NASA Contractor Report 172549

PROBABILISTIC COMPUTER MODEL OF OPTIMAL RUNWAY TURNOFFS

M. L. Schoen, O. W. Preston, L. G. Summers
B. A. Nelson, L. VanderLinden, M. C. McReynolds

McDonnell Douglas Corporation
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Long Beach, California 90846

Contract NAS1-16202
April 1985

National Aeronautics and
Space Administration

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INTRODUCTION

Landing delays are currently a problem at major air carrier airports, and most forecasters agree that they will get worse by the end of the century. It is anticipated that some types of delays can be reduced by an efficient high speed runway exit system, allowing the increased approach volumes necessary to assist congested airports.

This report defines a computerized Probabilistic Runway Turnoff Model developed in Ref. 1, which analyzes exit utilization and operational characteristics for varying aircraft types.

To achieve an increase in arrivals at congested airports, methods of minimizing both runway occupancy time and its related standard deviation must be achieved. Reliability is the major factor--thus it was established that one miss for every 10,000 turnoffs per week per airfield (2 runways) or 3.75 standard deviations above average, is an appropriate goal. When considering congested existing airports only experiencing approximately 2,000 weekly landings per runway, compared to the goal of 10,000, the 1/10,000 reliability looks extremely attractive. (See Table 1)

With this level of reliability, separation distances between aircraft could be decreased to provide an increase in density of arrivals.

Table 1

RELIABILITY OF RUNWAY OPERATIONS

Number of Weekly Landings Per Runway	Probability of One Missed Turnoff Per Week Per Runway	No. of Std Devs. From the Mean	Example Airport Experiencing This Activity per Runway
5,000	.0002	3.75	N/A
4,000	.00025	3.45	N/A
1,700	.00059	3.23	LaGuardia
1,200	.00083	3.15	LAX
			Denver

Ref. 2

Total aircraft movements (52 wks/yr x 2 (approaches/departures) x number of runways used for departures.)

PROBABILISTIC RUNWAY TURNOFF MODEL

PROGRAM FUNCTION

The computer probabilistic model is comprised of two parts; 1) the time required from threshold to start of exit with a probability determination of an exit velocity and 2) a subroutine of time required in the turnoff to clear the runway using an optimized path. The times determined by each part are added together to yield the total runway occupancy time which, probabilistically, will be a unique value less than 40 seconds. The flow chart in Table 3 outlines the inputs, the major steps, and the iteration loops of the probabilistic runway turnoff model.

RUNWAY OCCUPANCY TIME

Runway occupancy time is defined as the average time plus the number of standard deviations for a required probability. Therefore, a maximum occupancy time limit, not an average, of 40 seconds or 90 landings per hour, was incorporated with the following rational.

If an average time was used in the analysis, assumed to be normally distributed, there would be a substantial number of aircraft with occupancy times approaching 30 seconds. However, the aircraft must be spaced on final approach with the intent of a 40 second occupancy time. Arrival separations and runway occupancy times are mutually exclusive events. The Air Traffic Controller is not capable of determining the amount of time any given aircraft will spend on the runway. Therefore, it was determined that the only real alternative with which to evaluate runway exit design would be to use a 40 second maximum. This time measurement is from the threshold to the point the aircraft has completely cleared the runway surface during exiting.

TOUCHDOWN SPEED AND LOCATION

Touchdown speed and location are assumed normally distributed even though existing data indicate the log-normal distribution is a better fit of touchdown location. The time from touchdown until start of deceleration is assumed normally distributed, and the speed is assumed constant from crossing the threshold to the start of deceleration.

BRAKING DECELERATION

Since most aircraft are capable of decelerating faster than is normally practical, a conservative deceleration rate is used.

The deceleration process has a number of factors contributing to the total deceleration force. As Figure 1 shows, the major force is from the application of brakes, followed by aerodynamic drag at higher speeds and then reverse thrust. However, during deceleration, modern aircraft hold a constant deceleration rate controlled by avionics equipment which controls brakes at increased levels after reverse thrust is shut down and aerodynamic drag has decreased. This auto-braking system allows different combinations of braking versus thrust reversal to be utilized to account for different weather conditions. Therefore, a constant deceleration rate is maintained down the runway to the beginning of the exit path. Because all of the pilot's attention is required during his exiting procedures, reverse thrust is shut down before exiting rather than during exiting and deceleration is decreased through the path, helping maneuverability performance.

This deceleration rate named XA, Table 2, is an input to the model which allows for changes of deceleration rates to the user's choice.

PROBABILITY EXIT SPEED

Speeds and distances from the exit entrance are assumed normally distributed. A 50-percentile cumulative normal distribution speed, named YA, initializes the program. A higher YA speed (YA + YS) yields a high probability of combined variables achieving 40-second maximum runway occupancy time, while a lower YA speed (YA - YS) gives a lower probability. The approach to finding the 99 percent to 100 percent probability speed of exiting with a 40-second maximum runway occupancy time is achieved.

If the 40-second criterion is not met, the time is proportioned based on 40 seconds, and repetitive substitutions of deceleration and exit to threshold distances (CDIST) are made until the 40 seconds maximum is met.

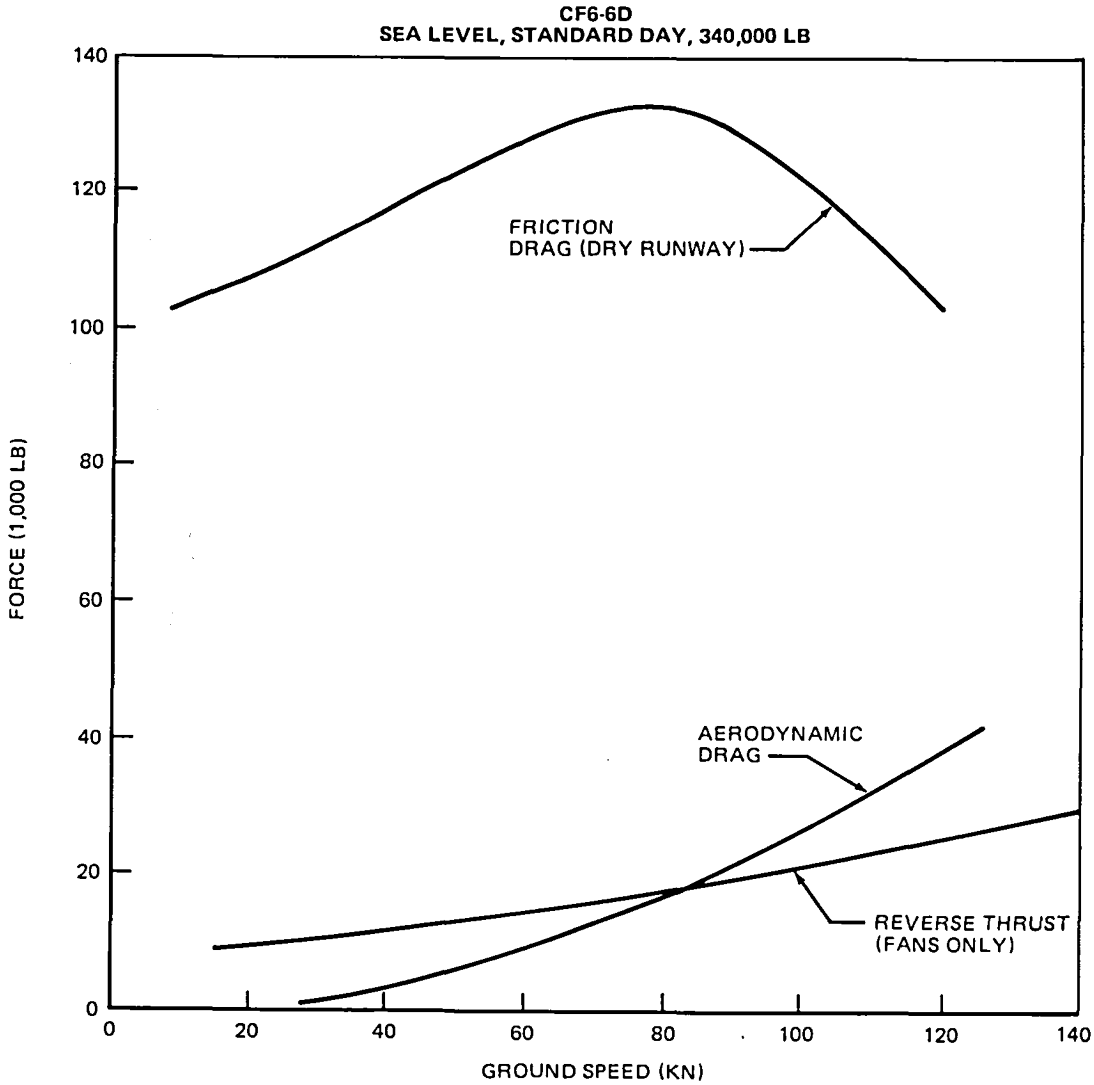


FIGURE 1. SUMMARY OF AIRPLANE FORCES DURING LANDING GROUND RUN MODEL DC-10 SERIES 10

Table 2

PROGRAM LABELS

Parameter	Average	Standard Deviation	For aircraft traveling one standard deviation below the average speed
Touchdown location (distance from threshold)	UA	US	
Touchdown speed	VA	VS	
Time from touchdown until start of deceleration	WA	WS	
Deceleration rate	XA	XS	
Probability speed	YA	YS	
Speed at which reverse thrust stops	ZA	SDB	SB'
Speed at exit of study	ASC	SDC	SC'
Speed at point where deceleration starts For aircraft traveling	ASA	SDA	SA'
		Average	For aircraft traveling one standard deviation below the average speed
Distance from threshold where deceleration starts		A	A'
Distance from threshold where reverse thrust stops		B	B'
Distance to threshold of exit being studied		C	C'
Average runway occupancy time at A		TA	TA'
Average runway occupancy time at B		TB	TB'
Average runway occupancy time at C		TC	TC'

Distances UA, A, B, and C in Figure 2 are used through the flow chart, Table 3, and the reader must be familiar with them to adequately understand the model logic.

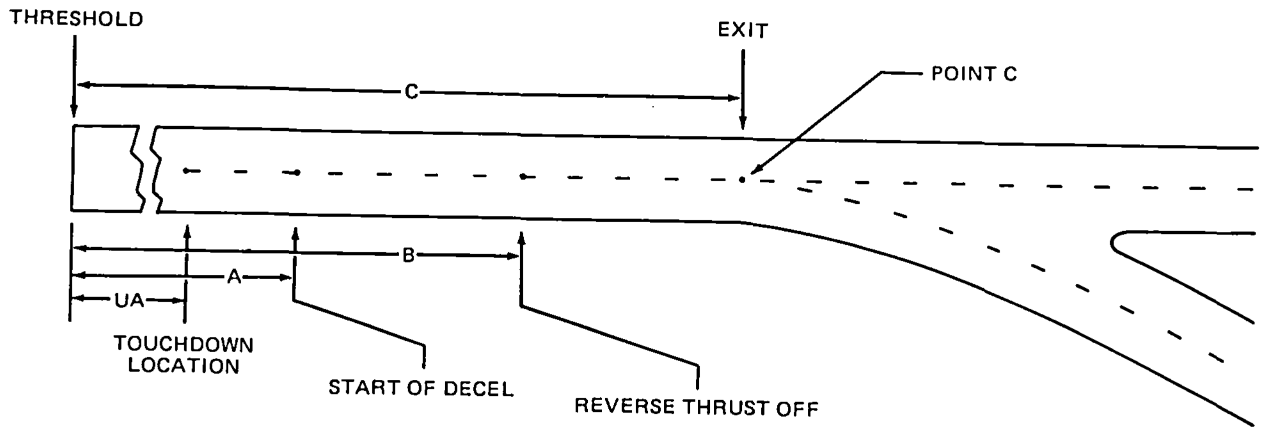


FIGURE 2. RUNWAY OPERATIONS

ALTERNATE PROGRAM MODES

When initially developed, the model was programmed to solve the 40 second occupancy time criterion via the Mode 1 iterative process. Since iteration leaves too many variables, accuracy in every case becomes difficult. Therefore, Modes 2 and 3 were introduced to allow the user to choose his own values for YA.

Mode 2 allows the user to initiate a YA, then the program reduces YA by a value of 1.0, for 15 iterations through the probabilistic model and prints the values in descending order. This becomes useful when evaluating the impact of YA on exiting probability and runway occupancy time for a closed data set.

Mode 3 is the quickest method of obtaining direct solutions for a given YA value. After each completed run, the user is asked to submit a new YA value if not satisfied with the probability. When satisfaction is reached, the user enters 999 to print a completed list of the previously entered YA values and

TABLE 3
FLOWCHART - PROBABILISTIC RUNWAY
TURNOFF MODEL

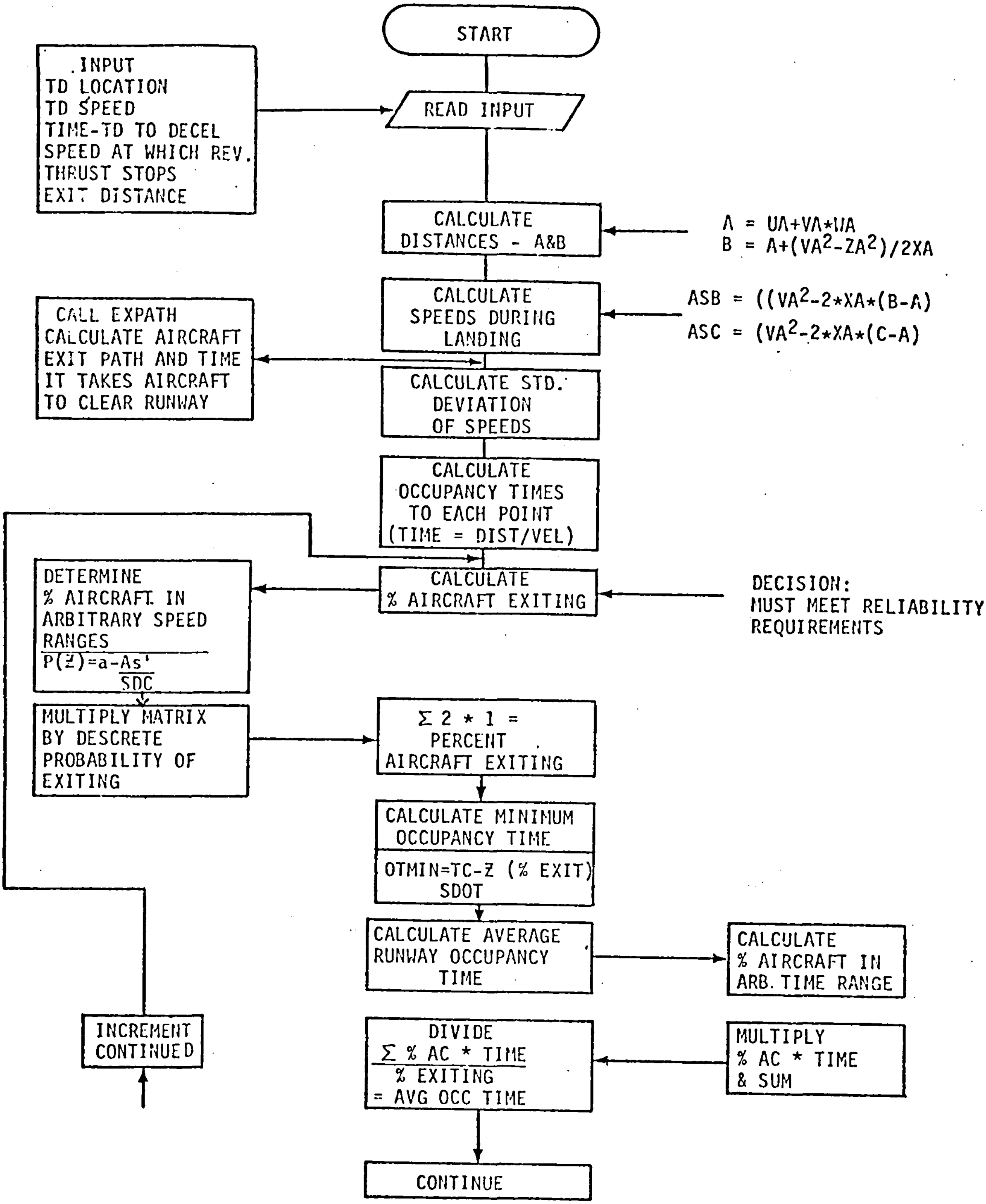


TABLE 3 (cont.)

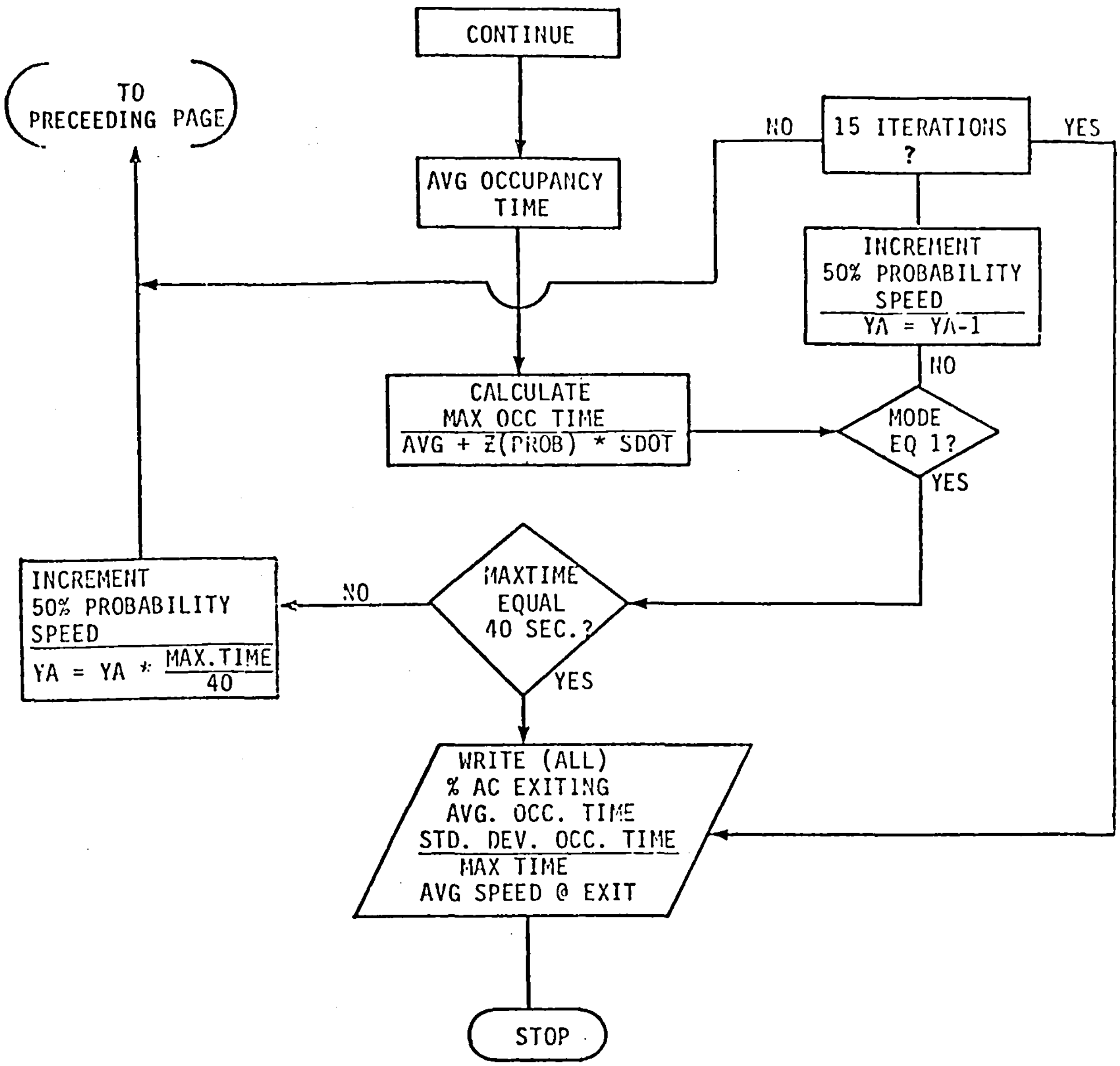
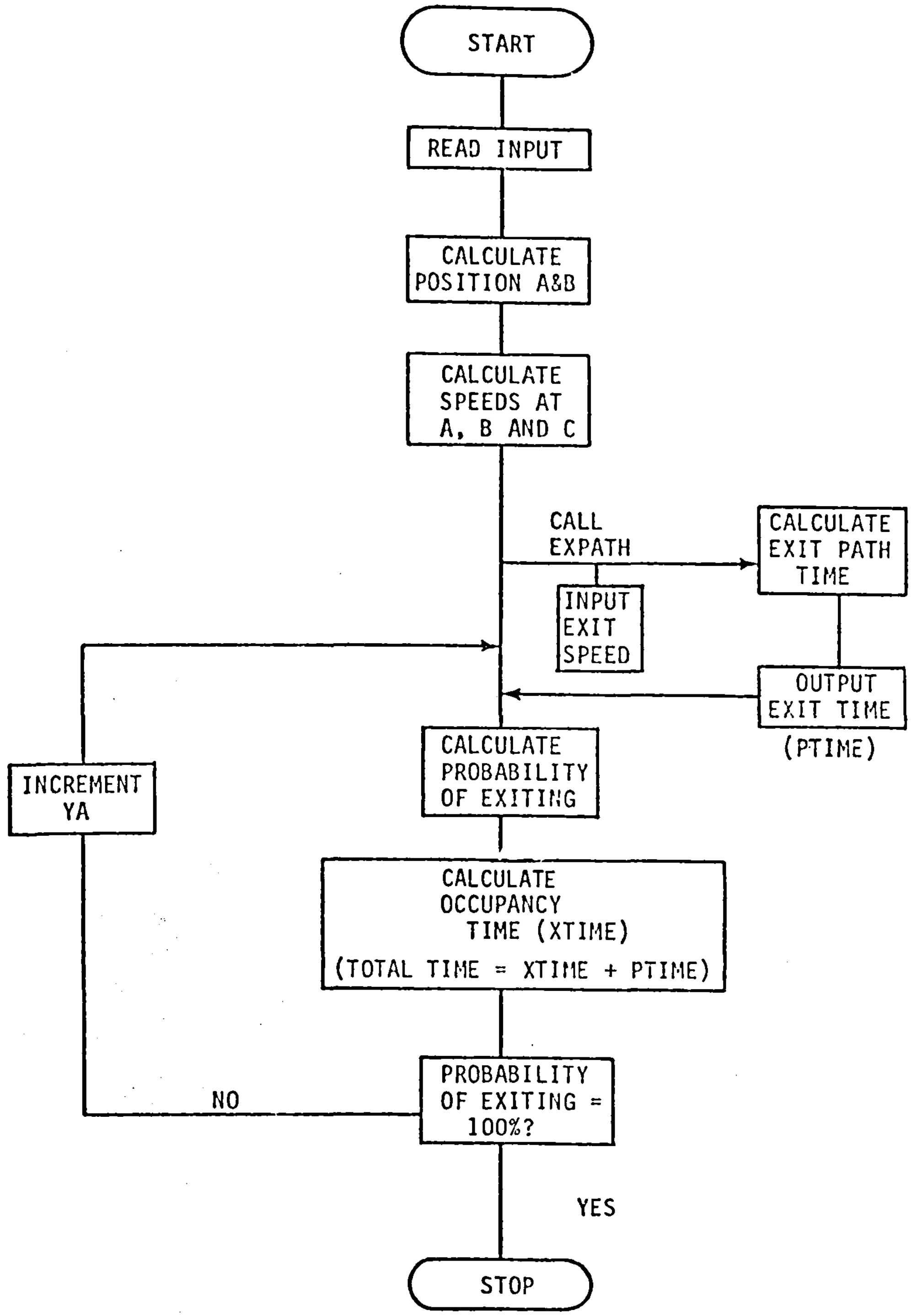

CONTINUE
TO PRECEEDING PAGE
AVG OCCUPANCY TIME
NO
15 ITERATIONS ?
YES
INCREMENT 50% PROBABILITY SPEED
YA = YA-1
NO
CALCULATE MAX OCC TIME
AVG + Z(PROB) * SDOT
MODE EQ 1?
YES
INCREMENT 50% PROBABILITY SPEED
YA = YA * MAX.TIME / 40
NO
MAXTIME EQUAL 40 SEC.?
YES
WRITE (ALL)
% AC EXITING
AVG. OCC. TIME
STD. DEV. OCC. TIME
MAX TIME
AVG SPEED @ EXIT
STOP

TABLE 3 (cont.)

EXPATH SUBROUTINE



their probability values. If the probability is less than 1.000 the YA value must be increased. However, if the probability is greater than 1.000, YA must be decreased to a probability of less than 1.000 to determine the breaking point of 1.000 and 0.999. This breaking point identifies the specific data set to be used in the input data. Tables 4-6 exemplify the three types of modes described above.

TABLE 4

MODE 1 EXAMPLE

```
ENTER: 5 FOR TERMINAL PRINTOUT
   6 FOR HARDCOPY PRINTOUT
5
R: 1 FOR STANDARD PRINT
   2 FOR INTERMEDIATE VALUES
   3 FOR FINAL VALUES ONLY
3
R: 1 TO SOLVE FOR 40 SEC OCCUPANCY
   2 TO SOLVE FOR MAXIMUM PROBABILITY
   3 FOR USER ENTRY OF YA VALUE
1
  ENTER INITIAL YA SPEED
300
```

REF. TERPS CATEGORY E AIRCRAFT

CALCULATED RESULTS

CRITICAL VALUES:

ASCSV	ASC	PTIME	CDIST	XDIST
276.22	264.01	6.06	8400.00	1634.71

71

PROB	AVG TIME	STD DEV	XTIME	TTIME	YA
1.0000	24.7617	2.3551	33.9466	40.0104	300.0000**
0.0000	24.7617	2.3551	33.9466	40.0104	254.5999**
0.0000	24.7617	2.3551	33.9466	40.0104	216.0699*
0.0000	24.7617	2.3551	33.9466	40.0104	183.3711*
0.0000	24.7617	2.3551	33.9466	40.0104	155.6207*
0.0000	24.7617	2.3551	33.9466	40.0104	132.0699*
0.0000	24.7617	2.3551	33.9466	40.0104	112.0832*
0.0000	24.7617	2.3551	33.9466	40.0104	95.1211*
0.0000	24.7617	2.3551	33.9466	40.0104	80.7260*
0.0000	24.7617	2.3551	33.9466	40.0104	68.5094*
0.0000	24.7617	2.3551	33.9466	40.0104	58.1415*
0.0000	24.7617	2.3551	33.9466	40.0104	49.3427*
0.0000	24.7617	2.3551	33.9466	40.0104	41.8754*
0.0000	24.7617	2.3551	33.9466	40.0104	35.5382*
0.0000	24.7617	2.3551	33.9466	40.0104	30.1601*

-- STOP

TABLE 5

MODE 2 EXAMPLE

```
ENTER: 5 FOR TERMINAL PRINTOUT
   6 FOR HARDCOPY PRINTOUT
5
R: 1 FOR STANDARD PRINT
   2 FOR INTERMEDIATE VALUES
   3 FOR FINAL VALUES ONLY
1
R: 1 TO SOLVE FOR 40 SEC OCCUPANCY
   2 TO SOLVE FOR MAXIMUM PROBABILITY
   3 FOR USER ENTRY OF YA VALUE
2
  ENTER INITIAL YA SPEED
300
```

TERPS CATEGORY E - LOCKHEED F-104

NASA HIGH SPEED EXIT 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	300.	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	0.200	-2.000

SYSTEM WIDTHS

RUNWAY	WINGSPAN	CLEAR DISTANCE
150.00	21.90	85.95

SCRUB CHARACTERISTICS

Y MU	RADIUS
0.0000	0.1E+32
0.0200	50.0

TABLE 5 (contd.)

CALCULATED RESULTS

CRITICAL VALUES:

ASCSV	ASC	PTIME	CDIST	XDIST
276.22	264.01	6.06	8400.00	1634.71

PROB	AVG TIME	STD DEV	XTIME	TTIME	YA
1.0000	24.7617	2.3551	33.9466	40.0104	300.0000**
1.0000	24.7617	2.3551	33.9466	40.0104	299.0000**
1.0000	24.7617	2.3551	33.9466	40.0104	298.0000**
1.0000	24.7617	2.3551	33.9466	40.0104	297.0000**
1.0000	24.7617	2.3551	33.9466	40.0104	296.0000**
1.0000	24.7617	2.3551	33.9466	40.0104	295.0000**
1.0000	24.7617	2.3551	33.9466	40.0104	294.0000**
1.0000	24.7617	2.3551	33.9466	40.0104	293.0000**
1.0000	24.7617	2.3551	33.9466	40.0104	292.0000**
0.9999	24.7617	2.3551	33.9466	40.0104	291.0000**
0.9975	24.7986	2.3551	33.9835	40.0473	290.0000**
0.9734	24.9313	2.3551	34.1162	40.1799	289.0000**
0.8768	25.3464	2.3551	34.5313	40.5951	288.0000**
0.7220	25.9089	2.3551	35.0938	41.1576	287.0000**
0.6196	26.2624	2.3551	35.4473	41.5110	286.0000**

-- STOP

TABLE 6

MODE 3 EXAMPLE

REF. TERPS CATEGORY E AIRCRAFT

```
ENTER: 5 FOR TERMINAL PRINTOUT
   6 FOR HARDCOPY PRINTOUT
5
   1 FOR STANDARD PRINT
   2 FOR INTERMEDIATE VALUES
   3 FOR FINAL VALUES ONLY
3
R: 1 TO SOLVE FOR 40 SEC OCCUPANCY
   2 TO SOLVE FOR MAXIMUM PROBABILITY
   3 FOR USER ENTRY OF YA VALUE
3
  ENTER INITIAL YA SPEED
6000
PROB =  1.0000
 ENTER NEW YA SPEED;  999 TO END
20
B =  0.0000
 ENTER NEW YA SPEED;  999 TO END
400
OB =  1.0000
 ENTER NEW YA SPEED;  999 TO END
200
B =  0.0000
 ENTER NEW YA SPEED;  999 TO END
300
B =  1.0000
 ENTER NEW YA SPEED;  999 TO END
270
B =  0.0029
 ENTER NEW YA SPEED;  999 TO END
295
PROB =  1.0000
 ENTER NEW YA SPEED;  999 TO END
290
B =  0.9975
 ENTER NEW YA SPEED;  999 TO END
294
B =  1.0000
 ENTER NEW YA SPEED;  999 TO END
293
B =  1.0000
 ENTER NEW YA SPEED;  999 TO END
292
B =  1.0000
 ENTER NEW YA SPEED;  999 TO END
291
B =  0.9999
 ENTER NEW YA SPEED;  999 TO END
999
```

TABLE 6 (contd.)

CALCULATED RESULTS

CRITICAL VALUES:

ASCSV	ASC	PTIME	CDIST	XDIST
276.22	264.01	6.06	8400.00	1634.71

PROB	AVG TIME	STD DEV	XTIME	TTIME	YA
1.0000	24.7617	2.3551	33.9466	40.0104	6000.0000++
0.0000	24.7617	2.3551	33.9466	40.0104	20.0000+
1.0000	24.7617	2.3551	33.9466	40.0104	400.0000++
0.0000	24.7617	2.3551	33.9466	40.0104	200.0000+
1.0000	24.7617	2.3551	33.9466	40.0104	300.0000++
0.0029	24.8021	2.3551	33.9869	40.0507	270.0000++
1.0000	24.7617	2.3551	33.9466	40.0104	295.0000++
0.9975	24.7986	2.3551	33.9835	40.0473	290.0000++
1.0000	24.7617	2.3551	33.9466	40.0104	294.0000++
1.0000	24.7617	2.3551	33.9466	40.0104	293.0000++
1.0000	24.7617	2.3551	33.9466	40.0104	292.0000++
0.9999	24.7617	2.3551	33.9466	40.0104	291.0000++

-- STOP

EXIT PATH (TRACKING) SUBROUTINE

The exit path subroutine is essentially the same program as the one developed in Ref. 1 with the following exceptions:

- Deceleration during the turn has been added as an input.
- Wing tip location has been added to tell when the aircraft has cleared the runway.
- Passenger comfort limitations (G_{max} and J_{max}) have been internally set to inifinity so that they are not limiting.

SUBROUTINE DEVELOPMENT

The exit path optimization subroutine flow chart is shown in Table 3. Basically, the subroutine computes the nose gear μ consumed in overcoming scrubbing and centrifugal forces, applies the net μ remaining to the yaw inertia to find the rate at which the turning radius is shrinking, and then integrates this rate of turn radius change along with the other motion terms. The integration step size is 0.001 seconds. Data output at print intervals is just prior to the integration equations. Figure 3 shows input nose gear μ required to overcome scrubbing forces.

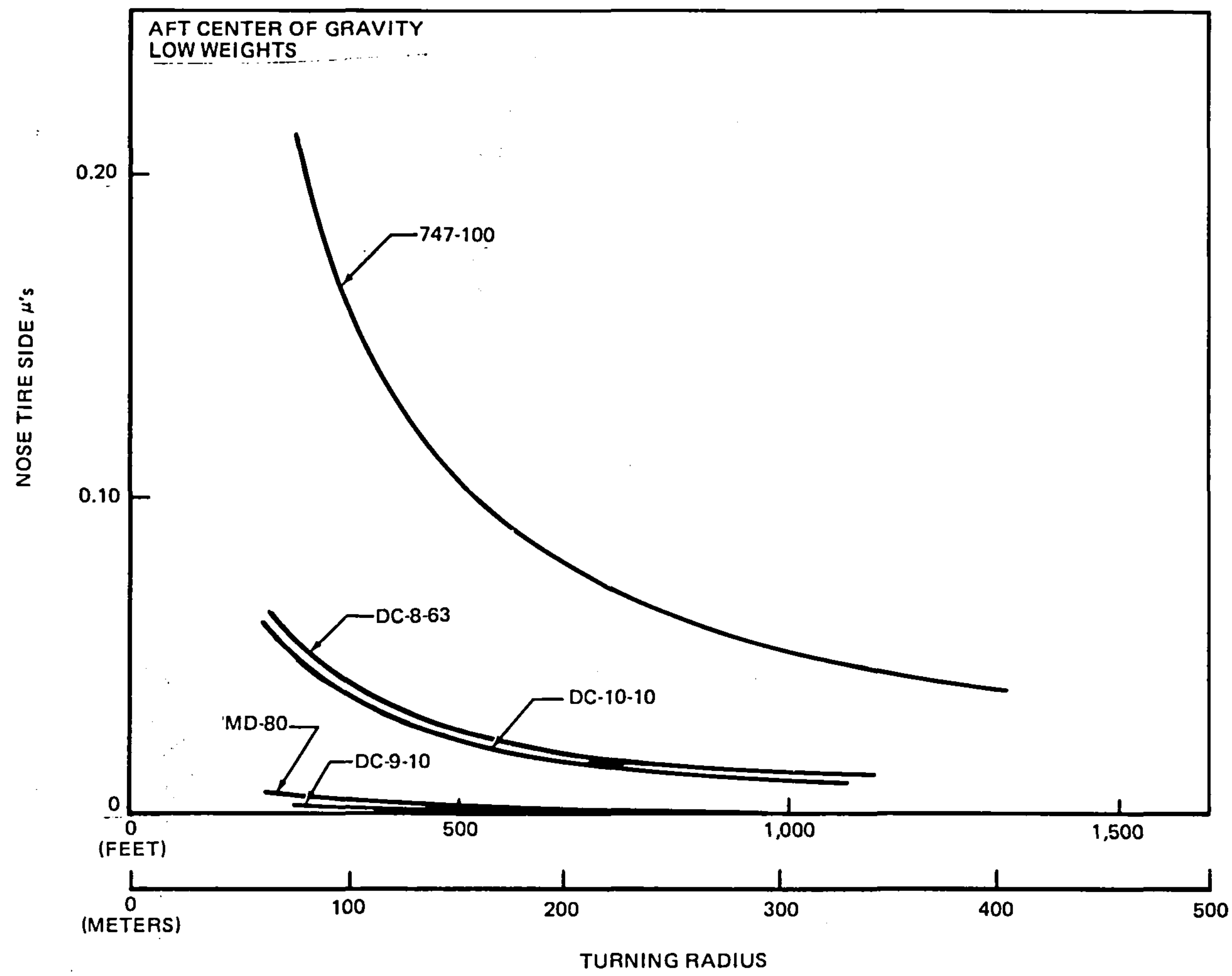


FIGURE 3. NOSE TIRE SIDE μ's VERSUS TURNING RADIUS DURING SLOW-SPEED TURNS

<u>LANDING GEAR FRICTION CHARACTERISTICS</u>

The ability of the nose gear to control the direction of the aircraft is a direct function of (1) its vertical load, (2) the side load it must develop to accomplish a particular maneuver, and (3) the ground coefficient of friction. For simplicity, the demand placed on the nose gear is expressed as the ratio where:

$$C_{NG} = \frac{\text{Side Load on Nose Gear}}{\text{Vertical Load on Nose Gear}}$$

This allows direct comparison to the available ground coefficients of friction which are:

Dry pavement:	0.8
Wet pavement:	0.4 (varies with speed)
Packed snow:	0.2
Ice:	0.1

The demand on the nose gear comes from three sources:

1. Centrifugal force:

$$C_{ay} = V^2/(g_c R)$$

where

V = velocity

g_c = acceleration of gravity

R = instantaneous turn radius

2. Rotation inertia resistance:

$$C_I = I \propto /(g_c)\ (W)\ (L_w)\ \ (\%M/100)\ (1-\%M/100))$$

where I = rotational inertia of aircraft

$\propto$ = rotational acceleration in radians/sec^2 = $-(V)\ (R')/R^2$

where R' = is the rate of change in turn radius

W = aircraft weight

Lw = aircraft wheelbase

$\%M$ = percent of gross weight supported by the main landing gears

3. Scrubbing resistance:

Figure 3 shows μ's for five airplanes. The aircraft's resistance to being turned is dependent upon the type of gears used and their location.

Duals are very easy to turn, whereas a configuration of two wing-mounted gears and two body-mounted gears 3.0 m aft is the most difficult of the commercial jets to turn.

Total maneuvering demand on the nose gear then is:

$$C_{ng} = Ca_y + C_I + C_s \qquad C_s = \mu's = \mu_{scrub}$$

A C_{ng} of 0.2 is considered to be a practical limit for maneuvering at speeds of 59-89 ft/s. This would leave the pilot with a margin of 4 against skidding on dry surfaces and a margin of 2 against skidding on wet surfaces. Pilots would probably refuse to consistently use margins less then 2.

Note that low weight, aft center of gravity conditions 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 weights. The listing in Table 7 is typical of the airplane data required by the program.

TABLE 7

AIRPLANE DATA FOR RUNWAY TURNOFF PROGRAM

Aircraft	Weight LB	Yaw Inertia 10^6Lb In^2	Wheelbase, LW FT	Wt Supported by Main Gear %
DC-9-10	65,372	4546	43.6	95.4
DC-9-80	102,418	17827	72.6	96.8
DC-8-63	173,630	51545	77.4	96.7
DC-10-10	290,850	75813	72.6	94.2
747-100	451,277	194627	84.0	96.4

PASSENGER COMFORT

Equations and logic are included in the subroutine for additionally limiting the computed turn, based on maximum allowable values of lateral acceleration and jerk. At present, these maximums are internally set to infinity and thus, ignored in the computation.

Available literature on passenger comfort, however, did not provide a means of evaluating the interactive effect of acceleration and jerk occurring simultaneously. Therefore, the following relationship was assumed because of its simplicity:

$$\frac{G}{G_{MAX}} + \frac{J}{J_{MAX}} \leqslant 1$$

Data on passenger comfort limitations are difficult to find. Data for trains indicate that lateral G's of 0.12 and lateral J's of 0.55 are comfortable to 90 percent of the passengers and rated acceptable by 95 percent. Higher levels are probably acceptable on a taxiing aircraft because of the short duration and improved seat design.

Equations are included to limit the rate of change in turn radius to acceptable levels for passenger comfort. These limits are presently internally set to infinity, but the equations follow the R dot equation and are:

$$n_y = V^2/(g_c R) = \text{lateral acceleration}$$

$$J_{available} = J_{max} \times (1 - (G/G_{max}))$$

$$R\ dot_{max} = - g_c \times R^2 \times J_{available} / V^2$$

Probabilistic Input

Operation of the Model requires two data sets, named HISPEX and SND. HISPEX is an input data set of landing characteristics and their related deviations supplied in the following format. As seen below there are only 3 cards in the input file, making it necessary to edit the file with every parameter change. The first line of 80 or less characters in a 20A4 format, is a title line to identify the data set. Lines two and three are landing characteristic data inputs, in a F5.0 format, identified as follows:

TITLE CARD			(Any user-desired message - up to 80 characters)			FORMAT 20A4
UA	US	VA	VS	WA	WS	6F5.0
XA	XS	YS	CDIST	ZA	NTIP	6F5.0

Card 1:

1. Title Card - any user desired message may be input, up to 80 characters in length. The message is printed with each run to allow the user to identify various cases.

Card 2:

1. UA - Touchdown location: Distance from runway threshold to point of touchdown (Feet).

2. US - Standard deviation of touchdown location, used in calculating average exit speed standard deviation (Feet).

3. VA - Touchdown speed - Average speed of aircraft between threshold and touchdown. Since flight test data indicates that a decrease in velocity from threshold to touchdown is usually on the order of 5 knots, the speed is averaged between the threshold and the start of deceleration (ft/sec).

4. VS - Standard deviation of touchdown speed (ft/sec).

5. WA - Time from touchdown to start of deceleration. Used to calculate speeds and occupancy time (seconds).

6. WS - Standard deviation of WA. Accounts for discrepancy of pilot technique in time to apply brakes and reverse thrust (seconds).

Card 3:

1. XA - Deceleration rate - Rate of change of aircraft speed from start of deceleration to start of exit (ft/sec^2).

2. XS - Standard deviation of deceleration rate. Accounts for discrepancy of pilot technique in aircraft deceleration (ft/sec^2).

3. YS - Standard deviation of 50% speed used in probability calculation. A value of 1.0 is acceptable for most cases (ft/sec).

4. CDIST - Exit location. Distance from threshold to point of which aircraft begins exit maneuver. This is the parameter to be varied to obtain a range of occupancy times. The solution for a specific set of input data is the exit location that satisfies a 40 second occupancy time and 100% probability (feet).

5. ZA - Speed at which reverse thrust is shut off, which calculates B distance on runway. (See Figure 2, page 7) This is used to check that reverse thrust is terminated prior to beginning exit maneuver, as it would not be practical to consider a case in which the pilot must be burdened with a workload of reverse thrust and exit maneuvering simultaneously (ft/sec).

6. NTIP - Distance from aircraft nose to wingtip, as measured along longitudinal axis of aircraft. (See Item 3, page 24) This parameter was added to the program to calculate the fraction of time the aircraft occupies the runway prior to wingtip over threshold. Since the optimum path program treats the aircraft as a single point located on its wingtip, occupancy time prior to wingtip occupancy is calculated by: (feet).

   Time = distance/speed $\Longrightarrow$ NTIP/Touchdown Speed

Table 8 shows the 5 terps category HISPEX. DAT inputs.

TABLE 8

High Speed Exit Data
(HISPEX.DAT)

```
   CESSNA 172 HAWK
500,    10,    97,    5,    3,    1
  3.5,    1,    1,    1.1777,    60,    27


   TERPS CATEGORY B - CESSNA CITATION SERIES 500
1000,    20,    184,    10,    4,    1
  6,    1,    1,    1.3762,    140,    19


   TERPS CATEGORY C - BOEING 747-100
1500,    30,    235,    10,    5,    1
  6,    1,    1,    1.4075,    150,    144


   TERPS CATEGORY C - DC-10 SERIES 10
1500,    30,    230,    10,    5,    1
  6,    1,    1,    1.5216,    150,    130


   TERPS CATEGORY D CONCORD
1500,    30,    275,    15,    5,    1
  6,    1,    1,    1.6300,    150,    150


   TERPS CATEGORY E - LOCKHEED F-104
1500,    30,    370,    25,    5,    1
  6,    2,    1,    1.8400,    150,    35
```

Input data set SND is a standard table of normal distribution values. The program reads in Table 9, as 10 lines in a 10F5.4 format, and calculates the probability value, given a Z value as input. These Z values are calculated at various points in the model by the standard probabilistic techniques:

$$\underline{Z(x) = x - x}$$
$$\sigma$$

TABLE 9

Standard Normal Probability Table
(SND.DAT)

.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

Incrementing by one, through the discrete probability and summing, minimum occupancy time, and arbitrary occupancy time, the program iteratively calculates values until the final value conditions are met.

Exit Path Subroutine Input

The subroutine named EXPATH tracks the aircraft through the exiting maneuver. The only input required by EXPATH that is dependent on the probabilistic model is exit speed (speed @ point C). A separate data file, named (PATH.DAT) is input to the path model, consisting of the data in Table 10.

TABLE 10

INPUT DATA TO EXIT PATH COMPUTATION

				FORMAT
A/C Weight	Yaw Inertia	Wheelbase	% Weight on Main Gear	F12.3
Theta Max	YMU	Deceleration		F12.3
Runway Width	Wingspan	Distance to Taxiway		F12.3
Y MU Scrub (1) Y MU Scrub (N)	Radius (1) Radius (N)			F5.4, G10.1

The input data required is described below:

1. Aircraft weight - Should be maximum landing weight to obtain critical case (pounds).

2. YAW Inertia - Resistance to movement about vertical axis of aircraft (slug-Ft^2).

3. Wheelbase - Distance from nose gear to main gear, along longitudinal axis of aircraft (feet).

4. Percent weight on main gear - Percent of total aircraft weight on main gear, in maximum landing weight configuration.

5. THETA MAX - The angle at which the wingtip and stabilizer tip are both touching the runway edge, Figure 4. The angles for all 5 Terps category aircraft are shown in Table 11. The tracking program checks to see that this angle is not exceeded during the exit maneuver. If the angle is exceeded, the program is terminated and an appropriate output message is printed on the screen.

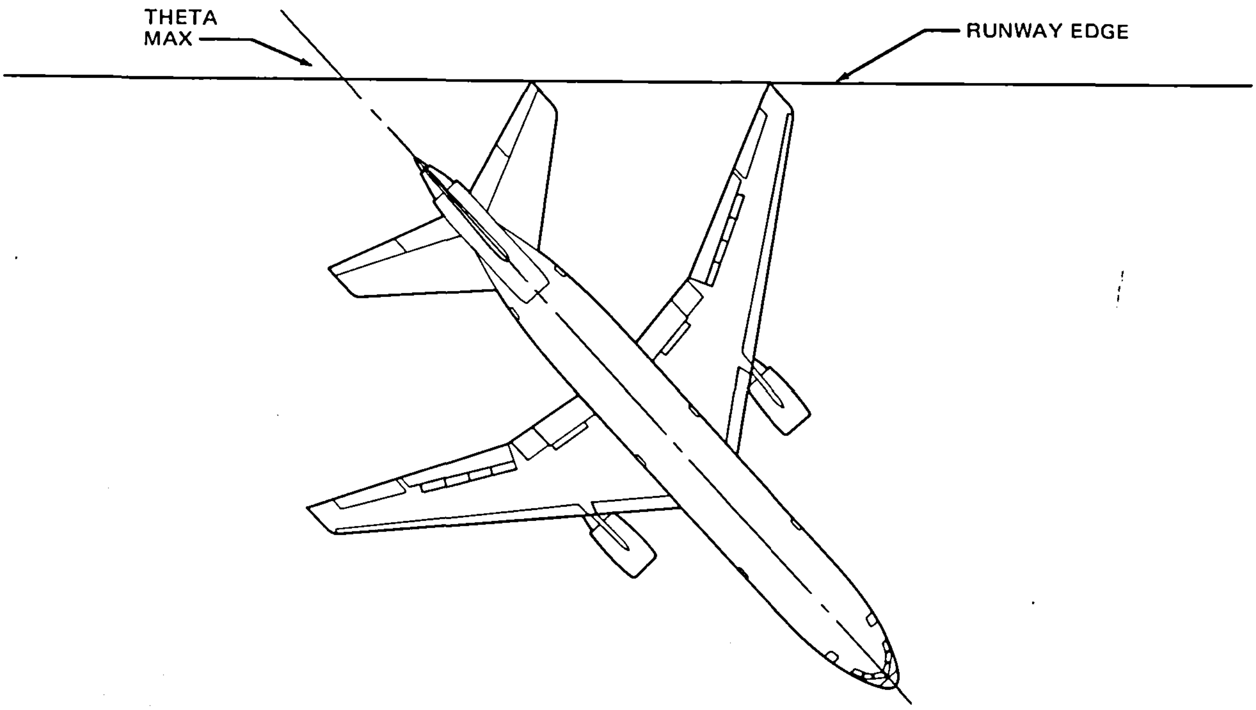


FIGURE 4. SKETCH OF THETA MAX

6. Y MU MAX - Measure of maximum resistance offered by nose gear. A MU (Cng) of 0.2 is considered to be a practical limit for maneuvering at speeds of 60 - 90 feet per second.

7. Deceleration rate - This is the deceleration rate employed in the model during the turning maneuver. This variable allows the analyst to vary deceleration on the runway and through the turn (ft/sec^2).

Table 11

Exit Path Data
(PATH.DAT)

CESSNA 172 HAWK

```
   2550.      2308.       5.4       75.
     41.        0.2      -2.0
    150.       35.9      600.
0.00  1.0E+31
0.02  50.
```

TERPS CATEGORY B - CESSNA CITATION SERIES 500

```
  11000.     59489.      15.7       88.
     38.        0.2      -2.0
    150.       43.8      600.
0.00  1.0E+31
0.02  50.
```

TERPS CATEGORY C - BOEING 747-100

```
  564000.  42000000.       84.      96.4
      45.        0.2      -2.0
     150.      195.7      600.
.00      0.1E+32
.01      5287.
.019     2638.
.039     1318.
.059      877.
.079      657.
.099      524.
.153      347.
.212      257.
.353      167.
.548      121.
.793       99.
```

TERPS CATEGORY C - DC-10 SERIES 10

```
  363500. 16350338.      72.5      93.4
      44.        0.2     -2.0
     150.      155.3     600.
 0.00  1.0E+31
 0.01   5000.
 0.02    2000.
0.025   1000.
0.027   800.
 0.03   200.
```

Table 11 (Cont.)

TERPS CATEGORY D - CONCORD

245000.	12664509.	59.7	94.7
37.	0.2	-2.0	
150.	83.8	600.	
0.00	0.1E+32		
0.01	1000.		
0.02	800.		
0.03	50.		

TERPS CATEGORY E - LOCKHEED F-104

22000.	137776.	15.0	92.3
20.	0.2	-2.0	
150.	21.9	600.	
0.00	0.1E+32		
0.02	50.		

8. Runway width - The width of the runway surface (feet).

9. Wingspan - Total straight line distance from aircraft wingtip to wingtip (feet).

10. Distance to Taxiway - The distance between the centerlines of the runway and a parallel taxiway (Feet).

11. YMU Scrub and Radius - These values are the scrub function as determined by Fig. 3. They vary for different aircraft type but are negligible for small aircraft with a dual main gear configuration.

Clearing Distance

Variables 8 and 9 are entered into the program to determine when the aircraft is clear of the runway. During the tracking calculation, the aircraft is regarded as a single point located on its wingtip. From Figure 5, it can be seen that as an aircraft proceeds down the runway, the

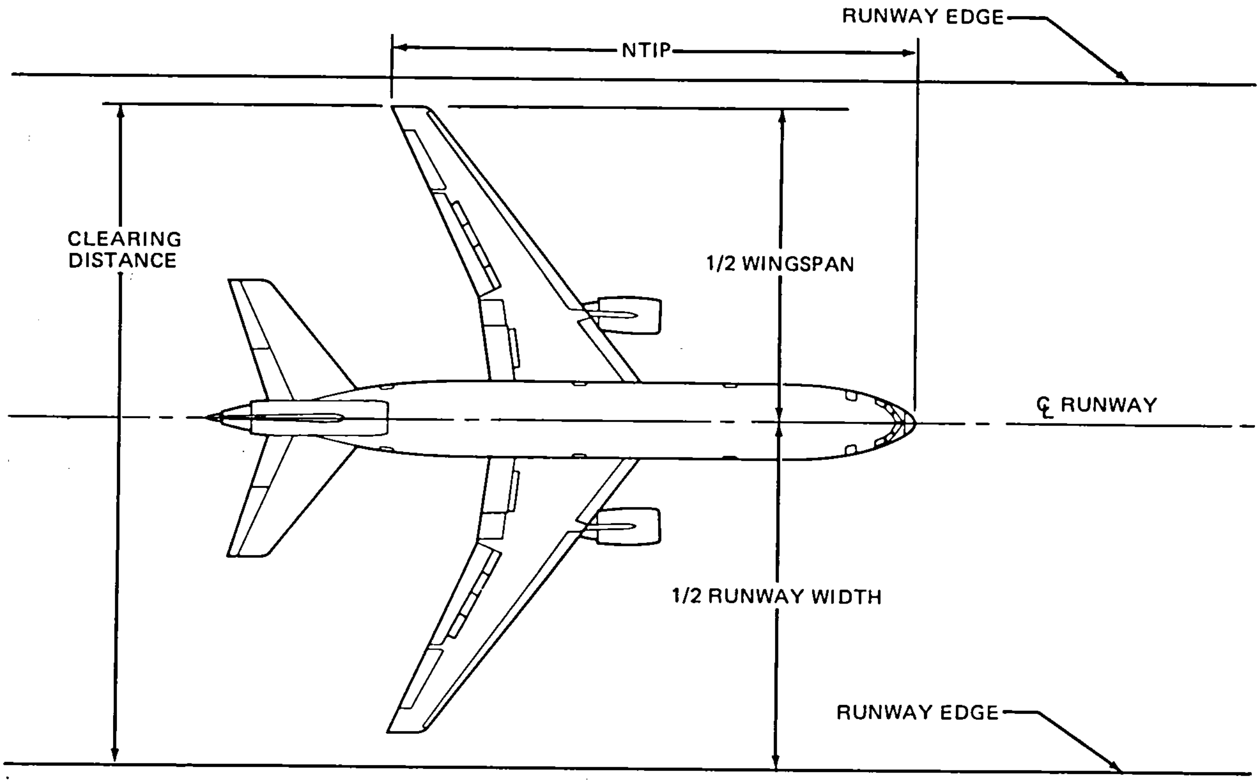


FIGURE 5. DEFINITION OF CLEARING DISTANCE

total distance necessary for the wingtip to travel in order to clear the runway can be given by:

$$\text{clearing distance} = \frac{(\text{Runway width} + \text{Wingspan})}{2}$$

At intervals of 1/1000 of a second, the model calculates the distance the wingtip has traveled laterally and compares this value to (RW + WS)/2. When Y $>$ (RW + WS)/2, the model checks to see if Theta $\leqslant$ Theta max, then returns the time lapsed to the probabilistic model (feet).

Output symbols for the Probabilistic Model

1. ASCSV - speed at the start of the exit maneuver (ft/sec).

2. ACS - speed at the end of the exit maneuver (ft/sec).

3. PTIME - time on exit (curved) path, to clearing the runway surface (seconds).

4. CDIST - distance from threshold to the beginning of the exit maneuver (feet).

5. XDIST - distance traveled during the exit maneuver, to clearing the runway surface only (feet).

6. TDIST - total distance traveled, CDIST plus XDIST (feet).

7. PROB - probability of using the high speed exit (percent).

8. AVG TIME - average time summed through the probability step incrementation (seconds).

9. STD DEV - standard deviation of calculated occupancy times.

10. XTIME - time from the threshold to the beginning of exit path (seconds).

11. TIME - total occupancy time, from threshold to clearing the runway surface (seconds).

12. YA - probability speed (ft/sec).

Output symbols for exit path

1. Time - time in seconds from the start of the exit path.

2. X - X-coordinate distance along the longitudinal axis of the runway from the beginning of the exit path (feet), Fig 6.

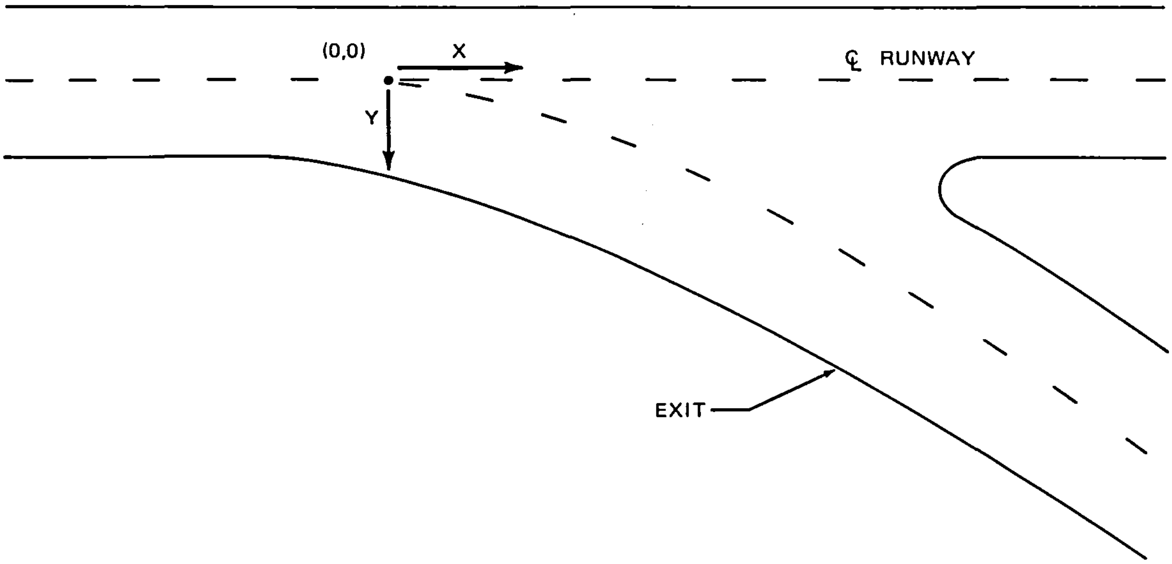


FIGURE 6. EXIT PATH COORDINATES

3. Y - Y-coordinate distance along the lateral axis of the runway from the beginning of the exit path (feet).

4. THETA - angle produced between X and Y coordinate (degree).

5. Radius - instantaneous radius of curve which would fit between two consecutive points along the path (feet).

6. R rate - instantaneous change in radius calculations.

7. Mu Scrub - coefficient of friction contribution from tire scrub - C_s, nose gear.

8. Mu Cent - coefficient of friction contribution from centrifugal forces (percent) - C_{ay}, nose gear.

9. Mu I - coefficient of friction contribution from rotational inertia of the aircraft - C_I.

10. G cent - centrifugal G forces.

11. Velocity - instantaneous speed at specific time (ft.sec).

RUNWAY TURNOFF MODEL APPLICATIONS

The following examples consider five Terps categories, as example aircraft which were used to run the program based on each of these aircraft's parameters.

Terps Category A

1. Cessna 172 Hawk

Terps Category B

1. Cessna Citation series 500

Terps Category C

1. Douglas DC-10 series 10
2. Boeing 747 series 100

Terps Category D

1. British/French Concord

Terps Category E

1. Lockheed F-104

Tables 12-23 are produced from the input data specified in Tables 8, 9, and 11. Speeds, times, probabilities, distances, and exit paths are shown for each following example.

A complete listing of the Fortran Programming can be found in the Appendix.

Table 12
TERPS CATEGORY A
CESSNA 172 HAWK

NASA HIGH SPEED EXIT ANALYSIS
INPUT SUMMARY

PROBABILISTIC MODEL

	AVERAGE	STD DEV	UNITS
TOUCHDOWN LOCATION	500.	10.	FEET
TOUCHDOWN SPEED	97.	5.	FT/SEC
TIME-TOUCHDOWN TO DECEL	3.	1.	SECONDS
DECELERATION RATE	3.50	1.00	FT/SEC**2
50% PROBABILITY SPEED	65.	1.	FT/SEC
DIST: THRESHOLD-START OF TURN	1777.		FEET
SPEED AT MAJOR DECEL REDUCE	60.		FT/SEC
NOSE-WINGTIP DIST	27.		FEET

AIRCRAFT TRACKING PROGRAM

AIRCRAFT CHARACTERISTICS

WEIGHT (LBS)	YAW INERTIA	WHEELBASE	% LOAD ON MAIN GEAR
2550.0	2308.0	5.4	75.0

FLIGHT CONDITIONAL PARAMETERS

EXIT VELOCITY	MAX EXIT ANGLE	MAX Y MU	DECEL RATE
50.070	41.000	0.200	-2.000

SYSTEM WIDTHS

RUNWAY	WINGSPAN	CLEARING DIST.	DIST TO TAXIWAY
150.00	35.90	92.95	600.00

SCRUB CHARACTERISTICS

Y MU	RADIUS
0.0000	0.1E+32
0.0200	50.0

TABLE 13

ALCULATED RESULTS

CRITICAL VALUES:

ASCSV	ASC	PTIME	CDIST	XDIST	TDIST
50.07	36.51	6.79	1777.00	269.04	2046.04

PROB	AVG TIME	STD DEV	XTIME	TTIME	YA
1.0000	21.5632	2.9004	32.6747	39.6604	65.0000**
0.9986	21.8324	2.9004	33.1439	39.9296	64.0000**

CONSTANT NLC SIDE LOAD ANALYSIS
PASSENGER COMFORT IGNORED

TIME	X	Y	THETA	RADIUS	R RATE	MU SCRUB	MU CENT	MU I	G CENT	VELOCITY
0.000	0.000	0.000	0.000	100000.00	-40041660.00	0.020	0.001	0.179	0.001	50.070
0.500	24.784	0.173	1.122	724.94	-920.69	0.020	0.103	0.077	0.103	49.070
1.000	49.048	1.126	3.521	500.48	-213.40	0.020	0.143	0.037	0.143	48.071
1.500	72.741	3.183	6.482	431.20	-90.23	0.020	0.160	0.020	0.160	47.072
2.000	95.793	6.453	9.717	396.92	-53.26	0.020	0.166	0.014	0.166	46.072
2.500	118.126	10.954	13.108	374.21	-39.63	0.020	0.169	0.011	0.169	45.073
3.000	139.665	16.661	16.608	356.01	-33.95	0.020	0.169	0.011	0.169	44.073
3.500	160.336	23.531	20.198	339.78	-31.25	0.020	0.170	0.010	0.169	43.074
4.000	180.067	31.509	23.870	324.57	-29.73	0.020	0.169	0.011	0.170	42.074
4.500	198.790	40.532	27.625	309.97	-28.69	0.020	0.169	0.011	0.169	41.075
5.000	216.439	50.527	31.463	295.84	-27.86	0.020	0.169	0.011	0.169	40.075
5.500	232.954	61.419	35.306	282.10	-27.11	0.020	0.168	0.012	0.168	39.076
6.000	248.279	73.125	39.400	268.72	-26.40	0.020	0.168	0.012	0.168	38.077
6.500	262.362	85.554	43.506	255.69	-25.70	0.020	0.167	0.013	0.167	37. 77
7.000	275.158	98.614	47.709	243.01	-25.02	0.020	0.166	0.014	0.166	36.078
7.500	286.628	112.206	52.013	230.67	-24.33	0.020	0.166	0.014	0.166	35.078
8.000	296.741	126.223	56.422	218.68	-23.65	0.020	0.165	0.015	0.165	34.077
8.500	305.471	140.559	61.942	207.02	-22.97	0.020	0.164	0.016	0.164	33.079
9.000	312.805	155.099	65.578	195.70	-22.29	0.020	0.163	0.017	0.163	32.·80
9.500	318.736	169.726	70.335	184.72	-21.63	0.020	0.162	0.018	0.162	31.080
10.000	323.269	184.323	75.219	174.08	-20.95	0.020	0.161	0.019	0.161	30.079
10.501	326.420	198.767	80.237	163.77	-20.28	0.020	0.160	0.020	0.160	29.079
11.001	328.214	212.938	85.394	153.80	-19.61	0.020	0.159	0.021	0.159	28.076
11.501	328.692	226.714	90.698	144.16	-18.93	0.020	0.158	0.022	0.158	27.076
12.001	327.906	239.974	96.157	134.86	-18.26	0.020	0.157	0.023	0.157	26.077
12.501	325.922	252.602	101.778	125.90	-17.59	0.020	0.155	0.025	0.155	25.077
13.002	322.819	264.406	107.571	117.27	-16.92	0.020	0.154	0.026	0.154	24.077
13.502	318.690	275.521	113.543	108.98	-16.26	0.020	0.152	0.028	0.152	23.076
14.002	313.642	285.611	119.706	101.01	-15.60	0.020	0.150	0.030	0.150	22.076
14.502	307.795	294.670	126.067	93.38	-14.94	0.020	0.148	0.032	0.148	21.075
15.002	301.282	302.626	132.639	86.07	-14.28	0.020	0.145	0.035	0.145	20.075
15.503	294.249	309.423	139.433	79.10	-13.63	0.020	0.143	0.037	0.143	19.075
16.003	286.848	315.023	146.459	72.44	-12.98	0.020	0.140	0.040	0.140	18.074
16.503	279.241	319.409	153.729	66.12	-12.33	0.020	0.137	0.043	0.137	17.074
17.002	271.594	322.587	161.257	60.11	-11.70	0.020	0.133	0.047	0.133	16.073
17.502	264.076	324.590	169.052	54.42	-11.06	0.020	0.130	0.050	0.130	15.073

OUT OF TABLE BOUNDS

TABLE 14

TERPS CATEGORY B - CESSNA CITATION SERIES 500

NASA HIGH SPEED EXIT ANALYSIS
INPUT SUMMARY

PROBABILISTIC MODEL

	AVERAGE	STD DEV	UNITS
TOUCHDOWN LOCATION	1000.	20.	FEET
TOUCHDOWN SPEED	184.	10.	FT/SEC
TIME-TOUCHDOWN TO DECEL	4.	1.	SECONDS
DECELERATION RATE	6.00	1.00	FT/SECOND**2
50% PROBABILITY SPEED	113.	1.	FT/SEC
DIST: THRESHOLD-START OF TURN	3762.		FEET
SPEED AT MAJOR DECEL REDUCE	140.		FT/SEC
NOSE-WINGTIP DIST	19.		FEET

AIRCRAFT TRACKING PROGRAM

AIRCRAFT CHARACTERISTICS

WEIGHT (LBS)	YAW INERTIA	WHEELBASE	% LOAD ON MAIN GEAR
11000.0	59489.0	15.7	88.0

FLIGHT CONDITIONAL PARAMETSRS

EXIT VELOCITY	MAX EXIT ANGLE	MAX Y MU	DECEL RATE
97.693	38.000	0.200	-2.000

SYSTEM WIDTHS

RUNWAY	WINGSPAN	CLEARING DIST.	DIST TO TAXIWAY
150.00	43.80	96.90	600.00

SCRUB CHARACTERISTICS

Y MU	RADIUS
0.0000	0.1E+32
0.0200	50.0

TABLE 15

CALCULATED RESULTS

CRITICAL VALUES:

ASCSV	ASC	TTIME	CDIST	XDIST	[illegible]
97.69	03.65	7.03	3762.00	625.64	[illegible]

PROB	AVG TIME	STD DEV	XTIME	TTIME	YA
1.0000	23.8997	2.3249	32.9669	39.9935	113.0000**
0.9999	23.8997	2.3249	32.9669	39.9935	112.0000**

CONSTANT NLG SIDE LOAD ANALYSIS
PASSENGER COMFORT IGNORED

TIME	X	Y	THETA	RADIUS	R RATE	MU SCRUB	MU CENT	MU I	G CENT	VELOCITY
0.000	0.000	0.000	0.000	100000.00	-5555410.00	0.020	0.003	0.177	0.003	97.693
0.500	48.596	0.110	0.354	4256.54	-6421.15	0.020	0.068	0.112	0.068	96.694
1.000	96.688	0.748	1.224	2637.92	-1609.30	0.020	0.108	0.072	0.108	95.694
1.500	144.261	2.232	2.355	2108.55	-689.83	0.020	0.132	0.048	0.132	94.695
2.000	191.290	4.751	3.768	1854.76	-371.53	0.020	0.147	0.033	0.147	93.696
2.500	237.742	8.413	5.272	1708.57	-229.93	0.020	0.156	0.024	0.156	92.696
3.000	283.580	13.279	6.865	1613.43	-157.99	0.020	0.162	0.018	0.162	91.697
3.500	328.767	19.377	8.521	1545.23	-118.44	0.020	0.165	0.015	0.165	90.697
4.000	373.263	26.716	10.224	1492.22	-95.54	0.020	0.167	0.013	0.167	99.698
4.500	417.027	35.292	11.962	1448.16	-81.79	0.020	0.169	0.011	0.169	88.698
5.000	460.021	45.092	13.731	1409.56	-73.26	0.020	0.169	0.011	0.169	87.699
5.500	502.206	56.099	15.526	1374.39	-67.79	0.020	0.170	0.010	0.170	86.699
6.000	543.544	68.288	17.345	1341.46	-64.17	0.020	0.170	0.010	0.170	85.700
6.500	583.997	81.635	19.186	1310.03	-61.67	0.020	0.170	0.010	0.170	84.701
7.000	623.528	96.111	21.049	1279.68	-59.84	0.020	0.170	0.010	0.170	83 [illegible]
.500	662.101	111.684	22.733	1250.12	-58.45	0.020	0.170	0.010	0.170	82.702
8.000	699.682	128.323	24.839	1221.19	-57.31	0.020	0.170	0.010	0.170	81.702
8.500	736.234	145.991	26.767	1192.78	-56.34	0.020	0.170	0.010	0.170	80.703
9.000	771.727	164.652	28.716	1164.83	-55.48	0.020	0.169	0.011	0.169	79.703
9.500	806.125	184.270	30.687	1137.29	-54.68	0.020	0.169	0.011	0.169	78.704
10.000	839.400	204.803	32.681	1110.14	-53.92	0.020	0.169	0.011	0.169	77.704
10.501	871.519	226.210	34.697	1083.37	-53.19	0.020	0.169	0.011	0.169	76.705
11.001	902.455	248.449	36.737	1056.95	-52.47	0.020	0.168	0.012	0.168	75.735
11.501	932.180	271.475	38.801	1030.89	-51.77	0.020	0.168	0.012	0.168	74.706
12.001	960.668	295.243	40.890	1005.18	-51.07	0.020	0.168	0.012	0.168	73.707
12.501	987.894	319.705	43.003	979.82	-50.38	0.020	0.168	0.012	0.168	72.707
13.002	1013.834	344.813	45.141	954.80	-49.69	0.020	0.167	0.013	0.167	71.708
13.502	1038.468	370.516	47.306	930.12	-49.01	0.020	0.167	0.013	0.167	70.708
14.002	1061.775	396.762	49.497	905.79	-48.32	0.020	0.167	0.013	0.167	69.709
14.502	1083.739	423.500	51.715	881.80	-47.64	0.020	0.166	0.014	0.166	68.709
15.002	1104.342	450.674	53.961	858.14	-46.96	0.020	0.166	0.014	0.166	67.710
15.503	1123.572	478.230	56.236	834.84	-46.28	0.020	0.166	0.014	0.166	66.710
16.003	1141.416	506.112	58.540	811.87	-45.60	0.020	0.165	0.015	0.165	65.711
16.503	1157.865	534.261	60.873	789.24	-44.92	0.020	0.165	0.015	0.165	64.712
17.002	1172.914	562.619	63.236	766.95	-44.24	0.020	0.164	0.016	0.164	63.712
17.502	1186.555	591.126	65.633	745.00	-43.56	0.020	0.164	0.016	0.164	62.713

FINAL VALUES

TIME	X	Y	THETA	RADIUS	R RATE	MU SCRUB	MU CENT	MU I	G CENT	VELOCITY
17.658	1190.524	600.042	65.633	738.22	-43.35	0.020	0.164	0.016	0.164	62.401

TABLE 16

TERPS CATEGORY C - DC-10 SERIES 10

NASA HIGH SPEED EXIT 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	6.00	1.00	FT/SEC**2
50% PROBABILITY SPEED	164.	1.	FT/SEC
DIST:THRESHOLD-START OF TURN	5216.		FEET
SPEED AT MAJOR DECEL REDUCE	150.		FT/SEC
NOSE-WINGTIP DIST	130.		FEET

AIRCRAFT TRACKING PROGRAM

AIRCRAFT CHARACTERISTICS

WEIGHT(LBS)	YAW INERTIA	WHEELBASE	% LOAD ON MAIN GEAR
363500.0	16350338.0	72.5	93.4

FLIGHT CONDITIONAL PARAMETERS

EXIT VELOCITY	MAX EXIT ANGLE	MAX Y MU	DECEL RATE
148.688	44.000	0.200	-2.000

SYSTEM WIDTHS

RUNWAY	WINGSPAN	CLEAR DIST.	DIST TO TAXIWAY
150.00	155.30	152.65	600.00

SCRUB CHARACTERISTICS

Y MU	RADIUS
0.0000	0.1E+32
0.0100	5000.0
0.0200	2000.0
0.0250	1000.0
0.0270	800.0
0.0300	200.0

TABLE 17

CALCULATED RESULTS

ITICAL VALUES:

ASCSV	ASC	PTIME	CDIST	XDIST	TDIST
140.69	130.30	9.20	5216.00	1260.66	6484.66

PROB	AVG TIME	STD DEV	XTIME	TTIME	YA
1.0000	25.6397	1.3255	38.8094	40.0075	[illegible]
0.9999	25.6397	1.3255	38.6094	40.0075	143.00601*

CONSTANT NLG SIDE LOAD ANALYSIS
PASSENGER COMFORT IGNORED

TIME	X	Y	THETA	RADIUS	R RATE	MU SCRUB	MU CENT	MU I	G CENT	VELOCITY
0.000	0.000	0.000	0.000	100000.00	-1223773.37	0.010	0.007	0.183	0.007	148.689
0.500	74.093	0.000	0.143	15359.79	-23157.03	0.010	0.044	0.146	0.044	147.689
1.000	147.685	0.508	0.534	9143.11	-6629.52	0.010	0.073	0.117	0.073	146.689
1.500	220.773	1.514	1.069	6892.57	-3057.40	0.010	0.076	0.094	0.096	145.689
2.000	293.345	3.277	1.735	5739.13	-1735.16	0.010	0.113	0.077	0.113	144.690
2.500	365.390	5.934	2.506	5045.25	-1107.27	0.010	0.127	0.063	0.127	143.690
3.000	436.871	9.508	3.361	4589.08	-746.22	0.011	0.138	0.051	0.138	142.691
3.500	507.828	14.318	4.282	4274.04	-534.18	0.012	0.146	0.042	0.146	141.691
4.000	578.178	20.180	5.255	4042.59	-401.71	0.013	0.152	0.035	0.152	140.692
4.500	647.919	27.214	6.273	3865.49	-312.83	0.014	0.157	0.029	0.157	139.693
5.000	717.025	35.448	7.324	3725.07	-252.31	0.014	0.160	0.025	0.160	138.693
5.500	785.471	44.897	8.404	3610.20	-209.47	0.015	0.163	0.022	0.163	137.694
6.000	853.231	55.571	9.508	3513.60	-178.18	0.015	0.165	0.020	0.165	136.694
6.500	920.278	67.474	10.632	3430.33	-155.68	0.015	0.167	0.018	0.167	135.695
7.000	986.587	80.603	11.774	3356.94	-138.65	0.015	0.168	0.017	0.168	134.695
7.500	1052.131	94.952	12.930	3290.97	-125.78	0.016	0.169	0.016	0.169	133.696
8.000	1116.824	110.513	14.101	3230.65	-115.94	0.016	0.169	0.015	0.167	132.696
8.500	1180.820	127.273	15.283	3174.66	-108.34	0.016	0.170	0.014	0.170	131.697
9.000	1243.915	145.219	16.477	3122.03	-102.41	0.016	0.170	0.014	0.170	130.697
9.500	1306.142	164.335	17.682	3072.03	-97.75	0.016	0.170	0.014	0.170	129.698
.000	1367.477	184.603	18.896	3024.12	-94.03	0.017	0.170	0.013	0.170	128.699
..501	1427.896	206.005	20.120	2977.87	-91.04	0.017	0.170	0.013	0.170	127.699
11.001	1487.376	228.520	21.353	2932.98	-88.61	0.017	0.170	0.013	0.170	126.700
11.501	1545.891	252.127	22.595	2889.20	-86.60	0.017	0.170	0.013	0.170	125.700
12.001	1603.420	276.805	23.845	2846.33	-84.91	0.017	0.170	0.013	0.170	124.701
12.501	1659.940	302.529	25.105	2804.24	-83.48	0.017	0.169	0.013	0.169	123.701
13.002	1715.429	329.277	26.373	2762.82	-82.24	0.017	0.169	0.013	0.169	122.702
13.502	1769.865	357.023	27.649	2721.97	-81.16	0.018	0.169	0.013	0.169	121.702
14.002	1823.227	385.743	28.934	2681.64	-80.19	0.018	0.169	0.014	0.169	120.703
14.502	1875.495	415.409	30.228	2641.77	-79.32	0.018	0.168	0.014	0.168	119.704
15.002	1926.649	445.995	31.531	2602.31	-78.51	0.018	0.168	0.014	0.168	118.704
15.503	1976.668	477.473	32.842	2563.24	-77.76	0.018	0.168	0.014	0.168	117.705
16.003	2025.535	509.816	34.162	2524.55	-77.05	0.018	0.168	0.014	0.168	116.705
16.503	2073.231	542.994	35.490	2486.19	-76.37	0.018	0.167	0.014	0.167	115.706
17.002	2119.739	576.978	36.828	2448.17	-75.73	0.019	0.167	0.015	0.167	114.706

FINAL VALUES

TIME	X	Y	THETA	RADIUS	R RATE	MU SCRUB	MU CENT	MU I	G CENT	VELOCITY
17.335	2150.047	600.044	36.828	2423.02	-75.30	0.019	0.167	0.015	0.167	114.041

TABLE 18

TERPS CATEGORY C - BOEING 747-100

NASA HIGH SPEED EXIT ANALYSIS
INPUT SUMMARY

PROBABILISTIC MODEL

	AVERAGE	STD DEV	UNITS
TOUCHDOWN LOCATION	1500.	30.	FEET
TOUCHDOWN SPEED	235.	10.	FT/SEC
TIME-TOUCHDOWN TO DECEL	5.	1.	SECONDS
DECELERATION RATE	6.00	1.00	FT/SEC**2
50% PROBABILITY SPEED	176.	1.	FT/SEC
DIST:THRESHOLD-START OF TURN	5125.		FEET
SPEED AT MAJOR DECEL REDUCE	150.		FT/SEC
NOSE-WINGTIP DIST	144.		FEET

AIRCRAFT TRACKING PROGRAM

AIRCRAFT CHARACTERISTICS

WEIGHT(LBS)	YAW INERTIA	WHEELBASE	% LOAD ON MAIN GEAR
564000.0	42000000.0	84.0	96.4

FLIGHT CONDITIONAL PARAMETERS

EXIT VELOCITY	MAX EXIT ANGLE	MAX Y MU	DECEL RATE
160.702	45.000	0.200	-2.000

SYSTEM WIDTHS

RUNWAY	WINGSPAN	CLEAR DIST.	DIST TO TAXIWAY
150.00	195.70	172.85	600.00

SCRUB CHARACTERISTICS

Y MU	RADIUS
0.0000	0.1E+32
0.0100	5287.0
0.0190	2638.0
0.0390	1318.0
0.0590	877.0
0.0790	657.0
0.0990	524.0
0.1530	347.0
0.2120	257.0
0.3530	167.0
0.5480	121.0
0.7930	99.0

TABLE 19

CALCULATED RESULTS

CRITICAL VALUES:

ASCSV	ASC	PTIME	CDIST	XDIST	TDIST
160.70	137.00	11.46	5125.00	1695.22	6820.22

PROB	AVG TIME	STD DEV	XTIME	TTIME	YA
1.0000	24.3797	1.0716	28.5591	40.0151	176.0000**
0.9999	24.3797	1.0716	28.5591	40.0151	175.0000**

CONSTANT NLC SIDE LOAD ANALYSIS
PASSENGER COMFORT IGNORED

TIME	X	Y	THETA	RADIUS	R RATE	MU SCRUB	MU CENT	MU I	G CENT	VELOCITY
0.000	0.000	0.000	0.000	100000.00	-443293.94	0.010	0.008	0.182	0.008	160.702
0.500	80.100	0.055	0.095	32008.69	-41501.80	0.010	0.025	0.165	0.025	159.702
1.000	159.701	0.307	0.282	19744.74	-14451.43	0.010	0.040	0.150	0.040	158.703
1.500	238.800	0.874	0.553	14613.70	-7270.37	0.010	0.053	0.137	0.053	157.703
2.000	317.394	1.860	0.898	11797.40	-4358.46	0.010	0.065	0.125	0.065	156.704
2.500	395.492	3.358	1.311	10019.33	-2898.75	0.010	0.075	0.115	0.075	155.704
3.000	473.055	5.448	1.726	8795.53	-2065.07	0.010	0.085	0.105	0.085	154.705
3.500	550.108	8.201	2.317	7902.15	-1545.03	0.010	0.093	0.097	0.093	153.705
4.000	626.631	11.681	2.899	7221.36	-1199.32	0.010	0.100	0.090	0.100	152.706
4.500	702.614	15.940	3.527	6685.27	-958.19	0.010	0.107	0.083	0.107	151.707
5.000	778.045	21.028	4.193	6251.96	-783.57	0.010	0.113	0.077	0.113	150.707
5.500	852.911	26.983	4.907	5894.20	-653.27	0.010	0.118	0.072	0.118	149.708
6.000	927.198	33.843	5.652	5593.50	-553.62	0.010	0.123	0.067	0.123	148.708
6.500	1000.850	41.637	6.430	5336.86	-475.84	0.010	0.127	0.063	0.127	147.709
7.000	1073.971	50.389	7.237	5115.72	-410.29	0.011	0.131	0.059	0.131	146.709
7.500	1146.424	60.122	8.072	4924.26	-357.43	0.011	0.134	0.055	0.134	145.710
8.000	1218.231	70.852	8.932	4756.50	-315.01	0.012	0.137	0.051	0.137	144.710
8.500	1289.373	82.591	9.814	4607.90	-280.50	0.012	0.139	0.048	0.139	143.711
9.000	1359.832	95.348	10.718	4474.95	-252.12	0.013	0.141	0.046	0.141	142.711
9.500	1429.588	109.130	11.641	4354.95	-228.54	0.013	0.143	0.044	0.143	141.712
10.000	1498.622	123.940	12.582	4245.75	-208.79	0.014	0.145	0.042	0.145	140.713
10.501	1566.914	139.779	13.539	4145.63	-192.11	0.014	0.146	0.040	0.146	139.713
11.001	1634.445	156.645	14.512	4053.21	-177.93	0.014	0.147	0.038	0.147	138.714
11.501	1701.195	174.535	15.500	3967.34	-165.81	0.014	0.148	0.037	0.148	137.714
12.001	1767.144	193.443	16.501	3887.11	-155.38	0.015	0.149	0.036	0.149	136.715
12.501	1832.273	213.361	17.515	3811.72	-146.35	0.015	0.150	0.035	0.150	135.715
13.002	1896.561	234.280	18.540	3740.55	-138.52	0.015	0.151	0.034	0.151	134.716
13.502	1959.990	256.191	19.570	3673.03	-131.67	0.015	0.151	0.033	0.151	133.716
14.002	2022.541	279.080	20.626	3608.73	-125.68	0.016	0.152	0.033	0.152	132.717
14.502	2084.194	302.935	21.685	3547.23	-120.40	0.016	0.152	0.032	0.152	131.718
15.002	2144.930	327.742	22.753	3488.22	-115.73	0.016	0.152	0.032	0.152	130.718
15.503	2204.733	353.485	23.832	3431.41	-111.59	0.016	0.152	0.031	0.152	129.719
16.003	2263.583	380.147	24.919	3376.56	-107.90	0.016	0.152	0.031	0.152	128.719
16.503	2321.463	407.711	26.016	3323.44	-104.60	0.017	0.152	0.031	0.152	127.720
17.002	2378.355	436.159	27.121	3271.89	-101.64	0.017	0.152	0.031	0.152	126.720
17.502	2434.245	465.470	28.235	[illegible]	[illegible]	0.017	0.152	0.031	0.152	125.721
18.002	2489.113	495.626	29.357	3172.87	-96.57	0.017	0.152	0.031	0.152	124.721
18.501	2542.946	526.605	30.487	3125.14	-94.38	0.017	0.152	0.031	0.152	123.722
19.001	2595.725	558.305	31.625	3078.46	-92.38	0.018	0.152	0.031	0.152	122.722
19.501	2647.439	590.945	32.771	3032.73	-90.56	0.018	0.152	0.031	0.152	121.723

FINAL VALUES

19.639	2661.522	600.065	32.771	3020.26	-90.08	0.018	0.152	0.031	0.152	121.447

TABLE 20

TERPS CATEGORY D - CONCORD

NASA HIGH SPEED EXIT ANALYSIS
INPUT SUMMARY

PROBABILISTIC MODEL

	AVERAGE	STD DEV	UNITS
TOUCHDOWN LOCATION	1500.	30.	FEET
TOUCHDOWN SPEED	275.	15.	FT/SEC
TIME-TOUCHDOWN TO DECEL	5.	1.	SECONDS
DECELERATION RATE	6.00	1.00	FT/SEC**2
50% PROBABILITY SPEED	201.	1.	FT/SEC
DIST:THRESHOLD-START OF TURN	6300.		FEET
SPEED AT MAJOR DECEL REDUCE	150.		FT/SEC
NOSE-WINGTIP DIST	150.		FEET

AIRCRAFT TRACKING PROGRAM

AIRCRAFT CHARACTERISTICS

WEIGHT(LBS)	YAW INERTIA	WHEELBASE	% LOAD ON MAIN GEAR
245000.0	12664509.0	59.7	94.7

FLIGHT CONDITIONAL PARAMETERS

EXIT VELOCITY	MAX EXIT ANGLE	MAX Y MU	DECEL RATE
185.809	37.000	0.200	-2.000

SYSTEM WIDTHS

RUNWAY	WINGSPAN	CLEAR DIST.	DIST TO TAXIWAY
150.00	83.80	116.90	600.00

SCRUB CHARACTERISTICS

Y MU	RADIUS
0.0000	0.1E+32
0.0100	1000.0
0.0200	800.0
0.0300	50.0

TABLE 21

CALCULATED RESULTS

CRITICAL VALUES:

ASCSV	AVC	PTIME	CDIST	XDIST	TDIST
185.01	160.60	0.57	6300.00	1511.92	7811.92

PROB	AVG TIME	STD DEV	XTIME	TTIME	YA
1.0000	25.8677	1.4237	31.4201	39.9909	201.0000**
0.9999	25.8677	1.4237	31.4201	37.9909	200.0000**

CONSTANT NLG SIDE LOAD ANALYSIS
PASSENGER COMFORT IGNORED

TIME	X	Y	THETA	RADIUS	R RATE	MU SCRUB	MU CENT	MU I	G CENT	VELOCITY
0.000	0.000	0.000	0.000	100000.00	-559291.56	0.010	0.011	0.179	0.011	185.807
0.500	92.654	0.081	0.124	27052.62	-36965.20	0.010	0.038	0.152	0.038	184.810
1.000	184.808	0.464	0.373	17249.42	-12123.59	0.010	0.061	0.129	0.061	183.810
1.500	276.458	1.331	0.723	13009.78	-5915.47	0.010	0.080	0.110	0.080	182.811
2.000	367.601	2.831	1.173	10740.90	-3473.17	0.010	0.076	0.094	0.096	181.611
2.500	458.227	5.087	1.693	9335.67	-2370.05	0.010	0.109	0.081	0.109	180.612
3.000	548.329	8.203	2.277	8334.48	-1591.86	0.010	0.120	0.070	0.120	179.812
3.500	637.892	12.260	2.919	7700.65	-1173.64	0.010	0.129	0.061	0.129	178.313
4.000	726.904	17.327	3.607	7186.90	-898.74	0.010	0.137	0.053	0.137	177.813
4.500	815.347	23.460	4.335	6787.58	-709.26	0.010	0.143	0.047	0.143	176.814
5.000	903.205	30.702	5.097	6468.54	-573.83	0.010	0.148	0.042	0.148	175.815
5.500	990.459	39.089	5.890	6207.70	-474.23	0.010	0.153	0.037	0.153	174.815
6.000	1077.089	48.648	6.710	5990.14	-399.28	0.010	0.157	0.033	0.157	173.816
6.500	1163.077	59.400	7.552	5805.46	-341.82	0.010	0.160	0.030	0.160	172.815
7.000	1248.399	71.362	8.414	5646.15	-297.10	0.010	0.162	0.028	0.162	171.817
7.500	1333.036	84.543	9.293	5506.75	-261.84	0.010	0.165	0.025	0.165	170.817
8.000	1416.965	98.950	10.191	5383.10	-233.72	0.010	0.166	0.024	0.166	169.818
8.500	1500.167	114.586	11.102	5272.08	-211.10	0.010	0.168	0.022	0.168	168.818
9.000	1582.617	131.452	12.025	5171.27	-192.75	0.010	0.169	0.021	0.169	167.819
9.500	1664.295	149.546	12.961	5078.76	-177.74	0.010	0.170	0.020	0.170	166.819
10.000	1745.179	168.862	13.907	4993.07	-165.40	0.010	0.171	0.019	0.171	165.820
10.501	1825.246	189.394	14.863	4913.00	-155.18	0.010	0.172	0.018	0.172	164.821
11.001	1904.477	211.134	15.829	4837.59	-146.67	0.010	0.172	0.018	0.172	163.821
11.501	1982.848	234.072	16.803	4766.09	-139.54	0.010	0.173	0.017	0.173	162.822
12.001	2060.339	258.196	17.786	4697.86	-133.57	0.010	0.173	0.017	0.173	161.822
12.501	2136.929	283.495	18.777	4632.40	-128.44	0.010	0.173	0.017	0.173	160.823
13.002	2212.595	309.954	19.775	4569.29	-124.11	0.010	0.174	0.016	0.174	159.823
13.502	2287.319	337.559	20.781	4508.18	-120.39	0.010	0.174	0.016	0.174	158.824
14.002	2361.080	366.295	21.793	4448.81	-117.18	0.010	0.174	0.016	0.174	157.824
14.502	2433.857	396.145	22.813	4390.93	-114.40	0.010	0.174	0.016	0.174	156.825
15.002	2505.631	427.092	23.840	4334.35	-111.96	0.010	0.174	0.016	0.174	155.826
15.503	2576.382	459.117	24.873	4278.92	-109.83	0.010	0.174	0.016	0.174	154.826
16.003	2646.090	492.203	25.913	4224.49	-107.92	0.010	0.174	0.016	0.174	153.827
16.503	2714.737	526.330	26.959	4170.96	-106.21	0.010	0.174	0.016	0.174	152.827
17.002	2782.304	561.478	28.012	4118.25	-104.68	0.010	0.174	0.016	0.174	151.828
17.502	2848.772	597.627	29.071	4066.27	-103.29	0.010	0.174	0.016	0.174	150.828

FINAL VALUES

TIME	X	Y	THETA	RADIUS	R RATE	MU SCRUB	MU CENT	MU I	G CENT	VELOCITY
17.535	2853.121	600.047	29.071	4062.86	-103.20	0.010	0.174	0.016	0.174	150.762

TABLE 22

TERPS CATEGORY E - LOCKHEED F-104

NASA HIGH SPEED EXIT 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	0.200	-2.000

SYSTEM WIDTHS

RUNWAY	WINGSPAN	CLEAR DIST.	DIST TO TAXIWAY
150.00	21.90	85.95	600.00

SCRUB CHARACTERISTICS

Y MU	RADIUS
0.0000	0.1E+32
0.0200	50.0

TABLE 23

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**
0.9999	24.7617	2.3551	33.9466	40.0104	291.0000**

CONSTANT NLG SIDE LOAD ANALYSIS
PASSENGER COMFORT IGNORED

TIME	X	Y	THETA	RADIUS	R RATE	MU SCRUB	MU CENT	MU I	G CENT	VELOCITY
0.000	0.000	0.000	0.000	100000.00	-963255.37	0.020	0.024	0.156	0.024	276.225
0.500	137.860	0.223	0.231	22530.26	-23733.96	0.020	0.104	0.076	0.104	275.217
1.000	275.212	1.256	0.654	16352.71	-6175.82	0.020	0.143	0.037	0.143	274.210
1.500	412.047	3.419	1.170	14333.35	-2428.62	0.020	0.161	0.019	0.161	273.203
2.000	548.353	6.862	1.731	13537.84	-1150.20	0.020	0.170	0.010	0.170	272.196
2.500	684.114	11.655	2.316	13111.48	-626.37	0.020	0.174	0.006	0.174	271.189
3.000	819.314	17.827	2.914	12864.03	-393.05	0.020	0.176	0.004	0.176	270.182
3.500	953.940	25.389	3.519	12697.89	-284.74	0.020	0.177	0.003	0.177	269.175
4.000	1087.976	34.344	4.128	12569.92	-233.25	0.020	0.178	0.002	0.178	268.168
4.500	1221.407	44.689	4.741	12460.26	-208.30	0.020	0.178	0.002	0.178	267.161
5.000	1354.217	56.419	5.356	12359.55	-195.94	0.020	0.178	0.002	0.178	266.154
5.500	1486.393	69.529	5.974	12263.33	-189.63	0.020	0.178	0.002	0.178	265.147
6.000	1617.919	84.012	6.595	12169.46	-186.20	0.020	0.178	0.002	0.178	264.140
6.500	1748.779	99.861	7.218	12076.90	-184.17	0.020	0.178	0.002	0.178	263.133
7.000	1878.960	117.068	7.843	11985.21	-182.87	0.020	0.178	0.002	0.178	262.125
7.500	2008.446	135.627	8.471	11894.07	-181.87	0.020	0.178	0.002	0.178	261.118
8.000	2137.224	155.528	9.101	11803.38	-181.01	0.020	0.178	0.002	0.178	260.111
8.500	2265.277	176.765	9.734	11713.05	-180.17	0.020	0.178	0.002	0.178	259.104
9.000	2392.593	199.329	10.369	11623.21	-179.52	0.020	0.178	0.002	0.178	258.097
9.500	2519.155	223.212	11.006	11533.70	-178.83	0.020	0.178	0.002	0.178	257.090
10.000	2644.949	248.405	11.646	11444.49	-178.09	0.020	0.178	0.002	0.178	256.083
10.501	2769.962	274.900	12.288	11355.82	-176.77	0.020	0.178	0.002	0.178	255.083
11.001	2894.183	302.688	12.933	11267.75	-175.71	0.020	0.178	0.002	0.178	254.083
11.501	3017.596	331.760	13.580	11180.16	-174.86	0.020	0.178	0.002	0.178	253.084
12.001	3140.186	362.107	14.230	11092.98	-174.08	0.020	0.178	0.002	0.178	252.085
12.501	3261.940	393.719	14.882	11006.12	-173.29	0.020	0.178	0.002	0.178	251.085
13.002	3382.843	426.587	15.537	10919.70	-172.61	0.020	0.178	0.002	0.178	250.086
13.502	3502.882	460.701	16.194	10833.64	-171.95	0.020	0.178	0.002	0.178	249.086
14.002	3622.043	496.050	16.854	10747.87	-171.23	0.020	0.178	0.002	0.178	248.087
14.502	3740.307	532.624	17.517	10662.42	-170.47	0.020	0.178	0.002	0.178	247.087
15.002	3857.667	570.413	18.182	10577.43	-169.87	0.020	0.178	0.002	0.178	246.088

FINAL VALUES

TIME	X	Y	THETA	RADIUS	R RATE	MU SCRUB	MU CENT	MU I	G CENT	VELOCITY
15.384	3946.475	600.017	18.182	10512.82	-169.31	0.020	0.178	0.002	0.178	245.326

Optimum High Speed Exit Paths

The 747 was used as an example aircraft because it is the largest, and therefore most difficult commercial aircraft to maneuver. Designing an exit for the 747 would insure that it could be used at the design speed by smaller aircraft.

Figure 7 shows three optimum exit turn paths for the Boeing 747. These paths were based on a limiting nose gear side μ of 0.2 and an aft c.g. Two speeds were used -- the 27 m/s (60 MPH) design speed of the present FAA exit and a 96 knot (110 MPH or 49 m/s) exit speed resulting from the 747 probabilistic studies. Additionally, the 27 m/s (60 MPH) exit was determined for both a constant-speed exit and a favored 0.61 m/s^2 (2 fpss) deceleration while in the exit. The deceleration resulted in reducing the longitudinal length of the exit by 16%, from 433 m (1422 ft.) to 364 m (1195 ft.).

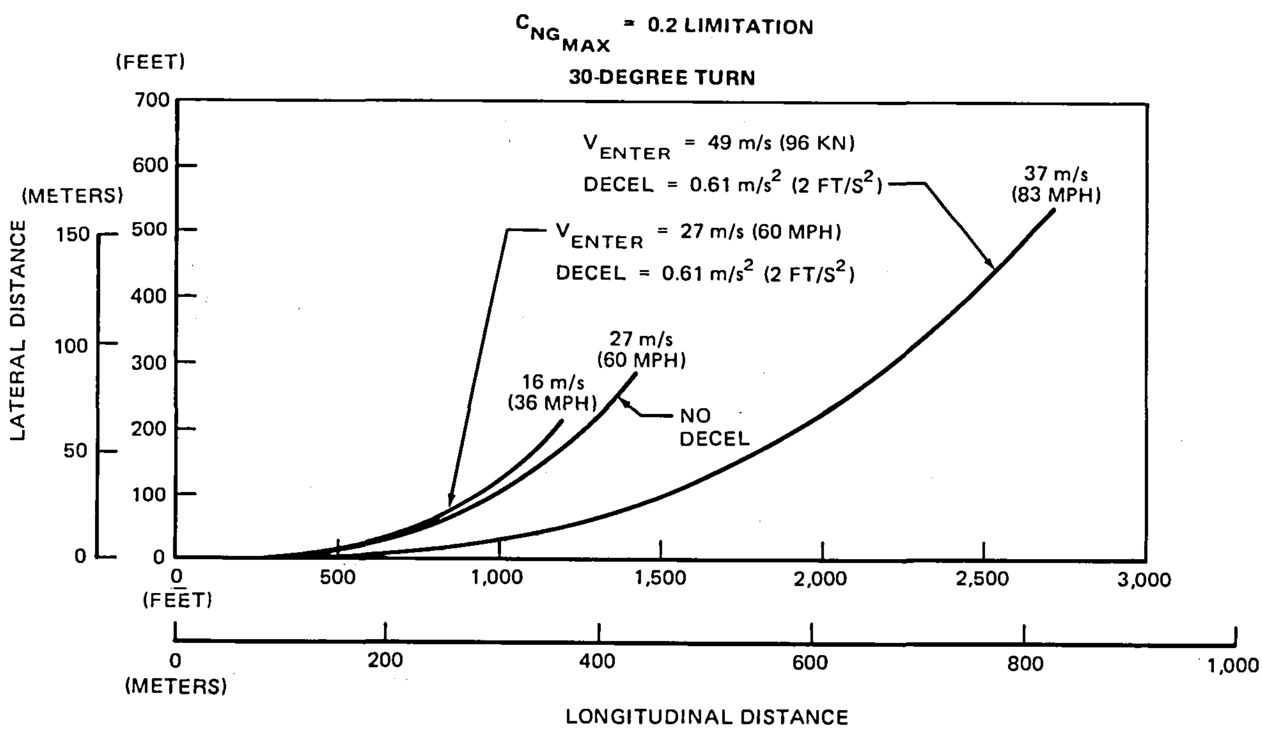


FIGURE 7. OPTIMUM HIGH-SPEED EXIT PATHS – 747

REFERENCES

1. Schoen, M. L.; Hosford, J. E.; Graham, J. M., Jr.; Preston, O. W.; Frankel, R. S.; and Erickson, J. B.: Aircraft and Avionics Related Research Required to Develop an Effective High-Speed Runway Exit System. NASA CR-159075, June 1979.

2. Airline Executive, May 1979, p. 55

APPENDIX

PROGRAM LISTING

PROBABILISTIC MODEL OF OPTIMAL HIGH SPEED
RUNWAY TURNOFFS

```
      REAL NTIP
      REAL*4 NTITLE(20)
       DIMENSION ARDS(16),DPX(16),P(16),DP(16)
       DIMENSION SND(400)
       DIMENSION ARBT(15),ARBI(15),DT(15)
       DIMENSION PEX(16),ZROT(15),Z(16),ZEX(16)
       CALL ASSIGN(1,'HISPEX.DAT')
       CALL ASSIGN(2,'SND.DAT;1')
       CALL ASSIGN(3,'SOLVIT.DAT;1')
      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(5,125)
 125   FORMAT(' ENTER: 5 FOR TERMINAL PRINTOUT'/,
    1         '        6 FOR HARDCOPY PRINTOUT')
       READ(5,*)IWRT
       WRITE(5,139)
 139   FORMAT(' ENTER: 1 FOR STANDARD PRINT ',/
    1         '        2 FOR INTERMEDIATE VALUES',/
    2         '        3 FOR FINAL VALUES ONLY')
       READ(5,*)IPRT
       WRITE(5,6)
 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(5,*)IYA
      WRITE(5,7)
 7    FORMAT('         ENTER INITIAL YA SPEED')
      READ(5,*)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 EXIT 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',/10X,'TIME-'
    2,'TOUCHDOWN TO DECEL',T40,2F10.0,T65,'SECONDS',/10X,
    2'DECELERATION RATE',T40,2F10.2,T65,'FT/SEC**2',
    3/10X,'50% PROBABILITY SPEED',T40,2F10.0,T65,'FT/SEC',/10X,
    3'DIST:THRESHOLD-START OF TURN',T40,F10.0,T65,'FEET',
    4/10X,'SPEED AT MAJOR DECEL REDUCE',T40,F10.0,T65,'FT/SEC'/,
    510X,'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 REDEFINED
C       TO SPEED AT END OF TURN.  AFTER THIS POINT,
C       AVG SPEED AT START OF TURN HAS BEEN REDEFINED AS 'ASCSV'
C
        TDIST = C + XDIST
  500   CONTINUE
        MS=' '
        MSP=' '
        ASC2=YAPERM-(1.5*YS)
        IF(ASCSV.LT.ASC2)MS='*'
        IF(IPRT.EQ.2)WRITE(5,600) ICK
        ICK=3
C
C       CALCULATE STANDARD DEVIATIONS
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
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(ASCP1.GT.ASCP)MSP='*'
C
C        CALCULATE OCCUPANCY TIMES
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(5,901)
  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
```

```
      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 AIRCRAFT 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(5,147)
  147 FORMAT(' PX VALUE NOT FOUND')
      STOP
```

```
  146   IBAN=I
        PXCH=IBAN/100.
        OTMIN = TC - PXCH * SDOT
        IF(IPRT.EQ.2)WRITE(IWRT,191)OTMIN
  191   FORMAT(T10,' MINIMUN OCCUPANCY TIME=',T43,F10.2,' SEC')
C
C       CALCULATE AVERAGE RUNWAY OCCUPANCY TIME
C
C
C       INITIALIZE ARBITRARY OCCUPANCY TIMES
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 INTERVAL 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 ANDTTIME
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(5,827) 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(5,823)
823    FORMAT('       ENTER NEW YA SPEED;  999 TO END')
       READ(5,*)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)
       CALL ASSIGN(3,'SOLVIT.DAT;1')
803    READ(3,700,END=808)O1,O2,O3,O4,O5,O6,O7,O8
       WRITE(IWRT,700)O1,O2,O3,O4,O5,O6,O7,O8
```

```
      GO TO 803
808   WRITE(5,920)
920   FORMAT(/ '      DO YOU WANT TO CONTINUE EXIT PATH TO TAXI-WAY '/,
     1 '        1=YES, 2=NO . ')
      READ(5,*)INASA
      IF (INASA .EQ. 2) STOP
      IFLAG=1
      CALL EXPATH(ASCSV,PTIME,XDIST,IWRT,IPRT,IFLAG)
      STOP
      END
```

Aircraft Tracking
(Subroutine EXPATH)

```
      SUBROUTINE EXPATH(V,PTIME,XDIST,IWRT,IPRT,IFLAG)
      DIMENSION RSCR(20), YMUSCR(20)
      DIMENSION XP(100),YP(100)
      INTEGER*4 IDO
      REAL JMAX
      CALL ASSIGN(4,'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
      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(5,800)
 800    FORMAT(' ENTER: 1 TO PRINT TRACKING RESULTS TO RUNWAY EDGE ',/
    1          '        2 TO WAIT FOR PRINT TO TAXIWAY EDGE')
        READ(5,*)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=2,20
 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(RDMX.GT.RD) RD=RDMX
        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(5,9000)
 9000   FORMAT(//'  WARNING!!  WINGTIP 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 COMFORT IGNORED')
 8000   FORMAT(4F10.3,2F12.2,5F10.3)
 8001   FORMAT(1H ,'***OUT OF TABLE BOUNDS***')
 8002   FORMAT(' LIMITED BY COMFORT')
 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',T79,'MU CENT',T90,'MU I',T100,'G CENT'
     1,T111,'VELOCITY'/)
        RETURN
        END
```

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Task 3 Final Report

16. Abstract

Landing delays are currently a problem at major air carrier airports and many forecasters agree that airport congestion will get worse by the end of the century. It is anticipated that some types of delays can be reduced by an efficient optimal runway exit system allowing increased approach volumes necessary at congested airports. This report defines a computerized Probabilistic Runway Turnoff Model which locates exits and defines path geometry for a selected maximum occupancy time appropriate for each TERPS aircraft category. The model includes an algorithm for lateral ride comfort limits.

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