Increasing Capacity by the Use of Optimal Runway Exits, Automated Landing, Roll Out and Turnoff in an Airport Environment

by

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(ABSTRACT)

This study outlines the development and use of several techniques providing an automated landing, roll out and turnoff of an aircraft, in an airport environment. A maximum runway occupancy time and a certain level of reliability are acheived by the use of a computer software called the Probabilistic Computer Model of Optimal Runway Turnoffs.

A bunching of eight optimal high speed exits, representing four TERPS categories, is performed on a single runway. Feasibility of the system is determined by the use of Inertial Navigation and other aids such as the Microwave Landing System, Filtering Devices, Electronic Cockpit Airfield Display Formats, Real Time Flight Simulation and Field Testing, and a Braking Guidance Policy. It is suggested that future testing and a review of the Model be done.

ACKNOWLEDGEMENTS

In view of the collaborative effort needed in the accomplishment of this work, heartfelt thanks are due to my family, friends and colleagues.

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CHAPTER 1 INTRODUCTION

1.1 AVIATION FORECASTS

The expanding demand of air transportation between 1971 and 1979 has led to compare the air transportation industry to an infant industry, growing at an exponential rate. The number of persons carried jumped from 174 millions to 321 millions in 8 years. US air passenger mileage was 4.3 billion passenger miles in 1944. In 1980, it grew up to 203 billion passenger miles (1).

The success of air transportation can be measured in terms of the overall increase of the domestic aviation activities since World War Two (2). In the United States, the Air traffic volume is expected to increase at a growing rate in the future. The Federal Aviation Administration (FAA) provides forecasts of the air travel activities which are summarized below for the years 1983 through 1994 (2&3).

1.1.Air carriers

- 5.1 percent annual increase in revenue passenger-miles

- 1.8 percent annual increase in air operations

- 4.6 percent annual increase in passenger enplanements

- about 60 percent increase in domestic load factor

1.1.2 Commuter carriers

- 5.8 percent annual increase in all fare paying passengers in scheduled domestic flights

- 10.2 percent annual increase in revenue passenger miles

- 8.4 percent annual growth in passenger enplanements

1.1.3 General Aviation

- 110 percent increase in the number of turbine powered general aviation aircrafts

- 48 percent increase in total number of general aviation aircrafts

1.1.4 Operations

- 5.8 percent increase of aircraft operations at FAA towers

- average annual growth rate by user groups are: general aviation, 4.9 percent; air carrier, 1.8 percent; commuter, 7.0 percent; military, 0.7 percent.

Figure 1 shows the historic trends of projections of world passenger movements.

1.2 THE PROBLEM

The number of airport operations in the United States has grown steadily during the last two decades. As of 1980, the FAA has published a report on the total aircraft and air carrier operations for annual and busy-hour traffic at selected hub and general aviation airports as shown in table 1.

As the table indicates, there is a need to accommodate the unprecedented growth in the demand for air transportation services, which are being stressed beyond the airports' design capabilities. This has caused a considerable emphasis on research to analyze the level and causes of capacity deficiencies. The FAA Advisory Circular (4) defines the concepts of capacity and delay as follows: "Capacity is the throughput rate i.e. the maximum number of operations that can take place in an hour. Delay is the difference in time between a constrained and an unconstrained aircraft operation".

This definition of capacity is referred to as the ultimate capacity, for an infinite queue. However demand is fluctuating and an airport capacity is influenced by other factors including FAA regulations, wake vortex turbulence, weather, airfield and airspace configurations, etc...

POSTWAR TRENDS IN AIR TRANSPORT

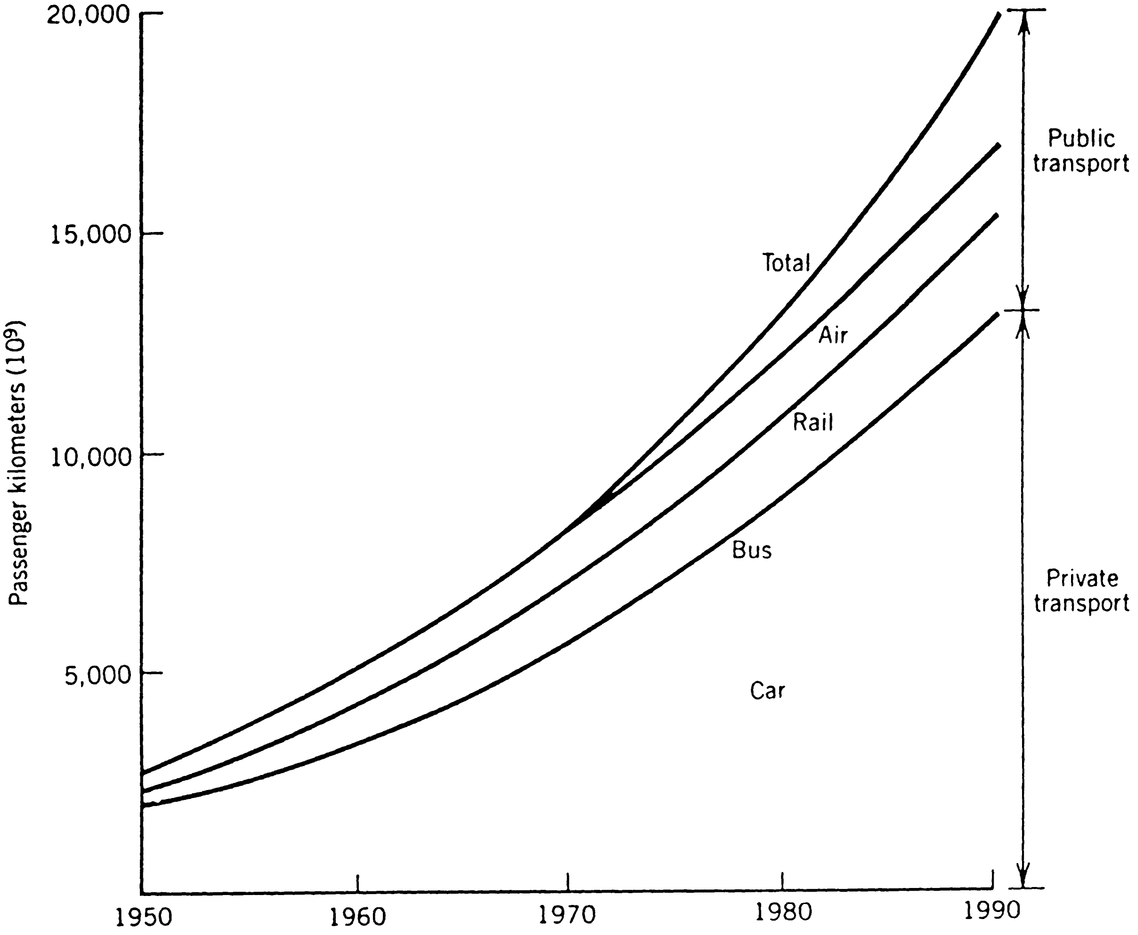


Figure 1. World Total Passenger Movements Distributed by Principal modes

(Source: Adapted from Reference 1)

Table 1. Annual and Busy-Hour Aircraft Operations at Selected U.S. Air Traffic Hub and General Aviation Airports, Fiscal Year 1980

(Source: Adapted from Reference 2)

Airport	Annual		Busy hour	
	Total	Air carrier	Total	Air carrier
Large hub airports:				
Chicago O'Hare International	734,555	577,671	178	141
Hartsheld-Atlanta Internatiomal	609,466	541,440	145	181
Los Angeles International	534,414	419,506	133	88
Denver Stapleton International	485,695	316,664	169	105
Miami International	376,820	283,457	111	84
Washington National	354,717	204,560	108	56
Boston Logan International	340,896	204,159	112	59
Medium hub airport:				
Memphis International	377,603	143,294	115	48
Salt Lake City International	285,104	83,723	155	27
Milwaukee-Mitchell Field	247,290	85,011	136	35
Portland International	219,404	75,827	107	37
Orlando Jetport	157,535	115,936	67	42
San Diego International	155,914	69,513	54	18
Greater Cincinnati	119,088	59,733	68	25
Small hub airports:				
San Jose Municipal	415,513	47,255	183	19
Daytona Beach Regional	292,534	15,030	164	9
Wichita Mid Continent	230,128	37,439	169	37
Sacramento Metro	170,733	36,749	106	20
Grand Rapids Kent County	167,922	27,334	126	11
Richmond Byrd International	163,998	33,813	75	17
Knoxville McGhee-Tyson	143,575	19,598	71	7
General Aviation:				
Fort Worth Meacham	400,722		284	
Pontiac	274,686		220	
Seattle Boeing Field	408,207		247	
Tamiami	422,867		236	
Teterboro	308,413		231	
Torrance Municipal	370,398		284	
Van Nuys	567,055		310	

The problem of how to increase capacity and minimize delay at airports can then be expressed in terms of time saved when the actual delay is reduced to an acceptable level. In 1980, the national cost associated with delay was estimated at 1.395 billion of dollars with an average delay of 5.9 minutes per operation (3). Table 2 shows the average delay per operation at some leading Air Carrier Airports. The average delay is the summation of delays during the four phase cycle. The four phases are: gate hold, taxi-out, airborne and taxi-in. Delay is common and becomes more critical during peak periods, when it can reach unreasonable values.

Then, the average delay an aircraft experiences per operation, in an airport system, takes place at different levels. It can be in the landing process, on the runway, on the taxiways or in the terminal area. Many techniques are available to minimize delay in the queueing system.

Even though airport congestion and delay problems are more likely to increase in major hub airports, aviation experts have predicted that no new major airport will be constructed in the U.S. for many reasons. Some of the major factors are (1) expensive land acquisition (2) strong community objections to the potential environmental pollution (3) lead time of at least a decade between inception and completion of the project.

Several issues are being addressed by NASA and FAA in an effort to increase the airport system's capacity. These issues deal with:

Table 2. Average Delay Per Operation at Leading Air Carrier Airports

(Source: Adapted from Reference 3)

(Minutes: Ranked by 1980 Delays)

Airport	1978	1977	1978	1979	1980
Atlanta (ATL)	8.85	10.61	10.11	10.81	9.46
New York (LGD)	9.35	8.20	9.34	9.76	9.31
New York (JFK)	10.75	9.99	11.14	9.76	9.25
Chicago (ORD)	9.09	9.30	9.67	10.17	8.89
Denver (DEN)	6.42	7.01	9.52	8.78	8.09
Boston (BOS)	6.60	7.49	6.98	7.90	7.15
St Louis (STL)	4.75	6.07	6.31	7.63	7.15
Los Angeles (LAX)	4.76	5.07	6.42	6.32	7.09
Washington D.C. (DCA)	6.22	6.82	6.67	6.74	6.41
Miami (MIA)	5.27	5.00	5.53	5.44	6.01
San Francisco (SFO)	5.42	4.95	4.62	5.22	5.89
Honolulu (HNL)	4.58	5.47	5.57	5.80	5.45
Dallas-Ft. Worth (DFW)	5.16	4.46	4.88	5.67	5.22
Houston (IAH)	4.19	4.13	4.93	5.42	5.17
Detroit (DTW)	4.13	4.67	4.91	4.74	3.99

- providing an efficient aircraft spacing, using the Microwave Landing System

- reducing the effects of wake vortex between small and bigger aircrafts

- upgrading the air traffic control

- optimizing the use of the facilities without degrading the system's safety

- introducing new techniques such as the high speed exit with automated landing, roll out and turnoff or the Brandt Drift-off

In that respect the National Aeronautic and Space Administration (NASA) has directed research and development programs in order to alleviate the problem previously stated. The programs have focused on several efforts. One of them is the high speed exit design with an early goal of maximum runway occupancy time of 40 seconds and an automated landing, roll out and turnoff (5&6).

The technique investigated in this study lies in increasing the landing capacity of the runway, airside/landside interface, and in decreasing the time separation between successive aircrafts in their landing approach with regard to FAA regulations related to wake turbulence. The minimum allowable horizontal separation is from 2 to 5 nautical miles (1).

The focus of this investigation is in the areas of optimal exit locations, the development of high speed turnoffs, the guidance of the aircraft by an automated curved path approach, landing, roll out and turnoff. These are studied as dependent solutions in increasing landing capacity.

1.3 RESEARCH OBJECTIVE AND SCOPE

The first part of this research is to slightly modify an existing computer software called the Probabilistic Computer Model of Optimal Runway Turnoffs (5) so that it can be run on the Personal Computer IBM PC XT in order to determine optimal exit locations on a single runway. An exit is said optimal for an aircraft when the maximum runway occupancy time is 40 seconds and the probability of making such an exit is 99.99 percent. The maximum runway occupancy time is the time elapsed between an aircraft crossing the runway threshold and its clearing of the runway edge along the exit path. At high speed, the wingtip is the part of the aircraft the most critical in clearing the runway.

Secondly, it is proposed a bunching of the optimal exit locations and path profiles, which would accommodate most aircraft mixes in a major airport environment. To cover the wide range of aircraft mixes, the four TERPS Categories A, B, C and D are used. The B 747 and Lockheed F 104 are added in the research to give an example of how a particular aircraft can fit in the design. The design must meet the requirements of time, safety and reliability.

The last part of the research is to perform a literature review on the Microwave Landing System and Guidewire Sensors, and the different components of the High Speed Exit Research that play important roles in smoothing and expediting the air traffic flow.

CHAPTER 2 AVIATION SYSTEM

2.1 AIRSIDE

2.1.1 Runway

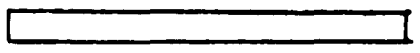
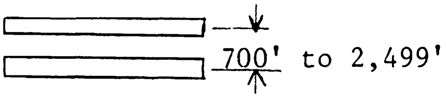
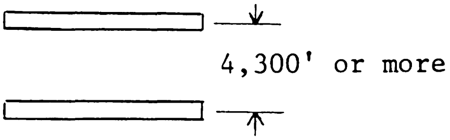
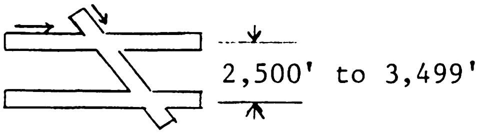
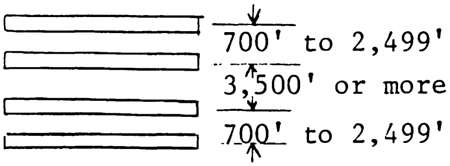
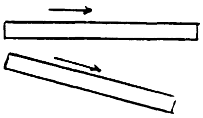
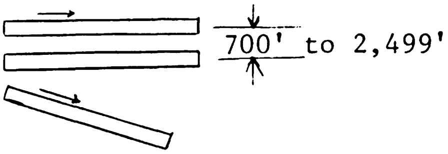
Many runway configurations exist, from the single runway to the parallels plus crosswinds R/W as shown in table 3. For the purpose of this study, it is used a single runway with different high speed turnoffs. In VFR its capacity is somewhere between 50 and 100 operations per hour; while in IFR, the capacity is reduced to between 50 and 70 operations (2). An operation consists of a landing, a take-off or a touch-and-go. The runway structural width is assumed to be 150 feet (5&6).

2.1.2 Taxiway

A taxiway connects the runway to the terminal building and service hangers. In cross section, it is similar in appearance to a runway. The dimensions are of course smaller. The usual procedure is to locate a taxiway parallel to the runway centerline.

Table 3. Runway Configuration Diagram

(Source: Adapted from Reference 1)

Configuration	Runway Configuration Diagram
A Single Runway	
B Dual Lane	
C Independent IFR Parallels	
D Parallels plus Crosswind R/W	
E Four Parallels	
F Open V Runways	
G Parallels plus Crosswind R/W	

2.2 TERMINAL AIRSPACE AND ENROUTE AIRSPACE

Terminal Airspace is commonly referred to as a distance of 25 to 50 miles from the airport; whereas the enroute airspace is comprised of the airways, jet routes and other parts of the airspace.

2.3 LANDSIDE

The landside is comprised of the terminal buildings and the vehicular circulation parking. It will not be an area of interest in this report. Fig 2 shows a diagram of the aviation system.

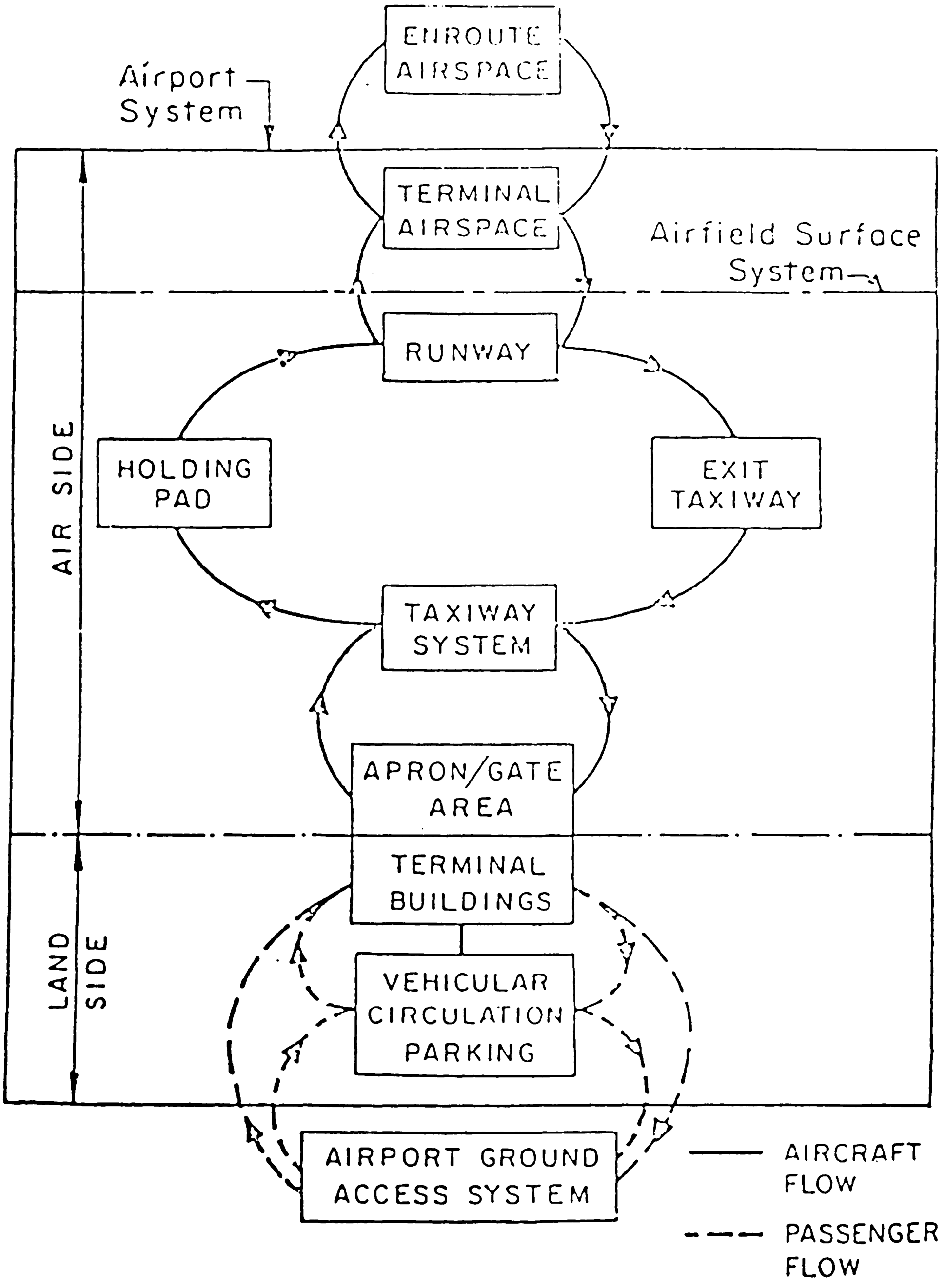


Figure 2. The aviation system

(Source: Adapted from Reference 16)

2.4 AIR TRAFFIC CONTROL

The control of traffic, arrivals and departures, from the boundary of the air traffic control tower to the limit of the terminal airspace, is under the jurisdiction of the terminal approach control facility. The air route traffic control centers have the responsibility of controlling the movement of aircrafts in the en route airspace.

The air traffic control system, which must accommodate the wide variety of airspace need in heavily trafficked areas, must meet the requirements of safety and efficiency. To be of value, this protection is to be achieved while capacity is increasing.

Visual Flight Rules (VFR) prevail when weather conditions are good enough and when traffic densities are low enough . The principle of "see and be seen" is generally accepted. However, when the visibility or the ceiling fall beyond the above limits, the Instrument Flight Rules apply. In the latter case, after some data are collected and processed, a decision is made and transmitted to the pilot to avoid air conflicts.

In the immediate area of the terminal,the landing operations require, in addition, the use of special navigation aids. These include the Instrument Landing System (ILS), Precision Approach Radar (PAR), the Airport Surveillance Radar (ASR), the Microwave Landing System (MLS).

2.4.1 Instrument Landing System (ILS)

ILS is the most widely used method as an approach and landing aid. The system guides the pilot by the use of two radio transmitters located in the airport. These radio transmitters are the localizer and the glide slope. Their function is to indicate to the pilot what his position should be, relative to the runway centerline, so that a safe landing can be achieved. In addition to the transmitters, two low power fan markers are located along the runway to inform the pilot of his closeness. Figure 3 shows a schematic diagram of the ILS.

But the ILS has some limitations:

- it is not completely reliable because the signals can be deteriorated by mobile and stationary objects

- it restricts the pilot in his landing approach, confining him in the airspace from many miles out

- it aggravates the queueing subsystem associated with the fix, for arriving aircrafts. The queue discipline is on a first-come first-served basis.

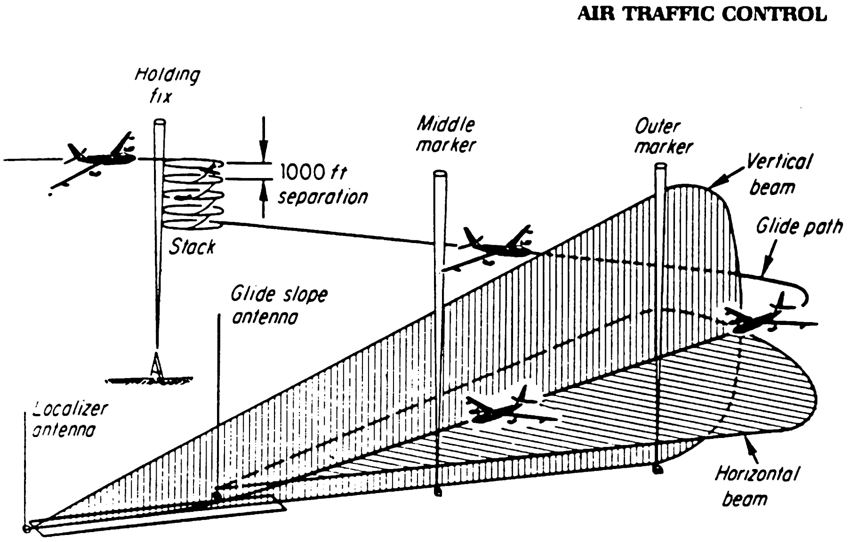


Figure 3. Schematic Diagram of the ILS

(Source: Adapted from Reference 2)

2.4.2 Microwave Landing System

The MLS which eliminates most of the problems present in the ILS is still at the testing age. Its coordinate system shown in Fig 4 uses conical coordinates of azimuth, elevation and range. A coordinate transformation is made to position the aircraft in the runway inertial system. Fig 5 shows a schematic diagram of the MLS.

The beam transmitted by the localizer is confined by a waveguide antenna and is less likely to be distorted. By providing a multitude of paths in space in the horizontal plane, within an angle of 120 degrees around the runway centerline, it also allows the pilot to approach the runway at a much steeper angle, up to 20 degrees in the vertical plane. At the same time, the use of higher frequencies increases the number of frequency channels available, over the many routes. Continuous information on the aircraft closeness to the runway is provided.

As can also be seen in fig 6, due to the flexibility of the system, the problems of wake vortex, aircraft separation and delay associated with the fix (ILS) are greatly reduced, and capacity is increased.

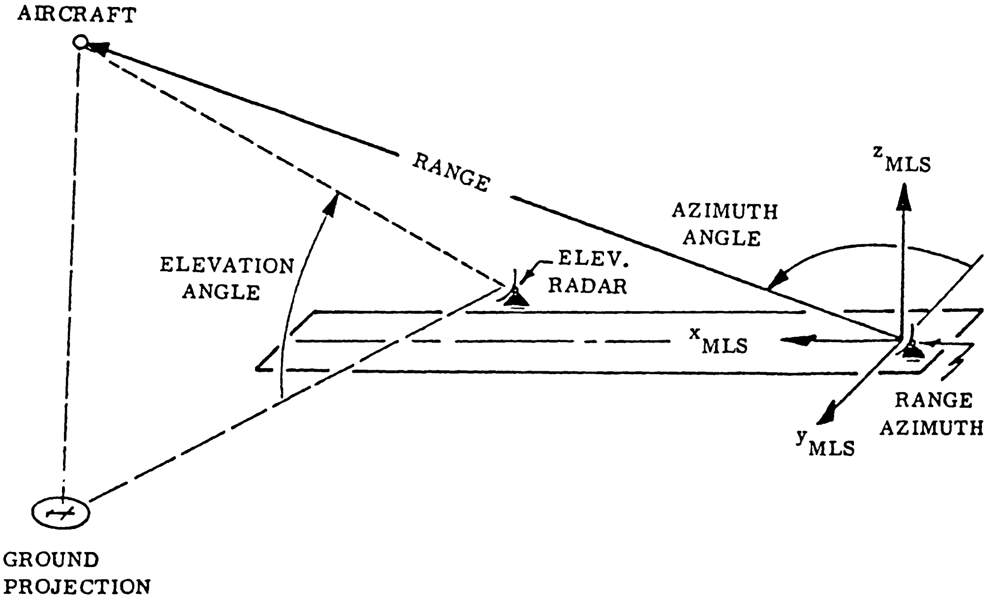


Figure 4. The MLS Coordinate System

(Source: Adapted from Reference 8)

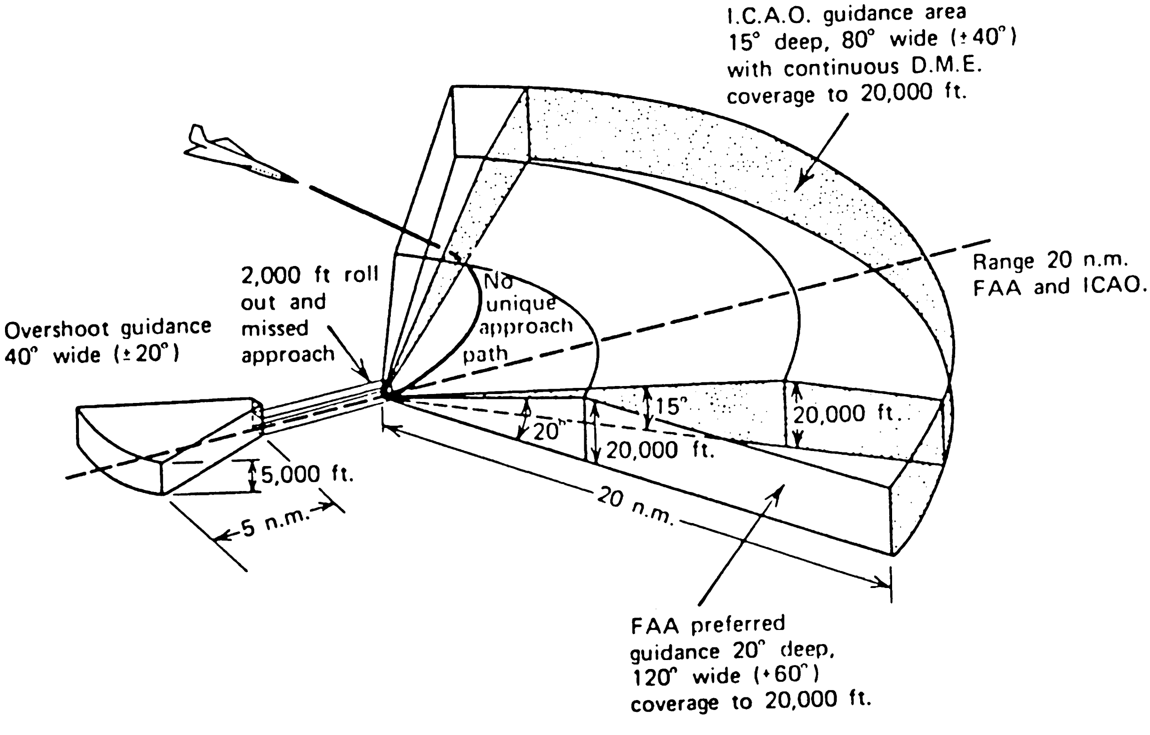


Figure 5. The Microwave Landing System

(Source: Adapted from Reference 1)

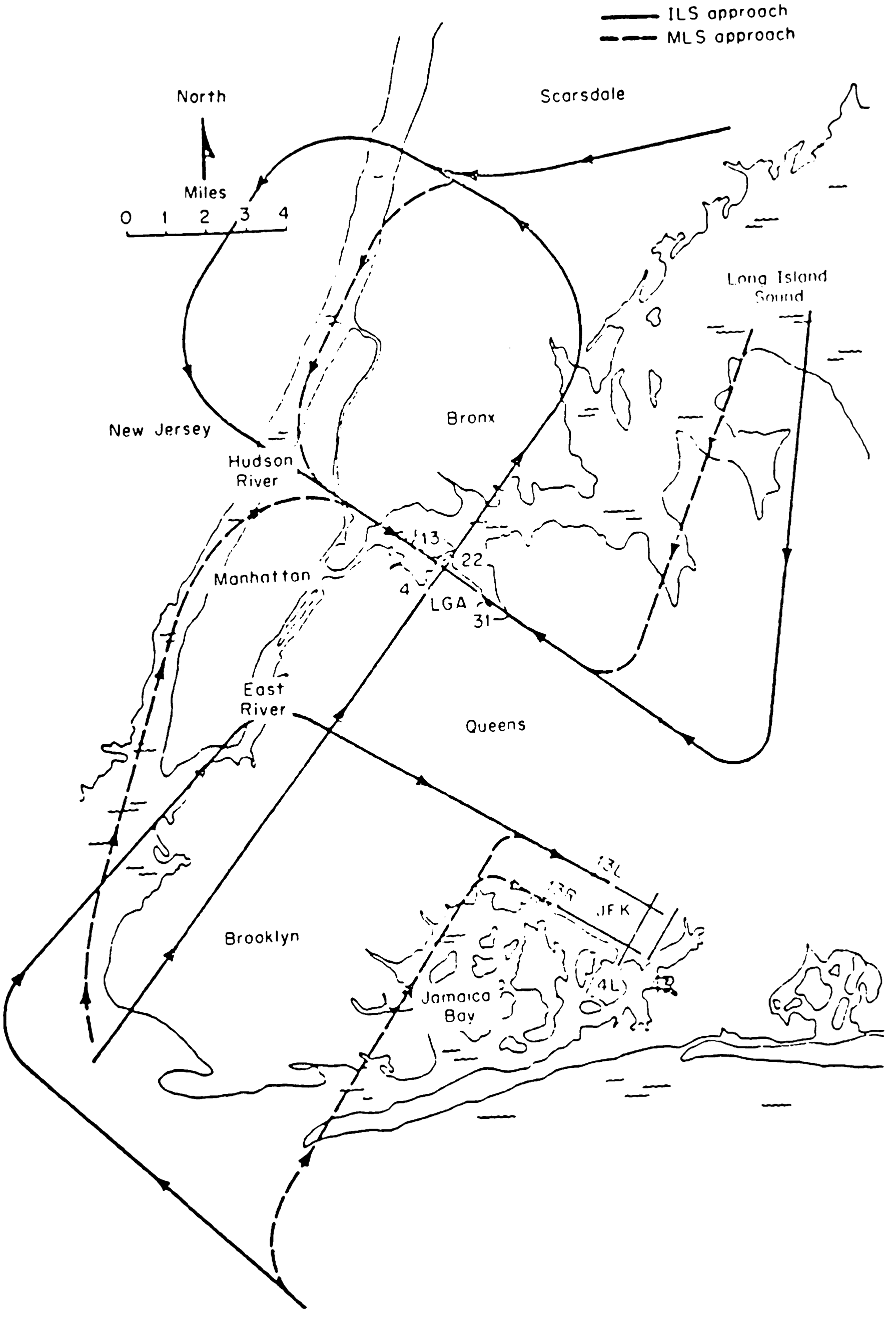


Figure 6. Differences Between an ILS and an MLS Approach to Kennedy (JFK) and La Guardia (LGA) Airports in the New York Area

(Source: Adapted from Reference 2)

CHAPTER 3 LITERATURE REVIEW

Research has started in the early 1950's and was mainly done through observations. Robert Horenjeff, a pioneer in this domain, has conducted field testing in order to determine the minimum permissible turning radius for different types of aircraft. The empirical work gives the cornering limits of an aircraft, as can be seen in fig 7. These results were validated by flight simulation and flight test data later by the Langley Visual Motion Simulation and at Columbia Airport, at speeds averaging 60 knots (10).

The literature review developed in this research has the purpose of identifying the important features related to the high speed exit feasibility.

3.1 MATHEMATICAL MODEL FOR LOCATING EXIT TAXIWAYS

Traffic handling capacity has been a concern since the 1950's. A team of Operations Researchers and Engineers got involved with the problem (9) and studied a Mathematical Model for locating exit taxiways in 1958 in order to determine the effectiveness in terms of acceptance rate. The results showed that "the optimal locations and the corresponding acceptance rates are quite sensitive to aircraft population, exit speed and number of exits".

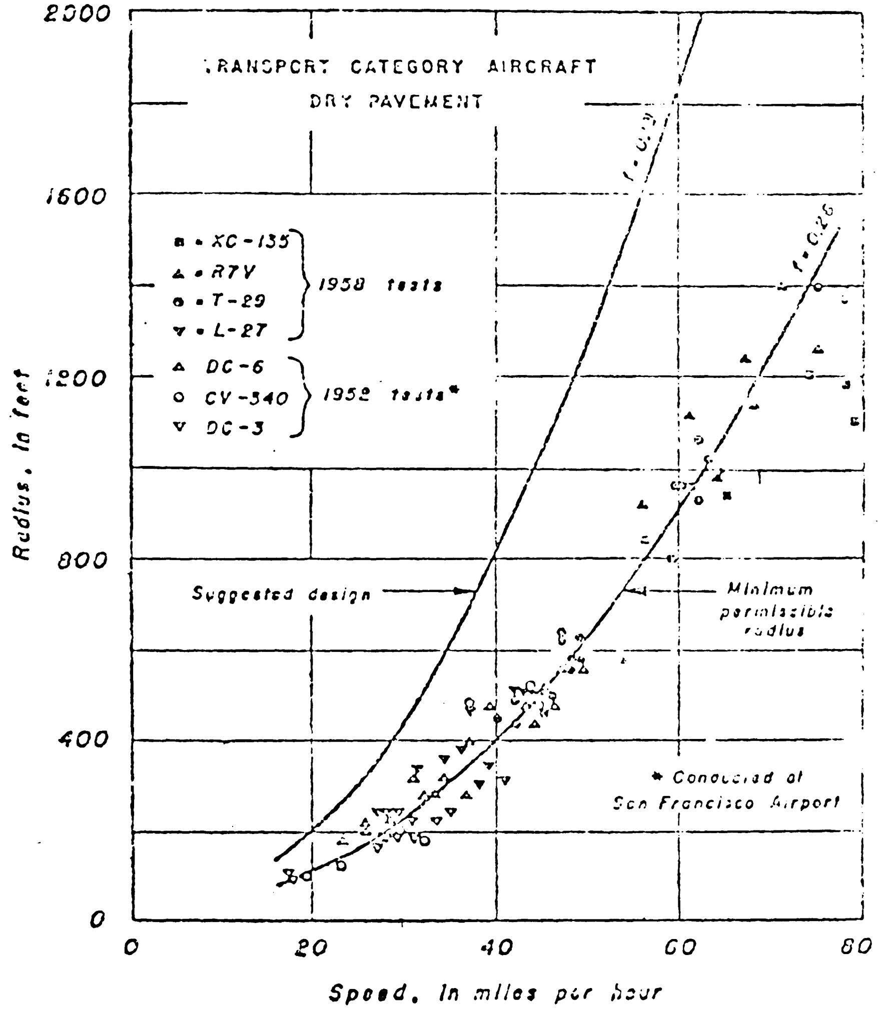


Figure 7. Raduis vs. Speed; Transport Category Aircraft; Dry Pavement

(Source: Adapted from Reference 6)

Due to the lack of data and avoiding over complexity, the mathematical model was oversimplified, assuming for example that:

- no accident would occur
- no change in environmental patterns
- fixed interval of time and distance
- fixed exit speeds of 40 and 60 mph
- fixed aircraft mix

The results were presented in the form of charts and graphs, or probabilities of wave off and optimization of acceptance rates. This approach can be somewhat controversial as said in the analysis of of results: "Suppose it is desirable to provide exits so that the runway could accept about 60 aircrafts per hour. In terms of acceptance rate, two exits would practically do the job (55.73 aircrafts). A third exit increases the acceptance rate to 59.87 aircrafts, a gain of only 4 aircrafts. If the designer bases his decision strictly from the view point of acceptance, the addition of a third exit might be difficult to justify. If, however, the percentage of wave offs is considered, the picture is somewhat different. For three exits, the percentage of wave offs is considerably lower than for two exits. This points to the facts that a prime justification for an additional taxiway may not be to increase the acceptance rate but to decrease wave offs".

3.2 AUTOMATED LANDING, ROLL OUT, AND TURNOFF USING THE MLS AND MAGNETIC CABLE SENSORS

A simulation program, which is proved to be both feasible and practical for commercial type aircraft in the terminal area control, is described in a NASA report (8). The report studies the landing approach, roll out and turnoff of the B 707-100, using the new inertial navigation aids and the present navigation aids in order to: "(1) investigate the compatibility of existing autoland guidance laws utilizing a Microwave Landing System in place of the conventional Instrument Landing System navigation aids during landing approach; and (2) to expand the concept of automated flight to roll out and turnoff for reduced runway occupancy time during normal and adverse landing conditions."

For more accurate results, a magnetic cable is buried in the runway and the aircraft is equipped with three coil magnetic pickups to correct for errors. In addition, a Kalman type filtering and a fixed gain complementary filtering are induced in the model to correct for error sources generated in the simulation run by a computer program called ALERT. The error sources include gyro drift, accelerometer and sensor aid biases, etc....

3.2.1 Description of the Simulation Model

A coordinate transformation of the aircraft is made from the rectangular coordinates to the three-unit-body-axes vectors in terms of the Euler angles of roll, pitch and yaw, from magnetic north, as shown in figures 8, 9 and 10. Then the aircraft forces and moments are calculated using the equations of motion in respect to constant wind, gust and wind shear vectors, and friction and rolling coefficients, during the different phases of landing, roll out and turnoff.

The main forces on the so called aircraft stability axis system (a1 a2 a3) are the lift, the drag and the side forces. The estimated aircraft position in the body and runway frame, called "dread reckoning" are first corrected by the Kalman filter which uses an a-priori statistical technique. Then a second fixed gains complementary filter is applied based on the observation residuals.

3.2.2 Navigation and Kalman Filtering

The aircraft is equipped with a computer which monitors acceleration gyro rates. It is reported that "past experience has shown that the square root implementation of the optimal filter algorithm can reduce the effects of numerical errors to insignificant levels. The square root implementation is therefore incorporated in the proposed design. Modeling errors

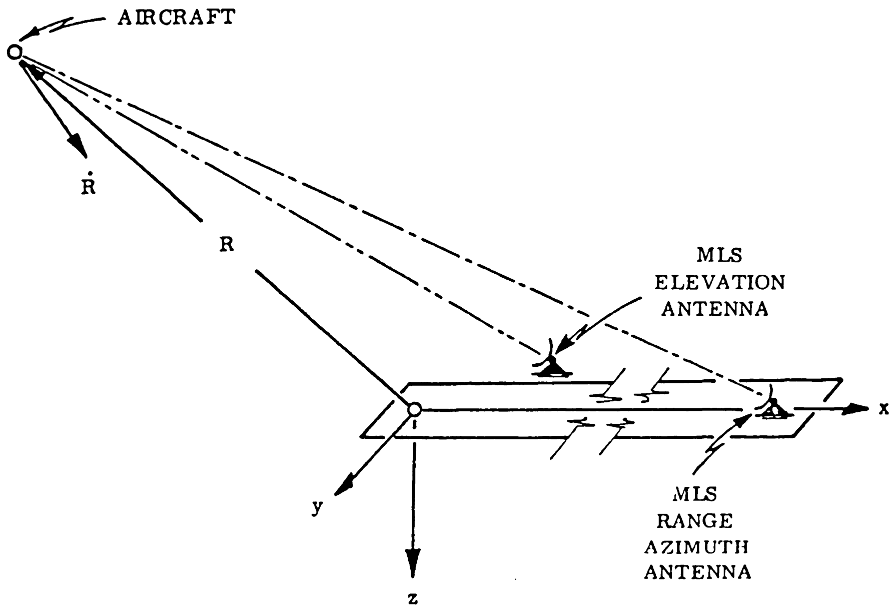
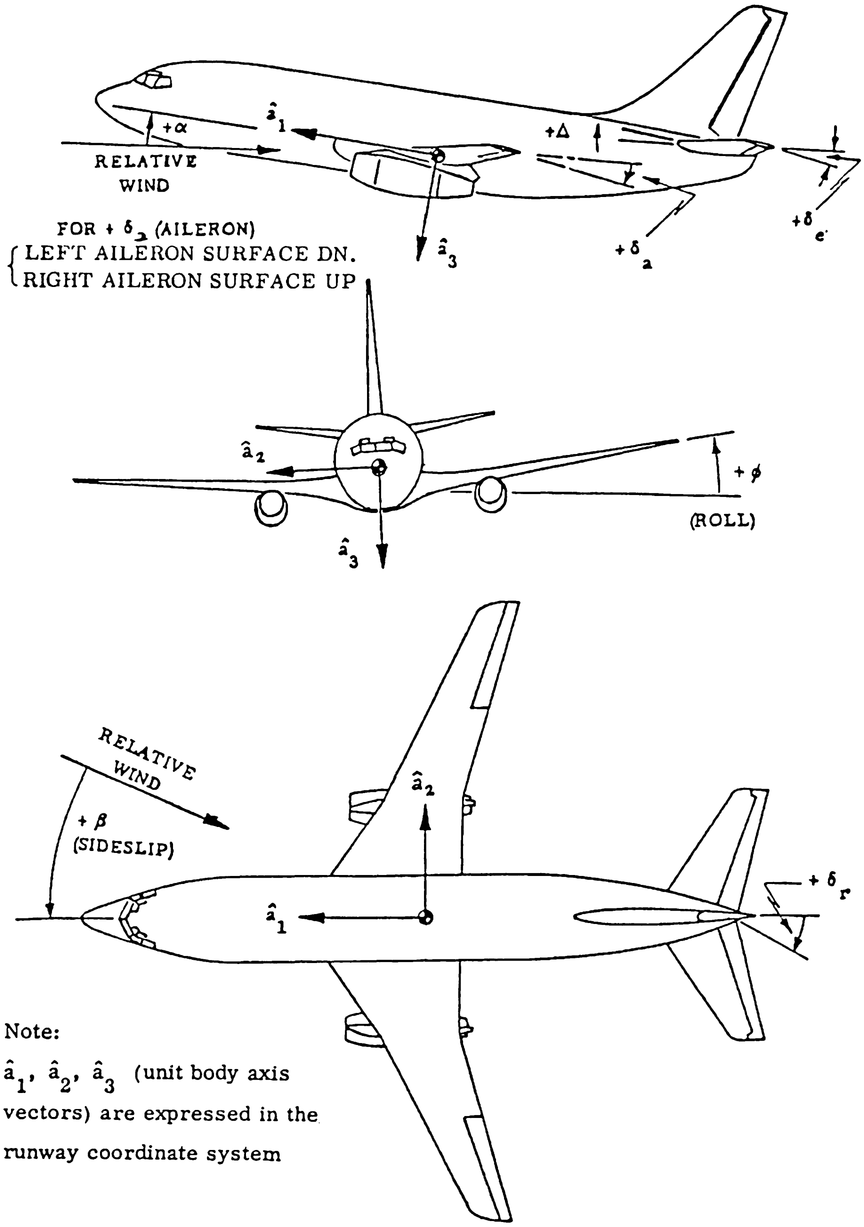


Figure 8. Runway (Inertial) Coordinates and Aircraft Position, Velocity Vectors

(Source: Adapted from Reference 8)



Note:

$\hat{a}_1$, $\hat{a}_2$, $\hat{a}_3$ (unit body axis vectors) are expressed in the runway coordinate system

Figure 9. Aircraft Body Coordinate System, Control Surface Deflections, and Aerodynamic Angles

(Source: Adapted from Reference 8)

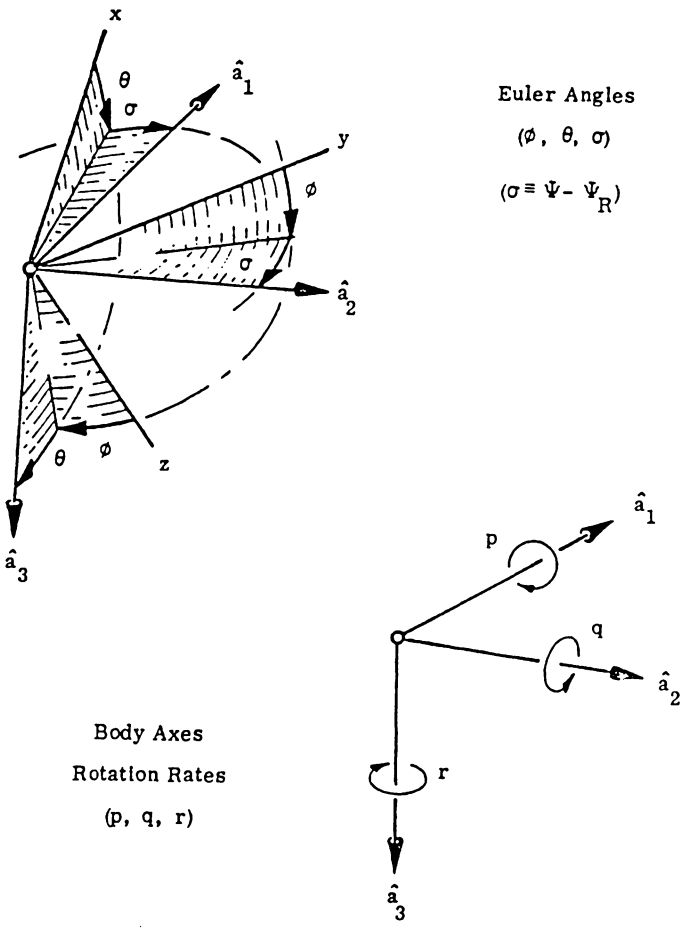


Figure 10. Euler Angles and Rotation Rates Defined

(Source: Adapted from Reference 8)

are compensated for by the appropriate use of random forcing functions. This technique causes the more recent measurements to be weighed higher than past measurements; therefore the estimates tend to follow the more recent measurements."

An error state vector of 15 variables is used. It consists of errors in position, velocity, vertical accelerometer scale factor, horizontal wind, biases in observables and gyro drift rate. The Kalman filter updates are every second for the aircraft coordinates and .05 second for the dead reckoning estimates. The accelerometers and gyros, the observations, and the filter are sampled respectively at rates of 20, 10 and 1 Hz. The error rate is assumed to obey a linear differential equation.

3.2.3 Complementary Filter

It is reported that "A complementary filter can be designed to provide a set of non varying gains, without any relationship to the uncertainty in the aircraft state or the biases in the INS and MLS measurements. By adjusting the complementary filter gains to pass the relative low frequency of the true aircraft acceleration, it is possible to filter out the high frequency noise in the MLS measurements. The main criteria for such a filter is to provide a stable estimator, one that decays disturbances exponentially and let the low frequency motions persist."

It is also noted that "the complementary filter provides no corrections to the errors in the estimates of aircraft altitude due to gyro drift or the position errors due to MLS biases".

3.2.3 Magnetic Leader Cable Sensors

There is a need of a navigation sensor aid to correct for multipath distortion and other biases still present in the MLS, upon touchdown. A single magnetic leader cable is embedded along the runway centerline. Then, a magnetic field is created by a detector to generate voltage. The detector consists of three (3) coils mounted as shown in figure 11. The 3 induced voltages are used to correct the yaw and lateral displacement errors.

Nevertheless, few distortions are still present; but, they remain in a narrow range of plus or minus 2 ft. They are due partly to ground conduction increasing with the presence of steel, and non-linearity.

Such navigational aids as Vortac Range and bearing devices, and a baro-altimeter are used for navigation between way points away from the terminal area. The relatively large bias they produce need only be corrected by a kalman filter for the purpose they fulfill.

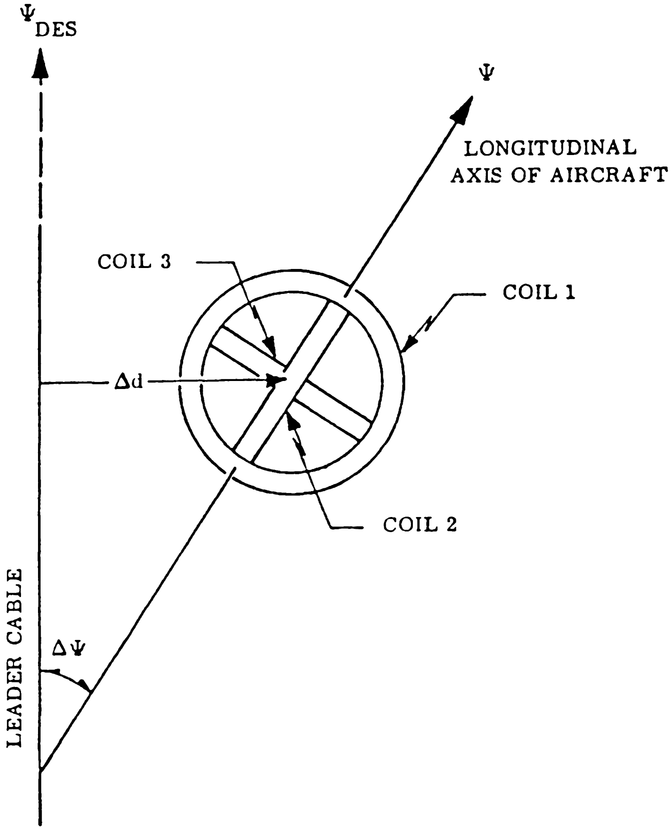


Figure 11. Magnetic Leader Voltage Signals

(Source: Adapted from Reference 8)

3.3 TERMINAL AREA AUTOMATIC NAVIGATION, GUIDANCE, AND CONTROL USING THE MLS

In an effort to reduce runway occupancy time, an automated uniform braking and reverse thrust guidance policy is modeled for dry and wet runways. Different aids such as the inertial navigation system, the MLS and the buried magnetic cable leader, aircraft sensors, and modern digital computers are used so that landing, roll out and turnoff can be executed more precisely and at a very short period of time.

Under the effects of drag, reverse thrust and braking, the deceleration of an aircraft can be expressed mathematically (12). Closed loop guidance laws for braking and reverse thrust are used as functions of the landing speed, the desired taxi speed and the distance to go. Braking is used as a modulating feedback device in coordination with the reverse thrust to achieve the desired deceleration. The ground rule is "to decelerate mainly with reverse thrust using modulated braking for fine control and using nominal breaking only if the maximum specified reverse thrust cannot decelerate the aircraft to the specified exit".

The desired reverse thrust is calculated and additional brake deceleration is computed depending on the runway conditions. Tire skidding is taken into account by brake limitations for wet runway conditions. For dry conditions, braking is limited to prevent excessive tire wear. Hydroplaning is also checked by computing the speed at which it occurs. It is given by the following formula:

Xh (knots)= .9 * tire pressure

A steering guidance logic is also incorporated to track the aircraft through straight line segments, circular segments and centered parabolic segments.

However certain types of errors occur. Continuous measurements of acceleration are provided by body mounted accelerometers. These measurements are noisy and are subject to errors (misalignment and scale factor errors). They can be filtered by using methods described earlier.

It is said that "upon touchdown the major error source in the aircraft position is the down range position error due to the MLS range bias which cannot be removed by filtering. The range bias produces errors in the guidance signals which result in large tracking errors during the turn. To eliminate this error source we recommend that the aircraft should receive a short radio blip signal as it passes a known position along the runway during roll out. By correcting the X coordinate to the known runway position, the offset problem disappears and good turnoff may be realized".

During the simulation runs, a sensitivity study of the Langley TCV B 747 aircraft was made by varying numerous factors. It is concluded that "In general, runway occupancy time can be significantly reduced by use of automated roll out and turnoff capability. The aircraft can be clear of the runway within 20 sec for dry runway and 30 sec for wet runway".

It is recommended that roll out and turnoff guidance laws be investigated to reduce cross track errors due to wind and that "slow in" logic be also investigated to ease the onset of turn acceleration".

3.4 ASSESSMENT OF AN ELECTRONIC COCKPIT AIRFIELD DISPLAY FORMAT FOR AUTOMATED RUNWAY EXITS

Experiments have been made to monitor the automatic landing, roll out and turnoff, and to track an aircraft along an exit path. The experiments consist of a real time flight simulation displaying the aircraft dynamic characteristics in the system, in the cockpit.

It is said that (11) "considerable research and development have brought electronic type air navigational display concepts to applications (DC 9-80, 1011, B 757 aircrafts), but the Category 3 (c) (zero ceiling, zero runway visual range) landing and exit capability has yet to be put into practice".

The Automatic Microwave Landing System/Guidewire System provides the aircraft coordinates and it is displayed in the aircraft cockpit the Automatic Turnoff Predictor (ATP), the Critical Distance Predictor (CDP) and the Breaking Distance Predictor (BDP).

As their names indicate, the CDP is the critical point on the runway where the aircraft should be to reach a given velocity at exit, at maximum deceleration rate. It is noted that maximum deceleration is federally certified on the basis of wheel braking, only. The BDP projects the point in the runway where the exit velocity will be achieved if the breaking rate is fixed. The ATP assigns the pilot an exit number.

Displaying all these informations in the dynamic electronic cockpit allows the pilot to read the data provided and to take his own decision after correcting for weather conditions. This illustrates the independence of the display logic. During the observations, the ATP was unavailable to the pilots. The procedure provided an adequate validation of the model.

Reliability of the design could be expressed in the following terms: "the assessment process was primarily qualitative based on the credibility which the pilots found in the displayed information and confidence that the displays communicated navigation information useful for zero visibility runway maneuvers".

Two basic test plans were used: the Chronodrasic Aided Limit Turn Vector Display (LTVD) and the Spatiumdrasic Aided Display. The Chronodrasic display provides the pilot with a matrix of exit conditions depending on the exit velocity; whereas the Spatiumdrasic display used the Glide Path Intercept Points. The Boeing Chronodrasic Monitor uses a proprietary time critical algorithm. Zero time is indicated on a clock device when the required exit velocity cannot be reached and the aircraft has to take another exit. The Spatiumdrasic Monitor uses a distance critical algorithm. The critical distance concept takes into account the Limit Turn Vector Display.

Reliability of the system was measured by the prediction success rate and the relative pilot confidence number. Four research pilots were selected to fly the Terminal Configured Vehicle (TCV) flight simulator. These tests were said to be feasible and encouraging as noted in the concluding remarks "Real time flight simulation tests of landing, deceleration , turnoff, and exiting taxi maneuvers in zero visibility conditions have demonstrated the feasibility of cockpit CRT type displays as monitors for automatic ground navigation systems. Automatic ground guidance and control algorithms, displayed runway surfaces, ground navigation and maneuvering information, and critical decision making features were integrated into a comprehensible cockpit display format which resulted in significantly encouraging research pilot's confidence in zero visibility ground operations. The Limit Turn Vector Concept was found effective for monitoring turns and the distance-referenced turnoff prediction symbology was favored by the research pilots over the time-referenced format. Further ground navigation displays testing is required in order to obtain additional piloting experience with the formatting under all surface conditions and to assess display effectiveness during manual reversions".

Other aiding symbologies such as braking status and digital display of ground speed, planed exit velocity and map scale are incorporated in the simulation model.

3.5 ASSESSMENT OF HIGH SPEED RUNWAY EXIT MANEUVER SMOOTHNESS

Ernest W. Millen (9) researching on the Assessment of High Speed Runway Exit Maneuver Smoothness stated that "the study showed that the use of large, constant radii entrance curves need not be constrained by a rapid onset of lateral acceleration at high speeds; however, maneuver smoothness could be improved by the use of non-circular, hyperbolic-type exit paths. The test data also validated an extrapolation of the Horenjeff minimum permissible radii-criteria for narrow-body, transport- type aircraft on ungrooved, dry pavement".

The approach consists of investigating the increase of exit velocities instead of optimizing the braking capabilities of the aircraft which would result in the drastic increase of the maintenance cost of the air carrier fleet. However concern must be given to the effect of adverse surface responses and smoothness of turning maneuvers. An indication of the smoothness of a turning maneuver is achieved by measuring the intensity of both lateral acceleration and lateral jerk, and by counting the number of jerks.

Lateral acceleration is a function of the mass, ground speed and turn radius of the aircraft. It also varies along the exit path profile from zero to some value. Jerk is a product of the rate of change of lateral acceleration through onset as perceived by the aircraft passengers.

Field tests were made using the Transport Systems Research Vehicle (TSRV), a narrow-body jet type transport. It is a sophisticated aircraft equipped with electronic devices and operating at exit speeds ranging from 30 to 90 knots. A real time flight simulator was also used. Even though early studies have been made on assessing passenger comfort in the field of rail and road transportation since the 1960's, there is much to be done about an aircraft using a high speed runway exit. Lateral jerks are reported to be perceptible at 0.03 g/sec and comfortable up to .07 g/sec by approximately 90 percent of train passengers. Acceptable longitudinal jerks caused by normal braking reach the value of 0.3 g/sec for train passengers facing forward or backward, while emergency braking jerks extend the acceptable level to 3.-4. g/sec.

Only one researcher, Hirshfeld, documented empirical data relating human responses to combined acceleration and jerk values. The scale was called an "Index of Disturbance". He acknowledged that "although the work was based upon a particular position, he felt that it would apply to other positions as well".

No experimental lateral jerk data were found in the extensive aeronautical literature reviewed. The following algorithm derived from rail transportation is proposed:

G/Gmax + J/Jmax = 1, where

- G= lateral acceleration
- Gmax= maximal permissible G value (.12g)
- J= lateral jerk
- Jmax= maximum permissible J value (.055g/sec)

3.6 LANDING GEAR FRICTION CHARACTERISTICS

The decelerative forces normally developed on the aircraft during landing, roll out and turnoff are generated from reverse thrust, drag and wheel brakes. As shown in figure 12, the major force is from the application of brakes. At speeds above 80 knots, aerodynamic drag and reverse thrust play an important role.

But with the introduction of modern aircrafts, an autobraking system is made available by the use of avionics equipment. This system provides a constant deceleration rate by using different combinations of the decelerative forces. However a conservative deceleration rate was used (5) to determine the optimal exit locations.

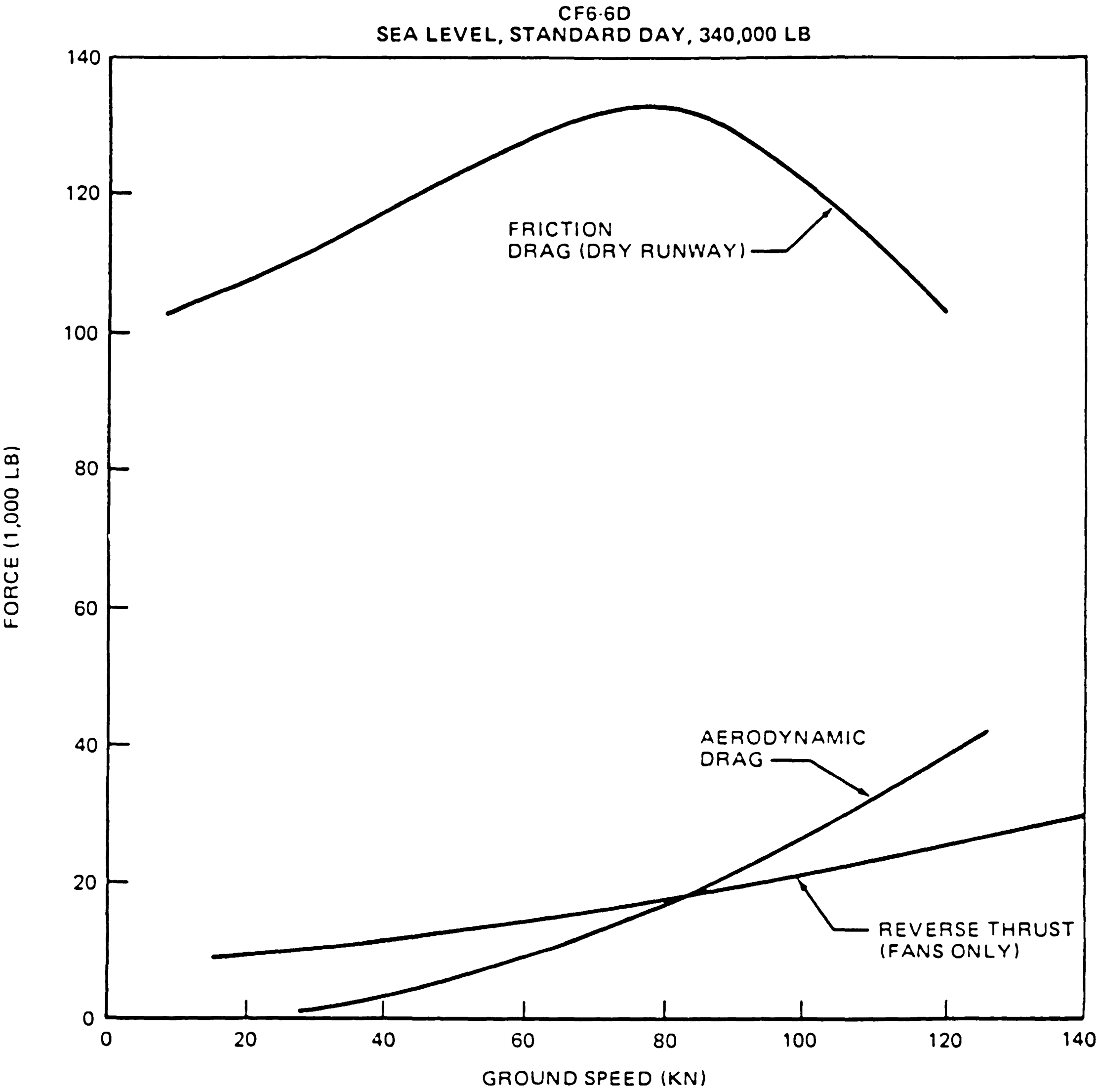


Figure 12. Summary of Airplane Forces during Landing Ground Run-Model DC 10 Series 10

(Source: Adapted from Reference 5)

It has been shown from an Aircraft Accident Report (13) that: "optimum braking force is achieved when the aircraft's wheels are rotating at a speed about 8 to 10 percent slower than a free wheeling tire would rotate"; and that "after the airplane lands, however, the aerodynamic surfaces continue to produce some lift, which balances a percentage of the weight and thus reduces the braking force. The extension of ground spoilers, the application of reverse thrust, and subsequent deceleration of the airplane will reduce the lift and increase the effective weight of the airplane acting through the tire to the runway thus increasing the braking force which can be generated etc.... The runway coefficient of friction and thus the braking coefficient which an airplane can develop after landing are significantly reduced if the runway surface is covered with standing water, snow, ice or any combination of such contaminants".

As the stability of the aircraft during touchdown and roll out can be expressed by the ratio: side load on nose gear/vertical load on nose gear, called its Cng, a comparison to the available ground coefficients of friction leaves the pilot with a margin of 2 against skidding on wet surface and a margin of 4 against skidding on dry surface (5).

It is also noted that "low weight and aft center of gravity are the most critical. Aft center of gravity results in the least weight to the nose gear. Both rotational inertia and main gear turning resistance remain fairly high at low weight".

3.7 BRAKING OF AN AIRCRAFT TIRE ON GROOVED AND POROUS ASPHALTIC CONCRETE AND ON PORTLAND CONCRETE CEMENT

Conrcern should be given to the danger of hydroplaning, which increases at high speed, particularly at touchdown, on a water covered runway. Dynamic and viscous hydroplaning are predominant at the tire-runway interface in the presence of water. Different techniques are used to relief the fluid viscous pressures in both cases. One efficient solution lies in using transverse runway grooving and micro textural aggregates. Figure 13 shows the effects on tire wear and braking performance for different runway conditions.

A series of tests have been conducted to show the effects of the surface treatment on the breaking performance of an aircraft tire (14). It is proved in a two phase experimental program over a speed range from 70 to 150 knots, that in a portland cement concrete surface, "the conventional saw-cut grooves spaced at 3 inches or less will provide "acceptable braking performance"to an aircraft tire on water covered runways, and the installation cost of the 3 inch spaced grooves could be 25 percent less than that of the installation cost of grooves spaced at 1 1/4 inch. The results further showed that the reflex-percussive grooves, an alternative to conventional saw cut grooves, provided sufficient braking to allow an aircraft to stop without experiencing hydroplaning".

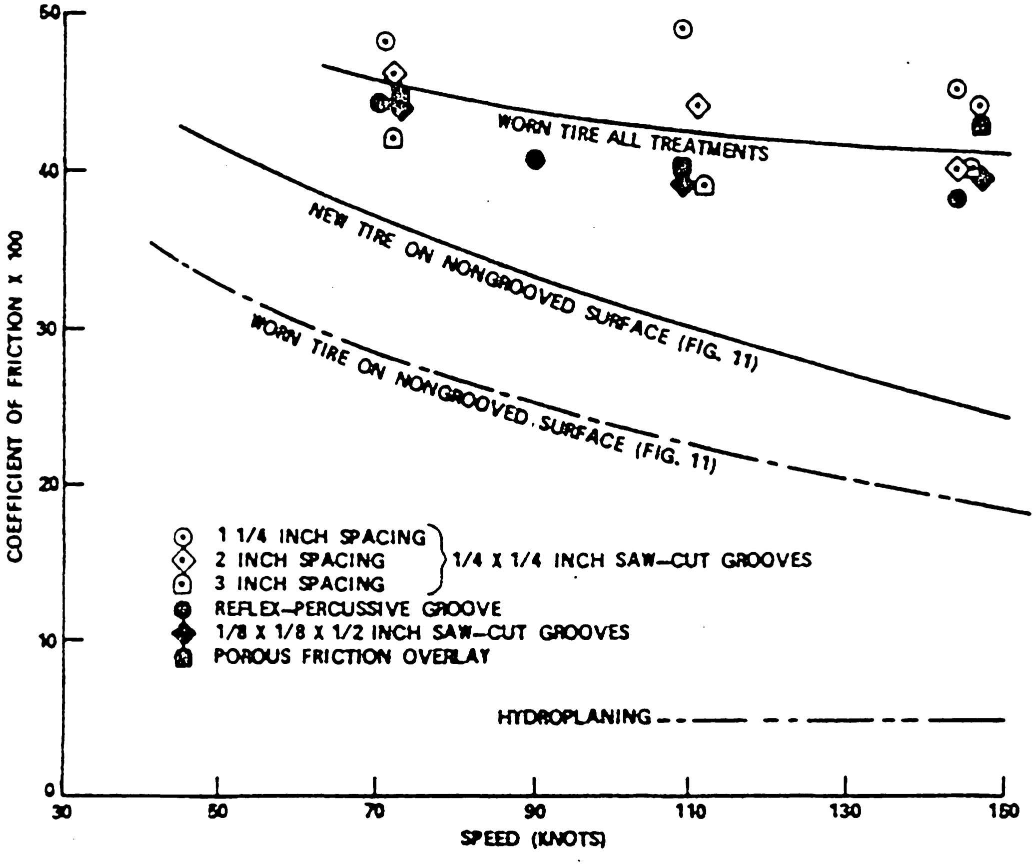


Figure 13. Braking Performance of a Worn Tire on Wet Surface

(Source: Adapted from Reference 14)

On the other hand, on asphaltic concrete surfaces, it was showed that: "the reflex-percussive grooves, the porous friction overlay and the conventional saw grooves spaced at 3 inches perform comparably. The closely spaced conventional saw-cut grooves are desirable where the seasonal and topographical conditions consistently produce "puddled" water conditions on the runways. The "puddled" conditions represent average water depth of approximately 0.10 inch".

3.8 TAXIWAY GUIDANCE AND CONTROL SYSTEM

Confusion is of primary concern if a certain degree of reliability is to be achieved during the process of exiting. The problem becomes more acute when poor visibility conditions prevail. A state-of-the-art (15) Survey has focused in that and has reached the same conclusions of the Visual Aids Panel, in 1966. It is recommended that green exit lights be used along the runway centerline as it was first introduced in the Gatwick Airport of London in the late 1950's. The recommendations also included a 50 foot spacing for simulated visibilities of 200 feet and more.

The guidance element should provide information which enables the pilot to expeditiously exit the runway. He should also be directed by the air traffic controllers to follow a designated route by visual means, without using oral instructions transmitted by radio.

The need of such warnings was demonstrated by some flight tests in fog an was expressed by Charles A. Douglas (15): "As a result of the problems encountered during flight tests conducted in visibilities as low as 300 ft, the Landing Aids Experiments Station recommended that "taxiway markings be devised and standardized to give a prewarning of turns and intersections"".

The research recommended also that "the type L-829 designed for use both as directional signs and as intersection locators..., were required to be at least at a distance of 500 ft. However, these signs are so large that they cannot be placed sufficiently close to the runway edge to serve as exit locators".

CHAPTER 4 PROBABILISTIC COMPUTER MODEL OF OPTIMAL RUNWAY TURNOFFS

In the attempt to reduce runway occupancy time for landing aircrafts, NASA/Langley conducted a contract with MC Donnel Douglas Corporation (5). A goal was set for the purpose of optimizing a high speed turnoff under the constraints of time and reliability allowing a maximum occupancy time of 40 seconds and a reliability of one miss for 10000 landing aircrafts. A model has been developed and is comprised of two parts: (1) a main program defining an optimal exit location, an exit speed and a probability of making such an exit; (2) a subroutine tracking the aircraft along an optimized compound-curve exit path.

The model contributes in increasing capacity. FAA regulations prohibit that an aircraft be allowed to operate on the runway when it is occupied by a landing aircraft. A good parameter of the runway occupancy time and its related standard deviation provides the best tool to the air traffic controllers to schedule aircraft spacing in the terminal airspace.

Therefore, a maximum runway occupancy time is preferred to an average runway occupancy time due to variations. Compared to the present day situation of 40 to 50 landings per hour, the application of the model, allowing 90 landings per hour, represents a very substantial increase of 80 percent in landing capabilities.

4.1 DESCRIPTION OF THE MODEL

4.1.1 Main program

After reading the data input, the program computes sequentially, the following:

- distances A and B
- speeds during landing at B and C
- standard deviations of the speeds at A, B and C
- occupancy times at A, B and C
- distances A, B and C for aircraft travelling one standard deviation below the average
- speeds at A, B and C for aircraft travelling one standard deviation below the average
- occupancy time at A, B and C for aircraft travelling one standard deviation below average
- specification of arbitrary speed range

- probability associated with speed range
- discrete intervals of speed range
- probability of exiting
- discrete probability and cumulative probability
- minimum occupancy time
- initialization of arbitrary occupancy time
- Z values of occupancy time (Normal distribution assumed)
- interval midpoints
- discrete probability and cumulative probability
- average runway occupancy time
- average runway occupancy time + 3 times its standard deviation
- percent aircraft exiting
- average speed at exit

4.1.2 Subroutine Expath

It tracks the aircraft from the beginning of the turn to the clearing of the runway, based upon the speed at exit calculated by the main program and the Path data. It performs the following steps:

- computation of X and Y coordinates of the aircraft at 1/1000 seconds along an optimized exit path, the shortest path with which sliding doesn't occur

- checking for the aircraft performance limits

- time at which the aircraft clears the runway edge after exiting

A flowchart of the probabilistic model is shown in table 4.

Table 4. Flowchart-probabilistic runway turnoff model

(Source: Adapted from Reference 5)

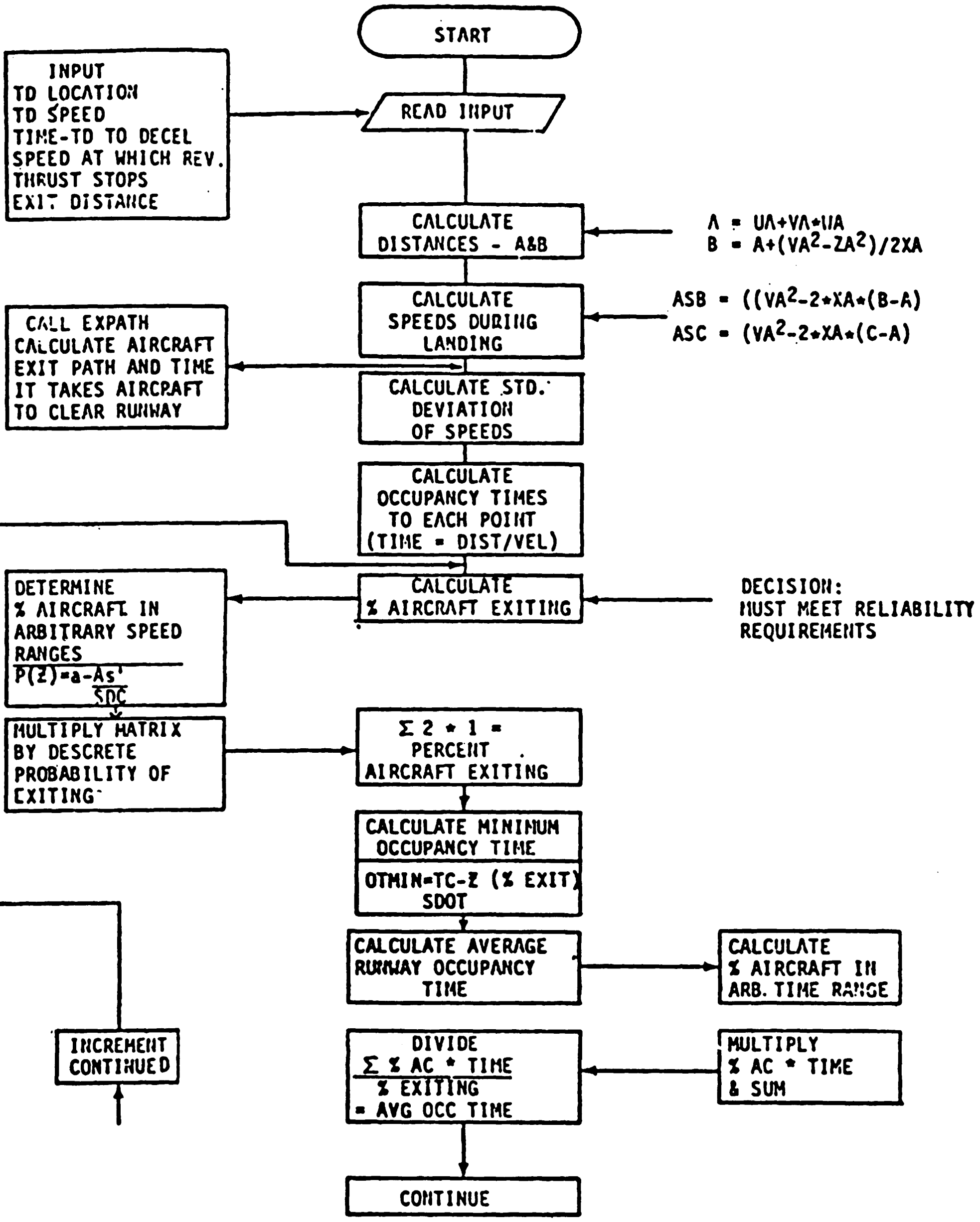


Table 4. (continued)

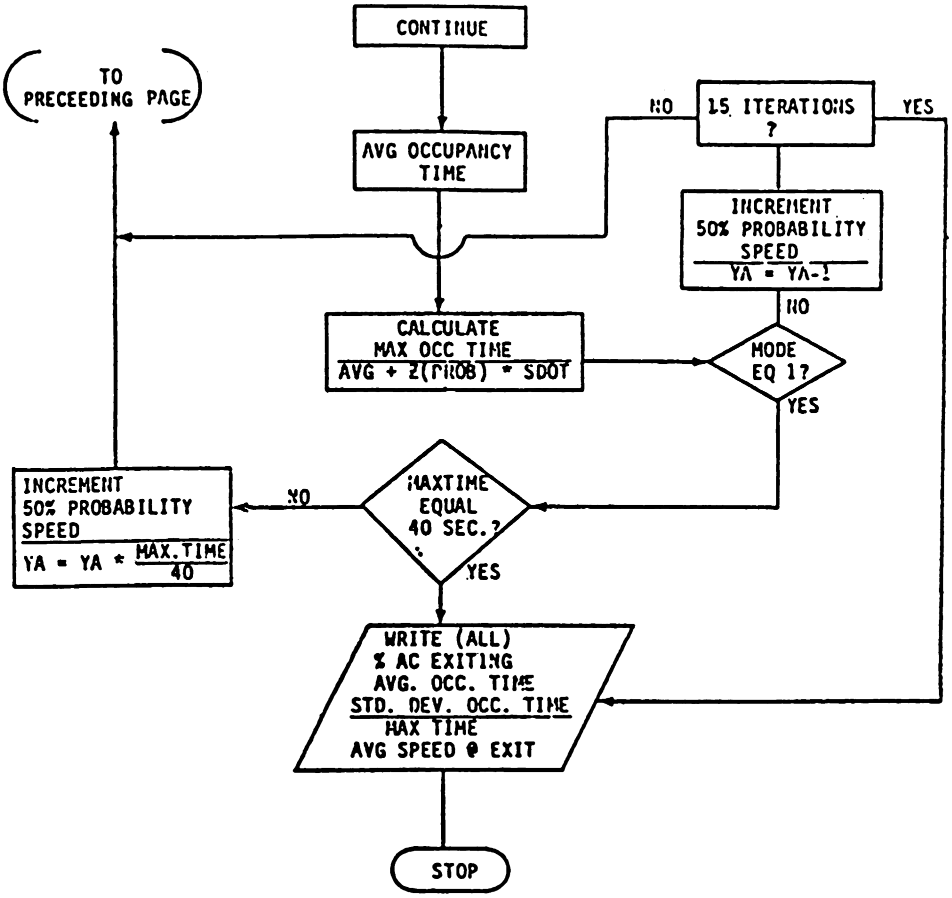
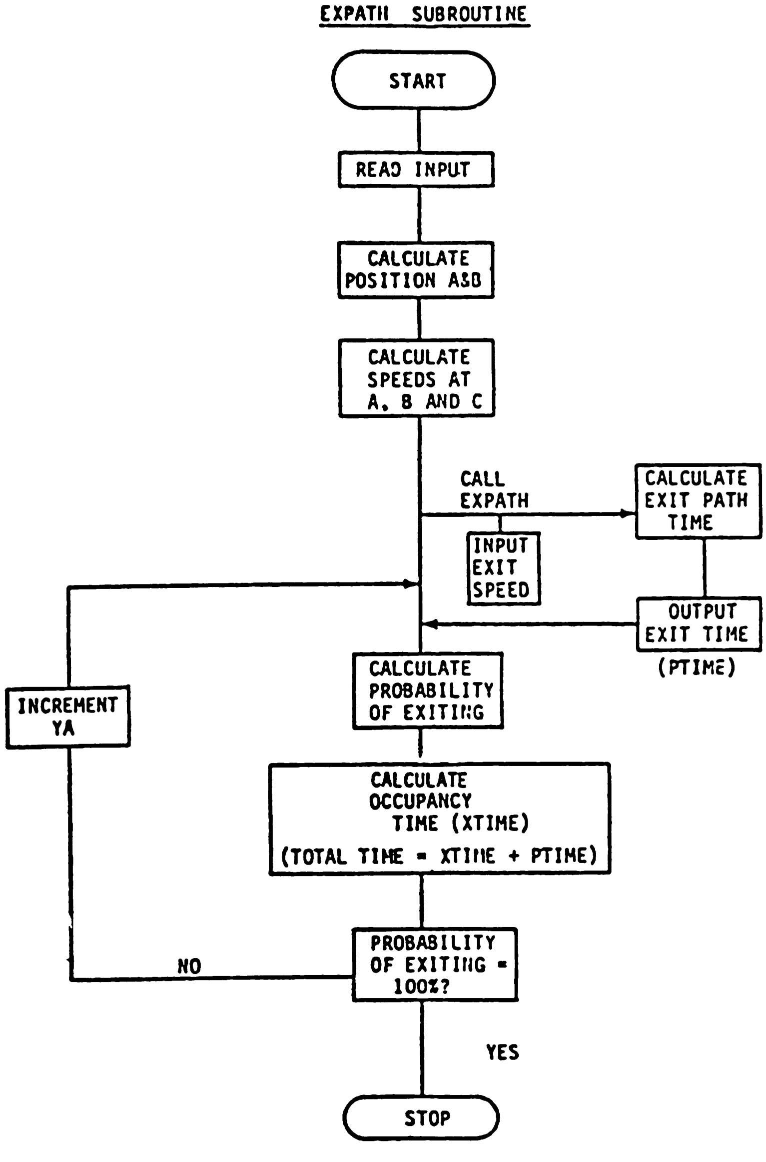


Table 4. (continued)



4.2.1 Mode 1

Initially, the Mode 1 process was used to solve for the maximum 40 seconds occupancy time. The process is iterated until the total runway occupancy is equal to 40 seconds. YA, the 50 percentile exit speed distribution is prorated using the following formula:

YA= YA * MAX.TIME/40

But this is a very long process, leaving no control in the desired speed range.

4.2.2 Mode 2

Mode 2 has been added to the model to allow the user to choose his speed values over a range which goes from YA to YA minus 14. It is faster than mode 1.

4.2.3 Mode 3

This mode also allows the user to choose its own speed value. After each YA entry and a complete run, the user is asked a new YA value until he is satisfied with the exiting probability. Because Mode 3 is the fastest of all and it allows to test the model's sensitivity more easily, it will be referred to.

4.3 DATA FILE

Use of the model requires data files for both the main program and the subroutine.

4.3.1 Main Program

4.3.1.1 High Speed Exit Data or Hispex Data

Hispex data is a collection of data related to the landing characteristics and their corresponding standard deviations. They are:

- UA (ft) : touchdown location, from threshold
- US (ft) : standard deviation of UA
- VA (ft/sec) : the aircraft speed at touchdown
- VS (ft/sec) : standard deviation of VA
- WA (sec) : time from touchdown to start of deceleration before exit
- WS (sec) : standard deviation of WA
- XA (ft/sec**2) : deceleration rate or rate of change of aircraft speed before exit

- XS (ft/sec**2) : standard deviation of XA

- YS (ft/sec) : standard deviation of YA, 50-percentile cumulative normal distribution of speeds at exit entrance

- CDIST (ft) : exit location,distance from threshold to exit entrance

- ZA (ft) : speed at which reverse thrust is shut off

- NTIP (ft) : distance from aircraft nose to wingtip

The high speed exit (Hispex) data are shown in the following table 5.

Table 5. Hispex Data

(Source: Adapted from Reference 5&6)

GENERIC AIRCRAFT					
UA	US	VA	VS	WA	WS
XA	XS	YS	C	ZA	NT
GENERIC AIRCRAFT AS					
500.	10.	66.	5.	3.	1.
2.5	1.	1.		.55.	39.
GENERIC AIRCRAFT AF					
500.	10.	118.	5.	3.	1.
2.5	1.	1.		.55.	40.
GENERIC AIRCRAFT BS					
1000.	20.	110.	10.	4.	1.
4.	.5	1.		.90.	34.
GENERIC AIRCRAFT BF					
1000.	20.	164.	10.	4.	1.
4.	.5	1.		.155.	56.
GENERIC AIRCRAFT CS					
1500.	30.	181.	10.	5.	1.
5.	.5	1.		.155.	48.
GENERIC AIRCRAFT CF					
1500.	30.	230.	10.	5.	1.
5.	.5	1.		.175.	103.
GENERIC AIRCRAFT DS					
1500.	30.	211.	15.	5.	1.
5.	.5	1.		.175.	87.
GENERIC AIRCRAFT DF					
1500.	30.	260.	15.	5.	1.
5.	.5	1.		.225.	150.
GENERIC AIRCRAFT WIDE BODY					
1500.	30.	230.	10.	5.	1.
5.	1.	1.		.190.	130.
TERPS CATEGORY E-LOCKHEED F-104					
1500.	30.	370.	25.	5.	1.
6.	2.	1.		.150.	35

4.3.1.2 SND Data

SND data is a standard table of the Normal distribution and is shown in table 6.

Fig 14 shows a schematic diagram of the runway operations, where

- A : distance from threshold where deceleration starts
- B : distance from threshold where reverse thrust stops
- C : distance from threshold to exit entrance

4.3.2 Subroutine Expath

Besides the exit speed given by the probabilistic model, it is required a set of data called Path data. They are:

- aircraft weight(lbs) : landing critical weight
- yaw inertia (slug-ft**2) : resistance to movement
- wheel base (ft) : distance from nose gear to main gear

Table 6. Standard Normal Table

(Source: Adapted from Reference 5)

.0000	.0040	.0080	.0120	.0160	.0199	.0239	.0279	.0319	.0359
.0398	.0438	.0478	.0517	.0557	.0596	.0636	.0675	.0714	.0753
.0793	.0832	.0871	.0910	.0948	.0987	.1026	.1064	.1103	.1141
.1179	.1217	.1255	.1293	.1331	.1368	.1406	.1443	.1480	.1517
.1554	.1591	.1628	.1664	.1700	.1736	.1772	.1808	.1844	.1879
.1915	.1950	.1985	.2019	.2054	.2088	.2123	.2157	.2190	.2224
.2257	.2291	.2324	.2357	.2389	.2422	.2454	.2486	.2517	.2549
.2580	.2611	.2642	.2673	.2704	.2734	.2764	.2794	.2823	.2852
.2881	.2910	.2939	.2967	.2995	.3023	.3051	.3078	.3106	.3133
.3159	.3186	.3212	.3238	.3264	.3289	.3315	.3340	.3365	.3389
.3413	.3438	.3461	.3485	.3508	.3531	.3554	.3577	.3599	.3621
.3643	.3665	.3686	.3708	.3729	.3749	.3770	.3790	.3810	.3830
.3849	.3869	.3888	.3907	.3925	.3944	.3962	.3980	.3997	.4015
.4032	.4049	.4066	.4082	.4099	.4115	.4131	.4147	.4162	.4177
.4192	.4207	.4222	.4236	.4251	.4265	.4279	.4292	.4306	.4319
.4332	.4345	.4357	.4370	.4382	.4394	.4406	.4418	.4429	.4441
.4452	.4463	.4474	.4484	.4495	.4505	.4515	.4525	.4535	.4545
.4554	.4564	.4573	.4582	.4591	.4599	.4608	.4616	.4625	.4633
.4641	.4649	.4656	.4664	.4671	.4678	.4686	.4693	.4699	.4706
.4713	.4719	.4726	.4732	.4738	.4744	.4750	.4756	.4761	.4767
.4772	.4778	.4783	.4788	.4793	.4798	.4803	.4808	.4812	.4817
.4821	.4826	.4830	.4834	.4838	.4842	.4846	.4850	.4854	.4857
.4861	.4864	.4868	.4871	.4875	.4878	.4881	.4884	.4887	.4890
.4893	.4896	.4898	.4901	.4904	.4906	.4909	.4911	.4913	.4916
.4918	.4920	.4922	.4925	.4927	.4929	.4931	.4932	.4934	.4936
.4938	.4940	.4941	.4943	.4945	.4946	.4948	.4949	.4951	.4952
.4953	.4955	.4956	.4957	.4959	.4960	.4961	.4962	.4963	.4964
.4965	.4966	.4967	.4968	.4969	.4970	.4971	.4972	.4973	.4974
.4974	.4975	.4976	.4977	.4977	.4978	.4979	.4979	.4980	.4981
.4981	.4982	.4982	.4983	.4984	.4984	.4985	.4985	.4986	.4986
.4987	.4987	.4987	.4988	.4988	.4989	.4989	.4989	.4990	.4990
.4990	.4991	.4991	.4991	.4992	.4992	.4992	.4992	.4993	.4993
.4993	.4993	.4994	.4994	.4994	.4994	.4994	.4995	.4995	.4995
.4995	.4995	.4995	.4996	.4996	.4996	.4996	.4996	.4996	.4997
.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4998
.4998	.4998	.4998	.4998	.4998	.4998	.4998	.4998	.4998	.4998
.4998	.4998	.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999
.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999
.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999
.5000	.5000	.5000	.5000	.5000	.5000	.5000	.5000	.5000	.5000

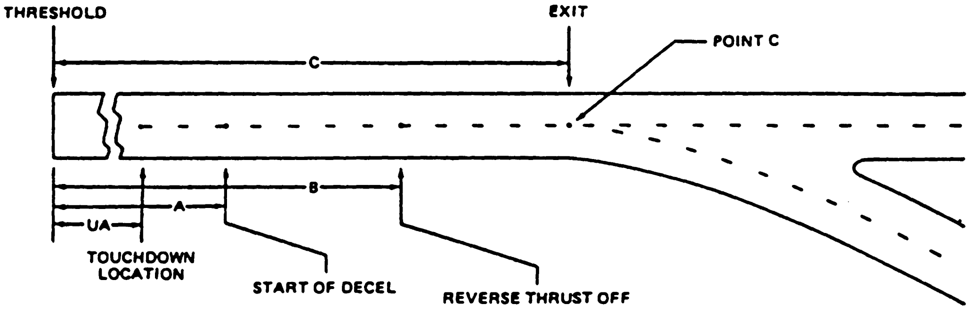


Figure 14. Runway Operations

(Source: Adapted from Reference 5)

- percent weight on main gear

- Ymu max : measure of maximum resistance offered by nose gear

- theta max (deg) : the angle formed by the longitudinal axis of the aircraft and an imaginary line joining the edges of the wingtip and the stabilizer, as shown in figure 15

- deceleration rate (ft/sec**2) : rate of change of aircraft speed from the start of exit

- runway width (ft) : width of runway surface

- wingspan (ft) : distance between the wingtips

- distance to taxiway (ft) : distance between the centerlines of the and a parallel taxiway

- Ymu scrub and radius (ft) : these values refer to the scrubbing characteristics of the aircraft on curves, as shown in fig 16

The data input or path data are shown in table 7

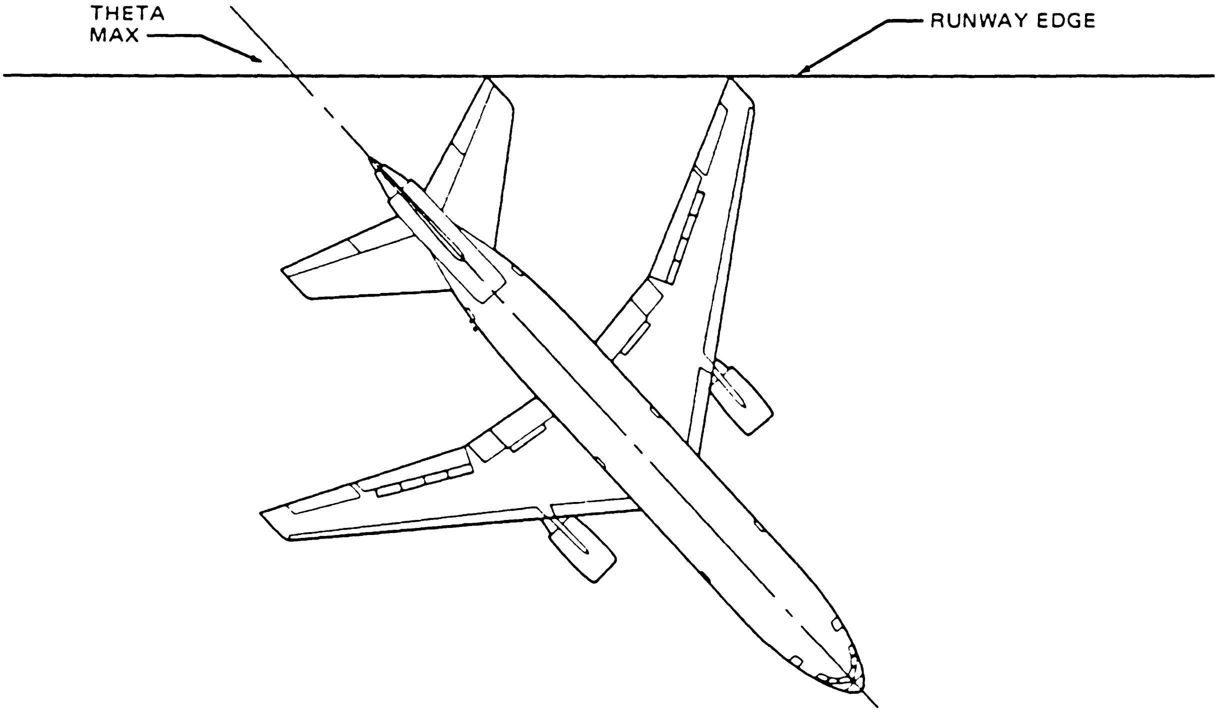


Figure 15. Theta max

(Source: Adapted from Reference 5)

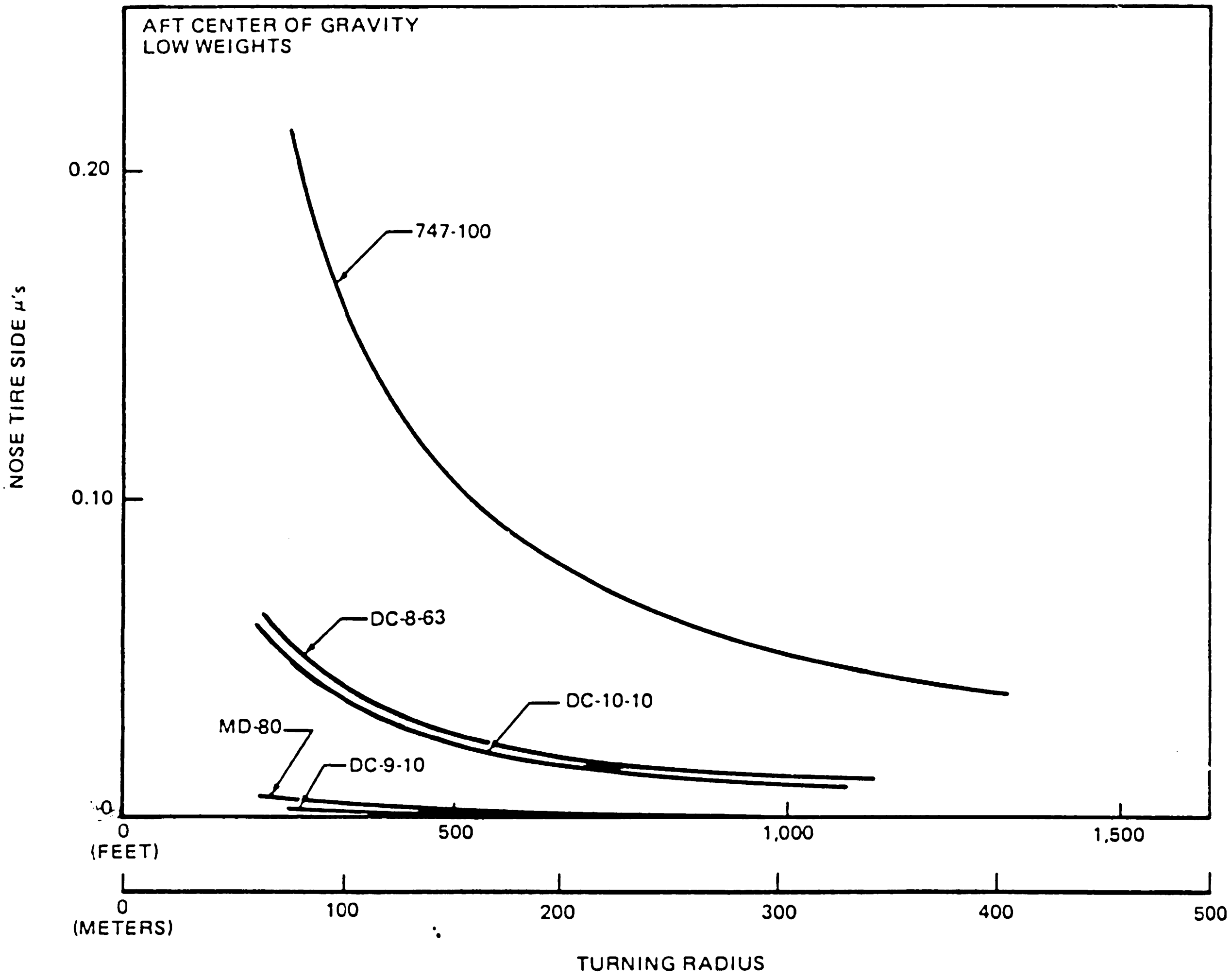


Figure 16. Ymu scrub and radius

(Source: Adapted from Reference 5)

Table 7. Path Data

(Source: Adapted from Reference 6)

A/C Weight	Yaw Inertia	Wheel Base	% Weight on Main Gear
Theta Max	YMU	Deceleration	
R/W Width	Wingspan	Dist to T/W	
YMU Scrub(1)	Raduis(1)		
YMU Scrub(N)	Raduis(N)		
GENERIC AIRCRAFT AS			
2040.	2310.	5.3	72.
90.	.25	-1.5	
150.	32.	600.	
.00	1.0 E+31		
.02	50.		
Generic Aircraft AF			
24000.	300000.	23.	93.
41.	.25	-2.	
150.	42.	600.	
.00	1.0 E+31		
.02	50.		
GENERIC AIRCRAFT BS			
24000.	300000.	23.	93.
38.	.25	-1.5	
150.	36.	600.	
.00	1.0 E+31		
.023	50.		
GENERIC AIRCRAFT BF			
48000.	800000.	36.	95.
38.	.25	-1.5	
150.	49.	600.	
.00	1.0 E+31		
.023	50.		
GENERIC AIRCRAFT CS			
48000.	800000.	36.	95.
33.	.25	-1.75	
150.	85.	600.	
.00	1.0 E+31		
.025	50.		
GENERIC AIRCRAFT CF			
120000.	4.2E+6	61.	95.
39.	.25	-1.75	
150.	141.	600.	
.00	1.0 E+31		
.025	50.		

Table 7. (continued)

```
  GENERIC AIRCRAFT DS
120000.        4.2E+6          61.        95.
37.            .25             -1.75
150.           87.             600.
.000           1.0 E+31
.01            5000.
.012           2000.
.018           1000.
.023           500.
.03            50.

    GENERIC AIRCRAFT DF
400000.        40.0E+6          84.        96.
45.            .25             -1.75
150.           207.           600.
.000           1.0 E+31
.01            5287.
.019           2638.
.039           1318.
.059           877.
.079           657.
.099           534.

  WIDE BODY AIRCRAFT
564000.        42000000.       84.        96.4
45.            0.2             -2.
150.           195.7           600.
0.00           1.0 E+31
0.01           5287.
0.019          2638.
0.039          1318.
0.059          877.
0.079          657.
0.099          524.
.153           347.
.212           257.
.353           167.
.548           121.
.793           99.

   LOCKHEED F 104
22000.         137776.         15.0       92.3
20.            .2              -2.
150.           21.9            600.
.00            .1 E+32
.02            50.
```

4.4 TECHNICAL APPROACH AND ASSUMPTIONS

Practical utilization of the model required a categorization of the aircrafts to cover a wide range of weight and speed, a runway clearance algorithm, the use of realistic aircraft characteristics, a lateral ride-comfort algorithm and some assumptions. The concepts of reliability and runway occupancy time are defined.

4.4.1 Reliability

Along with the efforts of reducing runway occupancy time, reliability is a major factor. Reliability can be expressed in terms of probability. A goal of one miss for every 10000 turnoffs or a reliability of 99.99 percent seems very appropriate compared to the present level experienced in major airports, as shown in table 8.

4.4.2 Runway Occupancy Time

Runway occupancy time is defined as the average occupancy plus 3 standard deviations. Its maximum has been set at 40 seconds, which corresponds to 90 landings per hour. It is the time elapsed from the threshold until the aircraft has cleared the runway. It is also the summation of times calculated in the two (2) parts of the probabilistic model.

Table 8. Reliability of runway operations

(Source: Adapted from Reference 5)

Number of Weekly landing per runway	Probability of one missed per week per landing	Number of STD from the mean	Example airport experiencing this activity per R/W
1200	.00083	3.15	LAX
1700	.00059	3.23	La Guardia
4000	.00025	3.45	N/A
5000	.0002	3.75	N/A
10000*	.0001	3.9	GOAL

* not weekly

4.4.3 Categorization of aircrafts

A variety of aircrafts operate in an airport environment, from the general aviation type to the wide body jet transport. Such characteristics as an aircraft mass and its dimensions, or its cornering limits play a very important role in the design of an airport in general, and the design of a high speed exit in particular. In order to bracket the high speed turnoff performance variability that could occur in a given category , two generic aircrafts are defined in each category. The categorization of aircraft is influenced by the wide range of approach speeds and aircraft weights. The four TERPS Categories are used (6) "since the cornering characteristic is a strong function of mass, the selection of aircraft categories for the study was influenced by the obsolete TERPS document rather than by the current revision which classifies on the basis of approach speed, only".

TERPS stands for the U.S. Standards For Terminal Instrument Procedures (7). Its article 212 related to approach categories stipulates that "Aircraft performance differences have an effect on the airspace and visibility needed to perform certain maneuvers. Because of the differences, aircraft manufacturer/operational directives assign an alphabetical category to each aircraft so that the appropriate obstacle clearance areas and landing and departure minimums can be established in accordance with the criteria in this manual. The categories (CAT) used and referenced through this manual are: CAT A, B, C, D and/or E. Aircraft categories are defined in Federal Aviation Regulations (FAR) Part 97".

Thus, the maximum landing weight is varied from 2040 to 400000 lbs and the touchdown speed ranges from 66 to 260 ft/sec (5). In addition the Boeing 747 and the lockheed F 104 have been included in the research to reach a maximum landing weight and a touchdown speed as high as, respectively, 564000 lbs and 370 ft/sec (5). The F104 is classified in the category E.

4.4.4 Runway Clearance Algorithm

High speed turnoffs are assumed so that the runway clearance is a function of the wingtip length and theta max. At low ground speeds, the wingtip may not be critical. This happens when the aircraft tail is the last part to clear the edge of the runway. The model checks whether the heading change, theta angle, is greater than the maximum angle, theta max. If so, the program stops running.

4.4.5 Lateral Ride Comfort

Lateral acceleration and jerk, in consideration of ride comfort, are included in the expath subroutine. However, they are ignored in the computations because the optimal values are set equal to infinity. The algorithm assumed that the two parameters are related by the following formula:

$$G/GMAX + J/JMAX = 1$$

The lateral ride comfort is discussed in an earlier chapter.

4.4.6 Assumptions

- arrival separations and runway occupancy times are mutually exclusive events
- touchdown speed and touchdown location are normally distributed
- time from touchdown until start of deceleration is normally distributed
- speed is constant from threshold to start of deceleration
- deceleration rate is constant
- speeds at start of exit follows a normal distribution

4.4.7 Maneuvering Demand on the Nose Gear

The total maneuvering gear demand, Cng, is given by the following equation, where

$$Cng = Cay + Ci + Cs$$

- Cay comes from centrifugal force
- Ci from rotation inertia resistance

- Cs from scrubbing resistance

A maximum Cng of 0.2 is assumed to be practical. Compared to the ground coefficient of friction, it leaves a margin of 2 against skidding on wet surfaces and a margin of 4 against skidding on dry surfaces.

CHAPTER 5 RESULTS AND ANALYSIS

5.1 OPTIMAL EXIT LOCATIONS

As can be seen from table 9 and figure 17, the optimal exit locations vary from 1286 ft to 5860 ft for the 8 generic aircrafts of the 4 TERPS Categories. The B 747 and Lockheed F 104 have their optimal exit locations at 5170 ft and 8400 ft. Table 9 also shows the maximum occupancy times, the deceleration rates before and after exit.

5.2 BUNCHING OF EXITS

The smallest distance between any two consecutive optimal exits is 70 ft (2355-2285), corresponding to BS and AF generic aircrafts. Further investigation gives in table 10 the distance separations between the successive exit locations.

Eight different exits would be necessary if it were to accommodate the 8 generic aircrafts. A close look at the exit separations suggests that the exit locations are closely spaced. Concerns are that there is a potential of aircraft collision, confusion of the pilot about the exit to take, inefficient operation control and non-cost efficiency of the system.

Table 9. Optimal Exit Locations

				Generic Aircrafts							
Exit		AS	AF	BS	BF	CS	CF	DS	DF	WB	F104
1286	*	2.5									
	**	1.5									
	***	39.76									
2285				4.0							
				1.5							
				39.97							
2355			2.5								
			2.0								
		****	38.01								
3654					4.0						
					1.5						
					39.99						
4225						5.0					
						1.75					
						39.95					
4805								5.0			
								1.75			
								39.96			
5515							5.0				
							1.75				
							40.00				
5860									5.0		
									1.75		
									39.95		
5170										5.0	
										2.0	
										39.98	
8400											6.0
											2.0
											40.01

Notes: * deceleration rate on runway
** deceleration rate on exit path
*** runway occupancy time
**** the 40 sec cannot be achieved. The runway occupancy time jumps drastically from 38.06 to 41.42 sec for an exit location changing from 2357 to 2360 ft. This is due to the standard deviation of time which increases from 1.87 to 2.79 sec.

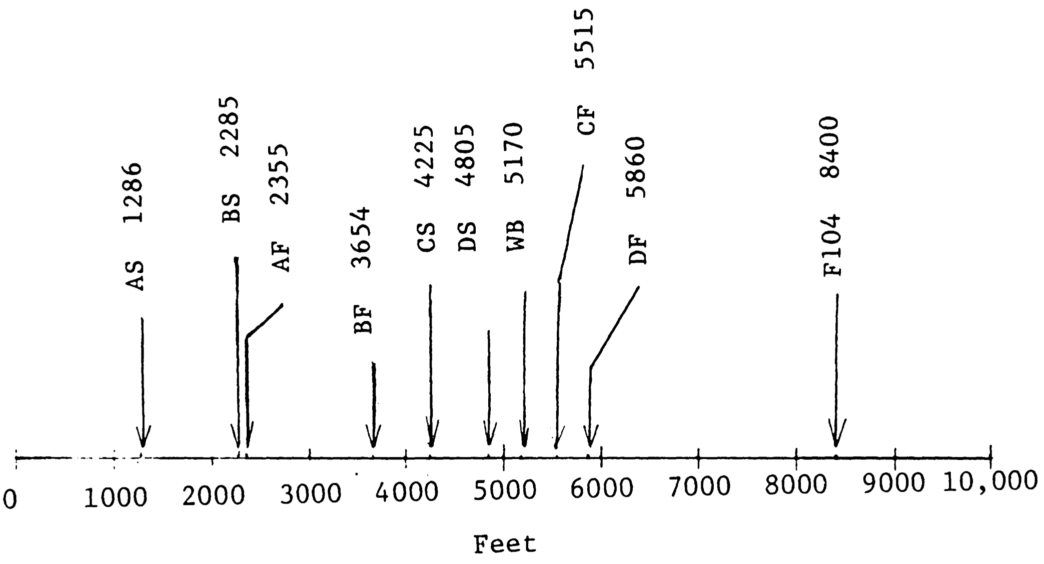


Figure 17. Optimal Exit Locations

Table 10. Exit Separations

Gener Airc	AS		BS		AF		BF		CS		DS		CF		DF
Exit locations	1286		2285		2355		3654		4225		4805		5515		5860
Exit separations		999		70		1299		571		580		710		345	

It is proposed in this research to minimize the number of exits and, at the same time, to accommodate the 8 generic aircrafts with regard to the following criteria:

5.2.1 Runway Occupancy Time

The maximum runway occupancy time remains 40 seconds for each generic aircraft.

5.2.2 Reliability

The 99.99 percent chance of exiting must also be achieved for every aircraft.

5.2.3 Exit Separation

The factors that control the exit separations are the avoidance of aircraft collision, FAA regulations and the aircraft cornering characteristics.

5.2.3.1 Aircraft Collision

Assuming that the critical wingtip is the longest aircraft wingtip, any distance from centerline to centerline of all consecutive exits should be greater than 207 ft. Adjustments are required to take into account the pilot's inability to follow a predetermined exit path at high speed.

5.2.3.2 FAA regulations

The minimum standard separation is 750 ft (16). It is easily noted that the FAA regulations satisfy already the above minimum.

5.2.3.3 Cornering Characteristics

To avoid much demand on the aircraft nose gear, an aircraft is not allowed to take an exit which is at least 750 earlier than its optimal exit. This is also correlated to the pilot's confidence, or lateral acceleration and jerk felt by the passengers.

5.3 SOLUTIONS

Abiding by the above criteria, it can be proved that an exit located 1286 ft is required and that the following pairs of exits are mutually exclusive: (2285, 2355); (3654, 4225); (4225, 4805); (4805, 5515) and (5515, 5860).

The second stage required additional computer runs in which some parameters are varied, sometimes to the limits. However the variable parameters leave few options. They are the deceleration rates before and after exit and the exit location. But beside the exit location, the model is only sensitive to the deceleration rate before turnoff, as can be seen in table 11. The deceleration rate on the exit path has very little effect on the runway occupancy time and the path profile.

Some possible solutions are presented in table 11 as follows.

A factor that needs to be considered is the effects of combining exit paths, in the same exit, on the probability of exiting and the runway occupancy time. A critical path is determined by choosing the aircraft which is the most constrained along the exit path. That aircraft tends to follow a path closer to the runway. It also has the largest turning radius. The problem may arise when another aircraft has to take the same exit and is not fast enough to clear the runway within 40 seconds. Fig 18 gives the picture of the problem.

5.3.1 exit location for AF and BS generic aircrafts

As discussed earlier, the runway occupancy time is very sensitive around the 2355 ft optimal exit location. A lateral displacement of only 5 ft along the exit centerline can result in the BS aircraft missing the 40 sec occupancy time. Besides the 2355 ft exit is not optimally located. These reasons lead to choose the 2285 ft exit to accommodate the AF and BS aircrafts.

5.3.2 exit location for BF and CS

Both exits meet the requirements at 3654 ft and 4225 ft. However if BF takes the 4225 ft exit, it would require a deceleration rate below 0.5

Table 11. Possible Bunching Solutions

	Exit locations				
Generic Aircraft	1286	2285	2355	3654	4225
AS	2.5 1.5 39.8				
AF		2.5 2.0 36.3	2.5 2.0 38.0		
BS		4.0 1.5 40.0	3.0 1.5 39.71		
BF					.5 1.5 39.5
				2.0 1.5 36.2	0.5 1.75 39.5
				4.0 1.5 39.99	
CS				5.0 1.0 33.39	2.0 1.75 32.03
					3.0 1.75 37.49
					4.0 1.0 38.47
					5.0 1.0 39.82
					5.0 1.75 39.95

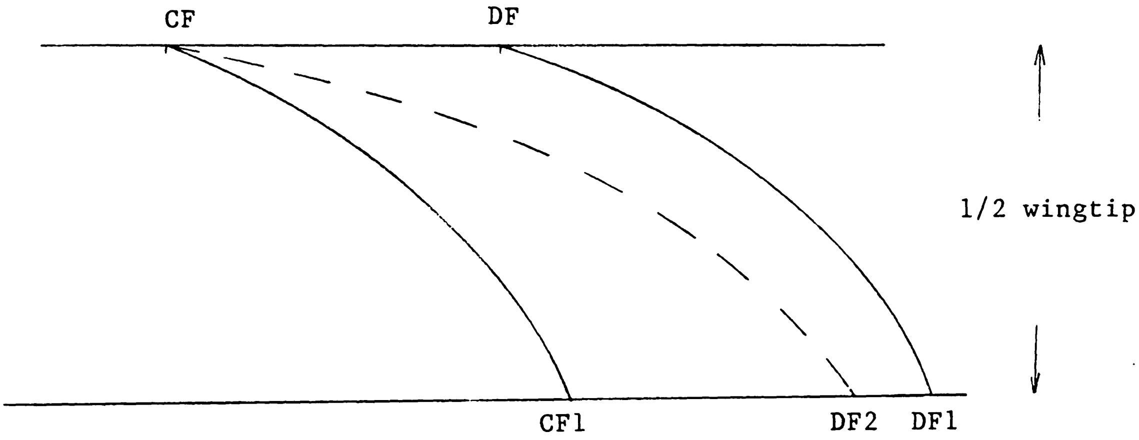


Figure 18. Bunching problem along an exit path

ft/sec**2 to follow the critical path and to be under the 40 seconds maximum runway occupancy time. Counting with drag and rolling friction, it seems risky to assume that this will be practically feasible. An exit at 3654 ft decreases the distance separation between the second and third exits from 1940 to 1369 ft. These factors lead to choose the 3654 ft exit for BS and CS.

5.3.3 Exit location for DS

An exit is required for DS at 4805 ft because it cannot take the following exit in the time limit, DF dictating the critical path.

5.3.4 Exit location for CF and DF

An exit located at 5515 ft would be too close to the 4805 ft exit. the 5860 ft exit is selected for CF and DF.

5.3.5 Final solution

Table 12 and figure 19 give the final solution, with 5 optimal exit locations for the 8 generic aircrafts. Another exit is proposed for the Lockheed F104 at 8400 ft. Similarly one or more exits may be required for aircrafts which characteristics are within the range of the generic aircraft DF and the Lockheed F 104.

The B 747 which optimal exit is located at 5170 ft cannot take any exit of the design because of its restraining cornering characteristics or the time constraint. Figure 19 also shows that the solution is unique. If the 5515 ft exit were chosen to accommodate CF and DF, the previous exit would be located at 4225 ft, and the 3654 ft exit will not exist. Then, at least, DS and/or CF would not meet the requirements.

Table 12. Final Solution

	Generic aircrafts							
Exit locations	AS	BS	AF	BF	CS	DS	CF	DF
1286	2.5 1.5 39.76							
2285		3.5 1.5 39.03	2.5 2.0 36.3					
3654				1.5 1.5 36.	5.0 1.75 33.4			
4805						5.0 1.75 39.96		
5860							.5 .5 37.4	5. 1.75 39.95

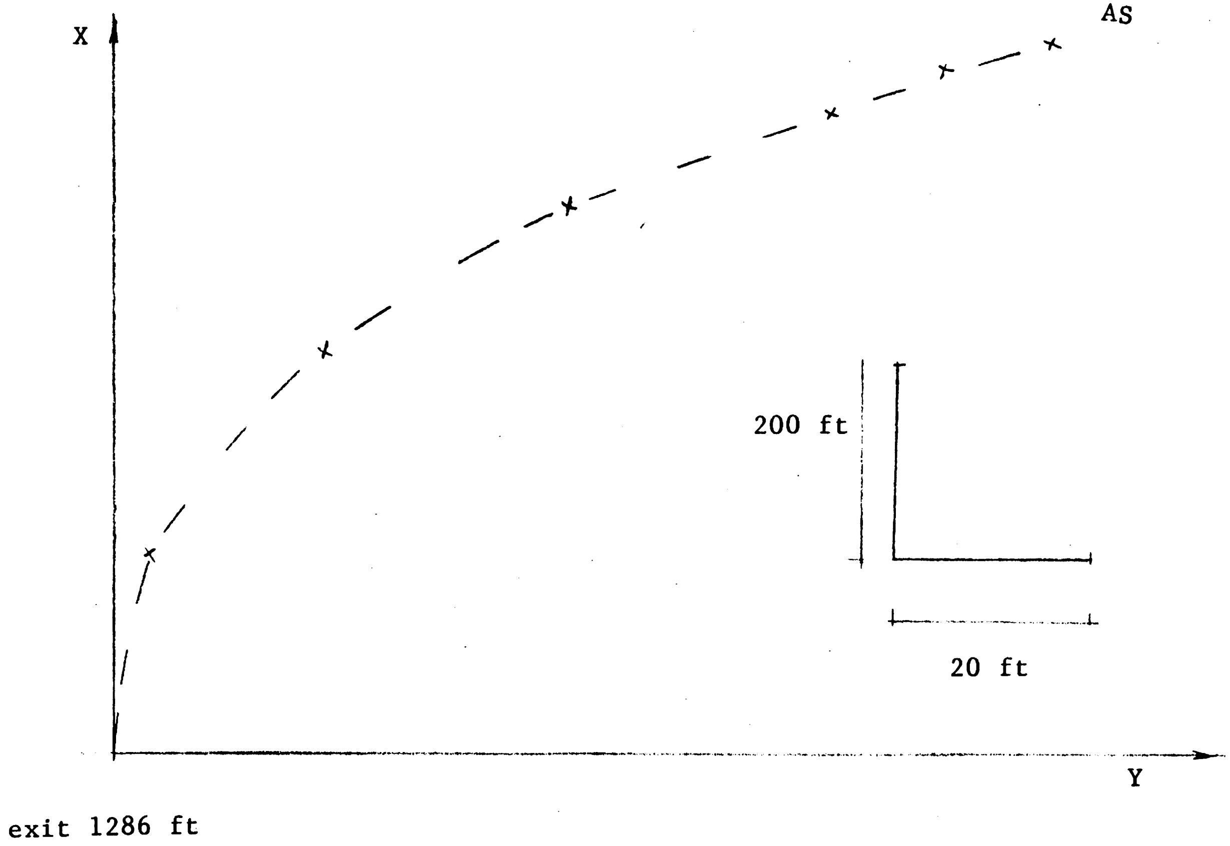


Figure 19. Final solution

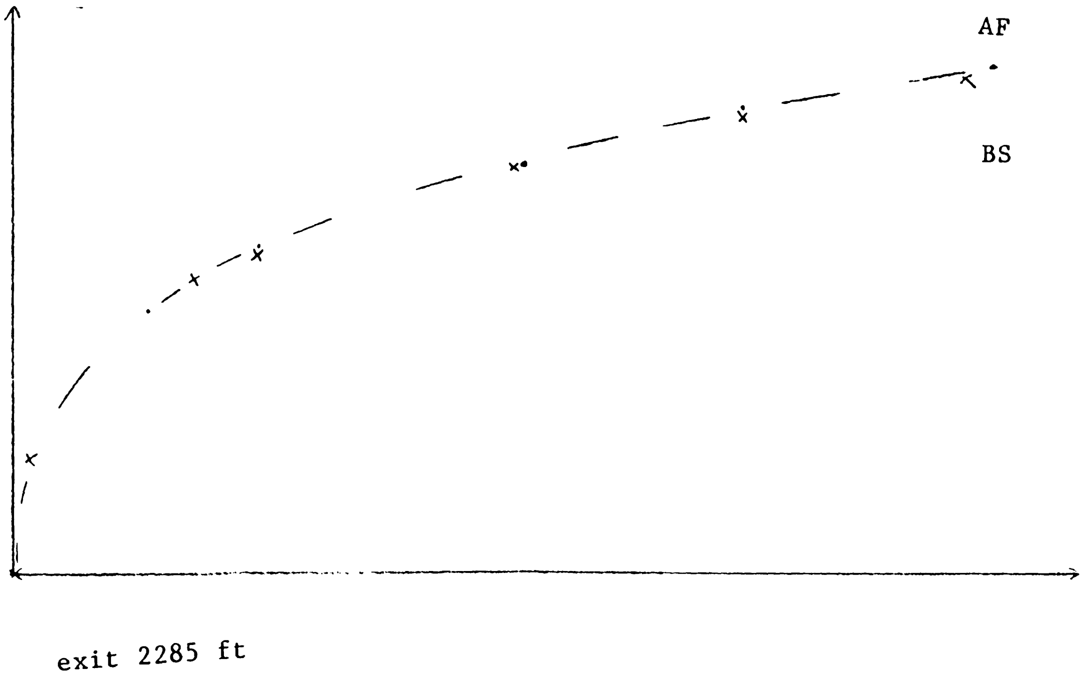


Figure 19. (continued)

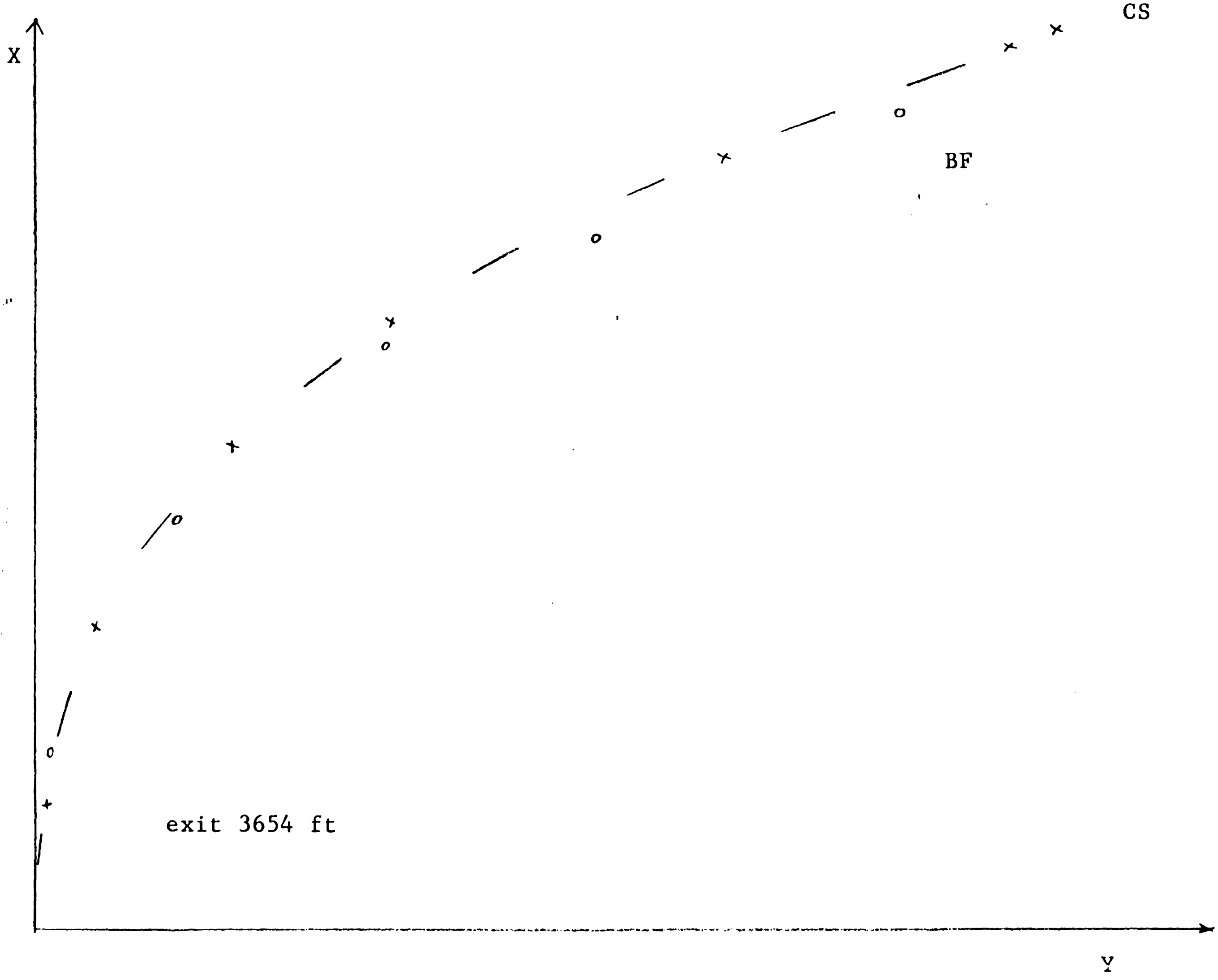


Figure 19. (continued)

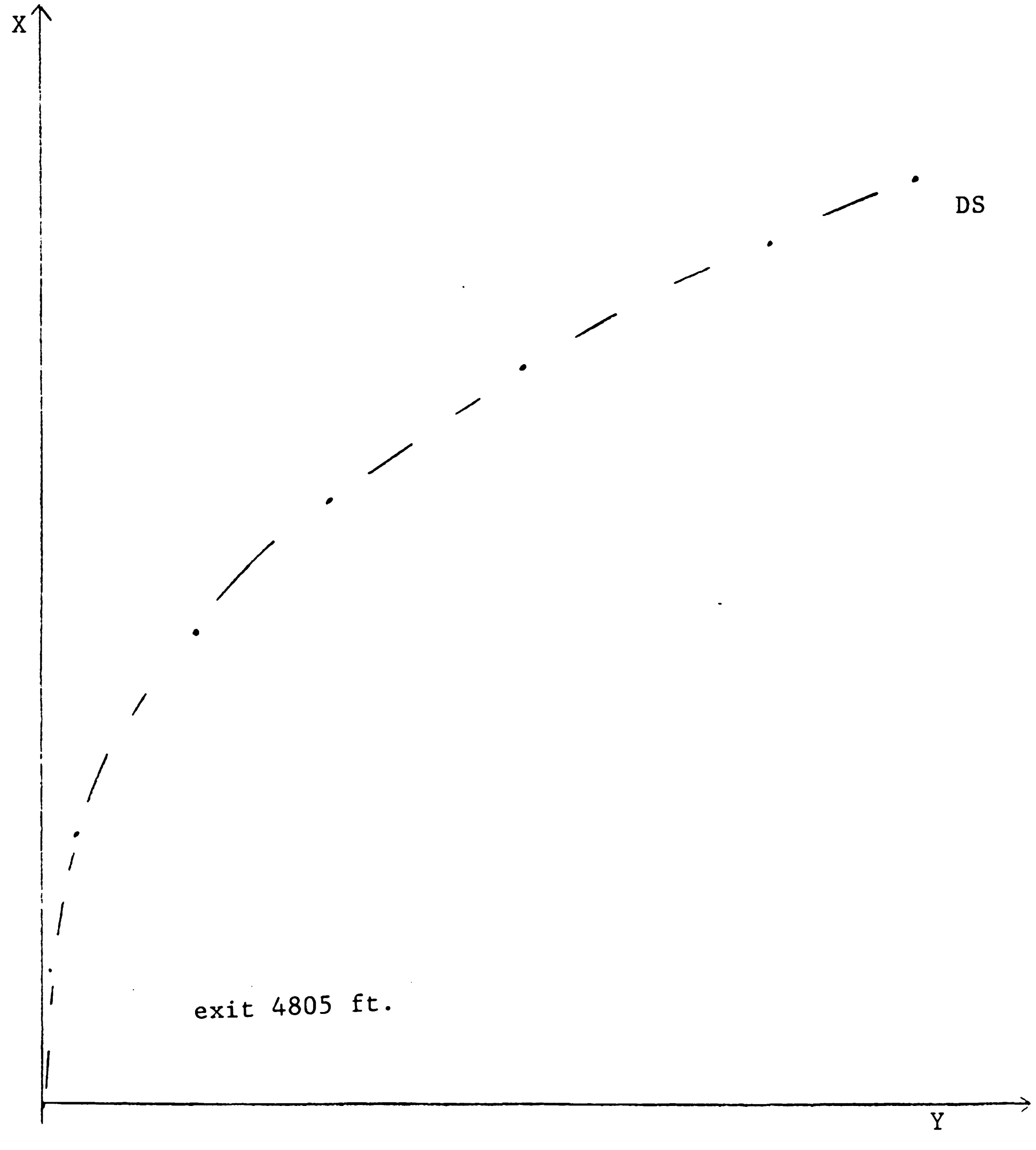


Figure 19. (continued)

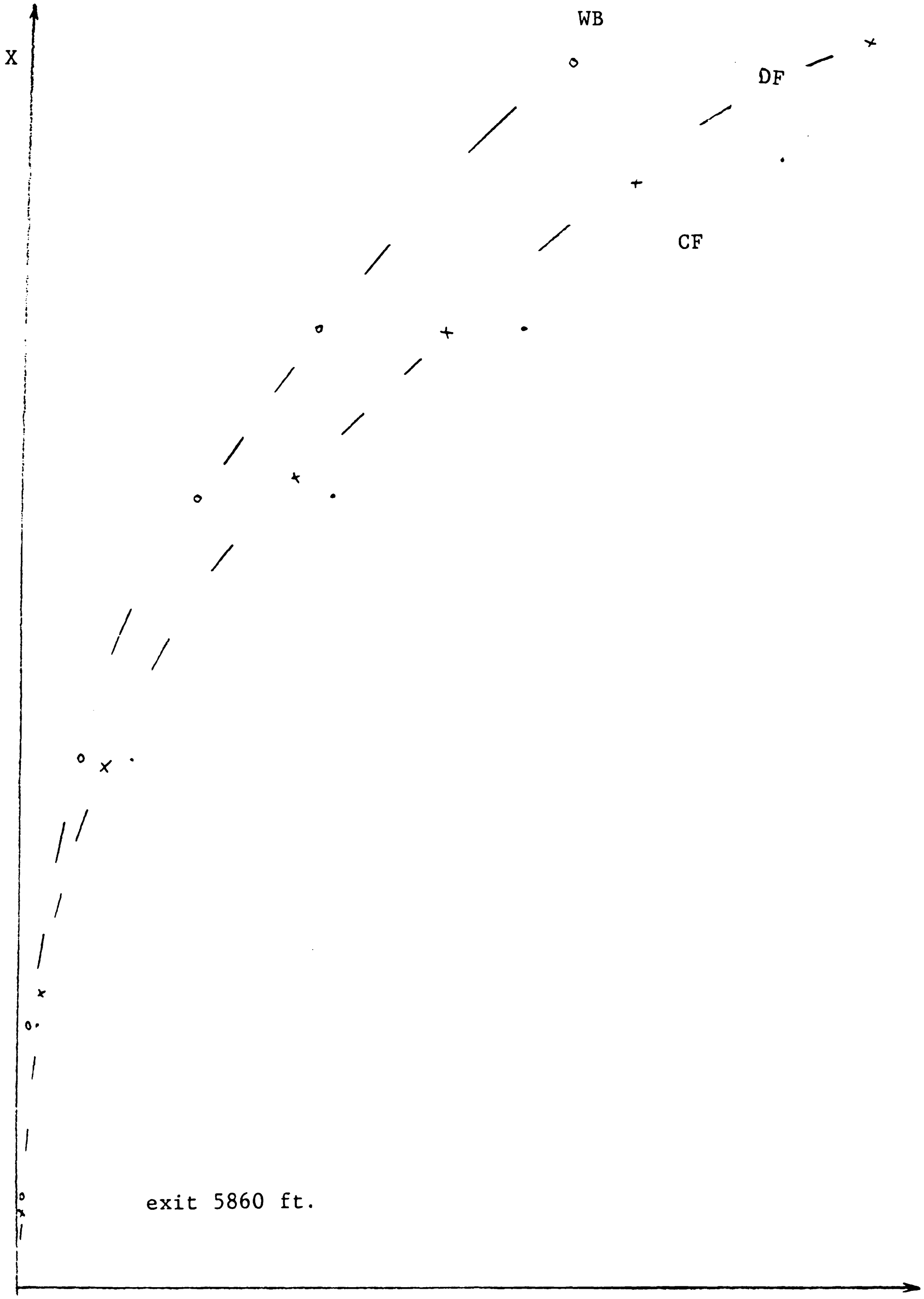


Figure 19. (continued)

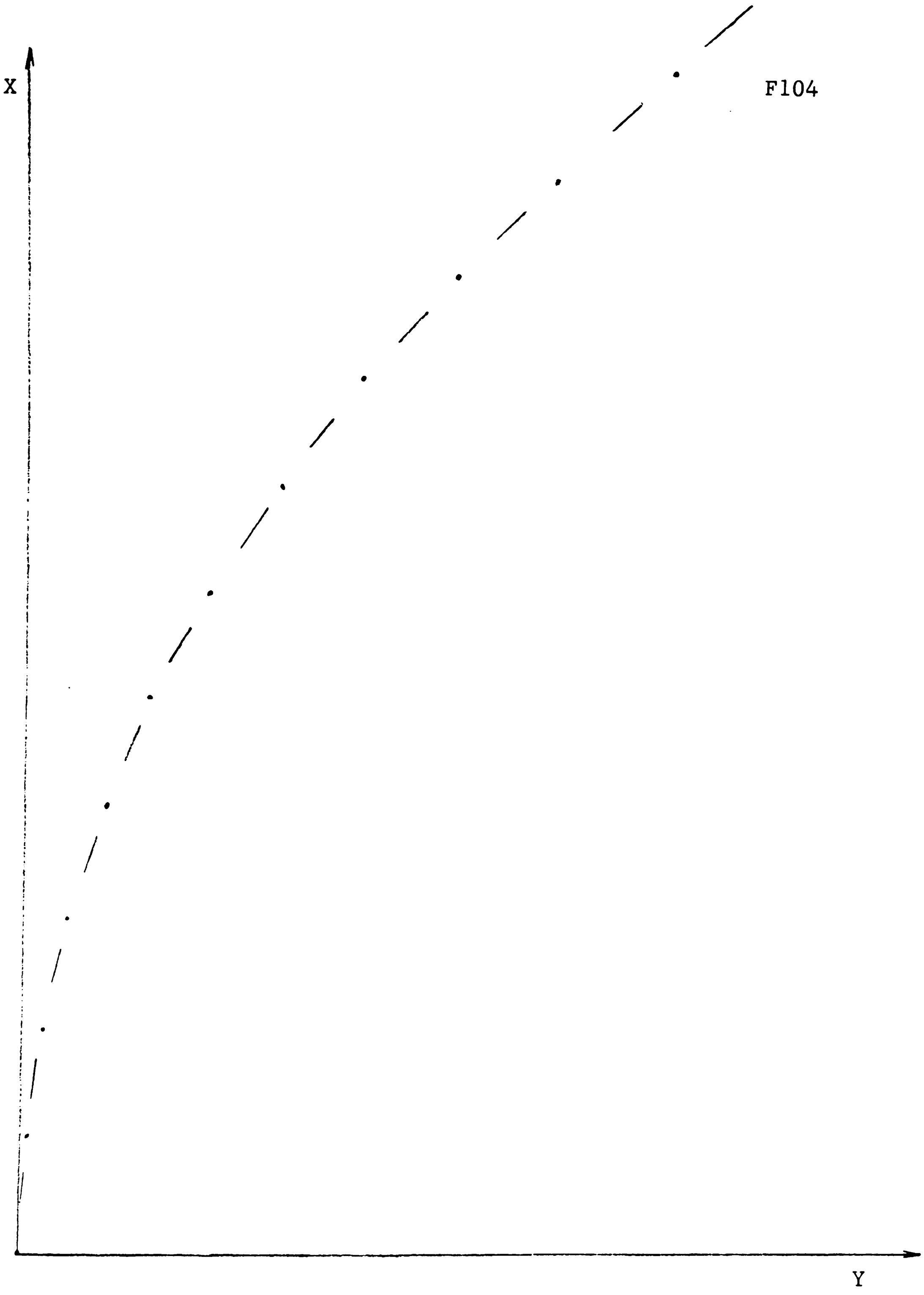
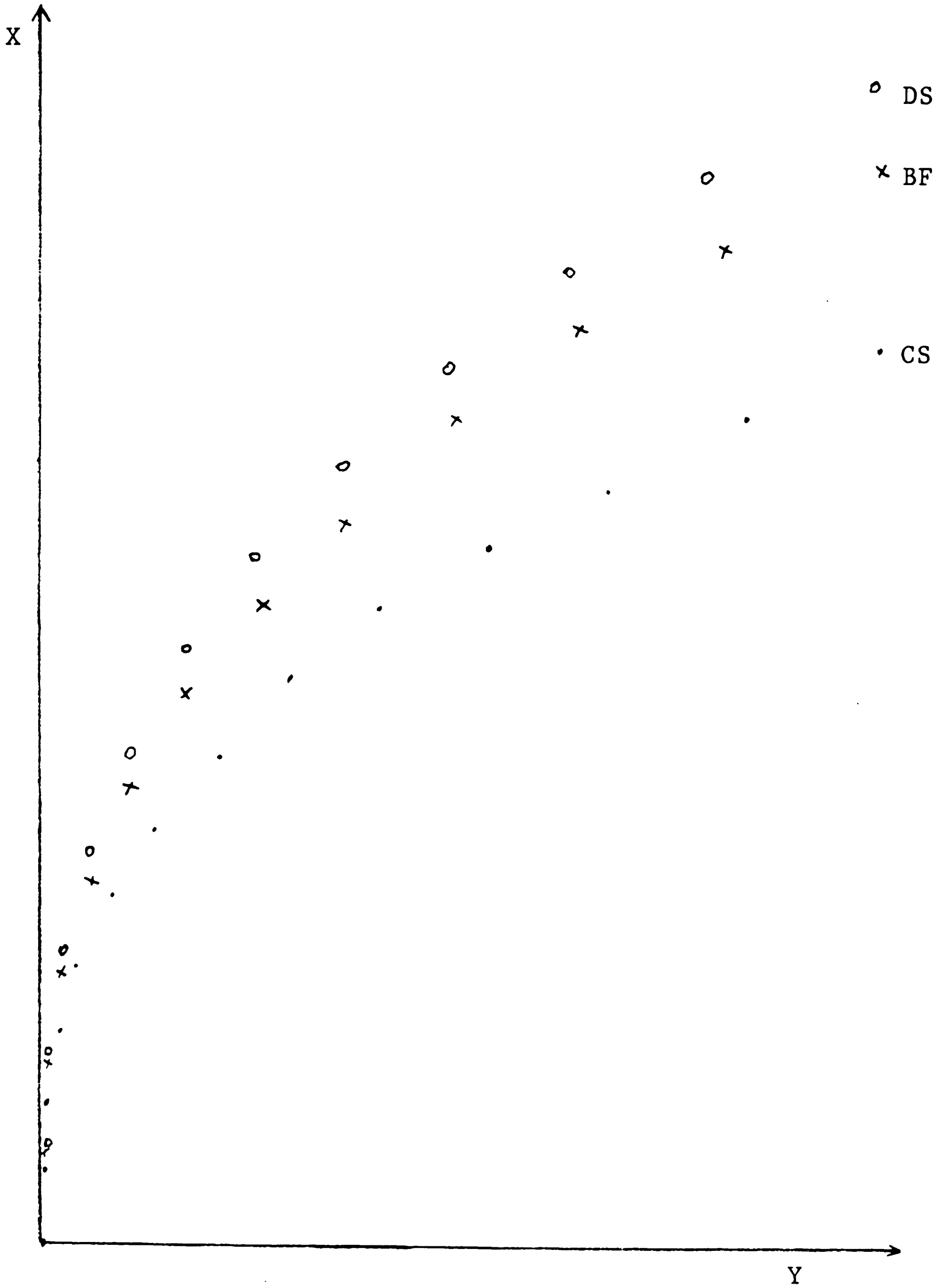


Figure 19. (continued)

exit 8400 ft.



exit 4225 ft.

Figure 19. (continued)

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

As can be readily seen, the development of optimal high speed exits is very promising. It is relatively cheap compared to the Brandt Drift- off system or to the construction of a new runway and it can perform comparatively to them under certain conditions to accommodate efficiently the increasing demand of traffic (3).

Another attractiveness of the design is that it is not sensitive to aircraft mix and it is very reliable. It is not based on an average occupancy time, which makes it a better tool in the ultimate spacing of landing aircrafts.

However the Probabilistic Computer Model of Optimal Runway Turnoffs can be improved to include such factors as the temperature and the elevation variability. A subroutine can also be added to the model to ease the computational procedure of bunching of any particular aircraft in the proposed design. For the full use of the model further investigation needs to be performed to integrate the high speed runway exit maneuver smoothness. A more reasonable skewed curve would be preferred to the normal distribution assumed for the touchdown speed and the touchdown location.

The introduction of the MLS is essential in releasing delay in the landing process. It provides an approach curve path which alleviates the many problems present in the ILS. An hypothetical example (1) shows the great role that the MLS plays in increasing capacity in an airport environment; considering an airport serves aircrafts which land at a speed of 165 mph with an average occupancy time of 25 sec, and an average spacing of 3 nautical miles; the minimum interarrival time is (3*6076*3600/165*5280), 75 sec, which corresponds to a maximum of 48 landings per hour, nearly half of the high speed exit design.

The automation of the system requires the introduction of filters and other navigational aids so that aircrafts can be directed efficiently from the terminal airspace to the taxiways. The advancement of the autobraking guidance laws , the use of a conservative deceleration rate and the airborne hardware/software packages makes the system more reliable.

The literature reviewed shows that the simulation runs and the field tests have been proved to be successful and feasible at speeds up to 150 mph. With the exit speeds obtained in the research further investigation is needed in the the areas of ride comfort, braking performance in all weather conditions, exit presignalization, and the aircraft cornering characteristics.

It is suggested that the development of high speed turnons be also incorporated in the design and that the effects of different runway configurations on the design be investigated. To allow landing from both sides of the runway, due to the variability of wind configurations, a symmetrical design around the midpoint of the runway centerline is required.

APPENDIX A. PROBABILISTIC MODEL

MAIN PROGRAM

```
$DEBUG
C$JOB
C       CHARACTER  MS, MSP
        REAL NTIP
        REAL*4 NTITLE(20)
        DIMENSION ARBS(16),DPX(16),P(16),DP(16)
        DIMENSION SND(400)
        DIMENSION ARBT(16),ARBI(15),DT(15)
        DIMENSION PEX(16),ZROT(15),Z(16),ZEX(16)
        OPEN(1,FILE='HISPEX.DAT')
        OPEN(2,FILE='SND.DAT')
        OPEN(3,FILE='SOLVIT.DAT',STATUS='NEW')
        READ(1,11) (NTITLE(I),I=1,20)
   11   FORMAT(20A4)
        READ(1,10) UA, US, VA, VS, WA, WS
        READ(1,10) XA, XS, YS, C, ZA, NTIP
   10   FORMAT(6F5.0)
        IBIRD=0
        IFLAG=0
C
        WRITE(*,125)
  125   FORMAT('ENTER:  5 FOR TERMINAL PRINTOUT'/,
     1        '         6 FOR HARDCOPY PRINTOUT')
        WRITE(*,126)
  126   FORMAT(4X,'IF THE PROGRAM ASK ABOUT UNIT 5, ENTER CON:',/4x,
     1  'IF THE PROGRAM ASK ABOUT UNIT 6, ENTER LPT|:')
```

```
      READ(*,*)IWRT
      WRITE(*,139)
139   FORMAT(' ENTER: 1 FOR STANDARD PRINT ',/
   1          '        2 FOR INTERMEDIATE VALUES',/
   2          '        3 FOR FINAL VALUES ONLY')
      READ(*,*)IPRT
      WRITE(*,6)
6     FORMAT(' ENTER: 1 TO SOLVE FOR 40 SEC OCCUPANCY'/,
   1          '        2 TO SOLVE FOR MAXIMUM PROBABILITY',/
   2          '        3 FOR USER ENTRY OF YA VALUE')
      READ(*,*)IYA
      WRITE(*,7)
 7    FORMAT('    ENTER INITIAL YA SPEED')
      READ(*,*)YA
      IF(IPRT.EQ.3) GO TO 750
      WRITE(IWRT,3) (NTITLE(I),I=1,20)
 3    FORMAT(29X,20A4/)
      WRITE(IWRT,1)
 1    FORMAT(30X,' NASA HIGH SPEED ANALYSIS',/,
     135X,' INPUT SUMMARY,'//,T35,'PROBABILISTIC MODEL',
     2/T43,'AVERAGE    STD DEV    UNITS,'/)
      WRITE(IWRT,2)UA,US,VA,VS,WA,WS,XA,XS,YA,YS,C,ZA,NTIP
 2    FORMAT(10X,'TOUCHDOWN LOCATION',T40,2F10.0,T65,'FEET',
     1/10X,'TOUCHDOWN SPEED',T40,2F10.0,T65,'FT/SEC',
     2/10X,'TIME-TOUCHDOWN TO DECEL',T40,2F10.0,T65,'SECONDS',
     2/10X,'DECELERATION RATE',T40,2F10.2,T65,'FT/SEC**2',
```

```
     3/10X,'50%PROBABILITY SPEED',T40,2F10.0,T65,'FT/SEC',
     3/10X,'DIST:THRESHOLD-START OF TURN',T40,F10.0,T65,'FEET',
     4/10X,'SPEED AT MAJOR DECEL REDUCE',T40,F10.0,T65,'FT/SEC',
     5/10X,'NOSE-WINGTIP DIST',T40,F10.0,T65,'FEET',//)
  750  READ(2,20) SND
   20  FORMAT(10F5.4)
       YAPERM = YA
C
C      CALCULATE DISTANCES
C
        A = UA + VA*WA
       B = A + (VA**2-ZA**2)/(2.*XA)
C
C      CALCULATE SPEEDS DURING LANDING
C
       ASB = (VA**2-2*XA*(B-A))**0.5
       IF(VA**2.GT.(2*XA*(C-A))) GO TO 825
       WRITE(IWRT,821)
  821  FORMAT('   SPEED AT EXIT IS NEGATIVE')
       STOP
  825  CONTINUE
       ICK=1
  600  FORMAT(' AT POSITION ',I2)
       IF(IPRT.EQ.2)WRITE(5,600)ICK
       ICK=2
       ASC = (VA**2-2*XA*(C-A))**0.5
```

```
      ASCSV = ASC
C
C     CALL EXPATH TO DETERMINE EXIT PATH
C            TIME AND DISTANCE
C
      CALL EXPATH(ASC,PTIME,XDIST,IWRT,IPRT,IFLAG)
C
C     UPON RETURNING FROM EXPATH,THE VALUE OF ASC
C     (AVG SPEED AT START OF TURN)HAS BEEN REDIFINED
C     TO SPEED AT END OF TURN.AFTER THIS POINT,
C     AVG SPEED AT START OF TURN HAS BEEN REDIFINED AS 'ASCSV'
C
      TDIST= C + XDIST
  500 CONTINUE
      MS=0
      MSP=1
      ASC2=YAPERM-(1.5*YS)
      IF(ASCSV.LT.ASC2)MS=1
      IF(IPRT.EQ.2)WRITE(5,600) ICK
      ICK = 3
C
C     CALCULATE STANDARD DEVIATION
C
      SDA= (VS**2+(US*XA/VA)**2 + (WS*XA)**2)**0.5
      IF(IPRT.EQ.2)WRITE(5,600)ICK
      ICK=4
```

```
         SDB=(SDA**2 +( 2*XS*(B-A)/(VA+ZA))**2)**0.5
         IF(IPRT.EQ.2)WRITE(5,600)ICK
         ICK=5
         SDC= (SDA**2 + (2*XS*(C-A)/(VA+ASCSV))**2)**0.5
         IF(IPRT.EQ.2)WRITE(5,600)ICK
         ICK=6
C
C        CALCULATE OCCUPANCY TIMES
c
         ASA=VA
         TA = ((UA+NTIP)/VA) + WA
         IF(B.GT.C) GO TO 100
         TB = TA + 2*(B-A)/(ASA+ASB)
         TC = TB + 2*(C-B)/(ASB+ASCSV)
         GO TO 110
  100    TC = TA + 2*(C-A)/(ASA+ASCSV)
  110    CONTINUE
C        CALCULATE DATA FOR AIRCRAFT TRAVELING
C        ONE STANDARD DEVIATION BELOW NORM
C
C        CALCULATE DISTANCES
C
         AP = A
         BP = AP + (B-A)*((ASA-SDA)-ZA)/((ASA-SDA)-(ZA-SDB))
         CP = C
C
```

```
C       CALCULATE SPEEDS
C
        ASAP = ASA - SDA
        ASBP = ZA
        ASCP = ASCSV - SDC
        ASCP1 = YA - 1.5*YS
        IF(ASPC1.GT.ASCP)MSP=2
C
C       CALCULATE OCCUPANCY TIME
C
        TAP = 2*A/(VA-VS+ASAP)
        IF(BP.GT.CP) GO TO 120
        TBP = TAP + 2*(BP-AP)/(ASAP+ASBP)
        TCP = TBP + 2*(CP-BP)/(ASBP+ASCP)
        GO TO 130
 120    TCP =TAP +2*(CP-AP)/(ASAP+ASCP)
 130    SDOT = TCP - TC
        IF(SDOT.GT.0.) GO TO 900
        WRITE(*,901)
 901    FORMAT('/STANDARD DEVIATION LESS THAN ZERO')
        STOP
 900    CONTINUE
C
C
C       WRITE INTERMEDIATE VALUES FOR CHECKOUT
C
```

```
        IF(IPRT.NE.2) GO TO 138
        WRITE(IWRT,135)A,B,ASB,ASC,SDA,SDB,SDC,ASA,TA,TB,TC
  135   FORMAT(' INTERMEDIATE RESULTS IN ORDER:'/,
     1' A,B,ASB,ASC,SDA,SDB,SDC,ASA,TA,TB,TC'/,' AP,BP,CP,ASAP,ASBP,'
     2'ASCP,TAP TAP,TBP,TCP,SDOT',//11F8.2)
        WRITE(IWRT,136)AP,BP,CP,ASAP,ASBP,ASCP,TAP,TBP,TCP,SDOT
  136   FORMAT(10F8.2)
C
C       CALCULATE PERCENT AIRCRAFT EXITING
C
C       SPECIFY ARBITRARY SPEED RANGE
C
  138   CONTINUE
        ITEMP = ASCSV-3.
        ARBS(1) =ITEMP
        DO 140 I=2,16
  140   ARBS(I) = ARBS(I-1) + 1.
C
C       CALCULATE PROBABILITY FOR SPEED RANGE
C
        DO 150 I=1,15
        Z(I)=(ARBS(I)-ASCSV)/SDC
        IF(ABS(Z(I)).GT.3.99)Z(I)=3.99
        ZZ=(ABS(Z(I))+0.01)*100.
        ICNT=ZZ
        P(I)=0.5+SND(ICNT)
```

```
      IF(Z(I).LT.0.)P(I)=0.5-SND(ICNT)
 150  CONTINUE
C
C     CALCULATE DISCRETE INTERVALS
C
      DP(1) = P(1)
      TOT = P(1)
      DO 160 I=2,15
      DP(I) = P(I) - P(I-1)
 160  TOT = TOT + DP(I)
      DP(16) =1.-TOT
C
C     CALCULATE PROBABILITY OF EXITING
C
      DO 170 I=1,16
      ZEX(I) = (YA-(ARBS(I)-0.5))/YS
      IF(ZEX(I).GT.3.99) ZEX(I)=3.99
      IF(ZEX(I).LT.-3.99) ZEX(I)=-3.99
      ZZ=(ABS(ZEX(I))+0.01)*100.
      ICNT=ZZ
      PEX(I)=0.5+SND(ICNT)
      IF(ZEX(I).LT.0.)PEX(I)=0.5-SND(ICNT)
 170  CONTINUE
C
C     CALCULATE DISCRETE PROBABILITY AND SUM
C
```

```
      PX = 0.
      DO 180 I=1,16
      DPX(I) = DP(I)*PEX(I)
 180  PX = PX + DPX(I)
C
C     WRITE INTERMEDIATE VALUES
C
      IF(IPRT.NE.2) GO TO 185
      WRITE(IWRT,181)
 181  FORMAT(/T10,' PERCENT AIRCRAT EXITING CALC'/,'  ARBS'
     1,T13,'Z',T21,'P',T29,'DP',T37,'ZEX',T45,'PEX',T53,'DPX'/)
      DO 184 I=1,16
      WRITE(IWRT,183) DP(I),ZEX(I),PEX(I),DPX(I)
  184 WRITE(IWRT,187)ARBS(I),Z(I),P(I)
 183  FORMAT(24X,F8.4,F8.3,2F8.4)
 187  FORMAT(F8.1,F8.3,F8.4)
      WRITE(IWRT,188)PX
 188  FORMAT(/T10,' PERCENT AIRCRAFT EXITING = ',T43,F10.4)
 185  CONTINUE
C
C     CALCULATE MINIMUM OCCUPANCY TIME
C
      PXC =ABS(PX-0.5)
      DO 145 I=1,400
 145  IF((PXC.GT.SND(I)).AND.(PXC.LE.SND(I+1))) GO TO 146
      WRITE(*,147)
```

```
 147    FORMAT('/PX VALUE NOT FOUND')
        STOP
 146    BAN=I
        PXCH=BAN/100.
        OTMIN = TC-PXCH*SDOT
        IF(IPRT.EQ.2)WRITE(IWRT,191)OTMIN
 191    FORMAT(T10,' MINIMUM OCCUPANCY TIME=',T43,F10.2,' SEC')
C
C       CALCULATE AVERAGE RUNWAY OCCUPANCY TIME
C
C
C       INITIALIZE ARBITRARY OCCUPANCY TIME
C
        ITMIN=OTMIN
        ARBT(1) = ITMIN
        DO 190 I=2,15
        ARBT(I) = ARBT(I-1) + 1.
 190    CONTINUE
        ARBT(1)=OTMIN
C
C       COMPUTE Z VALUES
C
        DO 200 I=1,15
        ZROT(I) = (ARBT(I)-TC)/SDOT
        IF(ABS(ZROT(I)).GT.3.99) GO TO 201
        ZZ=(ABS(ZROT(I))+0.01)*100.
```

```
        ICNT=ZZ
        P(I)=0.5+SND(ICNT)
        IF(ZROT(I).LT.0.)P(I)=0.5-SND(ICNT)
 200    CONTINUE
 201    IBAN=I-1
C
C       CALCULATE INTERVALE MIDPOINTS
C
        ARBI(1) = (ARBT(1)+ARBT(2))/2.
        DO 210 I=2,IBAN
 210    ARBI(I) = ARBT(I) + 0.5
C
C       CALCULATE DISCRETE PROBABILITY AND SUM
C
        PSUM=0.
        TSUM=0.
        P(IBAN+1)=1.
        DO 220 I=1,IBAN
        DP(I) = P(I+1) - P(I)
        DT(I) =DP(I)*ARBI(I)
        PSUM = DP(I) + PSUM
        TSUM = DT(I) + TSUM
 220    CONTINUE
        AROTEX = TSUM /PSUM
C
```

```
C      WRITE FINAL PARAMETERS
C
       IF(IPRT.NE.2)GO TO 230
       WRITE(IWRT,231)
 231   FORMAT(/ ' AVERAGE RUNWAY OCCUPANCY TIME CALC ',/,
     1' ARBT',T12,'ZROT',T21,'P' ,T29,'ARBI',T37,'DP',T45,'DT'/)
       DO 232 I=1,IBAN
       WRITE(IWRT,233) ARBT(I),ZROT(I),P(I)
 232   WRITE(IWRT,234)ARBI(I),DP(I),DT(I)
 233   FORMAT(F8.2,F8.3,F8.4)
 234   FORMAT(24X,F8.2,F8.4,F8.3)
       WRITE(IWRT,235)PSUM,TSUM
 235   FORMAT(/' AREA SUM=',T20,F10.4,/' TIME SUM=',T20,F10.2)
       WRITE(IWRT,238)AROTEX
 238   FORMAT(T10,' AVERAGE RUNWAY OCCUPANCY TIME=',T43,F10.2,'SEC')
 230   CONTINUE
C
C      CALCULATE XTIME AND TTIME
C
       XTIME=AROTEX+3.9*SDOT
       TTIME=XTIME+PTIME
       IF(IPRT.EQ.2)WRITE(IWRT,651)SDOT
 651   FORMAT(T10,' STANDARD DEVIATION=',T43,F10.2,' SEC')
       IF(IPRT.EQ.2)WRITE(IWRT,650)XTIME
 650   FORMAT(T10' AVG TIME PLUS 3 STD DEV='T43,F10.2,'SEC')
       WRITE(3,700) PX,AROTEX,SDOT,XTIME,TTIME,YA,MS,MSP
```

```
        IF(IYA.EQ.3) WRITE(*,827) PX
827     FORMAT(' PROB=',F7.4)
        IF((XTIME.LT.39.99).OR.(XTIME.GT.40.01)) GO TO 800
810     CONTINUE
        PXX=PX*100.
        WRITE(IWRT,853)PXX
853     FORMAT(/T10,' PERCENT AIRCRAFT EXITING= ',T43,F10.4)
        WRITE(IWRT,238)AROTEX
        WRITE(IWRT,651) SDOT
        WRITE(IWRT,650) XTIME
        WRITE(IWRT,850) YA
850     FORMAT(T10,' FINAL 50% PROBABILITY SPEED=',T43,F10.2,' M/SEC')
        WRITE(IWRT,852) ASCSV
852     FORMAT(T10,' AVERAGE SPEED At EXIT=',T43,F10.2,'M/SEC')
        WRITE(IWRT,851) IBIRD
851     FORMAT(T20,' PERFORMED IN ',I3,' ITERATIONS'/)
        GO TO 801
800     CONTINUE
        IF(IYA.EQ.1) YA=YA*XTIME/40.
        IF(IYA.EQ.2) YA=YA-1.
        IF(IYA.LT.3) GO TO 824
        WRITE(*,823)
823     FORMAT('      ENTER NEW YA SPEED;   999 TO END')
        READ(*,*)YA
        IF(YA.EQ.999.) GO TO 801
700     FORMAT(6F12.4,2A1)
```

```
824    IBIRD=IBIRD+1
       IF(IBIRD.LT.15) GO TO 500
801    CONTINUE
       WRITE(IWRT,820)
820    FORMAT(/'     CALCULATED RESULTS'/)
       WRITE(IWRT,822) ASCSV,ASC,PTIME,C,XDIST,TDIST
822    FORMAT(/'      CRITICAL VALUES:'/,T10,'ASCSV',T25,'ASC',T40,
    1'PTIME',T55,'CDIST',T70,'XDIST',T85,'TDIST'/,T5,6(F10.2,5X))
       WRITE(IWRT,807)
807    FORMAT(//6X,'PROB',T18,'AVG TIME',T30,'STD DEV',T42,'XTIME',T54,
    1'TTIME',T66,'YA'/)
       CLOSE(UNIT=3)
       OPEN(3,FILE='SOLVIT.DAT',STATUS='OLD')
803    READ(3,700,END=808)Q1,Q2,Q3,Q4,Q5,Q6,Q7,Q8
       WRITE(IWRT,700)Q1,Q2,Q3,Q4,Q5,Q6,Q7,Q8
       GO TO 803
808    WRITE(*,920)
920    FORMAT(/ '      DO YOU WANT TO CONTINUE EXIT PATH TO TAXI-WAY '/
    1'      1=YES, 2=NO .')
       READ(*,*)INASA
       IF (INASA.EQ.2) STOP
       IFLAG=1
       CALL EXPATH(ASCSV,PTIME,XDIST,IWRT,IPRT,IFLAG)
       STOP
```

```
        END
C$ENTRY
C$STOP
```

<u>SUBROUTINE</u>

```
$DEBUG
C$JOB
        SUBROUTINE EXPATH(V,PTIME,XDIST,IWRT,IPRT,IFLAG)
        DIMENSION RSCR(20), YMUSCR(20)
        DIMENSION XP(100),YP(100)
        INTEGER*4 IDO
        REAL JMAX
        OPEN(4,FILE='PATH.DAT')
C
C       READ INPUT PARAMETERS
C
        READ(4,10) WT,YAWI,WHLB,PCTM
        READ(4,10) THETMX,YMUMAX,DECEL
        READ(4,10) RWIDTH, WSP, TAXDIS
        TWTH= (RWIDTH+WSP)/2.
 10     FORMAT(4F12.3)
        DO 20 I=1,20
 20     READ(4,11,END=30) YMUSCR(I),RSCR(I)
 11     FORMAT(F5.4,G10.1)
 30     ICNT=I-1
        REWIND 4
C       CLOSE(UNIT=4)
        IF(IPRT.EQ.3.OR.IFLAG.EQ.1) GO TO 37
        WRITE(IWRT,35)
 35     FORMAT(/T32,'AIRCRAFT TRACKING PROGRAM'//)
        WRITE(IWRT,50) WT,YAWI,WHLB,PCTM
```

```
      WRITE(IWRT,60) V, THETMX, YMUMAX,DECEL
      WRITE(IWRT,75) RWIDTH,WSP,TWTH,TAXDIS
      WRITE(IWRT,70)
      WRITE(IWRT,80) YMUSCR(1),RSCR(1)
      WRITE(IWRT,81) (YMUSCR(I),RSCR(I), I=2,ICNT)
 50   FORMAT(T5,'AIRCRAFT CHARACTERISTICS'/,T10,'WEIGHT(LBS)',T25
     1,'YAW INERTIA',T43,'WHEELBASE',T57,'% LOAD ON MAIN GEAR',/
     2T10,4(F12.1,3X)/)
 60   FORMAT('     FLIGHT CONDITIONAL PARAMETERS'/,T10,
     1'EXIT VELOCITY',T25,'MAX EXIT ANGLE',T45,'MAX Y MU',
     2T60,'DECEL RATE',/
     2T10,4(F10.3,5X)/)
 70   FORMAT(/'      SCRUB CHARACTERISTICS'/,T10,'Y MU',T20,'RADIUS'/)
 75   FORMAT('      SYSTEM WIDTHS'/,T15,'RUNWAY',T28,'WINGSPAN',
     1T42,'CLEAR DIST.',T61,'DIST TO TAXIWAY'/T10,3(F10.2,5X),T61,F10.2)
 80   FORMAT(T5,F10.4,G10.1)
 81   FORMAT(T5,F10.4,f10.1)
C
 37   JMAX=10.0E20
      GMAX=10.0E20
C     INITIALIZE VARIABLES
C
 85   CONTINUE
      IF(IFLAG.EQ.1) THETMX=180.
      IF(IFLAG.EQ.1) TWTH=TAXDIS
      G=0.000001
```

```
      T=0.0
      X=0.0
      Y=0.0
      THETA=0.0
      R=100000.
      IPRINT=10000
      THETMX=THETMX*3.1416/180.
      DT=0.001
C
C     CONSTANT NLG SIDE MU
C
      ITR=2
      IF(IPRT.EQ.3.OR.IFLAG.EQ.1) GO TO 810
      WRITE(*,800)
 800  FORMAT(/' ENTER: 1 TO PRINT TRACKINNG RESULTS TO RUNWAY EDGE ',/
     1       '        2 TO WAIT FOR PRINT TO TAXIWAY EDGE')
      READ(*,*) ITR
 810  CONTINUE
      IF(IFLAG.EQ.1) ITR=1
      IF(ITR.EQ.1) WRITE(IWRT,8010)
      IF(ITR.EQ.1) WRITE(IWRT,96)
      IF(ITR.EQ.1) WRITE(IWRT,8011)
      DO 200 IDO=1,60000
      DO 90 J=2,ICNT
 90   IF(R.GE.RSCR(J)) GO TO 92
 92   JJ=J-1
```

```
      YMUSC=YMUSCR(JJ)+(YMUSCR(J)-YMUSCR(JJ))*(RSCR(JJ)-R)
     1 /(RSCR(JJ)-RSCR(J))
      IF(RSCR(J).LE.0.) WRITE(IWRT,8001)
      IF(R.GT.RSCR(1)) WRITE(IWRT,8001)
      IF(RSCR(J).LE.0.OR.R.GT.RSCR(1)) STOP
      YMUC = V**2/(32.2*R)
      YMUI = YMUMAX-YMUSC-YMUC
      RD =-(YMUI*R**2/(YAWI*V))*WT*WHLB*(PCTM/100.)*(1.-PCTM/100.)
      G=V**2/(R*32.2)
      GDMX=JMAX*(1.-G/GMAX)
      RDMX =-32.2*R**2*GDMX/V**2
      IF(Y.GE.TWTH) GO TO 500
      IF(IPRINT.LT.500) GO TO 110
  100 TH = THETA*180./3.1416
      IBC=IBC+1
      XP(IBC)=X
      YP(IBC)=Y
      IF(ITR.EQ.1) WRITE(IWRT,8000) T,X,Y,TH,R,RD,YMUSC,YMUC,YMUI,G,V
      IF(RD.EQ.RDMX) WRITE(IWRT,8002)
      IPRINT=0
  110 CONTINUE
C
C     INTEGRATE
C
      T=T+DT
      V=V+DECEL*DT
```

```
      IPRINT=IPRINT+1
      X=X+V*DT*COS(THETA)
      Y=Y+V*DT*SIN(THETA)
      THETAD=V/R
      THETA=THETA+THETAD*DT
      R=R+RD*DT
 200  CONTINUE
C
C     PRINT FINAL TIME VALUE
C
 500  IF(THETA.LE.THETMX) GO TO 520
      WRITE(*,9000)
 9000 FORMAT(//'  WARNING!!  WINTIP NOT CRITICAL POINT!'//)
      STOP
 520  IF(ITR.EQ.1) WRITE(IWRT,8600)
 8600 FORMAT(//'    FINAL VALUES'/)
      IF(ITR.EQ.1) WRITE(IWRT,8000)T,X,Y,TH,R,RD,YMUSC,YMUC,YMUI,G,V
      PTIME=T
      XDIST=X
C
C     FORMAT LIST
C
 96   FORMAT('/    PASSENGER CONFORT IGNORED')
 8000 FORMAT(4F10.3,2F12.2,5F10.3//)
 8001 FORMAT(1H ,'***OUT OF TABLE BOUND***')
 8002 FORMAT(' LIMITED BY CONFORT')
```

```
 8010   FORMAT(//'   CONSTANT NLG SIDE LOAD ANALYSIS')
 8011   FORMAT(//T5,'TIME',T17,'X',T27,'Y',T35,'THETA',T46,'RADIUS',T58,
     1'R RATE',T68,'MU SCRUB',T81,'MU CENT',T92,'MU I',T102,'G CENT'
     1,T113,'VELOCITY'/)
        RETURN
        END
C$ENTRY
C$STOP
```

APPENDIX B. COMPUTER OUTPUTS

OPTIMAL EXIT LOCATIONS

COMPUTER OUTPUTS

OPTIMAL EXIT LOCATIONS

GENERIC AIRCRAFT AS

```
                               NASA HIGH SPEED ANALYSIS
                                    INPUT SUMMARY,
                                  PROBABILISTIC MODEL
                                          AVERAGE    STD DEV     UNITS,
          TOUCHDOWN LOCATION                 500.        10.     FEET
          TOUCHDOWN SPEED                     66.         5.     FT/SEC
          TIME-TOUCHDOWN TO DECEL              3.         1.     SECONDS
          DECELERATION RATE                  2.50       1.00     FT/SEC**2
          50%PROBABILITY SPEED                52.         1.     FT/SEC
          DIST:THRESHOLD-START OF TURN      1286.                FEET
          SPEED AT MAJOR DECEL REDUCE         55.                FT/SEC
          NOSE-WINGTIP DIST                   39.                FEET
                               AIRCRAFT TRACKING PROGRAM
    AIRCRAFT CHARACTERISTICS
     WEIGHT(LBS)    YAW INERTIA       WHEELBASE     % LOAD ON MAIN GEAR
               2040.0         2310.0           5.3           72.0
     FLIGHT CONDITIONAL PARAMETERS
         EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU       DECEL RATE
             37.630         90.000           .250         -1.500
      SYSTEM WIDTHS
           RUNWAY       WINGSPAN      CLEAR DIST.        DIST TO TAXIWAY
             150.00          32.00          91.00               600.00
      SCRUB CHARACTERISTICS
         Y MU      RADIUS
         .0000    .1E+32
         .0200      50.0
   CONSTANT NLG SIDE LOAD ANALYSIS
       TIME      X         Y       THETA   RADUIS    R RATE        MU SCRUB    MUCENT     MUI      GCENT  VELOCITY
      .000      .000      .000      .000   100000.00-57563830.00      .020      .000      .230      .000    37.630
      .500    18.626      .151     1.329      439.42     -661.36      .020      .096      .134      .096    36.880
     1.000    36.855     1.036     4.474      274.66     -162.32      .020      .148      .082      .148    36.131
     1.500    54.613     3.059     8.683      221.07      -70.58      .020      .176      .054      .176    35.381
     2.000    71.786     6.415    13.542      194.62      -39.86      .020      .191      .039      .191    34.631
     2.500    88.233    11.174    18.821      178.39      -26.72      .020      .200      .030      .200    33.882
     3.000   103.807    17.331    24.392      166.81      -20.30      .020      .204      .026      .204    33.132
     3.500   118.361    24.828    30.183      157.59      -16.89      .020      .207      .023      .207    32.383
     4.000   131.755    33.572    36.156      149.67      -14.95      .020      .208      .022      .208    31.633
     4.500   143.863    43.443    42.287      142.52      -13.75      .020      .208      .022      .208    30.883
     5.000   154.568    54.299    48.568      135.85      -12.96      .020      .208      .022      .208    30.134
     5.500   163.775    65.977    54.995      129.52      -12.38      .020      .207      .023      .207    29.384
     6.000   171.404    78.304    61.566      123.45      -11.92      .020      .206      .024      .206    28.635
    FINAL VALUES
     6.497   177.365    91.013    61.566      117.63      -11.53      .020      .205      .025      .205    27.890
```

```
CALCULATED RESULTS
 CRITICAL VALUES:
    ASCSV          ASC            PTIME         CDIST          XDIST          TDIST
    37.63          27.89           6.50        1286.00         177.37        1463.37

 PROB       AVG TIME    STD DEV     XTIME       TTIME       YA
 1.0000     22.3087      2.8087     33.2626     39.7593     52.0000
  .9987     22.5098      2.8087     33.4637     39.9604     51.0000
```

GENERIC AIRCRAFT AF

```
                            NASA HIGH SPEED ANALYSIS
                                 INPUT SUMMARY,
                               PROBABILISTIC MODEL
                                       AVERAGE    STD DEV    UNITS,
          TOUCHDOWN LOCATION              500.        10.    FEET
          TOUCHDOWN SPEED                 118.         5.    FT/SEC
          TIME-TOUCHDOWN TO DECEL          3.          1.    SECONDS
          DECELERATION RATE               2.50       1.00    FT/SEC**2
          50%PROBABILITY SPEED             95.         1.    FT/SEC
          DIST:THRESHOLD-START OF TURN   2355.               FEET
          SPEED AT MAJOR DECEL REDUCE      55.               FT/SEC
          NOSE-WINGTIP DIST                40.               FEET
                            AIRCRAFT TRACKING PROGRAM
    AIRCRAFT CHARACTERISTICS
         WEIGHT(LBS)    YAW INERTIA       WHEELBASE     % LOAD ON MAIN GEAR
              24000.0      300000.0            23.0            93.0
     FLIGHT CONDITIONAL PARAMETERS
         EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU       DECEL RATE
             80.119         41.000            .250         -2.000
      SYSTEM WIDTHS
             RUNWAY        WINGSPAN      CLEAR DIST.         DIST TO TAXIWAY
             150.00          42.00          96.00               600.00
      SCRUB CHARACTERISTICS
         Y MU       RADIUS
         .0000     .1E+32
         .0200       50.0
   CONSTANT NLG SIDE LOAD ANALYSIS
/    PASSENGER CONFORT IGNORED
    TIME         X          Y        THETA      RADIUS      R RATE    MU SCRUB    MU CENT    MU I      G CENT     VELOCITY
      .000      .000       .000       .000   100000.00 -3408886.00      .020       .002      .228      .002      80.119
      .500    39.809       .051       .209     5870.30   -10271.80      .020       .033      .197      .033      79.119
     1.000    79.117       .363       .754     3221.61    -2724.04      .020       .059      .171      .059      78.120
     1.500   117.918      1.139      1.583     2303.77    -1235.06      .020       .080      .150      .080      77.120
     2.000   156.202      2.543      2.659     1837.93     -702.15      .020       .098      .132      .098      76.121
     2.500   193.949      4.708      3.946     1555.88     -453.01      .020       .113      .117      .113      75.121
     3.000   231.135      7.741      5.416     1366.35     -317.16      .020       .125      .105      .125      74.122
     3.500   267.728     11.727      7.046     1229.78     -235.29      .020       .135      .095      .135      73.123
     4.000   303.691     16.728      8.817     1126.23     -182.35      .020       .143      .087      .143      72.123
     4.500   338.984     22.792     10.710     1044.60     -146.30      .020       .150      .080      .150      71.124
     5.000   373.560     29.951     12.713      978.17     -120.75      .020       .156      .074      .156      70.124
     5.500   407.372     38.226     14.814      922.69     -102.05      .020       .161      .069      .161      69.125
     6.000   440.370     47.623     17.002      875.33      -88.02      .020       .165      .065      .165      68.125
     6.500   472.502     58.141     19.270      834.11      -77.27      .020       .168      .062      .168      67.126
     7.000   503.717     69.768     21.611      797.66      -68.87      .020       .170      .060      .170      66.126
     7.500   533.963     82.484     24.018      764.95      -62.21      .020       .172      .058      .172      65.127
    FINAL VALUES
     7.991   562.672     96.005     24.018      735.74      -56.93      .020       .174      .056      .174      64.145
     CALCULATED RESULTS
      CRITICAL VALUES:
         ASCSV          ASC           PTIME        CDIST        XDIST        TDIST
         80.12          64.15          7.99       2355.00       562.67      2917.67
```

```
PROB        AVG TIME     STD DEV      XTIME        TTIME        YA
 .9999      22.7291       1.8695      30.0200      38.0106      95.0000
```

```
                              NASA HIGH SPEED ANALYSIS
                                   INPUT SUMMARY,
                                 PROBABILISTIC MODEL
                                          AVERAGE    STD DEV    UNITS,
          TOUCHDOWN LOCATION                 500.        10.    FEET
          TOUCHDOWN SPEED                    118.         5.    FT/SEC
          TIME-TOUCHDOWN TO DECEL              3.         1.    SECONDS
          DECELERATION RATE                  2.50       1.00    FT/SEC**2
          50%PROBABILITY SPEED                94.         1.    FT/SEC
          DIST:THRESHOLD-START OF TURN      2360.               FEET
          SPEED AT MAJOR DECEL REDUCE         55.               FT/SEC
          NOSE-WINGTIP DIST                   40.               FEET
                              AIRCRAFT TRACKING PROGRAM
    AIRCRAFT CHARACTERISTICS
         WEIGHT(LBS)    YAW INERTIA      WHEELBASE     % LOAD ON MAIN GEAR
              24000.0      300000.0          23.0           93.0
     FLIGHT CONDITIONAL PARAMETERS
         EXIT VELOCITY  MAX EXIT ANGLE     MAX Y MU       DECEL RATE
             79.962         41.000           .250          -2.000
      SYSTEM WIDTHS
              RUNWAY        WINGSPAN     CLEAR DIST.        DIST TO TAXIWAY
             150.00          42.00         96.00                600.00
      SCRUB CHARACTERISTICS
         Y MU      RADIUS
         .0000    .1E+32
         .0200      50.0
   CONSTANT NLG SIDE LOAD ANALYSIS
/    PASSENGER CONFORT IGNORED
    TIME        X          Y        THETA      RADIUS       R RATE    MU SCRUB     MU CENT      MU I        G CENT      VELOCITY
      .000      .000       .000      .000   100000.00 -3415659.00       .020        .002       .228        .002     79.962
      .500    39.731       .051      .209     5858.47   -10254.00       .020        .033       .197        .033     78.963
     1.000    78.961       .363      .754     3214.48    -2719.10       .020        .059       .171        .059     77.964
     1.500   117.684      1.137     1.584     2298.31    -1232.82       .020        .080       .150        .080     76.964
     2.000   155.889      2.538     2.660     1833.32     -700.89       .020        .098       .132        .098     75.965
     2.500   193.559      4.699     3.947     1551.77     -452.21       .020        .112       .118        .112     74.965
     3.000   230.667      7.728     5.418     1362.57     -316.62       .020        .125       .105        .125     73.966
     3.500   267.182     11.706     7.050     1226.23     -234.90       .020        .135       .095        .135     72.966
     4.000   303.067     16.699     8.821     1122.86     -182.05       .020        .143       .087        .143     71.967
     4.500   338.282     22.753    10.717     1041.35     -146.06       .020        .150       .080        .150     70.967
     5.000   372.781     29.902    12.721      975.03     -120.56       .020        .156       .074        .156     69.968
     5.500   406.516     38.163    14.824      919.64     -101.89       .020        .161       .069        .161     68.969
     6.000   439.437     47.546    17.015      872.35      -87.89       .020        .164       .066        .164     67.969
     6.500   471.492     58.047    19.286      831.20      -77.15       .020        .168       .062        .168     66.970
     7.000   502.631     69.656    21.629      794.80      -68.76       .020        .170       .060        .170     65.970
     7.500   532.800     82.353    24.039      762.14      -62.11       .020        .172       .058        .172     64.971
    FINAL VALUES
     7.997   561.778     96.024    24.039      732.64      -56.78       .020        .174       .056        .174     63.977
     CALCULATED RESULTS
      CRITICAL VALUES:
         ASCSV          ASC          PTIME          CDIST          XDIST          TDIST
         79.96          63.98         8.00        2360.00         561.78        2921.78
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PROB       AVG TIME    STD DEV     XTIME       TTIME       YA
 .9999     22.5485      2.7898     33.4289     41.4255     94.0000
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GENERIC AIRCRAFT BS

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                              NASA HIGH SPEED ANALYSIS
                                   INPUT SUMMARY,
                                 PROBABILISTIC MODEL
                                         AVERAGE    STD DEV    UNITS,
          TOUCHDOWN LOCATION               1000.       20.     FEET.
          TOUCHDOWN SPEED                   110.       10.     FT/SEC
          TIME-TOUCHDOWN TO DECEL             4.        1.     SECONDS
          DECELERATION RATE                4.00       .50      FT/SEC**2
          50%PROBABILITY SPEED               88.        1.     FT/SEC
          DIST:THRESHOLD-START OF TURN     2285.               FEET
          SPEED AT MAJOR DECEL REDUCE        90.               FT/SEC
          NOSE-WINGTIP DIST                  34.               FEET
                              AIRCRAFT TRACKING PROGRAM
      AIRCRAFT CHARACTERISTICS
           WEIGHT(LBS)   YAW INERTIA       WHEELBASE     % LOAD ON MAIN GEAR
                24000.0    300000.0            23.0            93.0
       FLIGHT CONDITIONAL PARAMETERS
           EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU       DECEL RATE
               73.075       38.000             .250        -1.500
        SYSTEM WIDTHS
                RUNWAY        WINGSPAN      CLEAR DIST.         DIST TO TAXIWAY
               150.00          36.00          93.00               600.00
        SCRUB CHARACTERISTICS
           Y MU       RADIUS
           .0000    .1E+32
           .0230      50.0
     CONSTANT NLG SIDE LOAD ANALYSIS
/      PASSENGER CONFORT IGNORED
      TIME        X          Y         THETA       RADIUS       R RATE      MU SCRUB      MU CENT      MU I       G CENT       VELOCITY
        .000       .000       .000       .000   100000.00 -3693768.00        .023          .002       .225        .002     73.075
        .500     36.349       .046       .206     5415.26    -9568.13        .023          .030       .197        .030     72.324
       1.000     72.322       .329       .748     2953.06    -2526.77        .023          .054       .173        .054     71.572
       1.500    107.912      1.037      1.581     2102.48    -1143.27        .023          .074       .153        .074     70.821
       2.000    143.110      2.329      2.666     1671.65     -648.67        .023          .091       .136        .091     70.069
       2.500    177.898      4.334      3.972     1411.37     -417.44        .023          .106       .121        .106     69.318

       3.000    212.252      7.161      5.471     1236.98     -291.28        .023          .118       .109        .118     68.566
       3.500    246.140     10.896      7.140     1111.80     -215.15        .023          .128       .099        .128     67.815
       4.000    279.527     15.608      8.959     1017.36     -165.84        .023          .137       .090        .137     67.063
       4.500    312.370     21.353     10.912      943.34     -132.19        .023          .145       .082        .145     66.312
       5.000    344.624     28.170     12.982      883.53     -108.28        .023          .151       .076        .151     65.560
       5.500    376.238     36.086     15.159      833.98      -90.75        .023          .156       .071        .156     64.809
       6.000    407.159     45.118     17.431      792.05      -77.55        .023          .161       .066        .161     64.057
       6.500    437.335     55.273     19.790      755.91      -67.40        .023          .165       .062        .165     63.308
       7.000    466.710     66.547     22.227      724.27      -59.46        .023          .168       .059        .168     62.558
       7.500    495.226     78.929     24.736      696.18      -53.14        .023          .170       .057        .170     61.808
       8.000    522.828     92.400     27.312      670.92      -48.06        .023          .173       .054        .173     61.059
      FINAL VALUES
       8.022    524.021     93.017     27.312      669.86      -47.86        .023          .173       .054        .173     61.026
       CALCULATED RESULTS
        CRITICAL VALUES:
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   ASCSV          ASC           PTIME          CDIST          XDIST         TDIST
   73.08          61.03          8.02        2285.00         524.02       2809.02
PROB       AVG TIME    STD DEV     XTIME       TTIME       YA
1.0000     22.6144      2.3934     31.9487     39.9703     88.0000
 .9989     22.6391      2.3934     31.9733     39.9949     87.0000
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GENERIC AIRCRAFT BF

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                              NASA HIGH SPEED ANALYSIS
                                   INPUT SUMMARY,
                                 PROBABILISTIC MODEL
                                         AVERAGE    STD DEV    UNITS,

          TOUCHDOWN LOCATION                1000.       20.      FEET
          TOUCHDOWN SPEED                    164.       10.      FT/SEC
          TIME-TOUCHDOWN TO DECEL              4.        1.      SECONDS
          DECELERATION RATE                 4.00       .50      FT/SEC**2
          50%PROBABILITY SPEED               119.        1.      FT/SEC
          DIST:THRESHOLD-START OF TURN      3654.                FEET
          SPEED AT MAJOR DECEL REDUCE        155.                FT/SEC
          NOSE-WINGTIP DIST                   56.                FEET
                              AIRCRAFT TRACKING PROGRAM
    AIRCRAFT CHARACTERISTICS
         WEIGHT(LBS)    YAW INERTIA       WHEELBASE      % LOAD ON MAIN GEAR
              48000.0       800000.0           36.0             95.0
     FLIGHT CONDITIONAL PARAMETERS
         EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU       DECEL RATE
            104.461         38.000            .250          -1.500
      SYSTEM WIDTHS
              RUNWAY       WINGSPAN      CLEAR DIST.         DIST TO TAXIWAY
             150.00         49.00          99.50               600.00
      SCRUB CHARACTERISTICS
         Y MU       RADIUS
         .0000     .1E+32
         .0230       50.0
   CONSTANT NLG SIDE LOAD ANALYSIS
/    PASSENGER CONFORT IGNORED
    TIME         X          Y        THETA       RADIUS      R RATE     MU SCRUB      MU CENT     MU I       G CENT      VELOCITY
      .000      .000       .000       .000    100000.00 -2196285.00       .023         .003       .224        .003   104.461
      .500    52.042       .061       .186      8924.04   -14935.64       .023         .037       .190        .037   103.709
     1.000   103.707       .418       .649      5023.10    -4059.80       .023         .066       .161        .066   102.958
     1.500   154.990      1.294      1.347      3651.38    -1849.04       .023         .089       .138        .089   102.206
     2.000   205.879      2.873      2.242      2954.43    -1048.71       .023         .108       .119        .108   101.455
     2.500   256.359      5.306      3.305      2534.31     -672.23       .023         .124       .103        .124   100.703
     3.000   306.406      8.713      4.510      2254.25     -466.17       .023         .138       .089        .138    99.952
     3.500   355.990     13.193      5.838      2054.63     -341.69       .023         .149       .078        .149    99.200
     4.000   405.078     18.824      7.271      1905.25     -261.09       .023         .158       .069        .158    98.449
     4.500   453.633     25.668      8.794      1789.23     -206.19       .023         .166       .061        .166    97.697
     5.000   501.612     33.772     10.396      1696.36     -167.32       .023         .172       .055        .172    96.946
     5.500   548.972     43.169     12.066      1620.14     -138.94       .023         .177       .050        .177    96.194
     6.000   595.665     53.882     13.795      1556.21     -117.71       .023         .182       .045        .182    95.443
     6.500   641.645     65.927     15.577      1501.57     -101.52       .023         .185       .042        .185    94.691
     7.000   686.862     79.308     17.406      1454.07      -88.96       .023         .188       .039        .188    93.940
     7.500   731.267     94.024     19.277      1412.15      -79.09       .023         .191       .036        .191    93.188
    FINAL VALUES
     7.676   746.695     99.520     19.277      1398.50      -76.12       .023         .192       .035        .192    92.924
     CALCULATED RESULTS
      CRITICAL VALUES:
         ASCSV          ASC            PTIME           CDIST           XDIST           TDIST
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  104.46          92.92          7.68       3654.00          746.69          4400.69
PROB        AVG TIME    STD DEV     XTIME       TTIME       YA
1.0000      25.3241      1.7919     32.3124     39.9880    119.0000
 .9987      25.3320      1.7919     32.3202     39.9959    118.0000
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GENERIC AIRCRAFT CS

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                              NASA HIGH SPEED ANALYSIS
                                   INPUT SUMMARY,
                                PROBABILISTIC MODEL
                                        AVERAGE    STD DEV    UNITS,

          TOUCHDOWN LOCATION             1500.        30.     FEET
          TOUCHDOWN SPEED                 181.        10.     FT/SEC
          TIME-TOUCHDOWN TO DECEL           5.         1.     SECONDS
          DECELERATION RATE               5.00        .50     FT/SEC**2
          50%PROBABILITY SPEED            135.         1.     FT/SEC
          DIST:THRESHOLD-START OF TURN   4225.                FEET
          SPEED AT MAJOR DECEL REDUCE     155.                FT/SEC
          NOSE-WINGTIP DIST                48.                FEET
                              AIRCRAFT TRACKING PROGRAM
    AIRCRAFT CHARACTERISTICS
         WEIGHT(LBS)    YAW INERTIA       WHEELBASE     % LOAD ON MAIN GEAR
              48000.0     800000.0            36.0             95.0
     FLIGHT CONDITIONAL PARAMETERS
         EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU       DECEL RATE
            120.669         33.000            .250        -1.750
      SYSTEM WIDTHS
              RUNWAY        WINGSPAN       CLEAR DIST.         DIST TO TAXIWAY
             150.00          85.00          117.50                600.00
      SCRUB CHARACTERISTICS
         Y MU      RADIUS
         .0000    .1E+32
         .0250      50.0
   CONSTANT NLG SIDE LOAD ANALYSIS
/    PASSENGER CONFORT IGNORED
    TIME        X          Y        THETA       RADIUS      R RATE     MU SCRUB     MU CENT     MU I       G CENT     VELOCITY
      .000       .000       .000      .000   100000.00 -1874636.00      .025        .005       .220       .005   120.669
      .500     60.116       .072      .187    10415.47   -16929.20      .025        .043       .182       .043   119.795
     1.000    119.793       .481      .641     5968.18    -4652.88      .025        .074       .151       .074   118.922
     1.500    179.026      1.474     1.314     4394.23    -2123.18      .025        .098       .127       .098   118.048
     2.000    237.804      3.245     2.168     3594.17    -1203.11      .025        .119       .106       .119   117.175
     2.500    296.109      5.951     3.172     3112.61     -769.61      .025        .135       .090       .135   116.301
     3.000    353.918      9.715     4.301     2792.34     -532.40      .025        .148       .077       .148   115.428
     3.500    411.201     14.633     5.534     2564.60     -389.34      .025        .159       .066       .159   114.554
     4.000    467.926     20.781     6.855     2394.54     -297.00      .025        .168       .057       .168   113.680
     4.500    524.055     28.216     8.250     2262.62     -234.38      .025        .175       .050       .175   112.807
     5.000    579.551     36.977     9.708     2157.05     -190.28      .025        .180       .045       .180   111.933
     5.500    634.371     47.096    11.220     2070.30     -158.30      .025        .185       .040       .185   111.060
     6.000    688.473     58.589    12.779     1997.36     -134.57      .025        .189       .036       .189   110.186
     6.500    741.813     71.468    14.379     1934.75     -116.63      .025        .192       .033       .192   109.313
     7.000    794.346     85.732    16.015     1880.02     -102.85      .025        .194       .031       .194   108.439
     7.500    846.029    101.379    17.683     1831.39      -92.12      .025        .196       .029       .196   107.565
    FINAL VALUES
     7.975    894.298    117.514    17.683     1789.61      -84.05      .025        .198       .027       .198   106.736
     CALCULATED RESULTS
      CRITICAL VALUES:
         ASCSV          ASC             PTIME          CDIST          XDIST          TDIST
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  120.67          106.74           7.97       4225.00         894.30        5119.30
PROB       AVG TIME   STD DEV    XTIME       TTIME       YA
1.0000     25.6212     1.6276    31.9687     39.9433    135.0000
 .9987     25.6285     1.6276    31.9760     39.9506    134.0000
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                              NASA HIGH SPEED ANALYSIS
                                   INPUT SUMMARY,
                                 PRCBABILISTIC MODEL
                                         AVERAGE    STD DEV    UNITS,

          TOUCHDOWN LOCATION                1500.       30.     FEET
          TOUCHDOWN SPEED                    230.       10.     FT/SEC
          TIME-TOUCHDOWN TO DECEL             5.         1.     SECONDS
          DECELERATION RATE                  5.00       .50     FT/SEC**2
          50%PROBABILITY SPEED               170.        1.     FT/SEC
          DIST:THRESHOLD-START OF TURN      5515.               FEET
          SPEED AT MAJOR DECEL REDUCE        175.               FT/SEC
          NOSE-WINGTIP DIST                  103.               FEET
                              AIRCRAFT TRACKING PROGRAM
    AIRCRAFT CHARACTERISTICS
         WEIGHT(LBS)    YAW INERTIA      WHEELBASE     % LOAD ON MAIN GEAR
             120000.0     4200000.0           61.0             95.0
     FLIGHT CONDITIONAL PARAMETERS
         EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU       DECEL RATE
            155.724         39.000            .250        -1.750
      SYSTEM WIDTHS
              RUNWAY       WINGSPAN      CLEAR DIST.         DIST TO TAXIWAY
             150.00         141.00        145.50                600.00
      SCRUB CHARACTERISTICS
         Y MU       RADIUS
         .0000    .1E+32
         .0250      50.0
   CONSTANT NLG SIDE LOAD ANALYSIS
/    PASSENGER CONFORT IGNORED
    TIME         X          Y         THETA       RADIUS       R RATE     MU SCRUB      MU CENT      MU I       G CENT      VELOCITY
      .000       .000       .000       .000   100000.00 -1156104.00        .025         .008       .217        .008    155.724
      .500     77.642       .085       .165    15935.32   -24202.22        .025         .047       .178        .047    154.847
     1.000    154.844       .540       .542     9414.16    -6995.16        .025         .078       .147        .078    153.969
     1.500    231.601      1.615      1.091     7028.21    -3243.73        .025         .104       .121        .104    153.092
     2.000    307.904      3.511      1.780     5802.00    -1848.86        .025         .124       .101        .124    152.215
     2.500    383.736      6.389      2.586     5061.43    -1183.78        .025         .141       .084        .141    151.337
     3.000    459.079     10.375      3.487     4569.22     -817.14        .025         .154       .071        .154    150.460
     3.500    533.908     15.568      4.468     4220.36     -594.93        .025         .165       .060        .165    149.582
     4.000    608.196     22.046      5.514     3961.23     -451.04        .025         .173       .052        .173    148.705
     4.500    681.914     29.871      6.615     3761.59     -353.25        .025         .180       .045        .180    147.828
     5.000    755.028     39.086      7.763     3603.12     -284.32        .025         .186       .039        .186    146.950
     5.500    827.506     49.726      8.950     3474.08     -234.34        .025         .191       .034        .191    146.073
     6.000    899.311     61.813     10.170     3366.60     -197.27        .025         .194       .031        .194    145.196

     6.500    970.407     75.363     11.419     3275.26     -169.30        .025         .197       .028        .197    144.318


     7.000   1040.760     90.384     12.693     3196.19     -147.87        .025         .200       .025        .200    143.441
     7.500   1110.330    106.879     13.990     3126.58     -131.25        .025         .202       .023        .202    142.563
     8.000   1179.082    124.843     15.305     3064.33     -118.22        .025         .203       .022        .203    141.686
     8.500   1246.979    144.272     16.638     3007.89     -107.92        .025         .205       .020        .205    140.809
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FINAL VALUES
 8.531  1251.159   145.524    16.638     3004.55     -107.36      .025      .205      .020      .205   140.754
 CALCULATED RESULTS
  CRITICAL VALUES:
     ASCSV          ASC            PTIME          CDIST          XDIST          TDIST
    155.72         140.75           8.53         5515.00        1251.16        6766.16
  PROB       AVG TIME    STD DEV     XTIME       TTIME       YA
  1.0000     26.8287      1.1898     31.4688     39.9996    170.0000
   .9986     26.8346      1.1898     31.4747     40.0055    169.0000
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GENERIC AIRCRAFT DS

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                         NASA HIGH SPEED ANALYSIS
                              INPUT SUMMARY,
                            PROBABILISTIC MODEL
                                         AVERAGE    STD DEV    UNITS,
       TOUCHDOWN LOCATION                 1500.       30.      FEET
       TOUCHDOWN SPEED                     211.       15.      FT/SEC
       TIME-TOUCHDOWN TO DECEL               5.        1.      SECONDS
       DECELERATION RATE                   5.00       .50      FT/SEC**2
       50%PROBABILITY SPEED                163.        1.      FT/SEC
       DIST:THRESHOLD-START OF TURN       4805.                FEET
       SPEED AT MAJOR DECEL REDUCE         175.                FT/SEC
       NOSE-WINGTIP DIST                    87.                FEET
                         AIRCRAFT TRACKING PROGRAM
   AIRCRAFT CHARACTERISTICS
        WEIGHT(LBS)    YAW INERTIA      WHEELBASE     % LOAD ON MAIN GEAR
           120000.0     4200000.0          61.0             95.0
    FLIGHT CONDITIONAL PARAMETERS
        EXIT VELOCITY  MAX EXIT ANGLE     MAX Y MU       DECEL RATE
          148.395        37.000           .250          -1.750
     SYSTEM WIDTHS
              RUNWAY       WINGSPAN      CLEAR DIST.        DIST TO TAXIWAY
             150.00         87.00         118.50              600.00
     SCRUB CHARACTERISTICS
        Y MU       RADIUS
        .0000     .1E+32
        .0100     5000.0
        .0120     2000.0
        .0180     1000.0
        .0230      500.0
        .0300       50.0
  CONSTANT NLG SIDE LOAD ANALYSIS
/   PASSENGER CONFORT IGNORED
   TIME        X         Y        THETA      RADIUS      R RATE    MU SCRUB    MU CENT    MU I      G CENT     VELOCITY
    .000      .000      .000       .000   100000.00 -1300748.00     .010       .007      .233       .007   148.395
    .500    73.978      .084       .172    14358.77   -22323.09     .010       .047      .193       .047   147.517
   1.000   147.515      .540       .573     8385.23    -6365.42     .010       .080      .160       .080   146.640
   1.500   220.607     1.627      1.162     6218.46    -2940.53     .010       .106      .134       .106   145.763
   2.000   293.242     3.556      1.906     5107.44    -1674.74     .010       .128      .112       .128   144.885
   2.500   365.404     6.494      2.779     4437.40    -1069.52     .010       .145      .094       .145   144.008
   3.000   437.072    10.576      3.759     3992.93     -737.65     .011       .159      .080       .159   143.130
   3.500   508.217    15.906      4.827     3677.96     -537.30     .011       .171      .068       .171   142.253
   4.000   578.808    22.568      5.970     3443.81     -407.81     .011       .180      .059       .180   141.376
   4.500   648.813    30.626      7.176     3263.19     -319.85     .011       .188      .051       .188   140.498
   5.000   718.193    40.129      8.434     3119.59     -257.83     .011       .194      .045       .194   139.621
   5.500   786.910    51.111      9.738     3002.49     -212.80     .011       .199      .040       .199   138.744
   6.000   854.924    63.599     11.080     2904.84     -179.35     .011       .203      .035       .203   137.866

   6.500   922.193    77.606     12.455     2821.76     -154.04     .011       .207      .032       .207   136.989
   7.000   988.674    93.142     13.860     2749.80     -134.59     .012       .209      .029       .209   136.111
   7.500  1054.327   110.207     15.290     2686.43     -119.46     .012       .211      .027       .211   135.234
   FINAL VALUES
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7.729  1084.107   118.533    15.290     2659.75     -113.66      .012      .212      .026      .212   134.832
CALCULATED RESULTS
 CRITICAL VALUES:
    ASCSV          ASC            PTIME          CDIST          XDIST          TDIST
   148.39         134.83           7.73        4805.00        1084.11        5889.11
 PROB        AVG TIME    STD DEV     XTIME        TTIME        YA

  .9999      25.0418      1.8425     32.2276      39.9562    163.0000
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GENERIC AIRCRAFT DF

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                              NASA HIGH SPEED ANALYSIS
                                   INPUT SUMMARY,
                                 PROBABILISTIC MODEL
                                         AVERAGE    STD DEV    UNITS,
          TOUCHDOWN LOCATION              1500.        30.     FEET
          TOUCHDOWN SPEED                  260.        15.     FT/SEC
          TIME-TOUCHDOWN TO DECEL            5.         1.     SECONDS
          DECELERATION RATE               5.00        .50      FT/SEC**2
          50%PROBABILITY SPEED             207.         1.     FT/SEC
          DIST:THRESHOLD-START OF TURN    5860.                FEET
          SPEED AT MAJOR DECEL REDUCE      225.                FT/SEC
          NOSE-WINGTIP DIST                150.                FEET
                              AIRCRAFT TRACKING PROGRAM
    AIRCRAFT CHARACTERISTICS
         WEIGHT(LBS)   YAW INERTIA       WHEELBASE     % LOAD ON MAIN GEAR
             400000.0    40000000.0          84.0            96.0
     FLIGHT CONDITIONAL PARAMETERS
         EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU       DECEL RATE
            192.354         45.000            .250        -1.750
      SYSTEM WIDTHS
              RUNWAY        WINGSPAN      CLEAR DIST.        DIST TO TAXIWAY
             150.00          207.00        178.50               600.00
      SCRUB CHARACTERISTICS
         Y MU       RADIUS
         .0000     .1E+32
         .0100     5287.0
         .0190     2638.0
         .0390     1318.0
         .0590      877.0
         .0790      657.0
         .0990      534.0
   CONSTANT NLG SIDE LOAD ANALYSIS
/    PASSENGER CONFORT IGNORED
    TIME          X          Y         THETA       RADIUS       R RATE     MU SCRUB      MU CENT     MU I        G CENT     VELOCITY
      .000       .000       .000        .000   100000.00  -383189.50        .010         .011      .229         .011   192.354
      .500     95.957       .075        .106    35269.88   -43528.70        .010         .032      .208         .032   191.476
     1.000    191.475       .406        .308    22170.15   -15730.62        .010         .051      .189         .051   190.599
     1.500    286.552      1.144        .596    16546.72    -8027.21        .010         .068      .172         .068   189.722
     2.000    381.184      2.419        .962    13425.20    -4848.87        .010         .082      .158         .082   188.844
     2.500    475.367      4.349       1.399    11442.87    -3238.13        .010         .096      .144         .096   187.967
     3.000    569.091      7.040       1.901    10074.32    -2311.48        .010         .108      .132         .108   187.090
     3.500    662.349     10.583       2.461     9073.95    -1730.38        .010         .119      .121         .119   186.212
     4.000    755.127     15.060       3.075     8311.63    -1342.49        .010         .128      .112         .128   185.335
     4.500    847.411     20.545       3.737     7711.91    -1071.04        .010         .137      .103         .137   184.457
     5.000    939.185     27.101       4.444     7228.07     -873.90        .010         .145      .095         .145   183.580
     5.500   1030.432     34.784       5.191     6829.61     -726.42        .010         .152      .088         .152   182.703
     6.000   1121.131     43.644       5.975     6495.80     -613.37        .010         .158      .082         .158   181.825
     6.500   1211.261     53.723       6.794     6212.05     -524.95        .010         .164      .076         .164   180.948
     7.000   1300.800     65.058       7.643     5967.77     -454.61        .010         .169      .071         .169   180.071
     7.500   1389.724     77.680       8.522     5755.12     -397.83        .010         .173      .067         .173   179.193
     8.000   1478.006     91.617       9.427     5568.17     -351.42        .010         .177      .063         .177   178.316
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 8.500  1565.622   106.889   10.356     5402.32    -313.07      .010      .181      .059      .181   177.438
 9.000  1652.544   123.516   11.308     5254.04    -280.52      .010      .184      .056      .184   176.561
 9.500  1738.746   141.510   12.281     5121.19    -251.68      .011      .187      .052      .187   175.684
10.000  1824.198   160.884   13.273     5001.55    -227.53      .011      .190      .049      .190   174.806
FINAL VALUES
10.428  1896.560   178.525   13.273     4908.23    -209.93      .011      .192      .047      .192   174.057
 CALCULATED RESULTS
  CRITICAL VALUES:
     ASCSV          ASC           PTIME         CDIST         XDIST         TDIST
    192.35         174.06         10.43        5860.00       1896.56       7756.56
  PROB       AVG TIME    STD DEV     XTIME       TTIME      YA
   .9999     24.8770      1.1902     29.5186     39.9462   207.0000
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                              NASA HIGH SPEED ANALYSIS
                                   INPUT SUMMARY,
                                 PROBABILISTIC MODEL
                                         AVERAGE     STD DEV    UNITS,
          TOUCHDOWN LOCATION               1500.        30.     FEET
          TOUCHDOWN SPEED                   230.        10.     FT/SEC
          TIME-TOUCHDOWN TO DECEL            5.          1.     SECONDS
          DECELERATION RATE                 5.00       1.00     FT/SEC**2
          50%PROBABILITY SPEED              181.         1.     FT/SEC
          DIST:THRESHOLD-START OF TURN     5170.                FEET
          SPEED AT MAJOR DECEL REDUCE       190.                FT/SEC
          NOSE-WINGTIP DIST                 130.                FEET
                              AIRCRAFT TRACKING PROGRAM
    AIRCRAFT CHARACTERISTICS
         WEIGHT(LBS)    YAW INERTIA       WHEELBASE     % LOAD ON MAIN GEAR
           400000.0    40000000.0           84.0            96.0
     FLIGHT CONDITIONAL PARAMETERS
         EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU       DECEL RATE
            166.433         45.000            .250          -2.000
      SYSTEM WIDTHS
              RUNWAY        WINGSPAN      CLEAR DIST.         DIST TO TAXIWAY
            150.00          207.00          178.50                600.00
      SCRUB CHARACTERISTICS
         Y MU       RADIUS
         .0000     .1E+32
         .0100     5287.0
         .0190     2638.0
         .0390     1318.0
         .0590      877.0
         .0790      657.0
         .0990      534.0
   CONSTANT NLG SIDE LOAD ANALYSIS
/    PASSENGER CONFORT IGNORED
    TIME        X          Y         THETA      RADIUS       R RATE     MU SCRUB     MU CENT    MU I       G CENT      VELOCITY
     .000       .000       .000       .000   100000.00  -448465.80       .010        .009      .231        .009   166.433
     .500     82.966       .059       .099    31607.94   -41512.79       .010        .027      .213        .027   165.434
    1.000    165.432       .333       .297    19351.20   -14442.17       .010        .043      .197        .043   164.434
    1.500    247.397       .952       .584    14227.78    -7259.16       .010        .058      .182        .058   163.435
    2.000    328.856      2.034       .952    11415.50    -4353.06       .010        .072      .168        .072   162.435
    2.500    409.807      3.684      1.397     9639.21    -2896.76       .010        .084      .156        .084   161.436
    3.000    490.241      5.996      1.910     8415.88    -2065.01       .010        .095      .145        .095   160.436
    3.500    570.149      9.056      2.487     7522.24    -1546.02       .010        .105      .135        .105   159.437
    4.000    649.522     12.936      3.123     6840.82    -1200.82       .010        .114      .126        .114   158.438
    4.500    728.346     17.705      3.812     6303.92     -959.84       .010        .122      .118        .122   157.438
    5.000    806.606     23.421      4.552     5869.80     -785.14       .010        .129      .111        .129   156.439
    5.500    884.285     30.135      5.338     5511.31     -654.60       .010        .136      .104        .136   155.439
    6.000    961.364     37.893      6.167     5210.12     -553.16       .010        .142      .098        .142   154.440
    6.500   1037.823     46.735      7.035     4954.85     -471.22       .011        .148      .091        .148   153.440
    7.000   1113.641     56.694      7.940     4735.91     -406.92       .012        .152      .086        .152   152.441
    7.500   1188.794     67.799      8.878     4545.72     -355.60       .013        .157      .081        .157   151.441
    8.000   1263.259     80.072      9.848     4378.65     -314.02       .013        .161      .076        .161   150.442
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  8.500  1337.010    93.533    10.846     4230.42     -279.91      .014      .164      .072      .164   149.443
  9.000  1410.022   108.195    11.871     4097.75     -251.61      .014      .167      .069      .167   148.443
  9.500  1482.269   124.069    12.921     3978.02     -227.91      .014      .170      .066      .170   147.444
 10.000  1553.723   141.164    13.994     3869.20     -207.90      .015      .172      .063      .172   146.444
 10.501  1624.357   159.481    15.089     3769.61     -190.87      .015      .174      .061      .174   145.445
 FINAL VALUES
 10.989  1692.479   178.540    15.089     3680.03     -176.60      .015      .176      .058      .176   144.469
  CALCULATED RESULTS
   CRITICAL VALUES:
      ASCSV          ASC           PTIME          CDIST          XDIST          TDIST
     166.43         144.47         10.99         5170.00        1692.48        6862.48
   PROB      AVG TIME    STD DEV     XTIME       TTIME      YA
    .9999     24.7989      .9884     28.6537     39.6425   181.0000
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TERPS CATEGORY E-LOCKHEED F-104

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                              NASA HIGH SPEED ANALYSIS
                                   INPUT SUMMARY,
                                 PROBABILISTIC MODEL
                                         AVERAGE    STD DEV    UNITS,
          TOUCHDOWN LOCATION               1500.        30.    FEET
          TOUCHDOWN SPEED                   370.        25.    FT/SEC
          TIME-TOUCHDOWN TO DECEL            5.          1.    SECONDS
          DECELERATION RATE                 6.00       2.00    FT/SEC**2
          50%PROBABILITY SPEED              292.         1.    FT/SEC
          DIST:THRESHOLD-START OF TURN     8400.               FEET
          SPEED AT MAJOR DECEL REDUCE       150.               FT/SEC
          NOSE-WINGTIP DIST                  35.               FEET
                              AIRCRAFT TRACKING PROGRAM
    AIRCRAFT CHARACTERISTICS
         WEIGHT(LBS)    YAW INERTIA       WHEELBASE     % LOAD ON MAIN GEAR
              22000.0       137776.0           15.0            92.3
     FLIGHT CONDITIONAL PARAMETERS
         EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU       DECEL RATE
            276.225        20.000             .200         -2.000
      SYSTEM WIDTHS
              RUNWAY       WINGSPAN      CLEAR DIST.         DIST TO TAXIWAY
             150.00          21.90         85.95                600.00
      SCRUB CHARACTERISTICS
         Y MU       RADIUS
         .0000     .1E+32
         .0200       50.0
   CONSTANT NLG SIDE LOAD ANALYSIS
/    PASSENGER CONFORT IGNORED
    TIME          X          Y       THETA       RADIUS       R RATE     MU SCRUB      MU CENT     MU I        G CENT     VELOCITY
     .000       .000       .000       .000   100000.00   -963255.40       .020         .024       .156         .024   276.225
     .500    137.860       .223       .231    22530.26    -23733.96       .020         .104       .076         .104   275.217
    1.000    275.212      1.256       .654    16352.71     -6175.82       .020         .143       .037         .143   274.210
    1.500    412.047      3.419      1.170    14383.35     -2428.62       .020         .161       .019         .161   273.203
    2.000    548.353      6.862      1.731    13537.84     -1150.20       .020         .170       .010         .170   272.196
    2.500    684.114     11.655      2.316    13111.48      -626.37       .020         .174       .006         .174   271.189
    3.000    819.314     17.827      2.914    12864.03      -393.05       .020         .176       .004         .176   270.182
    3.500    953.940     25.389      3.519    12697.89      -284.74       .020         .177       .003         .177   269.175
    4.000   1087.976     34.344      4.128    12569.92      -233.25       .020         .178       .002         .178   268.168
    4.500   1221.406     44.689      4.741    12460.26      -208.30       .020         .178       .002         .178   267.161
    5.000   1354.217     56.419      5.356    12359.55      -195.94       .020         .178       .002         .178   266.154
    5.500   1486.393     69.529      5.974    12263.33      -189.63       .020         .178       .002         .178   265.147
    6.000   1617.918     84.012      6.595    12169.46      -186.20       .020         .178       .002         .178   264.140
   FINAL VALUES
    6.064   1634.705     85.965      6.595    12157.56      -185.88       .020         .178       .002         .178   264.011
    CALCULATED RESULTS
     CRITICAL VALUES:
        ASCSV          ASC            PTIME          CDIST          XDIST          TDIST
       276.22         264.01           6.06         8400.00        1634.71       10034.71
     PROB       AVG TIME     STD DEV     XTIME        TTIME        YA
     1.0000     24.7617      2.3551      33.9466      40.0104     292.0000
      .9999     24.7617      2.3551      33.9466      40.0104     291.0000
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BUNCHING OF OPTIMAL EXIT LOCATIONS

GENERIC AIRCRAFT AF

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                              NASA HIGH SPEED ANALYSIS
                                   INPUT SUMMARY,
                                 PROBABILISTIC MODEL
                                         AVERAGE    STD DEV    UNITS,
          TOUCHDOWN LOCATION               500.        10.     FEET
          TOUCHDOWN SPEED                  118.         5.     FT/SEC
          TIME-TOUCHDOWN TO DECEL           3.          1.     SECONDS
          DECELERATION RATE                2.50       1.00     FT/SEC**2
          50%PROBABILITY SPEED              97.         1.     FT/SEC
          DIST:THRESHOLD-START OF TURN    2285.                FEET
          SPEED AT MAJOR DECEL REDUCE       55.                FT/SEC
          NOSE-WINGTIP DIST                 40.                FEET
                              AIRCRAFT TRACKING PROGRAM
    AIRCRAFT CHARACTERISTICS
         WEIGHT(LBS)   YAW INERTIA      WHEELBASE     % LOAD ON MAIN GEAR
             24000.0     300000.0          23.0            93.0
     FLIGHT CONDITIONAL PARAMETERS
         EXIT VELOCITY  MAX EXIT ANGLE     MAX Y MU      DECEL RATE
            82.274         41.000          .250         -2.000
      SYSTEM WIDTHS
             RUNWAY        WINGSPAN      CLEAR DIST.        DIST TO TAXIWAY
            150.00          42.00         96.00              600.00
      SCRUB CHARACTERISTICS
         Y MU      RADIUS
        .0000     .1E+32
        .0200      50.0
   CONSTANT NLG SIDE LOAD ANALYSIS
/    PASSENGER CONFORT IGNORED
    TIME        X         Y        THETA      RADIUS     R RATE     MU SCRUB    MU CENT    MU I      G CENT     VELOCITY
     .000      .000      .000      .000   100000.00 -3318003.00     .020       .002      .228      .002     82.274
     .500    40.887      .053      .210     6033.73   -10516.58     .020       .034      .196      .034     81.274
    1.000    81.272      .373      .753     3320.30    -2792.04     .020       .060      .170      .060     80.275
    1.500   121.151     1.169     1.579     2379.48    -1265.95     .020       .082      .148      .082     79.276
    2.000   160.511     2.608     2.649     1902.06     -719.49     .020       .100      .130      .100     78.276
    2.500   199.335     4.825     3.927     1613.10     -463.97     .020       .115      .115      .115     77.277
    3.000   237.596     7.929     5.384     1419.03     -324.65     .020       .127      .103      .127     76.277
    3.500   275.263    12.005     6.999     1279.28     -240.71     .020       .138      .092      .138     75.278
    4.000   312.299    17.118     8.750     1173.38     -186.45     .020       .146      .084      .146     74.278
    4.500   348.662    23.315    10.620     1089.92     -149.51     .020       .153      .077      .153     73.279
    5.000   384.307    30.629    12.597     1022.05     -123.35     .020       .159      .071      .159     72.279
    5.500   419.185    39.081    14.668      965.39     -104.23     .020       .163      .067      .163     71.280
    6.000   453.246    48.678    16.824      917.01      -89.89     .020       .167      .063      .167     70.281
    6.500   486.439    59.418    19.057      874.92      -78.91     .020       .170      .060      .170     69.281
    7.000   518.713    71.290    21.359      837.69      -70.35     .020       .173      .057      .173     68.282
    7.500   550.014    84.276    23.725      804.27      -63.57     .020       .175      .055      .175     67.282
    FINAL VALUES
     7.920   575.518    96.025    23.725      778.57      -58.91     .020       .176      .054      .176     66.443
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CALCULATED RESULTS
 CRITICAL VALUES:
    ASCSV          ASC            PTIME         CDIST          XDIST          TDIST
    82.27          66.44           7.92       2285.00         575.52        2860.52
 PROB       AVG TIME    STD DEV     XTIME      TTIME       YA
 1.0000     21.8697      1.6699     28.3822    36.3018     97.0000
  .9985     21.8781      1.6699     28.3905    36.3101     96.0000
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                                NASA HIGH SPEED ANALYSIS
                                     INPUT SUMMARY,
                                   PROBABILISTIC MODEL
                                          AVERAGE     STD DEV    UNITS,
          TOUCHDOWN LOCATION                1000.        20.     FEET
          TOUCHDOWN SPEED                    110.        10.     FT/SEC
          TIME-TOUCHDOWN TO DECEL              4.         1.     SECONDS
          DECELERATION RATE                  3.50        .50     FT/SEC**2
          50%PROBABILITY SPEED                93.         1.     FT/SEC
          DIST:THRESHOLD-START OF TURN      2285.                FEET
          SPEED AT MAJOR DECEL REDUCE         90.                FT/SEC
          NOSE-WINGTIP DIST                   34.                FEET
                                AIRCRAFT TRACKING PROGRAM
    AIRCRAFT CHARACTERISTICS
         WEIGHT(LBS)     YAW INERTIA      WHEELBASE      % LOAD ON MAIN GEAR
              24000.0        300000.0         23.0             93.0
     FLIGHT CONDITIONAL PARAMETERS
         EXIT VELOCITY   MAX EXIT ANGLE     MAX Y MU        DECEL RATE
             78.645          38.000          .250          -1.500
      SYSTEM WIDTHS
              RUNWAY        WINGSPAN      CLEAR DIST.         DIST TO TAXIWAY
             150.00          36.00         93.00               600.00
      SCRUB CHARACTERISTICS
         Y MU       RADIUS
         .0000     .1E+32
         .0230       50.0
/    PASSENGER CONFORT IGNORED
    TIME        X          Y       THETA     RADIUS       R RATE    MU SCRUB     MU CENT    MU I      G CENT     VELOCITY
       .000      .000      .000      .000   100000.00 -3428186.00      .023      .002      .225      .002    78.645
       .500    39.134      .050      .207     5841.02   -10217.21      .023      .032      .195      .032    77.893
      1.000    77.891      .354      .746     3207.63    -2706.14      .023      .058      .169      .058    77.142
      1.500   116.266     1.114     1.570     2296.50    -1224.64      .023      .079      .148      .079    76.390
      2.000   154.247     2.496     2.639     1835.14     -694.29      .023      .097      .130      .097    75.639
      2.500   191.816     4.637     3.921     1556.71     -446.23      .023      .112      .115      .112    74.887
      3.000   228.949     7.649     5.387     1370.43     -310.88      .023      .125      .102      .125    74.136
      3.500   265.613    11.622     7.013     1236.93     -229.24      .023      .135      .092      .135    73.384
      4.000   301.770    16.627     8.779     1136.39     -176.40      .023      .144      .083      .144    72.633
      4.500   337.379    22.721    10.669     1057.72     -140.37      .023      .152      .075      .152    71.881
      5.000   372.392    29.945    12.668      994.26     -114.81      .023      .158      .069      .158    71.130
      5.500   406.760    38.326    14.764      941.75      -96.10      .023      .163      .064      .163    70.378
      6.000   440.429    47.881    16.947      897.37      -82.05      .023      .168      .059      .168    69.627
      6.500   473.345    58.619    19.207      859.15      -71.28      .023      .171      .056      .171    68.875
      7.000   505.452    70.535    21.538      825.69      -62.87      .023      .175      .052      .175    68.124
      7.500   536.694    83.620    23.932      795.98      -56.22      .023      .177      .050      .177    67.372
    FINAL VALUES
      7.834   557.053    93.003    23.932      777.83      -52.52      .023      .179      .048      .179    66.870
     CALCULATED RESULTS
      CRITICAL VALUES:
         ASCSV           ASC            PTIME          CDIST          XDIST          TDIST
         78.64           66.87           7.83       2285.00         557.05        2842.05
      PROB       AVG TIME    STD DEV     XTIME       TTIME       YA
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1.0000     22.3429      2.2708     31.1991     39.0327     93.0000
 .9988     22.3605      2.2708     31.2167     39.0503     92.0000
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                              NASA HIGH SPEED ANALYSIS
                                   INPUT SUMMARY,
                                 PROBABILISTIC MODEL
                                         AVERAGE    STD DEV    UNITS,
          TOUCHDOWN LOCATION               1000.       20.     FEET
          TOUCHDOWN SPEED                   164.       10.     FT/SEC
          TIME-TOUCHDOWN TO DECEL             4.        1.     SECONDS
          DECELERATION RATE                1.00       .50     FT/SEC**2
          50%PROBABILITY SPEED              166.        1.     FT/SEC
          DIST:THRESHOLD-START OF TURN     3654.               FEET
          SPEED AT MAJOR DECEL REDUCE       155.               FT/SEC
          NOSE-WINGTIP DIST                  56.               FEET
                              AIRCRAFT TRACKING PROGRAM
      AIRCRAFT CHARACTERISTICS
           WEIGHT(LBS)    YAW INERTIA       WHEELBASE     % LOAD ON MAIN GEAR
                48000.0       800000.0          36.0           95.0
       FLIGHT CONDITIONAL PARAMETERS
           EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU       DECEL RATE
              151.327        38.000            .250         -1.500
        SYSTEM WIDTHS
                RUNWAY        WINGSPAN      CLEAR DIST.         DIST TO TAXIWAY
               150.00          49.00          99.50               600.00
        SCRUB CHARACTERISTICS
           Y MU      RADIUS
           .0000    .1E+32
           .0230      50.0
     CONSTANT NLG SIDE LOAD ANALYSIS
/      PASSENGER CONFORT IGNORED
      TIME         X          Y        THETA       RADIUS      R RATE    MU SCRUB      MU CENT      MU I        G CENT      VELOCITY
        .000       .000       .000       .000   100000.00 -1490842.00      .023        .007        .220        .007   151.327
        .500     75.476       .095       .193    13038.13   -20037.16      .023        .054        .173        .054   150.580
       1.000    150.577       .616       .640     7728.14    -5594.11      .023        .090        .137        .090   149.832
       1.500    225.295      1.853      1.287     5835.79    -2548.16      .023        .118        .109        .118   149.084
       2.000    299.618      4.028      2.091     4878.94    -1431.42      .023        .140        .087        .140   148.337
       2.500    373.525      7.313      3.019     4309.25     -903.87      .023        .157        .070        .157   147.589
       3.000    446.992     11.837      4.046     3935.83     -615.44      .023        .170        .057        .170   146.841
       3.500    519.989     17.699      5.151     3674.74     -442.15      .023        .180        .047        .180   146.094
       4.000    592.484     24.972      6.319     3483.30     -331.06      .023        .188        .039        .188   145.346
       4.500    664.440     33.709      7.538     3337.56     -256.45      .023        .195        .032        .195   144.598
       5.000    735.819     43.948      8.799     3223.04     -204.57      .023        .199        .028        .199   143.851
       5.500    806.584     55.716     10.093     3130.49     -167.54      .023        .203        .024        .203   143.103
       6.000    876.694     69.027     11.416     3053.80     -140.56      .023        .206        .021        .206   142.355
       6.500    946.109     83.890     12.763     2988.74     -120.59      .023        .208        .019        .208   141.608
      FINAL VALUES
       6.977   1011.647     99.517     12.763     2934.80     -106.22      .023        .210        .017        .210   140.894
       CALCULATED RESULTS
        CALCULATED VALUES:
          ASCSV          ASC             PTIME          CDIST          XDIST          TDIST
         151.33        140.89            6.98        3654.00        1011.65        4665.65
        PROB       AVG TIME    STD DEV     XTIME        TTIME       YA
        1.0000      23.1106     1.2630     28.0362      35.0128    166.0000
```

.9988	23.1154	1.2630	28.0410	35.0177	165.0000

GENERIC AIRCRAFT BF

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                              NASA HIGH SPEED ANALYSIS
                                   INPUT SUMMARY,
                                 PROBABILISTIC MODEL
                                         AVERAGE    STD DEV    UNITS,
         TOUCHDOWN LOCATION                1000.       20.     FEET
         TOUCHDOWN SPEED                    164.       10.     FT/SEC
         TIME-TOUCHDOWN TO DECEL              4.        1.     SECONDS
         DECELERATION RATE                  2.00       .50     FT/SEC**2
         50%PROBABILITY SPEED               152.        1.     FT/SEC
         DIST:THRESHOLD-START OF TURN      3654.               FEET
         SPEED AT MAJOR DECEL REDUCE        155.               FT/SEC
         NOSE-WINGTIP DIST                   56.               FEET
                              AIRCRAFT TRACKING PROGRAM
   AIRCRAFT CHARACTERISTICS
        WEIGHT(LBS)    YAW INERTIA       WHEELBASE      % LOAD ON MAIN GEAR
             48000.0       800000.0           36.0            95.0
    FLIGHT CONDITIONAL PARAMETERS
        EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU        DECEL RATE
           137.492         38.000            .250          -1.500
     SYSTEM WIDTHS
             RUNWAY        WINGSPAN      CLEAR DIST.         DIST TO TAXIWAY
            150.00          49.00          99.50               600.00
     SCRUB CHARACTERISTICS
        Y MU      RADIUS
        .0000    .1E+32
        .0230      50.0
  CONSTANT NLG SIDE LOAD ANALYSIS
    PASSENGER CONFORT IGNORED
   TIME         X          Y        THETA      RADIUS      R RATE    MU SCRUB      MU CENT     MU I       G CENT      VELOCITY
     .000      .000      .000       .000   100000.00 -1650124.00       .023         .006       .221        .006    137.492
     .500    68.559      .085       .191    11814.30   -18625.16       .023         .049       .178        .049    136.744
    1.000   136.742      .557       .643     6898.81    -5161.22       .023         .083       .144        .083    135.996
    1.500   204.543     1.690      1.305     5153.14    -2352.08       .023         .110       .117        .110    135.249
    2.000   271.949     3.697      2.134     4268.69    -1325.86       .023         .132       .095        .132    134.501
    2.500   338.942     6.746      3.100     3739.82     -841.55       .023         .149       .078        .149    133.753
    3.000   405.497    10.966      4.176     3391.16     -576.54       .023         .162       .065        .162    133.006
    3.500   471.584    16.457      5.341     3145.80     -416.97       .023         .173       .054        .173    132.258
    4.000   537.169    23.296      6.580     2964.71     -314.28       .023         .181       .046        .181    131.510
    4.500   602.215    31.540      7.879     2825.94     -244.94       .023         .188       .039        .188    130.763
    5.000   666.684    41.229      9.228     2716.27     -196.40       .023         .193       .034        .193    130.015
    5.500   730.534    52.393     10.618     2627.24     -161.48       .023         .198       .029        .198    129.267
    6.000   793.723    65.050     12.045     2553.23     -135.80       .023         .201       .026        .201    128.520
    6.500   856.209    79.210     13.501     2490.35     -116.60       .023         .204       .023        .204    127.771
    7.000   917.948    94.876     14.983     2435.83     -102.08       .023         .206       .021        .206    127.019
   FINAL VALUES
    7.140   935.095    99.532     14.983     2421.78      -98.66       .023         .206       .021        .206    126.809
    CALCULATED RESULTS
     CRITICAL VALUES:
        ASCSV          ASC            PTIME          CDIST          XDIST          TDIST
       137.49        126.81            7.14        3654.00         935.10        4589.10
     PROB       AVG TIME    STD DEV     XTIME         TTIME        YA
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  1.0000     23.6943      1.3833     29.0890     36.2287    152.0000
   .9988     23.7003      1.3833     29.0950     36.2347    151.0000
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                               NASA HIGH SPEED ANALYSIS
                                    INPUT SUMMARY,
                                  PROBABILISTIC MODEL
                                          AVERAGE    STD DEV     UNITS,
          TOUCHDOWN LOCATION                1500.       30.      FEET
          TOUCHDOWN SPEED                    181.       10.      FT/SEC
          TIME-TOUCHDOWN TO DECEL              5.        1.      SECONDS
          DECELERATION RATE                  5.00       .50      FT/SEC**2
          50%PROBABILITY SPEED               157.        1.      FT/SEC
          DIST:THRESHOLD-START OF TURN      3654.                FEET
          SPEED AT MAJOR DECEL REDUCE        155.                FT/SEC
          NOSE-WINGTIP DIST                   48.                FEET
                               AIRCRAFT TRACKING PROGRAM
    AIRCRAFT CHARACTERISTICS
         WEIGHT(LBS)    YAW INERTIA       WHEELBASE     % LOAD ON MAIN GEAR
              48000.0       800000.0           36.0            95.0
     FLIGHT CONDITIONAL PARAMETERS
         EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU       DECEL RATE
            142.376         33.000          .250         -1.750
      SYSTEM WIDTHS
              RUNWAY       WINGSPAN      CLEAR DIST.        DIST TO TAXIWAY
             150.00          85.00         117.50                600.00
      SCRUB CHARACTERISTICS
         Y MU      RADIUS
         .0000    .1E+32
         .0250      50.0
   CONSTANT NLG SIDE LOAD ANALYSIS
/    PASSENGER CONFORT IGNORED
    TIME        X         Y       THETA      RADIUS      R RATE    MU SCRUB      MU CENT    MU I      G CENT     VELOCITY
      .000      .000      .000      .000   100000.00 -1576042.00       .025      .006      .219      .006   142.376
      .500    70.968      .088      .190    12337.53   -19270.68       .025      .050      .175      .050   141.499
     1.000   141.496      .573      .637     7240.80    -5362.63       .025      .085      .140      .085   140.622
     1.500   211.577     1.729     1.287     5425.76    -2447.22       .025      .112      .113      .112   139.744
     2.000   281.199     3.772     2.100     4505.18    -1380.65       .025      .133      .092      .133   138.867
     2.500   350.343     6.864     3.043     3954.21     -877.21       .025      .150      .075      .150   137.989
     3.000   418.984    11.132     4.092     3590.54     -601.92       .025      .163      .062      .163   137.112
     3.500   487.094    16.672     5.225     3334.12     -436.36       .025      .173      .052      .173   136.235
     4.000   554.641    23.557     6.428     3144.30     -330.03       .025      .181      .044      .181   135.357
     4.500   621.588    31.838     7.688     2998.27     -258.42       .025      .187      .038      .187   134.480
     5.000   687.898    41.554     8.995     2882.24     -208.43       .025      .192      .033      .192   133.602
     5.500   753.533    52.730    10.341     2787.45     -172.59       .025      .196      .029      .196   132.725
     6.000   818.454    65.381    11.721     2708.03     -146.33       .025      .199      .026      .199   131.848
     6.500   882.618    79.513    13.129     2639.99     -126.75       .025      .202      .023      .202   130.970
     7.000   945.987    95.127    14.562     2580.47     -111.95       .025      .204      .021      .204   130.093
     7.500  1008.518   112.217    16.017     2527.44     -100.63       .025      .205      .020      .205   129.216
    FINAL VALUES
     7.647  1026.737   117.521    16.017     2512.86      -97.83       .025      .206      .019      .206   128.958
     CALCULATED RESULTS
      CRITICAL VALUES:
         ASCSV          ASC            PTIME          CDIST          XDIST           TDIST
        142.38         128.96           7.65       3654.00        1026.74         4680.74
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PROB       AVG TIME    STD DEV     XTIME       TTIME        YA
1.0000     21.2768      1.1700     25.8397     33.4863    157.0000
 .9988     21.2816      1.1700     25.8445     33.4911    156.0000
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GENERIC AIRCRAFT CF

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                             NASA HIGH SPEED ANALYSIS
                                  INPUT SUMMARY,
                                PROBABILISTIC MODEL
                                        AVERAGE    STD DEV    UNITS,
          TOUCHDOWN LOCATION              1500.        30.    FEET
          TOUCHDOWN SPEED                  230.        10.    FT/SEC
          TIME-TOUCHDOWN TO DECEL            5.         1.    SECONDS
          DECELERATION RATE                 .50        .50    FT/SEC**2
          50%PROBABILITY SPEED             237.         1.    FT/SEC
          DIST:THRESHOLD-START OF TURN    5860.               FEET
          SPEED AT MAJOR DECEL REDUCE      175.               FT/SEC
          NOSE-WINGTIP DIST                103.               FEET
                             AIRCRAFT TRACKING PROGRAM
    AIRCRAFT CHARACTERISTICS
         WEIGHT(LBS)    YAW INERTIA       WHEELBASE     % LOAD ON MAIN GEAR
             120000.0     4200000.0          61.0             95.0
     FLIGHT CONDITIONAL PARAMETERS
         EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU       DECEL RATE
            222.913        39.000             .250          -.500
      SYSTEM WIDTHS
              RUNWAY        WINGSPAN      CLEAR DIST.         DIST TO TAXIWAY
             150.00          141.00        145.50                600.00
      SCRUB CHARACTERISTICS
         Y MU       RADIUS
         .0000     .1E+32
         .0250      50.0
   CONSTANT NLG SIDE LOAD ANALYSIS
/    PASSENGER CONFORT IGNORED
    TIME         X          Y        THETA       RADIUS       R RATE     MU SCRUB       MU CENT      MU I        G CENT      VELOCITY
     .000       .000       .000       .000    100000.00   -778299.10        .025          .015        .210         .015    222.913
     .500    111.393       .137       .177     22749.25    -30271.10        .025          .068        .157         .068    222.661
    1.000    222.658       .809       .542     14399.43     -9131.32        .025          .107        .118         .107    222.409
    1.500    333.789      2.331      1.048     11280.89     -4226.77        .025          .136        .089         .136    222.157
    2.000    444.773      4.939      1.660      9696.01     -2359.71        .025          .158        .067         .158    221.905
    2.500    555.595      8.808      2.352      8764.52     -1460.72        .025          .174        .051         .174    221.654
    3.000    666.232     14.070      3.104      8169.12      -964.41        .025          .186        .039         .186    221.402
    3.500    776.663     20.820      3.901      7767.39      -665.27        .025          .196        .029         .196    221.150
    4.000    886.861     29.131      4.732      7485.87      -473.88        .025          .202        .023         .202    220.898
    4.500    996.800     39.054      5.589      7282.84      -346.17        .025          .208        .017         .208    220.647
    5.000   1106.450     50.627      6.466      7133.00      -258.34        .025          .211        .014         .211    220.395
    5.500   1215.784     63.876      7.358      7020.12      -196.58        .025          .214        .011         .214    220.143
    6.000   1324.771     78.821      8.261      6933.44      -152.45        .025          .217        .008         .217    219.891
    6.500   1433.384     95.472      9.174      6865.60      -120.53        .025          .218        .007         .218    219.640
    7.000   1541.592    113.838     10.094      6811.45       -97.22        .025          .219        .006         .219    219.388
    7.500   1649.366    133.920     11.019      6767.33       -80.09        .025          .220        .005         .220    219.136
    FINAL VALUES
    7.771   1707.589    145.522     11.019      6746.64       -72.76        .025          .221        .004         .221    219.000
     CALCULATED RESULTS
      CRITICAL VALUES:
         ASCSV          ASC            PTIME         CDIST          XDIST          TDIST
        222.91         219.00           7.77       5860.00        1707.59        7567.59
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PROB        AVG TIME     STD DEV      XTIME        TTIME        YA
1.0000      26.1421        .8096      29.2997      37.0703     237.0000
 .9987      26.1466        .8096      29.3041      37.0747     236.0000
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                              NASA HIGH SPEED ANALYSIS
                                   INPUT SUMMARY,
                                 PRC3ABILISTIC MODEL
                                         AVERAGE    STD DEV    UNITS,
          TOUCHDOWN LOCATION               1500.       30.     FEET
          TOUCHDOWN SPEED                   230.       10.     FT/SEC
          TIME-TOUCHDOWN TO DECEL            5.         1.     SECONDS
          DECELERATION RATE                 .50       1.00     FT/SEC**2
          50%PROBABILITY SPEED              237.        1.     FT/SEC
          DIST:THRESHOLD-START OF TURN     5860.               FEET
          SPEED AT MAJOR DECEL REDUCE       190.               FT/SEC
          NOSE-WINGTIP DIST                 130.               FEET
                              AIRCRAFT TRACKING PROGRAM
      AIRCRAFT CHARACTERISTICS
           WEIGHT(LBS)    YAW INERTIA       WHEELBASE     % LOAD ON MAIN GEAR
               400000.0    40000000.0          84.0            96.0
       FLIGHT CONDITIONAL PARAMETERS
           EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU       DECEL RATE
              222.913         45.000            .250          -.500
        SYSTEM WIDTHS
                RUNWAY        WINGSPAN      CLEAR DIST.        DIST TO TAXIWAY
               150.00          207.00         178.50               600.00
        SCRUB CHARACTERISTICS
           Y MU       RADIUS
           .0000     .1E+32
           .0100    5287.0
           .0190    2638.0
           .0390    1318.0
           .0590     877.0
           .0790     657.0
           .0990     534.0
     CONSTANT NLG SIDE LOAD ANALYSIS
/      PASSENGER CONFORT IGNORED
      TIME          X          Y          THETA       RADIUS       R RATE      MU SCRUB     MU CENT     MU I        G CENT      VELOCITY
        .000       .000       .000        .000    100000.00  -324956.00        .010        .015        .225        .015    222.913
        .500    111.393       .094        .114     39349.85   -45058.04        .010        .039        .201        .039    222.661
       1.000    222.660       .502        .321     25506.86   -16962.76        .010        .060        .180        .060    222.409
       1.500    333.797      1.391        .610     19394.29    -8791.11        .010        .079        .161        .079    222.157
       2.000    444.802      2.913        .974     15964.46    -5342.48        .010        .096        .144        .096    221.905
       2.500    555.668      5.203       1.404     13778.60    -3571.28        .010        .111        .129        .111    221.654
       3.000    666.386      8.380       1.893     12270.59    -2543.21        .010        .124        .116        .124    221.402
       3.500    776.945     12.549       2.436     11172.33    -1894.35        .010        .136        .104        .136    221.150
       4.000    887.331     17.806       3.026     10340.50    -1459.08        .010        .147        .093        .147    220.898
       4.500    997.530     24.232       3.658      9691.49    -1153.27        .010        .156        .084        .156    220.647
       5.000   1107.523     31.904       4.329      9173.22     -930.48        .010        .164        .076        .164    220.395
       5.500   1217.290     40.885       5.033      8751.58     -763.38        .010        .172        .068        .172    220.143
       6.000   1326.809     51.233       5.769      8403.26     -635.03        .010        .179        .061        .179    219.891
       6.500   1436.060     62.999       6.532      8111.82     -534.48        .010        .185        .055        .185    219.640
       7.000   1545.016     76.228       7.319      7865.30     -454.38        .010        .190        .050        .190    219.388
       7.500   1653.651     90.957       8.129      7654.81     -389.67        .010        .195        .045        .195    219.136
       8.000   1761.940    107.221       8.959      7473.61     -336.76        .010        .199        .041        .199    218.884
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 8.500  1869.856   125.048    9.806     7316.48     -293.04      .010      .203      .037      .203   218.632
 9.000  1977.369   144.462   10.670     7179.32     -256.60      .010      .206      .034      .206   218.381
 9.500  2084.452   165.485   11.548     7058.88     -225.97      .010      .209      .031      .209   218.129
FINAL VALUES
 9.792  2146.774   178.513   11.548     6995.21     -210.33      .010      .211      .029      .211   217.982
 CALCULATED RESULTS
  CRITICAL VALUES:
     ASCSV          ASC           PTIME          CDIST          XDIST          TDIST
    222.91         217.98          9.79        5860.00        2146.77        8006.77
  PROB       AVG TIME    STD DEV     XTIME       TTIME      YA
   .9999     26.2631       .8705     29.6578     39.4502   237.0000
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GENERIC AIRCRAFT BF

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                              NASA HIGH SPEED ANALYSIS
                                   INPUT SUMMARY,
                                 PROBABILISTIC MODEL
                                         AVERAGE    STD DEV    UNITS,
          TOUCHDOWN LOCATION               1000.       20.      FEET
          TOUCHDOWN SPEED                   164.       10.      FT/SEC
          TIME-TOUCHDOWN TO DECEL             4.        1.      SECONDS
          DECELERATION RATE                  .50       .50      FT/SEC**2
          50%PROBABILITY SPEED              170.        1.      FT/SEC
          DIST:THRESHOLD-START OF TURN     4225.                FEET
          SPEED AT MAJOR DECEL REDUCE       155.                FT/SEC
          NOSE-WINGTIP DIST                  56.                FEET
                              AIRCRAFT TRACKING PROGRAM
      AIRCRAFT CHARACTERISTICS
           WEIGHT(LBS)   YAW INERTIA       WHEELBASE     % LOAD ON MAIN GEAR
                48000.0      800000.0           36.0          95.0
       FLIGHT CONDITIONAL PARAMETERS
           EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU       DECEL RATE
              155.971         38.000            .250         -1.500
        SYSTEM WIDTHS
                RUNWAY       WINGSPAN      CLEAR DIST.         DIST TO TAXIWAY
               150.00         49.00          99.50                600.00
        SCRUB CHARACTERISTICS
           Y MU       RADIUS
           .0000     .1E+32
           .0230       50.0
     CONSTANT NLG SIDE LOAD ANALYSIS
 /     PASSENGER CONFORT IGNORED
      TIME       X          Y        THETA      RADIUS       R RATE     MU SCRUB      MU CENT     MU I       G CENT      VELOCITY
        .000      .000       .000      .000   100000.00 -1443540.00       .023         .008      .219        .008   155.971
        .500    77.798       .099      .194    13450.86   -20493.91       .023         .056      .171        .056   155.223
       1.000   155.220       .636      .639     8012.48    -5735.52       .023         .092      .135        .092   154.476
       1.500   232.260      1.907     1.282     6072.28    -2611.91       .023         .121      .106        .121   153.728
       2.000   308.904      4.137     2.077     5092.00    -1465.34       .023         .143      .084        .143   152.980
       2.500   385.132      7.499     2.993     4509.28     -923.56       .023         .160      .067        .160   152.233
       3.000   460.919     12.121     4.004     4128.10     -627.46       .023         .173      .054        .173   151.485
       3.500   536.236     18.101     5.090     3862.20     -449.73       .023         .183      .044        .183   150.737
       4.000   611.050     25.511     6.235     3667.71     -335.96       .023         .190      .037        .190   149.990
       4.500   685.326     34.403     7.429     3519.96     -259.70       .023         .197      .030        .197   149.242
       5.000   759.026     44.815     8.662     3404.08     -206.80       .023         .201      .026        .201   148.494

       5.500   832.114     56.770     9.926     3310.59     -169.16       .023         .205      .022        .205   147.747
       6.000   904.548     70.284    11.217     3233.18     -141.84       .023         .208      .019        .208   146.999
       6.500   976.291     85.363    12.530     3167.54     -121.69       .023         .210      .017        .210   146.251
      FINAL VALUES
       6.928  1037.124     99.516    12.530     3118.37     -108.55       .023         .211      .016        .211   145.611
       CALCULATED RESULTS
        CRITICAL VALUES:
           ASCSV          ASC            PTIME          CDIST          XDIST          TDIST
          155.97        145.61            6.93        4225.00        1037.12        5262.12
        PROB        AVG TIME    STD DEV     XTIME         TTIME         YA
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1.0000	26.4980	1.5457	32.5261	39.4538	170.0000
.9986	26.5044	1.5457	32.5325	39.4602	169.0000

GENERIC AIRCRAFT DS

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                              NASA HIGH SPEED ANALYSIS
                                   INPUT SUMMARY,
                                 PROBABILISTIC MODEL
                                         AVERAGE    STD DEV    UNITS,
          TOUCHDOWN LOCATION               1500.       30.     FEET
          TOUCHDOWN SPEED                   211.       15.     FT/SEC
          TIME-TOUCHDOWN TO DECEL             5.        1.     SECONDS
          DECELERATION RATE                  .50       .50     FT/SEC**2
          50%PROBABILITY SPEED              218.        1.     FT/SEC
          DIST:THRESHOLD-START OF TURN     5515.               FEET
          SPEED AT MAJOR DECEL REDUCE       175.               FT/SEC
          NOSE-WINGTIP DIST                  87.               FEET
                              AIRCRAFT TRACKING PROGRAM
    AIRCRAFT CHARACTERISTICS
         WEIGHT(LBS)    YAW INERTIA       WHEELBASE     % LOAD ON MAIN GEAR
             120000.0     4200000.0          61.0            95.0
     FLIGHT CONDITIONAL PARAMETERS
         EXIT VELOCITY  MAX EXIT ANGLE      MAX Y MU       DECEL RATE
            203.865        37.000             .250        -1.750
      SYSTEM WIDTHS
               RUNWAY        WINGSPAN      CLEAR DIST.        DIST TO TAXIWAY
              150.00          87.00         118.50               600.00
      SCRUB CHARACTERISTICS
         Y MU       RADIUS
         .0000     .1E+32
         .0100     5000.0
         .0120     2000.0
         .0180     1000.0
         .0230      500.0
         .0300       50.0
   CONSTANT NLG SIDE LOAD ANALYSIS
/    PASSENGER CONFORT IGNORED
    TIME         X          Y         THETA       RADIUS       R RATE     MU SCRUB     MU CENT     MU I       G CENT      VELOCITY

      .000      .000       .000        .000    100000.00   -922180.40      .010        .013       .227       .013    203.865
      .500   101.713       .126        .182     19683.64    -27650.95      .010        .065       .175       .065    202.988
     1.000   202.985       .765        .572     12138.82     -8177.81      .010        .105       .135       .105    202.110
     1.500   303.809      2.234       1.122      9347.16     -3790.43      .010        .135       .105       .135    201.233
     2.000   404.173      4.771       1.795      7919.60     -2140.26      .010        .157       .083       .157    200.356
     2.500   504.058      8.558       2.563      7067.73     -1350.71      .010        .175       .065       .175    199.478
     3.000   603.443     13.727       3.406      6510.56      -916.26      .010        .188       .052       .188    198.601
     3.500   702.299     20.380       4.306      6122.82      -654.64      .010        .198       .042       .198    197.723
     4.000   800.597     28.590       5.252      5840.24      -487.04      .010        .206       .034       .206    196.846
     4.500   898.307     38.411       6.234      5626.51      -374.83      .010        .212       .028       .212    195.969
     5.000   995.396     49.878       7.245      5459.60      -297.23      .010        .217       .023       .217    195.091
     5.500  1091.829     63.019       8.280      5325.46      -242.24      .010        .220       .020       .220    194.214
     6.000  1187.573     77.848       9.334      5214.78      -202.54      .010        .223       .017       .223    193.337
     6.500  1282.594     94.373      10.403      5121.13      -173.46      .010        .225       .015       .225    192.459
     7.000  1376.857    112.597      11.486      5040.04      -151.90      .010        .226       .014       .226    191.582
    FINAL VALUES
     7.153  1405.544    118.513      11.486      5017.22      -146.47      .010        .227       .013       .227    191.313
```

```
CALCULATED RESULTS
 CRITICAL VALUES:
    ASCSV          ASC            PTIME         CDIST          XDIST          TDIST
   203.87         191.31           7.15        5515.00        1405.54        6920.54
 PROB       AVG TIME    STD DEV     XTIME        TTIME        YA
  .9999     26.7904      1.6923     33.3903      40.5430    218.0000
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