Prestige
Elite

N77-18087

GENERAL AVIATION APPROACH AND LANDING PRACTICES

Loyd C. Parker
NASA Wallops Flight Center

Maxwell W. Goode
NASA Langley Research Center

SUMMARY

The characteristics of air traffic patterns at uncontrolled airports and techniques used by a group of general aviation pilots in landing light airplanes have been documented. The report contains the results of some 1600 radar tracks taken at four uncontrolled airports and some 600 landings made by 22 pilots in two, four-place, single-engine light airplanes. The results show that the uncontrolled traffic pattern is highly variable. The altitudes, distances, and piloting procedures utilized may affect the ability for pilots to see-and-avoid in this environment. Most landing approaches were conducted at an airspeed above recommended, resulting in significant floating during flare and touchdowns that were relatively flat and often nose-low.

INTRODUCTION

The National Aeronautics and Space Administration has undertaken research programs to document the practices used by general aviation pilots in the traffic pattern and during final approach and landing. These efforts were prompted by the general aviation safety records reflected in accident summary reports, reference 1, and mid-air collision reports, references 2, 3, and 4. These reports indicate that the most frequent accidents, under visual flight rules (VFR), occur at the airport during the approach and landing of single-engine light planes flown for pleasure. Additionally, most mid-air collisions occur in the traffic pattern at uncontrolled airports on final approach and involve lack of adherence to proper pattern procedures and failure of pilots to see-and-avoid. The vast majority of all accidents are attributed to the pilot, as the cause or a factor contributing to the accident.

7

For the air traffic pattern studies a tracking radar system was used to measure and record the position-time histories of general aviation airplanes on pattern entry and in the pattern legs. Data were collected at four uncontrolled airports each having a different environment and pattern procedures. Airplane separation data in the pattern was measured at the last airport visited using two radar systems. For each radar track, the runway, type airplane, surface winds, barometric pressure, visibility, and cloud ceilings were also recorded. Approximately 1400 individual radar tracks were taken to define air traffic pattern characteristics and 200 radar tracks taken to define normal general aviation separation practices. Preliminary results of the air traffic pattern studies were reported in reference 5.

Two modern, four-place, single-engine light airplanes (a low-wing and a high-wing) were leased from a fixed-based operator (FBO) and instrumented to obtain final approach and landing performance data. A cadre of 22 general aviation pilots with various backgrounds and experience was provided by the FBO to perform a series of landings on a long runway (1524 m - 5000 ft) and a short runway (762 m - 2500 ft). Approach and landing data were collected using the instrumented aircraft and a ground tracking system for approximately 150 landings of each airplane at each runway. All pilots were briefed on the purpose of the study and operation of the equipment prior to participating in the program. Pilots were asked to turn on the airborne data system just prior to final approach and to make normal landings based on their training and experience. Each pilot was scheduled to make a maximum of six landings in one day on one runway. To alleviate traffic conjestion on the long runway, touch-and-go landings with a significant ground roll were permitted. All landings on the short runway were completed to a full stop. Preliminary results of the low-wing aircraft phase of the approach and landing study were presented in reference 6.

TEST EQUIPMENT

Air traffic pattern measurements in the uncontrolled airport environment were made utilizing the MPS-19 tracking radar system, figure 1. Position-time histories of arriving airplanes were recorded on magnetic tape at one sample-per-second. Operators maintained a log of each track which included active runway, type airplane, surface wind, ceiling and visibility data. Radar data were rotated to the magnetic bearing of the landing runway and parallaxed to the landing runway threshold to create a normalized runway referenced coordinate system which permits direct comparison of pattern legs at each airport. During data reduction, operator log data were combined with each track and stored on computer disc files for retrieval and analysis. Position accuracy of the radar system is $\pm$ 9.5 m (10 yds) RMS in range and $\pm$ 1 mil RMS in angles.

Final approach and landing data were obtained using two instrumented airplanes, figure 2, and a ground tracking system, figure 3. Both airplanes, widely used in general aviation private flying, were leased from an FBO and instrumented to measure and record 21 different flight parameters, including airspeed, pitch attitude, flap position, and altitude. Modifications to the airplanes included a test boom on the left wing tip to measure airspeed, angle of attack and angle of sideslip; control switches on the instrument panel; and an instrumentation package located aft of the pilot's seat. The airborne data system increased the basic weight of the test airplanes approximately 86.2 kilograms (190 pounds). Both airplanes were flight tested by NASA research pilots before and after modification with the determination that the instrumentation had a negligible effect on the airplane handling characteristics.

The ground tracking system was used to obtain the flight path and touchdown data with respect to the runway. This system was comprised of a 16-mm motion picture camera and a 3.05 m (10 ft) high by 67.0 m (220 ft) long photographic grid. The grid consisted of a series of vertical and horizontal plastic strips which formed squares of 0.6 m (2 ft) on a side within the grid frame. Normal photogrammetric techniques were used to obtain the trajectory data from the motion picture film. The airplanes were assumed to be aligned with the runway center line for photographic analysis. A field survey of a typical grid installation indicated a tracking accuracy of ± 0.3 m (± 1 ft) or less.

AIRPORTS AND RUNWAYS

The location of the airports where data was taken during these studies are shown in figure 4. Air traffic pattern data were collected at Salisbury-Wicomico (SBY), Gaithersburg (GAI), Hyde (HYD), and Manassas (MAN) airports. Approach and landing data were collected at Hummel and Patrick Henry airports.

The Salisbury-Wicomico airport is located near Salisbury, Maryland, in a rural, low density traffic environment and has an airport elevation of 15.5 m (51 ft) above mean-sea-level (MSL), traffic pattern altitude (TPA) of 244 m (800 ft), three 1524 m (5000 ft) runways, an FAA Flight Service Station (FSS), VOR facility, commuter service, active flight school, airplane maintenance and service facilities, and approximately 25,000 operations per year of which one-third are estimated to be twin-engine aircraft. The Gaithersburg, Maryland, airport is located in a high density traffic environment north of the Washington, D.C., Terminal Control Area (TCA) and has an airport elevation of 165 m (540 ft) MSL, TPA of 183 m (600 ft), one 960 m (3150 ft) runway, right-hand pattern for runway 31, active flight school, significant airplane maintenance facilities, large number of resident private and corporate airplanes, and operations estimated at 50,000 per year of which 89% are single-engine airplanes. The Hyde airport is located near Clinton, Maryland, beneath the 457 m (1500 ft) floor of the Washington, D.C., TCA whose surface boundaries north, east, and west require all VFR traffic to enter from a south to southwest direction. The airport has an elevation of 76 m (249 ft) MSL, TPA of 244 m (800 ft), two runways - one of 976 m (3200 ft) and one of 640 m (2100 ft), another uncontrolled airport located approximately 1.5 n. mi. to the west, local pattern procedures which specify upwind pattern leg entry for runways 5 and 31, active flight school and flying club, large number of resident airplanes, service and maintenance facilities, and operations estimated at 25,000 per year of which 94% are single-engine airplanes. The Manassas, Virginia, (MAN) airport is located west of the Washington, D.C., TCA in a relatively low density traffic environment and has an elevation of 57 m (186 ft), TPA of 244 m (800 ft), one 1128 m (3700 ft) runway, commuter service, flight school, service and maintenance facilities, large number of resident airplanes and operations estimated at 25-35,000 per year.

Approach and landing data for a long runway of 1524 m (5000 ft) were collected on runway 2 and 20 at the Patrick Henry airport in Newport News, Virginia. The elevation of the airport is 12.5 m (41 ft) MSL and controlled traffic at the airport was very heavy at times necessitating extended downwind and long straight-in final approach legs. The short runway airport, Hummel, located near Saluda, Virginia, is a small uncontrolled airport with an elevation of 9.1 m (30 ft) serving a rural area. All landings were made on runway 18 which is 762 m (2500 ft) long. Final approach to the runway is over water with a tree line approximately one-quarter of a mile from threshold. The airport had very light traffic; consequently, the test subjects could fly the pattern without interference.

RESULTS AND DISCUSSIONS

The results of the uncontrolled air traffic pattern measurements study are based on a total of 1409 individual radar tracks at three airports and 208 radar tracks of airplane separation distance at one airport. Of the individual tracks obtained approximately 83% were single-engine airplanes and 17% were twin-engine airplanes. The results of the approach and landing performance study covers a total of 616 landings made by both airplanes at both runways. A total of 299 landings (144 long runway, 155 short runway) were made in the low-wing airplane and 307 (163 long runway, 154 short runway) were made in the high-wing airplane.

Uncontrolled Air Traffic Pattern

The generally recognized standard uncontrolled air traffic pattern is characterized by entry to the downwind leg at a 45-degree angle at a 244 m (800 ft) altitude above ground level (AGL) and "left-hand" turns from downwind to base and base to final legs, reference 7. A different pattern may be adopted at an individual airport to avoid a local problem. Two of the airports had local variations from the standard pattern. HYD has a local procedure of an upwind pattern leg entry for runways 31 and 5. GAI has a local pattern altitude of 183 m (600 ft) and a right-hand pattern for runway 31. At the time traffic measurements were conducted the FAA had issued NPRM 71-20, "Operations at Airports Without Control

Towers," which proposed a new uncontrolled traffic pattern concept, figure 5. FSS personnel at SBY encouraged local pilots to try out this proposal during the period air traffic measurements were conducted.

Pattern Entry

The lack of adherence to pattern entry procedures is a possible cause of mid-air collisions. The pattern leg entry locations were examined to determine the variations from local procedure. The results of this analysis for arriving airplanes, figure 6, illustrates the variations from local pattern entry procedure. In the higher traffic density environment of GAI, adherence to the pattern procedure was significantly better than either HYD or SBY. Approximately 51% at SBY, 12% for downwind and 66% for upwind runways at HYD, and 11% at GAI of the arriving traffic did not adhere to the local pattern entry procedure. Normal left- and right-hand traffic entering downwind at GAI are shown as a right-hand entry on figure 6 to illustrate deviations from the standard. At GAI 2% of the traffic failed to recognize the right-hand pattern established for runway 31 and used a left-hand approach opposite to local pattern. At SBY 4% of the traffic used a right-hand base entry opposite to the left-hand pattern.

Pattern Leg Distributions

In addition to the variation in pattern entry location, the distance and altitude variations within the pattern legs may increase the pilot's see-and-avoid problem. The ground track distributions observed in the pattern legs at SBY and HYD, figure 7, illustrate this variation between a low density (SBY) and high density (HYD) environment. Another factor affecting this difference is that SBY's traffic was 33% twin-engine as compared to only 6% twin-engine traffic of HYD. In either case, the pattern legs are wide and extend from a few tenths of a nautical mile out to greater than 1.5 n. mi. from the runway. General aviation pilots should expect conflicting traffic at distances up to several nautical miles when entering an uncontrolled traffic pattern. The cumulative distributions of distance for the downwind, base and final pattern legs are shown in figure 8. This figure further illustrates the difference between HYD's constrained environment and SBY. Conversely, the downwind cumulative distribution, figure 8a, for SBY and GAI, which has twice the traffic of SBY, are essentially the same out to the median pattern distance. The divergence beyond the median for the SBY and GAI suggest that this portion of the distribution may be a result of the twin-engine traffic percentage of 33% at SBY and 11% at GAI. On base and final legs little difference in the cumulative distribution is shown up to the 97% level, figure 8b and 8c.

Traffic Pattern Altitude Variation

A factor which may seriously influence a pilot's ability to detect another airplane is adherence to the established TPA. The cumulative distributions of the average altitude for all traffic at each airport on downwind, base and final legs are compared in figure 9. The variation from the downwind TPA of 183 m (600 ft) at GAI and 244 m (800 ft) at HYD and SBY is shown in figure 9a. Less than 1% of the traffic observed on downwind is below an altitude of approximately 122 m (400 ft). This figure also illustrates that 99% of the traffic on downwind for GAI and HYD was below 305 m (1000 ft) and at SBY was below 430 m (1410 ft). Variations of at least 183 m (600 ft) or greater in the TPA flown are shown at all airports. At HYD and SBY where the TPA was 244 m (800 ft), greater than 65% (SBY) and 90% (HYD) of the traffic was below this altitude on downwind leg. In comparison the GAI median altitude is essentially equal to the specified TPA, indicating that 183 m (600 ft) may be the more natural pattern altitude. In reference 8, pilots overwhelmingly indicated they preferred a TPA of 244 m (800 ft) or 305 m (1000 ft). Most pilots (95%) indicated they did not deviate from the TPA more than 45.6 m (150 ft),substantially less than was actually observed. The significant altitude variations on downwind leg are continued through base and final legs as shown on figures 9b and 9c. Most data shown for the final leg were taken at a distance greater than 762 m (2500 ft) from the runway threshold.

Croswind Leg

Departure airplanes may pass through portions of the crosswind leg creating potential mid-air collision (MAC) situation. This is illustrated by figure 10 which shows a cross section of a bivariate log-normal distribution of the crosswind leg at SBY and typical departure paths of a single-engine and twin-engine airplane. The conflict between departing and arriving airplanes has been recognized. The latest FAA Advisory Circular AC 90-60 "Recommended Standard Traffic Patterns for Airline Operations at Uncontrolled Airports", reference 9, recommends that a downwind entry mid-point of the runway be used and established specific departure procedures to minimize conflict with traffic using the crosswind leg. At airports where a crosswind pattern leg is utilized, specific procedures are needed for arrival and touch-and-go traffic.

Type of Aircraft

A comparison of the mean distance and altitude for single-engine high-wing (SEHW), single-engine low-wing (SELW), and twin-engine (TWIN) airplanes at SBY is shown in figure 11. The mean pattern distance, figure 11a, of the SEHW airplanes is approximately 0.2 n. mi. less than

SELW airplanes, and up to 0.5 n. mi. less than TWINS on base leg. TWINS were also found to fly above SEHW and SELW airplanes on all pattern legs, figure 11b, except base and final where TWINS transitioned to the lowest mean altitude. In the higher density environment of GAI and HYD, the difference in the mean pattern leg distance and altitude was found to have essentially the same characteristics.

In general SEHW airplanes fly closer to the runway and higher than SELW airplanes. TWIN airplanes fly higher and further from the runway than SEHW and SELW, except on base and final where they have transitioned to a lower mean altitude.

Closure Rate

Since all traffic generally occupies the same airspace in the uncontrolled air traffic pattern environment, closure rates between airplanes whose pilots fail to see the other becomes an important consideration in the development of any systems solution to the mid-air collision (MAC) problem. The average cumulative horizontal and vertical closure rates in the traffic pattern were determined for GAI and HYD, figure 12. The median closure rate between airplanes expected in a typical general aviation uncontrolled traffic pattern is 18 knots horizontally and 1.3 m/sec (258 ft/min) vertically. Peak closure rates in a typical general aviation environment within the pattern legs should not exceed 85 knots and 5.4 m/sec (1,068 ft/min) more than 2% of the time. If turbo-prop powered twin-engine airplanes use the environment, such as the case at SBY, the average closure rate in the pattern legs will be increased. For SBY, the median horizontal closure rate was found to be approximately 45 knots and exceeded 144 knots 2% of the time - a significant increase over the peak rates for HYD and GAI. Vertical closure rates also increased to a median of 1.9 m/sec (375 ft/min) and exceeded 7.3 m/sec (1437 ft/min) 2% of the time. The possible closure rates during and prior to pattern entry are even higher and exceed 360 knots in the SBY environment. Closure rates determine how far in advance of a MAC that a warning must be issued. To provide a 20-second warning time at a 360 knot closure rate would require issuing the warning when the airplanes were separated by greater than 2 n. mi. It is not considered unusual to have several airplanes with separations of less than 2 n. mi. at relatively high closure rates in a high density uncontrolled airport traffic area.

Separation Distance

Another factor which may affect MAC systems performance and required accuracy is the normal separation distances used by general aviation pilots in the uncontrolled traffic pattern. In reference 8, pilots indicated they used an average of approximately 1 n. mi. separation in the traffic pattern. The actual separation distances measured at a typical uncontrolled airport were generally less than 1 n. mi. This is illustrated by figure 13 in which a typical separation track shows much less separation than 1 n. mi. In fact, the minimum separation distance for a number of tracks was less than 0.1 n. mi. during a portion of the track. The cumulative distributions of the average separation distance and the minimum distance observed for each track are shown in figure 14. The median average separation distance for each pair of aircraft tracks was found to be 0.73 n. mi.; however, a significant percentage (16%) used an average separation of less than 0.5 n. mi. The median minimum separation distance observed for each pair of tracks was found to be 0.49 n. mi. and 10% of the aircraft closed to less than 0.[illegible] n. mi. The separation distances observed illustrate that general aviation pilots often use separations in the uncontrolled traffic pattern that are extremely close.

Final Approach Trajectories

Final approach trajectories, generally, show considerable variation from stabilized, steady flight paths. Profiles of the final approach trajectories for the high-wing airplane at the long runway are presented in figure 15. Included in the figure are the median and the 5- to 95-percentile spread of the data for the height of the airplane at the threshold and the touchdown distance from the threshold. For reference, 3° and 6° slopes passing through the median height at the threshold are included.

For both airplanes at both runways the average flight path angle ranged from 4.7° at the long runway to 6.1° at the short runway with individual flight paths ranging from 1° to 14° during portions of the approaches. The average flight path angle was approximately 1° steeper at the short runway than at the long runway.

The median height at the threshold was lower for the low-wing airplane than for the high-wing airplane at both runways. However, both airplanes were brought in lower over the threshold at the short runway than at the long runway, even though the average flight path angle was approximately 1° steeper.

The median touchdown distance was in direct relation to the median height of the respective airplanes at the threshold. That is, the lower the median height at the threshold the closer the median touchdown was to the threshold. The median touchdown distance for both airplanes at both runways was within the first third of the runway, but well beyond the runway designation numbers just past the threshold. The median touchdown for both airplanes at both runways ranged from 10 percent to 16 percent of the runway length.

Final Approach Airspeed

The average final approach airspeed and the average flap deflection measured at 5-second intervals for the 60-second period prior to touchdown are presented in figure 16 for the high-wing airplane at both runways. Also included in the figure are reference approach speeds and the measured stall speeds of the airplane at the nominal test weight. The reference approach speeds are interpolated values of the manufacturer's recommended approach speeds using the average flap deflection at each time period.

In general, the pilots flew the final approach with an average speed considerably faster than the reference speed. In fact, the average approach speeds were more than 5 knots in excess of the reference speeds until within 15 seconds or less of the touchdown, as indicated by the solid symbols in figure 16. The exception to this result was the low-wing airplane at the short runway in which case the average speed was only slightly in excess of the reference speed for the final 40 seconds prior to touchdown.

Another point of interest shown by the data is that the final approach speeds at the short runway were slower than those at the long runway for both airplanes. This correlates directly with the larger average flap deflection used at the short runway. However, the reduction in average approach speed (6 to 12 knots) was much greater than the difference in the reference approach speeds (1 to 2 knots). This difference would indicate that the pilots were concerned about the runway length and were paying closer attention to airspeed during the approaches to the short runway to assure landings with a comfortable margin between the stopping point and the end of the runway. Based on the manufacturer's published landing distances for the airplanes, the designated short runway was not, in fact, a "short runway" requiring maximum performance from either airplane or pilot to achieve a normal landing in the available distance.

Touchdown Airspeed

Cumulative distribution of airspeed at touchdown for the high-wing airplane at both runways is presented in figure 17. Included in the figure are the measured stall speeds of the airplane at the nominal test weight and the reference approach speeds based on the flap settings for the last 10 seconds of the approaches.

The data generally show that the pilots landed the airplane with speeds considerably in excess of the stall airspeed; this is most probably a direct result of the excessive airspeed used during the final approach. The median touchdown speed ranged from 13 percent to 48 percent above the measured flaps-up stall speed, and less than 6 percent of the landings were within the stall speed range. Except for the low-wing airplane at the short runway, a rather high percentage of the landings were made in excess of the reference approach speeds. The touchdown speeds at the short runway were significantly less than those at the long runway by approximately the same amount as the difference in the final approach speeds between runways.

Touchdown Pitch Attitude

Associated with the high touchdown speeds were pitch attitudes that were relatively flat for both airplanes at both runways. The cumulative distributions of pitch attitude at touchdown for the high-wing airplane are presented in figure 18. Included in the figure is a line indicating the in-flight three-point touchdown attitude which separates the regions of nose-wheel and main-wheel landing attitudes. In general, the touchdown pitch attitudes show little to no difference with respect to runways.

The data show that the pitch attitudes at touchdown were relatively flat for both airplanes at both runways. The median touchdown attitude ranged from only 1.4° to 2.6° above the three-point attitude (pitch-up). A significant percentage of the landings was made in which the nose wheel contacted the runway before the main wheels. Approximately 12 percent of the landings were nose wheel first, except for the low-wing airplane at the short runway where the percentage was 22 percent. Nose-wheel landings are almost invariably a direct result of allowing an airplane to touch down with an excessively high airspeed and certainly present the potential for a landing accident due to nose wheel collapse, porpoising of airplane, or unstable airplane motions referred to as wheel-barrowing.

Mid-Air Collision Simulation

Using the approach data presented in this paper a math model capable of simulating uncontrolled air traffic patterns has been developed. MAC simulations which duplicate the existing environment can provide a baseline for evaluating the effect of changing the uncontrolled pattern concept or the effect or improvements in general aviation piloting procedure. The technique utilized is illustrated in figure 19 which shows the position time histories of two airplanes in a typical approach procedure that are time normalized to have a MAC on final approach. The view angle from both airplanes to the other was computed based on their heading, bank angle, and relative positions. A time history of this data is plotted on the view envelope of each airplane, figure 20, and the percent of time each airplane is visible to the other pilot determined, reference 10. The result, figure 21, illustrates the cumulative percent of time each pilot had to detect the other from a separation distance of approximately 3 n. mi. The case shown is representative of normal general aviation approaches, yet, neither pilot could have seen the other airplane approximately 65 percent of his approach time. Using this technique the cumulative probability of a MAC can be estimated by including the probability of each pilot looking and the probability of seeing when he looks as a function of the separation distance. By simulating thousands of such MAC's in this manner and defining the baseline for the existing uncontrolled traffic pattern environment, the relative improvements that may be achieved through changes in piloting procedure or by new pattern concepts can be determined. Typical pattern concepts under consideration are shown in figure 22. General aviation pilots have indicated, reference 8, that approximately 44 percent preferred the standard left-hand pattern and 30 percent preferred the proposed pattern shown.

Systems Studies

The uncontrolled air traffic studies indicate that new piloting and/or pattern concepts may not adequately reduce the MAC hazard at high density uncontrolled airports. Based on the traffic characteristics observed a systems definition study is in progress to determine the feasibility of a low-cost Automated Pilot Advisory System (PAS), reference 11, for high density, uncontrolled airports. The system concept, figure 23, under evaluation would utilize a small skin tracking radar, microprocessors, weather sensors, and a VHF transmitter. The system functions identified for evaluation are:

1. Broadcast an airport advisory voice message once every two minutes which specifies the active runway, surface winds, barometric pressure, and temperature.

2. Broadcast an air traffic advisory voice message every two minutes which specifies the location of all traffic within 3 n. mi. of the airport.

3. Broadcast a mid-air collision advisory voice message whenever two airplanes exceed a 15-second Modified Tau Criteria, reference 12.

4. Provide the FBO with runway select and override functions and the capability to record limited cautionary messages to be included in airport advisory message.

5. Provide for remote access of system information, via telephone.

Pulse, pulse-doppler, and doppler radar systems are under evaluation for this application. Low-cost X-band radars which appear suitable for this application are readily available as marine and airborne weather radars.

The computer would provide the essential system logic and control functions. These include radar data processing, clutter rejection, track-while-scan, weather data processing, logic and generation of prestored advisory word message formats, power failure auto-restart function, FBO control functions and system self checks.

Whenever the various computer logic conditions are met, a voice message in a standard word sequence would be generated. Computer software will interlace proper key words into the standard format to complete the advisory message. Pre-recorded digital message sequences and vocoder voice sythesis techniques are under evaluation for this system. Typical message sequences with underlined key words follow:

AIRPORT ADVISORY - HYDE - ACTIVE RUNWAY - THREE-ONE - RIGHT HAND PATTERN - WIND - TWO-ONE-FIVE AT SIX KNOTS - ALTIMETER THREE ZERO POINT ZERO FOUR - TEMPERATURE IS TEN DEGREES.

or

- TRAFFIC ADVISORY - HYDE - AIRCRAFT AWAITING DEPARTURE - AIRCRAFT ON FINAL - TWO AIRCRAFT DOWNWIND - ARRIVING AIRCRAFT THREE MILES - NORTHEAST --- DEPARTING AIRCRAFT ONE MILE SOUTHEAST.

An experimental PAS will be configured to evaluate the various system performance options, message formats, and pilot reaction to system utility.

CONCLUING REMARKS

The characteristics of general aviation piloting procedures during approach and landing have been documented. Data presented illustrate the variability with which the uncontrolled air traffic patterns, and the approach and landing maneuvers are performed. Results confirm that pattern entry location and procedure are often inconsistent with the local or accepted standard pattern. The uncontrolled traffic pattern legs are up to 1 n. mi. wide for typical general aviation airports and may exceed 2 n. mi. in width in environments including high performance twin-engine airplanes. Significant variation from the established pattern altitude, ± 75 m (246 ft), is not unusual. At airports where a crosswind pattern leg is utilized, specific procedures are needed for arrival and touch-and-go traffic. Departure traffic should abide by the recommendations of FAA Advisory Circular AC No. 90-66. Systems to prevent MAC at high density uncontrolled airports must cope with very low and high closure rates and normal VFR traffic separation distances of 0.1 n. mi. or less.

The average final approach airspeeds were generally higher than recommended which produced significant floating during the landing flare, average touchdown speeds well above airplane stall speed and landing pitch attitudes that were generally flat or nose-low. On the average, pilots used higher flap deployment angles, steeper approaches, less speed and achieved landings closer to threshold on the short runway when compared to the long runway approaches.

The time available for pilots to see-and-avoid a MAC with other airplanes in the uncontrolled pattern environment may be relatively short. Manuevers and vision view field restrictions create this situation; however, the ability to detect other airplanes at greater than 1 n. mi., the percentage of time pilots spend looking for other airplanes, and rapid closure rates often involved are factors which increase the MAC hazard. The Pilot Advisory System concept may provide pilots with greater ability to locate and avoid conflicting traffic, if low-cost system feasibility is demonstrated.

REFERENCES

1. Anon.: Aircraft Accident Reports, Brief Format. National Transportation Safety Board. NTSB-BA-71-3, 1970.

2. 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. June 7, 1972.

3. 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, July 15, 1969.

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

5. Parker, L. C.: General Aviation Air Traffic Pattern Safety Analysis. NASA TM-X-6955, The System Safety Society Symposium, July 17, 1973.

6. O'Bryan, Thomas C.; Goode, Maxwell W.; and Harris, Randall L.: A Study of Light Airplane Pilot Landing Performance. Society of Automotive Engineers, Inc. 740350, 1974.

7. Anon.: Jeppesen Private Pilot Course. Times Mirror 1971.

8. Parker, Loyd C.: Pilot Preference and Procedures at Uncontrolled Airports. NASA TN D-7928, 1975.

9. Anon.: Recommended Standard Traffic Patterns for Airline Operations at Uncontrolled Airports. Department of Transportation, Federal Aviation Agency, AC 90-66, 1975.

10. Bashir, J. and Singh, R. P.. Aircraft Cockpit Vision Math Model. NASA CR-141406, July 1975.

11. Parker, Loyd C.: NASA Study of An Automated Pilot Advisory System. 760460, Society of Automotive Engineers, April 1976.

12. Britt, C. L.: A Look at Alarm Rates in Collision Warning Systems. Trans. of the 16th Annual Air Safety Forum, Airlines Pilots Assc-ciation, July 1969.

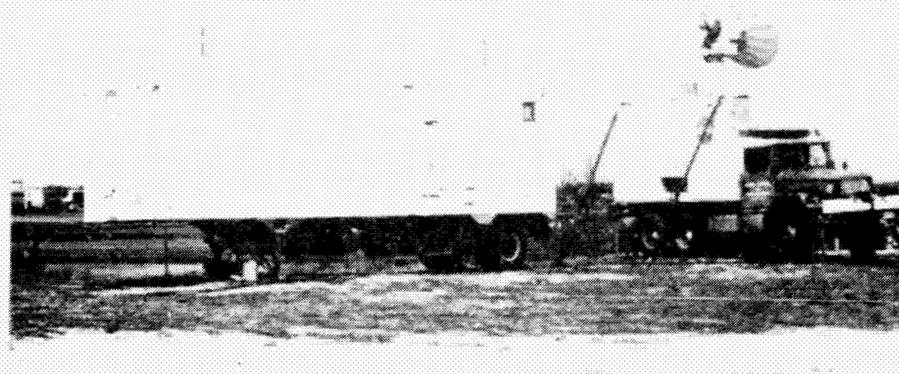


Figure 1.- MPS-19 radar system.

Figure 2.- Test airplanes.

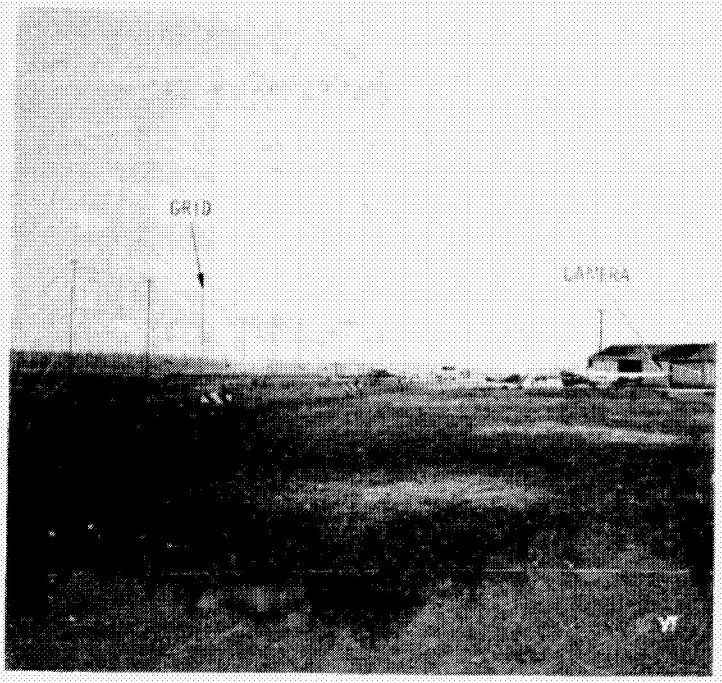


Figure 3.- Ground tracking system.

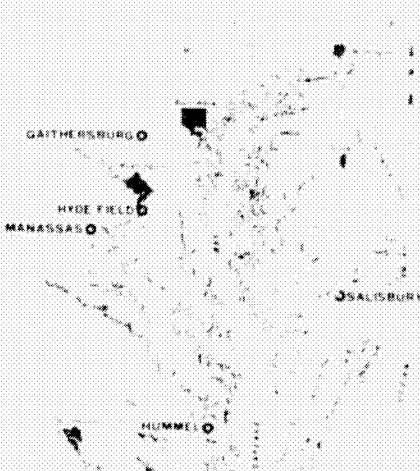


Figure 4.- Airport locations.

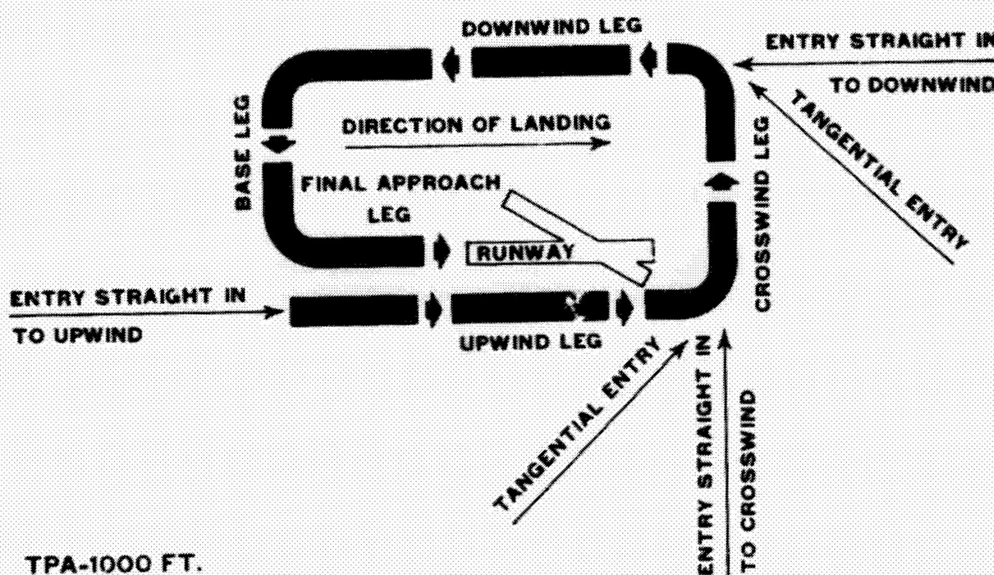


Figure 5.- Proposed uncontrolled air traffic pattern.

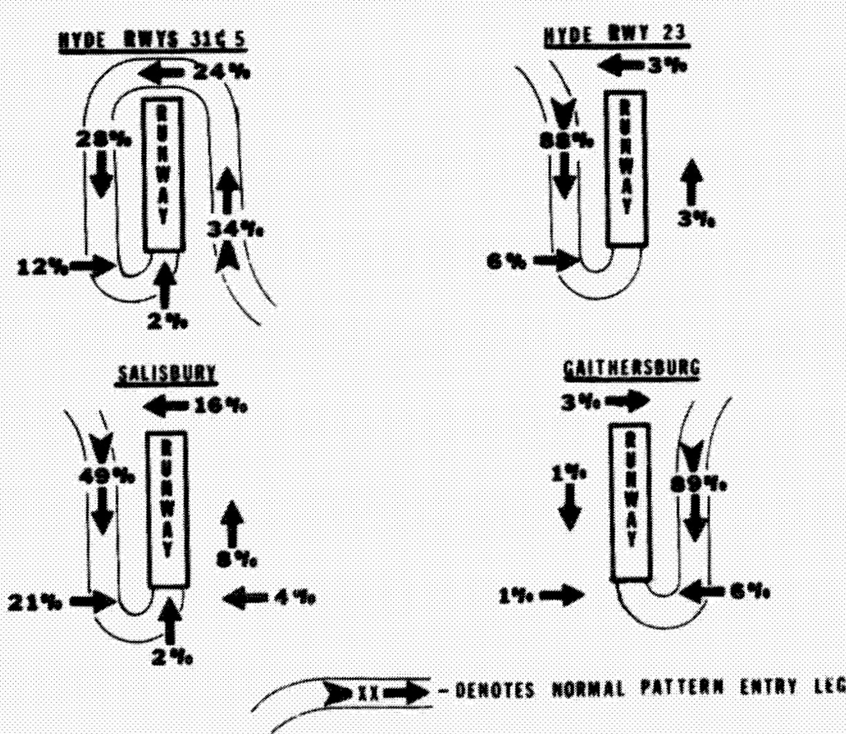
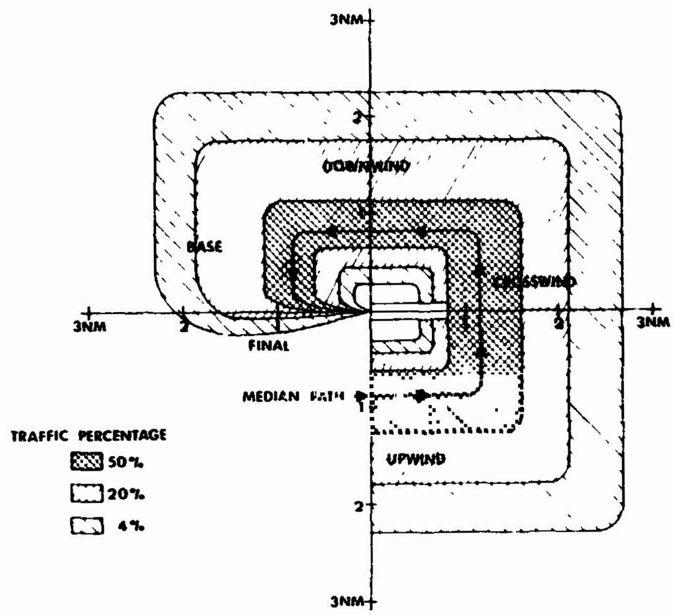
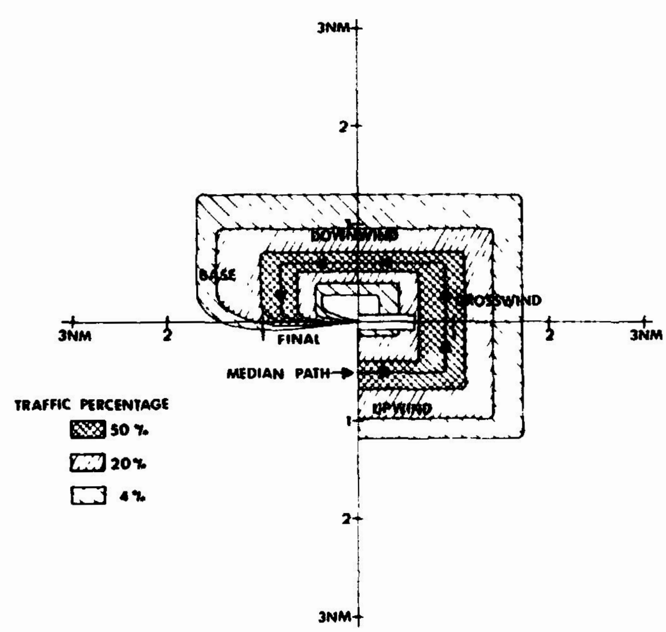


Figure 6.- Traffic pattern entry location.

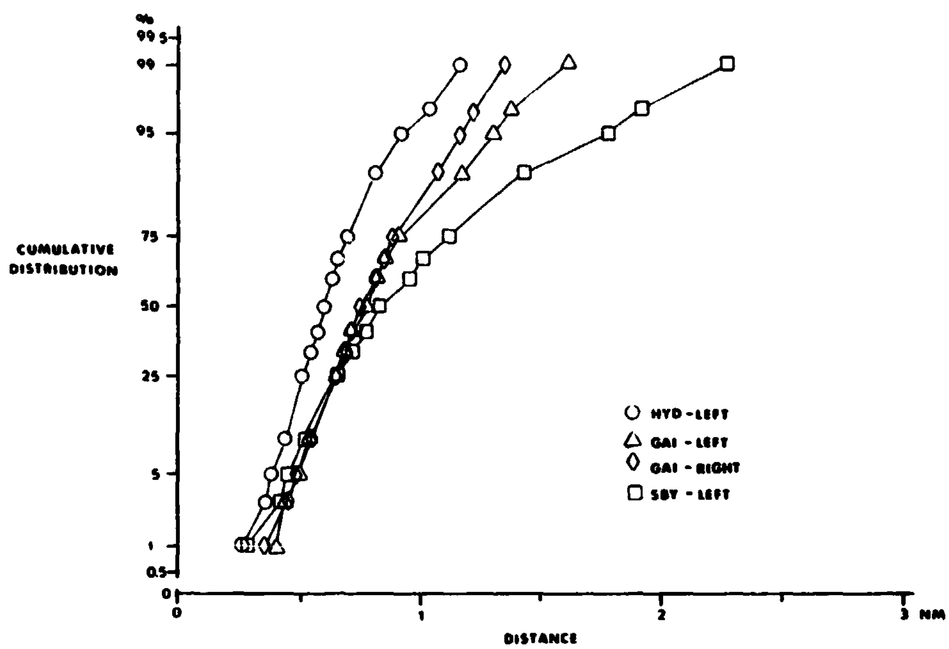


(a) Salisbury.

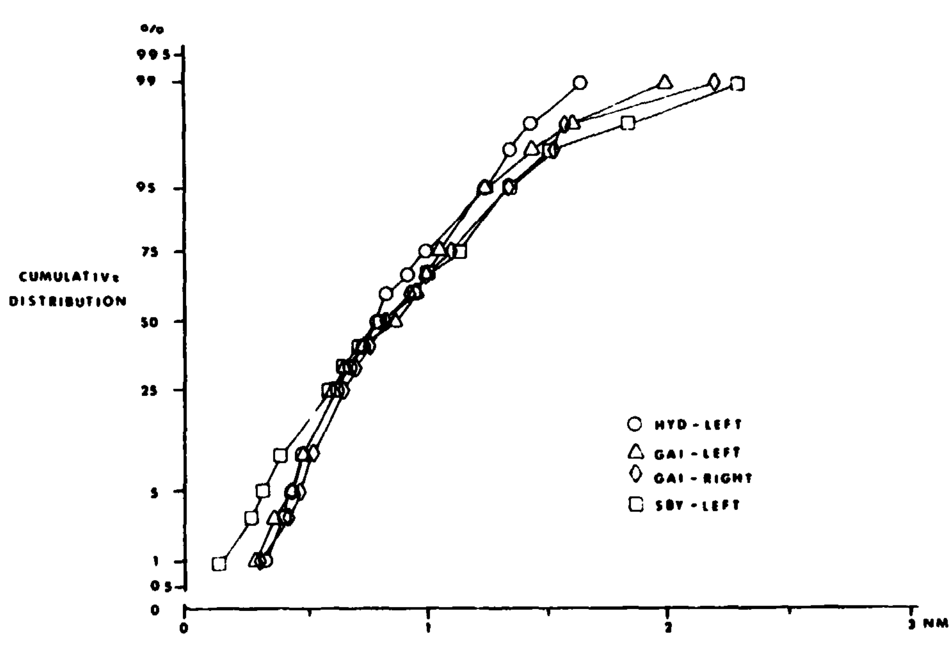


(b) Hyde.

Figure 7.- Traffic pattern leg distance distribution.

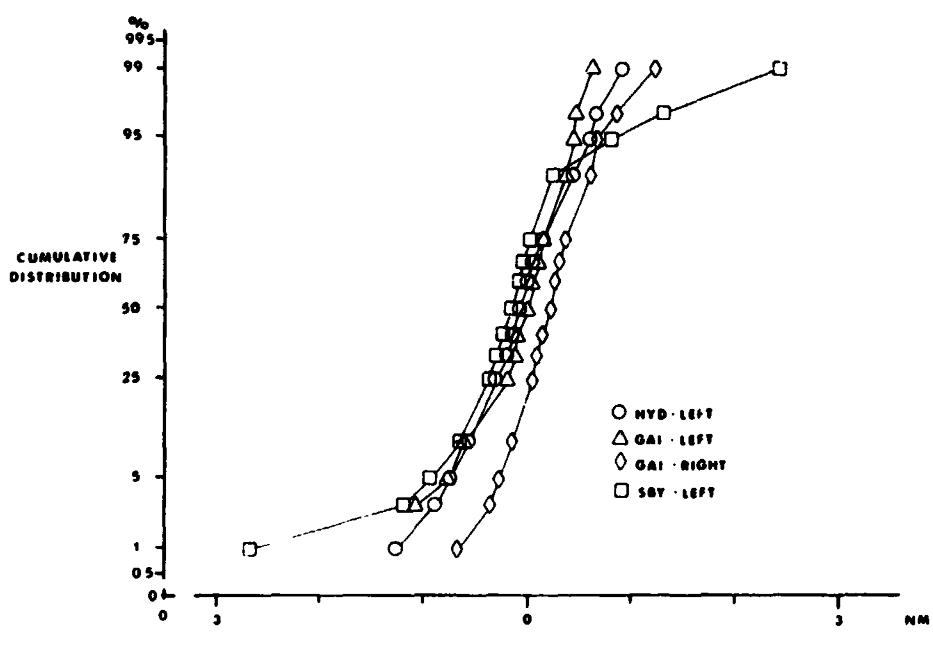


(a) Downwind leg.



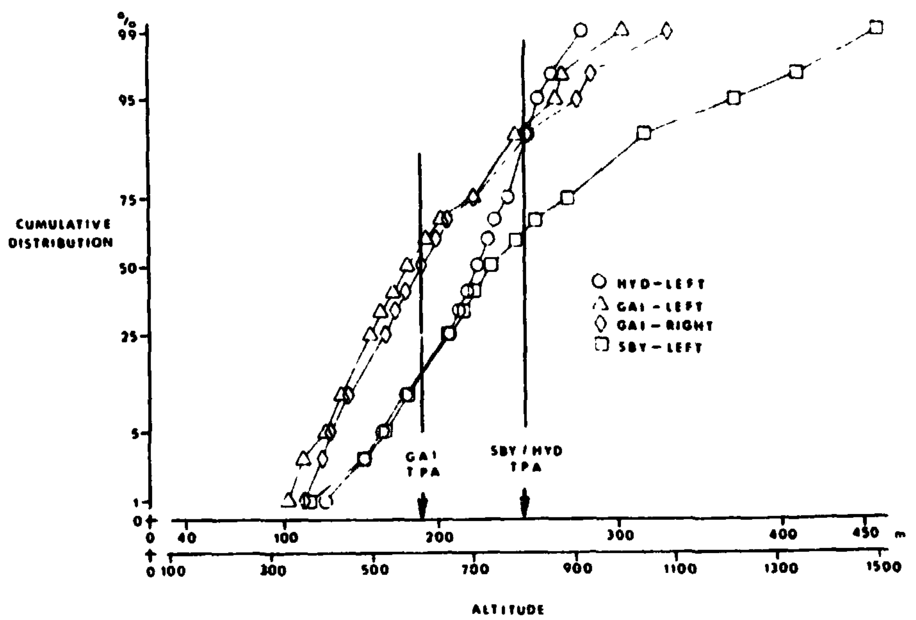
(b) Base leg.

Figure 8.- Cumulative distribution of pattern leg distance.

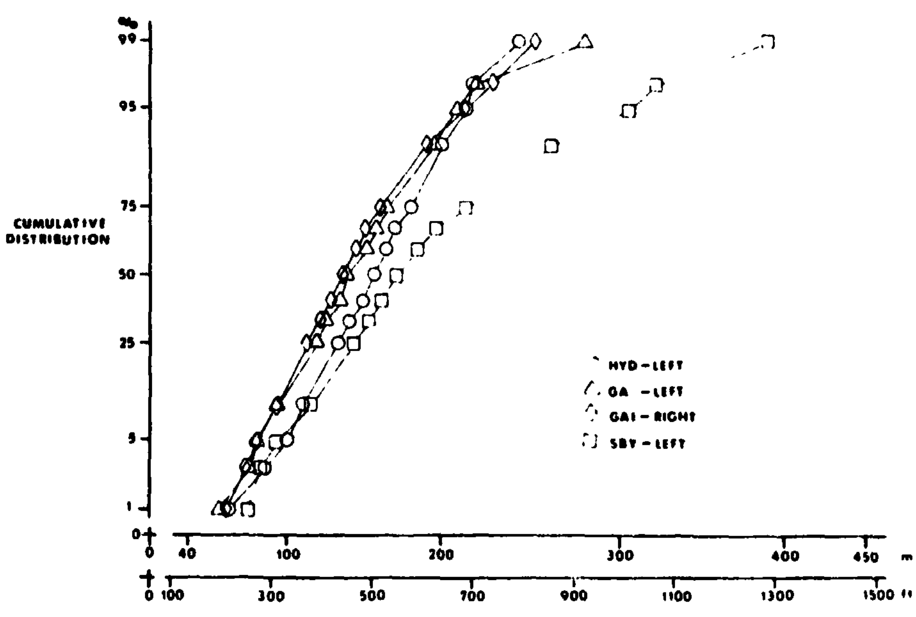


(c) Final leg.

Figure 8.- Concluded.

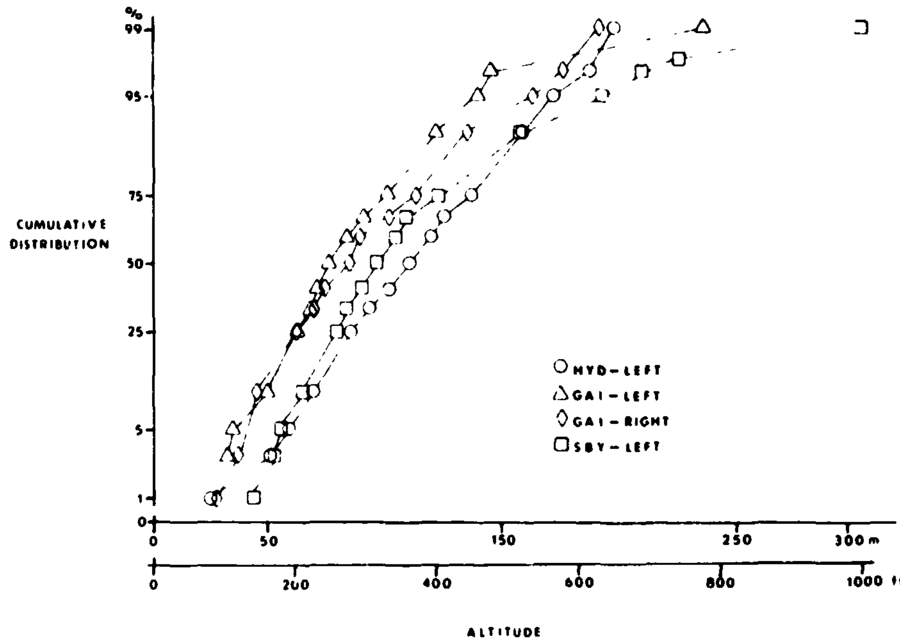


(a) Downwind leg.



(b) Base leg.

Figure 9.- Cumulative distribution of pattern leg altitude.



(c) Final leg.

Figure 9.- Concluded.

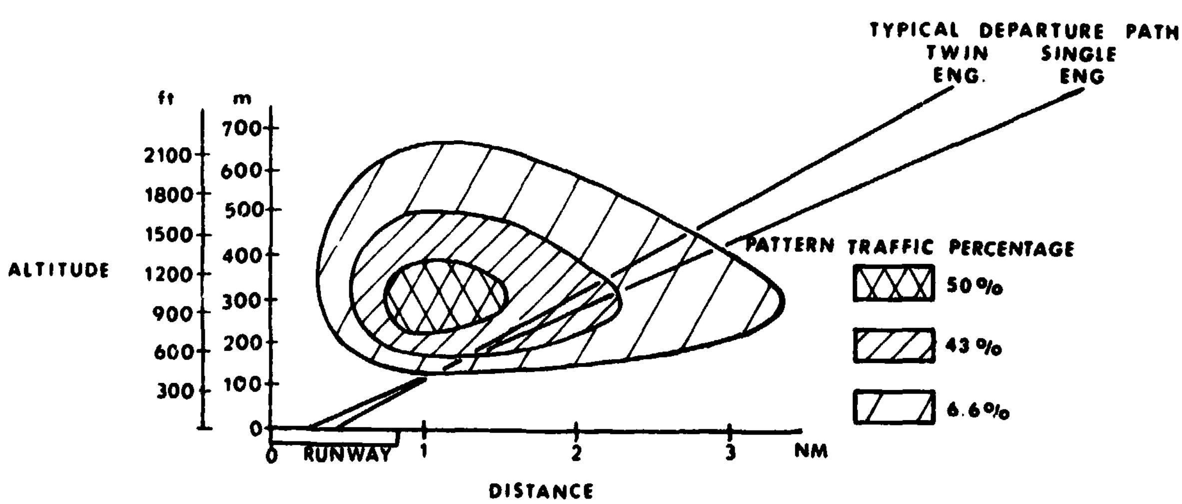
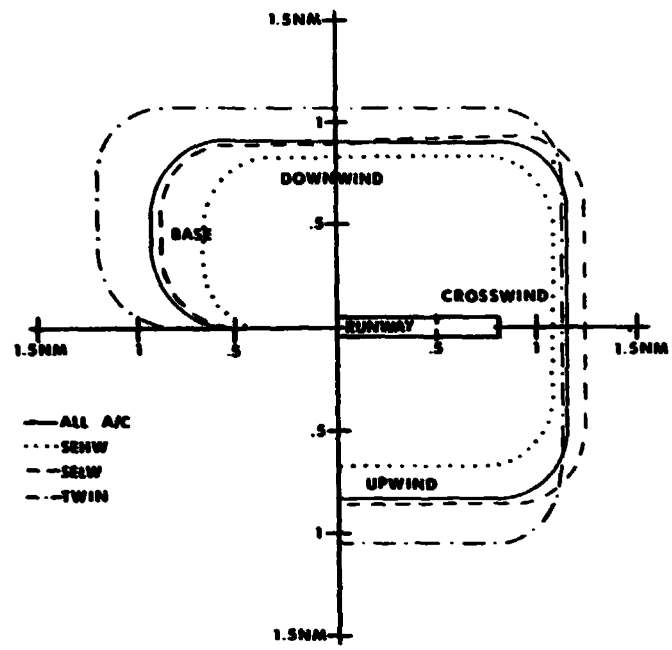
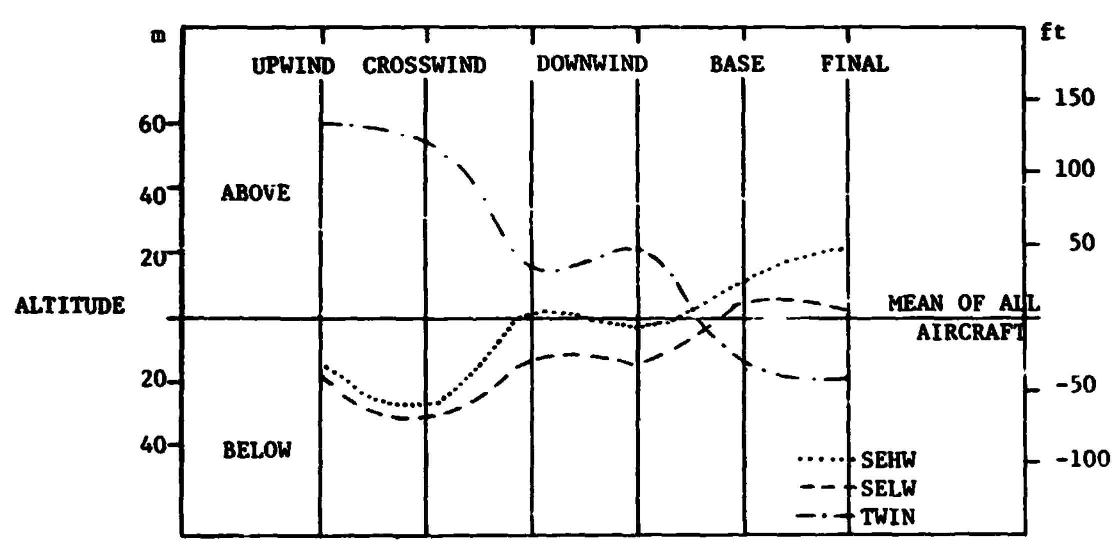


Figure 10.- Crosswind leg traffic percentage and typical departure paths.

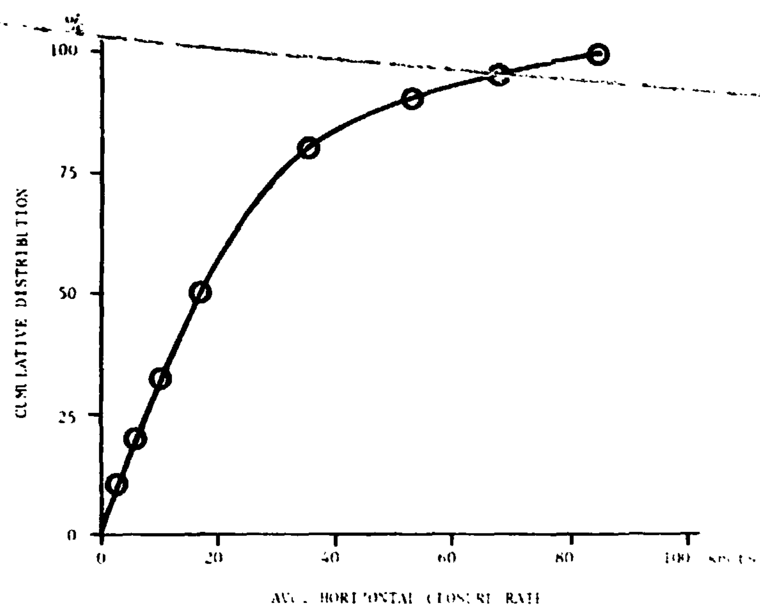


(a) Mean distance.

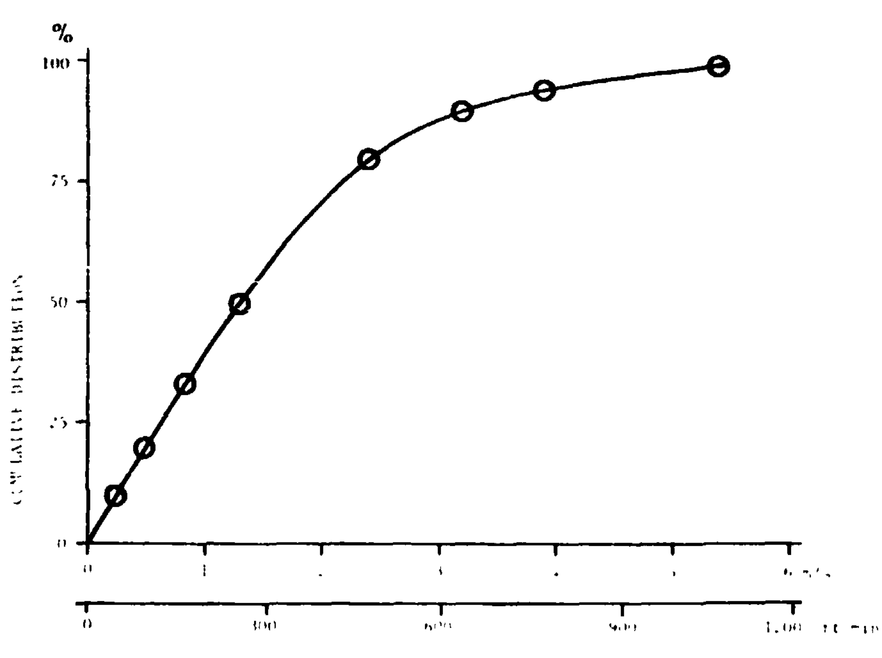


(b) Mean altitude.

Figure 11.- Comparison of mean distance and altitude by type of aircraft at SBY.



(a) Horizontal closure rate.



(b) Vertical clcsure rate.

Figure 12.- Expected horizontal and vertical closure rates.

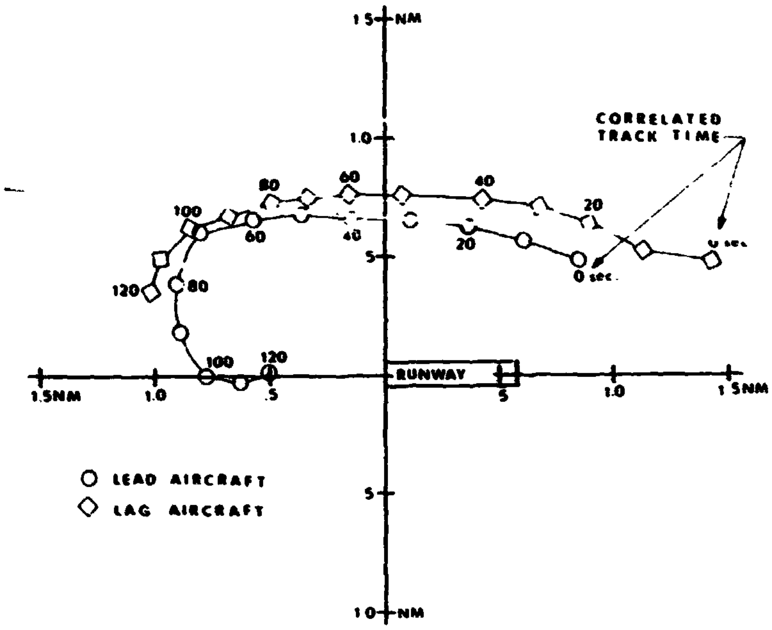


Figure 13.- Aircraft position — time separation tracks.

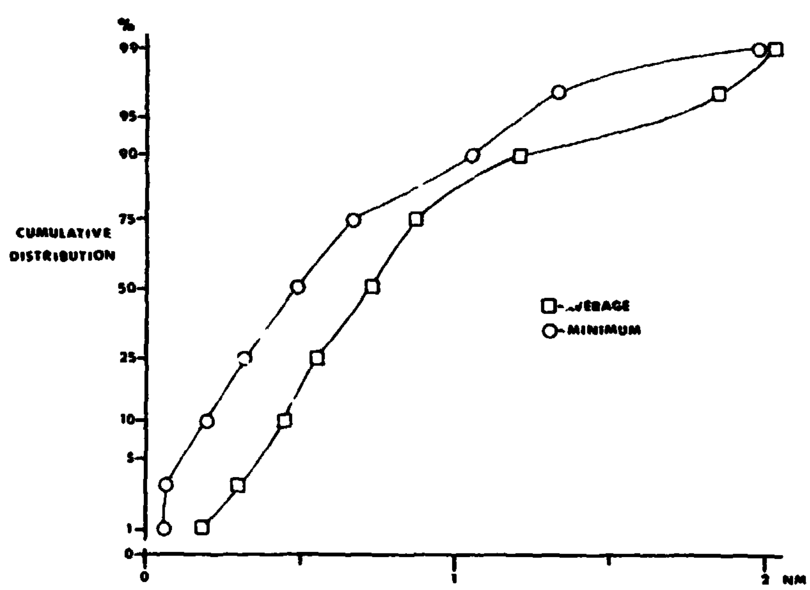


Figure 14.- Cumulative distribution of average and minimum separation distance.

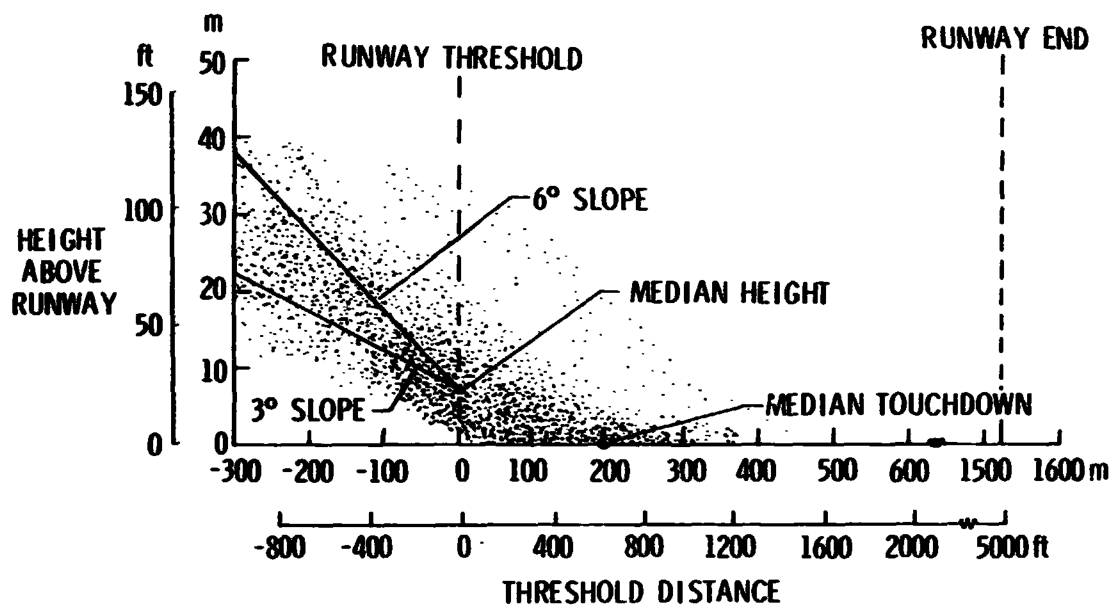


Figure 15.- Final approach trajectories for high-wing airplane on long runway.

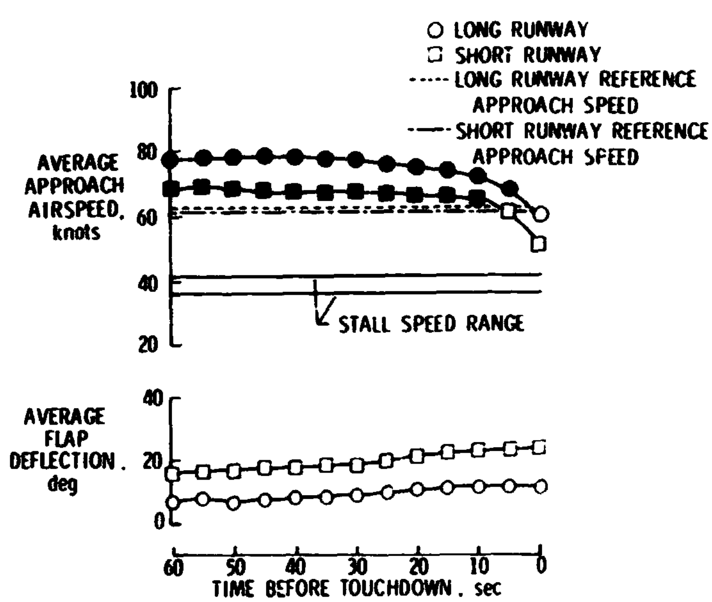


Figure 16.- Final approach airspeed and flap deflection for high-wing airplane.

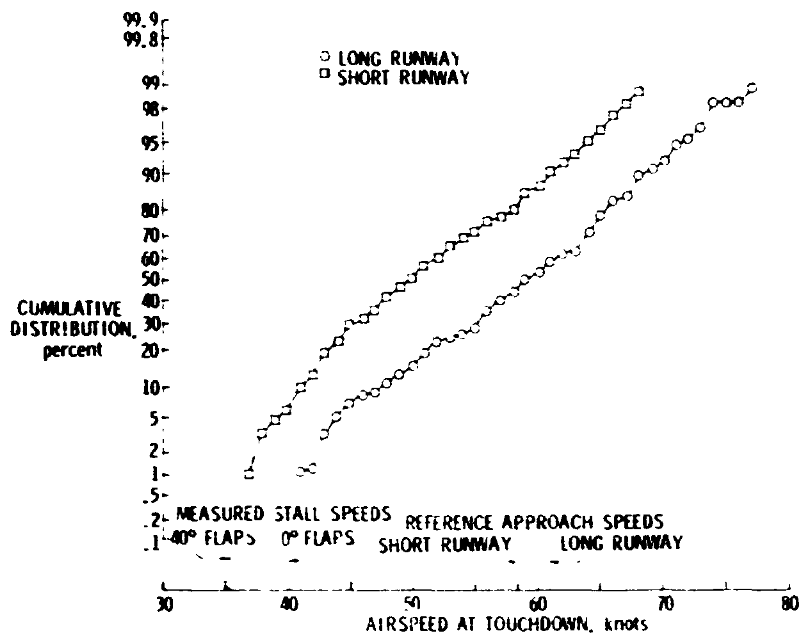


Figure 17.- Cumulative distribution of airspeed at touchdown for high-wing airplane.

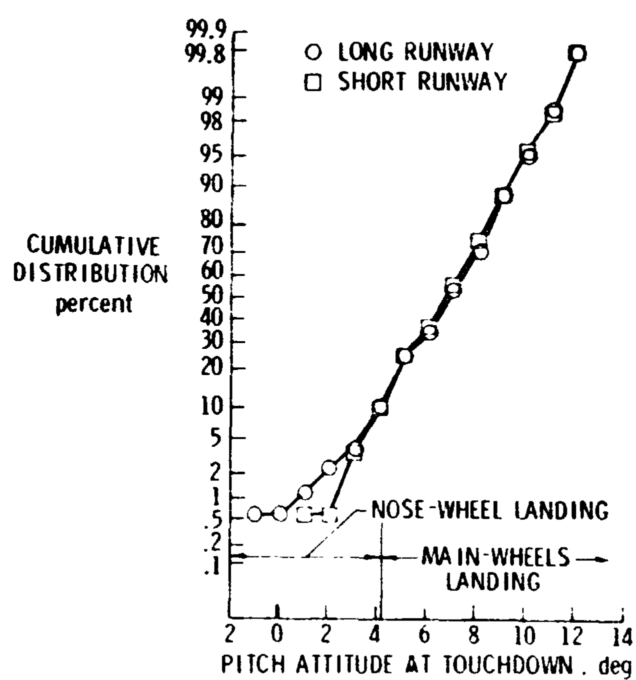


Figure 18.- Cumulative distribution of pitch attitude at touchdown for high-wing airplane.

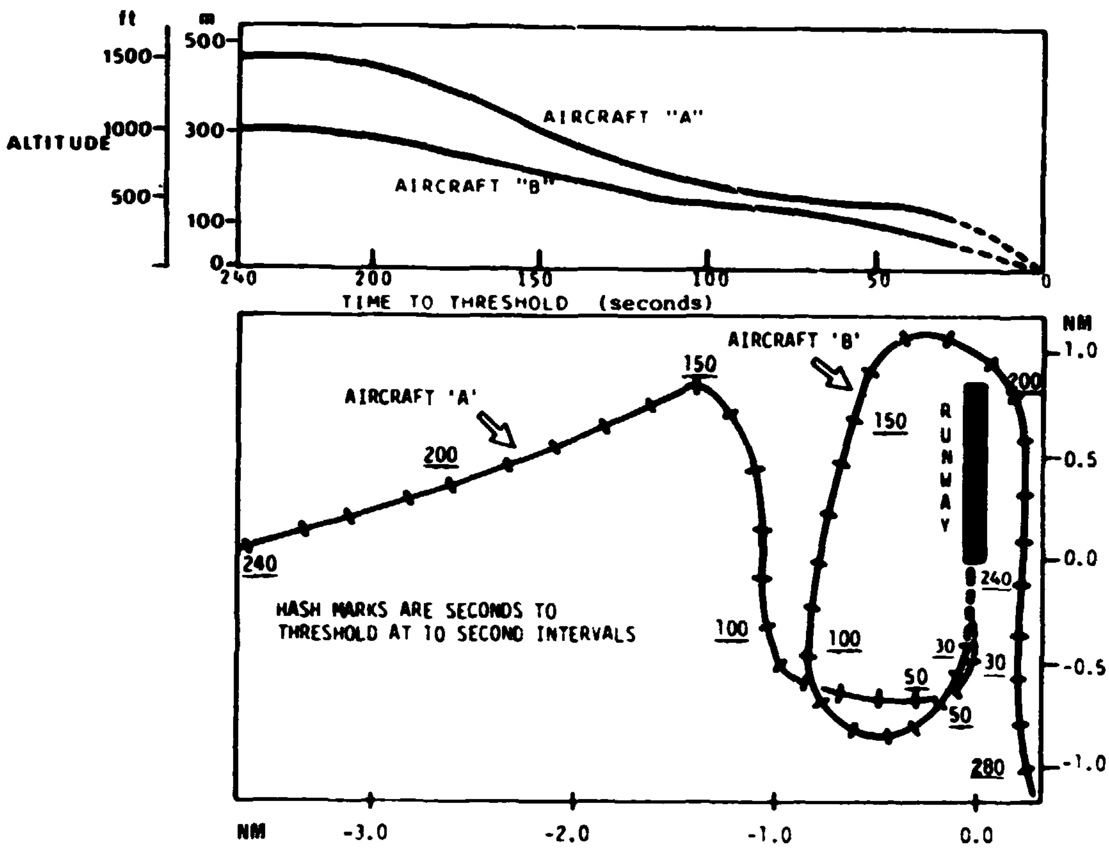


Figure 19.- Mid-air collision position and altitude time history.

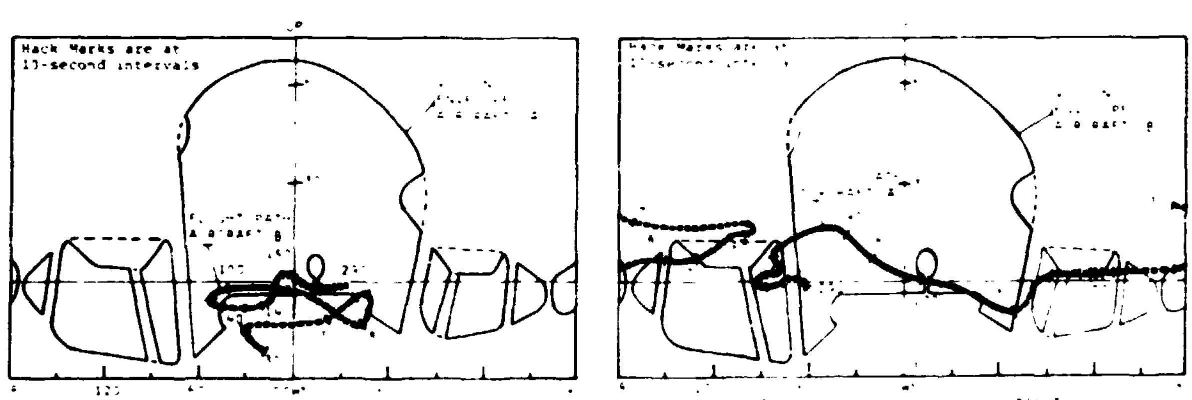


Figure 20.- Aircraft view envelopes.

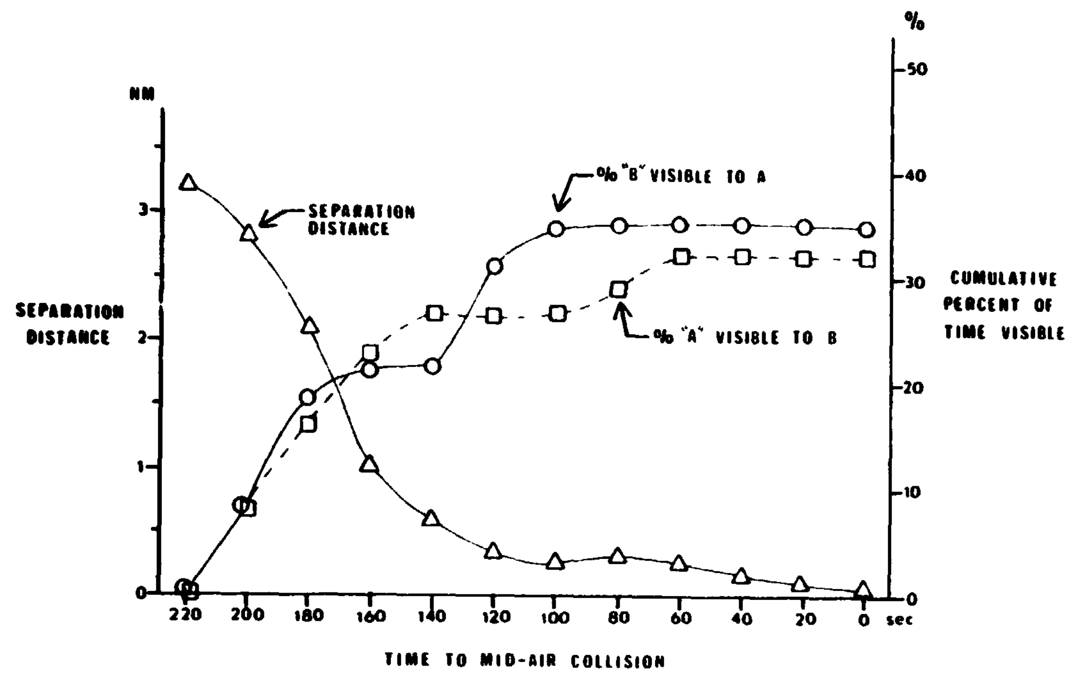


Figure 21.- Separation distance and cumulative percent of time visible as a function of time to MAC.

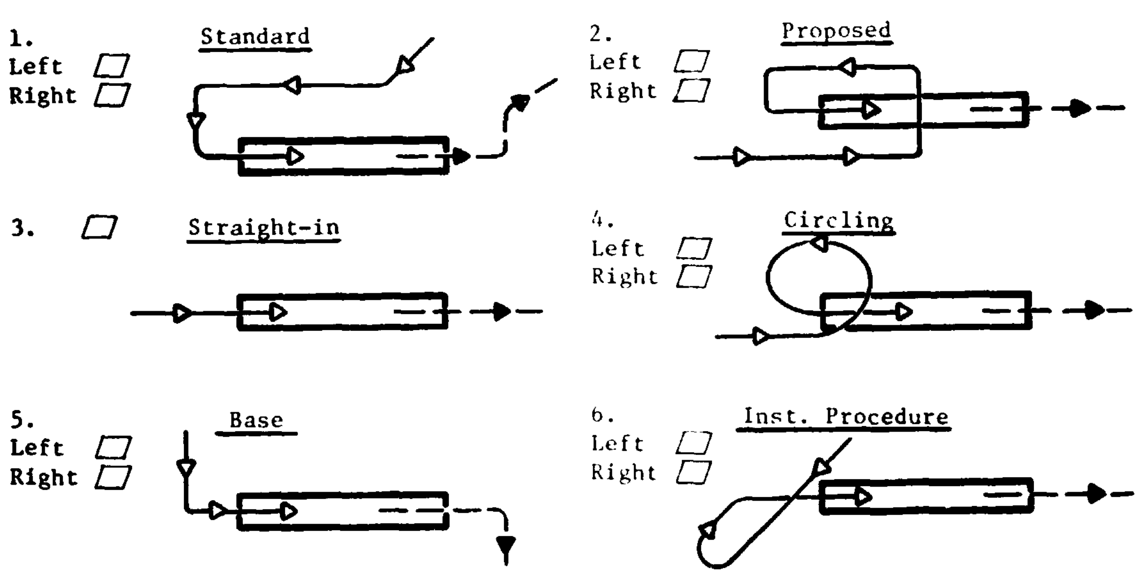


Figure 22.- Uncontrolled air traffic pattern concepts.

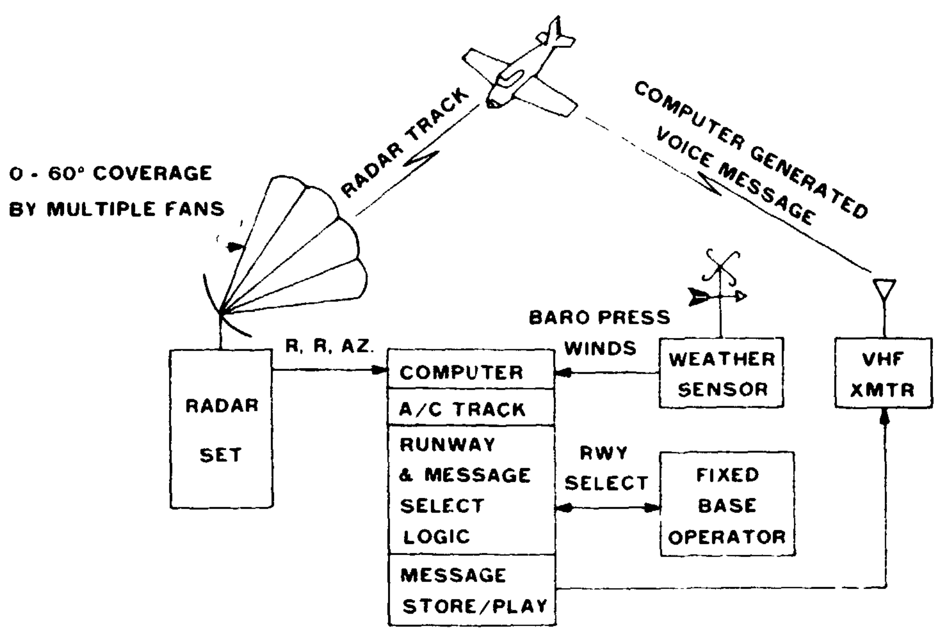


Figure 23.- Conceptual pilot advisory system.