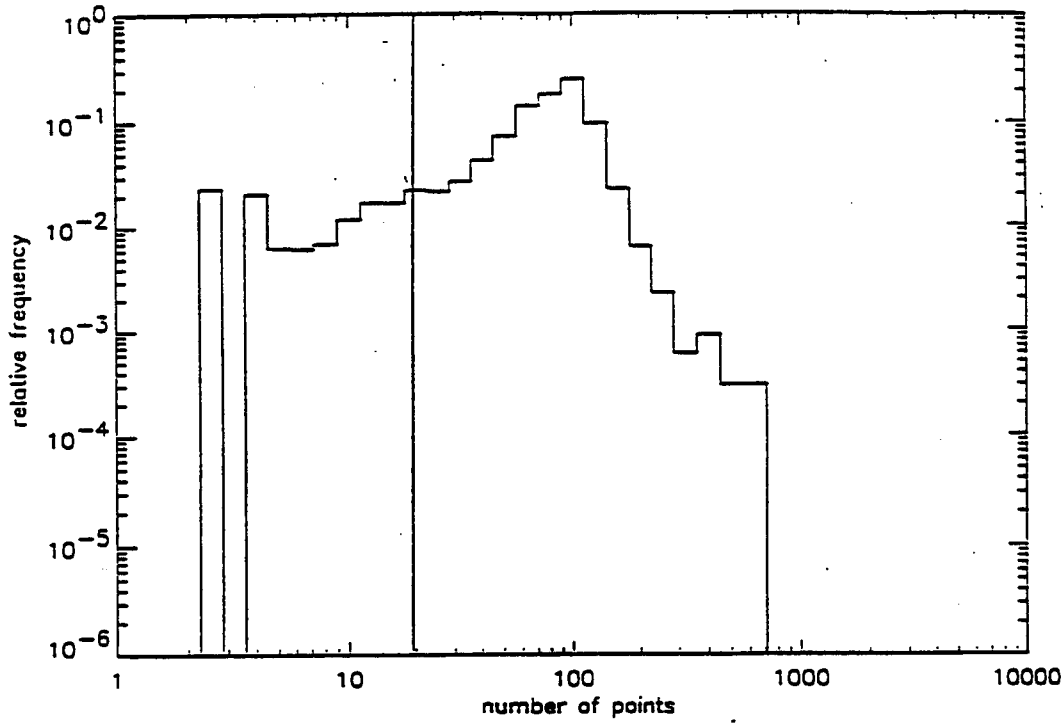

FIGURE 6. RELATIVE FREQUENCY HISTOGRAM FOR TOTAL NUMBER OF POINTS IN TRACKS SELECTED FOR NON-1200 CODE FLIGHTS

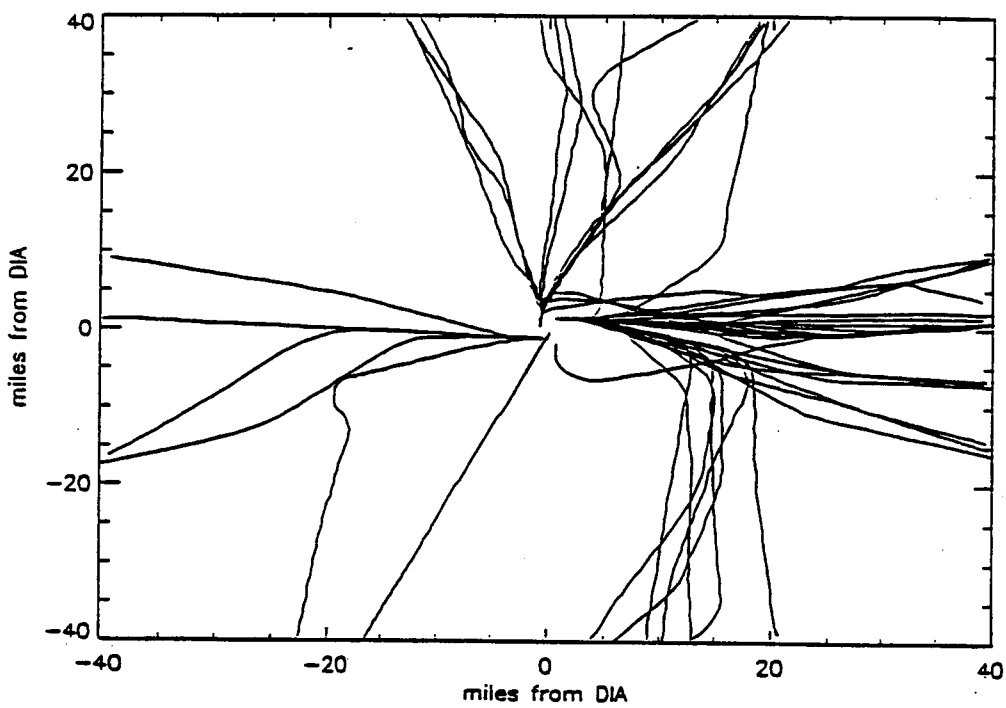

FIGURE 7. SAMPLE OF 50 TRACKS FOR FLIGHTS TAKING OFF FROM DENVER INTERNATIONAL AIRPORT

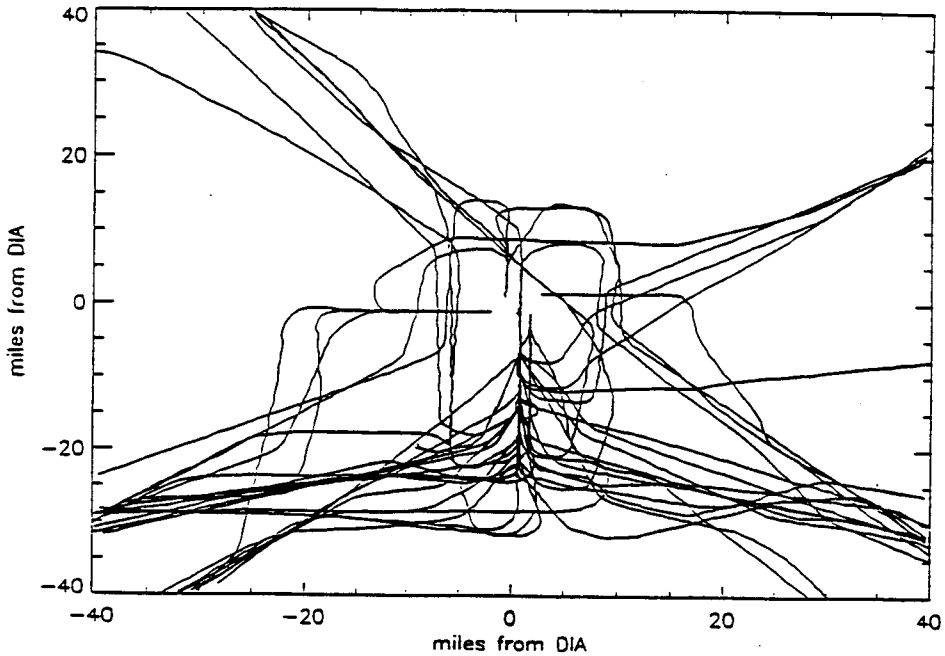

FIGURE 8. SAMPLE OF 50 TRACKS FOR FLIGHTS LANDING AT DENVER INTERNATIONAL AIRPORT

1200 CODE DATA.

SEPARATION INTO FLIGHT TRACKS. These non-1200 code data were at least well ordered and unique for a given flight track, requiring mainly the identification of start and stop points. However, the 1200 code data was much more entangled, requiring a different processing approach. It should first be noted that there were approximately 22,000 points with beacon 1200 code (< 5% of all the data). These flights are mainly of interest because they represent a different category of aircraft operation.

Most of the same quantities used in studying the non-1200 code data were also used for the 1200 code data but a different approach in track selection was necessary. For illustration of the problem, figure 9 shows all the 1200 code points found within a particular one-hour time interval. Several features are immediately evident. While the eye can pick out several apparently well formed tracks, there are excessively large gaps in both space and time occurring in these tracks. Furthermore, there are many points which do not seem to be associated with any identifiable tracks, indicating that caution is required in trying to link points up into tracks.

Figure 10 is a scattergram of the distance between successive points as a function of time over three days. It can be seen that at certain times of the day (early morning and late night) there is a lower density of points and the distance is usually less than 1 mile. It is tempting to identify these as times when there is only a single 1200 code aircraft operating in the Denver area. Close to midday there are many more points and while some of them have a character similar to the early/late day points, many more of them have separation distances of up to 100 miles. It is tempting to interpret this as the intermingling of points associated with different 1200 code

aircraft operating simultaneously but at considerable distance from each other. Histograms of the number of 1200 code points per minute versus time support this analysis, going from 5-6 points/minute early in the morning to 12-16 points/minute at midday.

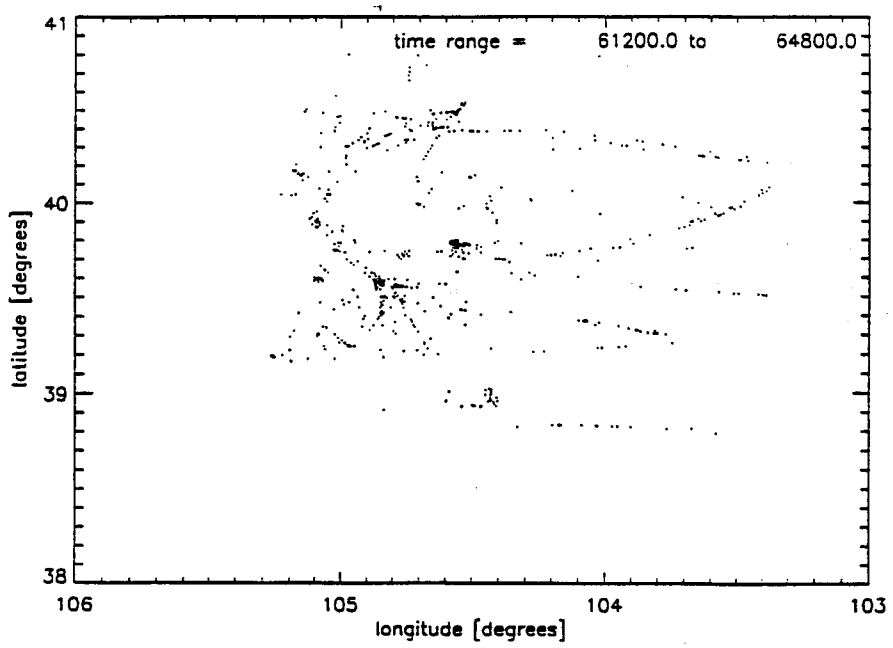

FIGURE 9. POSITIONS OF ALL 1200 CODE POINTS RECORDED IN A SAMPLE ONE-HOUR TIME PERIOD

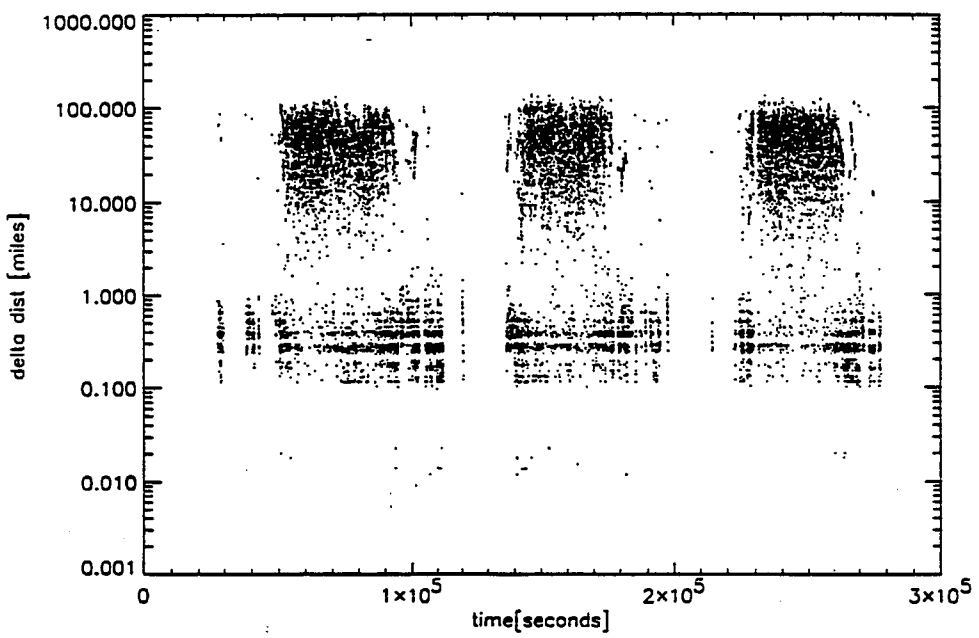

FIGURE 10. SCATTERGRAM OF TIME INTERVAL BETWEEN SUCCESSIVE POINTS RECORDED FOR 1200 CODE TRACKS VERSUS TIME FOR THE ENTIRE THREE-DAY PERIOD

Figures 11 and 12 examine distance and altitude difference between successive time-ordered points. Also on these plots are cut values; the regions below the lines are the acceptance regions used for assigning points to the same aircraft track. In addition to these first two requirements, it was required that associated points have time values within 60 seconds of each other. This is more limiting than the 300-second value used for non-1200 code points, but it is required by the higher level of ambiguity and data corruption in the 1200 code data.

The track identification procedure is serial in nature using the time ordering of the points:

1. The first unused point is selected as an initial reference point and now marked as used.

2. The next unused point in time is evaluated for satisfying the cut criteria with respect to the previous selected point.

3. Either the criteria are satisfied or not satisfied.

   - If the criteria are satisfied, the point is added to the track, marked as used, and becomes the reference point used for the next comparison. One then returns to step 2.

   - If the criteria are not satisfied, the track is terminated and stored. One then returns to step 1.

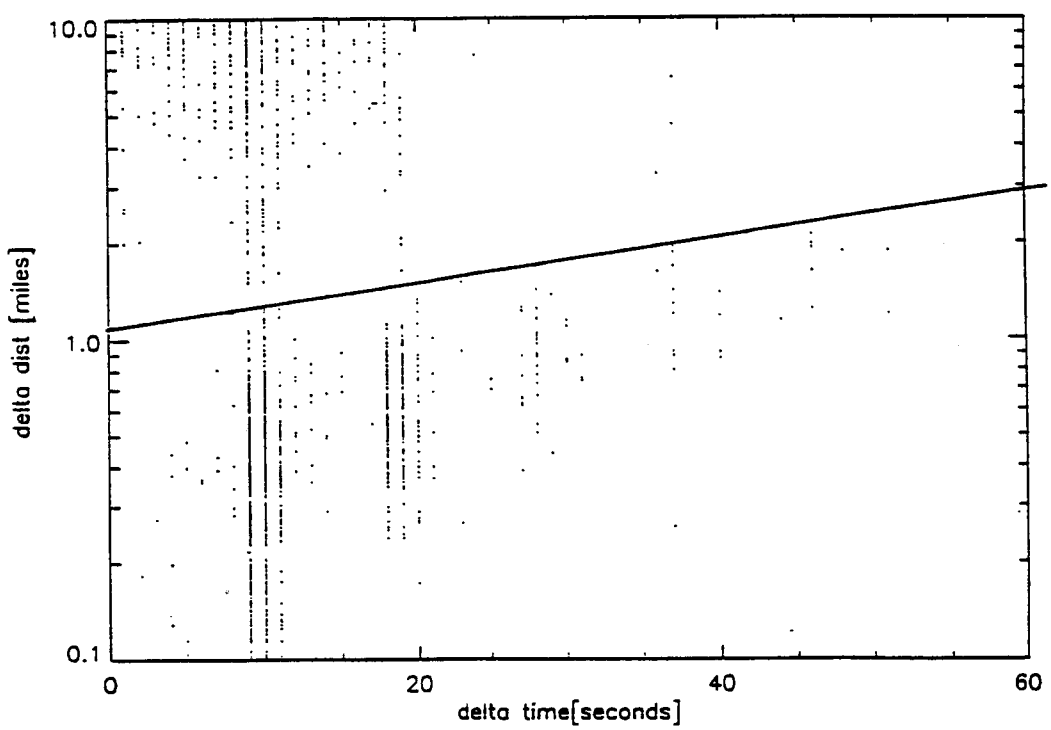

FIGURE 11. SCATTERGRAM OF THE DISTANCE BETWEEN SUCCESSIVE POINTS RECORDED FOR 1200 CODE TRACKS VERSUS THE TIME INTERVAL BETWEEN THE SAME TWO POINTS

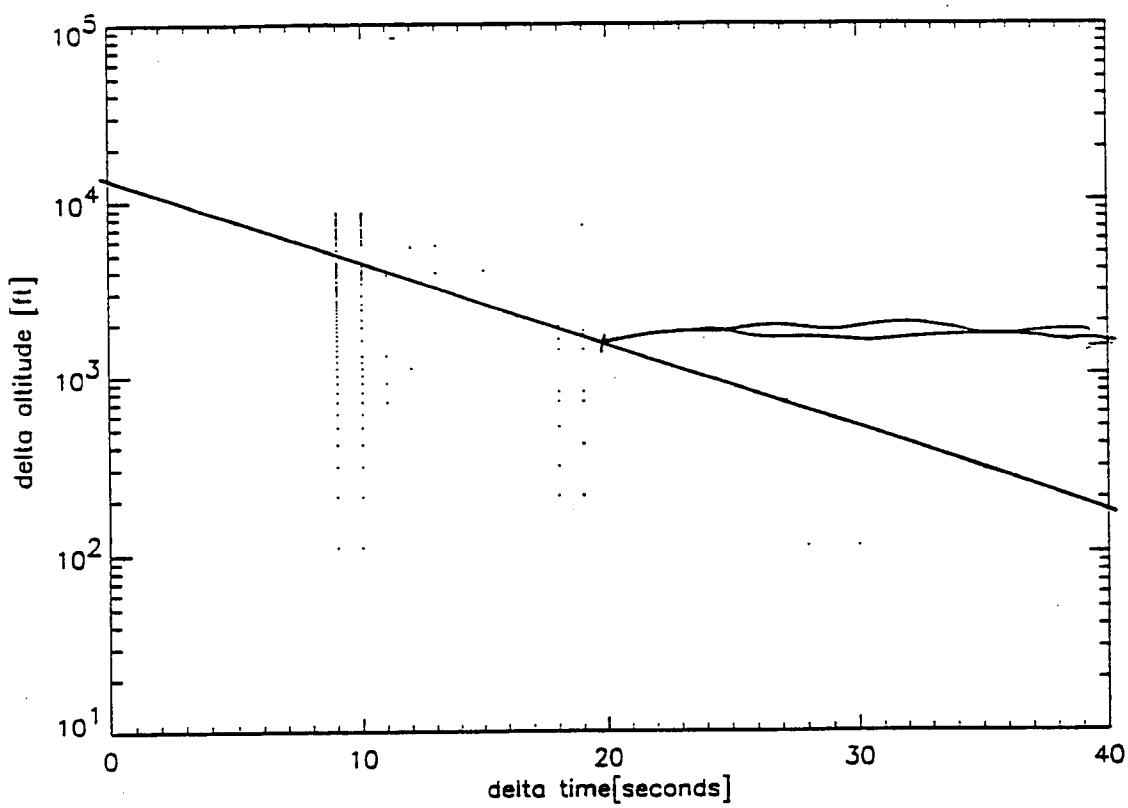

FIGURE 12. SCATTERGRAM OF THE DIFFERENCE IN ALTITUDE BETWEEN SUCCESSIVE POINTS RECORDED FOR 1200 CODE TRACKS VERSUS THE TIME INTERVAL BETWEEN THE SAME TWO POINTS

Figure 13 shows the dependence of the number of identified tracks upon the value used for the time interval cut. The same plot shows, also as a function of the time interval cut value, the number of "orphan points" (~25%) which cannot be associated with another point, to form a track. The number of tracks found (~3200) seems rather high for the number of points, and figure 14 shows a rather large number of tracks with 10 or fewer associated points. It appears that the gaps observed in figure 9 have resulted in breaking of a track into many subtracks by the algorithm used. Figures 15 and 16 show the tracks found and the remaining orphan points. While improvement in this area may be possible, the condition of the present data would make it difficult to achieve and it may not be necessary for this study.

QUALITY CONTROL AND ACCEPTANCE OF FLIGHT TRACKS. Quality control requirements may be imposed on the > 3200 tracks found. When a 5-minute track duration and 10-point minimum are required, the number of tracks decreases to ~ 212 with an average of ~ 28 points/track. This seems to confirm the earlier assessments of 1200 code data quality and gaps.

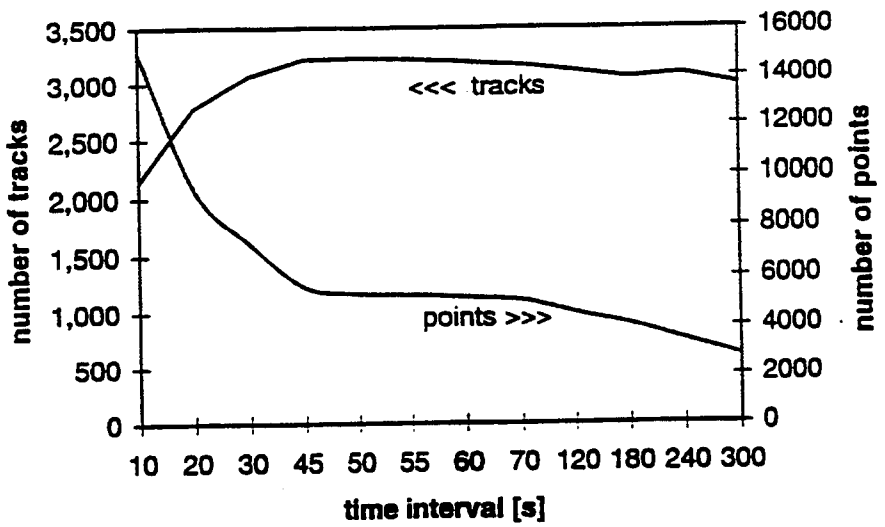

FIGURE 13. NUMBER OF 1200 CODE TRACKS AND ORPHAN POINTS VERSUS MAXIMUM TIME INTERVAL IN TRACK

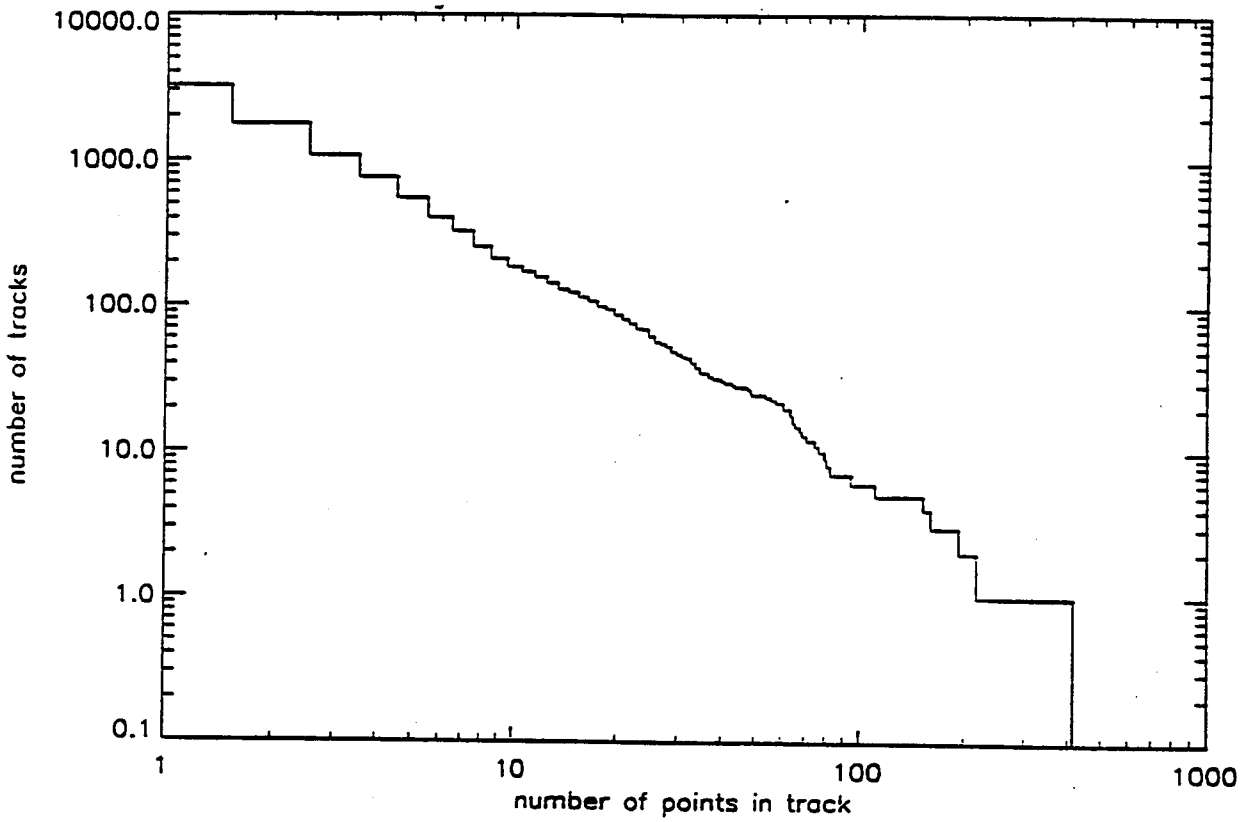

FIGURE 14. HISTOGRAM OF NUMBER OF POINTS IN 1200 CODE TRACKS

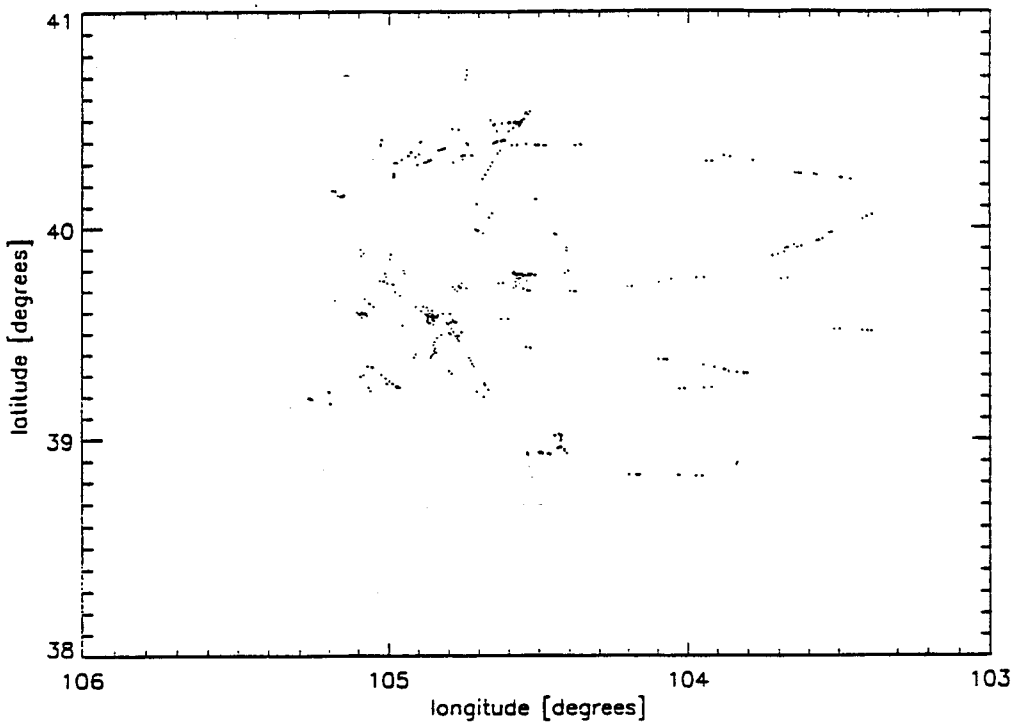

FIGURE 15. COMPARISON OF 1200 CODE TRACKS IN THE SAME SAMPLE ONE-HOUR TIME PERIOD AS DISPLAYED IN FIGURE 9

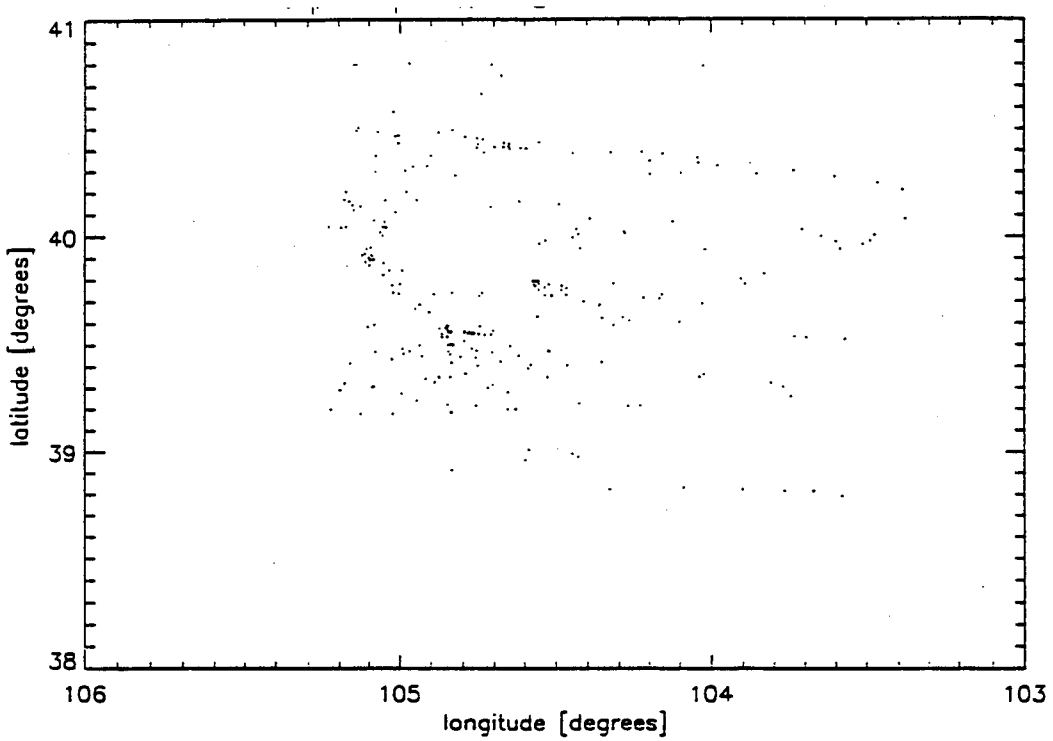

FIGURE 16. COMPARISON OF 1200 CODE ORPHAN POINTS IN THE SAME SAMPLE ONE-HOUR TIME PERIOD AS DISPLAYED IN FIGURE 9

CORRELATIONS OF EMITTERS AND FLIGHT POSITIONS

GENERAL PROCEDURE.

With both the emitter positions and the aircraft flight positions known, it is fairly straightforward to calculate the closest approach of each flight track to each emitter. From this the overall closest approach of a given aircraft track to any emitter is easily found. Two items in this procedure should be noted:

- Straight line interpolation between successive points on the track is used to find the closest approach for the entire trajectory, not just at the recorded points.
- No extrapolation is done. Often the radar does not track the aircraft on the ground in some positions. This means that tracks for takeoff and landing may be truncated slightly short of the ground. Some extrapolation was tried, but the quality of altitude (above ground level) data required for extrapolation did not appear to justify extensive effort in this area.

NON-1200 CODE FLIGHTS.

For all non-1200 code flight tracks, the correlation of emitters and aircraft flight positions through closest approach is shown in figure 17. For each aircraft track a line is drawn from the point of closest approach to the appropriate emitter, marked by a triangle. A variety of emitters and flight paths are seen to be represented. Figure 18 displays some of the geometric characteristics associated with the closest approach to an emitter. It is a scattergram of aircraft altitude (with respect to emitter height) versus horizontal distance from the emitter at the point of closest approach. From this plot, one may infer the elevation angle from the emitter to the aircraft. It is also clear that there are several categories of flight operations. Some are very high overflights at 15,000 ft or more. There is also a group of flights with closest approaches occurring for relative altitudes of 500- to 1500-ft range. Finally, there is a group with closest approach occurring at altitudes of < 300 ft which must correspond to takeoffs and landings.

Figure 19 represents the relative frequency of closest approach (or slant range). A single occurrence on this plot has a value of ~ 0.0002 corresponding to the approximately 5300 flight tracks considered. Note the log-log scale of the plot. Integration of the curve in figure 19 yields figure 20. This plot shows that a 1% level of closest approach occurs at a distance of approximately 200 ft.

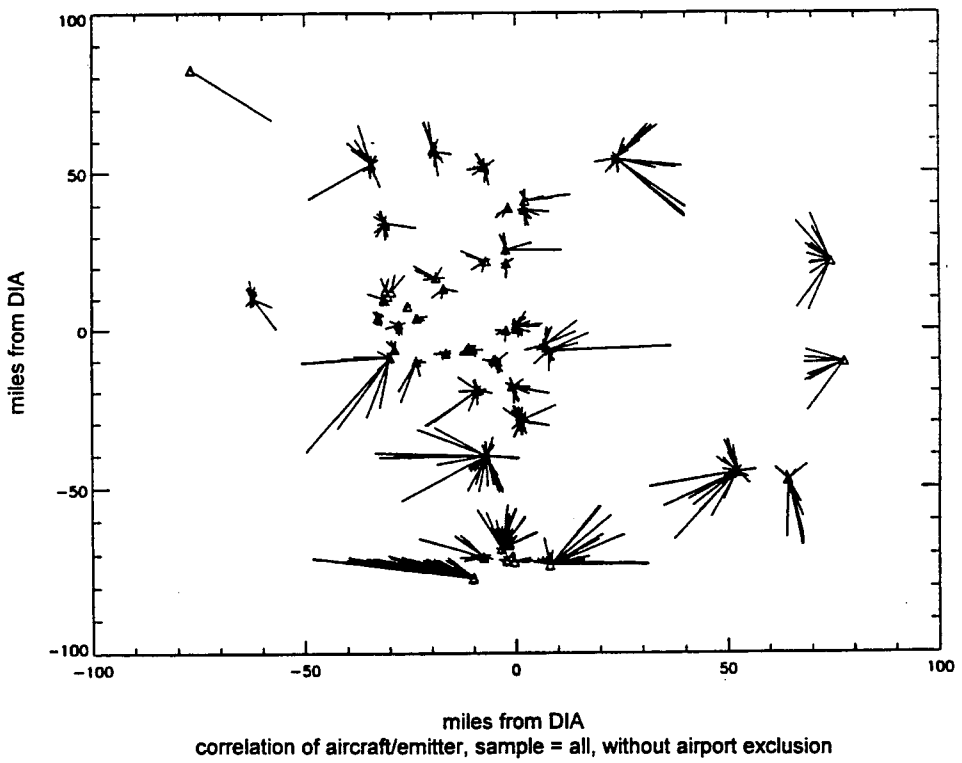

FIGURE 17. EMITTER LOCATIONS WITH VECTORS TO LOCATION OF CLOSEST APPROACH TO AIRCRAFT FLIGHT TRACKS, ALL NON-1200 CODE TRACKS

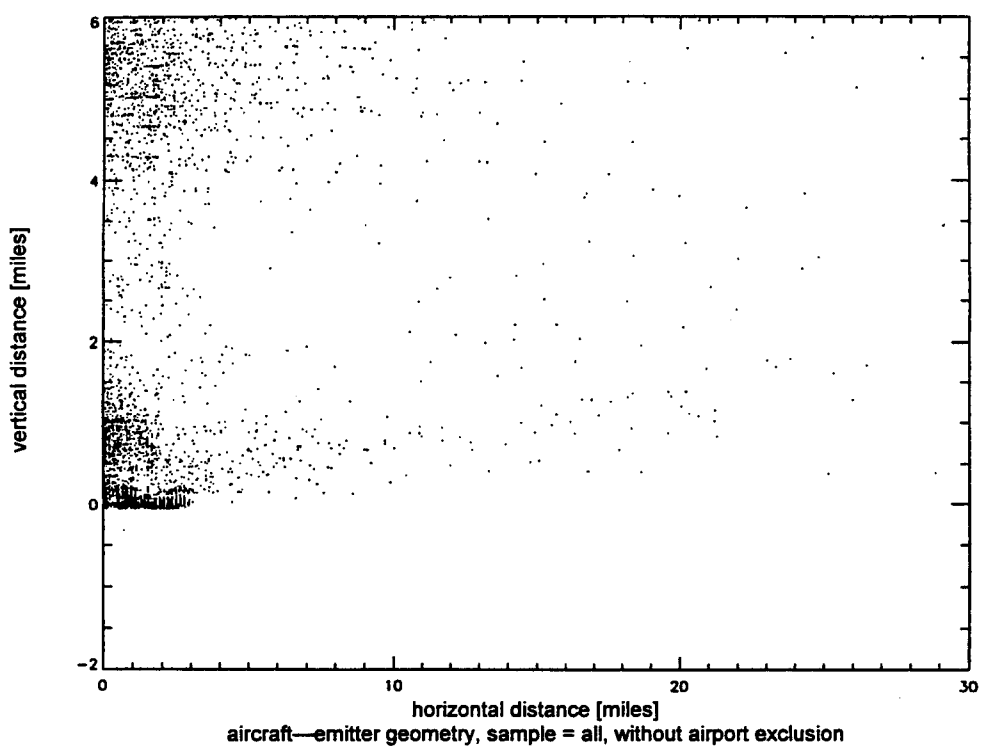

FIGURE 18. POSITION OF AIRCRAFT AT SMALLEST CLOSEST APPROACH WITH RESPECT TO EMITTER, ALL NON-1200 CODE TRACKS

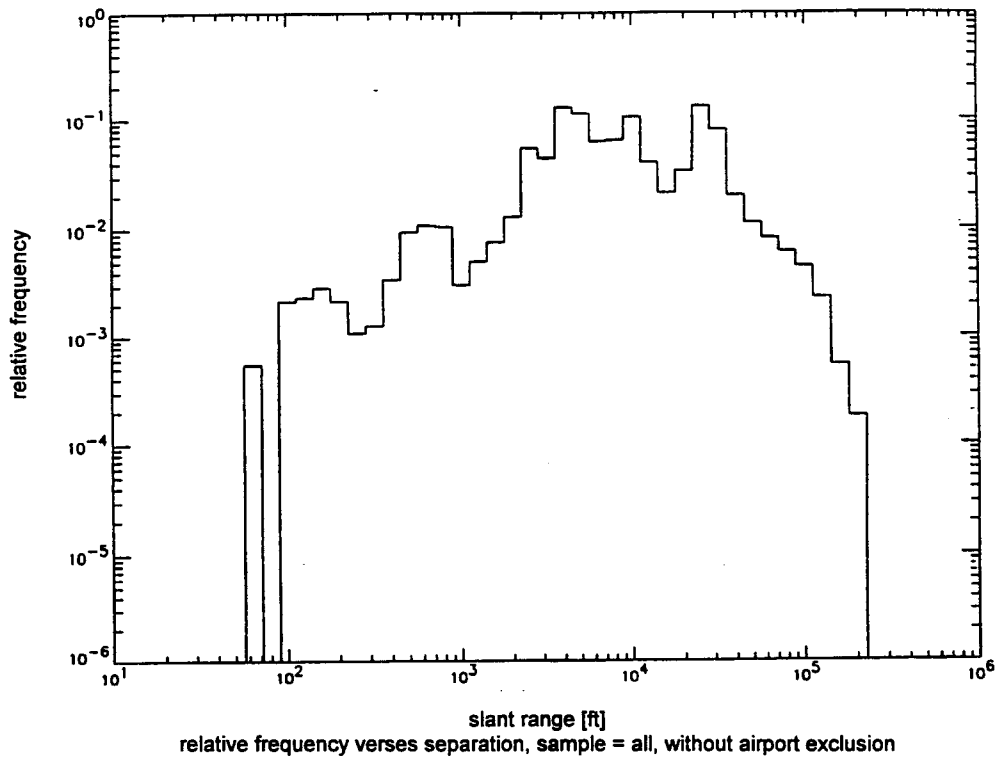

FIGURE 19. RELATIVE FREQUENCY DISTRIBUTION OF SMALLEST CLOSEST APPROACH TO EMITTER, ALL NON-1200 CODE TRACKS

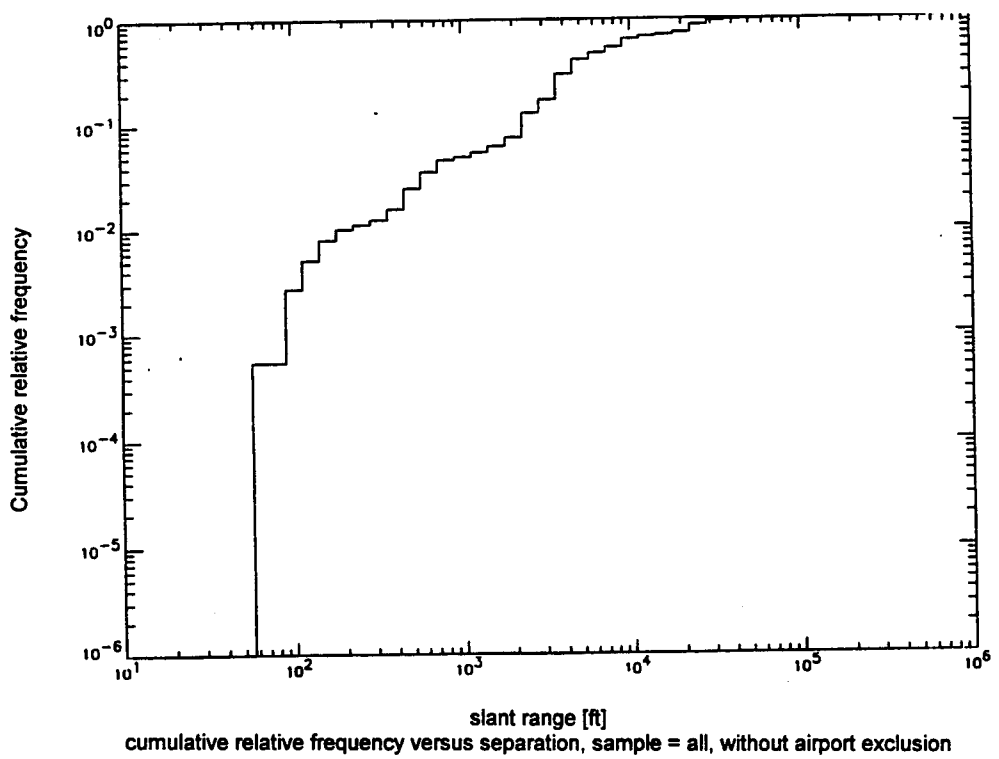

FIGURE 20. CUMULATIVE RELATIVE FREQUENCY DISTRIBUTION OF SMALLEST CLOSEST APPROACH TO EMITTER, ALL NON-1200 CODE TRACKS

AIRPORT ZONES.

The behavior of an aircraft in the immediate vicinity of an aircraft is somewhat less variable than elsewhere, being governed more tightly by both general landing/takeoff procedures and by the airport traffic control. Furthermore, a separate HIRF operating environment is under consideration for use in an airport neighborhood. It was, therefore, decided to investigate the effect of excluding airport vicinities from consideration when determining the distance of closest approach to emitters. To this end, a list of airports in the Denver area was obtained from the U.S. Government Public Airport/Facility Directory for the Southwest. From this listing (plus Buckley ANG), the latitude and longitude of the extremes of each airport's runways was determined with the provision for an additional buffer zone defined by extending the latitude and longitude limits of the runways. The airport plus buffer zone extended from ground level to 1500-ft AGL. Figure 21 illustrates the extent of runways at DIA.

The size of the buffer zone beyond the runway limits in each direction was varied to assess its importance. For a two-mile buffer zone, figure 22 shows the airport locations and the exclusion zones used for closest approach determination. Figure 23 shows the cumulative relative frequency plot versus distance of closest approach for additional buffers of zero, two, and four miles beyond the airport runways for non-1200 code tracks. The effect of the additional buffer zone is substantial, with minimum-closest approach distance going from ~ 200 ft with no additional buffer to ~ 1100 ft with four miles additional buffer.

Figure 24, also for non-1200 code tracks, compares the cumulative relative frequency plot versus distance of closest approach for no airport zone exclusion at all to the results for airport zone with a two mile buffer. In this case the smallest value is seen to shift from ~ 60 ft with no airport zone to ~ 600 ft with an excluded airport zone including a two-mile buffer; this is a full order of magnitude increase.

DIA TAKEOFFS AND LANDINGS.

A very important subset of the aircraft flight data examined involved takeoffs and landings at Denver International Airport. Approximately 3500 of the 550 non-1200 code flights originated and/or terminated at DIA. This classification was made by requiring either the first or last point of the track to occur within the airport boundaries with an altitude of less than 800 ft above ground level. Figure 25 shows the cumulative relative frequency for this class of aircraft operation. Also repeated on the same figure is the distribution for all non-1200 code flights. As far as the smallest value of distance of closest approach, it is clear that aircraft operations in and out of DIA generally have greater separation from emitters than do the remainder of the flights.

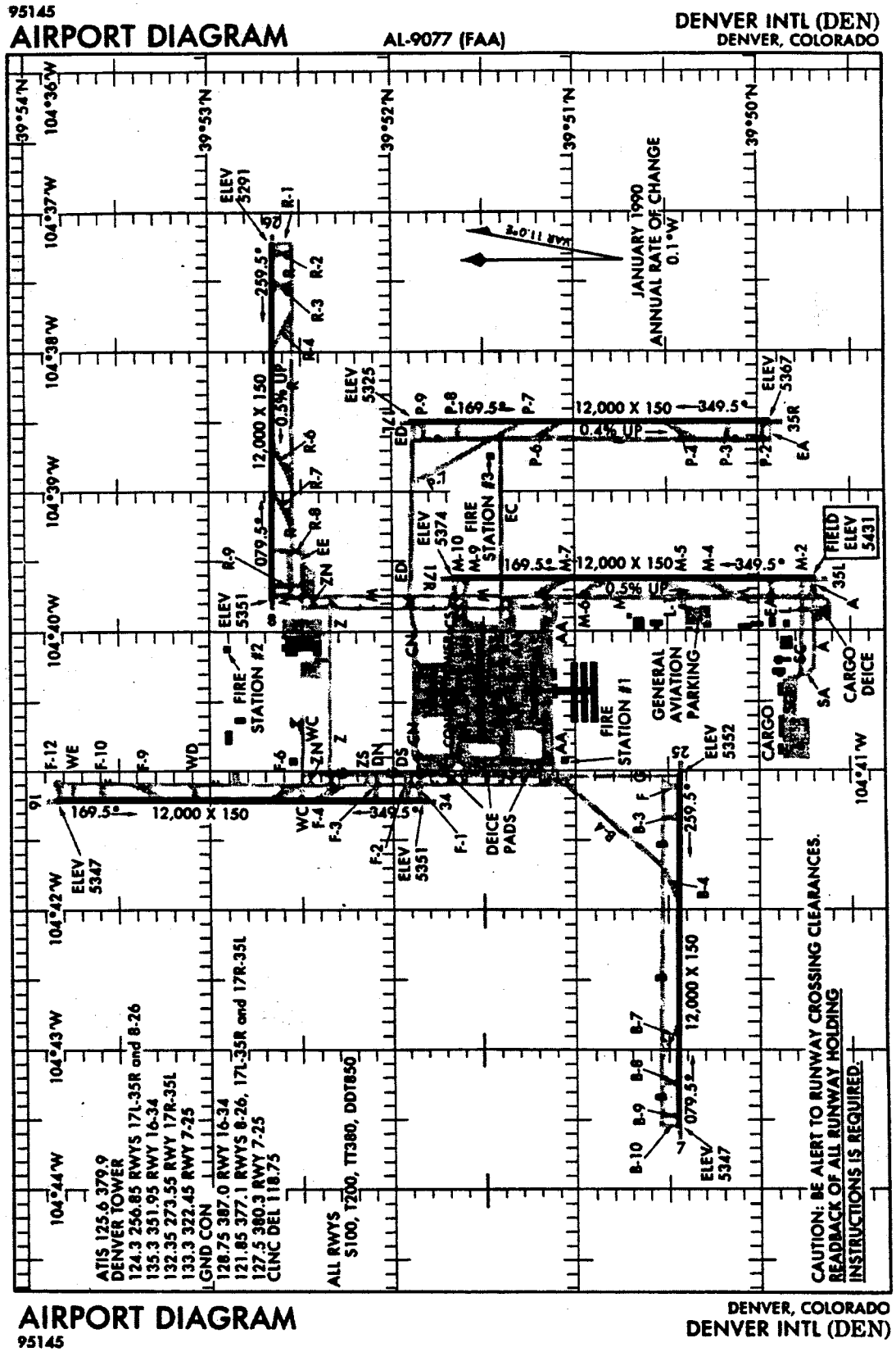

FIGURE 21. DENVER INTERNATIONAL AIRPORT DIAGRAM SHOWING LATITUDE AND LONGITUDE EXTENTS OF RUNWAYS

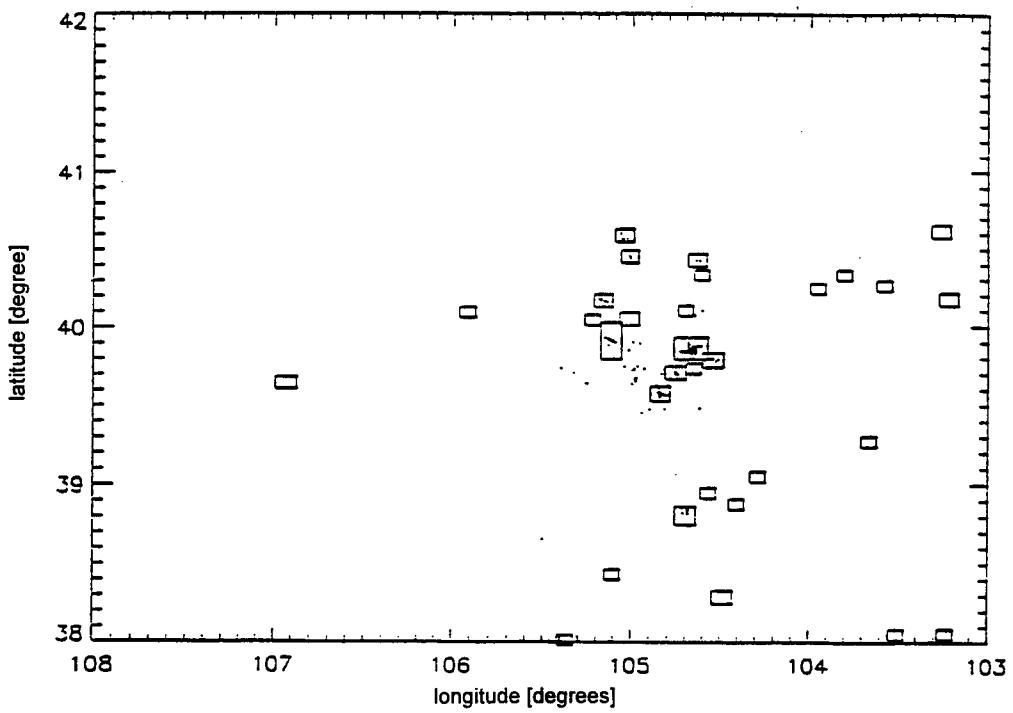

FIGURE 22. AIRPORT LOCATIONS IN THE DENVER AREA USING TWO-MILE BUFFER

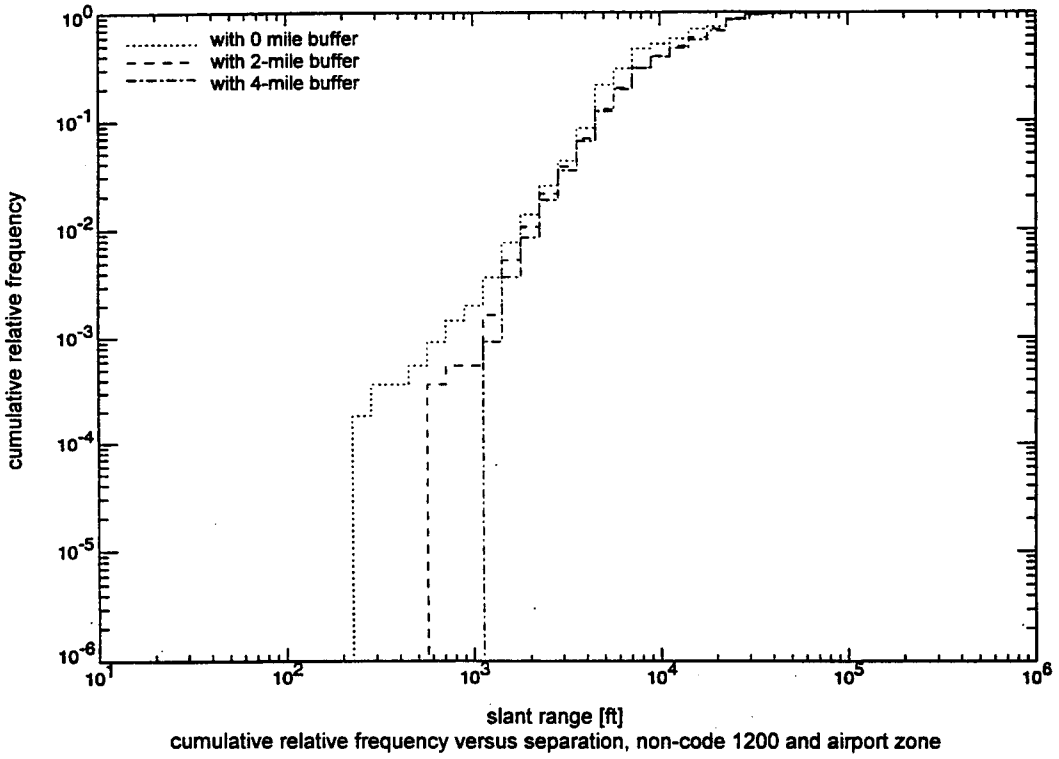

FIGURE 23. COMPARISON OF CUMULATIVE RELATIVE FREQUENCY OF SMALLEST CLOSEST APPROACH TO EMITTER FOR ALL NON-1200 CODE TRACKS USING AIRPORT ZONES WITH DIFFERENT BUFFERS

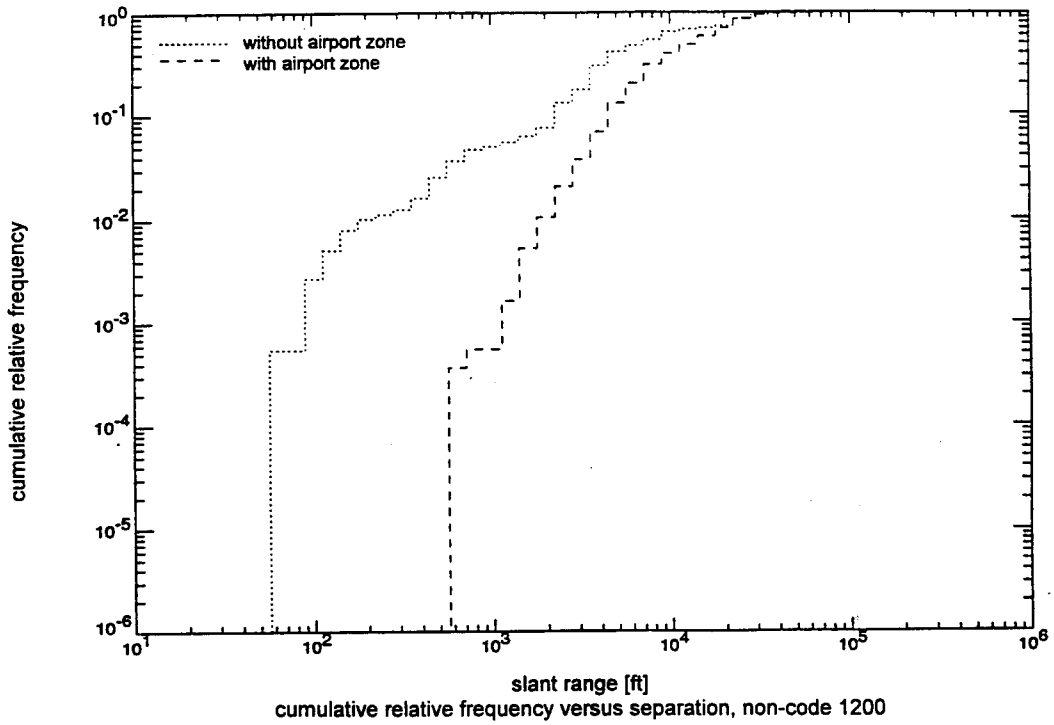

FIGURE 24. COMPARISON OF CUMULATIVE RELATIVE FREQUENCY OF SMALLEST CLOSEST APPROACH TO EMITTER FOR ALL NON-1200 CODE TRACKS WITH AND WITHOUT AIRPORT ZONES

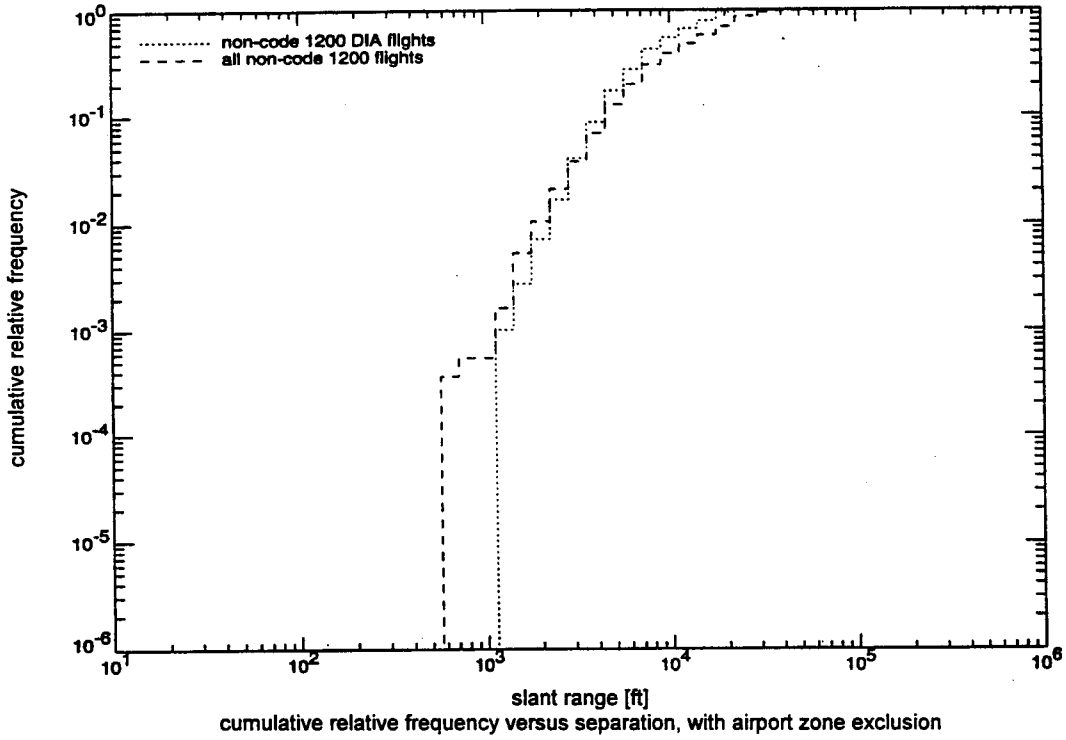

FIGURE 25. COMPARISON OF DISTANCE OF CLOSEST APPROACH FOR NON-1200 CODE TRACKS EXCLUDING AIRPORT ZONE FOR DIA FLIGHT OPERATIONS

1200 CODE FLIGHTS.

Since the track finding was somewhat impaired for 1200 code data, it is useful to take a first look at the distance of closest-approach cumulative relative frequency using only points. This is shown in figure 26 using an airport zone with a two-mile buffer; for comparison, a similar curve resulting for 1200 code data is also shown. For tracks, figure 27 compares distributions of 1200 code and non-1200 code flights using an airport zone with a two-mile buffer. When an airport zone is not excluded, the 1200 code tracks have a rather smaller minimum for the distance of closest approach. It also appears that interpolation between points results in a smaller minimum than does the use of only the recorded points in determining the distance of closest approach (at least without the exclusion of airport zones). Note in making comparison's that the normalization for point and track distributions for a given beacon code are different and, further, that point versus track normalization relations are different for different beacon codes.

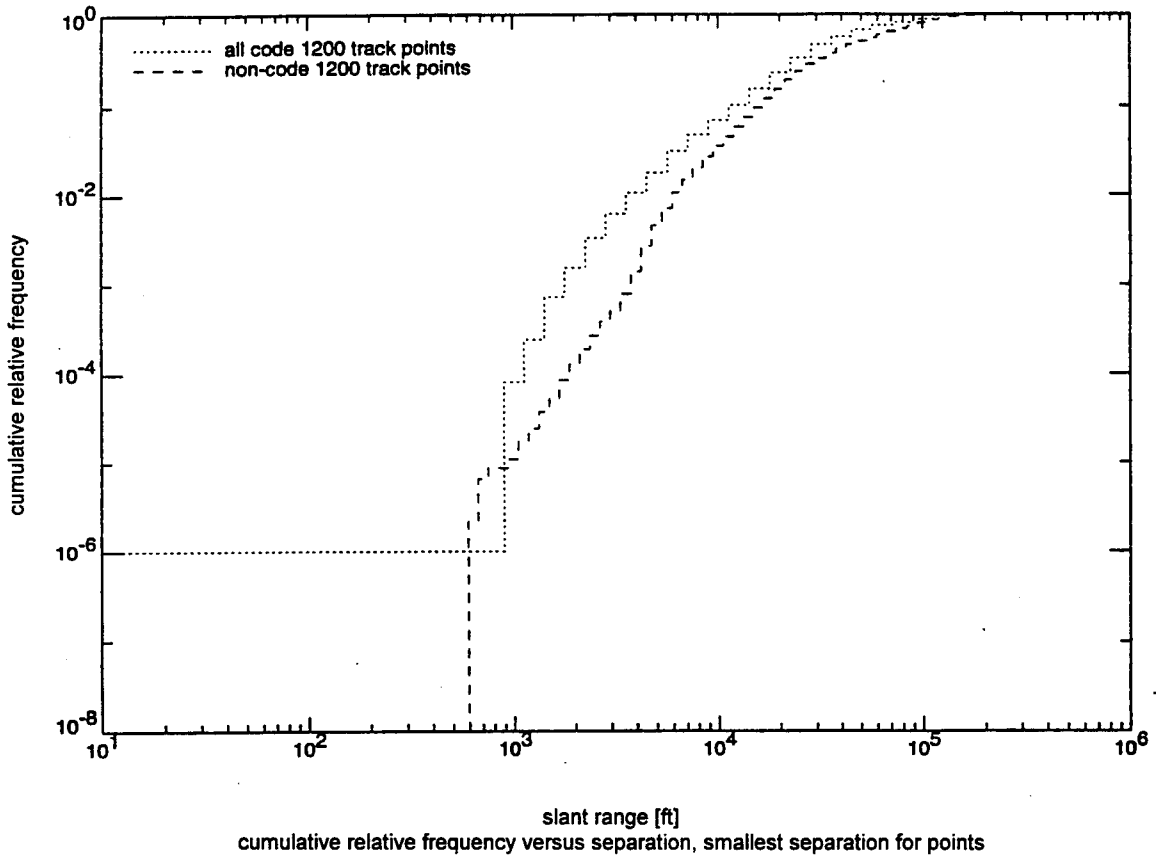

FIGURE 26. COMPARISON OF CUMULATIVE RELATIVE FREQUENCY OF SMALLEST CLOSEST APPROACH TO EMITTER USING POINTS FOR 1200 CODE TRACKS

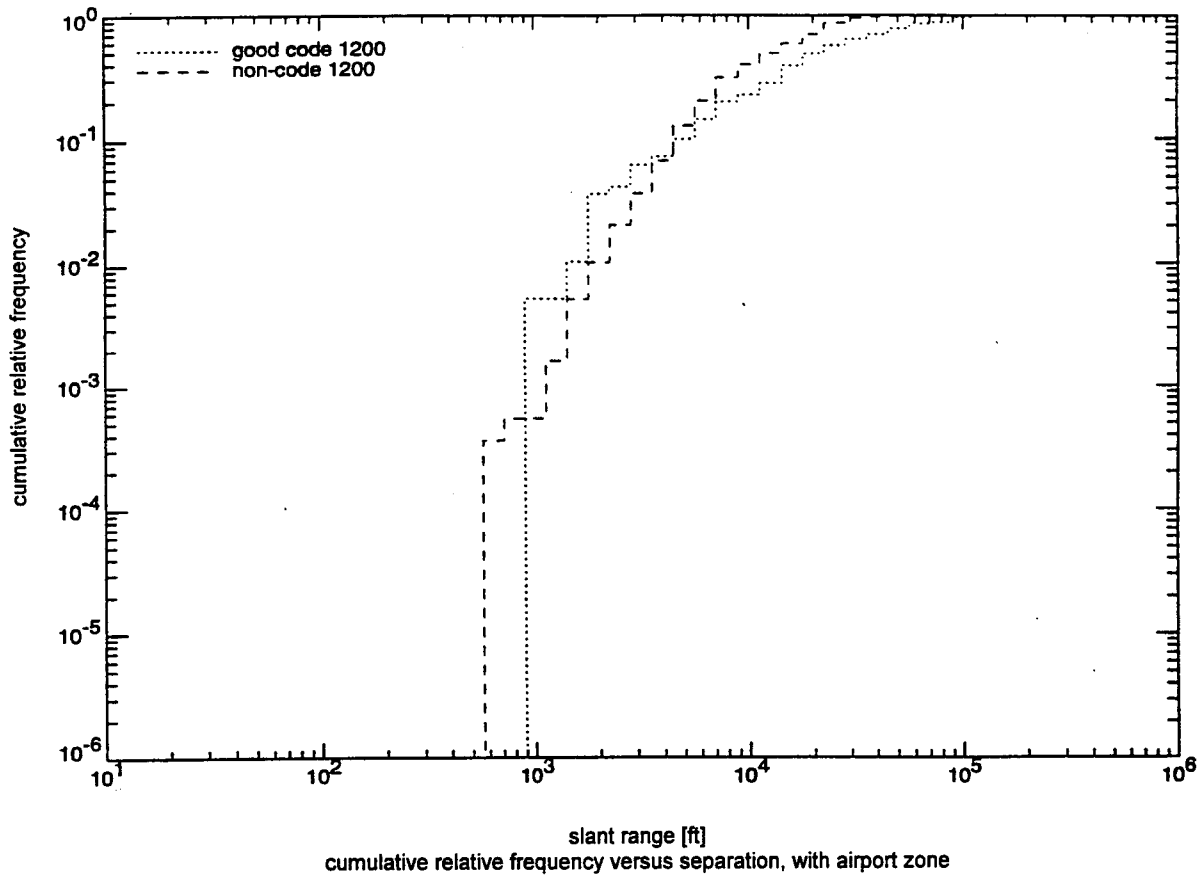

FIGURE 27. COMPARISON OF CUMULATIVE RELATIVE FREQUENCY OF SMALLEST CLOSEST APPROACH TO EMITTER USING TRACKS FOR 1200 CODE AND NON-1200 CODE

OTHER EXCEPTIONAL FLIGHT CODES.

Data from the 1200 code is presumed to represent a category of relatively local air traffic activity likely to be at lower altitude, flying slowly, and covering small distances. It has also been suggested that other flight activity of a local nature may be associated with certain beacon codes assigned by the DIA traffic control (TRACON). These beacon codes may have filed flight plans but may have fairly atypical flight patterns, e.g., traffic monitoring helicopters and some general aviation. Beacon codes with values of 03xx, 04xx, and 52xx are used for this type of activity in the Denver area. Figure 28 illustrates the flight track for this type of operation. Approximately 250 tracks have these beacon codes and 45 of these never exit the airport zones when a two-mile buffer is used. The effect of excluding these beacon codes from the cumulative relative frequency distribution is exhibited in figure 29 which shows a doubling in the minimum distance of closest approach when an airport zone with a two-mile buffer is used. This is a rather significant effect obtained by the elimination of only 250 of over 5000 tracks. Considering the minimum value of closest approach, these special beacon codes are more like 1200 codes than like other non-1200 codes. See figure 30.

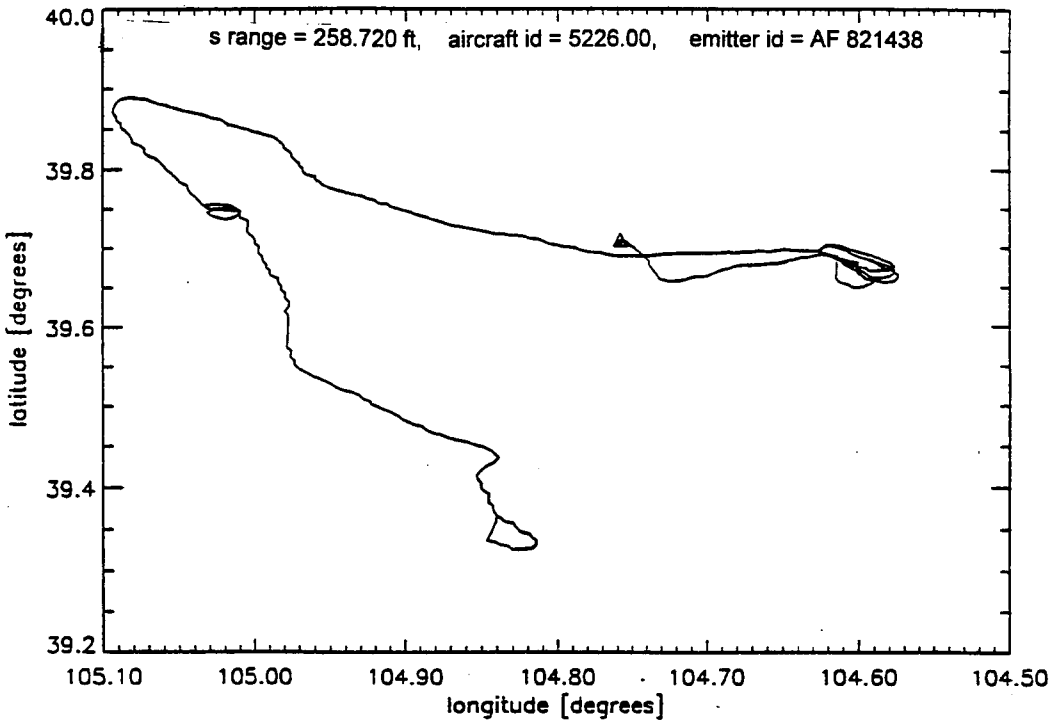

FIGURE 28. EXAMPLE OF THE FLIGHT TRACK FOR AN AIRCRAFT WITH THE SPECIAL BEACON CODE OF 52xx

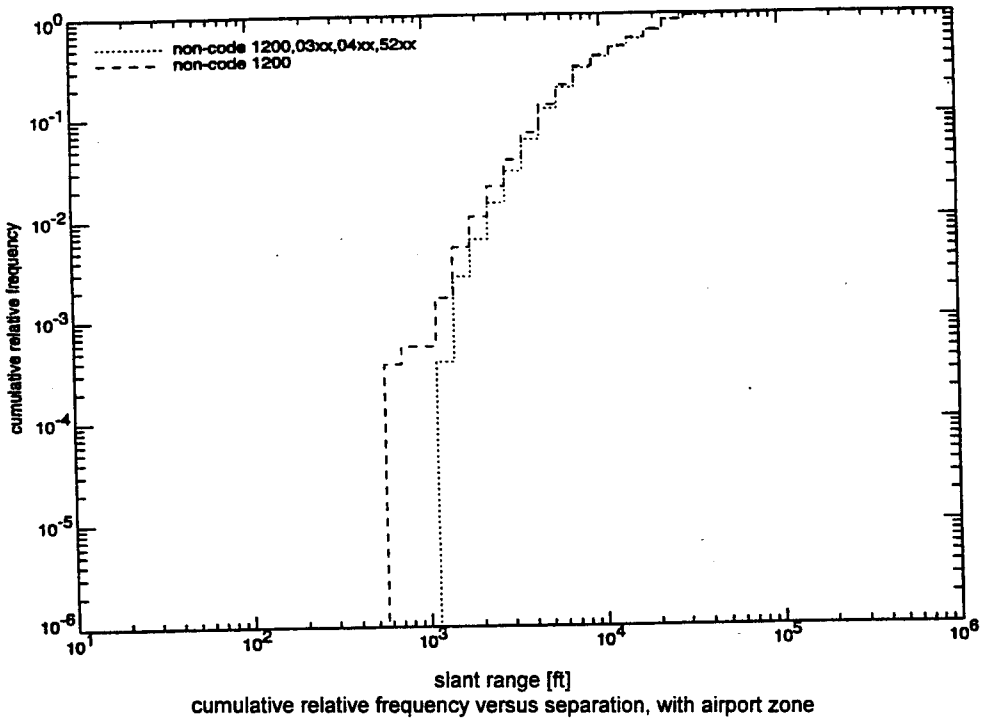

FIGURE 29. COMPARISON OF CUMULATIVE RELATIVE FREQUENCY OF SMALLEST CLOSEST APPROACH TO EMITTER FOR ALL NON-1200 CODE TRACKS EXCLUDING AIRPORT ZONES WITH BUFFER OF TWO MILES

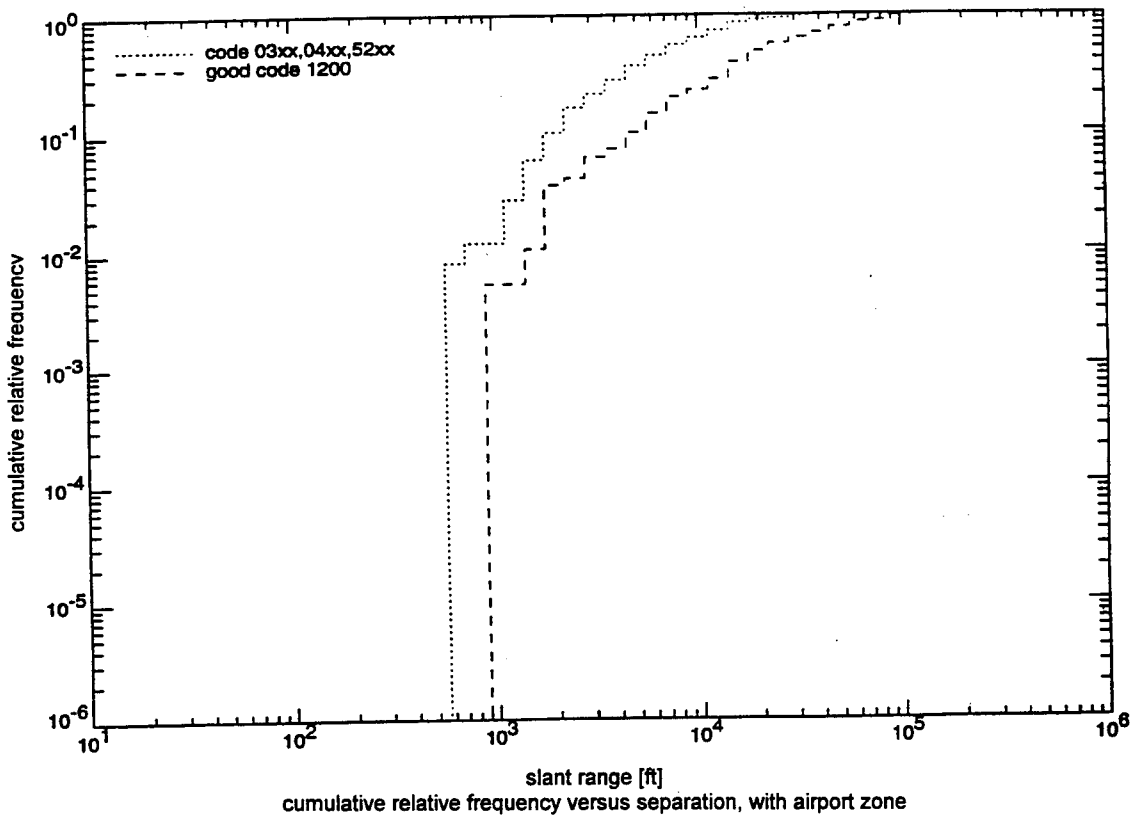

FIGURE 30. COMPARISON OF CUMULATIVE RELATIVE FREQUENCY OF SMALLEST CLOSEST APPROACH TO EXCLUDING AIRPORT ZONES WITH BUFFERS OF TWO MILES

DATA RESOLUTION AND UNCERTAINTY

There are several limitations and sources of uncertainty within the data used in this study. Many of these are technical in nature, arising from the inherent resolution of instrumentation such as radars or altimeters. Others are more procedural in nature such as computer code processing of radar data or accuracy/completeness in entering emitter data into the Government Master File. As needed, all of these factors have been dealt with for this study in ways previously described. For review, identified factors are separately listed below for emitter information and for flight position information.

Emitters Factors:

- lack of arc-second values latitude/longitude
- mobility of some transmitters within their assigned area
- missing or inaccurate site elevation or antenna height values
- ambiguity between transmitter power and effective radiated power

Flight Position Data Factors:

- radar resolution
- minimum altitude of radar tracking
- instrumentation and processing confusion for radar data
- limitations of NTAP for desired data selection
- altimeter resolution to nearest 100 ft
- inherent altimeter accuracy and barometric variations
- degeneracy of all 1200 code radar information

In addition to emitter and flight position information and data processing, there are issues associated with this investigation which affect its validity for use in a larger context. These issues mainly result from the limited sampling nature of the study.

Study Sampling Factors:

- one area - one airport, one set of emitters, one geography
- three-day sample period
- one weather pattern
- ~ 5500 flights - accuracy/confidence limit ~ 1/(number of samples)

CONCLUSIONS

The correlation of emitter positions and in-flight aircraft positions in the Denver area has been examined in detail for a three-day period. An initial set of > 3000 emitters was reduced to ~ 220 when frequency was restricted to > 400 MHz and a minimum potential electric field level was required. The resulting candidates were used in determining the closest approach of aircraft to emitters. In-flight aircraft positions as a function of time were obtained from FAA air traffic control with much processing and checking of the data to obtain the flight tracks for use in the correlation studies. Special considerations were given to the effects of

1. bounding the immediate vicinity of area airports.

2. the special category of beacon 1200 code corresponding to aircraft operations without filed flight plans.

3. the category of beacon codes 03xx, 04xx, and 52xx associated with special use and atypical aircraft operations.

The primary conclusions are as follows.

- The data used appears trustworthy and represents > 3000 emitters and > 5000 flights observed over an area approximately 120 x 120 square miles.

- The closest approach of aircraft to emitters in the Denver area involves > 40 different emitters spread throughout the region.

- With no exclusions, some aircraft are observed to pass within 100 ft of an emitter.

- If the zones around airports are excluded from consideration, the closest proximity of aircraft to emitters dramatically increases, doubling by merely using airport boundaries and increasing by an order of magnitude when an additional four-mile buffer is added to the airport zone.

- The closest approach of aircraft for non-1200 code flights occurs for 03xx/04xx/52xx beacon codes. When analyzing the data excluding airport zones, excluding flights with these beacon codes causes the smallest value observed for distance of closest approach to increase by an additional factor of two.

- 1200 code flight tracks share several characteristics with the code 03xx/04xx/52xx flight tracks, including similar minimum distances of closest approach when airport zones are excluded.

When beacon codes 1200, 03xx, 04xx, and 52xx are excluded and airport zones with a two-mile buffer are implemented, the minimum distance of closest approach observed is ~ 1100 ft and the 1% level occurs at ~ 2200 ft.

Recommendations:

- Determination of the generality of these results by a similar study at another airport and vicinity.

- The effect of exclusion zones around airports upon distance of closest approach to emitters be considered in assigning HIRF certification levels.

- The use of information regarding the different categories of aircraft operation, as evidenced by beacon codes such as 1200, 03xx, 04xx, and 52xx in assigning HIRF certification test levels.

- Extension of the present methodology to calculate the electric field value at the point of closest approach for each aircraft flight.

- Extension of the present methodology to calculate the angle and incidence and polarization of the illuminating EM field at the point of closest approach for each aircraft flight.

- Consideration of the effect of proposed free flight air traffic patterns upon the distribution of the closest approach of aircraft to emitters.