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SOME LOADING CONDITIONS IMPOSED BY GROUND TURNING MANEUVERS WITH THREE JET TRANSPORT AIRPLANES

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16. Abstract

Some loading conditions imposed during ground turning maneuvers are presented for arrival and departure operations at several airports with C-141A, 727, and DC-9 airplanes. The data presented for a total of 809 turns include: ground speed, lateral acceleration, the number of turns required during arrival and departure, and the magnitude of the turns.

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SOME LOADING CONDITIONS IMPOSED BY GROUND TURNING MANEUVERS WITH THREE JET TRANSPORT AIRPLANES

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SUMMARY

This paper presents some data defining ground turning maneuvers for several jet transport aircraft. These data were obtained during arrival and departure operations with a C-141A, 727, and DC-9 airplane at several United States and foreign military and commercial airports. The data show that on the average, about five ground turns were required for each arrival and five turns for each departure. The average maximum lateral acceleration measured during each turn was 0.046, 0.058, and 0.059 g units for the C-141A, 727, and DC-9 airplanes, respectively. The average ground speed for turns was 5.0, 10.4, and 12.1 knots for the C-141A, 727, and DC-9 airplanes, respectively.

INTRODUCTION

Part of the certification procedure for transport category aircraft requires a fatigue evaluation of the flight structure and of the landing gear. These fatigue evaluations must include, among other things, the typical loading spectrum to be expected in service. For this purpose, the NACA and, subsequently, the NASA have conducted research programs to define part of the loading spectrum for transport operations. Most of the past work has been devoted to airborne operations rather than to ground operations. Recently, however, some effort has been made to define sections of the loading spectrum to be expected for ground operations. Reference 1, for example, has provided data showing center-of-gravity vertical accelerations measured during taxiing, take-off, and landing operations with transport airplanes. This reference also provides a limited amount of longitudinal deceleration data measured during the landing rollout. In addition, a program to define the runway and taxiway roughness environment at typical large commercial airports has recently been completed by NASA. An example of these data is given in reference 2. There is little data available to define loading conditions imposed during ground turning maneuvers. The purpose of this paper is to present some recent data which can partially fill this need.

This paper presents some loading conditions imposed during ground turning maneuvers with three jet transport airplanes. Data were obtained during arrivals and departures at several United States and foreign military and commercial airports which were participating in a joint USAF/NASA runway traction program utilizing a C-141A airplane (ref. 3) and a joint USAF/FAA/NASA runway research program utilizing a 727 and a DC-9 airplane. The data presented herein include: airplane ground speed and lateral acceleration during ground turns, number of turns performed during arrival or departure, and the magnitude of the ground turns. At this time, there appears to be no similar data available for general reference.

SYMBOLS

a_y	lateral acceleration measured at airplane center of gravity, g units
f	observed frequency of occurrence for an event in a given class interval
g	acceleration due to gravity
N	total observed frequency for one sample of data
δ_n	nose-wheel steering angle
ψ	relative airplane heading

Designations:

C1,C2,etc.	United States commercial airports
F1,F2,etc.	foreign airports (military or commercial)
M1,M2,etc.	United States military airports
FAA	Federal Aviation Administration
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
USAF	U.S. Air Force

EQUIPMENT AND PROCEDURE

Aircraft and Instrumentation

The NASA has recently participated in several runway research programs related primarily to the stopping performance of aircraft. The aircraft utilized in these programs were an Air Force C-141A, an FAA 727, and an FAA DC-9. The NASA-installed instrumentation was very extensive for each airplane and similar to that which is described in reference 3 for the C-141A airplane. Only the instrumentation required to measure and record the magnitude of ground turns, lateral acceleration, and airplane ground speed was utilized for the data presented in this paper.

The magnitude of the ground-turn maneuvers for the C-141A airplane was indicated by the nose-wheel steering angle. The nose wheel of this airplane could be deflected from the center position to a maximum steering angle of 80° in each direction. Turn maneuvers were defined in this manner rather than by the change in airplane heading because the combat traction program (ref. 3) required a sensitive heading measurement relative to the initial heading; consequently, the heading time history was off scale during most of the ground-turn maneuvers.

A low sensitivity recording of relative heading was available for the programs involving the 727 and DC-9 airplanes. Therefore, the magnitude of the ground turns was indicated by the heading change for the 727 and DC-9 airplanes.

The lateral acceleration values were obtained by means of accelerometers located at the airplane center of gravity for all three airplanes and also in the cockpit for the 727 airplane. These accelerometers were alined to sense the acceleration normal to the plane of symmetry and the lateral acceleration data presented herein are uncorrected for the effect of airplane roll attitude. This correction to remove the component of acceleration due to gravity would be equal to the sine of the roll attitude.

The ground speed was obtained from measurements of wheel angular velocities. The ground-speed data were measured by the nose-wheel sensors for the 727 and DC-9 and by the left-rear-inboard main-wheel sensor for the C-141A.

Resolution of Data

The data were reduced and tabulated with the following resolution:

Nose-wheel steering angle	Nearest 0.8° (0.01 full scale)
Relative heading	Nearest 5.0°
Lateral acceleration	Nearest 0.01 g unit
Ground speed	Nearest 1.0 knot

Tests

As previously indicated, these airplanes were made available by the USAF and FAA and were instrumented by NASA for runway research programs related primarily to traction or stopping distance. The data for this paper were obtained on a noninterference basis during arrival and departure at the various airports which were participating in the basic runway research program. Arrival data were recorded from the time just prior to touchdown to the time when the airplane was finally parked. Departure data were recorded from the time the airplane left the parking ramp to the time the airplane was airborne.

RESULTS AND DISCUSSION

Scope of Data

It is believed that these data are the largest quantity that have ever been assembled to describe ground-turn maneuvers. Therefore, the data are expected to be useful in describing average operating conditions for jet transports similar to the C-141A, 727, and DC-9 airplanes. Certain limitations should be considered in the interpretation of these data which were obtained while in transit to various test sites for runway research programs. For example, it is probable that some of the arrivals and departures were not treated as routine operations by ground control personnel. It could also be argued that some of the operations at military airports do not accurately represent commercial operations. Furthermore, these data only represent the operational techniques of a small sample of pilots.

Description of Ground-Turn Maneuvers

For the C-141A, all nose-wheel steering deflections δ_n having both a duration of at least 5 seconds before returning to the center position and a magnitude of at least 0.11 of the maximum steering angle were assumed to indicate a deliberate turn maneuver. Time histories of lateral acceleration measured at the center of gravity a_y, relative heading ψ, and nose-wheel steering angle δ_n for five typical turn maneuvers for the C-141A are shown in figure 1. Figure 1(a) illustrates two turns, each having a short duration and a small heading change. For each turn, the ground speed, which was measured at the time of maximum δ_n, was 3 knots; and the maximum lateral acceleration for each turn was 0.02g. Figure 1(b) illustrates a turn of longer duration than that shown in figure 1(a). This turn is more typical of the turns represented by these data and it occurred as the airplane turned from the runway following a landing rollout. For this turn, the nose wheel was deflected for about 25 seconds, the ground speed was 6 knots, and the maximum lateral acceleration was 0.05g. Figure 1(c) illustrates a somewhat unusual maneuver which is probably a U-turn on the runway following a landing rollout.

The maneuver consisted of two continuous turns – first, a small swing to the right and then a large long duration turn to the left. The ground speed was 13 knots during the first turn and dropped to 2 knots during the last turn whereas the maximum lateral acceleration during each turn was 0.04g and 0.09g, respectively.

Turn maneuvers for the 727 and DC-9 were defined by the recorded time history of relative heading. Time histories of a_y at the center of gravity and ψ showing four typical turn maneuvers for the 727 and DC-9 are shown in figure 2. These turns show some similarity to those given in figure 1 for the C-141A. The 180° turn following landing rollout shown for the 727 in figure 2(a) is about the same duration as the turn following landing rollout shown for the C-141A in figure 1(c) which was also probably a 180° turn. The ground speed for the turn shown in figure 2(a) was 26 knots at the beginning and dropped to 8 knots at the completion of the turn. The two successive turns shown in figure 2(b) represent a maneuver that occurred occasionally with each airplane; that is, a small turn in one direction followed immediately by a larger turn in the opposite direction. The 90° right turn from the runway shown for the DC-9 in figure 2(c) is similar in duration to that shown for the C-141A in figure 1(b).

Number of Turns Performed During Ground Operations

The number of ground turns performed during arrival and departure is given in table I for each airport and airplane. These data represent arrival and/or departure operations at 31 United States military, 8 United States commercial, and 13 foreign military or commercial airports. Generally, these data were obtained during one arrival and departure from each airport. There are some variations from this pattern, for example, the C-141A had 10 operations at airport M2. Table I also shows that data were not obtained for every arrival or departure. These missing data were usually the result of priorities on personnel or on the data recording system related to the primary research program. A total of 635, 96, and 78 turns were performed by the C-141A, 727, and DC-9 airplanes, respectively. Of the 809 turns performed by all three airplanes during arrival and departure operations, 420 were to the left and 389 were to the right. Because of better visibility, the pilot would generally prefer to make a left turn if he has a choice of direction such as for a 180° turn. However, all the turn data in this paper are summarized without regard to algebraic signs relating to the direction of turn.

The number of ground-turn maneuvers required during arrival or departure at an airport should be essentially determined by the airport geometry, runway in use, ground traffic pattern, and airplane parking position. Particular airplane characteristics, such as the ability to make exit taxiways short of the runway end, and other factors could possibly affect the number of turns required at some airports. These effects are considered secondary and beyond the scope of the present data. Therefore, the data for the number of turns required for arrival or departure are grouped together for all three airplanes and are summarized at the bottom of table I. Based on 80 arrivals and 79 departures, these data show that, on the average, about five ground-turn maneuvers are required for each arrival and about five turns for each departure; thus, a total of 10 ground turns per flight are required.

The frequency distribution of the number of turns performed during each arrival and each departure is given in table II and figure 3. These data show that although the number of turns per arrival or departure operation ranged from 1 to 12, the frequency of occurrence was low for these extreme values. The relative frequency f/N was greater than 0.1 only for three, four, five, and six turns per operation.

Magnitude of Ground-Turn Maneuver

Because of instrumentation restrictions, the magnitude of the ground-turn maneuver for the C-141A can only be indicated indirectly by the nose-wheel steering angle. For the 727 and DC-9 airplanes, however, the measurement of relative heading is available to define the ground-turn angle precisely.

Nosewheel steering angle.- The frequency distribution of the maximum steering angle used during a turn is given in table III and figure 4 for arrival and departures at various airports with the C-141A airplane. The maximum steering angle used during a turn was less than one-half of the maximum available angle for more than 80 percent of the 635 turns for the C-141A airplane. The larger steering angles (0.9 to full deflection) were used for only 1.42 percent of the turns.

Ground-turn angle.- The frequency distributions of the turn angle, in degrees, for the turns performed during arrival and departure at various airports with the 727 and DC-9 airplanes are given in table IV and figure 5. Note that even though table I indicates 78 turns recorded for the DC-9 airplane, the recorded heading change was available only for 77 turns. These data show no appreciable difference between the separate or the combined data samples for the 727 and DC-9 operations. As discussed for the number of turns, it is felt that the magnitude of turns is not appreciably affected by small differences in airplane characteristics. A large number of turns (34.1 percent for the combined data) were in the 90° to 130° interval which includes the 90° turns. All the samples show that about 9 percent of the turns were in the 180° to 220° interval, most of which were 180° turns. All the data samples show that the average turn was about 80°.

Average turn rate.- The frequency distributions for the average turn rate are given in table V and figure 6 for ground turns performed with the 727 and DC-9 airplanes. The average turn rate represents the magnitude of each turn divided by the time required to complete the turn maneuver. Airplane characteristics would be expected to have a measurable effect on the turn rate; however, the mean value was about 4° per second for both the 727 and DC-9 airplanes. Neither airplane completed a turn at a rate greater than 9°

per second. The average times to complete ground-turn maneuvers with the 727 and DC-9 airplanes were about 20 seconds based on the average turn of 80° at 4° per second.

Lateral Acceleration During Ground Turns

C-141A airplane.- The frequency distribution of the maximum lateral acceleration measured at the center of gravity during each ground-turn maneuver with the C-141A airplane is given in table VI for 635 turns. The class interval selected for the lateral acceleration data was 0.02 g units and the mean value was 0.046 g units. From criteria given in reference 4, a Pearson type I frequency-distribution curve has been fitted to the observed data. The observed and fitted distributions were integrated to determine the probability that the lateral acceleration would be greater than a given value and these results are shown by the probability curve and data in figure 7. Based on the fitted distribution, it can be expected that for this type of operation, the lateral acceleration at the center of gravity will exceed 0.22 g units about once in 100 000 ground turning maneuvers or, based on the mean value of 10 turns per flight, this lateral acceleration will be exceeded one time in about 10 000 flights.

727 and DC-9 airplanes.- The frequency distributions of maximum lateral acceleration during each ground-turn maneuver are given in table VII for 96 turns and for 78 turns with the 727 and DC-9 airplanes, respectively. The class interval for lateral accelerations was 0.03 g units for these data. In addition to the maximum lateral accelerations measured at the airplane center of gravity, table VII also gives similar data measured at the cockpit of the 727 airplane. The mean values of the maximum lateral acceleration measured at the center of gravity during each turn are essentially the same (0.058 and 0.059 g units) for the 727 and DC-9 airplanes. The mean value of the maximum lateral acceleration measured in the cockpit of the 727 during each turn was 0.089 g units.

The data based on observed distributions of lateral acceleration for the 727 and DC-9 airplanes are shown in figure 8 along with the fitted probability curve for the C-141A lateral acceleration data. No attempt has been made to fit a frequency distribution curve to the data samples for the 727 and DC-9 airplanes. Although the 727 data shown in figure 8 seem to indicate a rather smooth variation of probability with lateral acceleration similar to the fitted curve for the C-141A data, the DC-9 data are scattered above and below the comparable 727 data for the accelerations measured at the airplane center of gravity. Thus, it appears that the probability of exceeding a given value of lateral acceleration measured at the center of gravity is about the same for the DC-9 as for the 727 and that this probability is greater than that for the C-141A.

The data for the 727 airplane in figure 8 show that the maximum lateral acceleration measured during a ground turn is greater when measured at the cockpit than when measured at the center of gravity. For example, about 1 out of 100 turns would be expected to have a lateral acceleration greater than 0.15g at the center of gravity and 0.18g at the cockpit.

Ground Speed During Turns

Based on a 4-knot class interval, the frequency distribution of the ground speed for the 635 turns with the C-141A airplane is given in table VIII. Based on a 5-knot class interval, the frequency distributions of the ground speed for the 96 and 78 turns with the 727 and DC-9 airplanes, respectively, are given in table IX. Histograms showing these distributions for the three airplanes are given in figure 9.

The ground speed for a turn with the C-141A airplane was arbitrarily defined as the speed measured at the time of maximum nose-wheel steering deflection. The ground speed for turns with the 727 and DC-9 airplanes was defined as the speed measured at the time of the initial heading change. For most of the turns the speed variation during the turn showed about equal probability of increasing, decreasing, or remaining essentially constant. Therefore, it would appear justifiable to compare quantitatively the C-141A data for speed during turns with the 727 and DC-9 data as shown in figure 9 even though the speeds were measured at different times during the turns. The average speed for the turns with the C-141A (5.0 knots) is about one-half of the average speeds for the 727 and DC-9 airplanes (10.4 and 12.1 knots, respectively). For the C-141A airplane, the average speed was 8.9 knots at the time of maximum nose-wheel steering angle during the turnoff of the runway following the landing rollout. For the 727 and DC-9 airplanes, the turnoff of the runway following the landing rollout was initiated at an average speed of 21.6 and 21.4 knots, respectively.

The probability of exceeding a given speed during a ground-turn maneuver with the C-141A, 727, and DC-9 airplanes is given in figure 10. For the C-141A airplane, these data show that one of every 10 turns will have a ground speed greater than 9 knots at the time of maximum nose-wheel steering angle. For the 727 and DC-9 airplanes, one of 10 turns will be initiated at a speed greater than 18 and 21 knots, respectively.

CONCLUDING REMARKS

Some data defining ground-turn maneuvers for jet transport aircraft have been obtained during arrival and departure operations at several United States and foreign military and commercial airports. These data represent 635, 96, and 78 turns performed with the C-141A, 727, and DC-9 airplanes, respectively, during a total of 80 arrivals and 79 departures. Analysis of these data has established the following results:

Based on the total operations for all three airplanes, the data show that on the average about 10 ground turns were required for each flight. These turns were about equally divided with an average of five turns each for arrival and departure.

Based on the 727 and DC-9 data, the average magnitude of turn was about 80° and the average time required to complete the turn was 20 seconds.

The mean value of the maximum lateral acceleration measured at the center of gravity during each turn was 0.046, 0.058, and 0.059 g units for the C-141A, 727, and DC-9 airplanes, respectively. For the C-141A, it can be expected that the lateral acceleration at the center of gravity will exceed 0.22 g units once in about 100 000 turns or about one time in 10 000 flights.

The average ground speed for turns was 5.0, 10.4, and 12.1 knots for the C-141A, 727, and DC-9 airplanes, respectively.

Langley Research Center,
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TABLE I.- NUMBER OF TURNS DURING ARRIVAL AND DEPARTURE FOR EACH AIRPORT AND AIRPLANE

Airport	Airplane	Number of turns		Airport	Airplane	Number of turns	
		Arrival	Departure			Arrival	Departure
M1	C-141A	6		M20	C-141A	5	4
M1		2	9	M21		5	6
M1		6		M22		1	1
M1		3	4	M23		4	4
M1		4	5	M24		8	
M2			9	M25		1	
M2		5	9	M26		2	3
M2		9	5	M27			5
M2		5	8	M28		4	4
M2		3	5	M29		3	3
M2		6	6	M30		4	3
M2		7	4	M30	DC-9	3	5
M2			7	M31	DC-9	5	5
M2			5	C1	C-141A	10	
M2			12	C1	727	8	
M3		5	6	C2	C-141A		6
M3		3	4	C3	727	4	4
M3		4		C4	727	5	5
M4		3	2	C4	DC-9	6	4
M4		5		C5	727	5	4
M5		4	4	C5	727	7	5
M5		4	4	C5	DC-9	5	4
M6		5	5	C6	727	12	12
M6		3	4	C7	727	6	
M6		3	4	C8	DC-9	6	6
M7		4	10	F1	C-141A	7	6
M7		7	3	F1		5	7
M8		3		F1		6	5
M8		4	3	F1		5	4
M9			7	F1			5
M9		5		F1		5	9
M9	727		9	F2		8	4
M9	DC-9		7	F2		8	3
M10	C-141A	4	4	F2		8	6
M11	C-141A	4	8	F2		9	6
M11	727	4	6	F3		2	1
M11	DC-9	6	5	F4		8	4
M12	C-141A	3	5	F5		3	3
M13		5	3	F6		4	
M14		7	5	F7		3	3
M15		6	5	F8		4	4
M16		5	6	F9		4	5
M17		4	9	F10			3
M18		8	3	F11		4	3
M19		4	5	F12		4	6
				F13	DC-9	5	6
Total number of turns						399	410
Number of arrivals or departures						80	79
Average number of turns per arrival or departure						4.988	5.190

TABLE II.- FREQUENCY DISTRIBUTIONS OF NUMBER OF GROUND TURNS PERFORMED DURING EACH ARRIVAL OR DEPARTURE AT VARIOUS AIRPORTS

Number of turns per operation	Observed frequency, f		Relative frequency, f/N	
	Arrival	Departure	Arrival	Departure
1	2	2	0.0250	0.0253
2	3	1	.0375	.0127
3	12	12	.1500	.1519
4	20	19	.2500	.2405
5	18	18	.2250	.2278
6	9	12	.1125	.1519
7	5	4	.0625	.0506
8	7	2	.0875	.0253
9	2	6	.0250	.0760
10	1	1	.0125	.0127
11	0	0	.0000	.0000
12	1	2	.0125	.0253
Total . . .	80	79	1.0000	1.0000

TABLE III.- FREQUENCY DISTRIBUTION OF MAXIMUM NOSE-WHEEL STEERING ANGLE USED FOR EACH GROUND TURN PERFORMED DURING ARRIVAL AND DEPARTURE AT VARIOUS AIRPORTS

[C-141A airplane]

Maximum steering angle used during turn, deg	Observed frequency, f	Relative frequency, f/N
*8.8 to 16.0	165	0.2598
16.8 to 24.0	162	.2551
24.8 to 32.0	92	.1449
32.8 to 40.0	101	.1591
40.8 to 48.0	49	.0772
48.8 to 56.0	30	.0472
56.8 to 64.0	22	.0346
64.8 to 72.0	5	.0079
72.8 to 80.0	9	.0142
Total	635	1.0000
Mean maximum steering angle, deg . . .	27.9	

*Threshold = 8.8°.

TABLE IV.- FREQUENCY DISTRIBUTIONS OF MAGNITUDE OF EACH GROUND TURN PERFORMED DURING ARRIVAL AND DEPARTURE AT VARIOUS AIRPORTS

[727 and DC-9 airplanes]

Magnitude of turn, deg	Observed frequency, f			Relative frequency, f/N		
	727	DC-9	Combined	727	DC-9	Combined
0 to 40	21	24	45	0.2187	0.3117	0.2601
45 to 85	26	18	44	.2708	.2338	.2543
90 to 130	36	23	59	.3750	.2987	.3410
135 to 175	4	5	9	.0417	.0649	.0520
180 to 220	9	7	16	.0938	.0909	.0925
Total	96	77	173	1.0000	1.0000	1.0000
Mean turn, deg	81.1	80.5	80.8			

TABLE V.- FREQUENCY DISTRIBUTIONS OF AVERAGE TURN RATE FOR EACH GROUND TURN PERFORMED DURING ARRIVAL AND DEPARTURE AT VARIOUS AIRPORTS

[727 and DC-9 airplanes]

Average turn rate, deg/sec	Observed frequency, f		Relative frequency, f/N	
	727	DC-9	727	DC-9
0 to 0.99	0	0	0.0000	0.0000
1 to 1.99	11	6	.1146	.0779
2 to 2.99	19	19	.1979	.2468
3 to 3.99	16	18	.1667	.2338
4 to 4.99	16	13	.1667	.1688
5 to 5.99	21	10	.2188	.1299
6 to 6.99	9	7	.0938	.0909
7 to 7.99	2	4	.0208	.0519
8 to 8.99	2	0	.0208	.0000
Total	96	77	1.0000	1.0000
Mean turn rate, deg/sec	4.07	3.95		

TABLE VI.- FREQUENCY DISTRIBUTION OF MAXIMUM LATERAL ACCELERATION AT THE CENTER OF GRAVITY DURING EACH GROUND-TURN MANEUVER

[C-141A airplane]

Lateral acceleration, g units	Observed frequency, f	Relative frequency, f/N	Cumulative frequency
0 to 0.01	70	0.1102	1.0000
0.02 to 0.03	178	.2803	.8898
0.04 to 0.05	183	.2882	.6095
0.06 to 0.07	110	.1732	.3213
0.08 to 0.09	61	.0961	.1481
0.10 to 0.11	17	.0268	.0520
0.12 to 0.13	13	.0205	.0252
0.14 to 0.15	2	.0031	.0047
0.16 to 0.17	1	.0016	.0016
Total	635	1.0000	
Mean, g units	0.046		

TABLE VII.- FREQUENCY DISTRIBUTIONS OF MAXIMUM LATERAL ACCELERATION DURING EACH GROUND-TURN MANEUVER

[727 and DC-9 airplanes]

Lateral acceleration, g units	Measured at center of gravity						Measured in cockpit		
	727			DC-9			727		
	f	f/N	Cumulative frequency	f	f/N	Cumulative frequency	f	f/N	Cumulative frequency
0 to 0.02	24	0.2500	1.0000	13	0.1667	1.0000	3	0.0313	1.0000
0.03 to 0.05	26	.2708	.7500	19	.2436	.8333	18	.1875	.9688
0.06 to 0.08	21	.2188	.4792	35	.4487	.5897	25	.2604	.7813
0.09 to 0.11	16	.1667	.2604	5	.0641	.1410	22	.2292	.5209
0.12 to 0.14	8	.0833	.0937	6	.0769	.0769	22	.2292	.2917
0.15 to 0.17	1	.0104	.0104	0	.0000	.0000	5	.0521	.0625
0.18 to 0.20	0	.0000	.0000	0	.0000	.0000	1	.0104	.0104
Total	96	1.0000		78	1.0000		96	1.0000	
Mean, g units	0.058			0.059			0.089		

TABLE VIII.- FREQUENCY DISTRIBUTION OF SPEED AT TIME OF MAXIMUM NOSE-WHEEL STEERING ANGLE FOR EACH GROUND-TURN MANEUVER

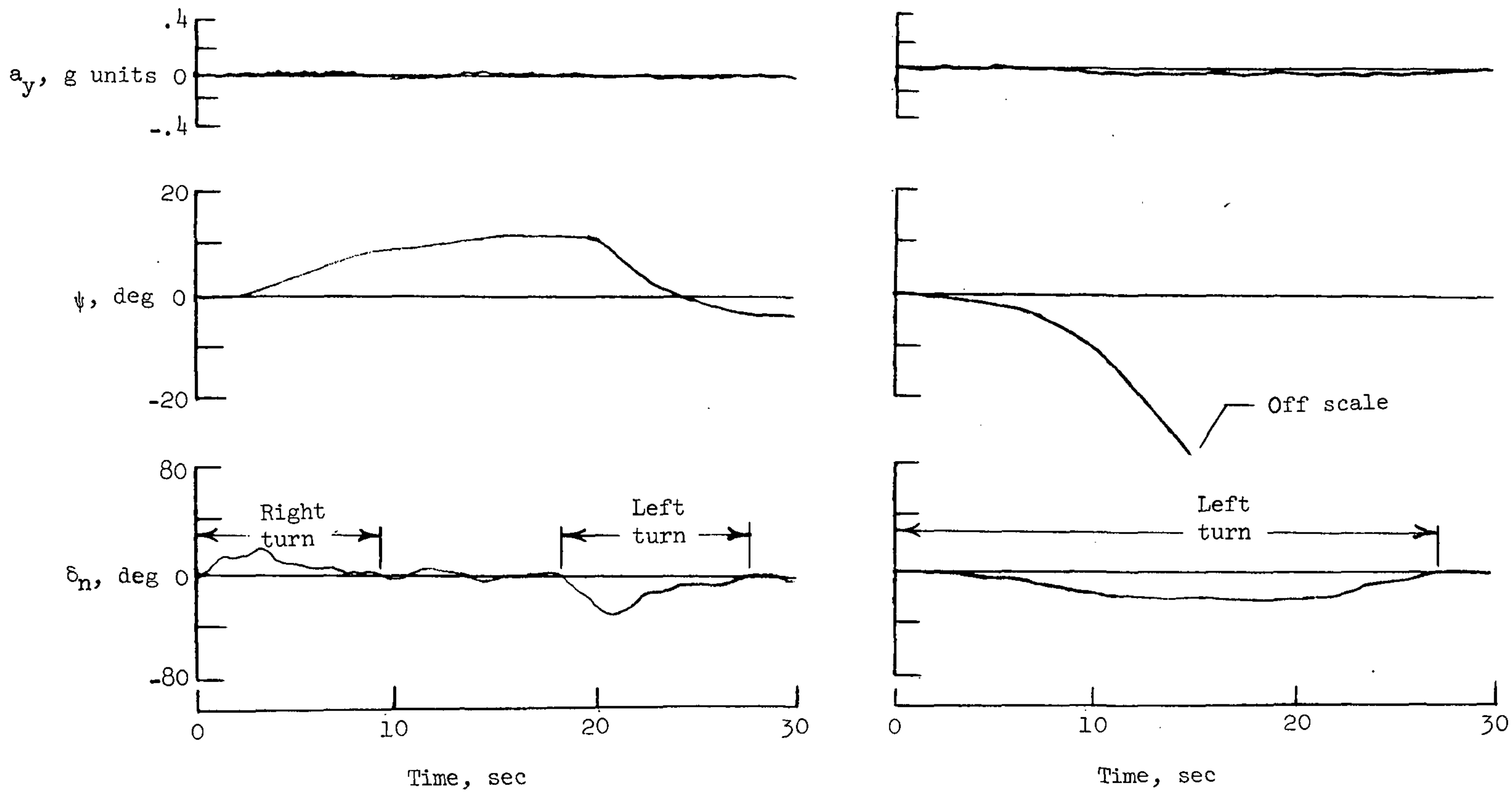
[C-141A airplane]

Speed, knots	Observed frequency, f	Observed frequency, f/N	Cumulative frequency
0 to 3	223	0.3512	1.0000
4 to 7	322	.5071	.6487
8 to 11	65	.1024	.1416
12 to 15	14	.0220	.0392
16 to 19	6	.0094	.0172
20 to 23	2	.0031	.0078
24 to 27	2	.0031	.0047
28 to 31	0	0	.0016
32 to 35	1	.0016	.0016
Total	635	1.0000	
Mean, knots	5.0		

TABLE IX.- FREQUENCY DISTRIBUTIONS OF SPEED AT BEGINNING OF EACH GROUND-TURN MANEUVER

[727 and DC-9 airplanes]

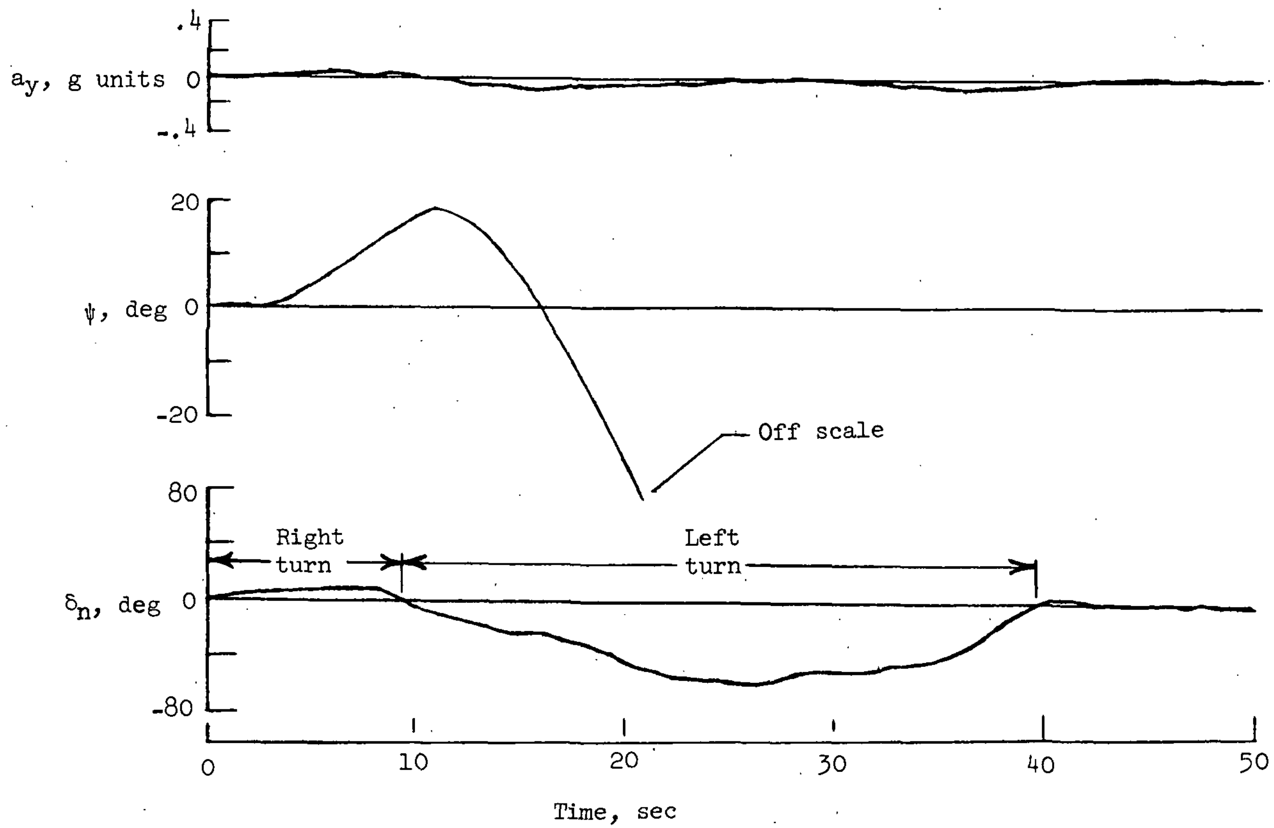
Speed, knots	Observed frequency, f		Relative frequency, f/N		Cumulative frequency	
	727	DC-9	727	DC-9	727	DC-9
0 to 4	26	13	0.2708	0.1667	1.0000	1.0001
5 to 9	15	14	.1563	.1795	.7292	.8334
10 to 14	32	27	.3333	.3462	.5729	.6539
15 to 19	17	13	.1771	.1667	.2396	.3077
20 to 24	3	7	.0313	.0897	.0625	.1410
25 to 29	1	3	.0414	.0385	.0312	.0513
30 to 34	0	0	0	0	.0208	.0128
35 to 39	1	1	.0104	.0128	.0208	.0128
40 to 44	1	0	.0104	0	.0104	0
Total	96	78	1.0000	1.0000		
Mean, knots	10.4	12.1				



(a) Two turns showing a short duration and a small heading change.

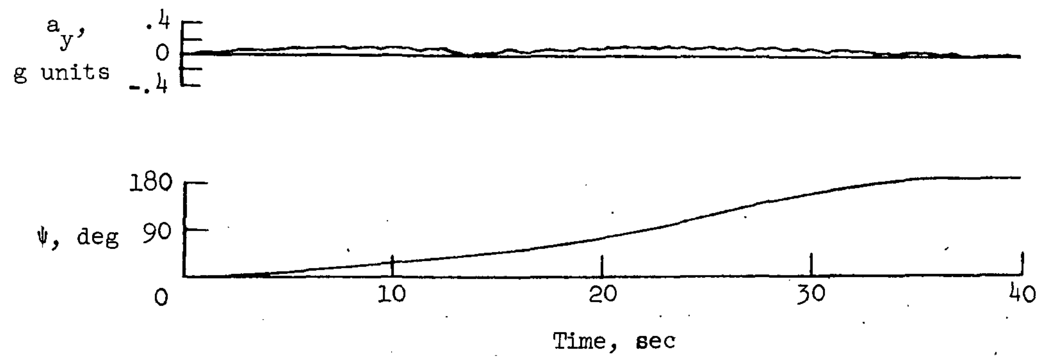
(b) Turn from runway following landing rollout.

Figure 1.- Time histories illustrating typical ground-turn maneuvers with the C-141A airplane.

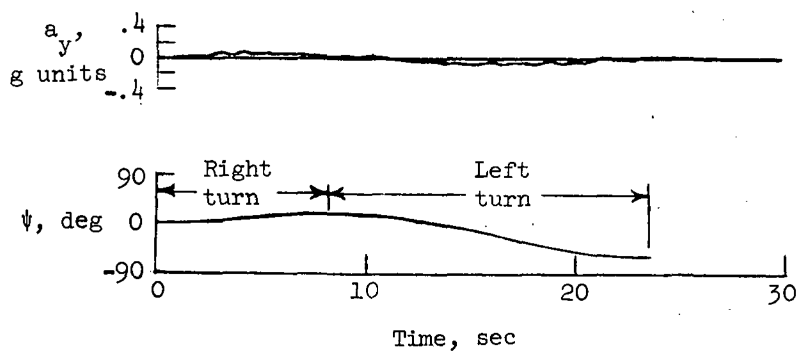


(c) Two continuous turns following the landing rollout (apparently, a U-turn on the runway).

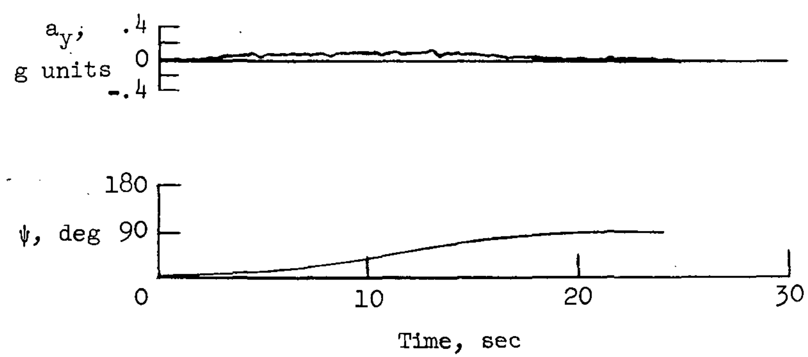
Figure 1.- Concluded.



(a) A 180° right turn following landing rollout. 727 airplane.



(b) Two successive turns, 20° right and 70° left. 727 airplane.



(c) A 90° right turn from runway following landing rollout. DC-9 airplane.

Figure 2.- Time histories illustrating typical ground-turn maneuvers with the 727 and DC-9 airplanes.

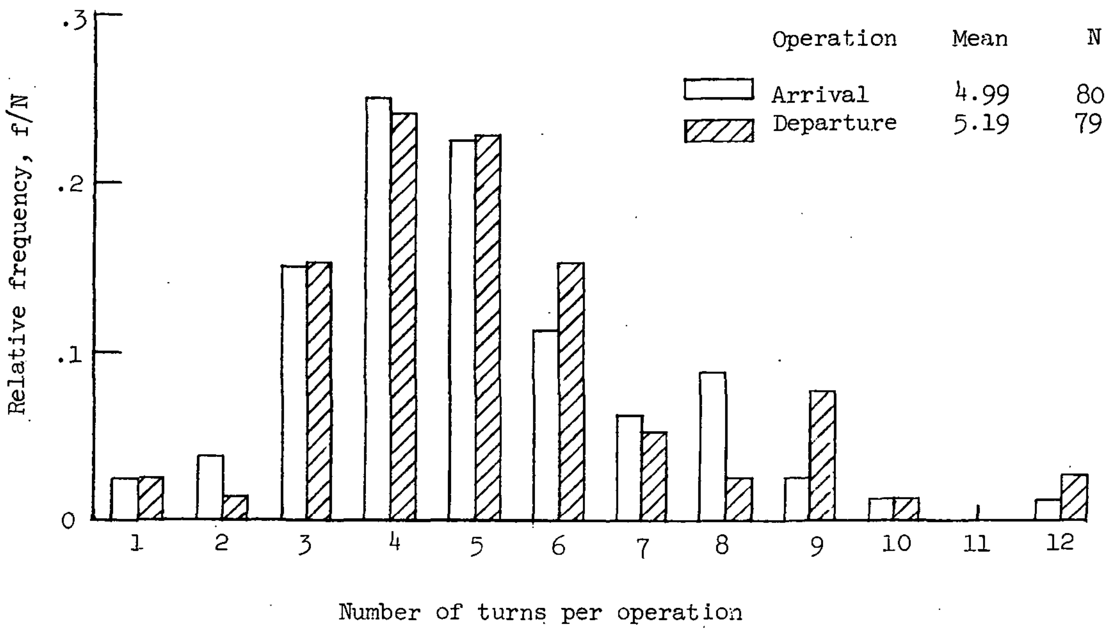


Figure 3.- Histograms of the number of turns performed during each arrival or departure at various airports. C-141A, 727, and DC-9 airplanes.

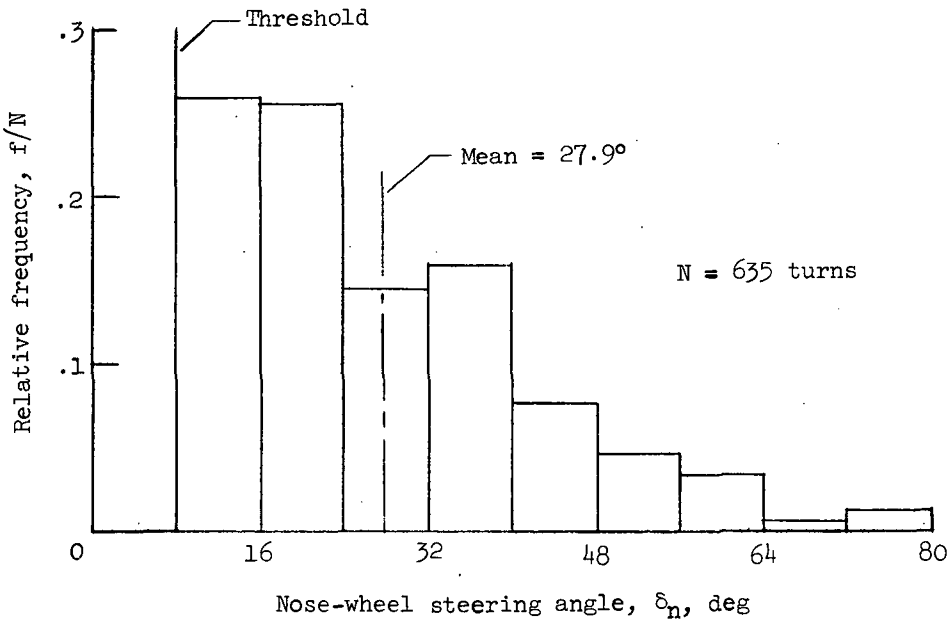


Figure 4.- Histogram of maximum nose-wheel steering angle used for each ground turn performed during arrival and departure at various airports. C-141A airplane.

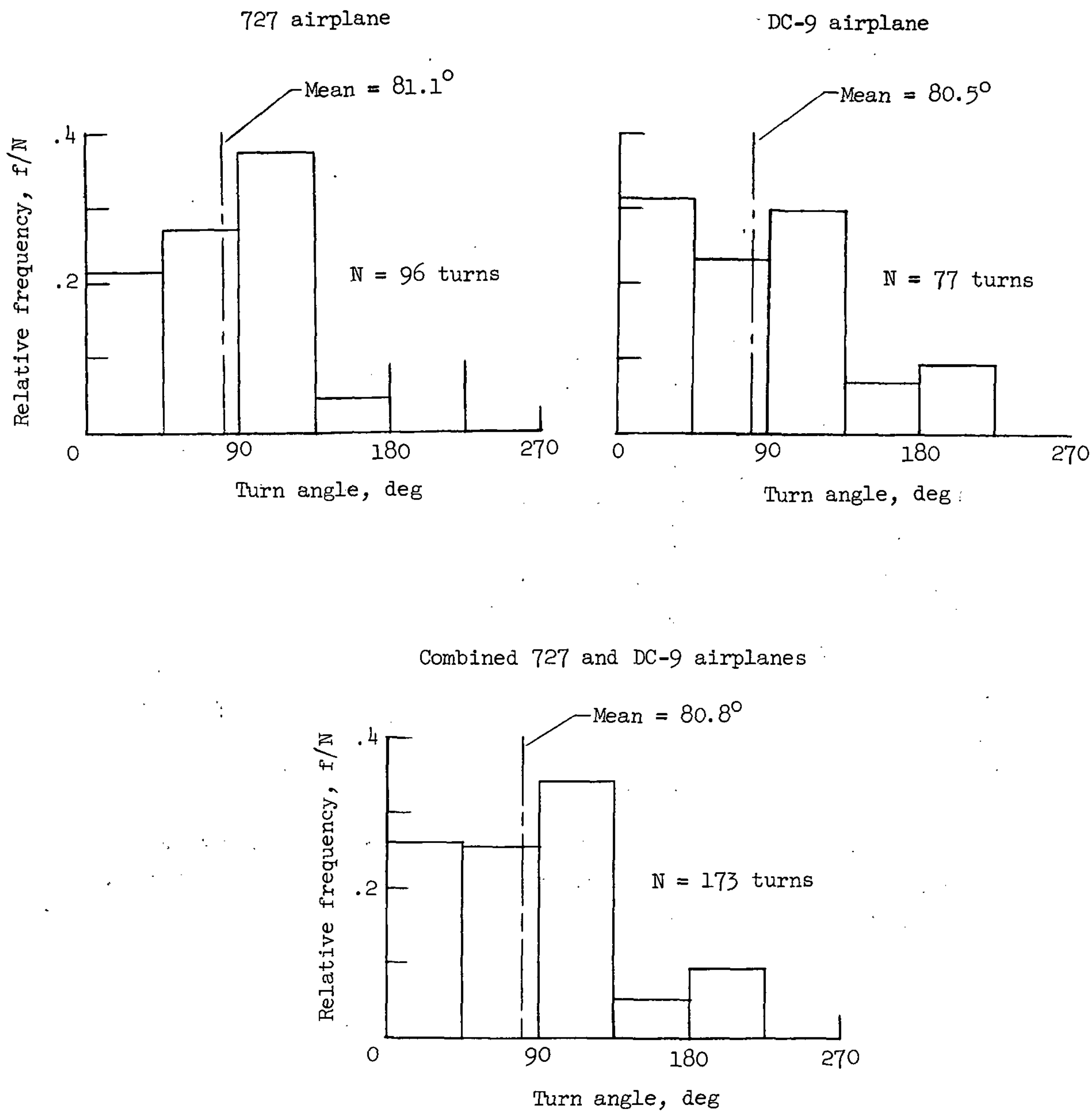


Figure 5.- Histograms of the magnitude of each ground turn performed during arrival and departure at various airports. 727 and DC-9 airplanes.

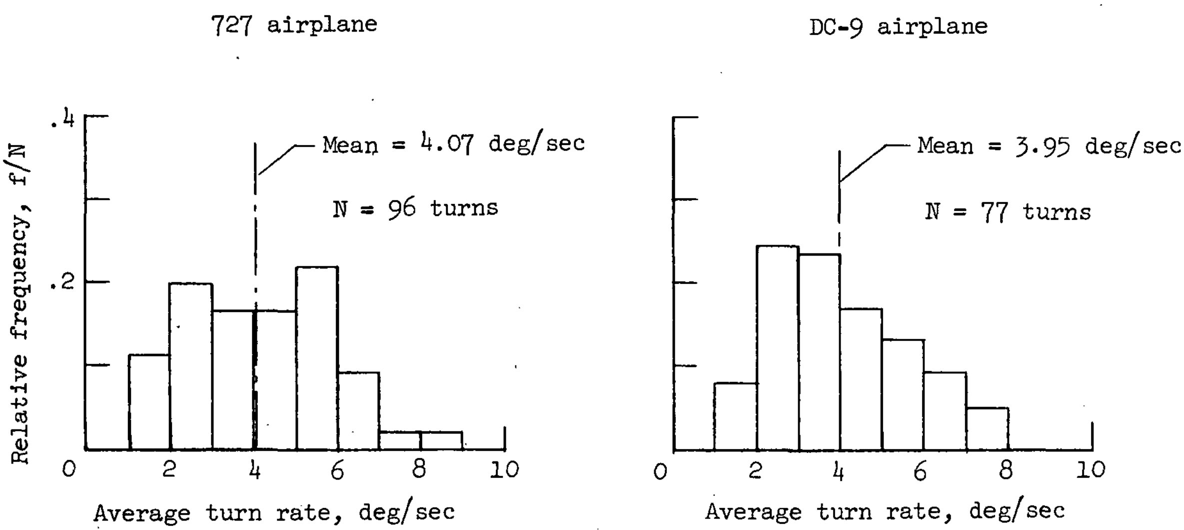


Figure 6.- Histograms of the average rate of turn for each ground turn performed during arrival and departure at various airports. 727 and DC-9 airplanes.

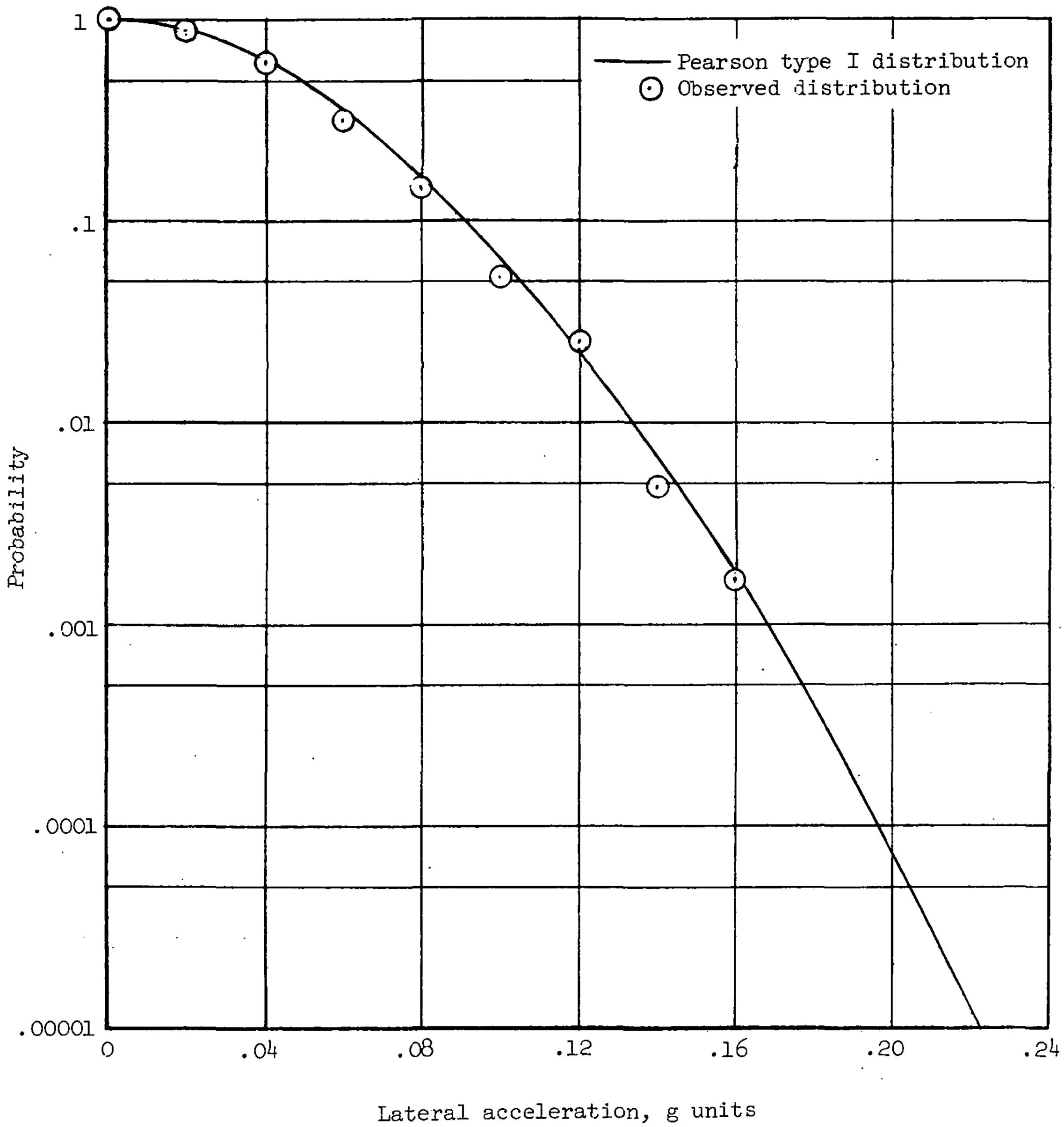


Figure 7.- Probability that the lateral acceleration at the center of gravity will exceed a given value during ground-turn maneuvers. C-141A airplane. N = 635 turns.

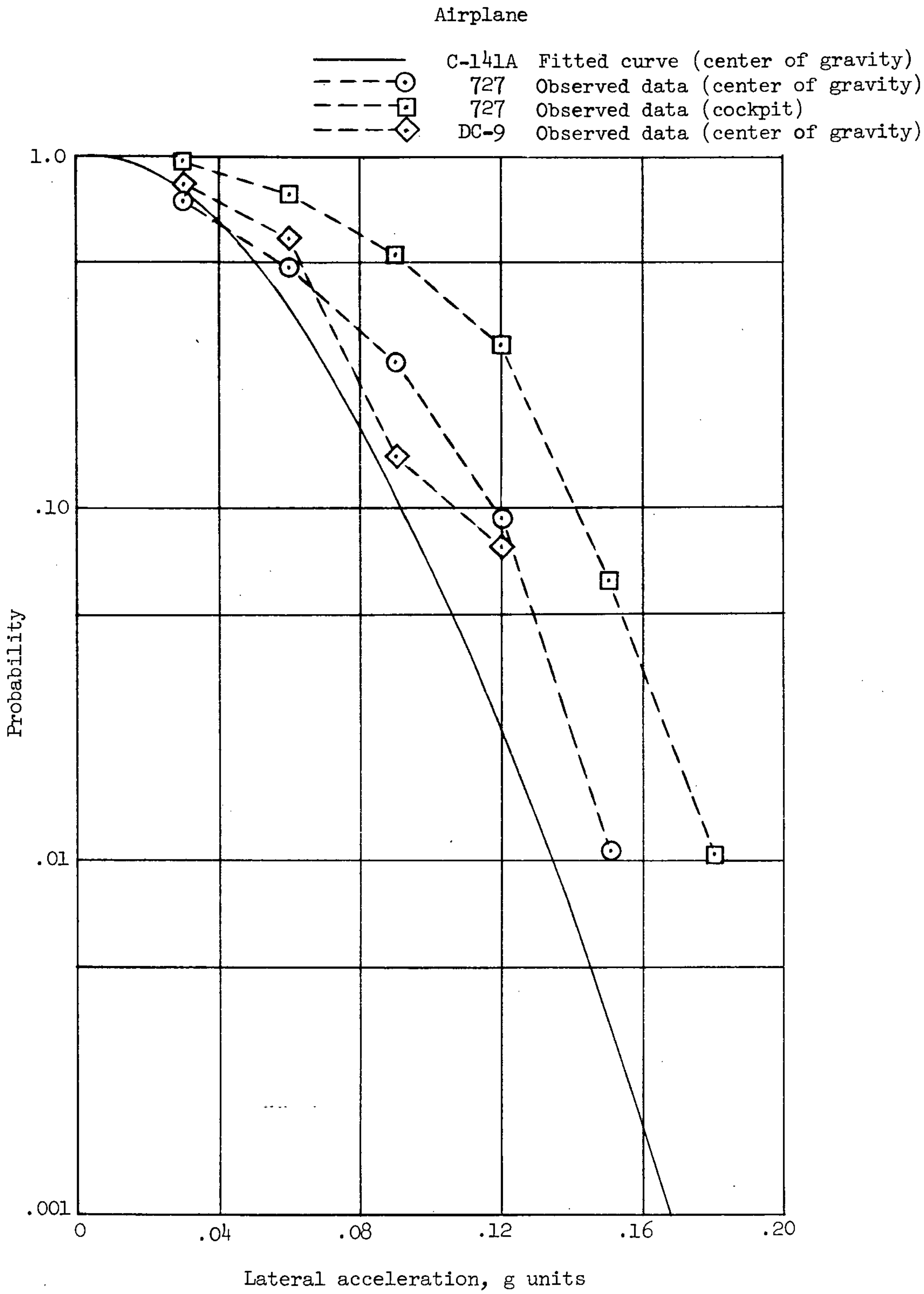


Figure 8.- Probability for several airplanes that the lateral acceleration will exceed a given value during ground-turn maneuvers.

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