NASA MEMO 1-17-59L

NASA MEMO 1-17-59L

NASA

MEMORANDUM

ANALYSIS OF ACCELERATION, AIRSPEED, AND GUST-VELOCITY DATA FROM A FOUR-ENGINE TRANSPORT AIRPLANE OPERATING OVER A NORTHWESTERN UNITED STATES-ALASKA ROUTE

By Jerome N. Engel and Martin R. Copp

Langley Research Center
Langley Field, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON
February 1959

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MEMORANDUM 1-17-59L

ANALYSIS OF ACCELERATION, AIRSPEED, AND GUST-VELOCITY DATA FROM A FOUR-ENGINE TRANSPORT AIRPLANE OPERATING OVER A NORTHWESTERN UNITED STATES-ALASKA ROUTE

By Jerome N. Engel and Martin R. Copp

SUMMARY

Acceleration, airspeed, and altitude data obtained with an NACA VGH recorder from a four-engine commercial transport airplane operating over a northwestern United States-Alaska route were evaluated to determine the magnitude and frequency of occurrence of gust and maneuver accelerations, operating airspeeds, and gust velocities. The results obtained were then compared with the results previously reported in NACA Technical Note 3475 for two similar airplanes operating over transcontinental routes in the United States.

No large variations in the gust experience for the three operations were noted. The results indicate that the gust-load experience of the present operation closely approximated that of the central transcontinental route in the United States with which it is compared and showed differences of about 4 to 1 when compared with that of the southern transcontinental route in the United States. In general, accelerations due to gusts occurred much more frequently than those due to operational maneuvers. At a measured normal-acceleration increment of 0.5g, accelerations due to gusts occurred roughly 35 times more frequently than those due to operational maneuvers.

INTRODUCTION

A considerable amount of data obtained with NACA V-G and VGH recorders has been collected by the National Aeronautics and Space Administration as part of a continuing study of the magnitude and frequency of occurrence of the gusts, gust accelerations, and maneuver accelerations experienced by different types of transport airplanes during various commercial operations. (See, for example, ref. 1). The present report represents a continuation of this work and presents an analysis of VGH data representing 672.9 flight hours of operation obtained from a four-engine commercial transport airplane operating between the northwestern portion of the United States and Alaska. Data from scheduled operations on northwestern United States-Alaska routes have not been previously obtained by means of NACA VGH recorders.

The VGH data for these operations are analyzed to determine the magnitude and frequency of occurrence of gust and maneuver accelerations, operating airspeeds, and gust velocities. The acceleration and gust histories are compared with those reported in reference 1 for two operations utilizing similar airplanes operating over transcontinental routes in the United States.

INSTRUMENTATION AND SCOPE OF DATA

The data were collected with an NACA VGH recorder which is described in detail in reference 2. The recorder obtains a time-history record of indicated airspeed, pressure altitude, and normal acceleration of the airplane. The operations covered a route between the northwestern portion of the United States and Alaska and included flights over mountainous and level terrain and also over water. Climatic conditions for the route ranged from temperate to subarctic. The data sample represents 263 flights totaling 672.9 flight hours of routine four-engine commercial transport operation and was obtained between April 1956 and March 1957. These flights averaged about 2.5 hours in length, and cruising altitudes ranged from 6,000 feet to 12,000 feet.

The characteristics of the airplane which are pertinent to the evaluation and analysis of the VGH data are presented in the following table:

Design gross weight, lb	70,700
Wing area, sq ft	1,461
Span, ft	117.5
Aspect ratio, A	9.4
Mean geometric chord, ft	12.4
Slope of lift curve per radian $\left(\text{computed from } \frac{6A}{A + 2};\right.$ see ref. 3$\left.\right)$	4.95
Design speed for maximum gust intensity (indicated), knots, (computed according to ref. 4)	144
Design cruising speed (indicated), knots	193
Design never-exceed speed (indicated), knots	231
Normal acceleration corresponding to the design limit-gust-load-factor increment, $a_{n,LLF}$, g units, (computed according to ref. 4)	1.42

The values listed in the table were obtained from the manufacturer's design data unless otherwise indicated.

EVALUATION OF DATA AND RESULTS

Gust Accelerations

Gust accelerations equal to or greater than a threshold of ±0.3g were read from the VGH records by using the steady-flight position of the acceleration trace as a reference. These data were formed into combined (positive and negative) frequency distributions of gust accelerations and are given in table I for class intervals of 0.1g for each flight condition (climb, en route, and descent) and for the total sample. The number of flight hours and flight miles represented by each distribution, the average indicated airspeeds for each phase of the operation, and the average number of accelerations equal to or greater than ±0.3g experienced per mile of flight are also given in table I.

The acceleration distributions given in table I cannot be used directly in comparing the gust loads for different airplanes because of differences in the design limit-gust-load factor. In order to compare the present operations with operations utilizing other airplanes, the acceleration distributions of table I are presented in figure 1 as a ratio of the measured normal-acceleration increment a_n to the normal acceleration corresponding to the computed limit-gust-load-factor increment $a_{n,LLF}$. The ordinate scale of the figure is in terms of the frequency of occurrences equal to or greater than ±0.3g per mile of flight. Similar distributions for operations A and B of reference 1 are also given in figure 1. Operations A and B involved four-engine transports operating over southern and central transcontinental routes in the United States, respectively. The values of $a_{n,LLF}$ used in obtaining figure 1 were 1.42g for the present operation, 1.54g for operation A, and 1.47g for operation B.

Maneuver Accelerations

Frequency distributions of positive and negative operational- and check-flight-maneuver accelerations are given in table II. The total number of flight hours, the amount of time actually spent in check flights, and the total flight miles represented by the distributions are also shown in the table.

The procedures used to evaluate these data have been used in previous investigations. (See, for example, ref. 5.) Many of the smaller values of operational-maneuver accelerations of ±0.1g to ±0.2g in table II(a) are probably due to hunting or minor oscillations of the automatic pilot and to minor pilot-induced control motions and are not values of the maneuver accelerations usually associated with changes in course or heading. These low acceleration values, however, are of interest for fatigue studies and are accordingly included.

Frequency distributions of combined (positive and negative) operational- and check-flight-maneuver accelerations for the present operation are shown in figure 2. For purposes of comparison, the gust-acceleration distribution is also shown in the figure.

Gust Velocities

Derived gust velocities were calculated by means of the revised gust-load formula of reference 6. The resulting frequency distributions of combined (positive and negative) gust velocities are presented in table III in class intervals of 4 fps for each altitude interval of 5,000 feet and for the total operation. The number of flight hours, flight miles, and the average number of gust velocities equal to or greater than 8 fps encountered per mile of flight for each altitude interval of 5,000 feet and for the total operation are also given in table III.

The frequency of occurrence of gust velocities for the present operation is plotted in figure 3 and is compared with gust-velocity distributions for the two transcontinental operations in the United States (ref. 1). The low gust velocities in figure 3 do not represent complete measurements because of the acceleration threshold of ±0.3g used in the data-reduction procedure.

Operating Airspeeds

The indicated airspeed was read from the VGH records for each 1-minute interval of flight. In order to classify the airspeeds according to operations in rough or smooth air, any portion of the VGH record was considered to represent rough air if the acceleration trace contained gust-acceleration peaks of at least ±0.3g. The remainder of the record was classified as representing smooth air. Average values of indicated airspeed in rough and smooth air were then computed from the 1-minute airspeed readings for the climb, en-route, and descent conditions and for the total data sample. These values are shown in table IV.

PRECISION AND RELIABILITY OF RESULTS

The present results are subject to errors arising from a number of factors which include instrument and associated installation errors, reading errors, and statistical sampling errors. Past experience has indicated that the instrument and installation errors associated with the data are negligible. Although reading errors are estimated to be small, they can still seriously affect the number of accelerations exceeding a given value. The results of previous studies (e.g., ref. 7) have indicated that the acceleration measurements equal to or greater than ±0.3g for individual records are reliable to within ±30 percent. As the sample size increases, however, the effect of reading errors tends to diminish. For the present sample, the readings of the gust frequencies are estimated to be reliable to within ±10 to ±15 percent.

In order to assess the statistical or sampling reliability of the present results, such as those shown in figure 1, an analysis of the data obtained from the individual VGH records was made by means of a method described in reference 8. Analysis of the variability in the frequency of various acceleration levels between the records permits the determination of confidence bands for the various distributions. These bands are shown in figure 4 and indicate the range within which the "true" value (value for extended operations) of the acceleration ratio $a_n/a_{n,LLF}$ may be expected to lie for a probability level of 95 percent. The confidence bands may also be used to determine whether the differences between two samples are statistically significant. For this purpose, the following crude criterion may be applied: The differences between two data samples are assumed to be statistically significant if their respective confidence bands do not overlap.

DISCUSSION

Accelerations

An examination of the acceleration data for the climb, en-route, and descent conditions (table I) indicates that approximately 50 percent of the total number of accelerations occurred during descent and less than 10 percent occurred during climb. When compared in terms of the average number of gust accelerations equal to or greater than ±0.3g per mile of flight, the highest and lowest frequencies occur during the descent and en-route conditions, respectively. The low frequency in the en-route flight condition can be attributed to the decrease in gust frequency with increasing altitude noted in table III. These results conform with the results previously reported in reference 1.

Gust and Gust-Load Histories

Inspection of figure 3 indicates that for derived gust velocities above about 20 fps the gust history for the northwestern United States-Alaska route falls about midway between the gust histories for the southern and central transcontinental routes. Maximum differences are about 3 to 1 in the frequency of occurrence for the higher gust velocities. Smaller differences are noted for gust velocities less than 20 fps.

The gust-load histories in figure 1 indicate close agreement between the data for the northwestern United States-Alaska route and the central transcontinental route in the United States. The gust loads for both these operations were somewhat more severe than those for the southern transcontinental operation in the United States, with maximum differences of about 4 or 5 to 1 in the gust-load frequencies per mile of flight.

In order to determine whether the differences noted between the three operations in figure 1 are significant or are merely the result of fluctuations between the samples, the same results are shown in figure 4 with the computed 95-percent confidence bands. Inspection of figure 4 indicates that the confidence bands overlap in the case of operation B but do not overlap in the case of operation A. Thus, when the criterion outlined previously is applied to the comparison of the present operation with those (operations A and B) of reference 1, no significant statistical differences apparently exist in the comparison of the present operation with operation B. However, significant statistical differences are suggested when the present operation is compared with operation A.

Maneuver Accelerations

Figure 2 shows that the maximum operational- and check-flight-maneuver accelerations experienced were 0.5g and 0.4g, respectively. The figure also indicates that at a value of a_n of 0.5g, the frequency of occurrence of the gust accelerations is roughly 35 times that of operational or check-flight-maneuver accelerations. At the low threshold value of 0.1g, the frequency of occurrence of operational-maneuver accelerations appears to be only slightly below that for the gust-acceleration frequency (if the gust acceleration should be extrapolated). These results are in contrast with those indicated for operations A and B of reference 1 which showed that maneuver accelerations formed a substantial part of the total gust-load history at the high values of acceleration. It is thus apparent that the frequency of occurrence of maneuver accelerations depends, to a large extent, upon a number of factors such as piloting techniques and operational procedures for the different airlines.

Airspeeds

An examination of the average indicated airspeeds in rough and smooth air (table IV), as well as an examination of the VGH records, indicates no general reduction in airspeed in rough air. Apparently, the level of turbulence for the present operation was not of sufficient intensity to necessitate a noticeable reduction in airspeed. These results are in agreement with other transport data previously reported.

CONCLUDING REMARKS

The results of an analysis of the data obtained with an NACA VGH recorder from a four-engine commercial transport airplane operating between the northwestern portion of the United States and Alaska have been compared with results previously reported in NACA Technical Note 3475 for two similar airplanes operating over transcontinental routes in the United States. These results indicated no large variations in the gust experience for the three operations. The gust-load experience of the present operation showed a close similarity to the operation for the central transcontinental route in the United States which partially covered similar terrain and showed differences of about 4 to 1 when compared with the operation for the southern transcontinental route in the United States. Gust accelerations occurred roughly 35 times more frequently than maneuver accelerations at a measured normal-acceleration increment of 0.5g.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., October 7, 1958.

REFERENCES

1. Copp, Martin R., and Coleman, Thomas L.: An Analysis of Acceleration, Airspeed, and Gust-Velocity Data From One Type of Four-Engine Transport Airplane Operated Over Two Domestic Routes. NACA TN 3475, 1955.

2. Richardson, Norman R.: NACA VGH Recorder. NACA TN 2265, 1951.

3. Donely, Philip: Summary of Information Relating to Gust Loads on Airplanes. NACA Rep. 997, 1950. (Supersedes NACA TN 1976.)

4. Anon.: Airplane Airworthiness - Transport Categories. Pt. 4b of Civil Air Regulations, Civil Aero. Board, U. S. Dept. Commerce, Dec. 31, 1953.

5. Coleman, Thomas L., and Copp, Martin R.: Maneuver Accelerations Experienced by Five Types of Commercial Transport Airplanes During Routine Operations. NACA TN 3086, 1954.

6. Pratt, Kermit G., and Walker, Walter G.: A Revised Gust-Load Formula and a Re-Evaluation of V-G Data Taken on Civil Transport Airplanes From 1933 to 1950. NACA Rep. 1206, 1954. (Supersedes NACA TN's 2964 by Kermit G. Pratt and 3041 by Walter G. Walker.)

7. Copp, Martin R., and Walker, Walter G.: Analysis of Operational Airline Data To Show the Effects of Airborne Weather Radar on the Gust Loads and Operating Practices of Twin-Engine Short-Haul Transport Airplanes. NACA TN 4129, 1957.

8. Press, Harry, and McDougal, Robert L.: The Gust and Gust-Load Experience of a Twin-Engine Low-Altitude Transport Airplane in Operation on a Northern Transcontinental Route. NACA TN 2663, 1952.

TABLE I.- FREQUENCY DISTRIBUTIONS OF GUST

ACCELERATIONS BY FLIGHT CONDITION

Normal acceleration (positive and negative), a_n, g units	Frequency of occurrence for -			Total
	Climb	En route	Descent	
0.3 to 0.4	126	775	775	1,676
.4 to .5	17	96	124	237
.5 to .6	13	30	35	78
.6 to .7	3	4	5	12
.7 to .8	2	3	3	8
.8 to .9	---	1	2	3
Total	161	909	944	2,014
Flight hours . . .	57.5	490.8	124.6	672.9
Flight miles . . .	0.97×10^4	10.7×10^4	2.6×10^4	14.2×10^4
Average indicated airspeed, knots	136.1	163.5	168.3	162.0
Average number of accelerations $\geqq \pm 0.3g$ per mile	1.65×10^{-2}	0.85×10^{-2}	3.63×10^{-2}	1.43×10^{-2}

TABLE II.- FREQUENCY DISTRIBUTIONS OF MANEUVER ACCELERATIONS

(a) Operational maneuvers

Normal acceleration, a_n, g units	Frequency of occurrence
0.5 to 0.6	3
.4 to .5	7
.3 to .4	33
.2 to .3	327
.1 to .2	5,859
-.1 to -.2	6,770
-.2 to -.3	328
-.3 to -.4	11
-.4 to -.5	1
Total	13,339
Flight hours	672.9
Flight miles	14.2×10^4

(b) Check-flight maneuvers

Normal acceleration, a_n, g units	Frequency of occurrence
0.4 to 0.5	2
.3 to .4	12
.2 to .3	54
.1 to .2	244
-.1 to -.2	282
-.2 to -.3	83
-.3 to -.4	11
-.4 to -.5	4
Total	692
Flight hours	676.0
Time spent in check flights, hr	3.1
Flight miles	14.3×10^4

TABLE III.- FREQUENCY DISTRIBUTIONS OF DERIVED GUST VELOCITIES

Derived gust velocity (positive and negative), fps	Frequency of occurrence for -			Total
	0 to 5,000 ft	5,000 to 10,000 ft	10,000 to 15,000 ft	
8 to 12	183	201	118	502
12 to 16	429	334	295	1,058
16 to 20	262	43	42	347
20 to 24	49	13	10	72
24 to 28	18	3	5	26
28 to 32	3	---	2	5
32 to 36	3	---	1	4
Total	947	594	473	2,014
Flight hours . . .	101.4	373.2	198.3	672.9
Flight miles . . .	1.8×10^4	7.8×10^4	4.4×10^4	14.2×10^4
Average number of gusts $\geqq \pm 8$ fps per mile	5.26×10^{-2}	0.73×10^{-2}	1.10×10^{-2}	1.43×10^{-2}

TABLE IV.- OPERATING AIRSPEEDS

Turbulence level	Average indicated airspeed, knots, for -			
	Climb	En route	Descent	Total
Smooth air . . .	136	163	168	162
Rough air . . .	138	165	170	163
Total	136	163	168	162

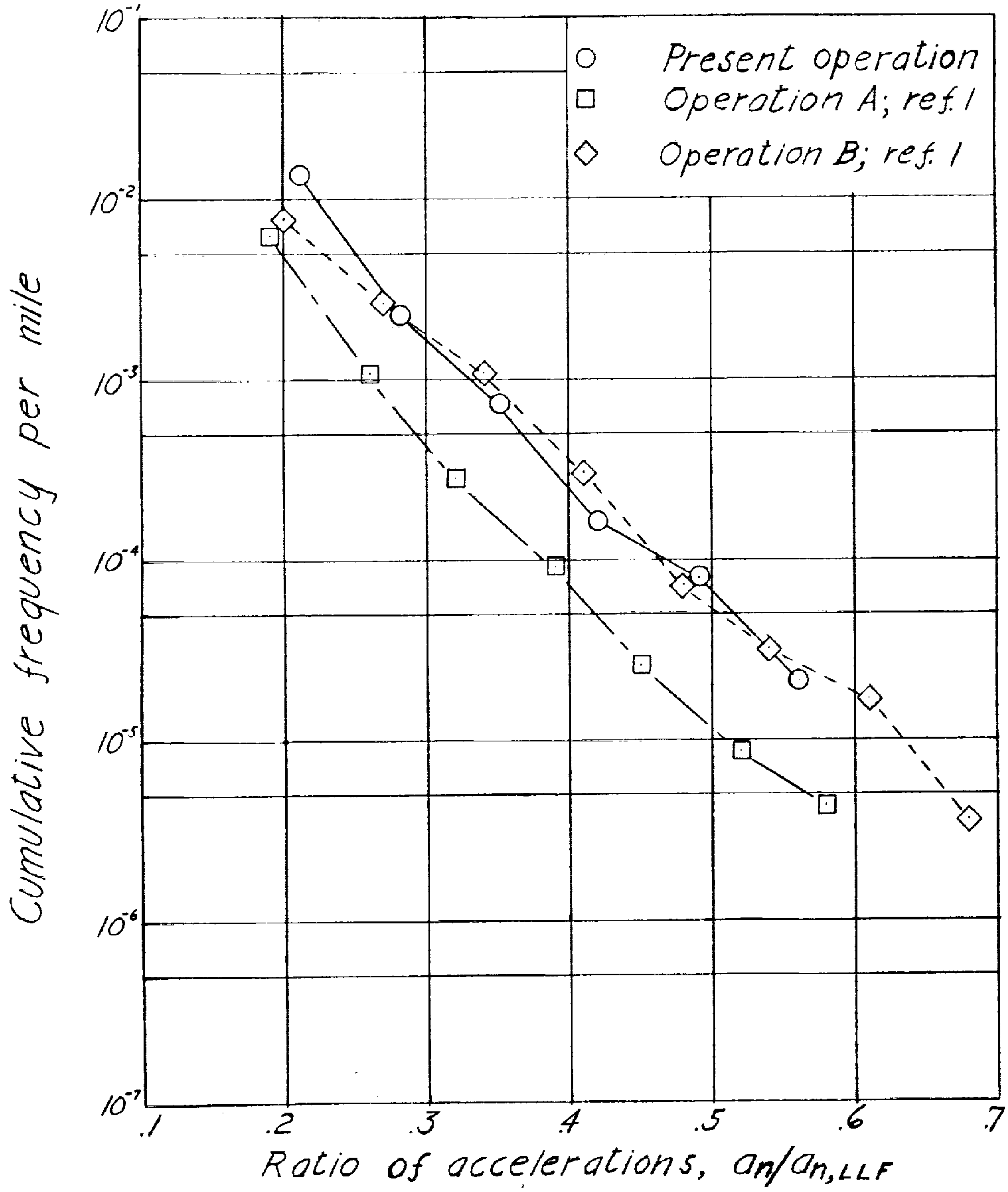


Figure 1.- Comparison of gust-load histories for three operations.

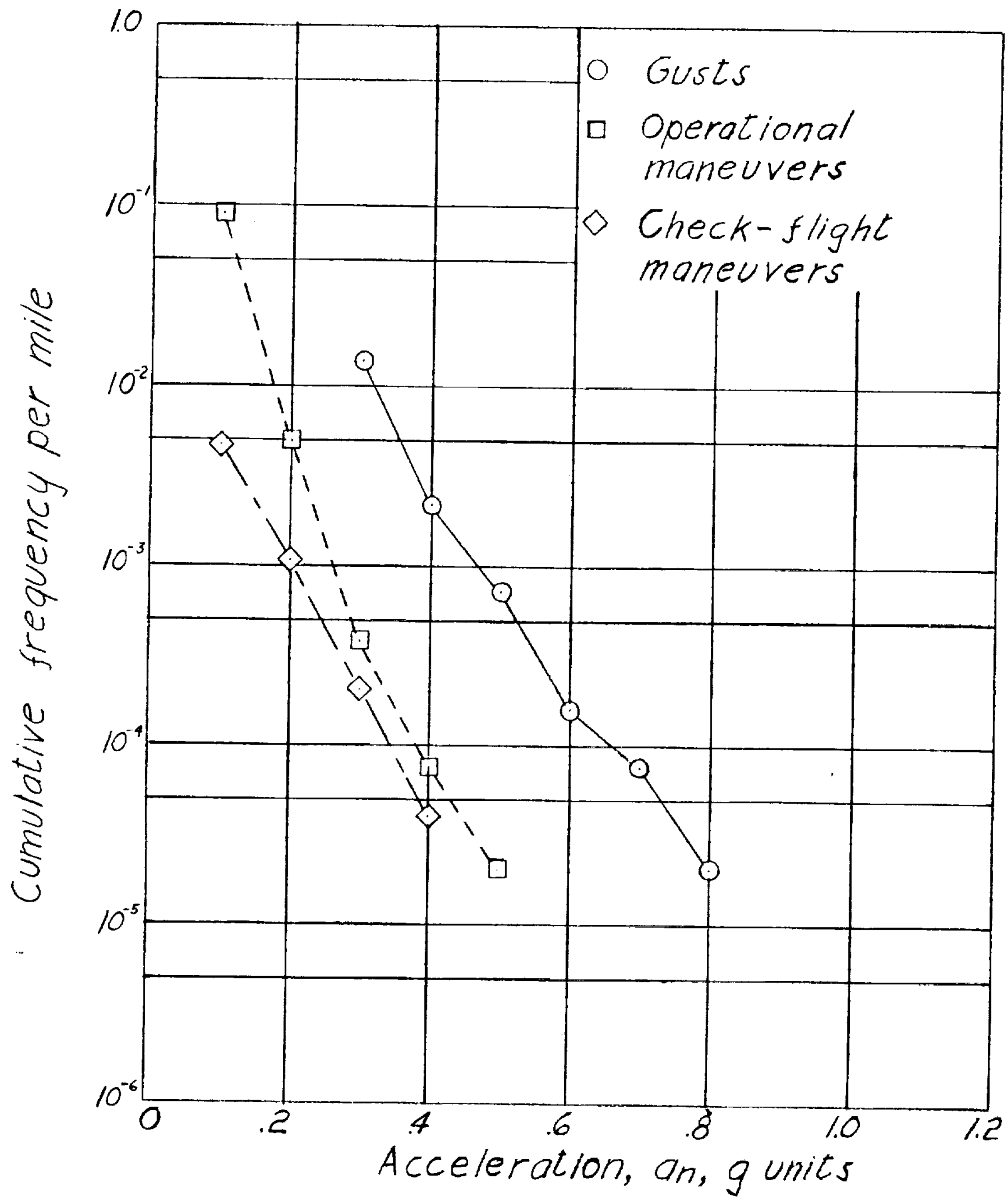


Figure 2.- Comparison of frequency of exceeding given values of gust and maneuver accelerations per mile of flight.

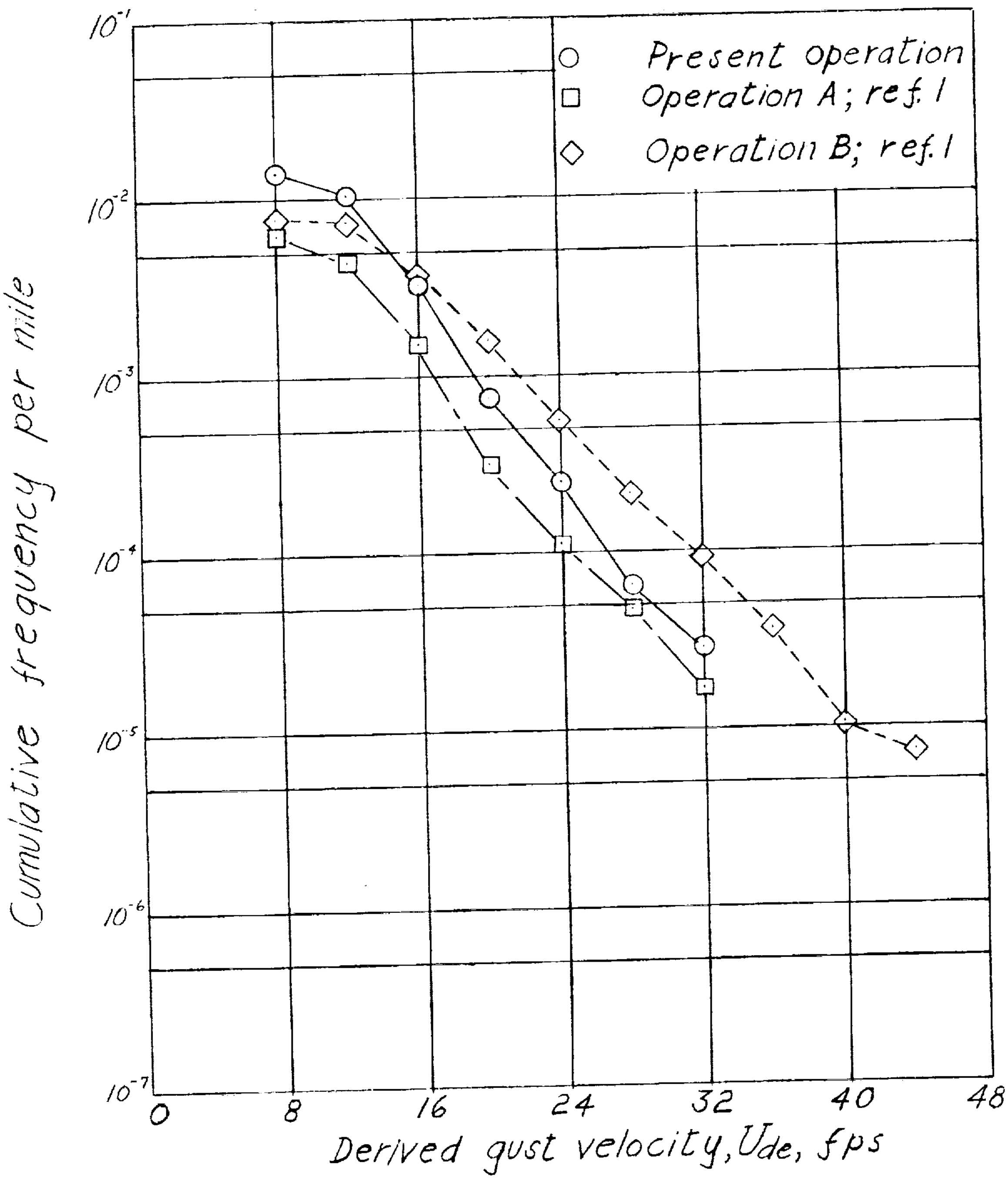
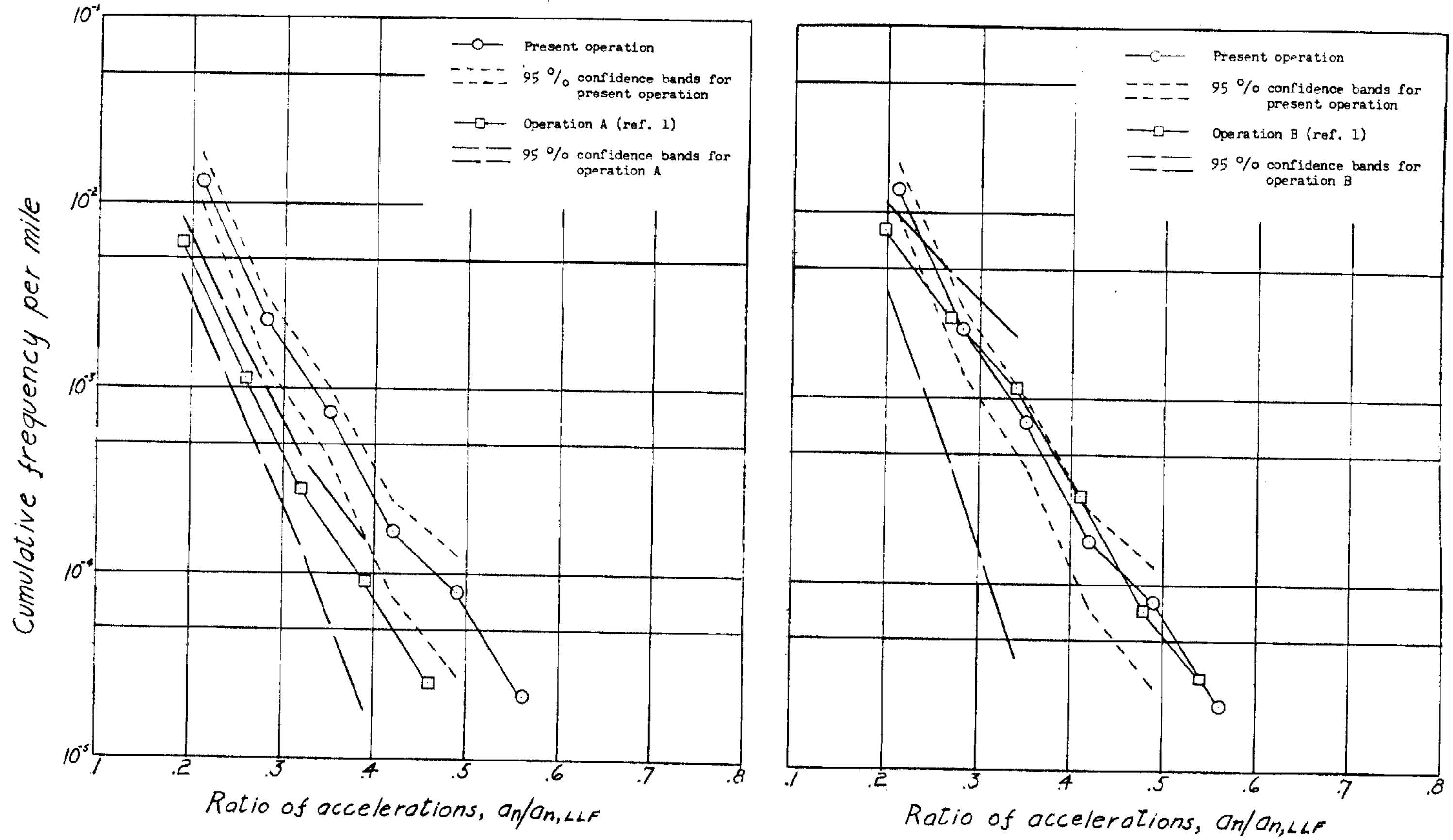


Figure 3.- Comparison of frequency of exceeding given values of derived gust velocity per mile of flight for three operations.



(a) Comparison of present operation with operation A (ref. 1).

(b) Comparison of present operation with operation B (ref. 1).

Figure 4.- Gust-load histories and computed 95-percent confidence bands.