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SUMMARY

A VGH data sample collected on two identical twin-engine turbojet airplanes during routine airline operations has been analyzed to determine the operational experiences of the airplanes. The results indicate that the gust and maneuver accelerations are comparable to corresponding results for turboprop airplanes. Accelerations due to oscillatory motions were of low amplitude, were experienced infrequently, and are considered insignificant in regard to the total airplane acceleration experience. The results indicate that the gust velocity experience for the twin-engine jet airplane is significantly lower than the experience for two types of turboprop airplanes and is comparable to that for a four-engine turbojet transport. Placard-speed exceedances were relatively infrequent and were generally less than 6 knots beyond the overspeed warning bell. The results indicate that, in general, airspeed reduction was practiced during the more severe turbulence. The landing-impact accelerations, which were quite severe during the initial airplane operation, were reduced to a level comparable to that of several other two- and three-engine jet transports after a modification of the landing gear.

INTRODUCTION

As a continuation of the long-standing NACA and NASA practice of analyzing operational experiences and practices of commercial transport airplanes (ref. 1), a sample of VGH (airspeed, normal acceleration, and altitude) time-history records has been collected on one type of twin-engine jet transport airplane. In the past, such VGH data have proved useful for comparison of the operational experiences of the airplanes with the concepts to which they were designed, for detection of new or unanticipated aspects of the operations, and as background information for application to the design of new airplanes. This paper summarizes the data reduced from the records and describes the airspeed and altitude operating practices; the gust, maneuver, and oscillatory acceleration experience; and the rough-air environment. The operational experiences for the twin-engine jet transport airplane are compared with results obtained for other types of transport airplanes.

SYMBOLS

Measurements for this investigation are given in both U.S. Customary Units and the International System of Units (SI). Factors relating the two systems are given in reference 2.

a_n	incremental normal acceleration, g units
c	mean geometric wing chord, ft (meters)
K_g	gust factor, $\frac{0.88\,\mu_g}{5.3 + \mu_g}$
m	lift-curve slope, per radian
S	wing area, ft^2 ($meters^2$)
U_{de}	derived gust velocity, ft/sec (meters/second)
V_e	equivalent airspeed, ft/sec (meters/second)
M_C	Mach number equivalent to design cruising speed
W	airplane weight, lb (newtons)
ρ	air density, $slugs/ft^3$ ($kilograms/meter^3$)
ρ_o	air density at sea level, $slugs/ft^3$ ($kilograms/meter^3$)
μ_g	airplane mass ratio, $\frac{2W}{m\rho cgS}$
g	acceleration due to gravity, 32.2 ft/sec^2 (9.81 $meters/second^2$)
$\overline{V}$	average speed, knots
V_A	design maneuvering speed, knots
V_C	design cruising speed, knots
V_D	design diving speed, knots

V_{MO} maximum operating limit speed, knots

M_D Mach number equivalent to design diving speed

M_{MO} Mach number equivalent to maximum operating limit speed

INSTRUMENTATION AND AIRPLANE

The data were obtained from NASA VGH recorders which are described in reference 3. Since reference 3 was published, several improvements have been made in the VGH recorder. One of these improvements is a change in the galvanometer which results in a combined accelerometer and galvanometer response that is flat (within ±1 percent) to beyond 10 cps. The VGH recorder produces a time-history record of indicated airspeed, pressure altitude, and normal acceleration.

The film transport speed was 0.008 inch (0.020 cm) per second. The acceleration transmitter was mounted on the keel beam in the wheel well, approximately 4 feet (1.22 m) from the usual center of gravity of the airplane, and the recorder base was installed in a compartment immediately behind the pilot. Pressures for the airspeed and altitude recordings were obtained from the copilot's pitot line and an auxiliary dual static line.

Some of the characteristics of the airplane that are pertinent to the evaluation of the data are:

Maximum design take-off weight	76 500 lb (340 289 newtons)
Wing area	980 ft^2 (91.0 meters^2)
Wing sweep	20° at quarter-chord line
Aspect ratio	8
Span	88.5 ft (26.98 meters)
Mean geometric chord	11.08 ft (3.38 meters)

The structural design speeds and the operational placard speeds are shown in figure 1.

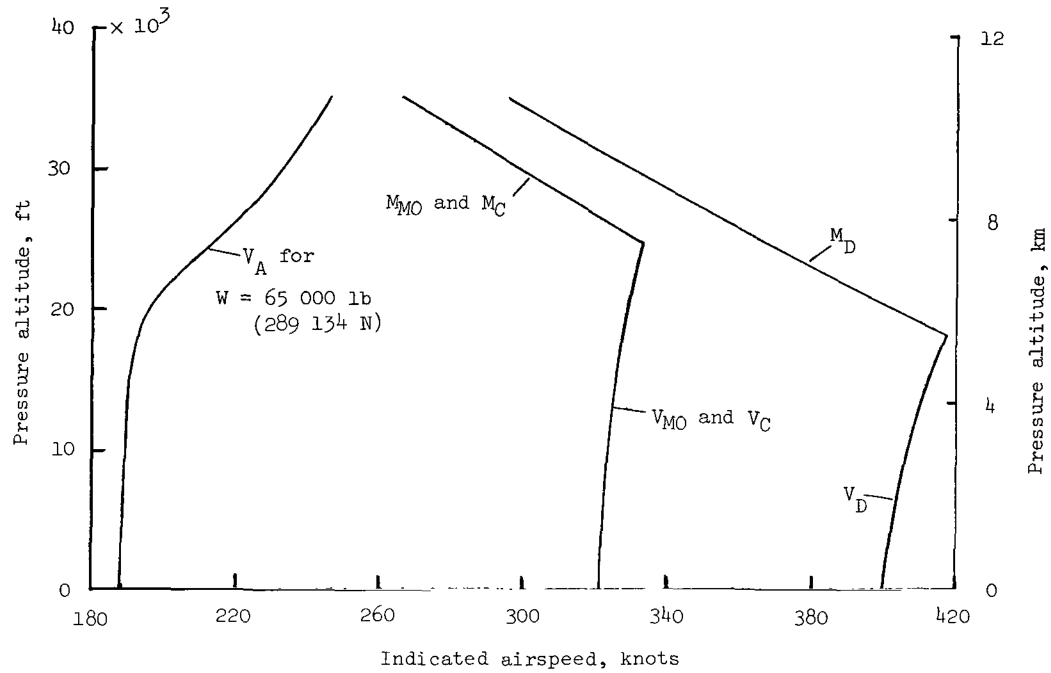

Figure 1.- Structural design speeds and maximum operational limit speed.

SCOPE OF DATA

The VGH data were collected on two airplanes operated on domestic routes by one U.S. airline between April 1965 and August 1966. The routes primarily covered the central area of the continental United States from the southern to the northern border. In addition, some landing-impact acceleration data were collected between September 1966 and April 1967 on one of the two airplanes. The distribution of the VGH record hours by year and month is given in figure 2.

The VGH data samples from each of the two airplanes and the total data sample are summarized in table I in terms of the total number of flight hours and flights available for evaluation. The total data sample covered 1846 hours of operational flights and 108 hours of airplane and pilot check flights. These flight hours represent 2573 operational flights and 156 check flights. Inasmuch as the total record sample was not required to give reliable results for certain phases of the analysis, the results presented were not in all cases based on the total sample size available. Therefore, in order to indicate the actual sample sizes used, table I gives the number of flight hours or number of flights from which the results were obtained.

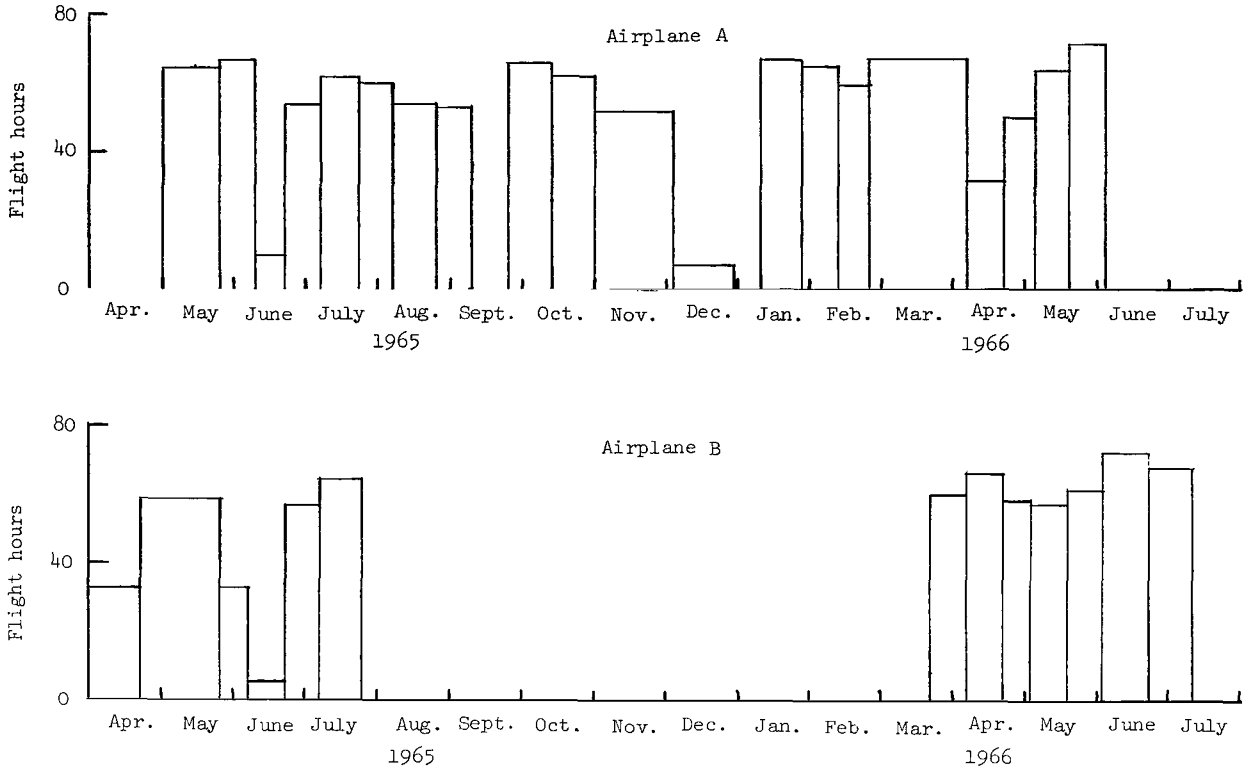

Figure 2.- Histograms of flight hours in VGH samples.

TABLE I.- SIZE OF VGH DATA SAMPLE

Data sample	Airplane A	Airplane B	Total
Total operational flight hours available	1156	690	1846
Total check-flight hours available	62	46	108
Total number of operational flights available	1655	918	2573
Total number of check-flights available	100	56	156
Flight hours evaluated for:			
Gust accelerations $\geqq \pm 0.2g$	1156	---	1156
Gust accelerations $\geqq \pm 0.5g$	1156	690	1846
Operational maneuvers $\geqq \pm 0.2g$	1156	---	1156
Operational maneuvers $\geqq \pm 0.5g$	1156	690	1846
Check-flight maneuvers $\geqq \pm 0.2g$	1218	---	1218
Check-flight maneuvers $\geqq \pm 0.5g$	1218	736	1954
Airspeed and altitude distributions	626	---	626
Placard speed exceedances	913	---	913
Flights evaluated for landing-impact accelerations:			
Initial sample	494	379	873
Sample after modification	281	762	1043

EVALUATION OF RECORDS

General

The VGH records were evaluated to obtain information on the gust, maneuver, and landing-impact accelerations; airspeed operating practices; and operational altitudes. Each flight on the records was classified as either a routine passenger-carrying operational flight or a check flight.

The operational flights were divided into three conditions: climb, cruise, and descent. The climb condition covered the time from take-off until the airplane began to maintain level flight consistently; the cruise covered the portion of the flight at essentially constant altitude; and the descent covered the portion of flight from the end of cruise until the airplane landed. Both the climb and descent flight conditions occasionally included short periods when the airplane was in level flight while holding as a result of operational or air traffic control procedures. Also, the cruise condition occasionally included periods when the airplane was climbing or descending to a different cruise altitude.

Accelerations

On the basis of the criteria described in reference 4, the accelerations of each operational flight were classed as results of either gusts or maneuvers. The peak values of each gust acceleration increment and each maneuver acceleration which equaled or exceeded selected threshold values were read by using the 1g position of the acceleration trace as the reference. In the event that gust accelerations were superimposed on a maneuver acceleration, the maneuver acceleration was used as the reference. As noted in table I, the threshold values used for all accelerations were ±0.2g for airplane A and ±0.5g for airplane B. For each acceleration value, the corresponding airspeed and altitude were also evaluated.

The initial landing-impact accelerations experienced during operational and check flights were read and tabulated in 0.1g class intervals. These accelerations were identified on the records by the impulse-like characteristics of the trace at the instant of landing impact. Two samples, covering two different time periods, were read. The second sample was read to determine the effect on the landing-impact accelerations of a modification which had been made to the landing gear. Details of the modification are given in the section entitled "Results and Discussion."

Airspeeds and Altitudes

Distributions of airspeed and altitude for the operational flights of airplane A were obtained by reading the indicated airspeed and pressure altitude for each minute of flight.

The airspeed data were sorted according to whether the airplane was in rough or smooth air. The airplane was assumed to be in rough air during the traverse of any continuous turbulent area which produced at least one acceleration corresponding to a derived gust velocity of about ±2 ft/sec (0.6 m/sec) or higher. This procedure is consistent with that followed in past analyses of NASA VGH-type data (ref. 5, for example).

In addition to the evaluation of airspeeds at 1-minute intervals, a more detailed evaluation was made of the occurrence of speeds in excess of the placard speeds. This evaluation consisted of determining the maximum speed and the altitude associated with each exceedance of the placard speed V_{MO} or M_{MO}. (See fig. 1.)

Gust Velocities

Gust accelerations and the corresponding altitudes and airspeeds were used to calculate gust velocities by means of the derived-gust-velocity equation described in reference 6:

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

where

U_{de}	derived gust velocity, ft/sec (meters/second)
W	airplane weight, lb (newtons)
a_n	nondimensional normal acceleration increment, g units
K_g	gust factor
ρ_o	air density at sea level, slugs/ft^3 (kilograms/meter^3)
V_e	equivalent airspeed, ft/sec (meters/second)
m	lift-curve slope, per radian
S	wing area, ft^2 (meters^2)

The gust factor K_g is a function of the mass ratio μ_g of the airplane, and therefore varies with altitude and lift-curve slope. Average values of K_g were computed for the midpoint of each 10 000-foot (3.05-km) altitude increment and each 0.1 increment in Mach number. An average operating weight of 61 780 pounds (274 811 N) was used in calculating the gust velocities. Estimates have shown that usual weight variations for this airplane would not cause appreciable errors in gust-velocity values. The variation of the lift-curve slope with Mach number (fig. 3) was calculated from the equation given in section IV of reference 1, which takes into account aspect ratio, Mach number, and sweep.

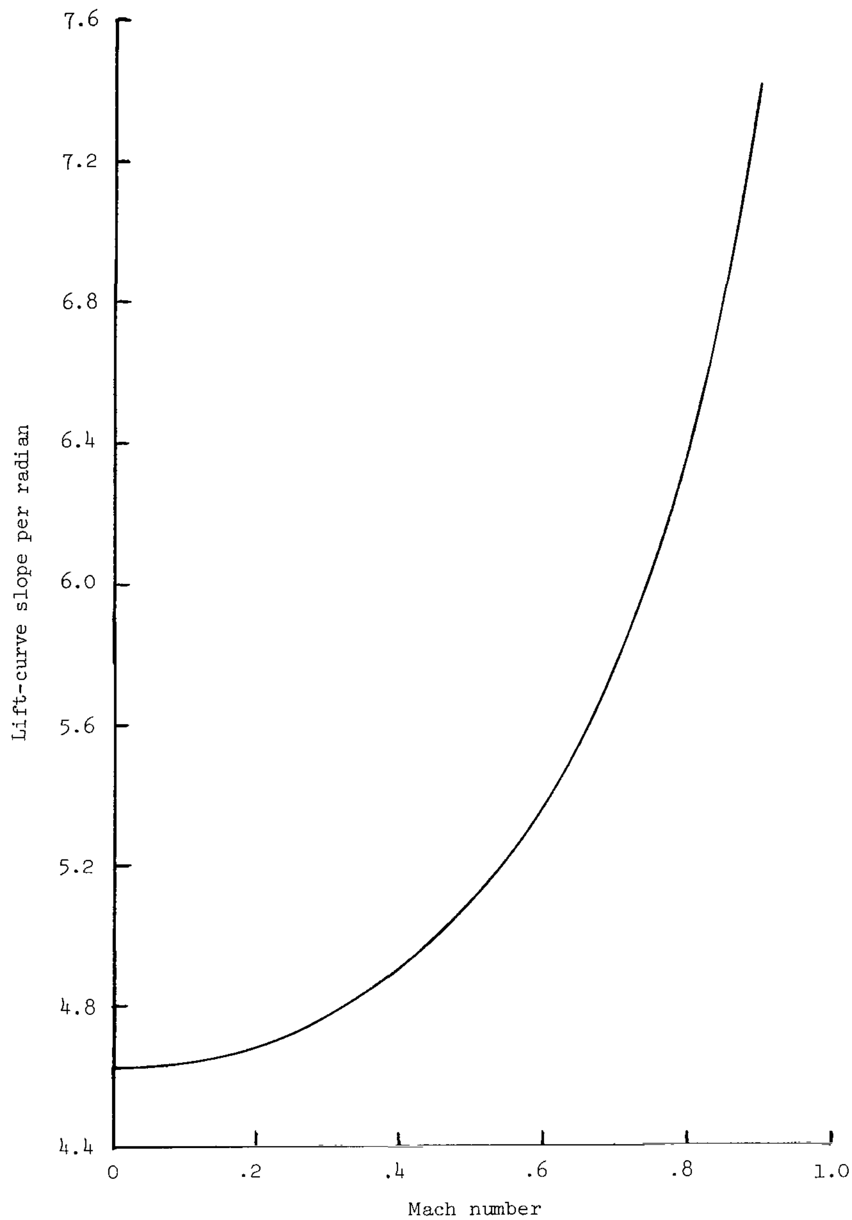

Figure 3.- Variation of computed lift-curve slope with Mach number.

RESULTS AND DISCUSSION

Description of Operations

The distribution of flight times for the operational flights is shown in figure 4. The flights did not exceed 180 minutes and most of the flights were between 15 minutes and 45 minutes long. The average duration of operational flights was 43 minutes.

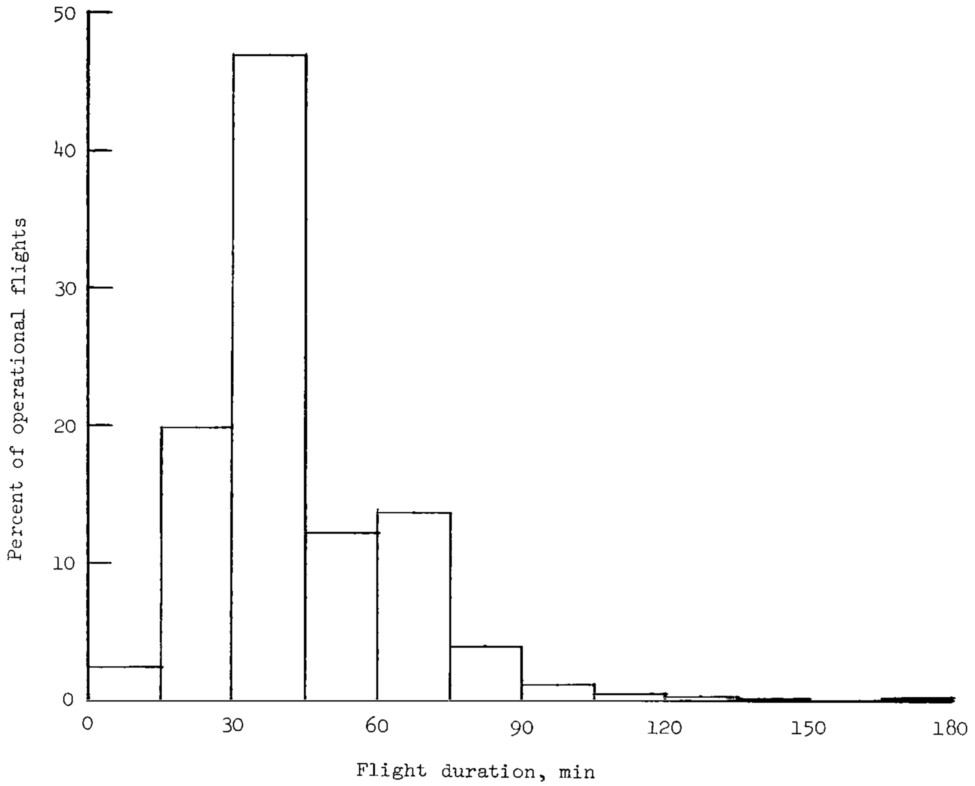

Figure 4.- Histogram of flight durations for operational flights.

TABLE II.- DISTRIBUTION OF FLIGHT TIME AND DISTANCE[a]

(a) By altitude

Pressure altitude, ft	Pressure altitude, km	Percent of time	Percent of distance
0 to 5 000	0 to 1.52	23.65	14.48
5 000 to 10 000	1.52 to 3.05	16.30	14.52
10 000 to 15 000	3.05 to 4.57	13.18	13.70
15 000 to 20 000	4.57 to 6.10	18.92	21.94
20 000 to 25 000	6.10 to 7.62	21.97	27.62
25 000 to 30 000	7.62 to 9.14	5.56	7.23
30 000 to 35 000	9.14 to 10.67	.42	.51

(b) By flight condition

Flight condition	Percent of time	Percent of distance
Climb	22.80	19.97
Cruise	38.93	48.18
Descent	38.27	31.85

[a]Based on 1156 flight hours.

Table II gives a breakdown of the total flight time into the percentage of time within each 5000-foot (1.52-km) altitude bracket and the percentage of time in the climb, cruise, and descent flight conditions. Although the airplanes were operated at altitudes up to 35 000 feet (10.67 km), the average cruise altitude was 20 200 feet (6.16 km). Approximately 22.8 percent of the flight time was spent in climb, 38.9 percent in cruise, and 38.3 percent in descent.

Accelerations

Operational maneuvers.- The frequency distributions of the operational maneuver accelerations are summarized in table III by flight conditions. The data in table III show that relatively few of the maneuvers occurred during cruise, and that the climb and descent had approximately an equal number of maneuvers. The operational maneuver data given in table III are plotted in figure 5 in terms of the cumulative frequency of

TABLE III.- FREQUENCY DISTRIBUTIONS OF OPERATIONAL MANEUVER-ACCELERATION INCREMENTS

Acceleration increment, a_n, g units	Frequency of occurrence for –						Total frequency of occurrence	
	Climb		Cruise		Descent			
	[a]A	[b]B	[a]A	[b]B	[a]A	[b]B	[a]A	[b]B
0.2 to 0.3	1691	-	288	-	2111	--	4090	--
.3 to .4	295	-	45	-	360	--	700	--
.4 to .5	37	-	13	-	49	--	99	--
.5 to .6	7	6	3	3	4	11	14	20
.6 to .7	1	3	1	1	1	--	3	4
.7 to .8	----	-	---	-	----	--	----	--
Total	2031	9	350	4	2525	11	4906	24
Flight hours	263.7	163	450.1	275	442.3	252	1156.1	690
Nautical miles	7.77×10^4	4.80×10^4	18.7×10^4	11.4×10^4	12.4×10^4	7.06×10^4	38.9×10^4	23.2×10^4

[a]Reading threshold, ±0.2g.

[b]Reading threshold, ±0.5g.

occurrence of given values of acceleration per flight mile. For this presentation, the positive and negative values of acceleration within each data sample (airplanes A and B) were combined without regard to sign. The two distributions were then combined and cumulated and divided by the total flight miles represented by the appropriate data sample to obtain the results given in figure 5. For comparison, corresponding results for a two-engine turboprop feeder-line transport (ref. 7) and a four-engine turboprop short-haul transport (unpublished data) are shown in the figure. The airplane operations represented by these two samples correspond most closely with the operation of the twin-engine jet transport. Therefore, the results from these two samples are used for comparison with the present results throughout this paper.

Figure 5 shows that the operational maneuver-acceleration experience for the twin-engine jet airplane corresponds closely to that for the four-engine turboprop airplane and is less severe than that for the twin-engine turboprop airplane.

Check-flight maneuvers.- Approximately 5.5 percent of the total flight time was spent in pilot and airplane check or training flights. Inasmuch as the data were recorded during the initial portion of the operation of the airplanes by the airline, the amount of check-flight time recorded may be more indicative of accelerated pilot training and checkout programs than of the practice to be expected over extended periods of operation. However, in reference 8 the average percentages of total flight time spent in check flights for three categories of transports are estimated to be 1 percent for piston transports, 3 percent for turboprop transports, and 5 percent for turbojet transports. Consequently, the amount of check flying performed with the twin-engine jet airplanes is comparable to that of the turbojet airplanes and does not appear to be unusual.

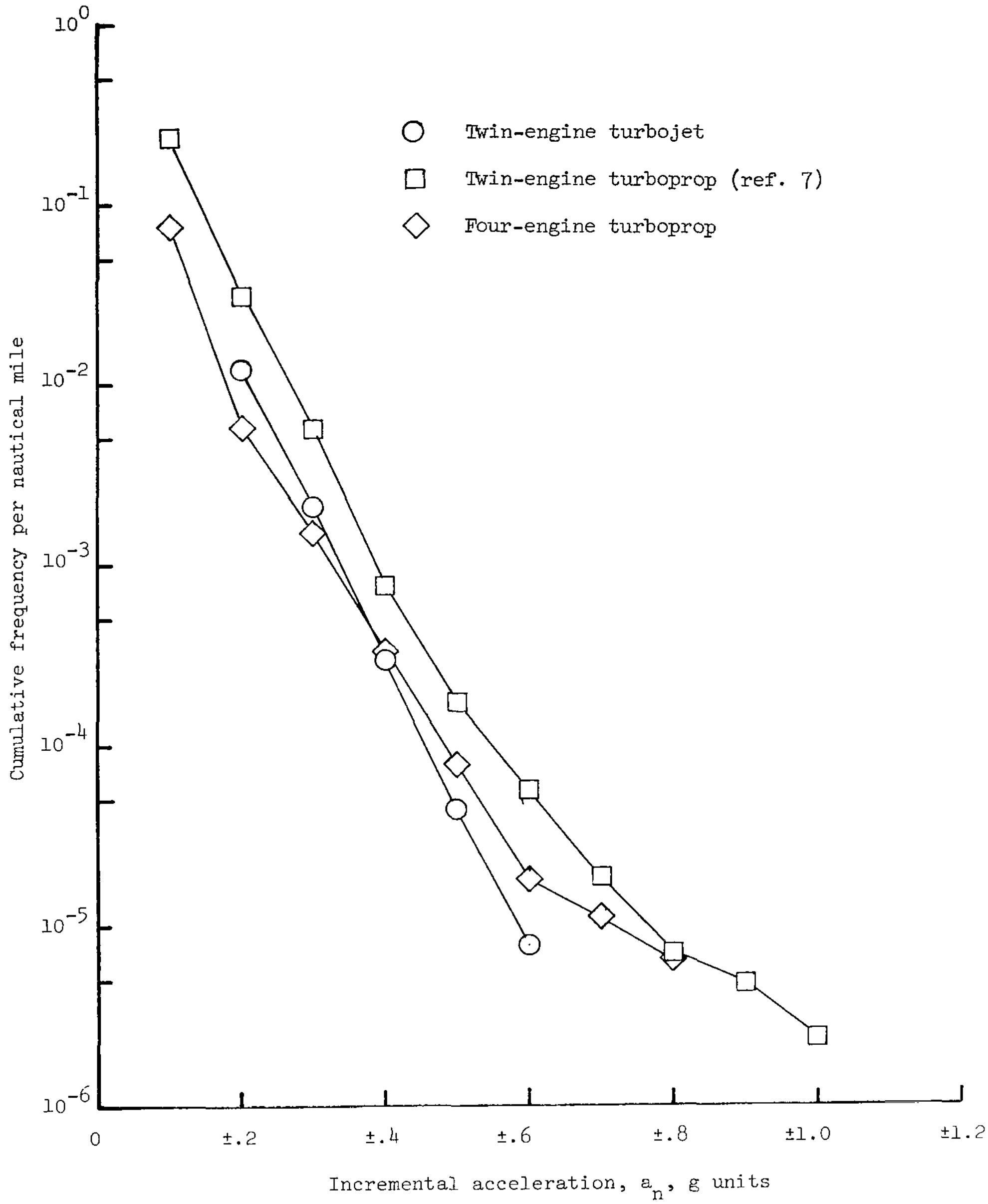

Figure 5.- Comparison of the operational maneuver-acceleration experience of the twin-engine jet transport with that of two turboprop transports.

The frequency distributions of the accelerations experienced during the check flights are given in table IV. These data are plotted in figure 6 in terms of the average frequency of occurrence of accelerations greater than given values. These results are based on the total flight miles (operational and check flights) represented in the data sample. For comparison, corresponding results for the two-engine turboprop airplanes and the four-engine turboprop airplanes are also presented in figure 6.

TABLE IV.- FREQUENCY DISTRIBUTIONS OF CHECK-FLIGHT MANEUVER-ACCELERATION INCREMENTS

Acceleration increment, a_n, g units	Frequency of occurrence for –	
	Airplane A	Airplane B
0.2 to 0.3	1509	---
.3 to .4	491	---
.4 to .5	171	---
.5 to .6	95	70
.6 to .7	45	42
.7 to .8	29	21
.8 to .9	16	11
.9 to 1.0	7	2
1.0 to 1.1	0	7
1.1 to 1.2	2	3
1.2 to 1.3	----	3
Total	2365	159
Check-flight hours . . .	62	46
Total flight hours . . .	1218	736
Nautical miles	4.02×10^5	2.42×10^5
Flights	1755	974

Results in figure 6 indicate that the check-flight maneuver-acceleration experience for the twin-engine jet airplane is similar to that for the twin-engine turboprop airplane and is more severe than that for the four-engine turboprop airplane. The maximum maneuver-acceleration increment recorded in the present data sample was 1.1g. No particular significance is attached to the maximum recorded acceleration, however, since it is less than the minimum design maneuver-load-factor increment of 1.5.

Gust accelerations.- The frequency distributions of the gust accelerations are given in table V by flight condition. The table shows that the largest number of accelerations was experienced during descent and the least number during cruise. In terms of the average frequency of occurrence per flight mile, figure 7 shows that gust accelerations were experienced most frequently in climb. The acceleration frequency was lowest during cruise. These results are a reflection of the relative amount of time spent in the various flight conditions, as shown in table II, and the lower average altitudes flown in climb and descent where exposure to turbulence is greater, as discussed in a subsequent section.

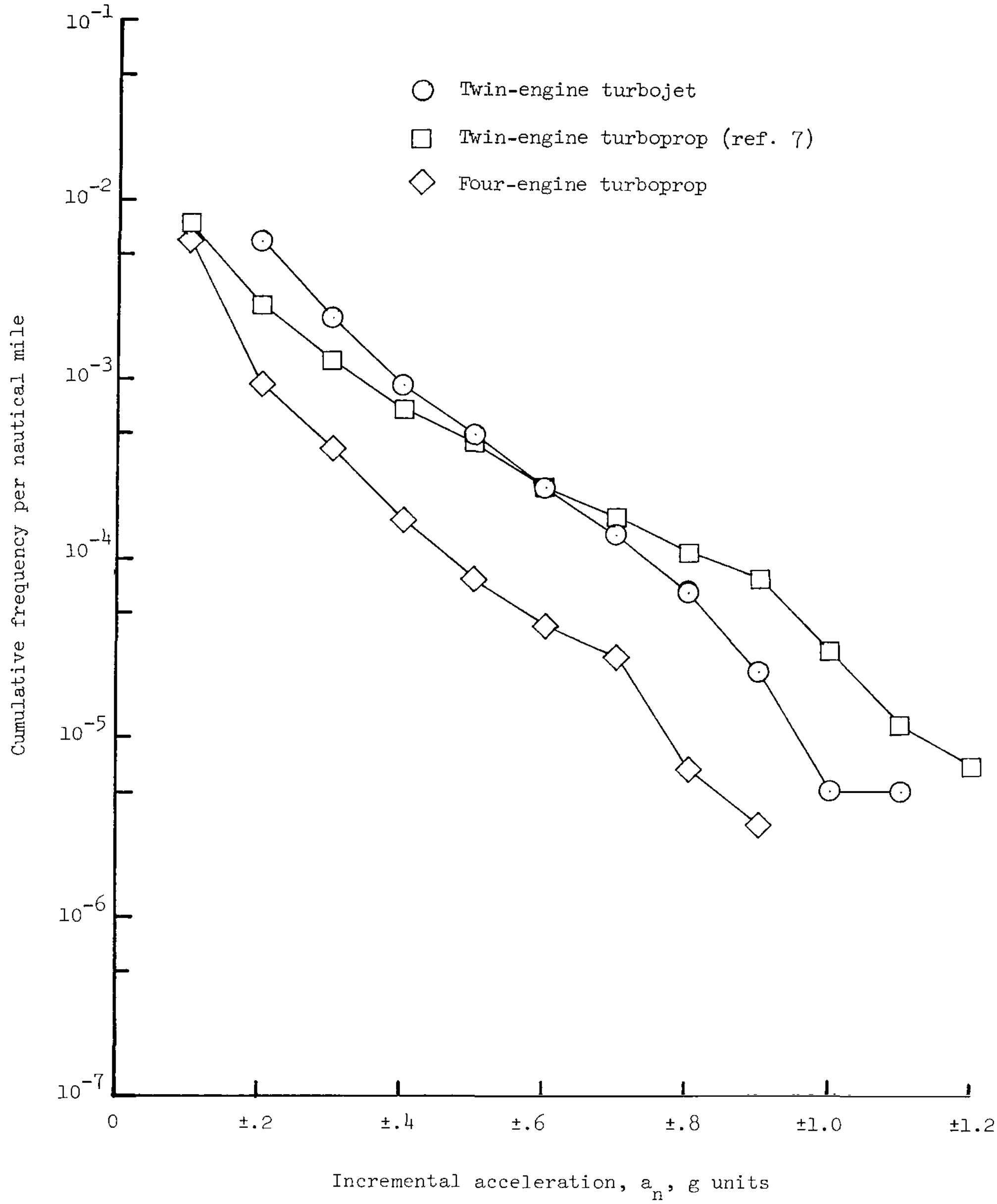

Figure 6.- Comparison of the check-flight maneuver-acceleration experience of the twin-engine jet transport with that of two turboprop transports.

TABLE V.- FREQUENCY DISTRIBUTIONS OF GUST ACCELERATIONS

Acceleration increment, a_n, g units	Frequency of occurrence for —						Total frequency of occurrence	
	Climb		Cruise		Descent			
	^aA	^bB	^aA	^bB	^aA	^bB	^aA	^bB
-0.9 to -1.0	---	2	---	-	----	--	----	2
-0.8 to -0.9	---	1	2	-	----	--	2	1
-0.7 to -0.8	---	0	1	-	----	1	1	1
-0.6 to -0.7	5	3	2	1	4	2	11	6
-0.5 to -0.6	9	15	6	6	15	14	30	35
-0.4 to -0.5	33	--	32	-	54	--	119	--
-0.3 to -0.4	193	--	108	-	360	--	661	--
-0.2 to -0.3	454	--	311	-	930	--	1695	--
Negative total	694	21	462	7	1363	17	2519	45
0.2 to 0.3	503	--	372	-	1142	--	2017	--
0.3 to 0.4	164	--	110	-	373	--	647	--
0.4 to 0.5	39	--	31	-	68	--	138	--
0.5 to 0.6	3	12	9	2	9	15	21	29
0.6 to 0.7	3	4	3	2	8	2	14	8
0.7 to 0.8	0	1	1	1	1	--	2	2
0.8 to 0.9	2	2	1	1	----	--	3	3
0.9 to 1.0	---	3	---	-	----	--	----	3
Positive total	714	22	527	6	1601	17	2842	45
Total	1408	43	989	13	2964	34	5361	90
Flight hours	263.7	163	450.1	275	442.3	252	1156.1	690
Nautical miles	7.77×10^4	4.80×10^4	18.7×10^4	11.4×10^4	12.4×10^4	7.06×10^4	38.9×10^4	23.2×10^4

^{a}Reading threshold, ±0.2g.
^{b}Reading threshold, ±0.5g.

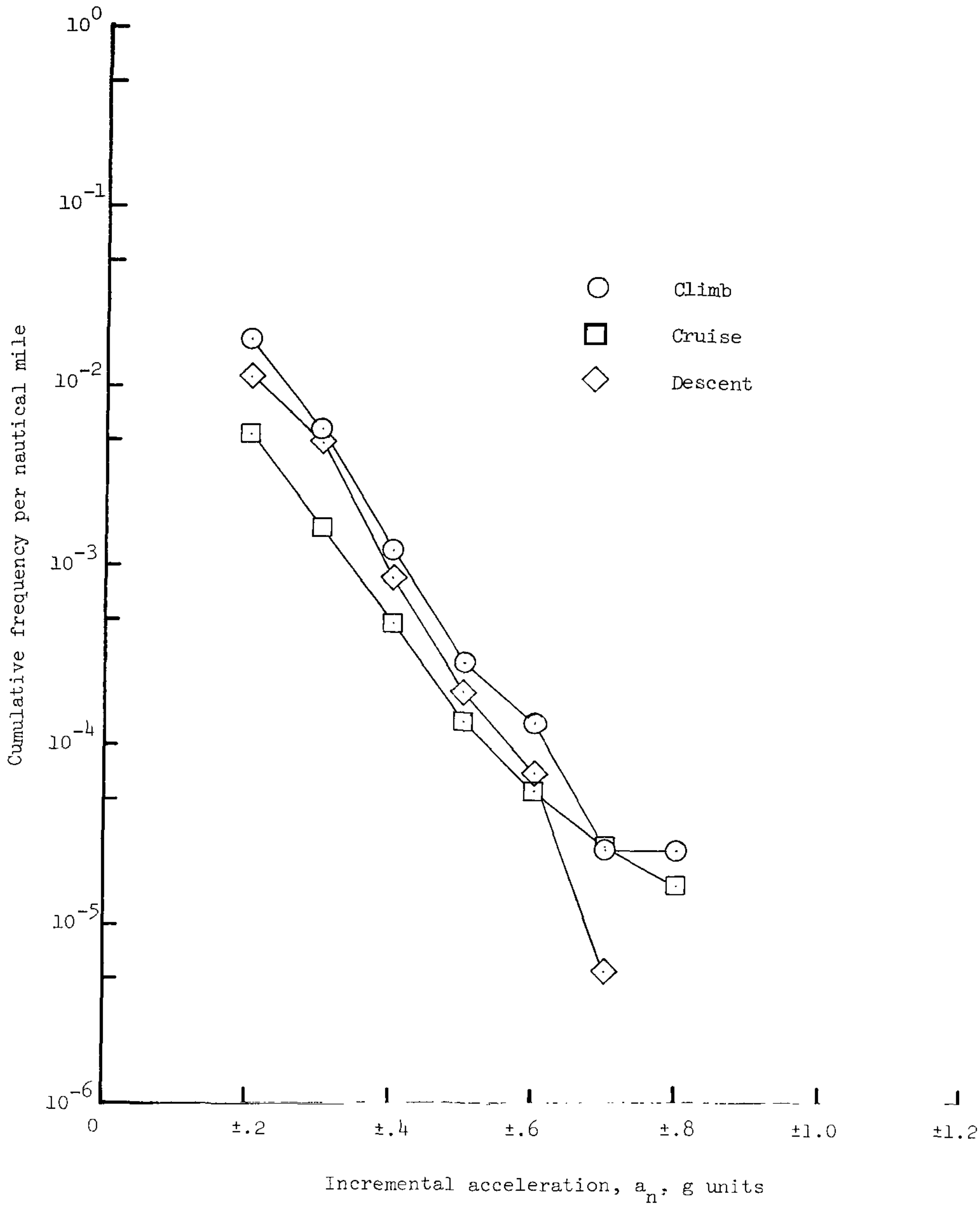

Figure 7.- Average frequency of occurrence of gust accelerations by flight condition.

The average frequency of occurrence of gust accelerations during operations in each 5000-foot (1.52-km) altitude interval is given in figure 8. In general, the gust-acceleration frequencies show a decrease with increasing altitude. This result is also primarily due to the decreased turbulence levels at the higher altitudes.

The cumulative frequency distribution of gust accelerations per flight mile based on the total VGH data sample is shown in figure 9. For comparison, corresponding results for the two-engine turboprop airplane and the four-engine turboprop airplane are

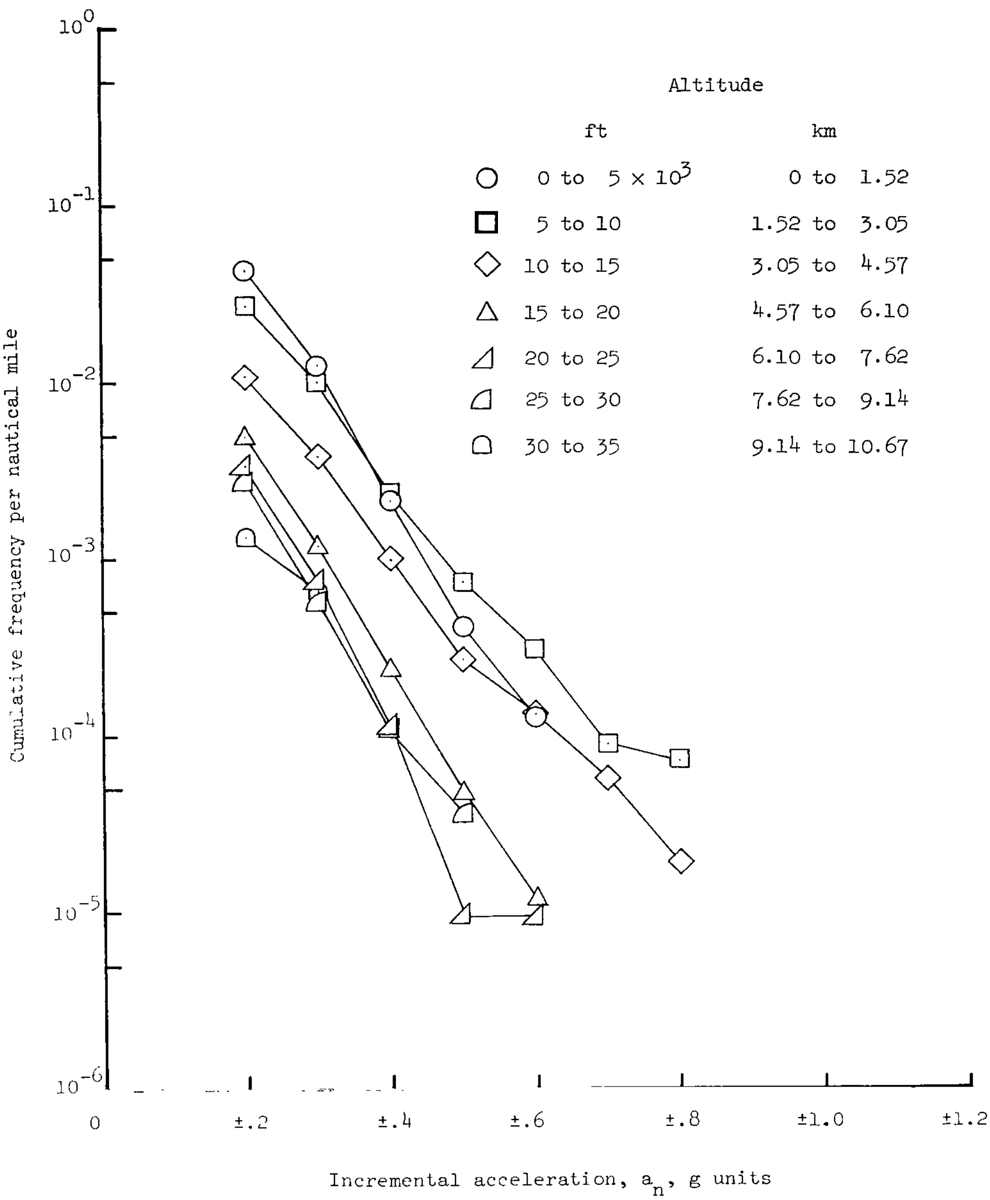

Figure 8.- Average frequency of occurrence of gust accelerations by altitude.

also shown in the figure. The results in figure 9 show that the acceleration distribution for the present operation has approximately the same slope as the other two samples, and that the gust-acceleration frequency is less than for either of the other two airplane operations. The lower gust frequency is attributed to the lessened turbulence associated with a higher average altitude and to the response characteristics of the twin-engine jet airplane.

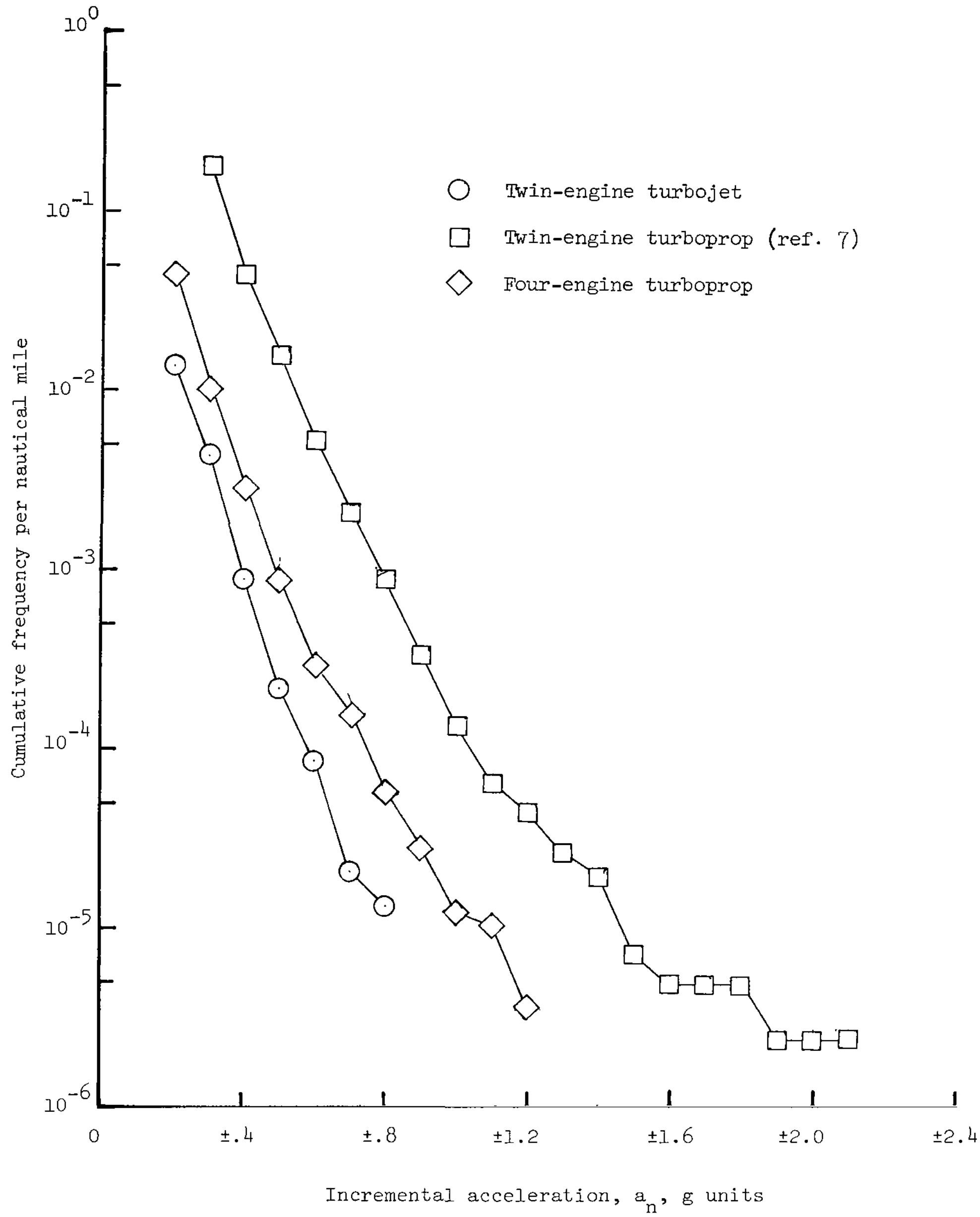

Figure 9.- Comparison of the gust acceleration experience for the twin-engine jet transport with that of two turboprop jet transports.

Oscillatory accelerations.- Past analyses have shown that an oscillatory type of acceleration was frequently experienced by most types of turbine-powered transports (refs. 1 and 7) on which VGH records have been collected. Consequently, the records from the twin-engine jet airplanes were inspected to determine whether these airplanes had also experienced oscillatory accelerations. This inspection did reveal several instances of a low-amplitude (a_n = 0.1g) long-period (15-second) oscillation. An example of this type of oscillation is shown in figure 10. In comparison with oscillations of other

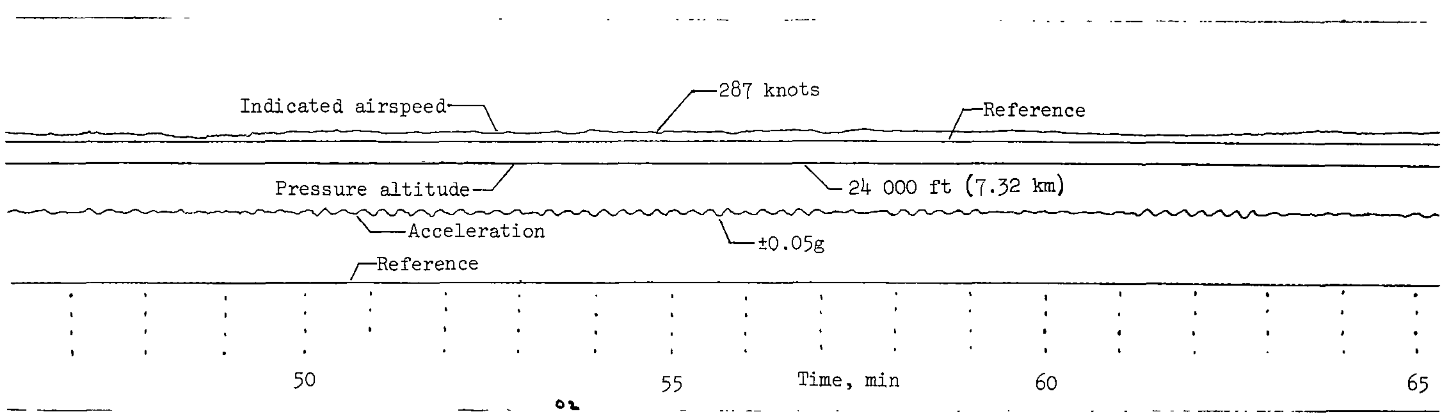

Figure 10.- Example of oscillatory acceleration from VGH record.

types of airplanes, the oscillations of the twin-engine jet airplanes occurred much less frequently, were of lower amplitude, and did not tend to diverge in amplitude. On the basis of the available VGH data sample, the oscillatory accelerations are so small and infrequent as to be insignificant in regard to the total acceleration experience of the twin-engine jet airplane.

Comparison of accelerations.- The accelerations caused by operational maneuvers, check-flight maneuvers, and gusts are compared in figure 11 in terms of the cumulative

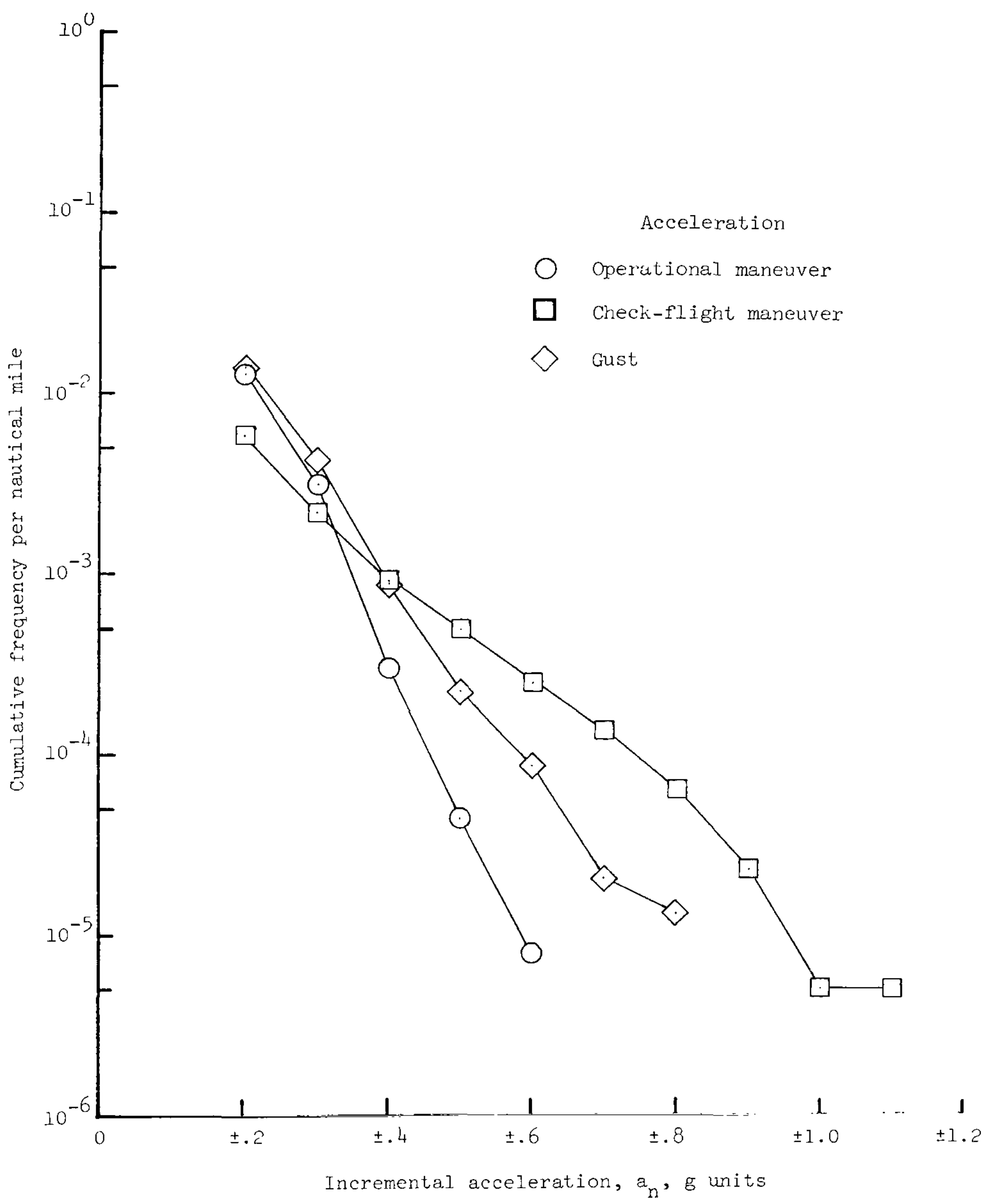

Figure 11.- Comparison of in-flight acceleration experiences from various sources.

frequency per flight mile. The results show that the frequencies of small (≦0.3g) accelerations caused by gusts, operational maneuvers, and check-flight maneuvers differ by a factor of about 2. For acceleration increments larger than about 0.5g, accelerations due to check-flight maneuvers occur several times more frequently than those due to gusts. Accelerations due to operational maneuvers occurred relatively infrequently. The predominance of check-flight maneuver accelerations is not unusual inasmuch as similar results have frequently been observed for turbojet airplanes.

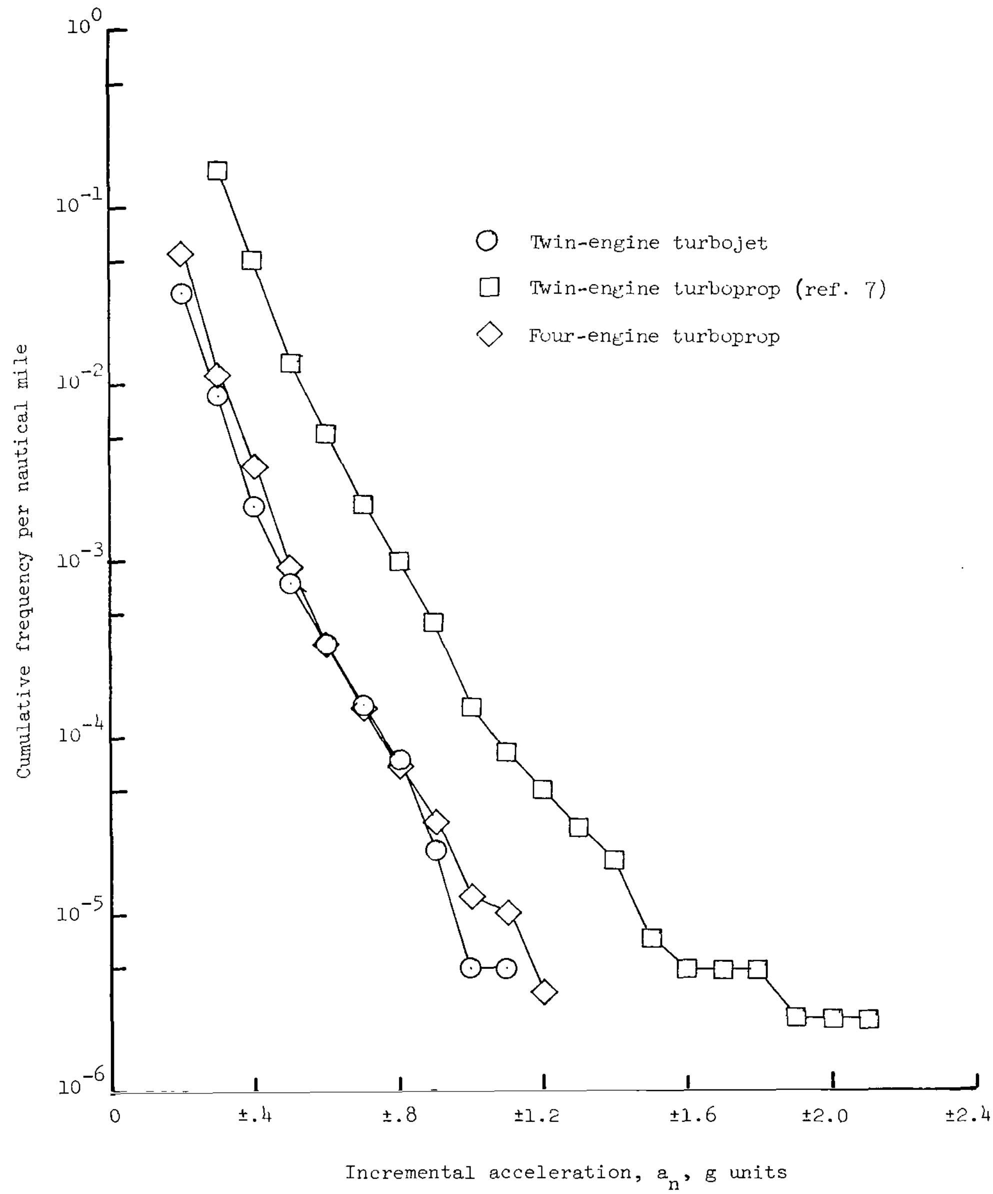

Figure 12.- Comparison of total in-flight acceleration experience for the twin-engine jet transport with that of two turboprop transports.

The total distribution of in-flight accelerations (obtained by summing the three distributions in fig. 11) is compared in figure 12 with corresponding results for the two-engine turboprop airplane and the four-engine airplane. The results show that the total in-flight acceleration experience for the twin-engine jet airplane is very similar to that for the four-engine turboprop airplane and is less severe than that for the twin-engine turboprop airplane.

Turbulence

Amount of rough air.- The percent of the time flown in rough air is given in table VI by 5000-foot (1.52-km) altitude intervals. For comparison, corresponding results for two other operations are also given in the table. The results in table VI show that differences as large as a factor of $1\frac{1}{2}$ exist among the amounts of rough air encountered by the three operations within given altitude intervals. Such differences are not unusual and result from both real differences in the amount of rough air encountered and from apparent differences arising from the difficulty of evaluating acceleration records to a constant rough-air threshold. In general, however, the amount of rough air encountered in the twin-engine jet airplane operation is not significantly different from that experienced in the other two operations.

TABLE VI.- DISTRIBUTION OF ROUGH AIR BY ALTITUDE

Altitude,		Percent of time in rough air for –		
ft	km	Twin-engine jet airplane	Four-engine turboprop	Two-engine turboprop
0 to 5 000	0 to 1.52	22.0	36.9	27.8
5 000 to 10 000	1.52 to 3.05	14.2	13.3	10.9
10 000 to 15 000	3.05 to 4.57	9.9	8.9	6.6
15 000 to 20 000	4.57 to 6.10	6.5	7.3	5.4
20 000 to 25 000	6.10 to 7.62	5.0	7.7	----
25 000 to 30 000	7.62 to 9.14	7.8	----	----
30 000 to 35 000	9.14 to 10.67	5.9	----	----

In figure 13, the amount of rough air encountered in the twin-engine jet airplane operation is compared with the estimated variation in the amount of rough air given in reference 9. The curve from reference 9 is the average variation based on data from a large number of investigations and is considered to be representative of worldwide airline operations. The percentage of rough air encountered by the twin-engine jet airplanes between 5000 feet (1.52 km) and 20 000 feet (6.10 km) is higher than that given

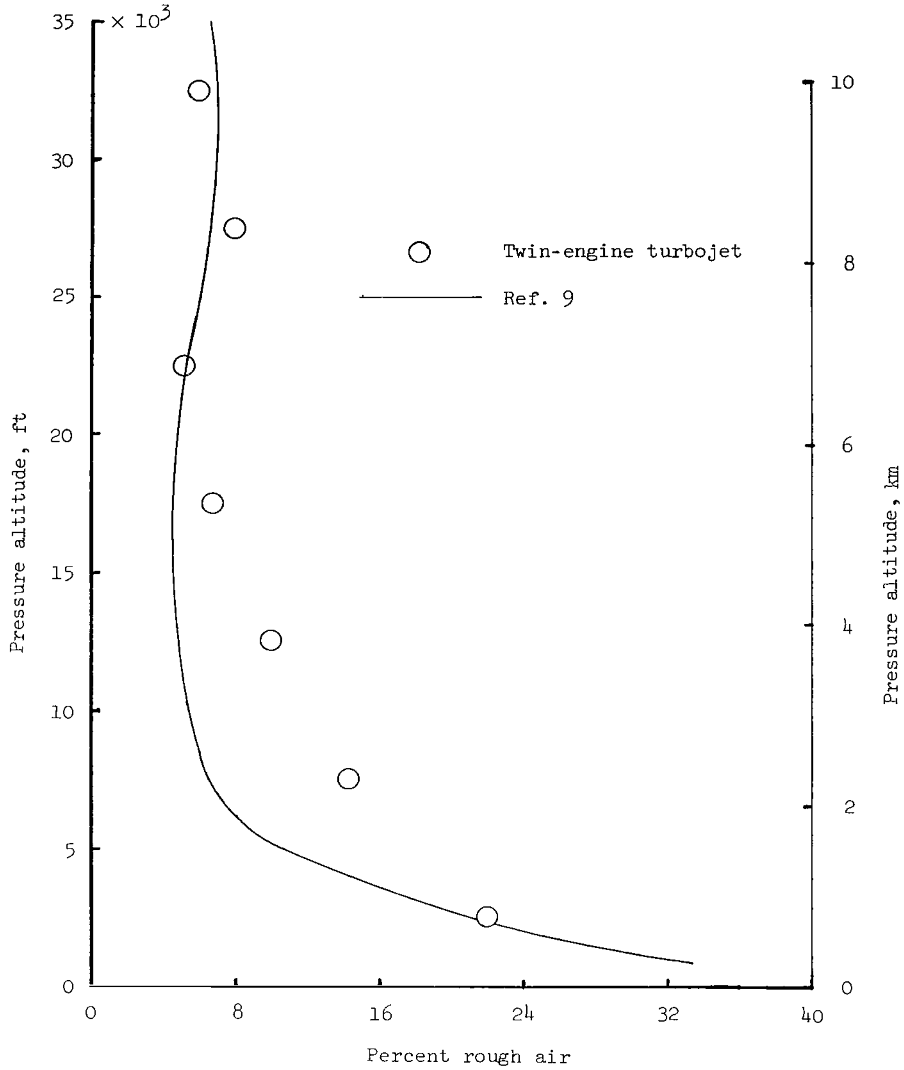

Figure 13.- Comparison of percent of time in rough air for the twin-engine jet transport operations with estimated rough-air exposure.

by the estimate from reference 9 but is in very good agreement for the other altitudes. On the basis of the results given in table VI and figure 13, the amount of rough air encountered by the twin-engine jet airplanes does not appear to be significantly different from that for other transport operations.

Gust velocities.- The frequency distributions of derived gust velocities by 5000-foot (1.52-km) altitude intervals are given in table VII. These data are shown in figure 14 in terms of the cumulative frequency distribution of gust velocity per flight mile within given altitude intervals. The results in figure 14 show a general decrease in the gust frequency with increasing altitude. This result is in agreement with information on the variation of gust velocities with altitude given in reference 9.

TABLE VII.- FREQUENCY DISTRIBUTIONS OF DERIVED GUST VELOCITY

Derived gust velocity, U_{de}		Frequency of occurrence for altitude –															
		0 to 5 000 ft (0 to 1.52 km)		5 000 to 10 000 ft (1.52 to 3.05 km)		10 000 to 15 000 ft (3.05 to 4.57 km)		15 000 to 20 000 ft (4.57 to 6.10 km)		20 000 to 25 000 ft (6.10 to 7.62 km)		25 000 to 30 000 ft (7.62 to 9.14 km)		30 000 to 35 000 ft (9.14 to 10.67 km)		0 to 35 000 ft (0 to 10.67 km)	
ft/sec	m/sec	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
4 to 8	1.22 to 2.44	648	--	685	--	383	--	325	-	305	--	69	-	1	-	2416	--
8 to 12	2.44 to 3.66	1252	--	665	--	159	--	81	-	56	--	8	-	1	-	2222	--
12 to 16	3.66 to 4.88	412	2	107	1	20	1	9	3	2	8	--	-	-	-	550	15
16 to 20	4.88 to 6.10	99	4	29	20	6	17	2	1	1	4	--	-	-	-	137	46
20 to 24	6.10 to 7.32	24	4	3	2	3	7	---	-	---	1	--	-	-	-	30	14
24 to 28	7.32 to 8.54	3	5	1	1	---	0	---	-	---	--	--	-	-	-	4	6
28 to 32	8.54 to 9.75	0	0	1	2	---	4	---	-	---	--	--	-	-	-	1	6
32 to 36	9.75 to 10.97	0	1	----	--	---	2	---	-	---	--	--	-	-	-	0	3
36 to 40	10.97 to 12.19	0	--	----	--	---	--	---	-	---	--	--	-	-	-	0	--
40 to 44	12.19 to 13.41	1	--	----	--	---	--	---	-	---	--	--	-	-	-	1	--
Total		2439	16	1491	26	571	31	417	4	364	13	77	0	2	0	5361	90
Flight hours		273.5	163.4	188.4	114.5	152.3	89.2	218.7	130.8	254.0	151.9	64.3	38.4	3.7	2.2	1155	690
Nautical miles		5.63×10^4	3.36×10^4	5.65×10^4	3.38×10^4	5.33×10^4	3.19×10^4	8.54×10^4	5.10×10^4	10.8×10^4	6.43×10^4	2.81×10^4	1.68×10^4	0.15×10^4	0.09×10^4	38.9×10^4	23.2×10^4

The gust-velocity experience of the twin-engine jet airplane is shown in figure 15 in terms of the cumulative frequency distribution of gust velocity per flight mile for the overall operations. For comparison, corresponding results for a large four-engine turbojet (ref. 10) and for the two-engine turboprop and the four-engine turboprop are included. The results show that the gust experience for the twin-engine jet airplane is significantly lower than that for the twin-engine turboprop and the four-engine turboprop and is approximately equal to that for the large four-engine turbojet airplane. From a consideration of the operational altitudes of the various airplanes, the gust experience for the twin-engine turbojet would be expected to be between those of the four-engine turboprop and the large four-engine turbojet airplanes. Consequently, the result obtained is somewhat unexpected. In regard to the results in figure 15, the gust experience of the particular four-engine turboprop operation shown for comparison was the most severe of the three four-engine turboprop operations that have been sampled. However, the gust experiences of the other two turboprop operations were also more severe than those of either of the turbojet operations. The present results therefore show the twin-engine turbojet operation to have an unusually low gust experience, the reason for which is not understood.

Airspeed.- The average airspeeds in rough and smooth air for each 5000-foot (1.52-km) altitude interval are shown in figure 16. The variation of the maximum operating limit speed (V_{MO} and M_{MO}) is shown in the figure for comparison with the average speeds. The results show that the average speeds were considerably below the V_{MO}, M_{MO} speeds throughout the operating altitude range. In general, the average indicated speeds tended to increase with altitude up to about 25 000 feet and to decrease

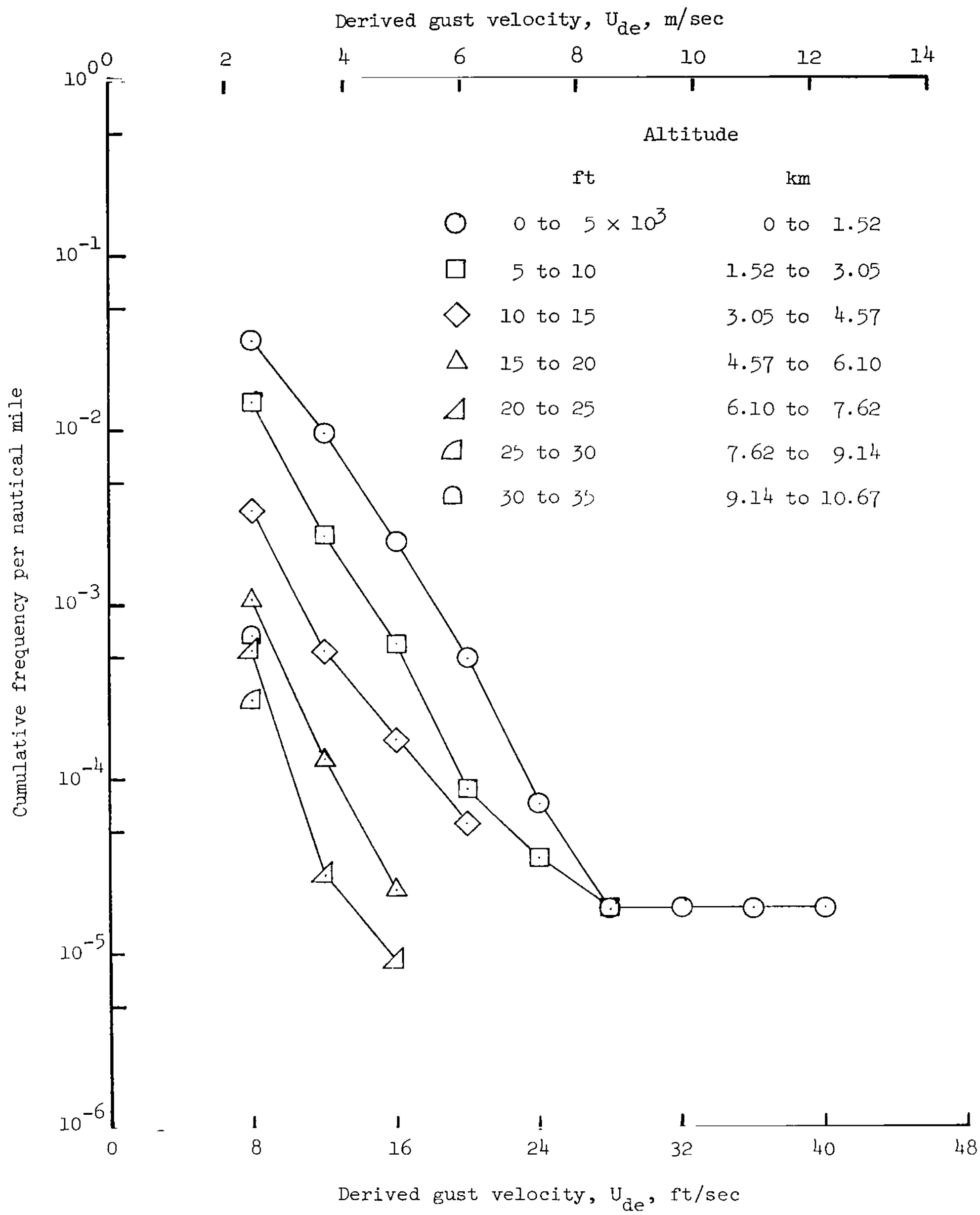

Figure 14.- Average frequency of occurrence of derived gust velocities by altitude.

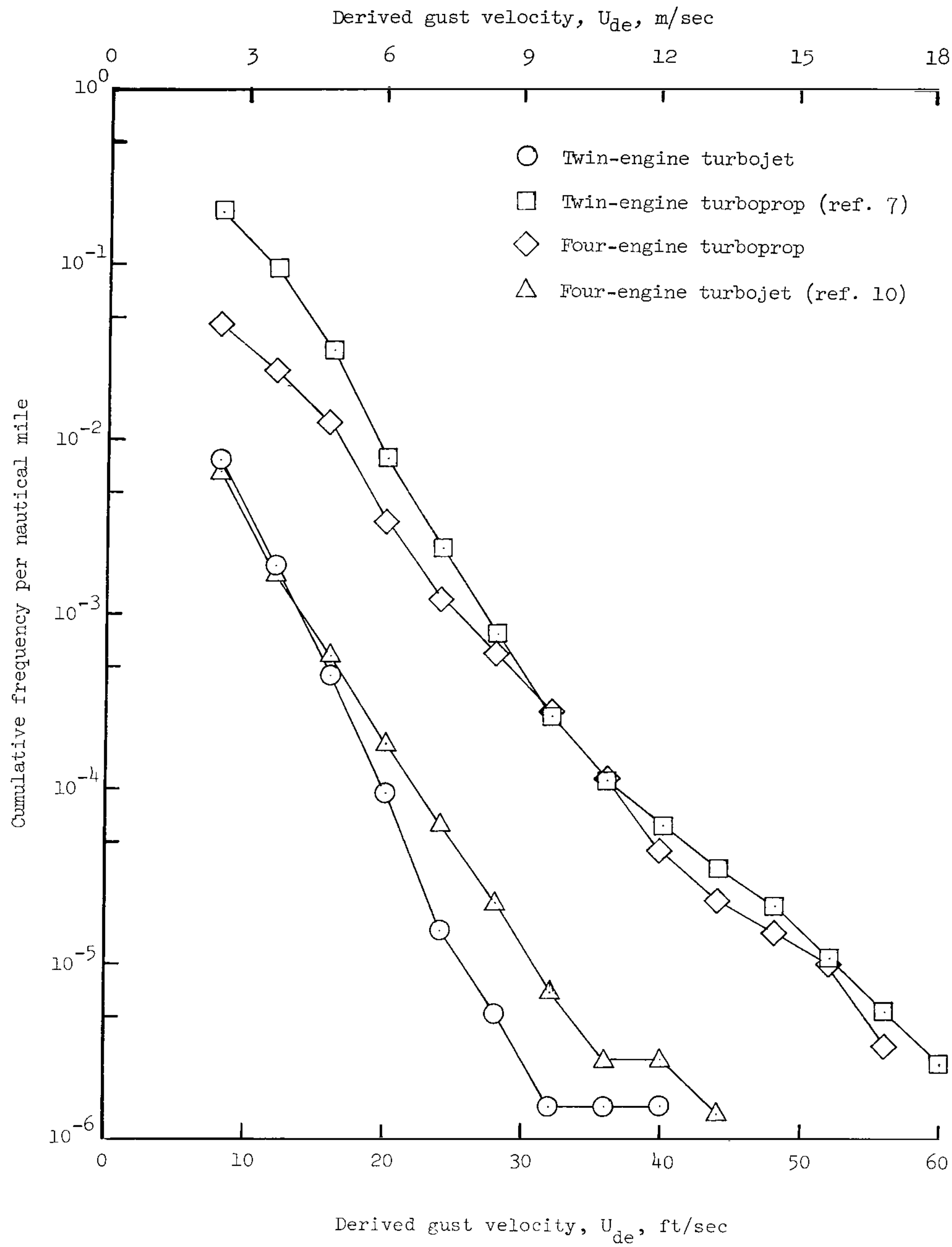

Figure 15.- Comparison of derived gust velocity experience for the twin-engine jet transport with that of three other transport airplanes.

above this altitude. Also, the margins between the average speeds and the V_{MO}, M_{MO} speed placard decreased as altitude increased. The results in figure 16 show that the average speeds in rough and smooth air usually differed by less than 10 knots. This result is in agreement with results previously found for other transport operations. (See ref. 7, for example.)

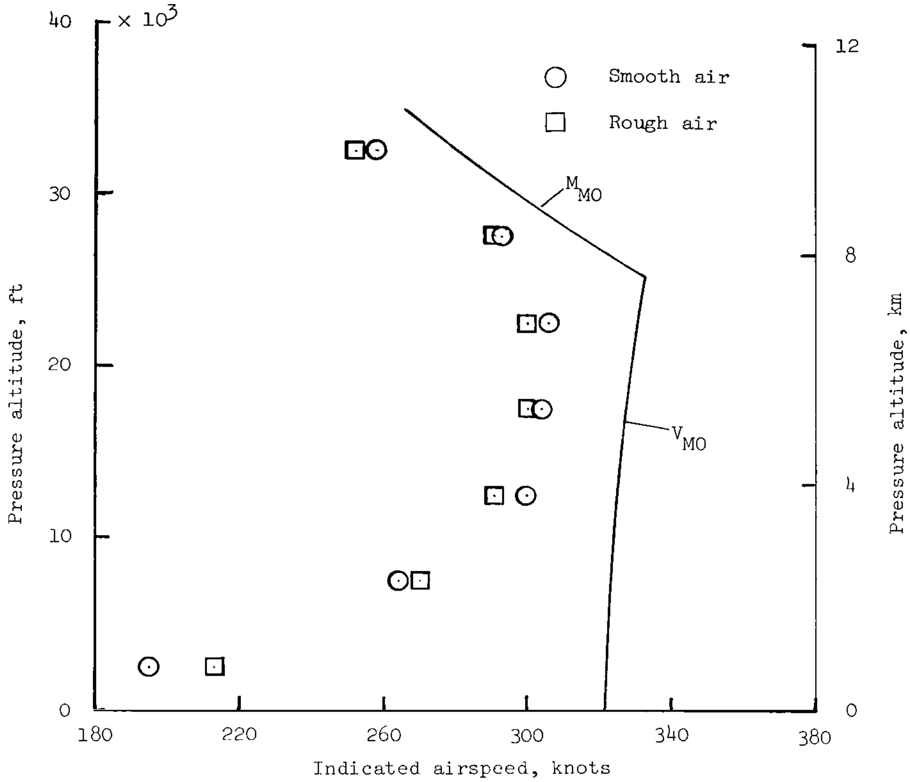

Figure 16.- Comparison of average airspeeds in rough and smooth air with maximum operating placard speed.

Because of the low turbulence threshold associated with the definition of rough air, the airspeeds are influenced by the relatively large amount of light turbulence encountered, for which airspeed reductions would not be expected. To determine whether airspeeds were reduced for more severe turbulence, the average airspeeds at which gust accelerations greater than $\pm 0.5g$ occurred were determined and are compared in figure 17 with the average airspeeds in rough air taken from figure 16. Except for the 0-to-5000-foot (1.52-km) altitude bracket, the average airspeeds at which the larger gust accelerations occurred were substantially lower than the average airspeeds in rough air. Thus, the results imply that airspeeds generally were reduced when more severe turbulence was encountered.

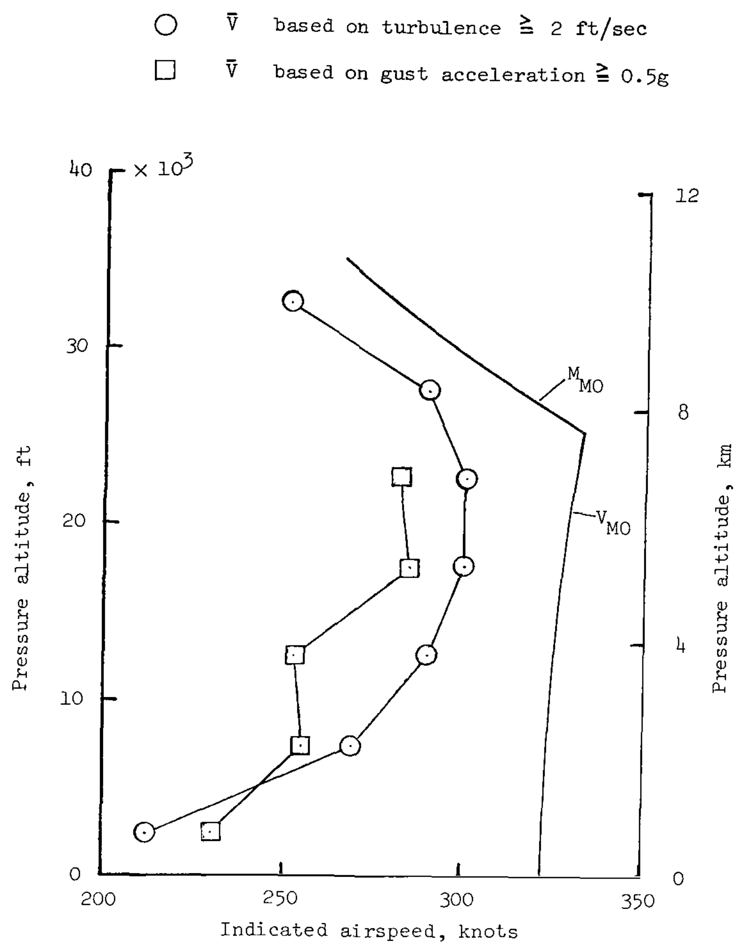

Figure 17.- Average airspeeds in rough air.

Information pertaining to airspeeds in excess of the placard operating limit speed V_{MO}, M_{MO} is presented in figure 18. The figure shows the maximum airspeed and the corresponding altitude for each exceedance of V_{MO} + 6 knots or M_{MO} + 0.01 which occurred in 913 hours of flight. The 6-knot increment above V_{MO} and the 0.01 increment above M_{MO} represent the margin on the overspeed warning bell which is permitted by the Civil Air Regulations (ref. 11). The results show that there were two exceedances in climb, 18 in cruise, and 33 in descent. All the exceedances were in the V_{MO} altitude range and the maximum exceedance of the bell warning was about 6 knots. The placard speed exceedances appear to be less frequent and the speed excursions seem to be smaller than those noted for several other types of transport airplanes (refs. 1 and 7).

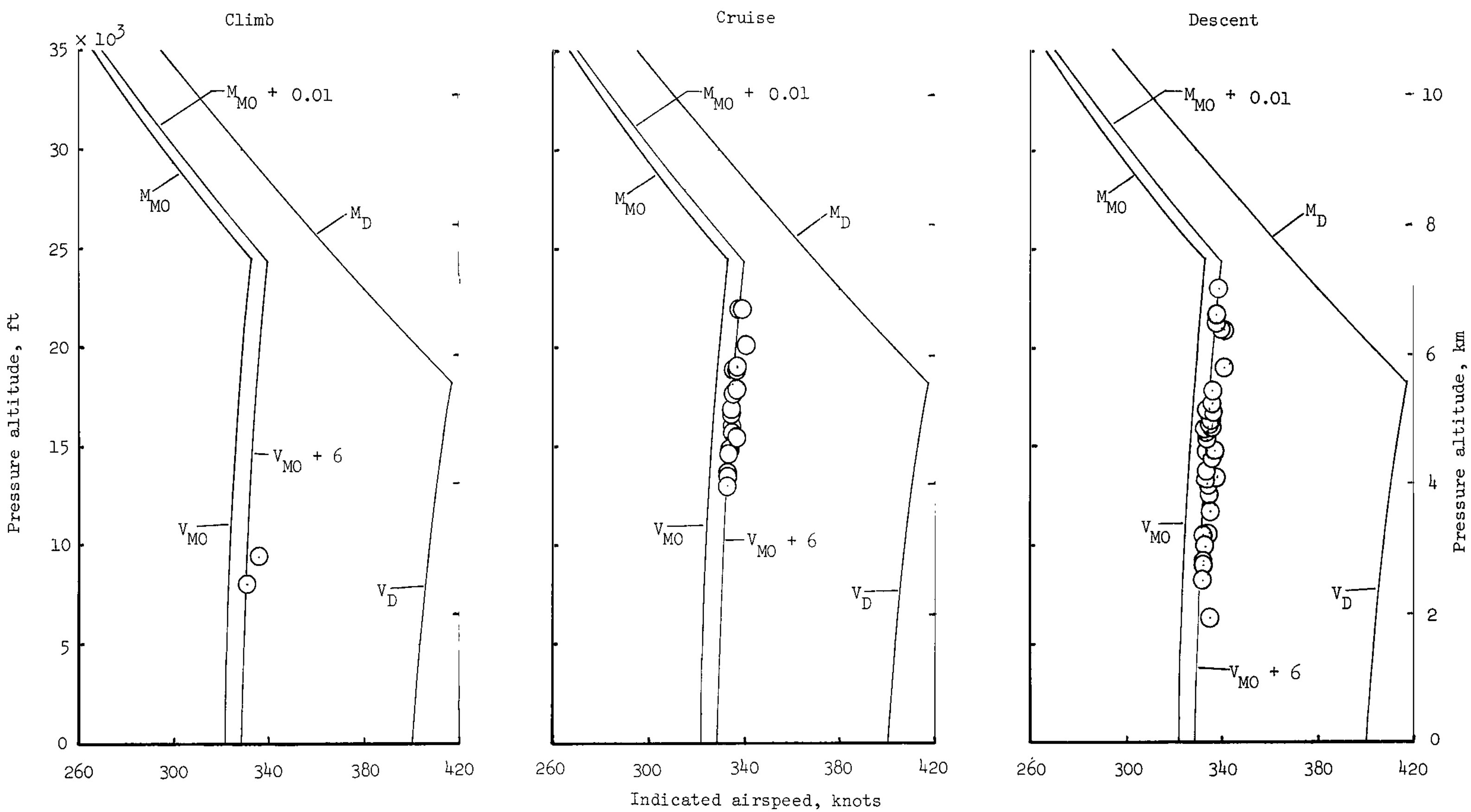

Figure 18.- Placard-speed exceedances by flight condition. (Based on 913 hours of VGH data.)

Landing-Impact Accelerations

The cumulative probability distributions of the initial positive landing-impact accelerations for the twin-engine jet airplane are shown in figure 19. Results are shown for a sample representing the initial 3 months of operation of the two airplanes and for a sample taken after a landing-gear modification was made. The first sample includes results of operational flights and combined operational and check flights, and the second includes only combined operational and check flights. For comparison, the range of distributions which have been observed for three- and four-engine turbojet transports and the distribution for another type of two-engine jet transport taken from reference 12 are also shown. During the initial airplane operations, the landing-impact accelerations for the twin-engine jet airplane were appreciably higher than for any of the transports

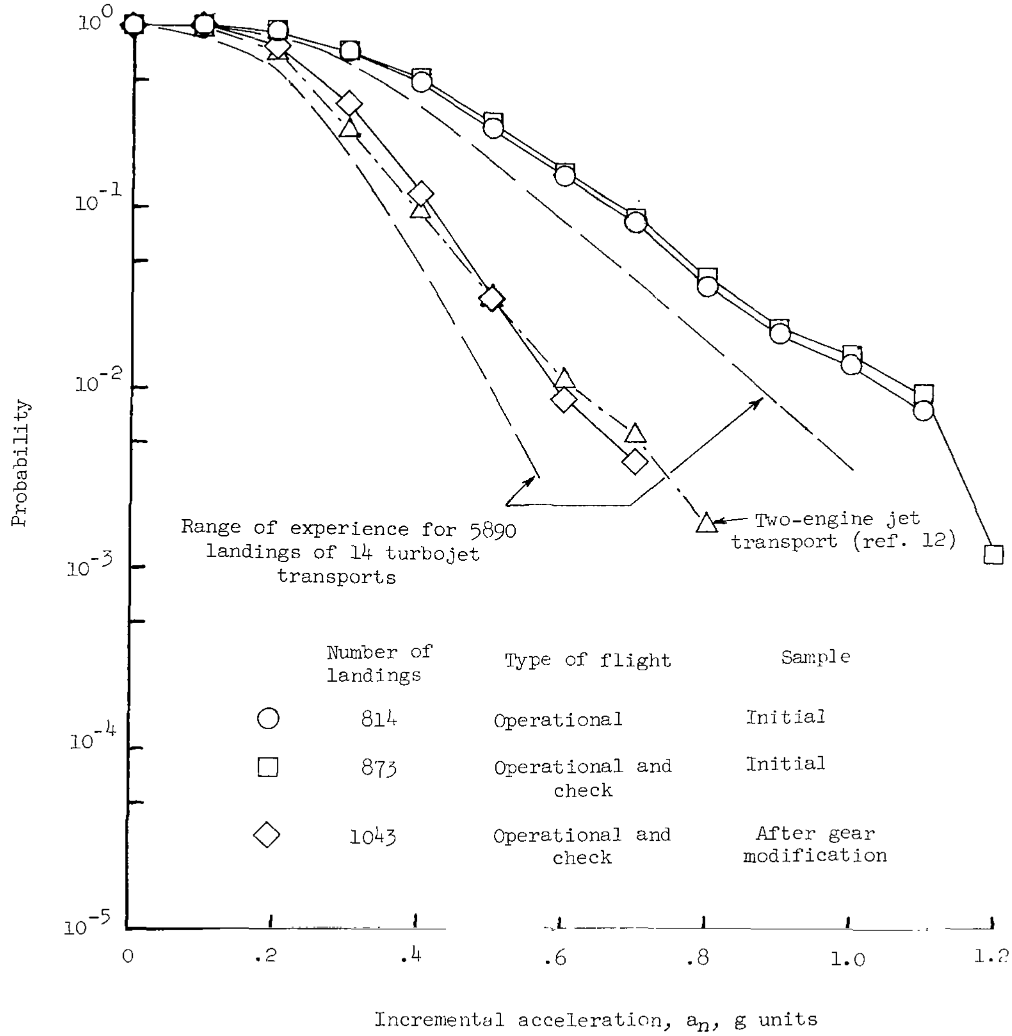

Figure 19.- Probability of exceeding given values of landing-impact acceleration for the twin-engine jet transport and for 16 other transport airplanes.

included in the range of experience. Approximately 6 months after airplane delivery, the landing gear was modified by the addition of 70-pound (311.38-N) weights to each landing-gear leg in order to change the frequency response of the landing gear. As shown in figure 19, the landing-impact accelerations obtained after the modification are about 40 percent lower than those obtained prior to the modification, and the resulting distribution is similar to that for another two-engine jet transport (ref. 12).

CONCLUDING REMARKS

A VGH data sample collected on two identical twin-engine turbojet airplanes during routine airline operations has been analyzed to determine the operational experiences of the airplanes. The results indicate that the gust and maneuver accelerations are comparable to corresponding results for turboprop airplanes. Accelerations due to oscillatory motions were of low amplitude, were experienced infrequently, and are considered to be insignificant in regard to the total airplane acceleration experience. The frequency of occurrence of derived gust velocities is significantly lower than that for two types of turboprop airplanes and is comparable to that for a four-engine turbojet transport. Placard speed exceedances were relatively infrequent, and generally were less than 6 knots beyond the overspeed warning bell. The results indicate that, in general, airspeed reduction was practiced when the airplanes were traversing heavy turbulence. The landing-impact accelerations, which were quite severe during the initial airplane operation, were reduced to a level comparable to that of several other two- and three-engine jet transports after a modification of the landing gear.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., January 17, 1968,
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