SESSION IIA
PAPER IIA-4

(NASA-TM-X-69455) GENERAL AVIATION AIR TRAFFIC PATTERN SAFETY ANALYSIS (NASA) 22 p HC $3 25 CSCL 17G

N74-13422

Unclas
G3/21 24337

GENERAL AVIATION AIR TRAFFIC PATTERN SAFETY ANALYSIS

by

LOYD C. PARKER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WALLOPS STATION

Wallops Island, Virginia

Presented at

THE SYSTEM SAFETY SOCIETY
SYMPOSIUM

TUESDAY, JULY 17, 1973

GENERAL AVIATION AIR TRAFFIC PATTERN SAFETY ANALYSIS

by

Loyd C. Parker
NASA Wallops Station

ABSTRACT

This paper describes a concept for evaluating the general aviation mid-air collision hazard in uncontrolled terminal airspace. Three-dimensional traffic pattern measurements were conducted at uncontrolled and controlled airports. Computer programs for data reduction, storage retrieval and statistical analysis have been developed. Initial general aviation air traffic pattern characteristics are presented. These preliminary results indicate that patterns are highly divergent from the expected standard pattern, and that pattern procedures observed can affect the ability of pilots to see and avoid each other.

INTRODUCTION

Numerous reports[1,2,3] have been written which characterize the mid-air collision hazard. In general, mid-air collisions occur in uncontrolled terminal airspace, involve two general aviation aircraft, occur in traffic patterns when both aircraft are in approach to landing on final, under VFR conditions, on a weekend and at low convergence angles and rates of closure. Mid-air collision reports usually contain the phrase "pilots failed to see-and-avoid." This hazard may be characterized by the factors shown in Figure 1. Mid-

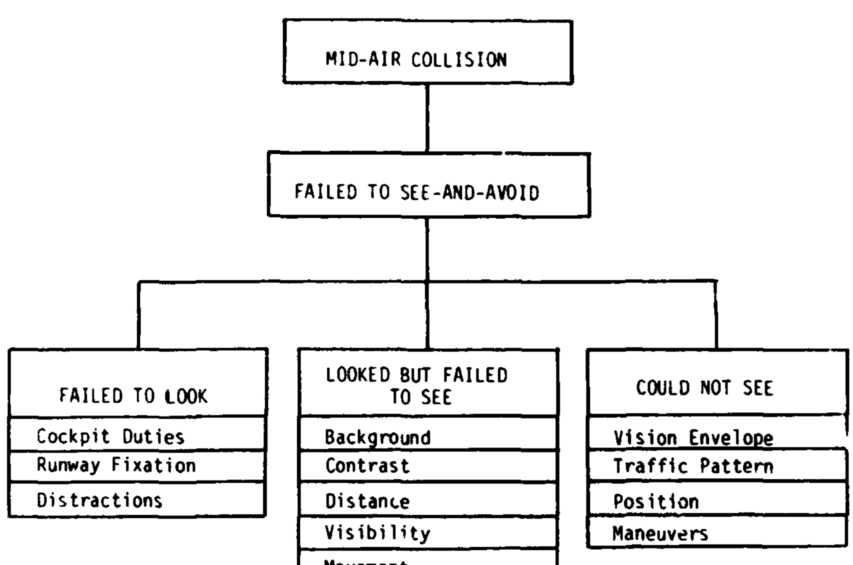

Figure 1.-Mid-air collision factors

air collisions occur because pilots fail to look, look but do not see, and cannot see because of view restrictions. Preliminary data obtained by P. M. Rich, Federal Aviation Administration (FAA), indicates that VFR general aviation pilots spend approximately 50% of their total flight time looking outside the cockpit. In the terminal area, however, this data indicates the time spent in air search is approximately 40%. Other studies[4 5 6] have shown that even when a pilot looks for a known aircraft at a distance greater than a mile, his probability of detection may be very low unless he looks longer than several seconds. At ranges less than one mile, detection is almost certain if the pilot looks and the other aircraft is within his view field. Pilots are being encouraged to scan properly and to increase their attention toward detecting other aircraft in the terminal area. It is our conclusion that, in many cases involving a mid-air collision in the traffic pattern, at least one of the pilots involved--and possibly both pilots--were unable to see one another during the critical last mile of closure because of vision envelope restrictions, the pattern flown and the maneuvers involved. The objective of the study being conducted is to evaluate the present uncontrolled patterns flown and to determine the improvements in a pilot's ability to see another aircraft (if he looks) for various changes in the traffic pattern concept.

DATA SYSTEM

It was determined in 1971 through an extensive literature search that air traffic pattern measurements of the uncontrolled environment were essentially non-existent. An MPS-19 tracking radar and data van (Figure 2) were used to obtain position time histories of

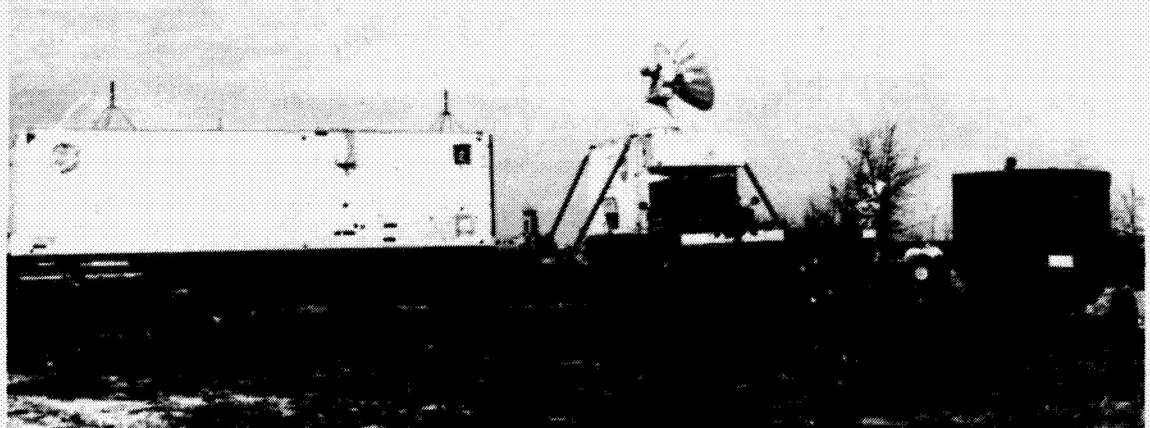

Figure 2.- MPS-19 radar and data van

arriving and departing aircraft at six airports. Traffic measurements were taken during approximate three-week periods at each airport from October 1971 through March 1972. The airport sites selected (Figure 3) were all within 150 NM of Wallops Station to assure good logistics support to the radar system.

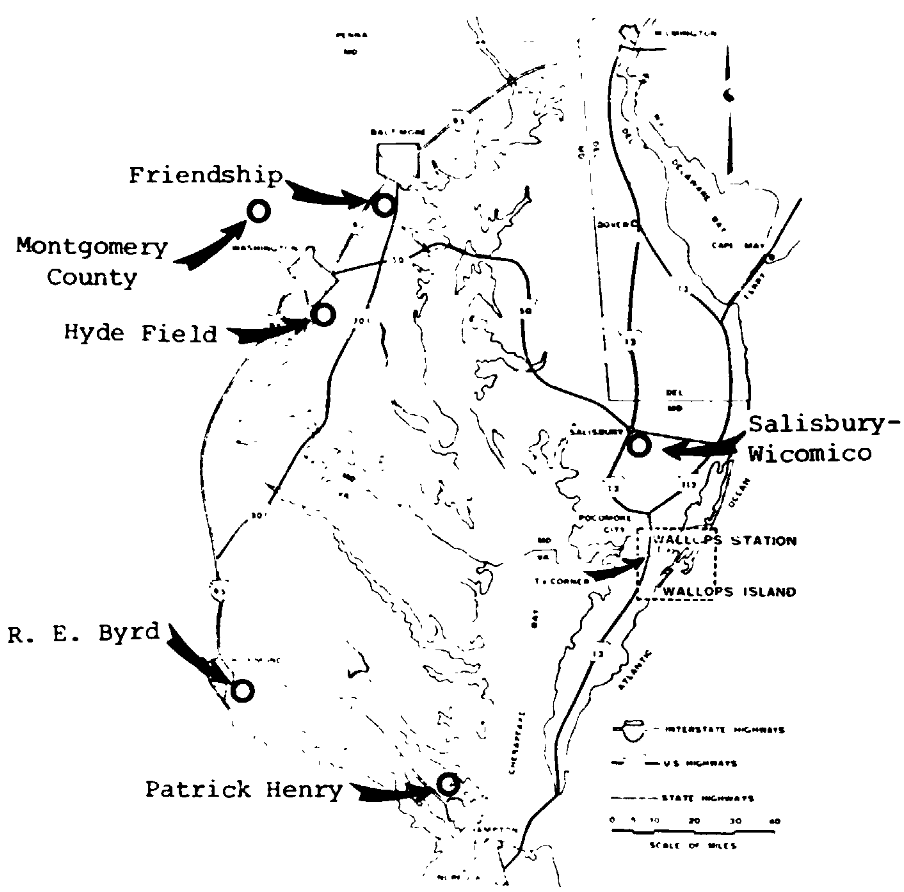

Figure 3. Airport locations

The uncontrolled airports selected were the Salisbury-Wicomico Airport, Salisbury, Maryland; Montgomery County Airport, Gaithersburg, Maryland; and Hyde Field at Clinton, Maryland. The Salisbury-Wicomico Airport had three 5,000-foot runways; has an FAA Flight Service Station at the airport, flight school, air taxi service, aircraft maintenance, VORTAC facility, commuter service to Washington-Baltimore and is located in a relatively low air traffic density region. The Montgomery County Airport is a very busy general aviation airport having a single runway, resident corporate, private and sales aircraft, repair and maintenance facilities, flight school and a radio beacon approach. Hyde Field is located under the

Washington, D. C. Terminal Control Area (TCA), has two runways, flight school and private aircraft, and has constrained patterns and altitudes because of an adjacent airport and the 1,500-foot TCA floor.

The controlled airports visited to obtain general aviation traffic pattern data in these environments were R. E. Byrd International (BYRD), Richmond, Virginia; Friendship International (BLT), Baltimore, Maryland; and Patrick Henry (PHF) Airport, Newport News, Virginia. Each of these terminals were served by commercial air carriers and have considerable general aviation activity. These airports were selected to obtain data on the tower only environment (PHF), Stage II service (BYRD) and Stage III service (BLT). A summary of the tracks obtained at each airport is shown in Table I, below.

TABLE I. - RADAR TRACKS OBTAINED

CATEGORY	SALISBURY-WICOMICO	MONTGOMERY COUNTY	HYDE FIELD	R.E. BYRD	FRIENDSHIP	PATRICK HENRY	TOTALS
NO. OF TRACKS	406	554	449	418	549	485	2861
LANDING	270	494	376	298	289	368	2095
DEPARTURE	0	10	36	70	200	70	386
FLY-BY	23	45	37	50	60	43	258
INSTRUMENT	25	0	0	20	49	69	163
SINGLE ENGINE	255	350	315	139	91	148	1298
TWIN ENGINE	120*	45	23	111	117	125	541
COMMERCIAL				120	329	80	529

*INCLUDES COMMUTER SERVICE

For each track, the radar range, azimuth, and elevation were recorded on magnetic tape at one-second intervals. The reference coordinate system developed (Figure 4) normalizes all traffic data

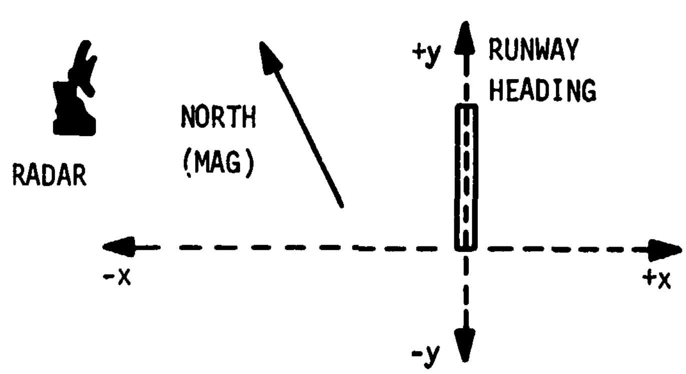

Figure 4.-Reference coordinate system

to the runway threshold and direction. This system enables all traffic pattern data obtained to be directly comparable regardless of the runway used for landing.

Radar data reduction, parallax, and rotation are performed by a GE-625 computer system and the reduced data is stored in a computer files management system illustrated by Figure 5 called Integrated Data Store (IDS)[7].

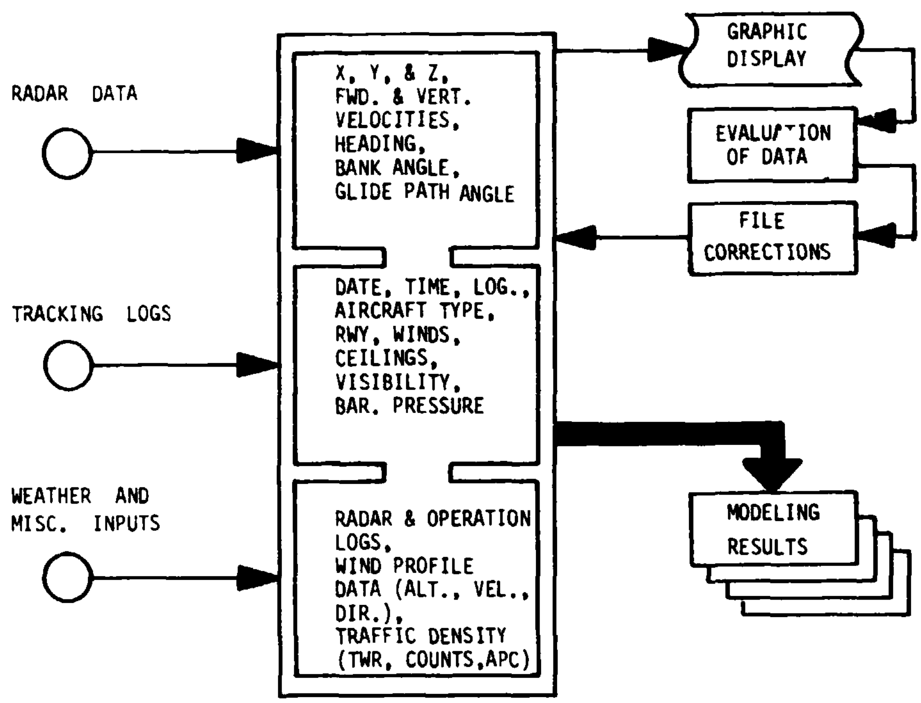

Figure 5.-Air traffic pattern data system

Other data recorded for each track were aircraft manufacturer and model, runway used, wind speed and direction, cloud ceilings, visibility, barometric pressure, approach type if IFR or unusual, and other operator comments. A site plan was obtained for each airport and a radar position survey relative to each runway was made. Traffic count data was taken by radar operators when it was not otherwise available at the uncontrolled airports.

The IDS program enables rapid access of all data from a remote graphics terminal This remote terminal will be used to edit, update and perform statistical analyses on the data base in IDS storage. With this system, the air traffic statistical properties for any given set of parametric conditions can be obtained.

ANALYTICAL CONCEPT

The air traffic data obtained will be utilized to generate math models of the uncontrolled traffic environment. To determine the statistical properties of various traffic parameters, data can be catalogued in airspace blocks--typically 500 ft. X 500 ft. X 100 ft. [illegible] -as shown by Figure 6. Each airspace block can be charac-

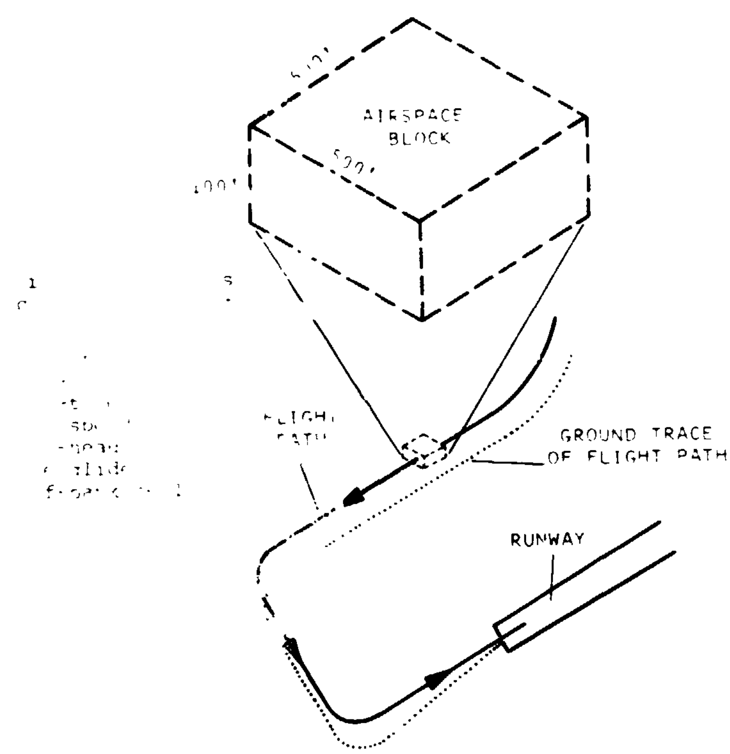

Figure 6.-Airspace block

terized by type of aircraft, speed, heading, bank angle, descent (ascent rate), time of day, weather conditions (winds, visibility, clouds, etc.), runway, airport, type of approach, and other conditions, such as touch-and-go traffic. From this airspace catalogue, the affect of various parametric conditions can be evaluated and statistical algorithms developed. For example, the utilization of a given airspace block may vary as a function of aircraft type, visibility, runway length, cloud ceiling, wind velocity/direction, day of week or the standard traffic pattern in effect at the airport.

Based on the airspace block data, a traffic pattern math model capable of simulating various air traffic situations is possible.

This model will utilize Monte Carlo or actual aircraft flights to simulate mid-air collision situations that occur in the uncontrolled terminal airspace. A weighted percentage of time that each pilot could have seen the other aircraft through his vision envelope (Figure 7) will be computed for each mid-air collision simulation.

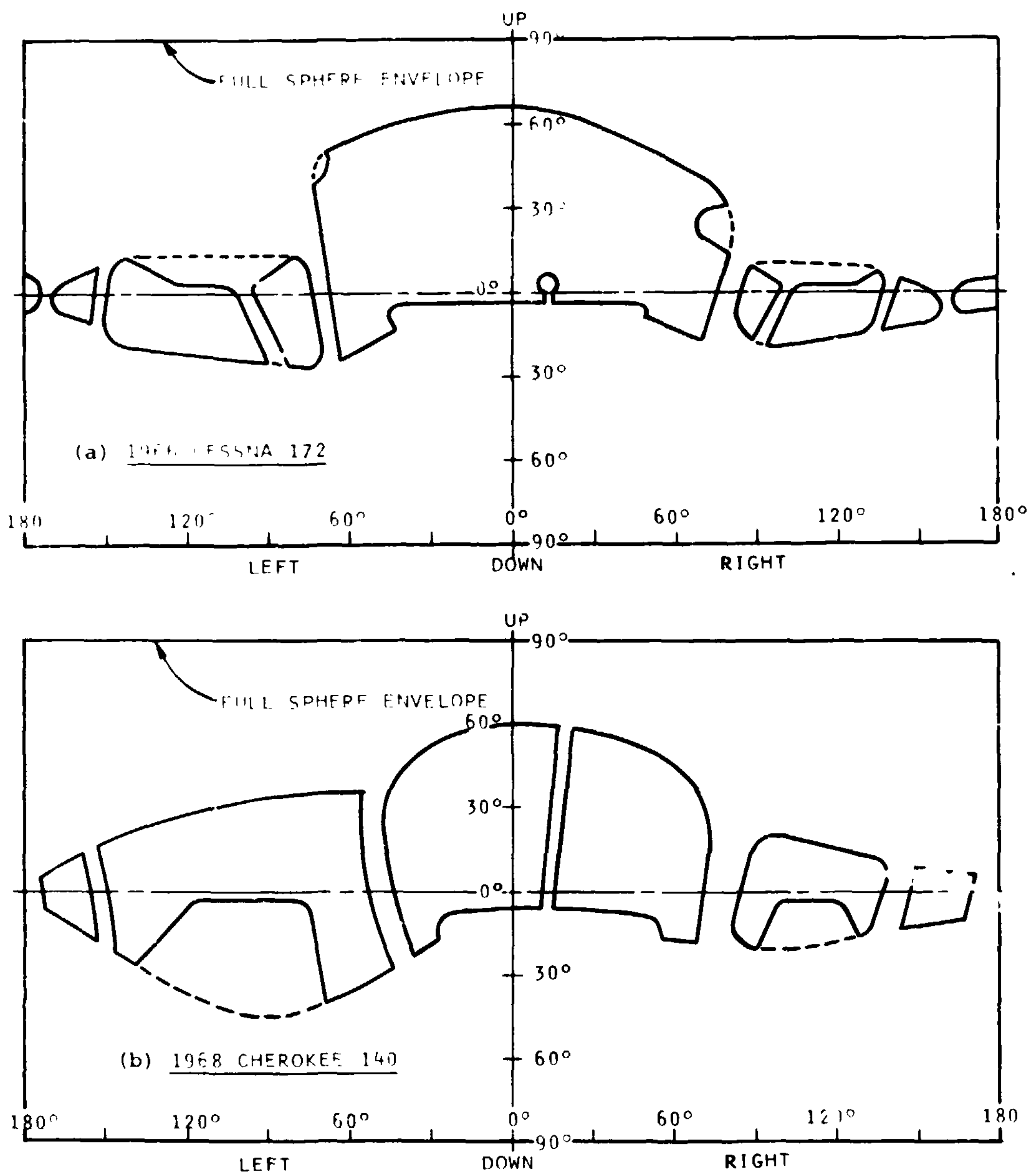

Figure 7.-Aircraft vision envelopes[8]

By simulation of all potential arrival combinations, a baseline measure of pilot procedure and pattern influence can be established for the present environment. This baseline measure can then be utilized to measure the relative improvement in the see-and-avoid environment for changes in the uncontrolled traffic pattern concept or for changes in pilot procedure in flying the pattern concept. For example, would there be a significant improvement in the see-and-avoid geometry and time if the standard pattern was a right circular pattern with bank angles limited to less than 15 degrees at an altitude of 1,000 ±200 feet? Would there be a significant improvement in the present pattern concept if bank angles were limited, pattern altitude was 400 feet, or if pattern altitude was maintained until turning final?

UNCONTROLLED TRAFFIC PATTERN CHARACTERISTICS

Pattern entry--To determine the initial traffic pattern characteristics for the development of final data reduction and analytical programs, the tracks obtained at the Salisbury-Wicomico Airport were processed with existing programs. From this data, we were able to identify some of the traffic pattern characteristics which exist for this airport. Mid-air collision reports have cited the lack of adherence to pattern procedures as a cause in some of the mid-air collisions[1 3]. At the Salisbury-Wicomico Airport, the locally established pattern altitude is 800 feet with entry to a downwind left-hand pattern. NPRM 71-20, "Operations at Airports Without Control Towers," had also been issued and established the pattern shown by Figure 8. Local FAA Flight Service Station personnel had

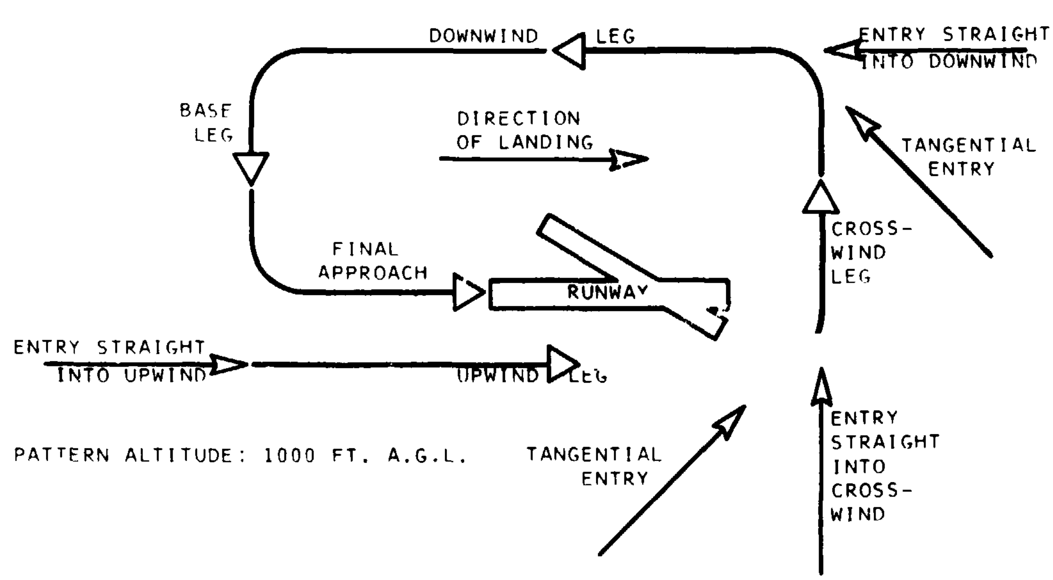

Figure 8.-Proposed uncontrolled air traffic pattern

encouraged local pilots to try out this new pattern. Therefore, either pattern procedure would have been proper at the time our measurements were made. Entry locations were analyzed for 175 aircraft tracked prior to pattern entry. The percentage of these tracks entering each leg is shown on Figure 9. (Those percentages

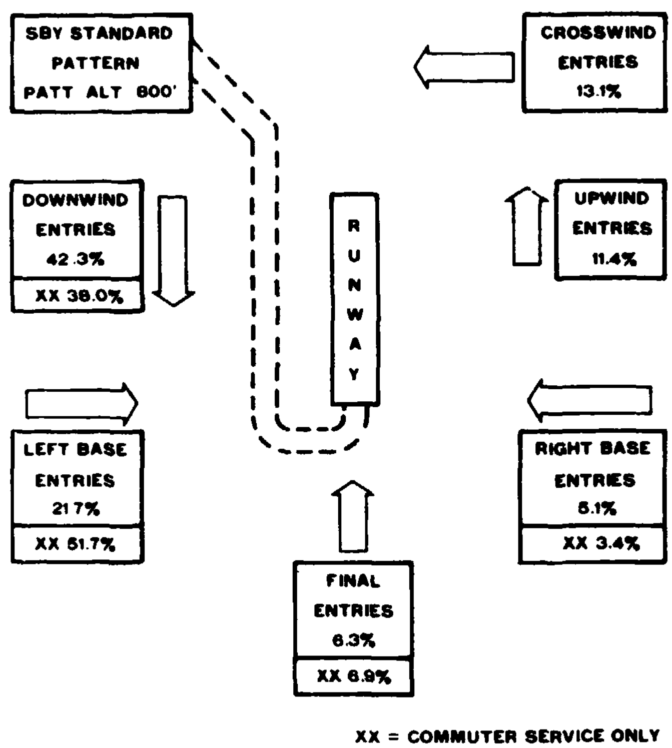

Figure 9.-Salisbury traffic pattern entry distribution

designated XX reflect only the distribution of the commuter service entries.) From this figure, we note that 33% of all entries did not adhere to either of the standards and were made to base (left or right) or final. In terms of commuter service only, 62% of the entries observed were made direct to base (left or right) and final.

In summary, a high percentage of the general aviation and commuter traffic did not adhere to established pattern entry rules. It is our opinion that the Salisbury percentages are considerably higher than other uncontrolled airports visited. The FAA Flight Service Station reports of (or the lack of) traffic to all arrival aircraft may be the factor which significantly influences these percentages.

Pattern leg characteristics--To determine the distribution of air traffic at various points in the traffic pattern, six vertical planes were established on the traffic pattern legs. The locations of these planes are shown in Figure 10. For each track obtained, the

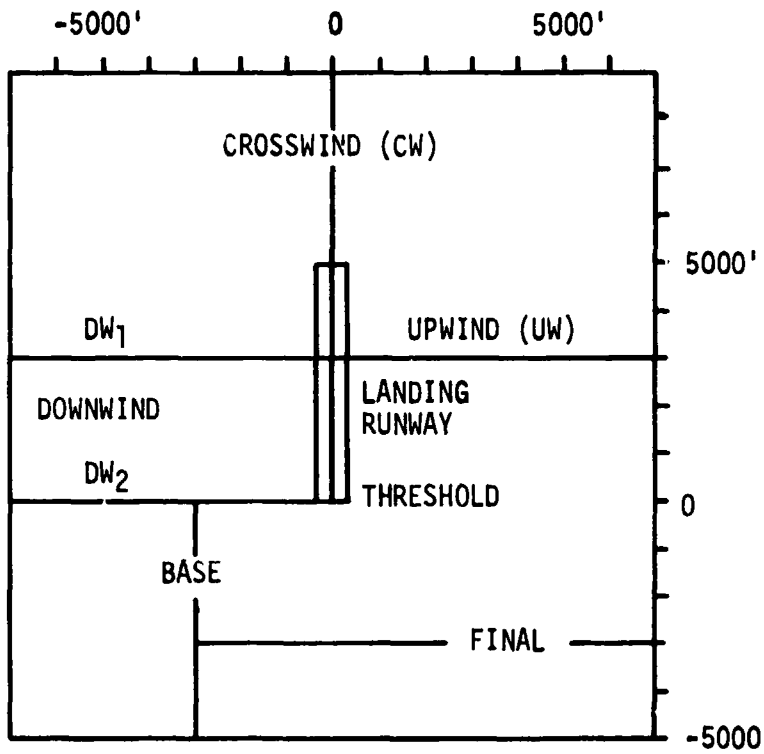

Figure 10.-Location of vertical planes

distance (X or Y) and altitude (Z) were tabulated for computation of statistical properties. A summary of these computations is shown in Table II for all aircraft and for the single-engine high-wing (SEHW), single-engine low-wing (SELW), and twin-engine (TE) aircraft which produced the total traffic distribution observed. A comparison of the mean distances and mean altitudes observed at each plane is shown in Figures 11a and 11b, respectively.

From Table II and Figure 11, we note that the mean pattern distance of the SEHW aircraft is approximately 0.2 NM less than SELW aircraft and approximately 0.3 - 0.4 NM less than TE aircraft. The TE aircraft mean altitude exceeds SEHW and SELW aircraft altitudes on all legs except base and final where TE aircraft transitions to the lowest mean altitude. The convergence of mean distance occurring on final is illustrated by these figures and supports mid-air collision data in this area. The standard deviation of distance about the mean for the traffic cases above is typically 0.3 - 0.4 NM except final where it has converged to approximately 200 feet. The standard deviation of altitude typically decreases at each

Table II.-Statistical properties

PATTERN	PARAMETER / PLANE	ALL		Single-Engine High-Wing		Single-Engine Low-Wing		Twin Engine	
		Dis.	Alt.	Dis.	Alt.	Dis.	Alt.	Dis.	Alt.
UPWIND	Number	14	-	4	-	7	-	3	-
	Mean (Ft.)	5186	943	4067	915	5309	903	6388	107[illegible]
	Std. Dev. (Ft.)	2674	210	2251	118	3294	223	1267	267
	Skewness	1.16	0.478	-0.045	-0.77	1.47	0.082	0.655	0.55
	Kurtosis	4.53	2.83	1.37	1.95	3.95	1.54	1.5	1.5
	Spearman Rank	0.29	-	-0.4	-	0.36	-	-	-
CROSSWIND	Number	43	-	15	-	13	-	15	-
	Mean (Ft.)	6978	1011	6583	949	7591	942	6842	1133
	Std. Dev. (Ft.)	2390	258	2650	287	2613	265	1931	180
	Skewness	0.197	0.509	-0.027	1.63	0.462	0.156	0.024	0.18
	Kurtosis	2.52	3.93	2.03	6.9	2.32	1.98	1.95	2.07
	Spearman Rank	-0.08	-	-0.10	-	-0.47	-	0.08	-
DW_1	Number	138	-	54	-	45	-	39	-
	Mean (Ft.)	5440	844	4491	844	5627	816	6539	876
	Std. Dev. (Ft.)	2402	197	2158	212	1828	194	2806	179
	Skewness	1.51	1.65	3.13	1.97	0.57	2.46	0.82	-0.11
	Kurtosis	7.05	8.17	16.96	9.06	3.63	11.1	4.62	3.25
	Spearman Rank	0.05	-	-0.10	-	0.39	-	0.21	-
DW_2	Number	159	-	64	-	50	-	45	-
	Mean (Ft.)	5600	780	4730	773	5577	749	6860	825
	Std. Dev. (Ft.)	2391	193	2441	209	1736	174	2434	187
	Skewness	1.597	1.23	3.3	1.64	0.72	1.17	0.27	0.54
	Kurtosis	7.49	6.14	16.7	7.8	4.02	5.3	3.45	3.9
	Spearman Rank	0.11	-	0.19	-	0.31	-	0.42	-
BASE	Number	225	-	77	-	71	-	77	-
	Mean (Ft.)	5535	552	3995	577	5331	562	7261	519
	Std. Dev. (Ft.)	2936	164	2543	164	2326	166	2914	159
	Skewness	1.34	1.37	2.81	1.7	0.998	0.95	1.2	1.6
	Kurtosis	6.48	6.7	16.7	9.1	4.68	4.68	5.9	6.8
	Spearman Rank	0.01	-	0.16	-	-0.03	-	0.49	-
FINAL	Number	159	-	42	-	59	-	58	-
	Mean (Ft.)	-41.7	252	-77	299	-29	261	-29	209
	Std. Dev. (Ft.)	196	93.2	187	99.6	248	97.9	135	60
	Skewness	2.87	1.13	0.47	0.37	3.64	1.35	0.76	0.85
	Kurtosis	27.14	4.8	6.17	2.96	26.8	5.8	8.3	3.8
	Spearman Rank	0.17	-	0.08	-	0.02	-	0.21	-

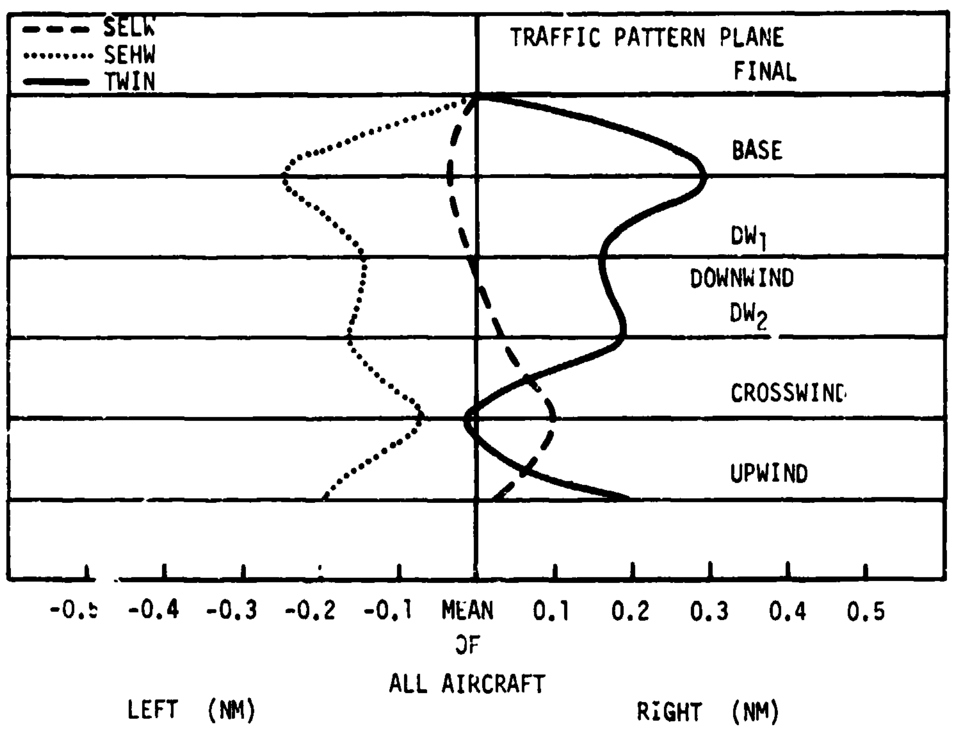

Figure 11a.-Ground range mean distance

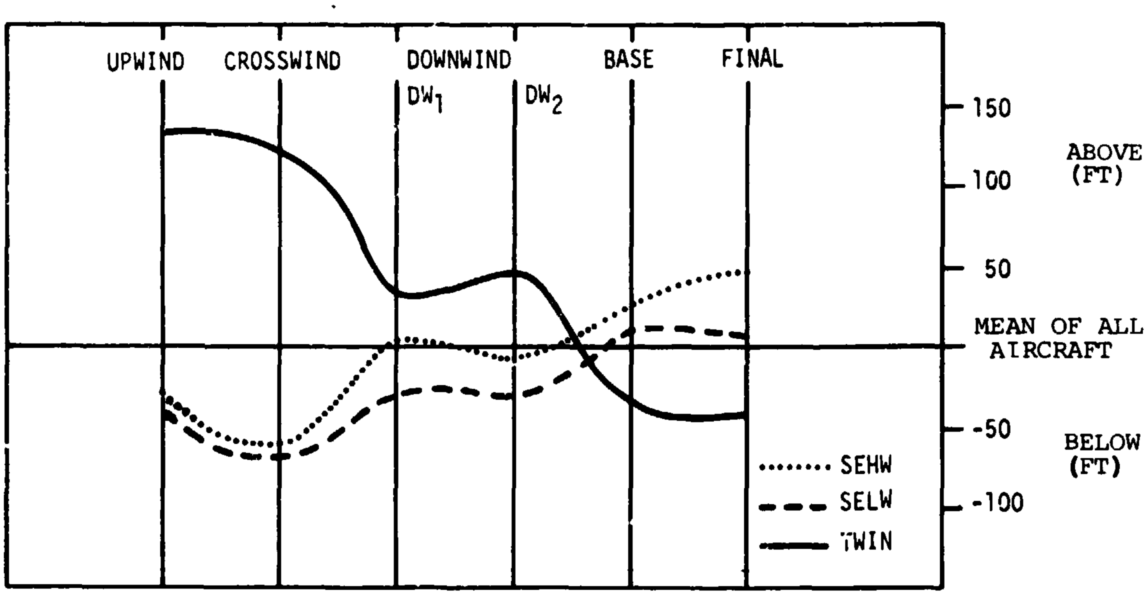

Figure 11b.-Mean altitudes

Figure 11.-Comparison of mean distances and altitudes

subsequent pattern leg plane and corresponds somewhat to the decrease in the mean altitudes observed. The skewness of the distributions in distance and altitude shown in Table II indicates that the distributions in general are not normal and are skewed to the side of the mean having greater distances or altitudes. (Skewness = 0 for normal distribution.) The kurtosis--normal distribution is 3--of the data obtained is generally a higher value than for a normal distribution which indicates a more peaked distribution shape than normal. The distance-altitude Spearman rank-correlation coefficient was computed for each plane and the values indicate little correlation exists between altitude and distance distributions.

Statistical analysis of the distributions observed indicates that Log Normal or Extreme Value (Fisher-Tippett Type 1)[9] distributions may be used to model the air traffic pattern legs for the Salisbury-Wicomico Airport. The theoretical Log-Normal distributions and the traffic percentiles observed at each pattern plane are shown in Figures 12a through 12f. From these figures, we see that the distribution of uncontrolled air traffic is far different from what one would expect from the pictorial pattern of Figure 8. The pattern legs extend from approximately 1/4 NM out to 3 NM in distance from the runway and from 400 feet to 1800 feet in altitude.

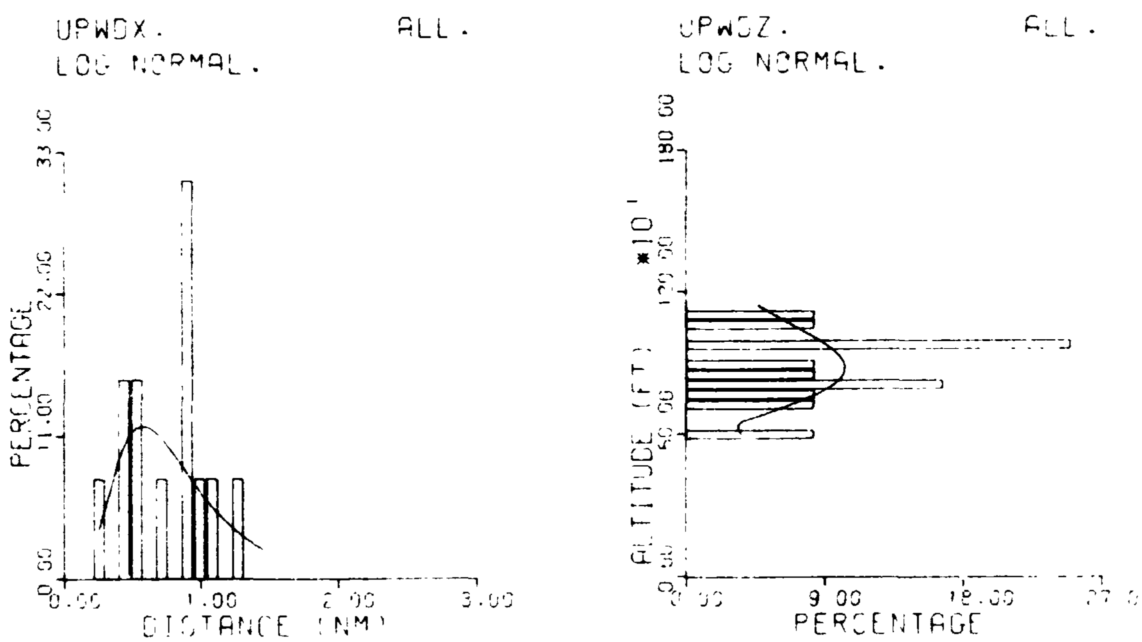

Figure 12a.-Upwind plane distributions

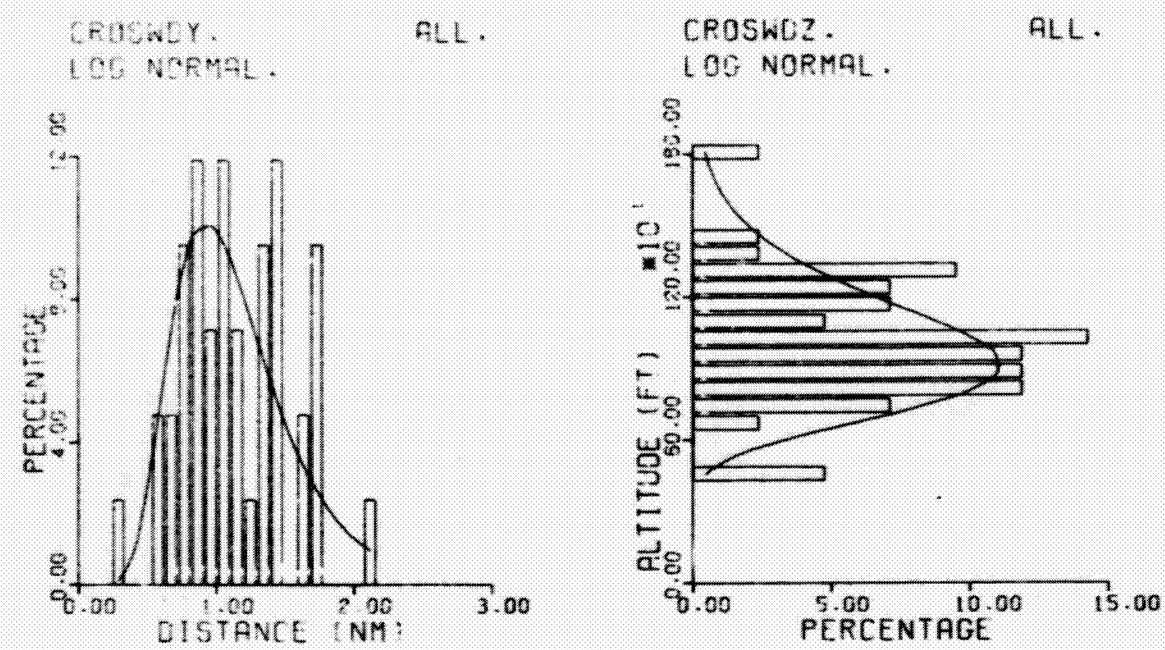

Figure 12b.-Crosswind plane distributions

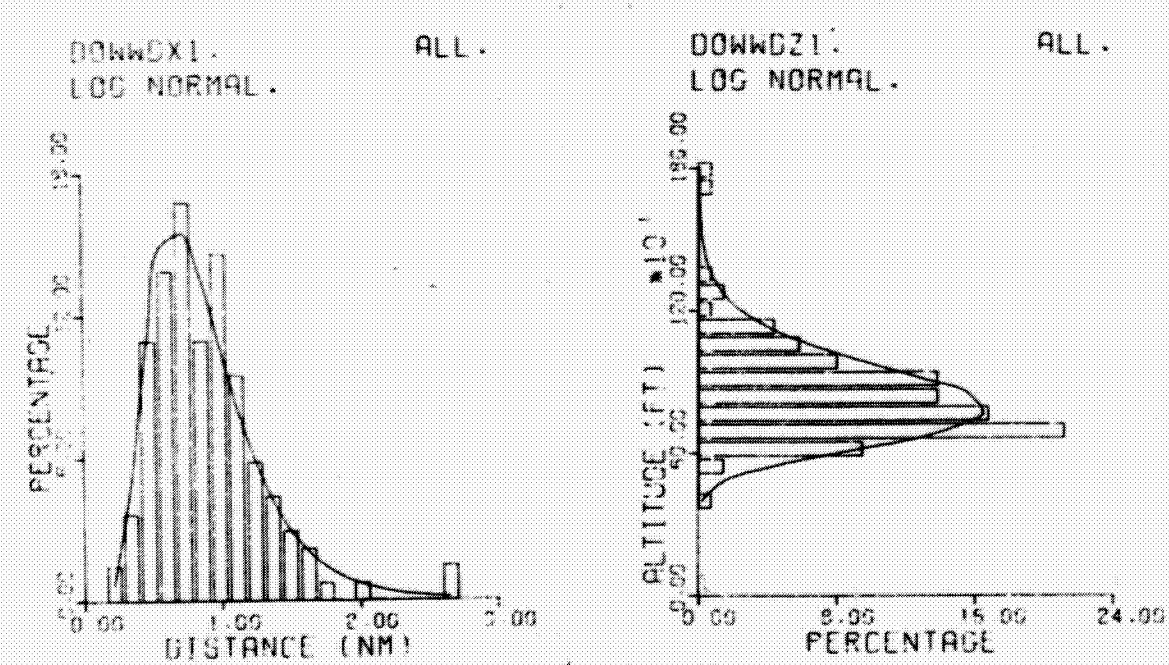

Figure 12c.-Downwind (DW_1) plane distributions

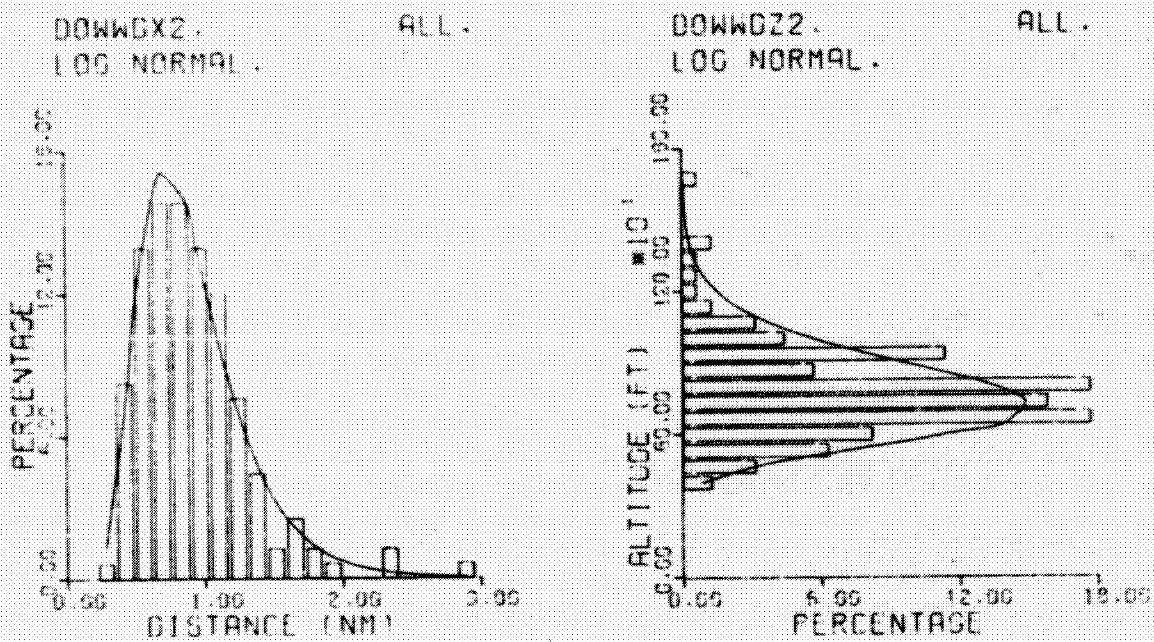

Figure 12d.-Downwind (DW_2) plane distributions

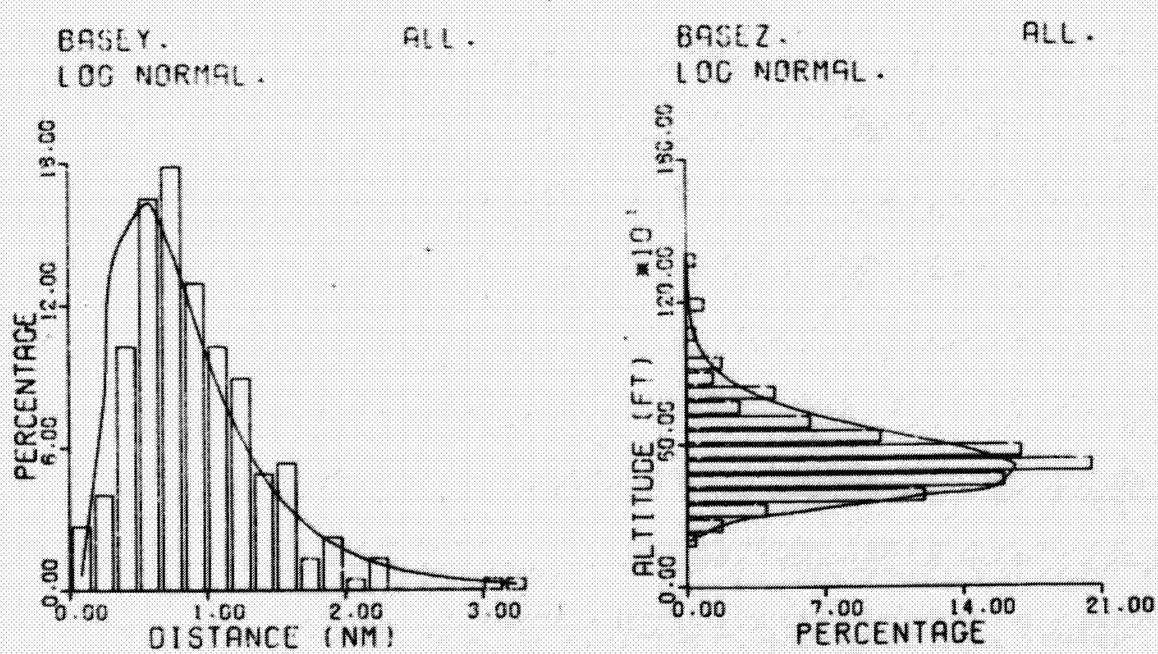

Figure 12e.-Base plane distributions

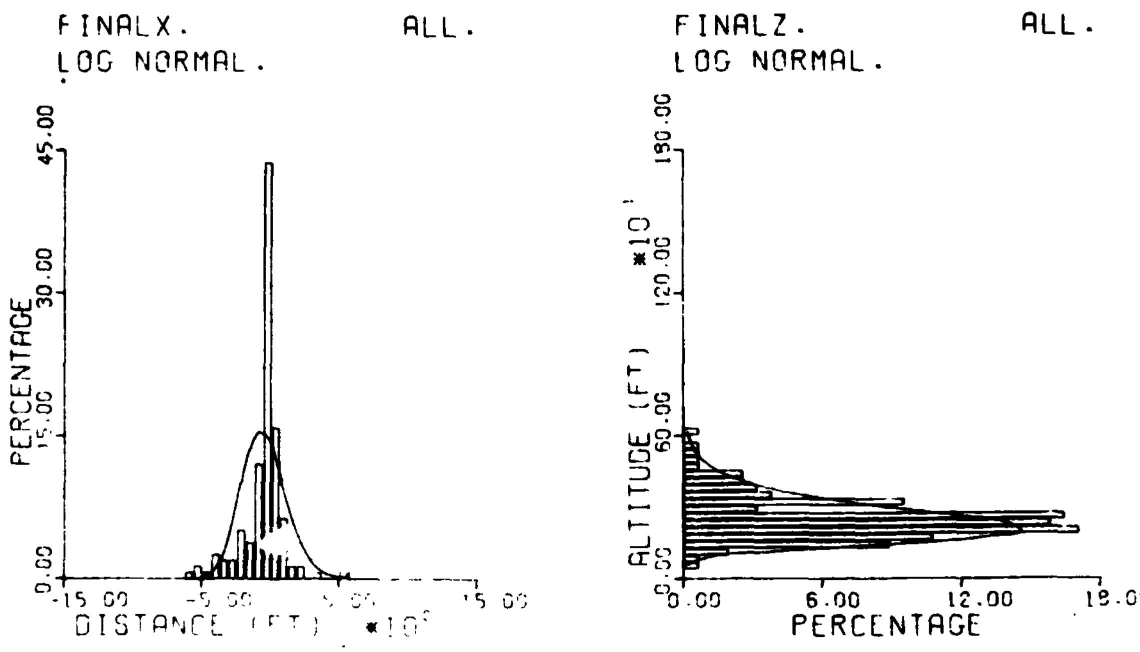

Figure 12f.-Final plane distributions

Since the Spearman rank-correlation coefficient test indicates little correlation between distance and altitude distributions, the combined Log Normal distributions can be represented in bivariate form[10] as shown in Figure 13. This figure illustrates the airspace

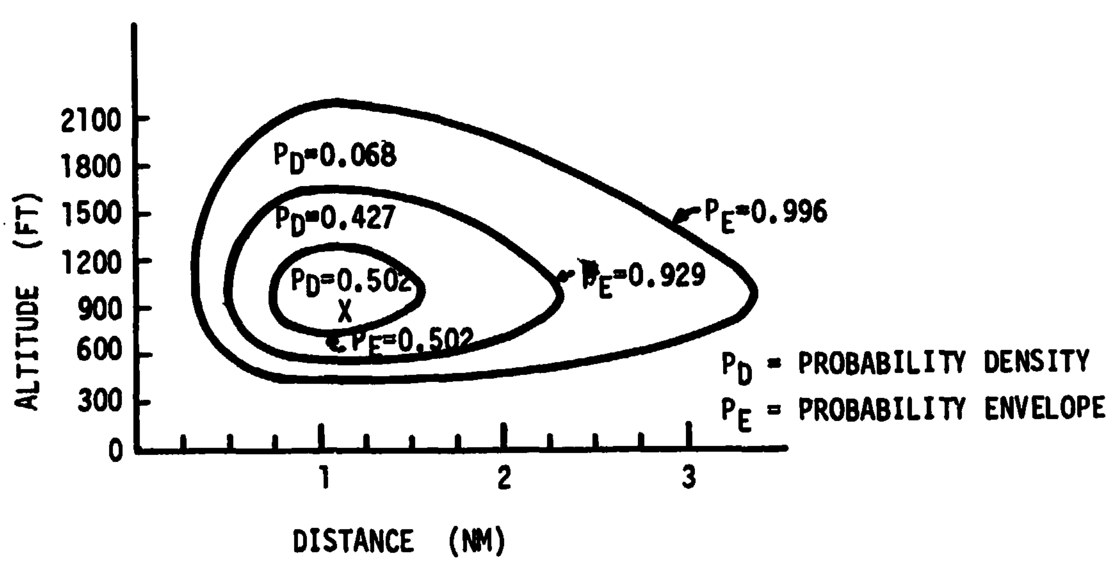

Figure 13.-Probability density & envelopes for crosswind leg

that the theoretical cross-section of the crosswind leg occupies, the associated probability density and envelopes, and exemplifies the large area of airspace a pilot must search to prevent a mid-air collision with another aircraft.

The distributions above represent all traffic observed at Salisbury, Maryland. This traffic was primarily single-engine (high and low wing) and twin-engine aircraft. An example of the contribution made by each type of aircraft for the DW_2 plane at Salisbury is shown in Figure 14. If the traffic distributions for these general aircraft classifications are consistent between airports, the uncontrolled traffic environment at any airport may be modeled when the arrival rates and population ratios are known.

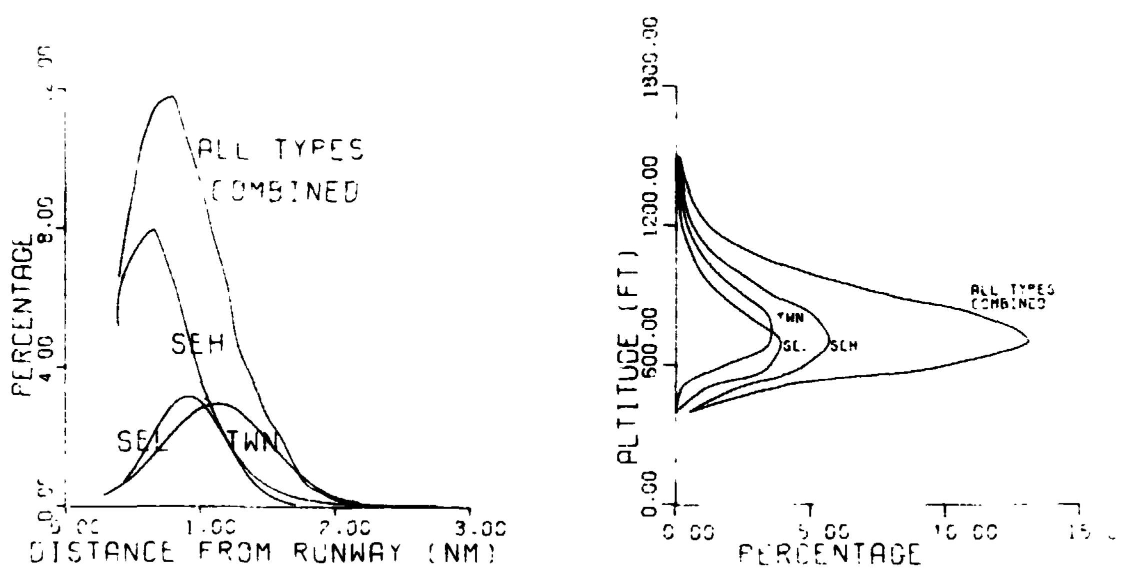

Figure 14.-Contribution by type to total distribution at DW_2

MID-AIR COLLISION SIMULATION

To illustrate a pilot's see-and-avoid problem and the method we plan to use for this study, two actual tracks at the Salisbury-Wicomico Airport were time normalized such that collision would occur at the runway threshold. The position (X, Y) and altitude (Z) time histories of these aircraft are shown on Figure 15. Both of these aircraft (A & B) were Cessna 172's that flew standard approaches at altitudes near the published pattern altitude.

The view angle from one aircraft to the other was computed for both aircraft depending on their heading, bank angle, and altitude and

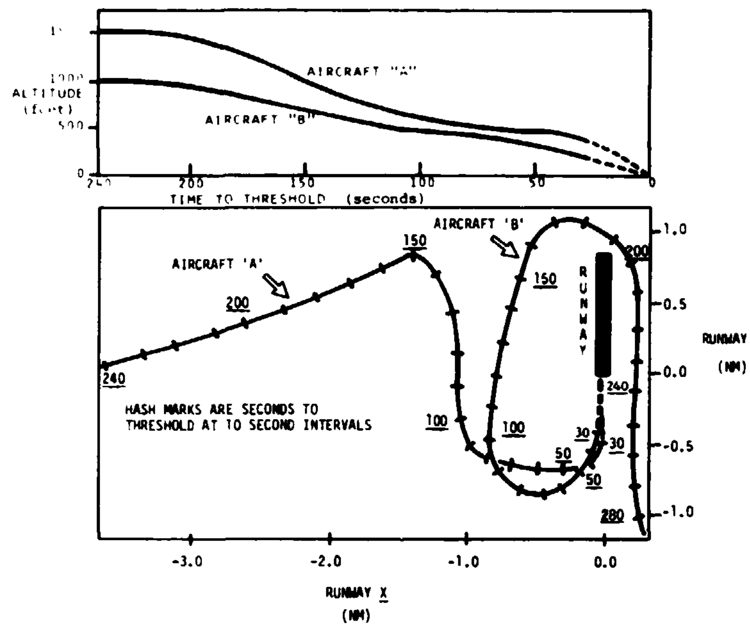

Figure 15.-Position & altitude time history

distance separation. A time history of this data was plotted on each aircraft's view envelope as shown in Figure 16. From this figure, it is obvious that there are considerable periods of time that the pilots cannot see each other.

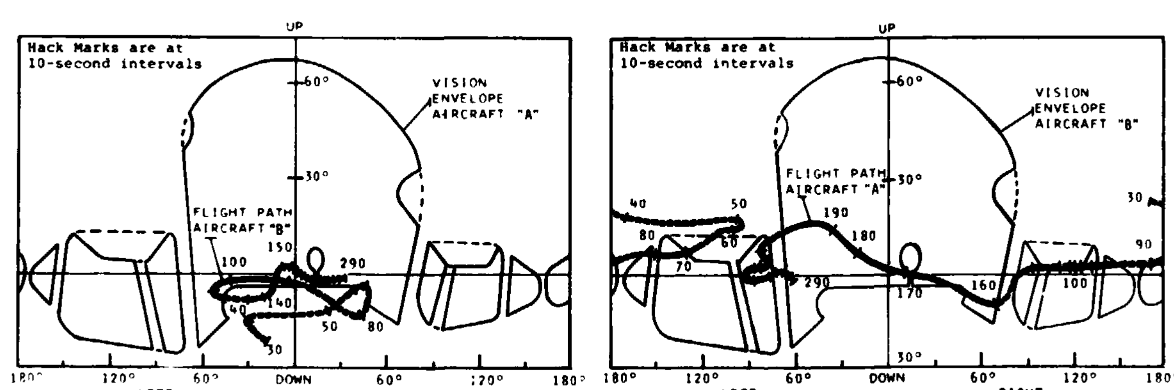

Figure 16.-Aircraft view envelopes

The time history of range between these aircraft and the periods each pilot could not see the other aircraft are shown on Figure 17. The pilot of aircraft A was able to see aircraft B approximately

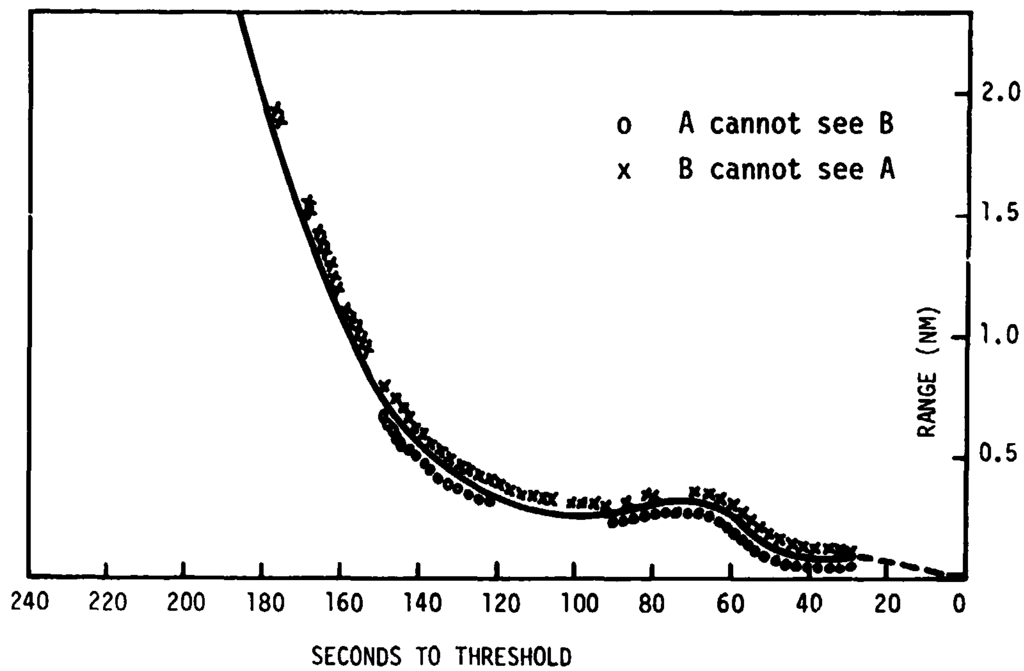

Figure 17.-Time history of range between aircraft

one-third of the time during the last 2 NM of closure with aircraft B. Other factors that would have reduced the chance of seeing aircraft B are that: (1) the pilot of A would have to detect B against an earth background; (2) B would have presented nearly a head-on profile during the closure from 2 to 3/4 NM and provided little relative movement in the A pilot's view field at that critical time; (3) the A pilot's attention during the 120 second - 90 second time period would probably be directed toward the runway in preparation for the base turn.

The pilot in B could have seen A only about one-tenth of the time during the last 2 NM of closure. His best opportunity to see A occurred during the turn to the downwind leg at 190 seconds. At this time, his attention could have been on downwind alignment rather than airsearch. Since B was below and ahead of A, the B pilot's detection of A after his turn downwind is very unlikely. This example illustrates the limited amount of time a pilot flying a near normal pattern may have for detecting other aircraft. These tracks were taken on different days; however, by chance could accurately represent a mid-air collision situation.

CONCLUSIONS

The initial data analyzed from the Salisbury-Wicomico Airport verifies that the uncontrolled air traffic patterns flown are highly variable. It can be demonstrated that normal pattern variations create mid-air collision situations in which one or both pilots involved may be unable to see one another at critical times during their approach. The high percentage of non-standard entries observed tends to verify NTSB conclusions that this condition may be a factor for concern. The sample traffic distributions obtained indicate that, in general, air traffic is not normally distributed about the mean paths in either distance or altitude. Most of the traffic pattern data observed, however, can be modeled using discrete distributions. Air traffic simulation utilizing these distributions should provide new insights to piloting procedures and traffic pattern concepts which enhance a pilot's see-and-avoid potential in the uncontrolled environment.

REFERENCES

1. "Mid-Air Collisions in U. S. Civil Aviation 1969 - 1970;" Special Study, National Transportation Safety Board, Report No. NTSB-AAS-72-6; Washington, D. C. 20591; June 7, 1972.

2. "Near Mid-Air Collision Report of 1968;" Department of Transportation, Federal Aviation Administration, Air Traffic and Flight Standards Technical Report, prepared by NMAC Study Group; 15 July 1969.

3. "Mid-Air Collisions in U. S. Civil Aviation - 1968 - A Special Accident Prevention Study;" National Transportation Safety Board, Washington, D. C.; July 1969.

4. "Air-to-Air Visual Detection Data;" Interim Report, Department of Transportation, Federal Aviation Administration, Systems Research and Development Service, Washington, D. C.; April 197?.

5. W. Graham & R. H. Orr, "Separation of Air Traffic by Visual Means: An Estimate of the Effectiveness of the See-and-Avoid Doctrine;" Proceedings of the IEEE, Vol. 58, No. 3, March 1970, pp. 337-361.

6. Gerald D. Edwards & James L. Harris, Sr.; "Visual Aspects of Air Collision Avoidance: Computer Studies on Pilot Warning Indicator Specifications;" Scripps Institution of Oceanography, Ref. 72-3, Final Report, NASA Ames Research Center Grant No. NCR-05-009-059, February 1972.

7. Charles W. Bachman; "Integrated Data Store;" General Electric Application Manual, Data Base Study, November 1966 (Rev. June 1968).

8. Robert W. Goldin; "Cockpit Vision Requirements Review;" Report No. RWG/71-11; Study sponsored by Air Safety Foundation, Aircraft Owners and Pilots Association, Washington, D. C.; April 1, 1971.

9. L. W. Falls; "A Computer Program for Standard Statistical Distributions;" NASA TMX-64588, National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama.

10. Robert V. Esperti; "Elliptical Normal Probability Function;" General Motors Corporation, April 6, 1960.