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ANALYSIS OF VGH DATA FROM TWO TYPES OF FOUR-ENGINE AIRPLANES IN COMMERCIAL CARGO SERVICE

by Frederick M. Healy

Langley Research Center
Hampton, Va. 23365

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16. Abstract

Data are presented for derived gust velocities and for incremental normal accelerations due to gusts, maneuvers, and landing impacts. The data were obtained from NASA VGH recorders installed on three four-engine cargo airplanes operated by three airlines. Continental United States and trans-Pacific routes were covered.

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ANALYSIS OF VGH DATA FROM TWO TYPES OF FOUR-ENGINE AIRPLANES IN COMMERCIAL CARGO SERVICE

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SUMMARY

An analysis of VGH records collected on three four-engine cargo airplanes has provided information on incremental normal acceleration and turbulence experienced. The airplanes, one on each of three airlines, included one which was turboprop powered and two which had piston engines. The turboprop airplane and one of those with piston engines were operated primarily in the continental United States, and the other airplane was operated on trans-Pacific routes.

The experiences of gust acceleration, operational maneuver acceleration, and check-flight maneuver acceleration were similar for the three cargo airplanes and were in good agreement with results obtained for a number of four-engine piston-powered airplanes in passenger service. The gust-velocity experience of the piston-engine cargo airplanes was in good agreement with that of the passenger airplanes. The gust-velocity experience of the turboprop airplane was less severe than the range of results obtained in piston-engine passenger operations. The landing-impact experience of the turboprop airplane was more severe than that of the piston-engine cargo airplanes.

INTRODUCTION

In a continuation of a project begun in 1946 by the National Advisory Committee for Aeronautics, the National Aeronautics and Space Administration has been collecting data on the incremental normal acceleration, airspeed, and altitude of airplanes representing a wide range of airplane characteristics and operational conditions. These measurements are being utilized to provide statistical data on a number of operational aspects of service experience, such as accelerations due to gusts, maneuvers, and oscillations; operating practices; and landing impact and other ground-induced accelerations. In the past, information obtained from the data collection program has proved useful for comparison of the operational experiences of airplanes with the concepts used in their design, for detection of new or unanticipated aspects of the operations, and as background information for application in the design of new airplanes. Typical results obtained for several types of airplanes are given in references 1 to 8.

This paper presents an analysis of the acceleration and gust-velocity experience of three four-engine airplanes, one turboprop powered and two with piston engines, in cargo operation. The results are compared with those for a number of four-engine piston-powered airplanes in passenger service.

SYMBOLS

The measurements of this investigation were made in U.S. Customary Units and are given in both the International System of Units (SI) and U.S. Customary Units. Factors relating the two systems are given in reference 9.

a_n	incremental normal acceleration, g units
c	wing chord, meters (feet)
g	acceleration due to gravity, 9.81 m/sec^2 (32.2 ft/sec^2)
K_g	gust factor, $\dfrac{0.88\mu_g}{5.3 + \mu_g}$
M_{NE}	never-exceed Mach number
M_{NO}	normal-operating limit Mach number
m	lift-curve slope, per radian
S	wing area, m^2 (ft^2)
U_{de}	derived gust velocity, m/sec (ft/sec)
V_A	maneuvering speed, knots indicated
V_e	equivalent airspeed, m/sec (ft/sec)
V_{NE}	never-exceed speed, knots indicated
V_{NO}	normal-operating limit airspeed, knots indicated

W airplane weight, newtons (pounds-force)

μ_g airplane mass ratio, $\frac{2W}{m\rho cgS}$

ρ atmospheric density, kg/m^3 ($slugs/ft^3$)

ρ_o atmospheric density at sea level, kg/m^3 ($slugs/ft^3$)

DATA

Instrumentation and Scope

The data were collected with NASA VGH recorders, which provide continuous time-history records of indicated airspeed, normal acceleration, and pressure altitude. A detailed description of the VGH recorder is given in reference 10. The normal accelerations were sensed by an accelerometer installed in proximity to the airplane center of gravity. Airspeed and altitude measurements were provided by total and ambient pressures obtained from the airplane pitot- and static-pressure sources.

The three airplanes were operated geographically as follows: for operation A (the turboprop airplane), transcontinental United States routes; for operation B, north-south routes in the eastern United States and to Puerto Rico; for operation C, trans-Pacific routes.

The scope of the data samples recorded is summarized in table I. As shown in the table, the sample sizes varied from 1233 hours for operation A to 727 hours for operation C. The time spent in check flights was much greater for operations A and B (4.04 and 3.43 percent, respectively) than for operation C (0.21 percent). The data collection periods were approximately $2\frac{1}{2}$ to 3 years for operations A and B and approximately 10 months for operation C. Because of the relatively short program duration and less flight time recorded in operation C, less confidence is placed in this sample than in those of operations A and B. Recording was almost continuous except for one period in operation B during which the VGH recording drums were not changed at the optimum schedule. To define the operation further, histograms of flight duration and of pressure altitude are shown in figure 1. Airplane characteristics pertinent to the evaluation of the data are given in table II.

Evaluation

On the VGH records each flight was classified as being either an operational flight (revenue producing) or a check flight (for pilot training or airplane testing). Check flights are distinguished from operational flights by the higher amplitude and frequency of occurrence of maneuver accelerations and by larger and more irregular variations in airspeed and altitude.

The operational flights were divided into three segments representing climb, cruise, and descent flight conditions. Both climb and descent occasionally included short periods of level flight as a result of operational or air-traffic-control procedures. The cruise condition occasionally included periods when the airplane was climbing or descending to a different cruise altitude. For operational flights, each minute was classified as flight in rough or smooth air. The airplane was considered to be in rough air during the traverse of any continuously turbulent area which produced at least one incremental normal acceleration corresponding to a gust velocity of about 0.6 m/sec (2 ft/sec) or higher. Turbulent areas were determined by the appearance of the acceleration and airspeed traces as described in the next section.

Accelerations.- The evaluation of accelerations consisted of reading positive and negative incremental acceleration peaks above a specified threshold by using the 1g position of the acceleration trace as a reference. Only the maximum peak for each crossing of the reference and threshold was read. For each gust- and maneuver-acceleration peak read, the corresponding airspeed and altitude were also read. In the event that a gust acceleration was superimposed on a maneuver acceleration, the instantaneous value of the maneuver acceleration rather than the 1g trace position was used as the reference. The criterion used to distinguish gust accelerations from maneuver accelerations was that gust accelerations have a much higher frequency content and are accompanied by high-frequency low-intensity fluctuations of the airspeed trace. The threshold values were ±0.2g for accelerations due to gusts and maneuvers.

Time in rough air.- The percent of time in rough air in each 1.52-km (5000-ft) altitude interval was determined by dividing the time in rough air in that altitude interval by the total flight time in the altitude interval.

Gust velocities.- A value of derived gust velocity U_{de} was calculated for each gust-acceleration peak by means of the revised gust-load formula of reference 11

$$U_{de} = \frac{2Wa_n}{K_g \rho_o V_e m S}$$

The airplane weights were averages based on representative operational load factors. The lift-curve slope m for a Mach number range was computed by use of the empirical formula given in paper VI of reference 4 and is shown in figure 2.

Operating airspeeds and altitudes.- The indicated airspeed and pressure altitude were read from the VGH records at each 1-minute interval of flight. The airspeed and altitude data were classified by flight condition and by rough or smooth air.

Reliability of Data

The reliability of the data is affected by instrument, installation, reading, and sampling errors. Total overall errors for the VGH recorder are discussed in paper I of reference 4 and are estimated (for representative values) to be

Acceleration, g units	±0.05
Indicated airspeed, knots:	
At 100 knots	±6
At 350 knots	±2
Indicated pressure altitude, m (ft):	
At 1.52 km (5000 ft)	±23 (75)
At 12.2 km (40 000 ft)	±152 (500)

Reading errors are believed to be small in terms of the magnitudes of the particular quantities read since each tabulation is checked and corrected before use. The reading error for acceleration, although small, may seriously affect the count of accelerations exceeding given values. Reading checks have indicated that for individual records, the number of counts above 0.3g is reliable within ±30 percent. Since the reading errors tend to balance out as the sample size increases, the values of cumulative frequency per nautical mile for the overall distributions of gust and maneuver accelerations and of gust velocity are estimated to be reliable within ±20 percent.

Past experience has indicated that 1000 hours of VGH data constitute a representative sample of the operational experience of an individual airplane. For applicability to extended periods of operation approaching the lifetime of a fleet of airplanes, however, it is estimated that the counts of gust and maneuver accelerations and of gust velocity are reliable within a factor of 3 to 4. (See ref. 2.)

RESULTS AND DISCUSSION

Flight Environment

The histogram of flight duration in figure 1(a) shows that for operation A, the flight-duration range in which the largest number of flights was recorded was from 60 to 75 minutes and that flights extended to 795 minutes. The average duration was 238.2 minutes, as indicated in table I. For operation B, the flight-duration range in which the largest number of flights was recorded was from 210 to 225 minutes; the maximum duration was 765 minutes, and the average duration was 210.5 minutes. For operation C, the flight-duration range in which the largest number of flights was recorded was from 90 to 105 minutes; the maximum duration was 810 minutes, and the average duration was 353.9 minutes. The average flight duration of the four-engine piston-powered passenger transport airplanes used for comparison in this report was approximately 143 minutes.

Figure 1(b) shows that for operation A, the largest percent of total operational time was spent in the interval from 4.57 to 6.10 km (15 000 to 20 000 ft), and table I indicates that the average altitude for the operation was 5.39 km (17 700 ft). For both operations B and C, the largest percent of total operational time was spent in the interval from 3.05 to 4.57 km (10 000 to 15 000 ft), and the average altitudes were 3.41 km (11 200 ft) for operation B and 3.75 km (12 300 ft) for operation C.

Accelerations Due to Gusts

The frequency distributions of the combined (positive and negative) accelerations due to gusts are given in table III by flight condition and for the total samples for each airplane. The flight time, average true airspeed, and distance flown associated with each distribution are listed. The flight miles used throughout this report are nautical miles, computed by multiplying appropriate values of time in hours and average true airspeed in knots. In figure 3(a) the cumulative-frequency distributions of accelerations per nautical mile are presented for total samples for each operation. These distributions were formed by progressively summing the frequency distributions of table III, beginning with the largest acceleration and dividing each sum by the flight distance of the sample. The figure also presents the limits of gust-acceleration experience based on a number of four-engine piston-powered passenger transport airplanes, results for which are reported in reference 2. The cumulative frequencies of accelerations per nautical mile for a cargo airplane considered representative of the three operations are presented in figure 3(b) by flight condition.

The results presented in figure 3(a) show that the cumulative frequencies of gust accelerations per nautical mile of flight were similar for the three cargo operations. Also, there was good agreement in the gust-acceleration experience for the cargo airplanes and that for the piston-engine passenger airplanes. The grouping of the data from the cargo airplanes along the lower boundary of that for the passenger airplanes is probably a result of better weather radar developed in the intervening 15 years.

The frequency distributions of gust accelerations greater than ±0.2g given in table III show that for each of the cargo airplanes, the largest number of gust accelerations occurred during cruise and the least number occurred during climb. Figure 3(b) shows, however, that the cumulative frequencies of gust accelerations per nautical mile of flight were highest during descent. Frequency distributions of gust accelerations by flight condition are not available for piston-engine passenger airplanes. Results presented for turbojet transports in references 7 and 8 show that the highest counts of gusts also occurred in cruise but that higher cumulative frequencies of gusts per nautical mile were encountered in climb and descent about equally. Both the cargo airplanes and the turbojet transports flew the greatest percent of total distance in cruise and a larger percent of total distance in descent than in climb. The cargo airplanes flew a greater percent of distance in cruise than the turbojet transports. The number of accelerations experienced in each of the three flight conditions was such as to produce the results shown in figure 3(b).

Accelerations Experienced During Maneuvers

Operational maneuvers.- Frequency distributions of the positive and negative operational maneuver accelerations by flight condition and by total count are given in table IV(a) for each airplane. Cumulative-frequency distributions of operational maneuver accelerations per nautical mile for the total samples, as well as limits of operational maneuver experience for a number of piston-engine passenger transport airplanes (ref. 2), are given in figure 4(a). The cumulative frequencies of accelerations per nautical mile for a cargo airplane considered representative of the three operations are presented in figure 4(b) by flight condition.

The cumulative-frequency distributions of operational maneuver accelerations in figure 4(a) show similar characteristics for the three cargo airplanes. The results for cargo airplanes are also in good agreement with those for piston-engine passenger airplanes.

The counts of operational maneuver accelerations for each operation by flight condition in table IV show that for the turboprop airplane the largest number of accelerations occurred in cruise, and for the piston-engine airplanes the largest number occurred in descent. However, as shown in figure 4(b), which is typical of the three operations, the cumulative frequencies of operational maneuver accelerations per nautical mile were lower in cruise than in climb or descent. Results of operational maneuver experience by flight condition for piston-engine passenger airplanes are not available, but results for two typical turbojet transports are reported in references 7 and 8. For one transport, the counts of operational maneuver accelerations were fairly evenly distributed between climb, cruise, and descent, and for the other transport, a greater number of accelerations were recorded in descent than in climb or cruise. The cumulative-frequency distributions for both types, however, were similar. The operational maneuver experience of the cargo airplanes by flight condition in cumulative frequencies of accelerations per nautical mile was in good agreement with that of the turbojet transports.

Check-flight maneuvers.- Frequency distributions of positive and negative check-flight accelerations for each airplane are given in table IV(b). The time spent in check flights, the total operational and check-flight recording time, and the distance associated with each distribution are listed. The nautical miles associated with check flights were computed as the product of the average true airspeed for check flights and the check-flight hours added to the mileage for operational flights and therefore correspond to the total distance traveled during the recording period. The use of total distance for check-flight maneuvers makes these distributions more directly comparable with those for gust and operational maneuver accelerations.

Cumulative-frequency distributions of check-flight maneuver accelerations per nautical mile are presented in figure 5 as positive and negative accelerations for each of the three cargo airplanes, together with limits of positive and negative accelerations for a number of passenger airplanes. The check-flight maneuver acceleration experiences are reasonably similar for operations A and B. The results for operation C in figure 5 appear somewhat less severe, but they may have lower statistical reliability because of the small sample size. The results for the three airplanes, however, are in good agreement with the range of values from the passenger operations.

Turbulence

Time in rough air.- The percent of time in rough air in each 1.52-km (5000-ft) altitude interval is presented in figure 6 for the three operations and for estimated data from reference 12, which are based on results from a wide variety of aircraft. As indicated in the figure, the rough-air exposure recorded by the airplanes of operations A, B, and C was consistently lower than the estimate of reference 12.

Gust velocities.- Cumulative-frequency distributions of derived gust velocity per nautical mile of flight are presented in figure 7 for the three cargo operations, together with limits of gust-velocity distribution for a number of piston-engine passenger airplanes. The gust-velocity experience for the cargo operations shows reasonably good agreement with that for the passenger operations, although the cumulative frequencies for the turboprop cargo airplane are generally somewhat lower than the range established in passenger service. This trend results from the higher average cruise altitude of the turboprop airplane.

Operating airspeeds and altitudes.- A comparison of the overall average airspeeds within 1.52-km (5000-ft) altitude intervals with various airplane placard and recommended operational speeds is shown in figure 8. Information on operating airspeeds and altitudes of piston-engine passenger transports for comparison with the results from cargo airplanes is not available. The operating experience of the two piston-engine airplanes differed significantly from that of the turboprop airplane. The average airspeeds for operations B and C were only moderately above the maneuvering speed V_A and were well within the V_{NO} (or M_{NO}) speeds. The maximum airspeed values recorded for these operations did not exceed V_{NE} (or M_{NE}) and exceeded V_{NO} (or M_{NO}) in only a few instances. Since the airplane of operation A had average airspeeds approximately equal to V_{NO} at intermediate altitude levels, it is evident that the airplane was frequently operated above V_{NO}. A small number of exceedances of V_{NE} (or M_{NE}) were also recorded for this operation.

Accelerations Due to Landing Impacts

The probability of exceeding given values of incremental normal acceleration at landing impact is shown in figure 9 for each of the three cargo airplanes, as well as limits for a number of piston-engine passenger airplanes reported in reference 4. The results for the piston-engine airplanes of operations B and C were similar and were also in good agreement with those of the passenger airplanes. The figure indicates more severe experience for operation C at higher acceleration; however, these results represent only two landings. The results for the turboprop airplane of operation A are much more severe than those for the piston-engine airplanes over most of the acceleration range. The reason for this effect is not known; however, the results show trends similar to those reported in references 5 and 6.

CONCLUDING REMARKS

An analysis of VGH records collected on three four-engine cargo airplanes has provided information on incremental normal accelerations and turbulence experienced and on airspeed operating practices. The airplanes, one on each of three airlines, included one which was turboprop powered and two which had piston engines. Two of the airplanes were operated primarily in the continental United States and the other airplane was operated on trans-Pacific routes.

The gust-acceleration experiences and the operational maneuver experiences of the three cargo airplanes were similar and were in good agreement with results previously obtained from piston-engine airplanes in passenger service. The check-flight maneuver acceleration experiences were in good agreement with the range of values from the passenger airplanes. The distributions of derived gust velocities for the three operations showed generally good agreement, although the cumulative frequencies were somewhat lower for the turboprop airplane. The average airspeeds of the turboprop airplane were significantly closer than those of the piston-engine airplanes to their respective placard speeds. The landing-impact experience of the turboprop airplanes was much more severe than that of the piston-engine airplanes. All aspects of the results for which comparable information is available for a number of airplanes in passenger service indicated very good agreement between cargo- and passenger-airplane experiences.

Langley Research Center,
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Hampton, Va., May 1, 1972.

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TABLE I.- SCOPE OF DATA

Type of data	Operation		
	A	B	C
Total flight time, hr	1233.4	1039.0	726.9
Total distance flown, n. mi.	3.84×10^5	2.53×10^5	1.82×10^5
Recording period	Nov. 1964 to Apr. 1967	Jan. 1963 to Feb. 1966	Aug. 1962 to May 1963
Operational flights:			
Total operational samples:			
Flight time, hr	1179.1	1003.3	725.4
Number of flights	297	286	123
Average duration, min	238.2	210.5	353.9
Average altitude, km (ft)	5.39 (17 700)	3.41 (11 200)	3.75 (12 300)
Average indicated airspeed, knots	242	208	208
Average true airspeed, knots	317	246	251
Distance flown, n. mi.	3.74×10^5	2.47×10^5	1.82×10^5
Climb condition:			
Flight time, hr	98.4	81.6	37.6
Average indicated airspeed, knots	186	177	175
Average true airspeed, knots	219	195	194
Distance flown, n. mi.	2.15×10^4	1.59×10^4	0.73×10^4
Cruise condition:			
Flight time, hr	979.0	810.7	641.4
Average altitude, km (ft)	5.88 (19 300)	3.78 (12 400)	3.99 (13 100)
Average indicated airspeed, knots	251	211	210
Average true airspeed, knots	334	253	256
Distance flown, n. mi.	3.27×10^5	2.06×10^5	1.64×10^5
Descent condition:			
Flight time, hr	101.6	111.0	46.3
Average indicated airspeed, knots	216	211	205
Average true airspeed, knots	249	231	226
Distance flown, n. mi.	2.53×10^4	2.57×10^4	1.05×10^4
Check flights:			
Flight time, hr	54.3	35.7	1.5
Number	117	49	4
Percent total time	4.04	3.43	0.21

TABLE II.- AIRPLANE CHARACTERISTICS

Characteristic	Operation A	Operations B and C
Span, m (ft)	43.36 (142.25)	38.86 (127.5)
Aspect ratio	9.76	9.93
Mean aerodynamic chord, m (ft)	4.45 (14.59)	3.91 (12.83)
Wing area, m^2 (ft^2)	192.8 (2075)	152.1 (1637)
Maximum take-off weight, N (lb)	934 126 (210 000)	636 095 (143 000)
Maximum landing weight, N (lb)	733 956 (165 000)	493 752 (111 000)
Wing loading based on maximum take-off weight, N/m^2 (lb/ft^2)	4845 (101.2)	4180 (87.3)
Wing sweep (nominal), deg	0	0

TABLE III.- FREQUENCY DISTRIBUTIONS OF INCREMENTAL GUST ACCELERATIONS BY FLIGHT CONDITIONS

Normal acceleration (positive and negative), a_n, g units	Frequency of occurrence for –									Total frequency of occurrence		
	Climb			Cruise			Descent					
	Airplane A	Airplane B	Airplane C	Airplane A	Airplane B	Airplane C	Airplane A	Airplane B	Airplane C	Airplane A	Airplane B	Airplane C
0.2 to 0.3	83	142	53	1022	1009	831	312	694	364	1417	1845	1248
0.3 to 0.4	15	28	4	245	253	228	59	206	62	319	487	294
0.4 to 0.5	2	4		40	76	55	9	41	15	51	121	70
0.5 to 0.6	1			12	30	10	1	5	7	14	35	17
0.6 to 0.7	3			6	8	3	2	2		11	10	3
0.7 to 0.8				2	2	2		1		2	3	2
0.8 to 0.9					2						2	
Total	104	174	57	1327	1380	1129	383	949	448	1814	2503	1634
Flight time, hr	98.4	81.6	37.6	979.0	810.7	641.4	101.6	111.0	46.3	1179.1	1003.3	725.4
Average true airspeed, knots . .	219.1	194.6	193.7	333.7	253.5	255.9	249.3	231.3	226.5	316.9	246.2	250.8
Distance flown, n. mi.	2.16×10^4	1.59×10^4	0.73×10^4	3.27×10^5	2.06×10^5	1.64×10^5	2.53×10^4	2.57×10^4	1.05×10^4	3.74×10^5	2.47×10^5	1.82×10^5

TABLE IV.- FREQUENCY DISTRIBUTIONS OF MANEUVER ACCELERATIONS

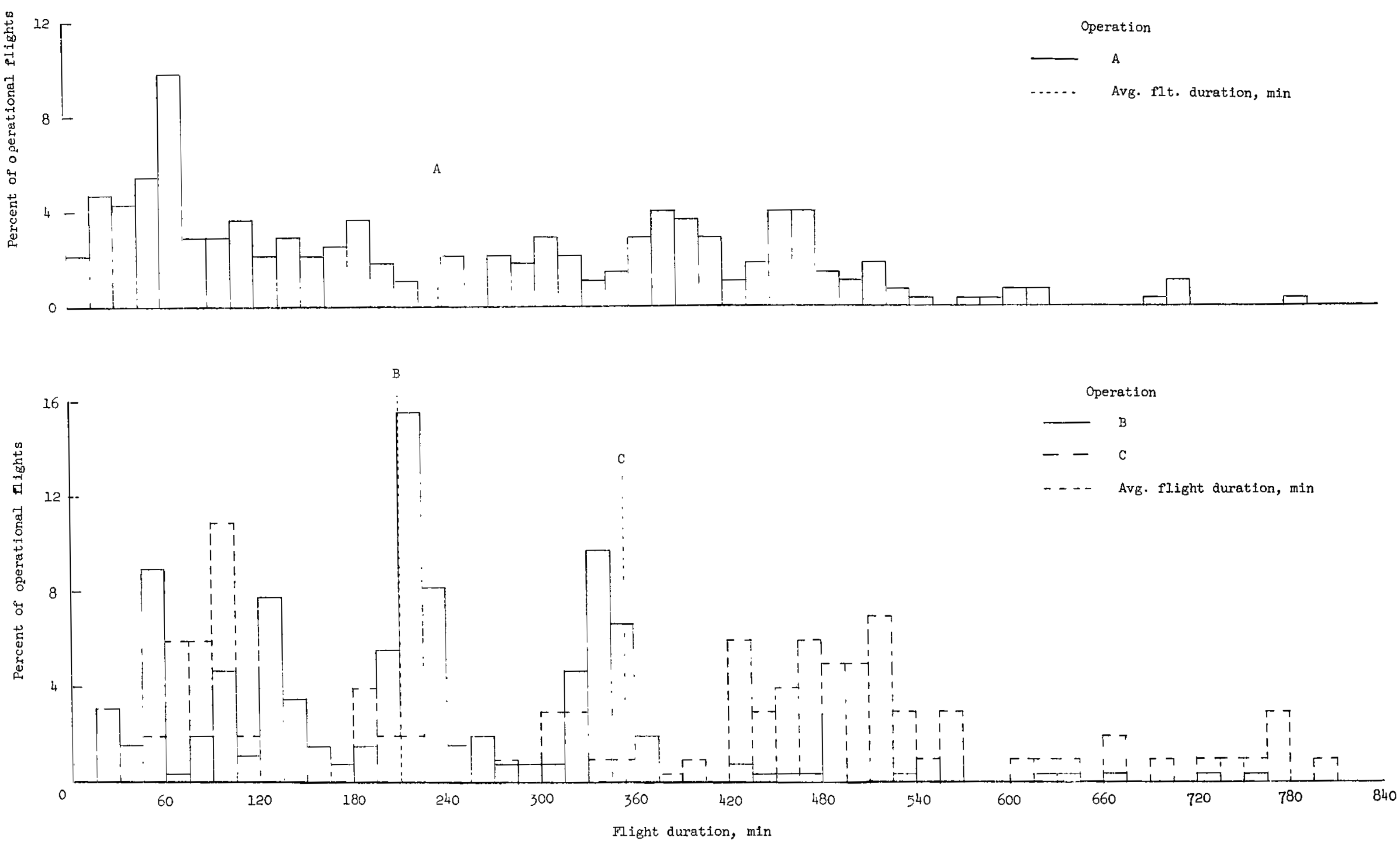
(a) Operational maneuver accelerations by flight conditions

Normal acceleration, a_n, g units	Frequency of occurrence for –									Total frequency of occurrence		
	Climb			Cruise			Descent					
	Airplane A	Airplane B	Airplane C	Airplane A	Airplane B	Airplane C	Airplane A	Airplane B	Airplane C	Airplane A	Airplane B	Airplane C
-0.5 to -0.6	1									1		
-0.4 to -0.5	1		1	5	1		1	2		7	3	1
-0.3 to -0.4	15	1	1	35	5	1	19	26	3	69	32	5
-0.2 to -0.3	124	26	13	252	44	18	177	114	59	553	184	90
Negative total	141	27	15	292	50	19	197	142	62	630	219	96
0.2 to 0.3	210	86	40	316	59	60	322	265	135	848	410	235
0.3 to 0.4	45	10	4	72	14	8	82	39	28	199	63	40
0.4 to 0.5	4	1		13		2	21	8	12	38	9	14
0.5 to 0.6	2	1		4			5	1	1	11	2	1
0.6 to 0.7				1			3		1	4		1
Positive total	261	98	44	406	73	70	433	313	177	1100	484	291
Total pos. and neg.	402	125	59	698	123	89	630	455	239	1730	703	387
Flight time, hr	98.4	81.6	37.6	979.0	810.7	641.4	101.6	111.0	46.3	1179.1	1003.3	725.4
Average true airspeed, knots . .	219.1	194.6	193.7	333.7	253.5	255.9	249.3	231.3	226.5	316.9	246.2	250.8
Distance flown, n. mi.	2.16×10^4	1.59×10^4	0.73×10^4	3.27×10^5	2.06×10^5	1.64×10^5	2.53×10^4	2.57×10^4	1.05×10^4	3.74×10^5	2.47×10^5	1.82×10^5

TABLE IV.- FREQUENCY DISTRIBUTIONS OF MANEUVER ACCELERATIONS – Concluded

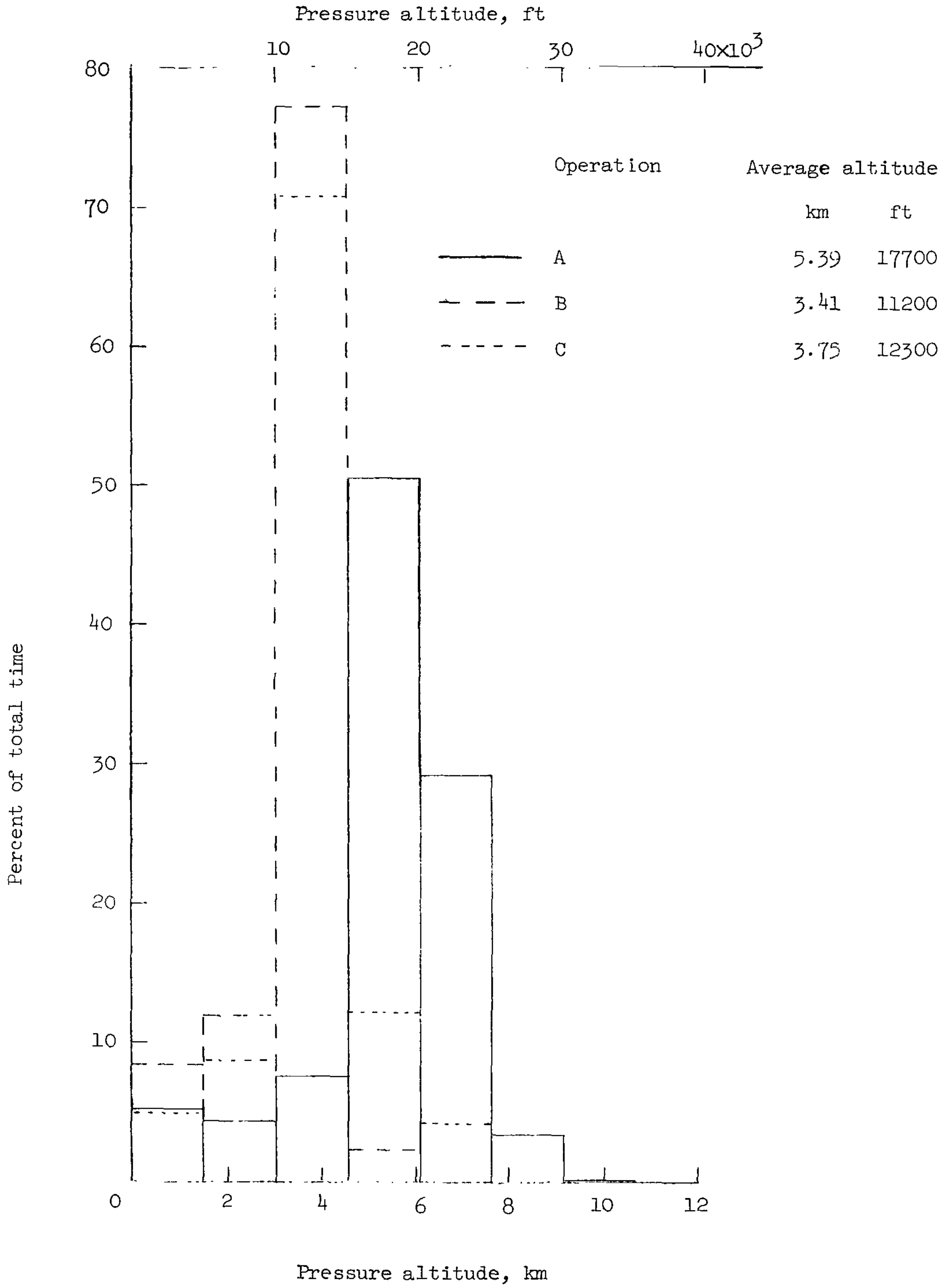
(b) Check-flight maneuver accelerations

Normal acceleration, a_n, g units	Frequency of occurrence for –		
	Airplane A	Airplane B	Airplane C
-0.6 to -0.7	2		
-0.5 to -0.6	4	4	
-0.4 to -0.5	28	7	
-0.3 to -0.4	148	33	3
-0.2 to -0.3	537	162	17
Negative total	719	206	20
0.2 to 0.3	971	395	33
0.3 to 0.4	315	132	10
0.4 to 0.5	103	67	1
0.5 to 0.6	61	28	1
0.6 to 0.7	40	8	1
0.7 to 0.8	23	4	1
0.8 to 0.9	11	1	
0.9 to 1.0	6	1	
1.0 to 1.1	1	1	
1.1 to 1.2			
1.2 to 1.3			
1.3 to 1.4	1		
Positive total	1532	637	47
Total pos. and neg.	2251	843	67
Check-flight time, hr	54.3	35.7	1.5
Total flight time, hr	1233.4	1039.0	726.9
Total distance flown, n. mi.	3.84×10^5	2.53×10^5	1.82×10^5



(a) Histogram of flight duration.

Figure 1.- Description of operation.



(b) Histogram of altitude.

Figure 1.- Concluded.

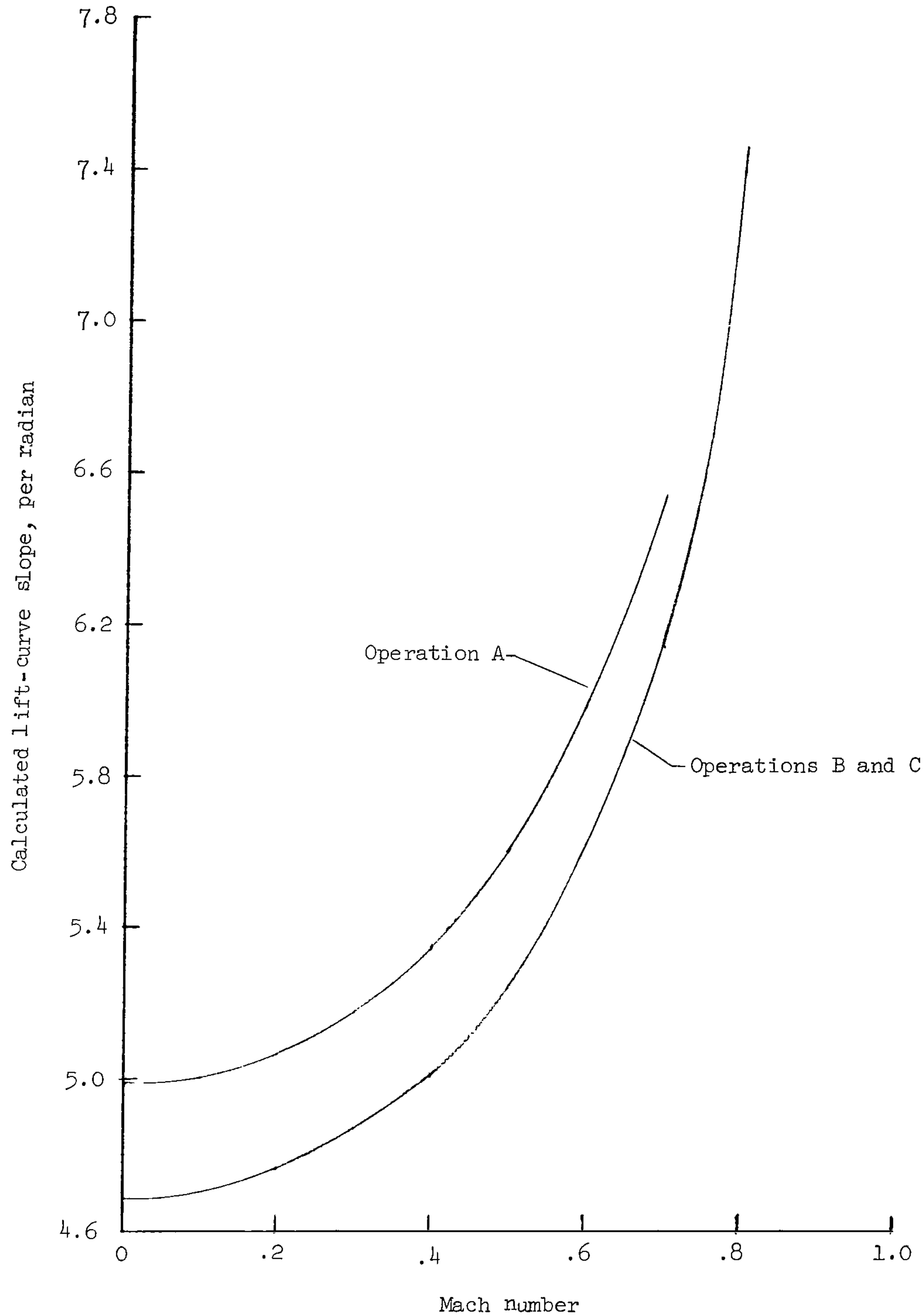
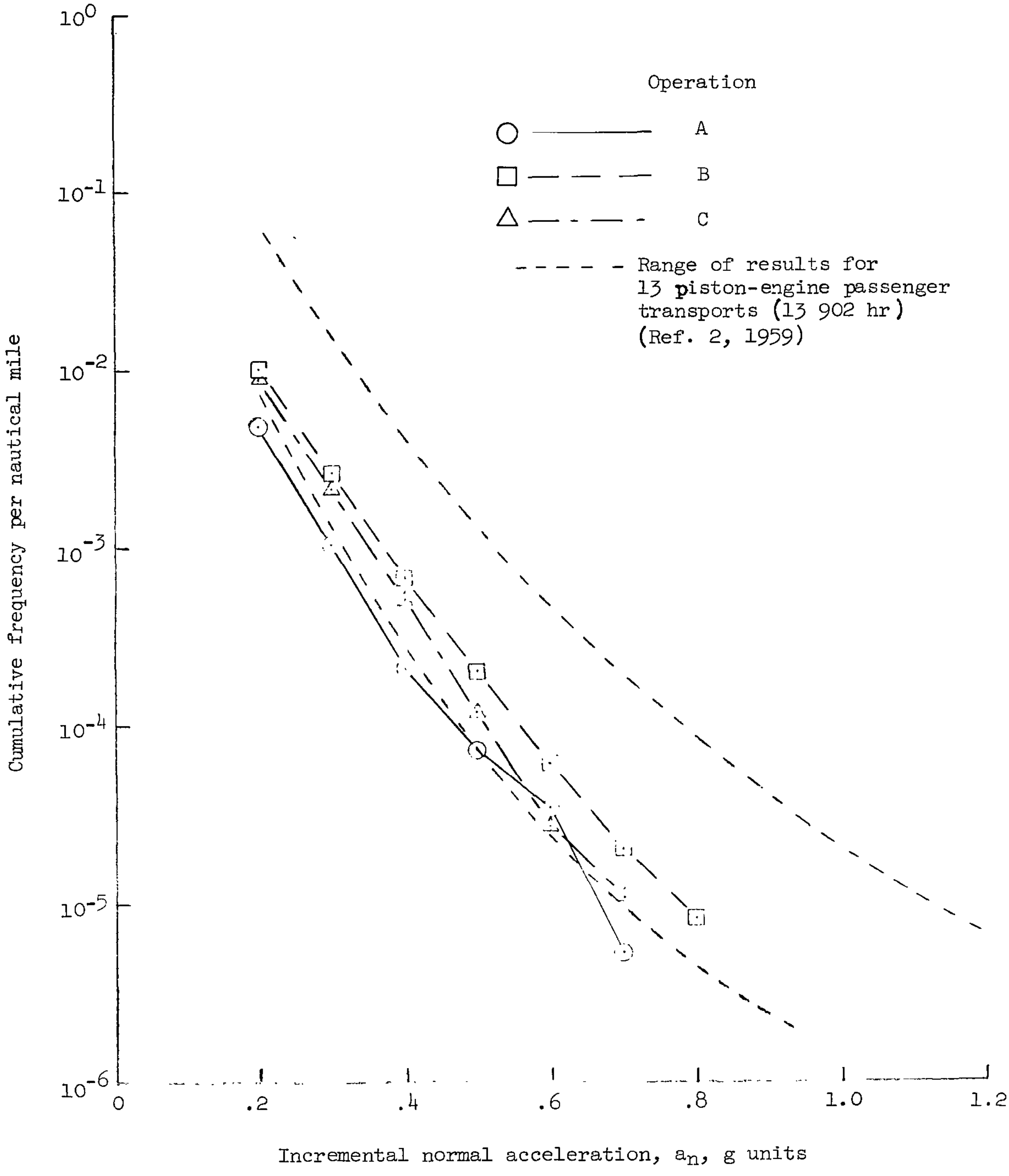
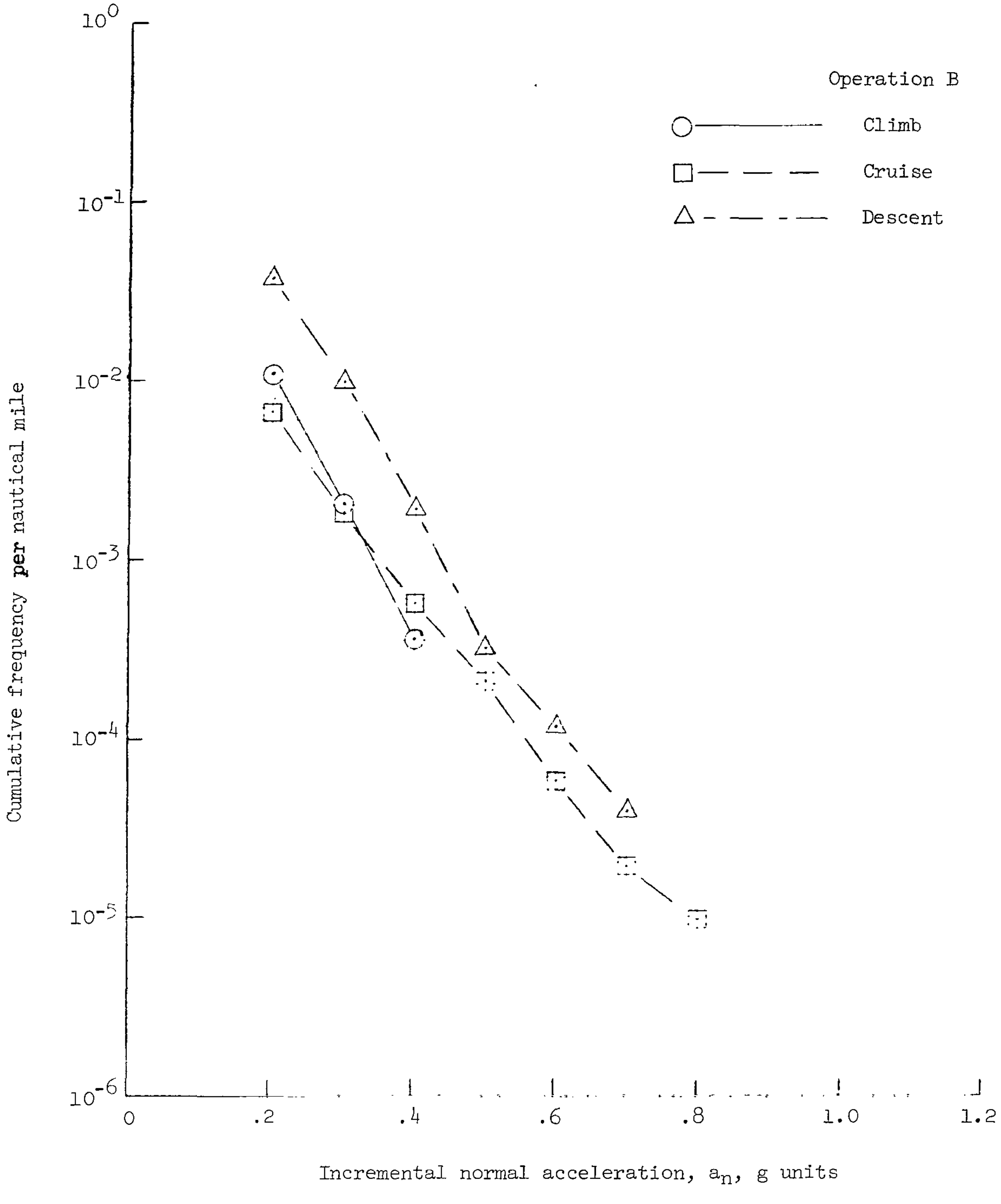


Figure 2.- Computed lift-curve slope with Mach number.



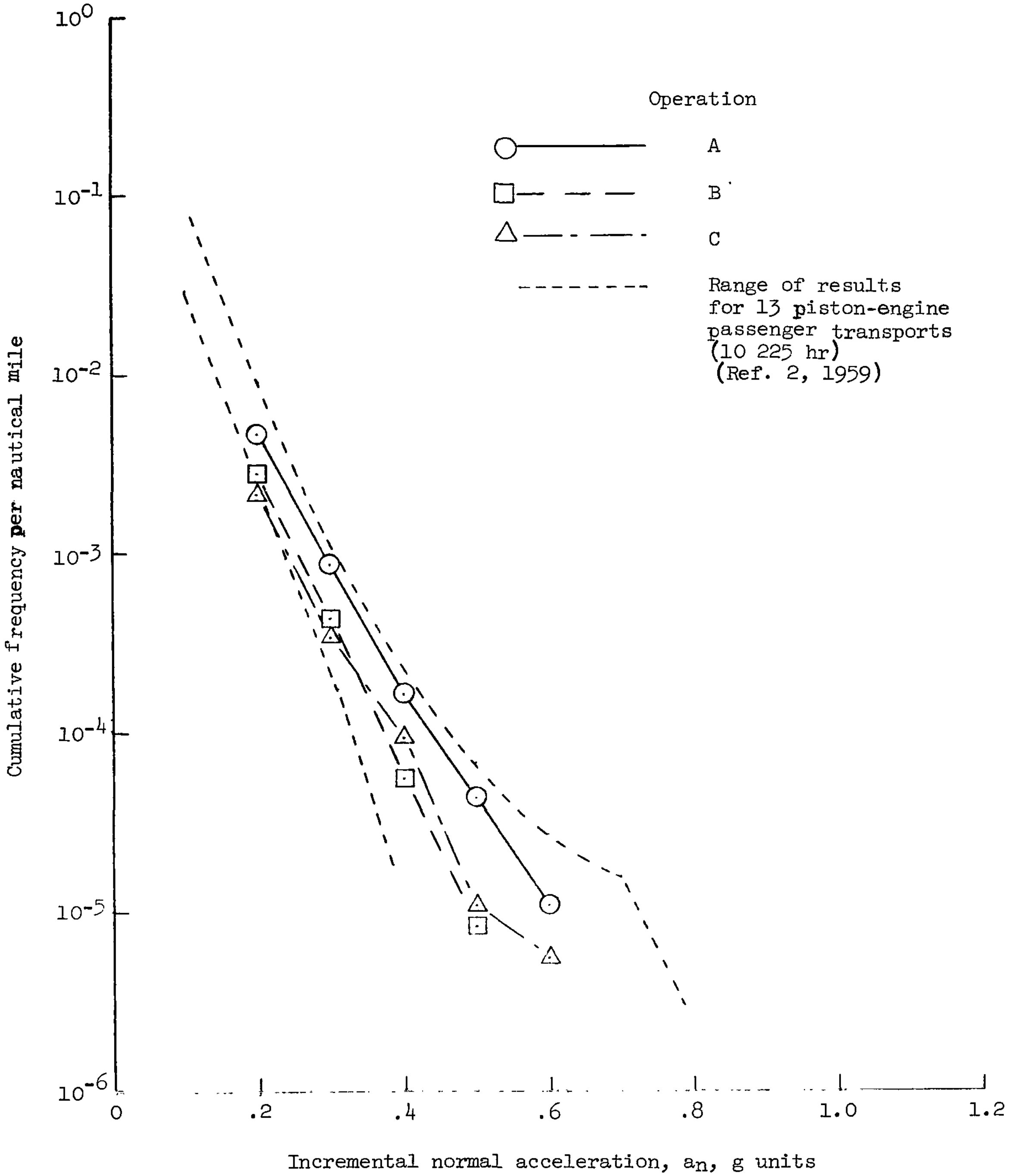
(a) Comparison of cargo operations and piston-engine passenger transports.

Figure 3.- Cumulative-frequency distributions of incremental gust accelerations per nautical mile.



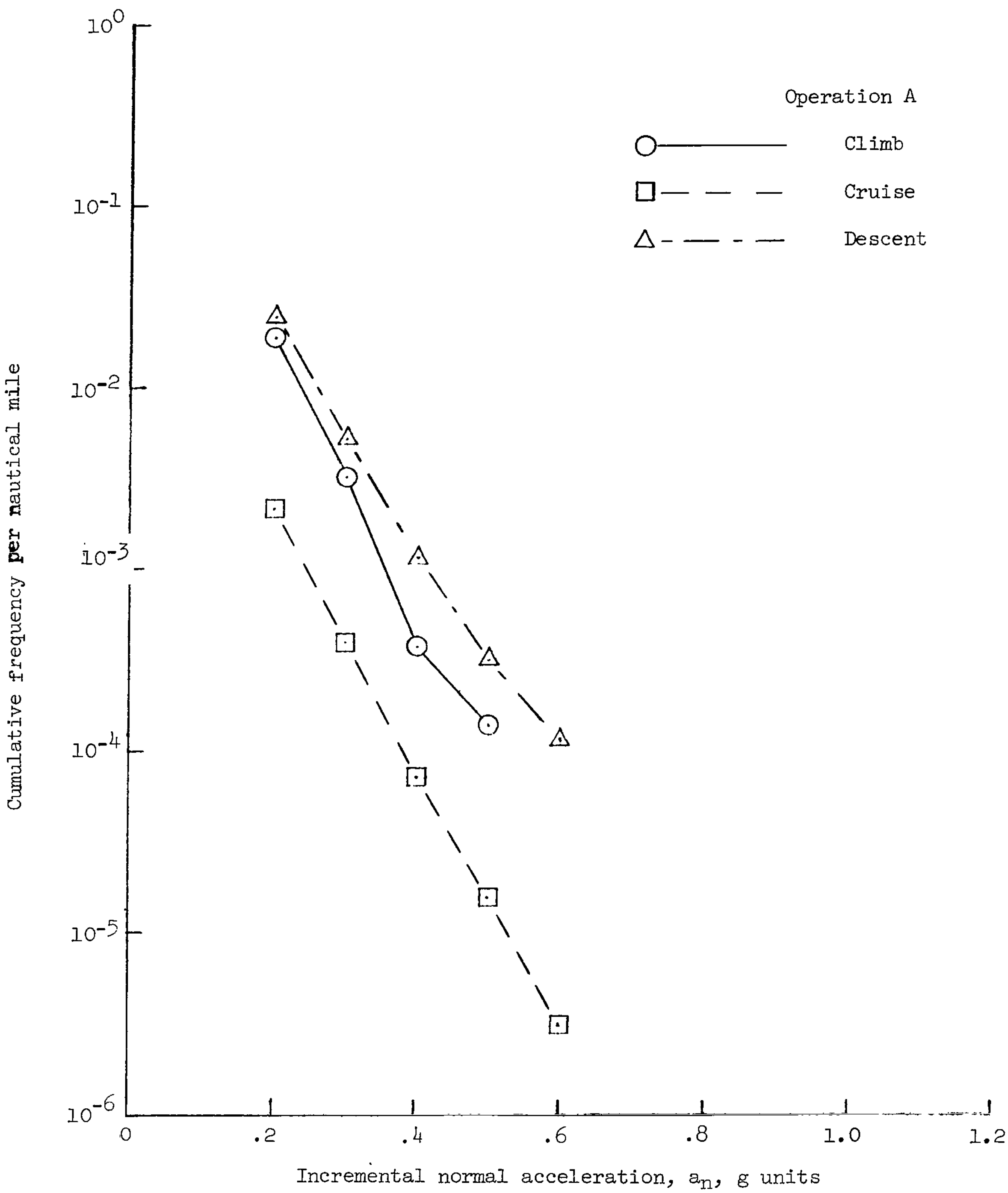
(b) Typical cargo operation by flight condition.

Figure 3.- Concluded.



(a) Comparison of cargo operations and piston-engine passenger transports.

Figure 4.- Cumulative-frequency distributions of operational maneuver accelerations per nautical mile.



(b) Typical cargo operation by flight condition.

Figure 4.- Concluded.

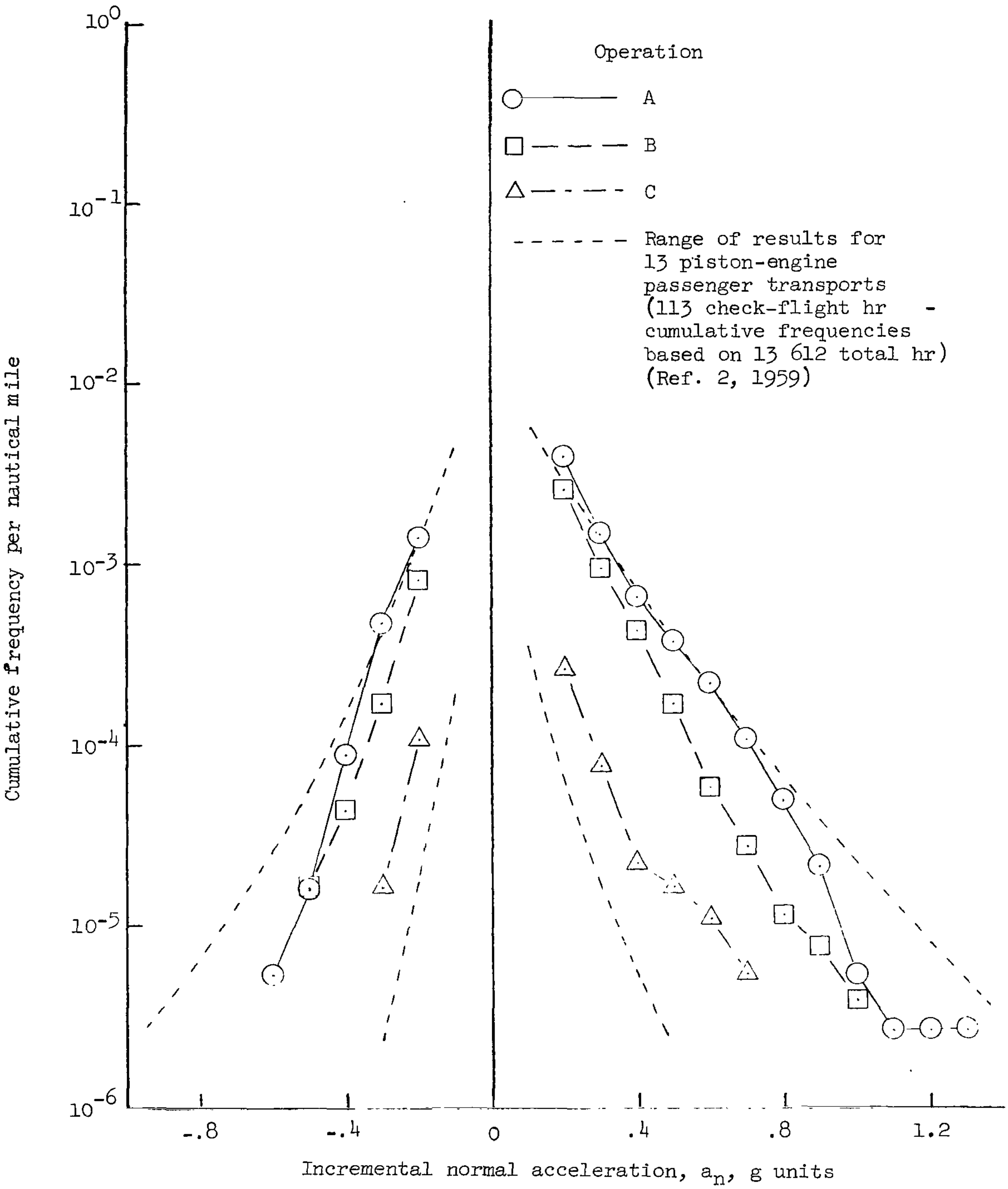


Figure 5.- Comparison of cumulative-frequency distributions of positive and negative check-flight maneuver accelerations per nautical mile for cargo operations and piston-engine passenger transports.

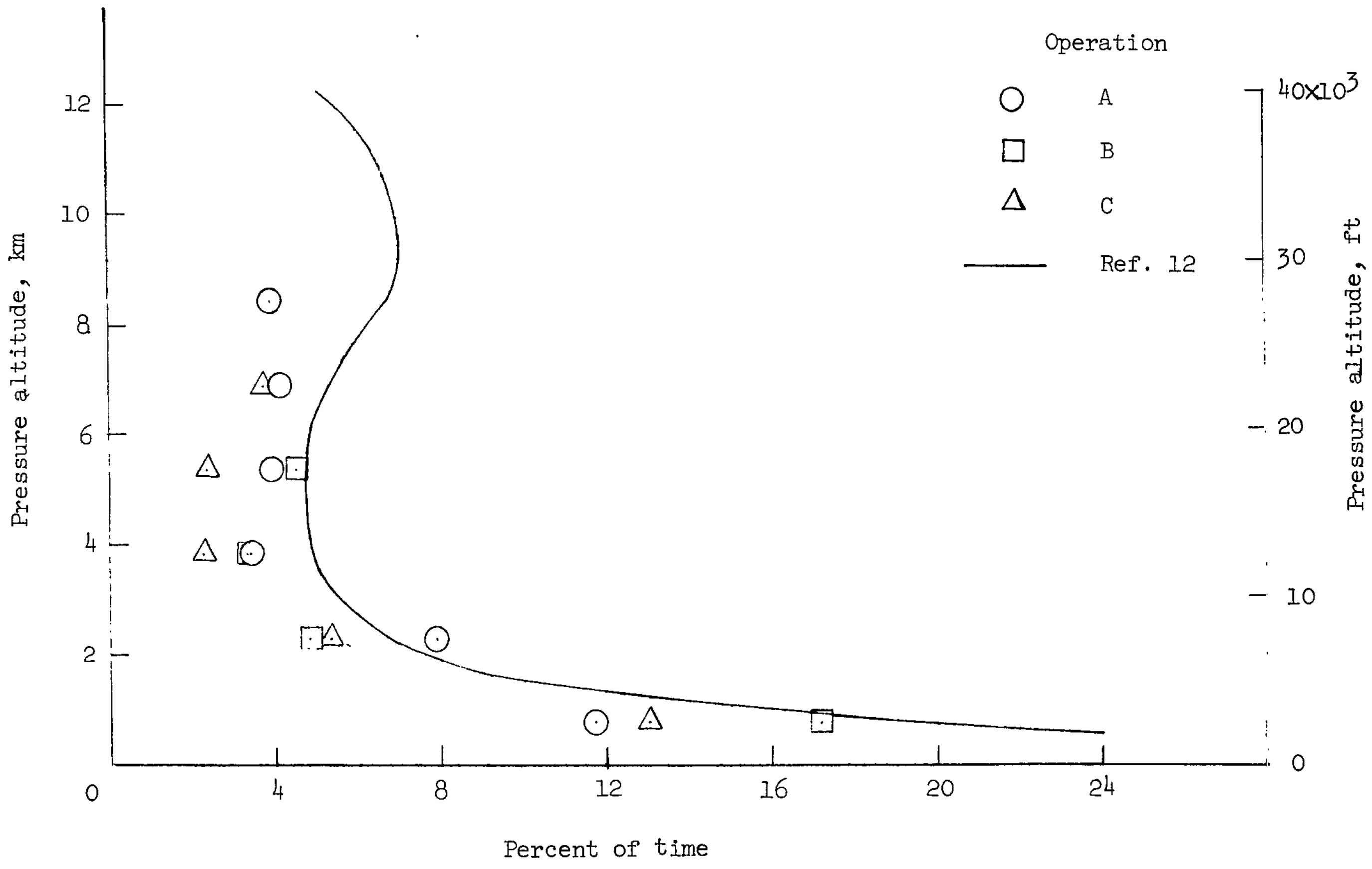


Figure 6.- Percent of time in rough air in each 1.52-km (5000-ft) altitude interval.

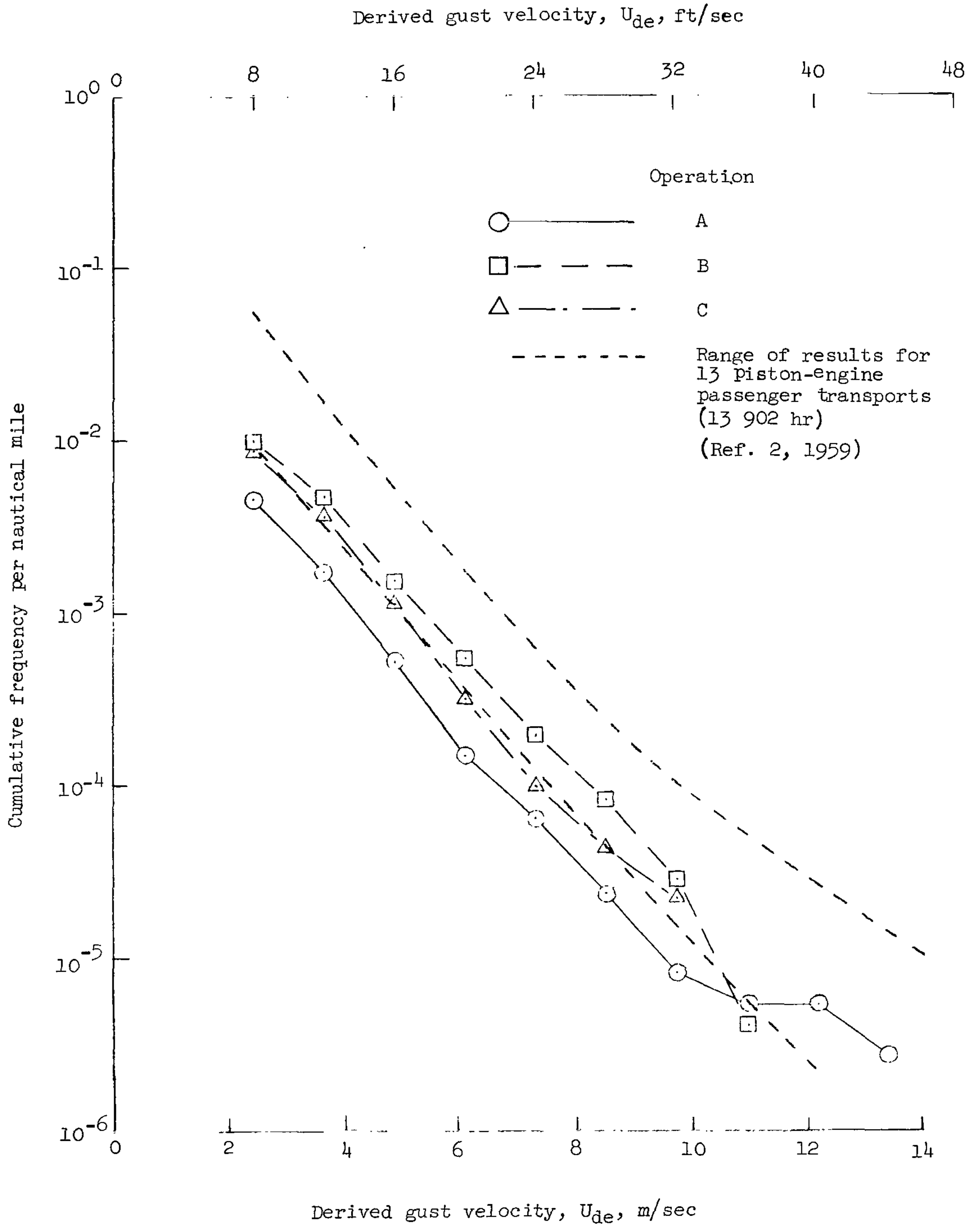


Figure 7.- Comparison of cumulative-frequency distributions of derived gust velocity per nautical mile for cargo operations and piston-engine transports.

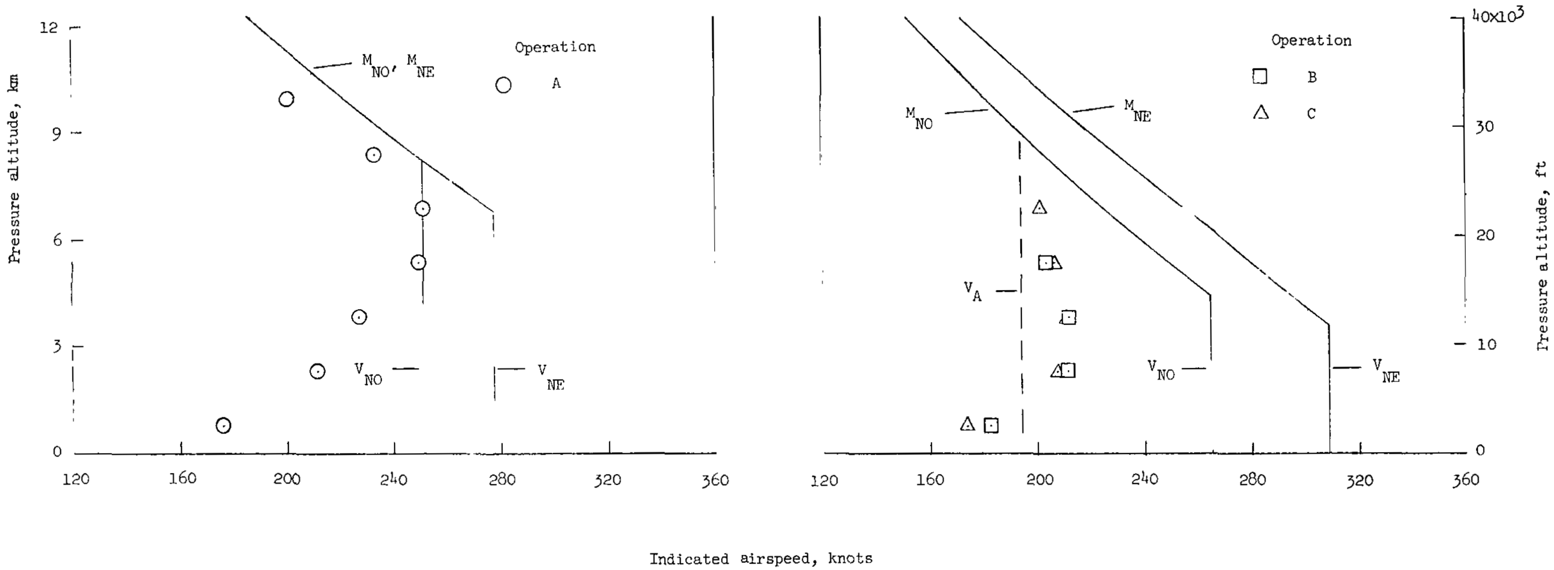


Figure 8.- Average indicated airspeeds in 1.52-km (5000-ft) altitude intervals.

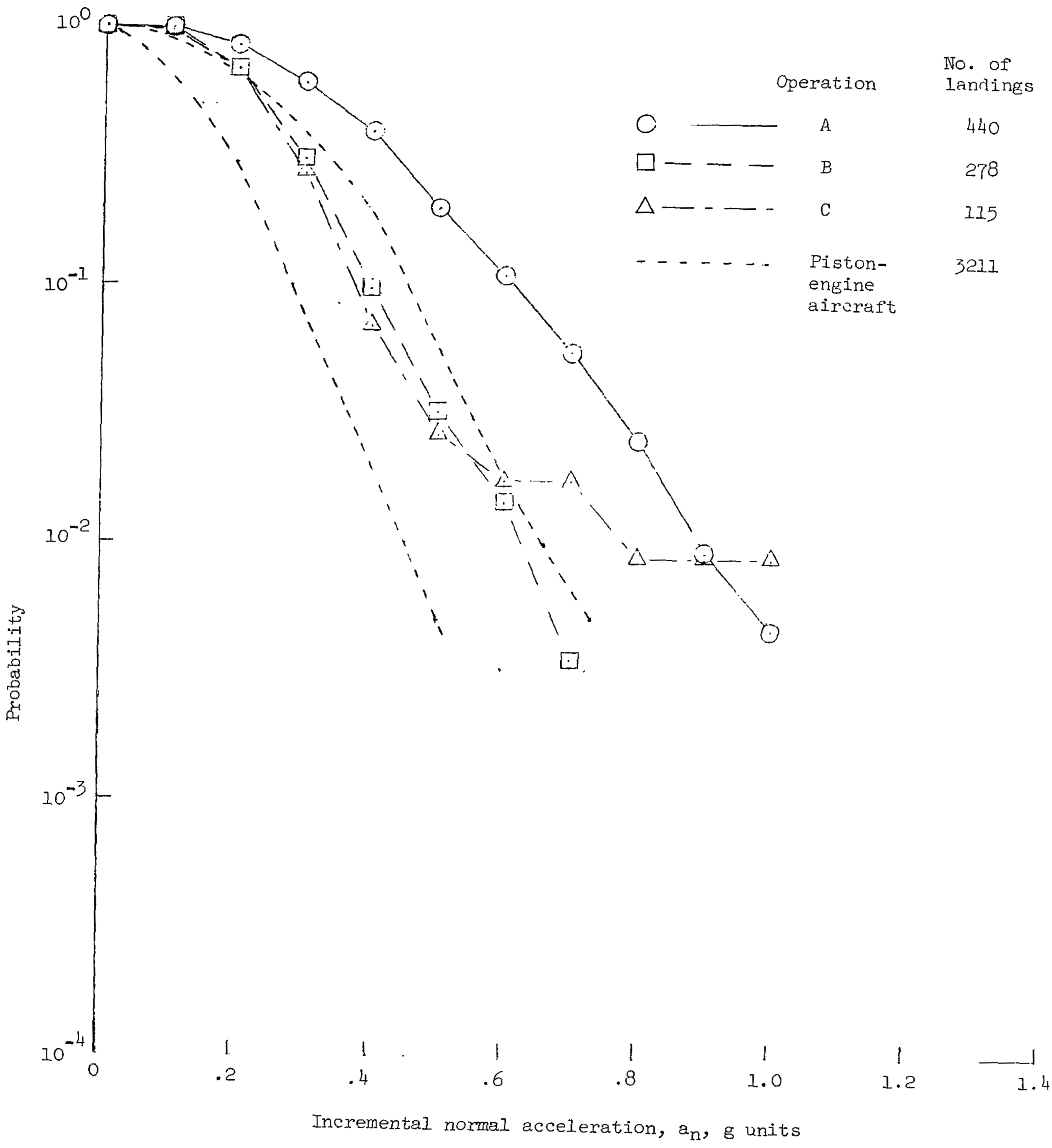


Figure 9.- Probability of exceeding given amplitudes of landing-impact accelerations.

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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