NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3750

AN ANALYSIS OF AIRSPEED, ALTITUDE, AND ACCELERATION DATA OBTAINED FROM A TWIN-ENGINE TRANSPORT AIRPLANE OPERATED OVER A FEEDER-LINE ROUTE IN THE ROCKY MOUNTAINS

By Martin R. Copp and Mary W. Fetner

Langley Aeronautical Laboratory
Langley Field, Va.

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SUMMARY

Time-history data of airspeed, altitude, and acceleration obtained with the NACA VGH recorder from a twin-engine airplane operated by a regional feeder airline in the Rocky Mountains are evaluated to determine the magnitude and frequency of occurrence of gusts and gust accelerations and the operating airspeeds and altitudes. The results obtained are compared with the results previously obtained from a representative short-haul and long-haul operation.

The larger amount of turbulence at the low operating altitudes over the mountainous terrain resulted in a higher frequency of occurrence of gusts of small intensity for the feeder-line operation than for the other operations. The gusts of larger intensity were more frequent for the short-haul and long-haul operations. The differences in the gust-load factors for the operations appeared to be a direct reflection of the gust intensities in that the small load factors were more frequent for the feeder-line operation, whereas the larger values were less frequent than those for the short-haul and long-haul operations.

INTRODUCTION

Data have been collected for a number of years by the National Advisory Committee for Aeronautics with the NACA V-G and VGH recorders in a continuing study of the gusts and gust accelerations experienced by commercial transport airplanes. This information has proven useful in the formulation of design requirements, in the study of fatigue problems, and in the prediction of gust and gust load histories for new types of operations. Most of these data have been obtained from the long-haul types of operations on domestic and transoceanic routes. No information has been obtained to date from the so-called regional or feeder-line types of operation. In order to sample these types of operations, VGH data have been obtained from feeder-line operations in the

Rocky Mountain area. These operations generally consisted of flights of short duration at relatively low altitudes above extremely rough terrain.

The VGH data for the feeder-line operations are analyzed in this paper to determine the magnitude and frequency of occurrence of gusts, gust and maneuver accelerations, and the operating airspeeds and altitudes. The gust and load histories are then compared with those obtained from representative short-haul and long-haul operations previously reported (ref. 1 and operation A of ref. 2). V-G data previously obtained from the feeder-line operation (ref. 3) are also used to supplement the VGH data in order to obtain an estimate of the overall gust and acceleration history for the operation.

INSTRUMENTATION AND SCOPE OF DATA

The data were collected with an NACA VGH recorder which is described in detail in reference 4. The recorder obtains a time-history record of the indicated airspeed, pressure altitude, and normal acceleration for each flight of the airplane.

The routes over which the present data were obtained are shown in figure 1. The relatively short flights and the rough terrain characteristics for these operations are evident from the figure. The VGH data represent a total of 1,291 flight hours which include 12.8 hours spent in check flights. In all, 2,029 flights were made between the individual stops in figure 1 during the record-collection period (February 1953 to August 1954) with an average flight duration of 38 minutes.

An examination of the VGH records indicated that the operations were generally conducted at pressure altitudes ranging from 5,000 to 15,000 feet. A consideration of the topography covered by the routes, however, indicates that most of the flights were at altitudes of less than 5,000 feet above the terrain.

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

Design gross weight, W, lb	25,200
Wing area, S, sq ft	987
Span, b, ft	95
Aspect ratio, A	9.1
Mean geometric chord, c, ft	10.4
Slope of lift curve, a, per radian $\left(\text{computed from } \frac{6A}{A+2}\text{, ref. 5}\right)$	4.92

Design speed for maximum gust intensity (indicated), V_B (computed according to ref. 6), mph 138

Design cruising speed (indicated), V_C (also manufacturer's design maximum level-flight speed V_L), mph 211

Design never-exceed speed (indicated), V_{NE}, mph 257

Normal acceleration corresponding to the design limit-gust-load-factor increment, $a_{n,LLF}$ (computed according to ref. 6), g units 2.34

Unless otherwise indicated, the values listed were obtained from the manufacturer's design data.

EVALUATION OF RECORDS AND PRESENTATION OF RESULTS

Frequency distributions of gust and maneuver accelerations, gust velocities, indicated airspeeds, and pressure altitudes were obtained by procedures such as those discussed in reference 2. These procedures and the results obtained are described briefly in the following sections.

Acceleration

Gust accelerations above a threshold of 0.3g were read from the VGH records by using the steady-flight position of the acceleration trace as a reference. The resulting frequency distributions of gust accelerations by flight condition (climb, en route, and descent) as well as the total frequency distribution are given in table I for class intervals of 0.1g. Positive and negative values of the gust accelerations have been combined in table I since the distributions were essentially symmetrical about zero g. The number of flight hours and flight miles represented by each distribution are also given as well as the average indicated airspeeds for each phase of the operation.

The total gust acceleration distribution of table I is shown in figure 2 in terms of the average number of accelerations greater than a given value exceeded per mile of flight. The solid line in the figure was faired through the data points to represent the distribution. For comparison, the corresponding gust acceleration distributions for a short-haul operation (ref. 1) and a long-haul operation (operation A of ref. 2) are also shown in figure 2. The pertinent operational data and characteristics of the airplanes involved in the three operations are given in table II. In order to express these data in a form suitable for load-factor comparison, the accelerations in figure 2 were divided by the acceleration $a_{n,LLF}$ corresponding to the computed limit-gust-load-factor increment for each airplane, and the results are presented in figure 3. The values of $a_{n,LLF}$ used in obtaining the data in figure 3 are given in table II.

Check-flight-maneuver accelerations were evaluated by reading the appropriate deflections of the acceleration trace greater than a threshold value of ±0.1g. The resulting distributions of the positive and negative accelerations are given in table III. The total number of record hours, the amount of time actually spent in check flights, and the flight miles represented by the distribution are also shown in table III.

Because in some past cases the maneuver accelerations have contributed substantially to the total acceleration history of the airplane, the combined positive and negative distributions of table III are compared with the gust acceleration distribution in figure 4. It was found impractical to evaluate the records for the additional maneuver accelerations experienced during the regular operational flights since these accelerations were relatively small and difficult to distinguish from the much larger number of gust accelerations.

Gust Velocities

Derived gust velocities U_{de} were calculated by means of the revised gust load formula of reference 7 for each gust acceleration peak and the corresponding indicated airspeed and altitude. The resulting frequency distributions are presented in table IV for class intervals of 4 feet per second for each flight condition and for the total operation. Only gust velocities greater than 8 feet per second are given in the table because the lower values corresponded to accelerations less than the threshold value of 0.3g. Positive and negative gust velocities were combined as in table I because the distributions were essentially symmetrical about zero gust velocity. The frequency of occurrence of gust velocities for the complete operation is plotted in figure 5. A solid line was faired through the data points to indicate the trend of the distribution. Gust-velocity distributions for the short-haul and long-haul operations previously discussed are also shown in figure 5 for comparison.

Operating Airspeeds and Altitudes

In order to define the operating airspeeds and altitudes for the feeder-line operations, the indicated airspeed and pressure altitude were read from the records for each 1-minute interval of flight. The distributions of indicated airspeed obtained from these readings for the climb, en-route, and descent conditions are shown in figure 6 as portions of the flight time spent within given airspeed intervals. The distributions of airspeed for which acceleration increments greater than 0.3g were experienced are also given in the figure to indicate any difference between the speeds in rough air and the overall speeds.

In figure 7, the distributions of pressure altitude for the climb, en-route, and descent conditions are shown as portions of the flight time spent within each interval of 1,000-foot altitude.

Estimation of Overall Acceleration and Gust Histories

V-G data covering longer periods of operation over the same routes have been combined with the VGH data in the past to obtain estimates of the total load and gust histories. (See, for example, refs. 1 and 2.) V-G data were available for 10,476 hours of operations from the same operator and for the same transports (operation C, ref. 3) as for the present VGH sample. These combined V-G and VGH samples of gust acceleration data are shown in figure 8. The V-G data are shown only for values greater than 1.0g since only at these larger values do they represent the frequency of occurrence of the gust accelerations encountered. The corresponding gust-velocity data are shown in figure 9. In both figures 8 and 9, a solid line has been faired through the data points to indicate the overall acceleration and gust histories for the extended samples.

PRECISION AND RELIABILITY OF RESULTS

Instrument and reading errors for the VGH recorder are discussed in detail in reference 4 and are not considered of sufficient magnitude to affect the reliability of the results. More serious questions concern how well the relatively small VGH samples represent the loads and gusts for extended or long-period operations. In order to obtain estimates of the reliability of the data sample, the variations between the distributions from individual records and from combinations of the records forming the total data sample have been checked. Based on these comparisons, the total distributions of gust accelerations and gust velocities are estimated to be reliable within a factor of about 2 on the ordinate scale at the smaller acceleration and gust-velocity values and within a factor of 3 at the higher values. The reliability of the check-flight-maneuver data may be somewhat less because of the small number of hours spent in check flights.

DISCUSSION

Gust Velocities

Figure 5 indicates that more gusts of smaller intensity and fewer of the larger gusts were encountered by the feeder-line operation than by the short-haul or long-haul operations. The high frequency of occurrence of the smaller gusts for the feeder-line operation probably resulted from the larger amount of turbulence at the lower altitudes over the mountainous terrain. In addition, little effort was probably made to climb above this turbulence because of the short duration of most of the flights. (See fig. 1.) The lower frequency of the larger gusts for the feeder-line operation may have resulted from more conservative operating practices in regard to such factors as severe weather avoidance.

It was also noted that the gust-velocity data indicated very little variation in gust frequency with an increase in pressure altitude for the altitude range covered by the data. This characteristic of the present data apparently resulted from the essentially constant flight altitude above terrain for all flight conditions. In many cases, mountain peaks near the flight path extended above the cruising altitudes for the present operations.

Gust Accelerations

Figure 2 indicates that the frequency of gust accelerations for the feeder-line operation is approximately 3 times greater than that for the short-haul operation and 30 times greater than that for the long-haul operation. Differences between the frequency of gust accelerations for various operations are primarily due to variations in the gust experiences, wing loadings, and the airspeeds flown in rough air. Since neither the gust experience, particularly for the larger gusts (fig. 5), nor the airspeeds in rough air (table II) were excessive for the feeder-line operation, its relatively high gust acceleration frequency is due almost entirely to the low wing loading of the airplane (table II).

Table I indicates that the number of gust accelerations experienced per mile of flight during the en-route portion of the present operation was greater than the number experienced in climb and approximately equal to the number experienced during descent. This result is in contrast to other operations (refs. 1, 2, 8, and 9) where the number of gust accelerations per mile of flight was less for the en-route condition than for either the climb or descent condition. The number of gust accelerations per mile for each flight condition was largely determined by the airspeeds for the climb, en-route, and descent conditions since, as previously noted, little variation in gust frequency with increasing altitude was evident for the feeder-line operation. This is apparent in table I which indicates that the average airspeeds and acceleration frequencies for the en-route and descent flight conditions are approximately similar.

Load Factors

Figure 3 indicates that the smaller load factors are most frequent for the feeder-line operation. The larger load factors, on the other hand, are more frequent for the short-haul and long-haul operations. The similarity between figures 3 and 5 would indicate that the differences in the load-factor histories are a direct reflection of the variations in the gust velocities encountered.

Check-Flight-Maneuver Accelerations

Figure 4 indicates that check-flight maneuvers contributed only a minor portion of the accelerations less than 0.8g. For values greater than 0.8g, however, check-flight-maneuver accelerations were a significant portion of the total acceleration history in the feeder-line operation. Similar results have been noted in reference 2 and for operations A, D, and E of reference 10.

Overall Acceleration and Gust Histories

Figure 8 indicates that the maximum acceleration encountered in the feeder-line operation for the total of about 11,800 hours of V-G and VGH data was considerably less than the acceleration corresponding to the design-gust-load-factor increment of 2.34. The faired curve indicates that an acceleration of 0.5g was exceeded on the average about 10^{-2} times per mile of flight, or once in every 100 miles. An acceleration of 1.0g was exceeded on the average once in about every 20,000 miles. The largest acceleration encountered for the feeder-line operation was 1.6g. It appears from these values that the chance of exceeding the design-gust-load-factor increment was very remote.

The faired curve for the feeder-line operation in figure 9 indicates that a 50-foot-per-second gust was exceeded on the average 6.0×10^{-7} times per mile of flight or once in every 1.7×10^{6} flight miles. For the short-haul operation (fig. 5 of ref. 1) a 50-foot-per-second gust was exceeded once in about 0.8×10^{5} flight miles, or approximately 20 times more frequently. V-G data were not available for determining the overall gust acceleration and gust-velocity distributions for the long-haul operation (operation A, ref. 2).

Operating Airspeeds and Altitudes

The overall airspeed distributions shown in figure 6 indicate that the airplane was operated at speeds substantially below the design cruising speed V_C of 211 miles per hour and averaged about $0.60V_C$ in the climb condition and about $0.72V_C$ in the en-route and descent conditions. Figure 6 also indicates negligible differences for all flight conditions between the overall airspeeds and the airspeeds in rough air (dashed curves). For the climb condition, the average airspeed in rough air was approximately 6 miles per hour less than the design speed for maximum gust intensity V_B of 138 miles per hour, whereas for the en-route and descent conditions the average rough-air speed was approximately 15 miles per hour higher than V_B. Although many factors such as the amount and severity of the turbulence or the operator's familiarity with conditions on the routes may affect the airspeeds, the data in figure 6 indicate that significant reductions in airspeed were not made when turbulence was encountered.

It may be noted from figure 7 that for this operation more than half the total flight time was spent in climb and descent.

CONCLUSIONS

An analysis of 1,291 hours of VGH data obtained from a twin-engine airplane operating over a feeder-line route in the Rocky Mountains has been made. A comparison of the results with those of a short-haul and a long-haul operation previously reported indicate the following:

1. The frequency of occurrence of gust accelerations for the feeder-line operation was approximately 3 times greater than that for the short-haul operation and 30 times greater than that for the long-haul operation.

2. The small gusts and load factors were more frequent for the feeder-line operation, whereas the larger values were less frequent for the feeder-line operation than those for the short-haul and long-haul operations.

3. Check-flight maneuvers contributed a significant portion of the larger loads experienced by the feeder-line operation.

4. A composite distribution of V-G and VGH data obtained from about 11,800 flight hours indicated that the maximum acceleration encountered by the feeder-line operation was considerably less than the acceleration corresponding to the design-gust-load-factor increment of 2.34. A 50-foot-per-second gust was exceeded on the average 6.0×10^{-7} times per mile of flight or once in every 1.7×10^{6} flight miles.

5. The feeder-line airplane was operated at speeds substantially below the design cruising speed V_C of 211 miles per hour in all flight conditions. The average speed during the climb was about $0.60V_C$, whereas the en-route and descent speeds averaged about $0.72V_C$. No significant reductions in the operating airspeeds in turbulence were noted.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 4, 1956.

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TABLE I.- FREQUENCY DISTRIBUTIONS OF GUST ACCELERATIONS

Acceleration (positive and negative), a_n, g units	Frequency distribution for-			
	Climb	En route	Descent	Total
0.3 to 0.4	4,714	17,164	15,787	37,665
.4 to .5	822	3,652	3,059	7,533
.5 to .6	206	1,029	840	2,075
.6 to .7	64	280	233	577
.7 to .8	18	84	50	152
.8 to .9	7	29	12	48
.9 to 1.0	2	6	3	11
1.0 to 1.1		3		3
Total	5,833	22,247	19,984	48,064
Flight hours	276.8	567.3	434.1	1,278.2
Flight miles	3.9×10^4	9.9×10^4	7.4×10^4	2.1×10^5
Average indicated airspeed, mph	126.5	151.1	152.1	146.2
Average number of accelerations $\geqq$ 0.3g per mile	1.50×10^{-1}	2.25×10^{-1}	2.70×10^{-1}	2.29×10^{-1}

TABLE II.- OPERATIONAL DATA

Operation	Route	Weight, lb	Wing loading, lb/sq ft	Average cruising altitude, ft	Average length of flight, hr	Average indicated airspeed, mph		V_C (indicated airspeed), mph	$\frac{V_{Rough\ air}}{V_C}$	$a_{n,LLF}$
						Overall	Rough air			
Feeder-line	Rocky Mountain region	25,200	25.5	9,600	0.63	146	150	211	0.71	2.34
Short-haul (ref. 1)	Transcontinental (New York - Los Angeles)	40,500	49.6	7,050	.78	201	199	280	.71	1.76
Long-haul (operation A of ref. 2)	Transcontinental (New York - Los Angeles, New York - San Francisco)	89,900	61.4	14,100	1.95	228	235	300	.78	1.54

TABLE III.- FREQUENCY DISTRIBUTION OF CHECK-FLIGHT-MANEUVER ACCELERATIONS

Acceleration, a_n, g units	Frequency distribution
1.2 to 1.3	1
1.1 to 1.2	0
1.0 to 1.1	2
.9 to 1.0	5
.8 to .9	7
.7 to .8	8
.6 to .7	20
.5 to .6	16
.4 to .5	39
.3 to .4	142
.2 to .3	468
.1 to .2	612
-.1 to -.2	674
-.2 to -.3	444
-.3 to -.4	130
-.4 to -.5	35
-.5 to -.6	9
-.6 to -.7	7
-.7 to -.8	1
-.8 to -.9	3
Total (positive and negative)	2,623
Flight hours	1,291.0
Time in check flights, hr	12.8
Flight, miles	2.1×10^5

TABLE IV.- FREQUENCY DISTRIBUTIONS OF DERIVED GUST VELOCITIES BY FLIGHT CONDITION

Gust velocity, U_{de}, fps	Frequency distribution for -			
	Climb	En route	Descent	Total
8 to 12	4,483	19,356	16,719	40,558
12 to 16	1,128	2,228	2,156	5,512
16 to 20	167	314	315	796
20 to 24	40	55	47	142
24 to 28	10	12	5	27
28 to 32	3	3	2	8
32 to 36		2		2
Total	5,831	21,970	19,244	47,045
Flight hours	276.8	567.3	434.1	1,278.2
Flight miles	3.9×10^4	9.9×10^4	7.4×10^4	2.1×10^5
Average number of gusts per mile	1.50×10^{-1}	2.22×10^{-1}	2.60×10^{-1}	2.24×10^{-1}

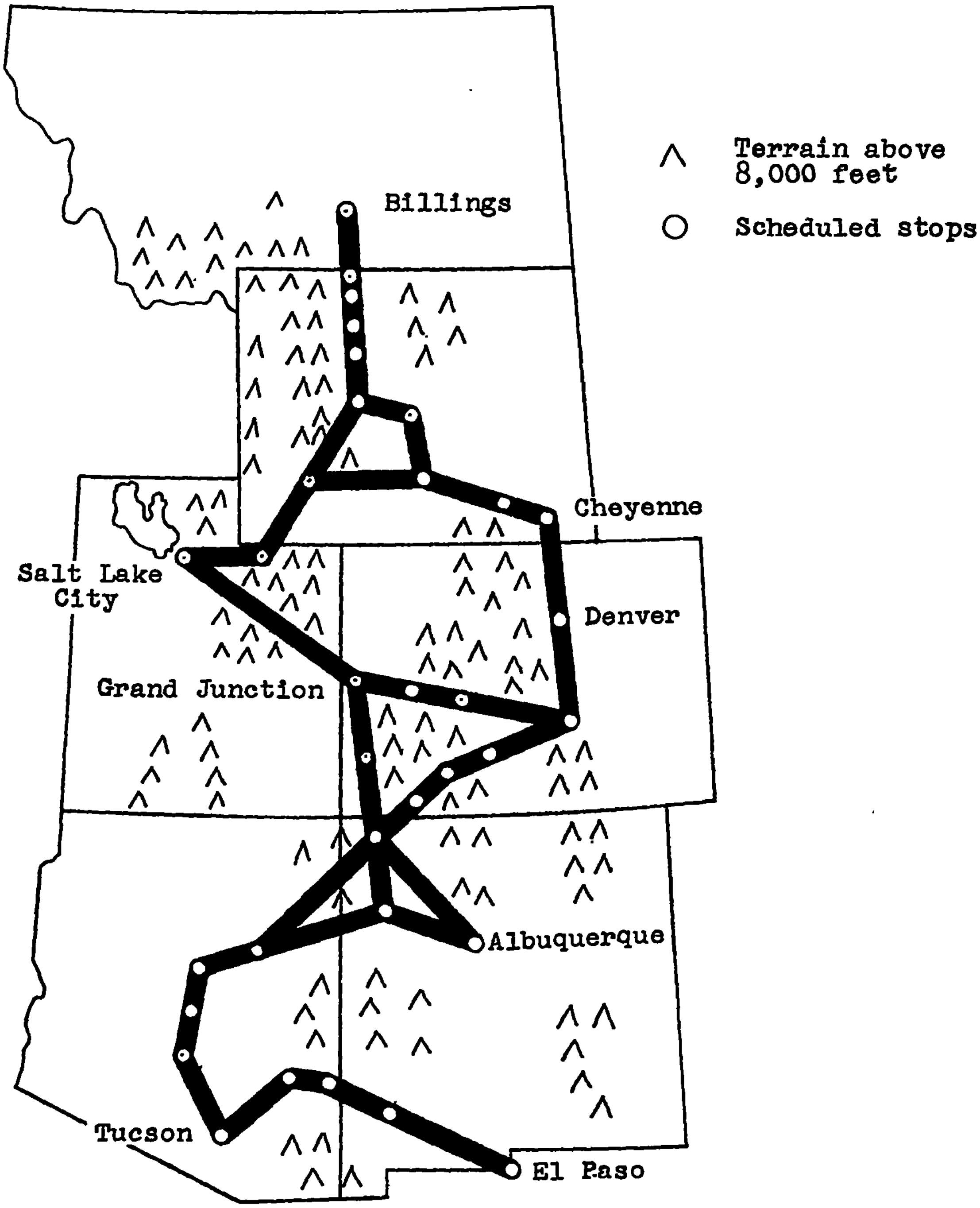

Figure 1.- Routes on which VGH records were collected.

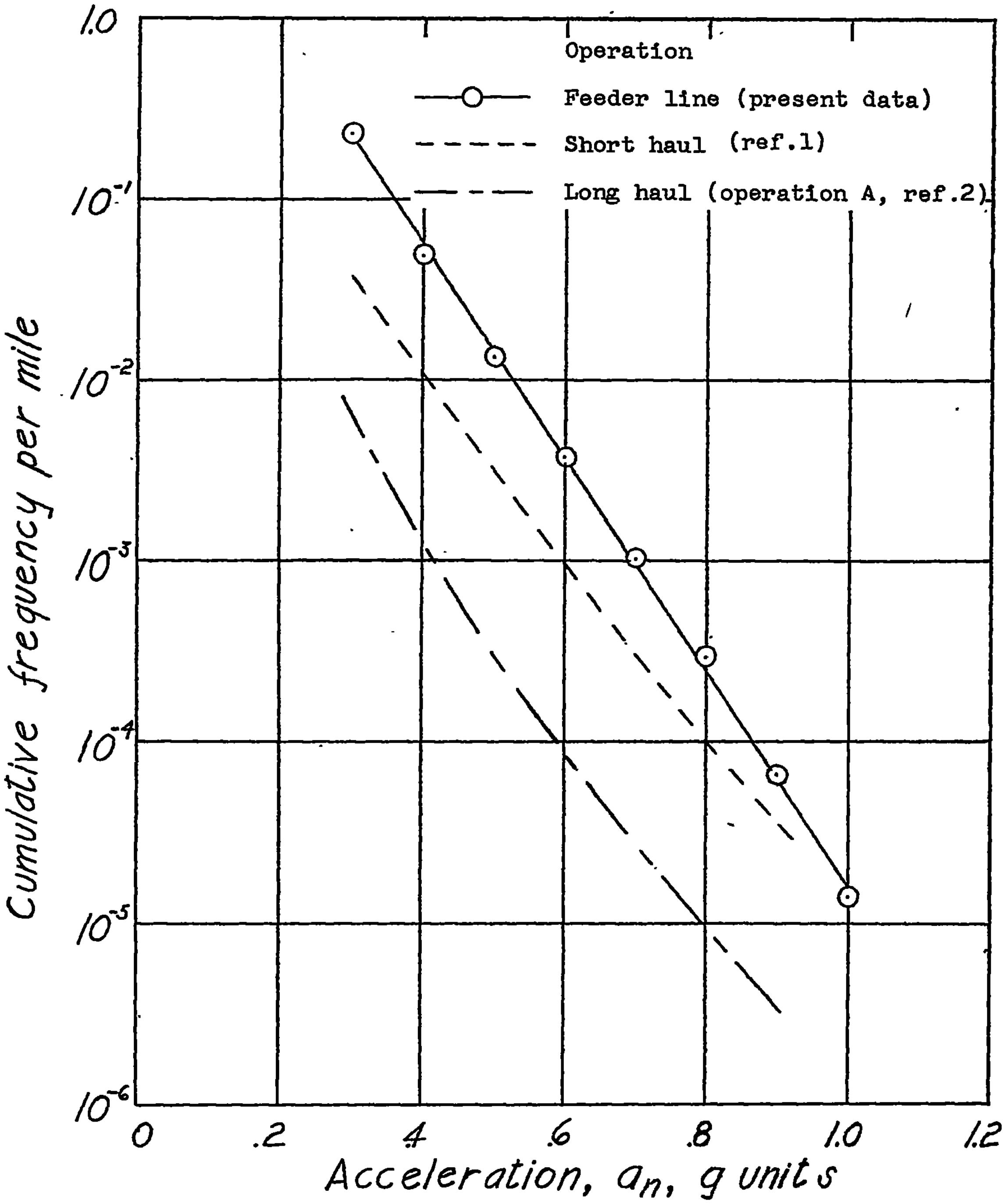

Figure 2.- Comparison of frequency of exceeding given values of gust acceleration per mile of flight for three operations.

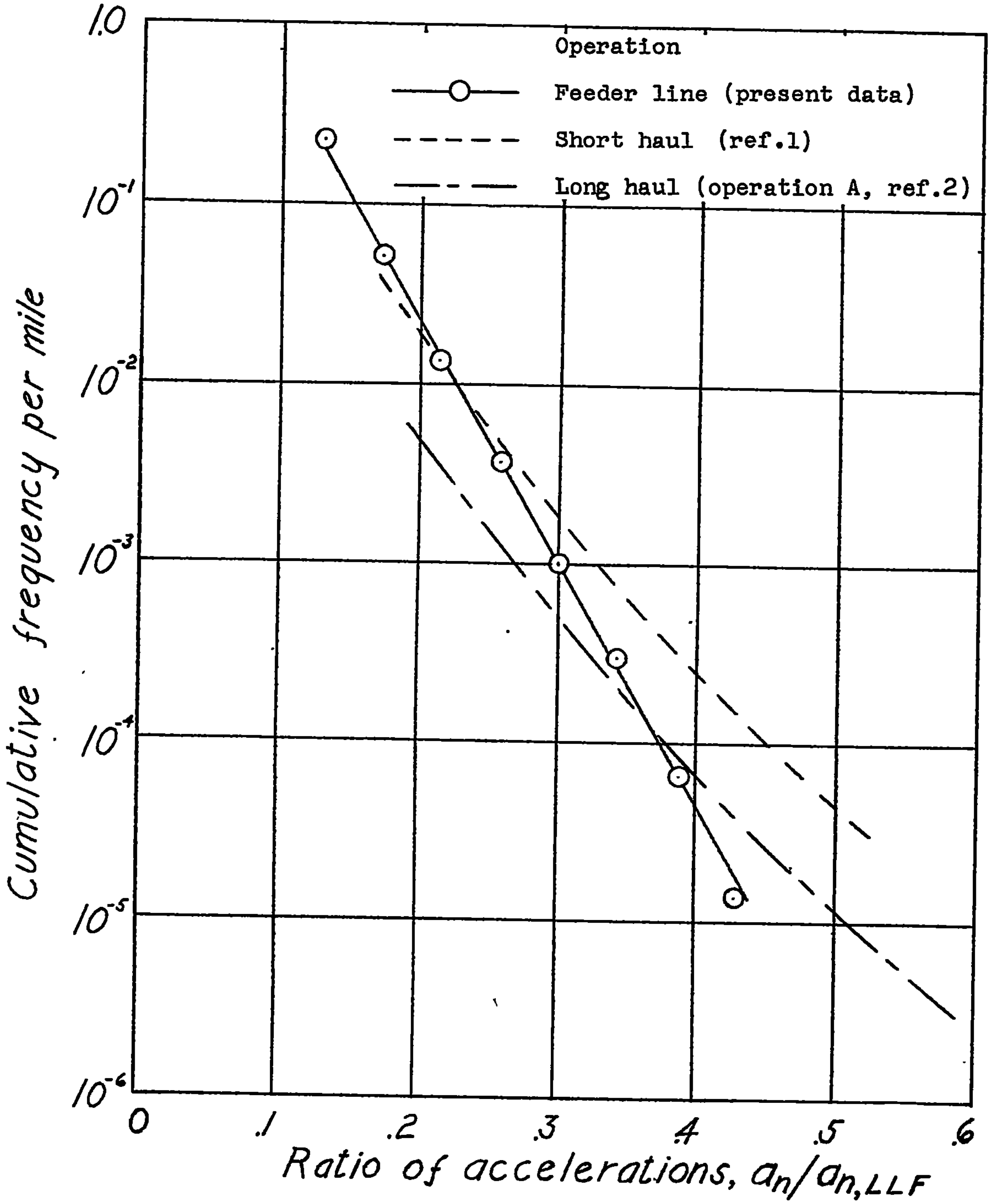

Figure 3.- Comparison of load-factor histories for three operations.

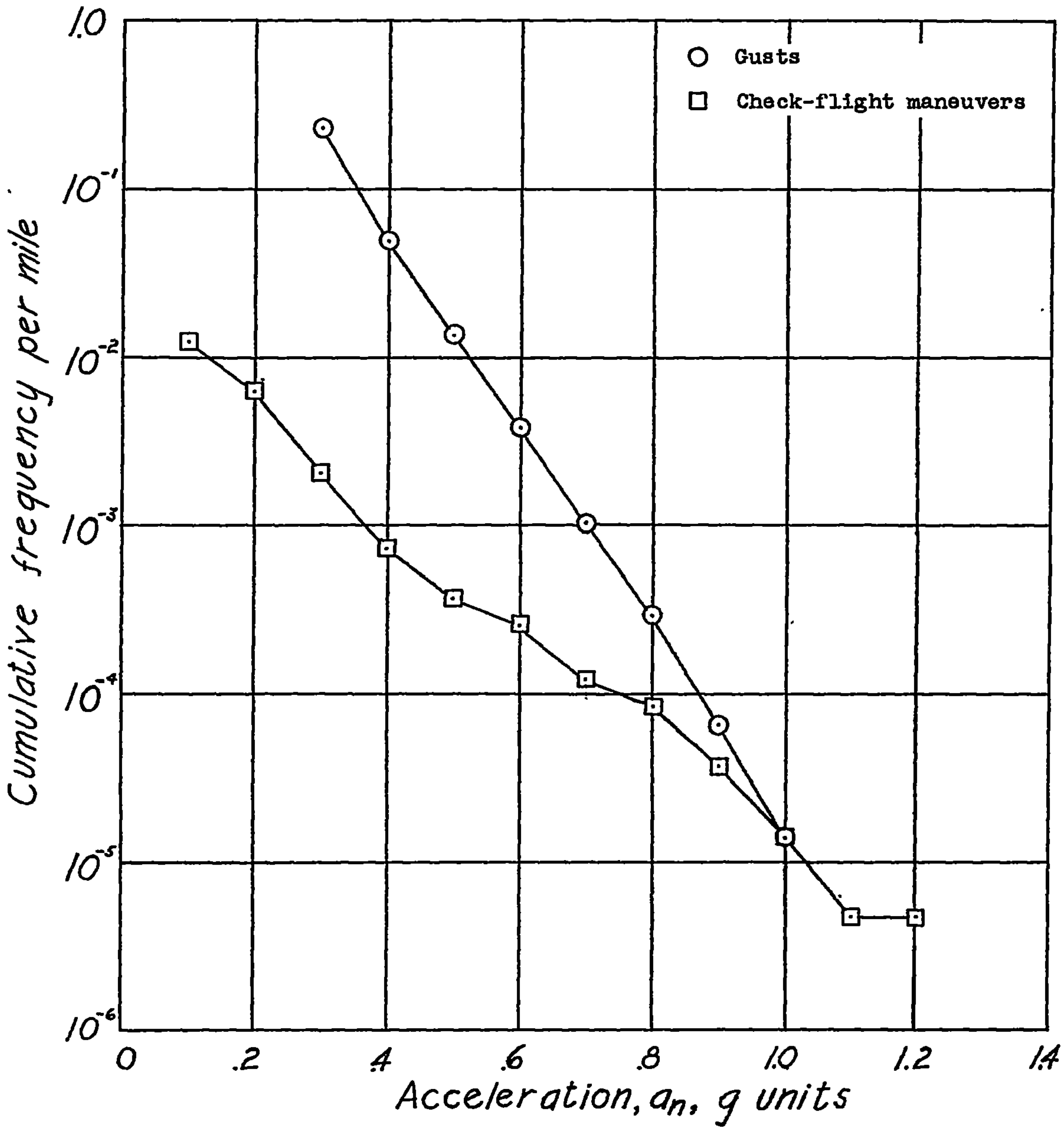

Figure 4.- Comparison of frequency of exceeding given values of gust and check-flight-maneuver accelerations per mile of flight.

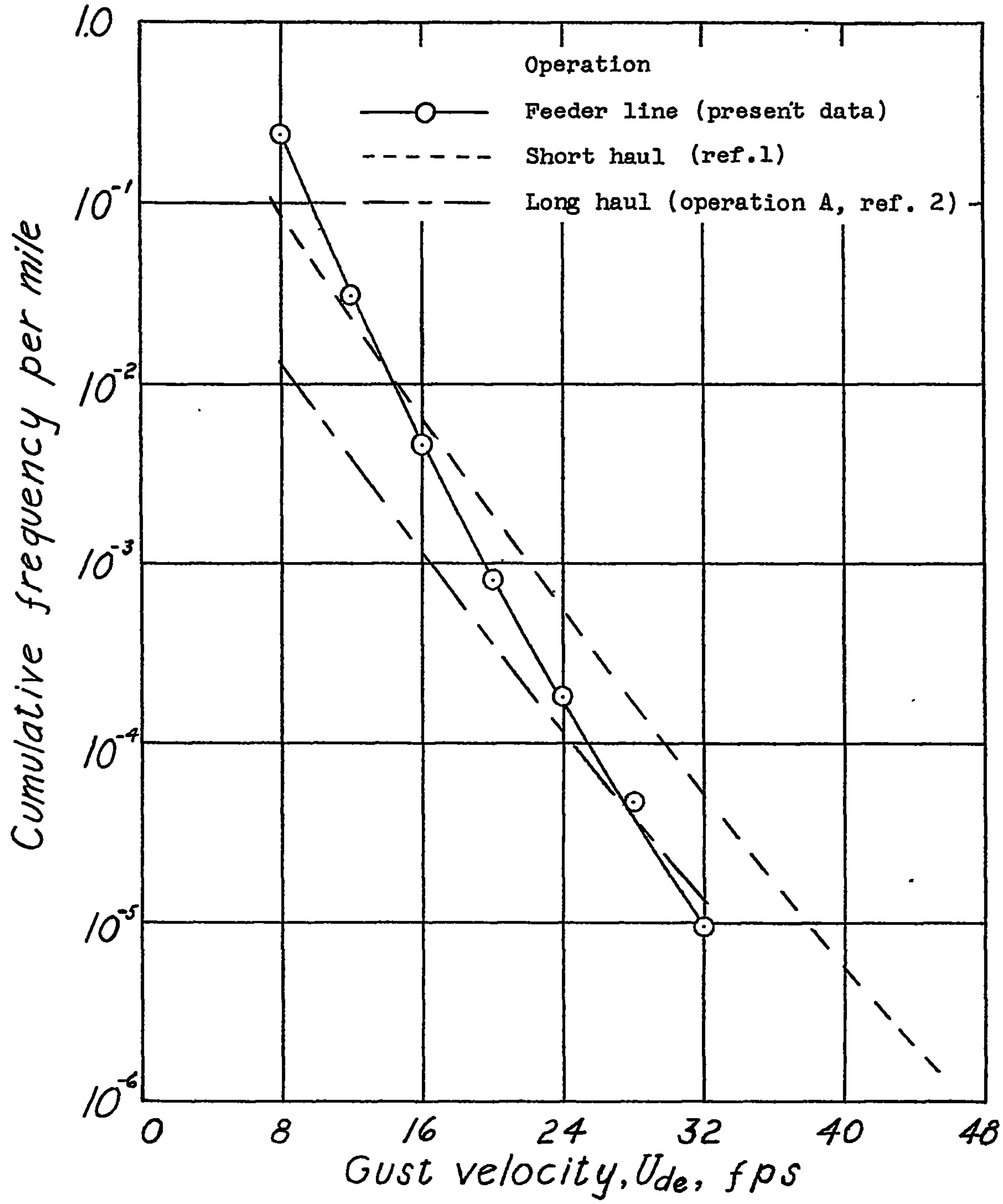

Figure 5.- Comparison of frequency of exceeding given values of derived gust velocity per mile of flight for three operations.

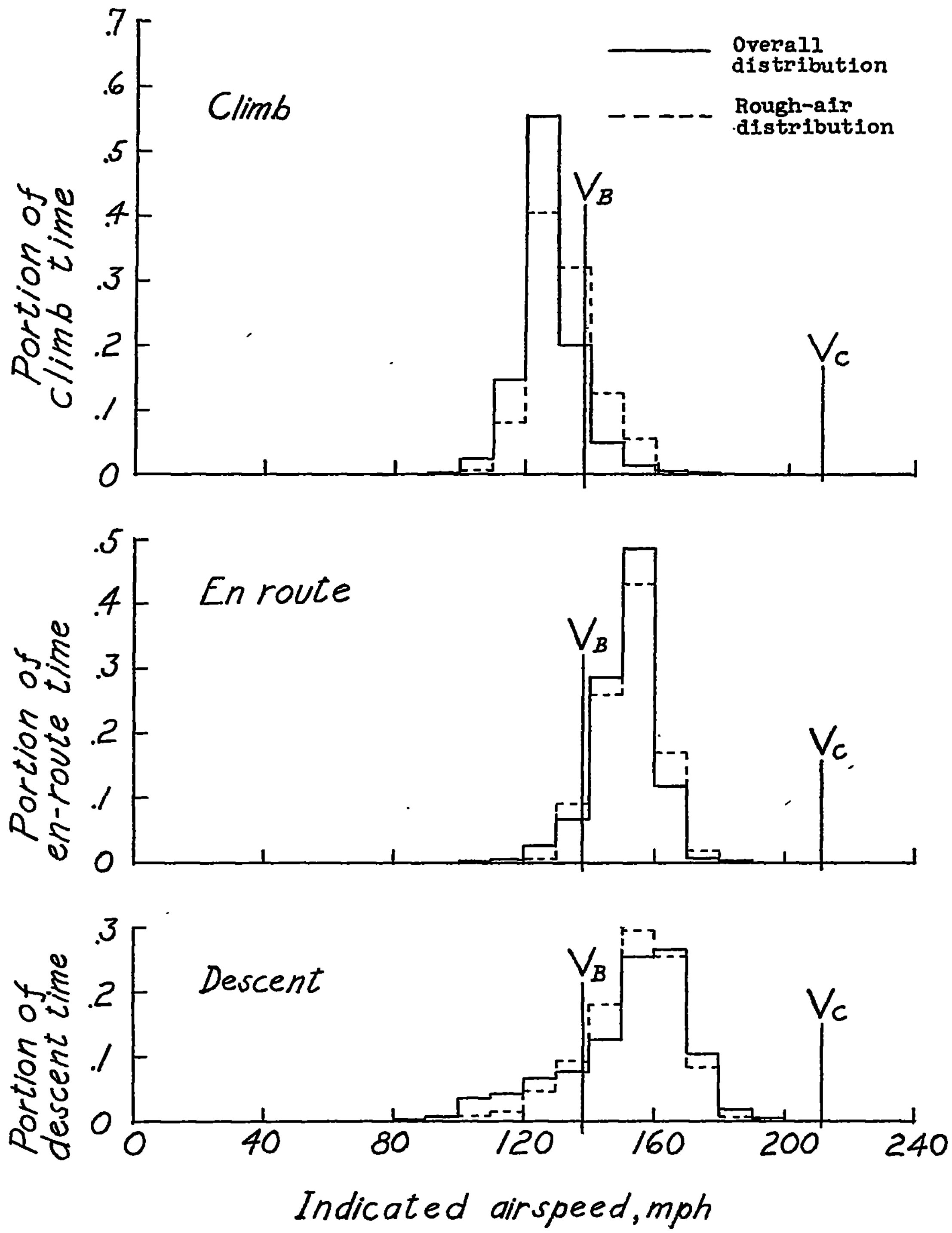

Figure 6.- Comparison of distributions of overall airspeed with the distributions of airspeed in rough air by flight condition.

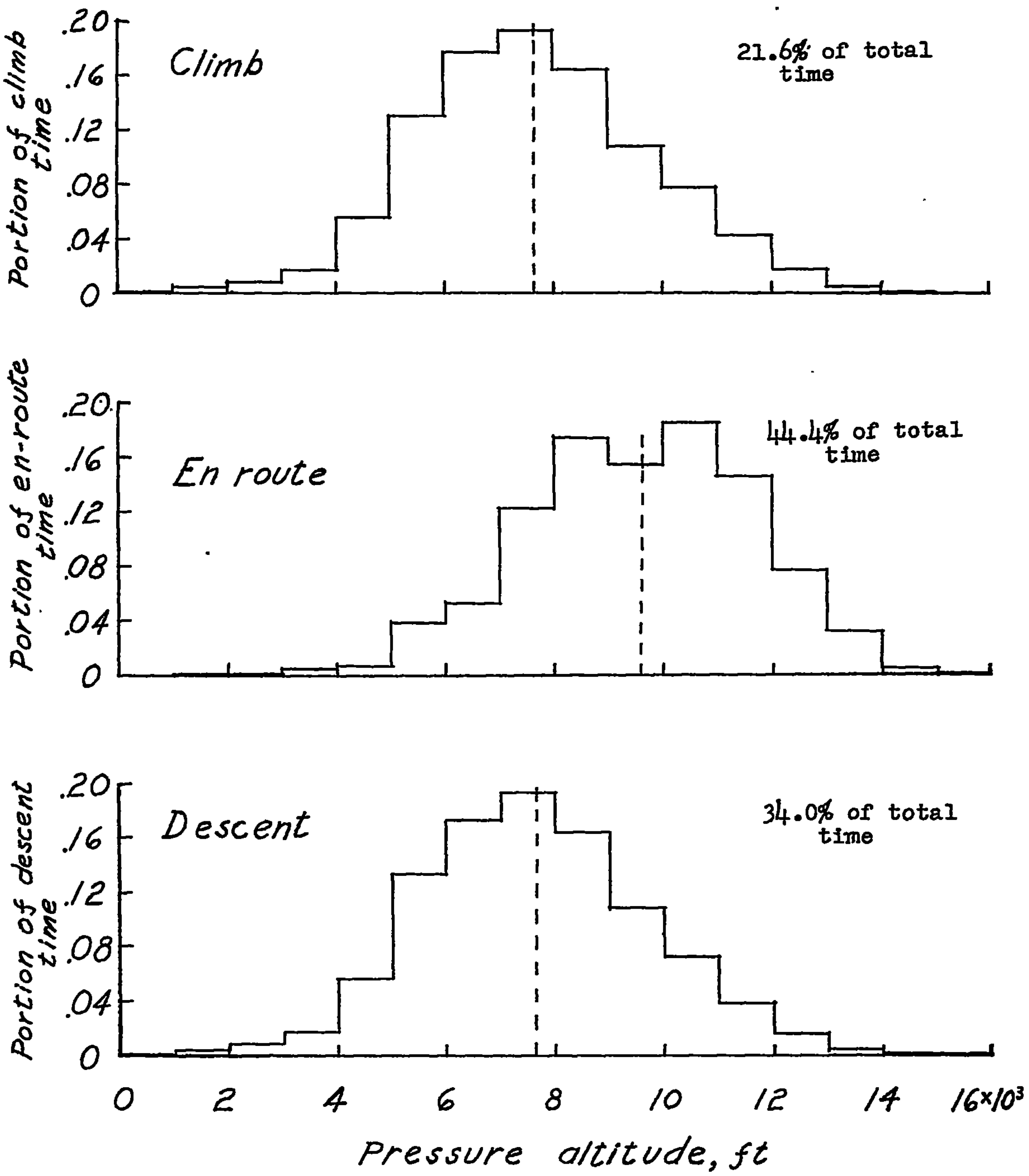

Figure 7.- Portion of time in each interval of 1,000-foot altitude for each flight condition.

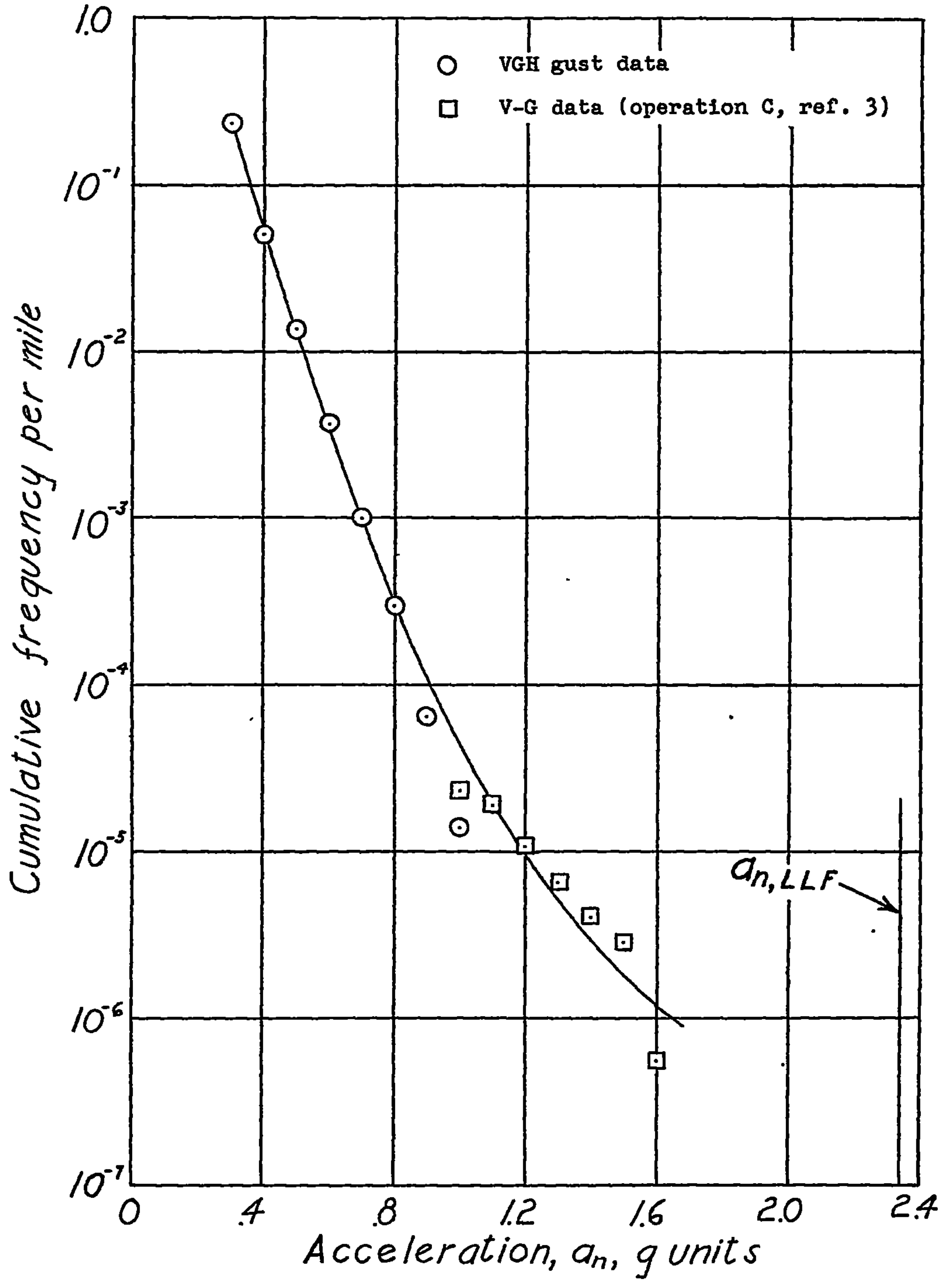

Figure 8.- Composite curve of frequency of exceeding given values of gust acceleration per mile of flight.

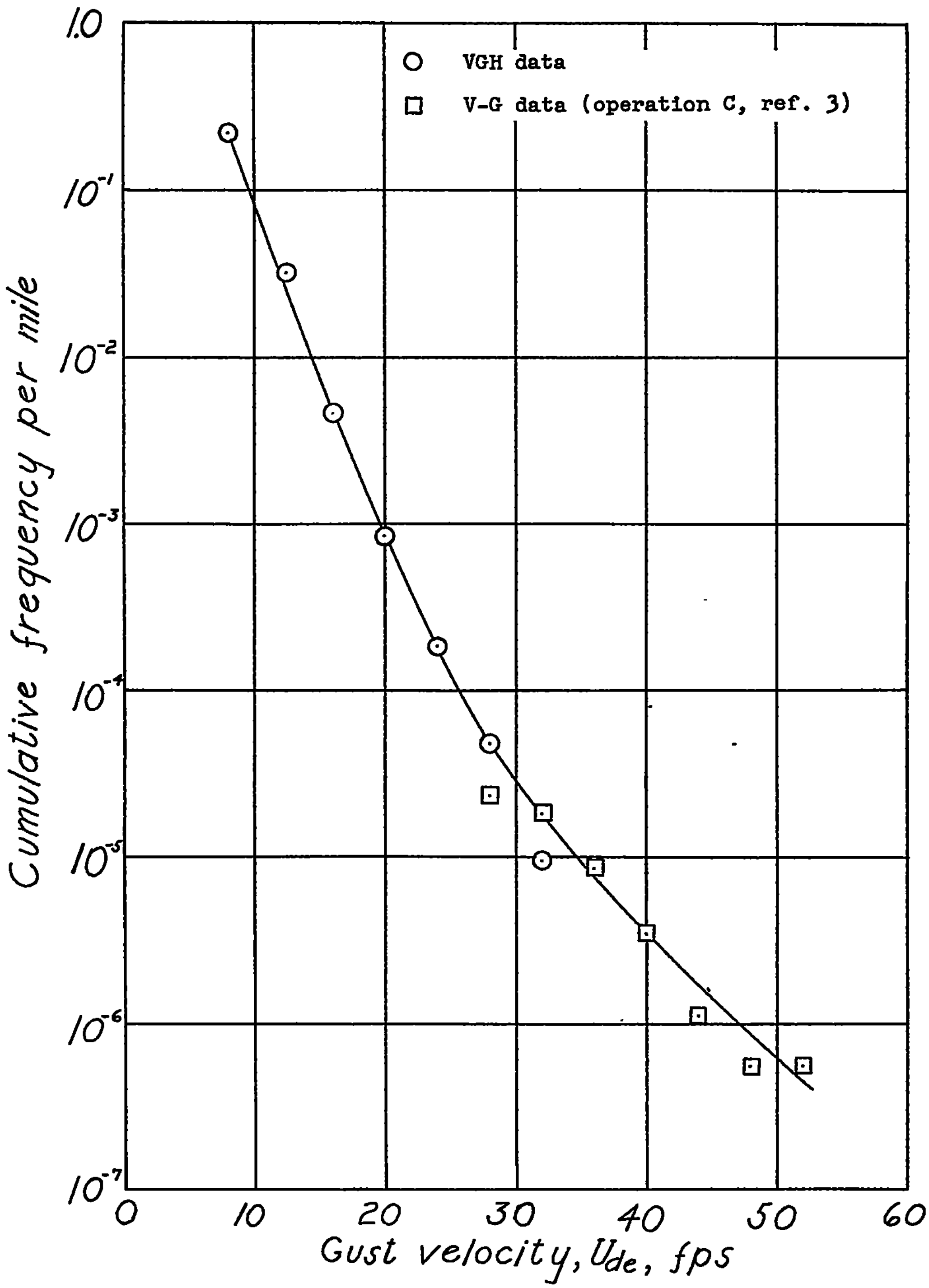

Figure 9.- Composite curve of frequency of exceeding given values of derived gust velocity per mile of flight.

NACA - Langley Field, Va.