NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3086

MANEUVER ACCELERATIONS EXPERIENCED BY FIVE TYPES OF COMMERCIAL TRANSPORT AIRPLANES DURING ROUTINE OPERATIONS

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SUMMARY

The magnitude and frequency of occurrence of maneuver accelerations experienced by five types of commercial transport airplanes during routine operations have been obtained from time-history (VGH) records and are presented herein. The results are compared with available gust-acceleration data for the operations considered. It is indicated that maneuver accelerations may contribute substantially to the total load histories of transport airplanes, particularly in the case of medium-altitude operations.

INTRODUCTION

Two classes of repeated flight loads are of principal significance to the design and operation of airplanes: maneuver loads, which are applied by the pilot in controlling the airplane, and gust loads, which occur unintentionally during flight through turbulent air. Gust loads are usually considered as being more frequent and larger than maneuver loads during normal airline operations and numerous studies have been made to determine their magnitude and frequency of occurrence for transport operations. (For example, see ref. 1.) Although maneuver loads may also contribute significantly to the total load histories of airplanes, little work has been done to determine their magnitude and frequency of occurrence on transports.

Time-history records of airspeed, acceleration, and altitude collected from NACA VGH recorders on commercial transport airplanes over the past few years for use in gust research constitute the largest available source of data from which information on maneuver loads may be obtained. The records, of course, contained both gust and maneuver accelerations, but it was possible to distinguish between the two types by considering the characteristics of the acceleration and airspeed traces. Moreover, it was possible to distinguish between maneuver loads in routine passenger-carrying flight and in airplane or pilot check flights. Some of the records have been evaluated, therefore, to determine the magnitude and frequency of occurrence of acceleration increments caused by maneuvers during operations of five types of commercial transport airplanes. The results are summarized herein as to the source of the accelerations; that is, whether from operational maneuvers during airplane routine passenger-carrying operations or from maneuvers performed during airplane or pilot check flights. In addition, the magnitude and frequency of occurrence of maneuver accelerations are compared with available data on the gust accelerations for these operations.

SCOPE AND EVALUATION OF RECORDS

The data presented herein were evaluated from time-history records of normal acceleration, airspeed, and altitude which were taken with the NACA VGH recorder (ref. 2) between 1949 and 1953. The records were obtained from five commercial transport airplanes during routine operations on three routes within the United States. A summary of the pertinent characteristics of the airplanes and of the operations from which the data were obtained is given in the following table:

Airplane	A (Two engine)	B (Two engine)	C (Four engine)	D (Four engine)	E (Four engine)
Design gross weight, lb	40,500	39,900	93,200	107,000	147,000
Wing loading, lb/sq ft	49.6	46.2	63.6	64.8	86.0
Routes flown	Transcontinental (N. Y. - Los Angeles)	Northern transcontinental	Transcontinental (N. Y. - Los Angeles)	North-South routes in Eastern U. S.	Northern transcontinental
Average length of flight, hr	0.85	1.00	1.88	1.98	2.03
Average operating altitude, ft	5,800	5,000	12,000	10,500	13,500
Average indicated airspeed, mph	196	203	225	225	218

In this paper, the operations at average altitudes below 10,000 feet are called low-altitude operations (airplanes A and B) and those at average altitudes between 10,000 and 25,000 feet are classed as medium-altitude operations.

Evaluation of the records required that maneuver accelerations be distinguished from gust accelerations, since both types were usually present on the records. The principal criterion used to identify the source of the accelerations was that, in general, maneuver accelerations (figs. 1(a) and 1(b)) have a much lower frequency than gust accelerations (fig. 1(c)). In addition, high-frequency low-intensity fluctuations of the airspeed trace occurred simultaneously with the gust accelerations but were not apparent during maneuvers. The occurrence of maneuvers and gusts at the same time caused difficulty in classifying the accelerations in several instances (fig. 1(d)). In these cases, the assumption was usually made that the accelerations were caused by gusts rather than maneuvers so that the number of maneuver accelerations read is probably slightly less than actually occurred. Therefore, the maneuvers evaluated are considered to have resulted from control motions by the pilot.

Comparison of the records showed that maneuvers performed during airplane or pilot check flights were quite different in magnitude and frequency of occurrence from those performed during routine operational flights. Consequently, the maneuver accelerations were classed according to the purpose of the flight on which they occurred, that is, as operational maneuvers or check-flight maneuvers.

The 1 g steady-flight position of the acceleration trace was used as a reference from which the maneuver-acceleration increments were read. Only the maximum incremental value was read for each deflection of the acceleration trace greater than given threshold values from the reference. A threshold of ±0.3g, which is the value normally employed in evaluating VGH records, was used for the check-flight maneuvers. The accelerations for the operational maneuvers were smaller, in general, than for the check-flight maneuvers, and in order to represent adequately the range of these accelerations, a reduction in the reading threshold to ±0.1 g was necessary for the operational maneuvers.

The number of flight hours evaluated for each type of maneuver acceleration and also the number of flight hours represented by the available gust data for each airplane are indicated in the following table:

Airplane		A	B	C	D	E
Total record hours available		684.4	1,089.7	648.1	783.3	1,012.5
Hours of operational flight available		676.0	1,085.0	644.0	771.0	1,005.0
Hours of record evaluated for check flight		684.4	1,089.7	648.1	783.3	1,012.5
Hours spent in check flight		8.4	4.7	4.1	12.3	7.5
Hours of operational flight evaluated	Maneuvers	234.6	65.9	62.0	309.4	48.7
	Gusts	676.0	833.9	644.0	771.0	886.0

The total record samples available for evaluation varied from about 648 to 1,090 flight hours for the different airplanes as shown in this table. All available records were evaluated for check-flight-maneuver accelerations. The time actually spent in check flights, however, varied from only 4.1 to 12.3 hours. The operational-maneuver data for each airplane were obtained from record samples covering about 50 to 300 flight hours. Although larger samples were available for evaluation, consideration of the data from samples of varying size indicated that the present samples were sufficiently adequate to provide fairly good estimates of the distribution of operational-maneuver accelerations. For instance, the results for airplanes A and D, which are based on samples of 234 and 309 flight hours, respectively, are quite similar to results which were based on only 60 flight hours from each airplane. Gust-acceleration data were available in unpublished form (except the data for airplane B which is given in ref. 1) for at least 80 percent of the total record sample for each airplane.

RESULTS

The frequency f of positive and negative acceleration increments (measured from the 1 g reference) caused by operational and check-flight maneuvers are given for each airplane in intervals of 0.1 g in tables I and II, respectively. The average indicated airspeed of each airplane for all flight conditions (determined from the VGH records), the hours of record evaluated, and the number of flight miles l represented by each distribution are given in the tables. The number of flight miles in each case was obtained by multiplying the total number of record hours from which the distribution was evaluated by the average indicated airspeed of the airplane. The percentage of total flight time spent in check flights (table II) was obtained by dividing the hours actually spent in check flights by the total record hours evaluated.

Each frequency f in tables I and II was progressively summed (starting with the frequency for the largest acceleration increment) to obtain the cumulative frequency Σf which gives the total number of acceleration increments equal to or greater than given values. The cumulative frequency was then divided by the number of flight miles l represented by the data to obtain the average number of acceleration increments equal to or greater than given values which were experienced per mile of flight $\Sigma f/l$. The values of $\Sigma f/l$ are plotted for each airplane in figures 2 and 3 for the operational and check-flight maneuvers, respectively. In order to illustrate the use of the curves, the point in figure 2 at 0.1 g for airplane A indicates that, on the average, 0.11 acceleration increments equal to or greater than 0.1 g occurred per mile of flight. The number of flight miles was chosen as a basis for presenting the results so that the maneuver data could be easily compared with gust data, which are usually presented in a similar manner.

In order that the operational- and check-flight-maneuver data from the various airplanes may be easily compared, the data given in figures 2 and 3 are also plotted for each airplane in figure 4. The ordinate values of the curves given in figure 4 were summed to obtain an estimate of the average number of positive and negative operational- and check-flight-maneuver-acceleration increments experienced per mile of flight and the resulting curves are given in figure 5. In performing the summations, no attempt was made to extrapolate the curves of figure 4 below the reading thresholds or to higher values than were recorded. Consequently, the total maneuver curves in figure 5 tend to underestimate slightly the frequency of occurrence of the maneuver-acceleration increments. The available gust-acceleration data for each airplane are plotted in figure 5 to allow comparison of the frequency of occurrence and magnitude of accelerations caused by maneuvers and gusts. For reference purposes, the frequency distributions of gust-acceleration increments used to plot the gust curves in figure 5 are given in table III. Separate positive and negative distributions of gust acceleration were not available for airplane B. For this airplane, therefore, it was assumed that the positive and negative distributions making up the total gust-acceleration distribution (given in ref. 1) were symmetrical.

RELIABILITY OF RESULTS

The reliability of the results from samples of the maneuver accelerations depends on the quality and quantity of the data collected and the instrument and reading errors. Insofar as is known, no special operating limitations which would affect the maneuvers were in force on the airplanes during the time the present data samples were being taken, and the operational maneuvers performed were accordingly felt to be representative of normal airline practice.

In addition to being representative of the operations under consideration, the sample must be of sufficient size to insure that unique occurrences do not bias the results. At the present time, the size of sample required to obtain adequate representation of operational-maneuver-acceleration distributions has not been determined. Comparison of frequency distributions obtained from various sample sizes has shown (as was previously noted) little difference between the results based on samples of 60 hours and 300 hours for airplanes A and D. The present samples covering 50 to 300 hours are, therefore, felt to be sufficient to give reasonably stable distributions which would change little with increasing sample sizes. The present samples are inadequate, however, to determine the manner of growth of the distributions (that is, maximum values and possible asymptotes) for extended operations.

Although the data on the maneuver-acceleration increments for the check flights were taken from samples covering 648 to 1,090 flight hours, the time actually spent in check flights amounted to only 0.43 to 1.6 percent of the total time (table II). Information received from operators of three of the airplanes indicated that for extended operations about 1 percent of the total flight time would be spent in airplane and pilot check flights. The present samples, therefore, appear to be representative of those obtained during standard airline operations.

The instrument accuracy is ±0.02g for the range of accelerations experienced. A more complete description of the accuracy is given in reference 2. As a check on reading accuracy, several records were reevaluated by different personnel. Comparisons between the frequency distributions from the same record indicated that variations not greater than 2 to 1 existed between the counts of the operational-maneuver accelerations. The variations between the counts of the check-flight accelerations were smaller and were considered negligible.

DISCUSSION

Consideration of figure 2 suggests that for each airplane the positive and negative distributions of acceleration increments caused by operational maneuvers are essentially symmetrical, although there is a slight tendency for the positive accelerations to be larger and more frequent. Comparison of the five curves for the negative accelerations and of the curves for the positive values indicates that the trends of the data from the various airplanes are similar. In general, the average number of acceleration increments equal to or greater than given values experienced per mile of flight $\Sigma f/l$ decreases by a factor of about 10 for each 0.1 g increase in acceleration. Variations of the order of 10 to 1 exist in the frequency of occurrence of given values of acceleration increments for the five airplanes. From the overall viewpoint, these differences do not appear to be too significant and are no greater than are commonly found among various sets of gust-acceleration data. The differences cannot be correlated with such parameters as airplane weight or length of flight and thus appear to be due to factors such as type of operation, pilot technique, airplane handling characteristics, and evaluation errors. The maximum acceleration increment for each airplane is about 0.5g which is smaller than the maximum gust-acceleration increment usually experienced by these airplanes. Although larger accelerations may result from operational maneuvers during extended operations, it would appear from the present data that operational maneuvers are primarily important for their effects on the fatigue life of the airplane.

The data of figure 3 show that, for each airplane, the magnitude and frequency of occurrence of positive acceleration increments caused by check-flight maneuvers are greater than those of the negative values. In contrast to the tendency of the negative distributions to form a single group, the positive distributions fall into two distinct groups with the accelerations for airplanes B and C being much less frequent and smaller in magnitude than for the other three airplanes. The lower frequency of occurrence and smaller magnitude of the positive accelerations for the two airplanes apparently is not related to the types of airplanes considered, since airplanes B and C are two engine and four engine, respectively. The fact that airplanes B and C spent a smaller percentage of their total flight time in check flights than the other three airplanes (table II) accounts only partly for the lower frequency of occurrence of positive accelerations for the two airplanes. The remainder of the difference is due to differences between airline and pilot practice in regard to the type, severity, and frequency of maneuvers performed during check flights. From figure 3, therefore, it appears that the positive check-flight-maneuver accelerations tend to be larger and more frequent than negative accelerations and that significant variations exist between the positive values for the different airplanes.

The results given in figure 4 indicate considerable variation in the magnitude and frequency of occurrence of acceleration increments caused by operational and check-flight maneuvers for the five airplanes. For each airplane, the maximum check-flight-maneuver accelerations, particularly the positive values, are greater than the maximum operational-maneuver accelerations. Although no fixed relation exists regarding the relative frequency of occurrence of operational and check-flight maneuvers, figure 4 indicates that, in general, operational- and check-flight-acceleration increments of 0.3g occur with about equal frequency. From the characteristics of the distributions in figure 4, acceleration increments below 0.3g appear to result primarily from operational maneuvers. Likewise, values greater than about 0.5g result largely from check-flight maneuvers. Combined distributions of operational- and check-flight-maneuver accelerations obtained by simply summing the ordinate values of the curves in figure 4 may be expected, therefore, to underestimate only slightly the frequency of occurrence of given values of acceleration increments. The manner in which the maneuver data should be extrapolated to represent extended operations has not been established. Consequently, for the present it can only be assumed (based on past experience with similar types of data) that the number of maneuver accelerations would increase in proportion to the flight miles and that larger accelerations than reported would occur for increased sample sizes.

Comparison of the distributions of acceleration increments caused by operational and check-flight maneuvers and by gusts in figure 5 shows large variations in the frequency of occurrence of accelerations from the two sources. For each of the five airplanes, the magnitude and frequency of occurrence of negative acceleration increments caused by gusts were greater than those of the accelerations caused by maneuvers. In addition, the positive accelerations on airplanes B and C were also caused predominately by gusts. For the other three airplanes, however, larger positive maneuver-acceleration increments were recorded and the frequency of occurrence of positive maneuver accelerations was equal to or greater than the frequency of gust accelerations for values of about 0.6g. As previously noted, these large maneuver accelerations occurred during check flights which covered less than 2 percent of the total flight time. From the characteristics of the curves in figure 5, it appears that for airplane E, and to a lesser degree for airplane C, maneuver-acceleration increments of 0.1 g to 0.2g are about as frequent as gust accelerations. From an overall viewpoint, therefore, figure 5 indicates that maneuver accelerations may in some cases be as frequent as gust accelerations and consequently may contribute substantially to the total load history of transport airplanes.

As indicated in figures 2 and 3, the distributions of operational- and check-flight-maneuver accelerations were more or less independent of the airplane types considered. In the case of gust accelerations, however, the twin-engine airplanes usually experience about 10 times as many accelerations of a given value as the four-engine airplanes because of the lower wing loading and the larger amount of time spent at the lower turbulent altitudes. If consideration is given to the indication that the maneuver accelerations are approximately the same for the low- and medium-altitude airplanes and that the medium-altitude transport experiences fewer gust accelerations of a given value, it appears that maneuvers are becoming of increasing importance for the medium-altitude transports. This conclusion is borne out to some extent by figure 5 where, in general, the difference between the frequencies of occurrence of gust and maneuver accelerations for the four-engine airplanes (airplanes C, D, and E) is less than for the twin-engine transports (airplanes A and B).

CONCLUDING REMARKS

VGH time-history records (containing both gust and maneuver accelerations) taken on five commercial transport airplanes during routine operations have been evaluated to determine the magnitude and frequency of occurrence of maneuver accelerations. The data are classed according to the source of the accelerations; that is, operational maneuvers performed during routine passenger-carrying flights and check-flight maneuvers occurring on airplane or pilot check flights. Comparison of the maneuver data with available gust data indicates that maneuver accelerations may contribute substantially to the total flight load histories of some transport airplanes, particularly the medium-altitude transports. The accelerations caused by operational maneuvers (those performed during passenger-carrying flights) are usually smaller and less frequent than gust accelerations and appear to be of concern only in that they contribute to airplane fatigue. Positive acceleration increments caused by maneuvers during airplane and pilot check flights are larger than those caused by operational maneuvers and may be as large and, for values above about 0.6g, as frequent as gust accelerations. This result appears to apply especially to the present medium-altitude transports on which the gust accelerations are smaller and less frequent than on low-altitude transports.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 5, 1954.

REFERENCES

1. 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.

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

TABLE I

OPERATIONAL-MANEUVER-ACCELERATION INCREMENTS

Acceleration increment, g units	Frequency f for -				
	Airplane A	Airplane B	Airplane C	Airplane D	Airplane E
0.5 to 0.6	0	0	0	3	2
0.4 to 0.5	1	3	1	8	2
0.3 to 0.4	34	12	3	57	1
0.2 to 0.3	439	62	121	204	106
0.1 to 0.2	4,596	772	355	2,124	256
-0.1 to -0.2	3,468	610	165	2,235	546
-0.2 to -0.3	166	34	42	161	167
-0.3 to -0.4	13	9	2	18	15
-0.4 to -0.5	1	0	0	3	2
-0.5 to -0.6	1	0	0	0	0
Hours of operational flight evaluated	234.6	65.9	62.0	309.4	48.7
Average indicated airspeed, mph	196	203	225	225	218
Flight miles, l	4.6×10^4	1.3×10^4	1.4×10^4	7.0×10^4	1.1×10^4

TABLE II

CHECK-FLIGHT-MANEUVER-ACCELERATION INCREMENTS

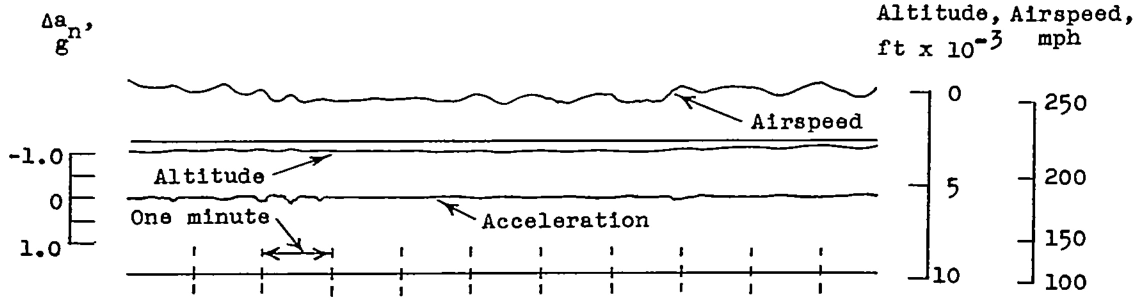
Acceleration increment, g units	Frequency f for -				
	Airplane A	Airplane B	Airplane C	Airplane D	Airplane E
1.1 to 1.2	0	0	0	1	0
1.0 to 1.1	1	0	0	0	2
0.9 to 1.0	0	0	0	1	2
0.8 to 0.9	8	0	0	4	11
0.7 to 0.8	5	2	1	15	9
0.6 to 0.7	17	0	2	10	20
0.5 to 0.6	12	4	2	38	25
0.4 to 0.5	38	12	6	36	39
0.3 to 0.4	37	19	14	38	44
-0.3 to -0.4	30	6	8	27	8
-0.4 to -0.5	13	5	2	12	4
-0.5 to -0.6	2	2	1	2	2
-0.6 to -0.7	1	0	2	2	2
-0.7 to -0.8	0	0	0	0	0
-0.8 to -0.9	1	0	0	0	0
Hours of record evaluated for check flights	684.4	1,089.7	648.1	783.3	1,012.5
Hours spent in check flights	8.4	4.7	4.1	12.3	7.5
Percentage of total time spent in check flights	1.23	0.43	0.63	1.6	0.74
Average indicated airspeed, mph	196	203	225	225	218
Flight miles, l	1.3×10^5	2.2×10^5	1.5×10^5	1.8×10^5	2.2×10^5

TABLE III

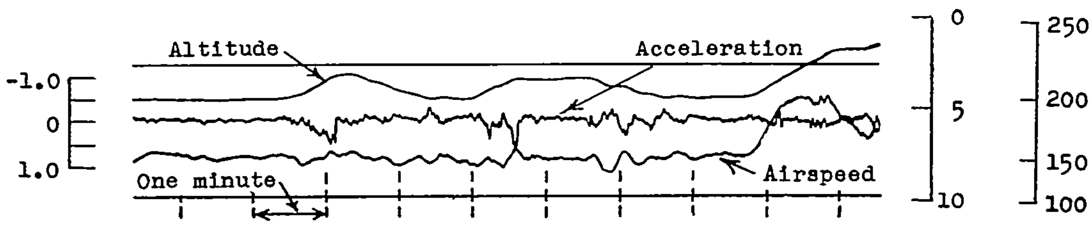
GUST-ACCELERATION INCREMENTS

Acceleration increment, g units	Frequency f for -				
	Airplane A	Airplane B (a)	Airplane C	Airplane D	Airplane E
1.3 to 1.4	-----	0.5	---	---	---
1.2 to 1.3	-----	0.5	---	---	---
1.1 to 1.2	-----	1.0	---	---	---
1.0 to 1.1	-----	1.5	---	---	---
0.9 to 1.0	1	9.5	1	2	---
0.8 to 0.9	6	10.5	0	2	---
0.7 to 0.8	8	38.5	1	7	2
0.6 to 0.7	38	126.5	5	20	2
0.5 to 0.6	146	413.0	13	46	15
0.4 to 0.5	538	2,148.5	59	201	81
0.3 to 0.4	2,286	7,554.5	310	891	364
-0.3 to -0.4	1,475	7,554.5	442	560	367
-0.4 to -0.5	339	2,148.5	81	107	57
-0.5 to -0.6	91	413.0	20	25	11
-0.6 to -0.7	28	126.5	3	14	7
-0.7 to -0.8	6	38.5	3	4	3
-0.8 to -0.9	3	10.5	1	2	---
-0.9 to -1.0	2	9.5	---	---	---
-1.0 to -1.1	0	1.5	---	---	---
-1.1 to -1.2	1	1.0	---	---	---
-1.2 to -1.3	-----	0.5	---	---	---
-1.3 to -1.4	-----	0.5	---	---	---
Hours of operational flight evaluated	676	834	644	771	886
Average indicated airspeed, mph	196	203	225	225	218
Flight miles, l	1.3×10^5	1.7×10^5	1.4×10^5	1.7×10^5	1.9×10^5

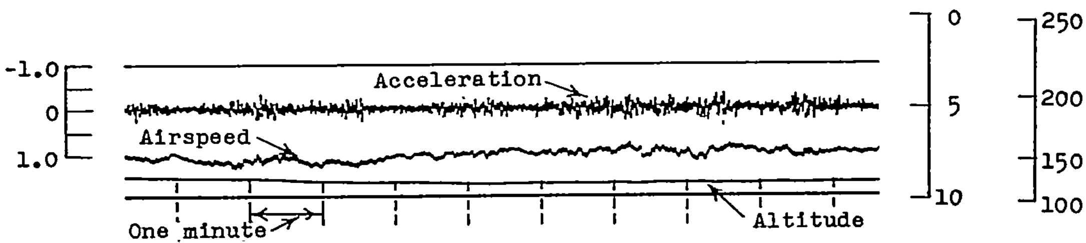
[a]Values given are based on frequencies of combined positive and negative acceleration increments from reference 1, which are assumed symmetrical.



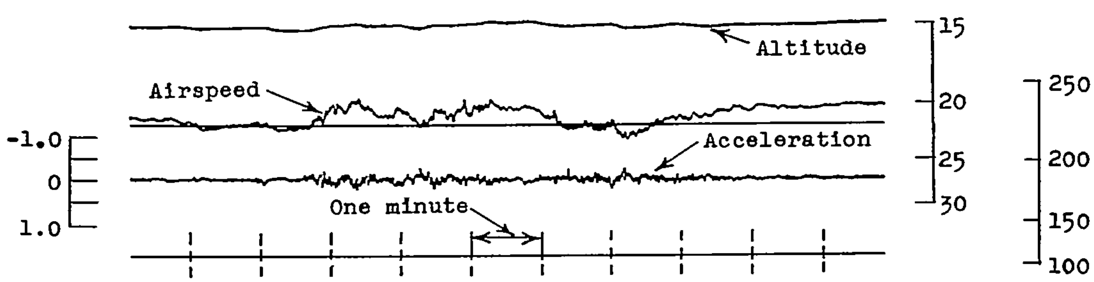
(a) Operational-maneuver accelerations.



(b) Check-flight-maneuver accelerations.



(c) Gust accelerations.



(d) Combination of maneuver and gust accelerations.

Figure 1.- VGH records showing three classes of accelerations.

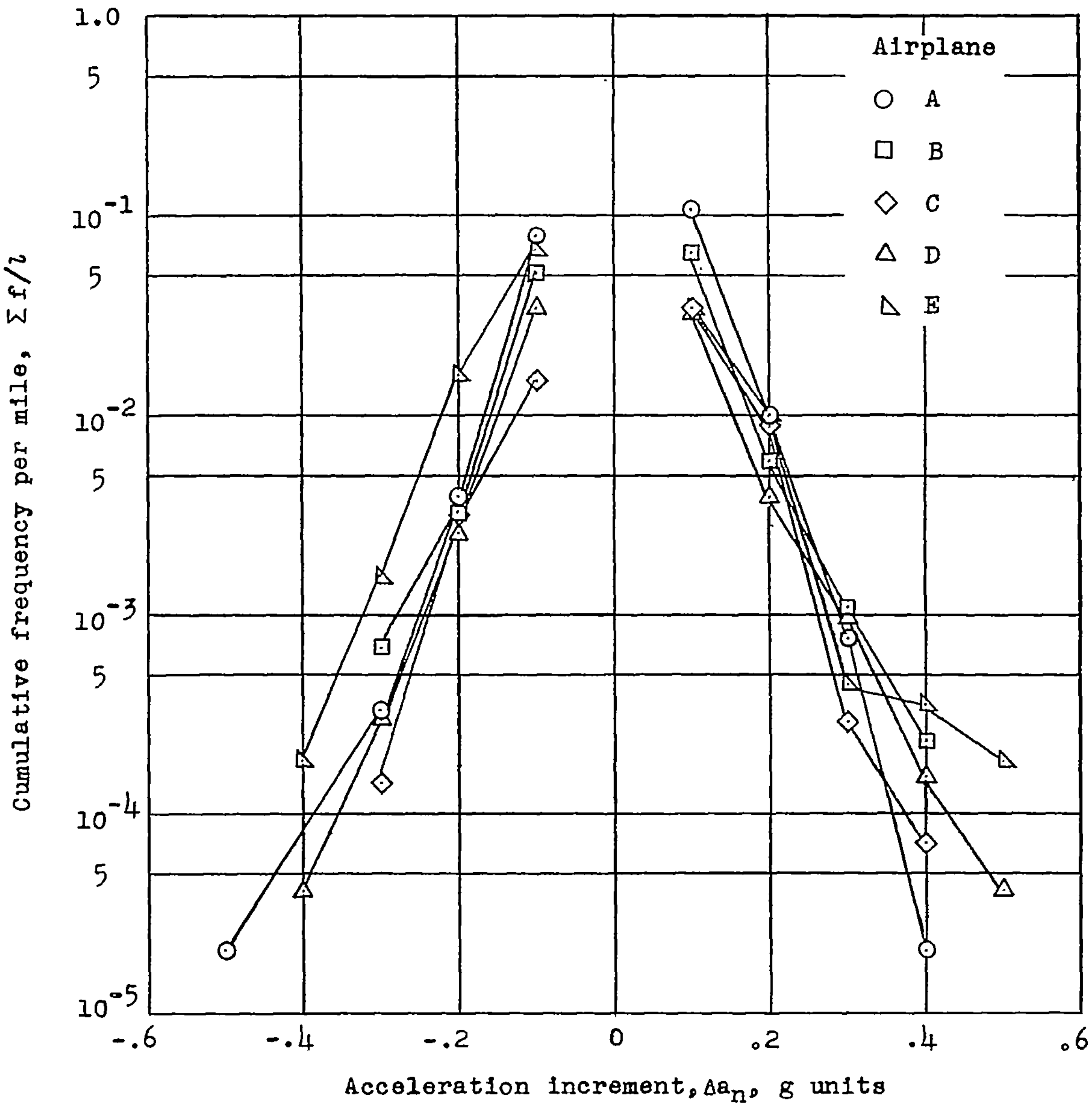


Figure 2.- Comparison of acceleration increments caused by operational maneuvers on five airplanes.

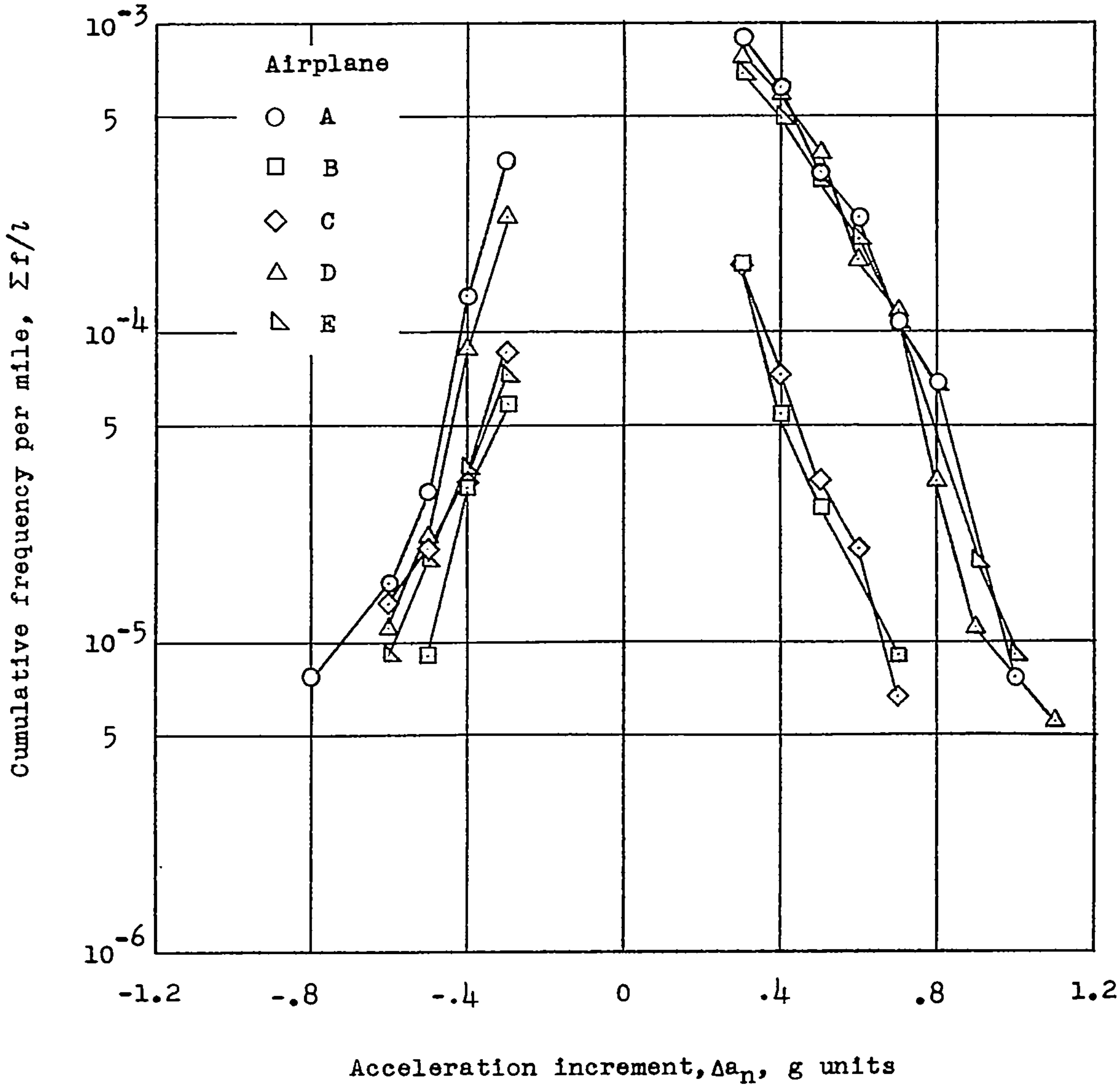
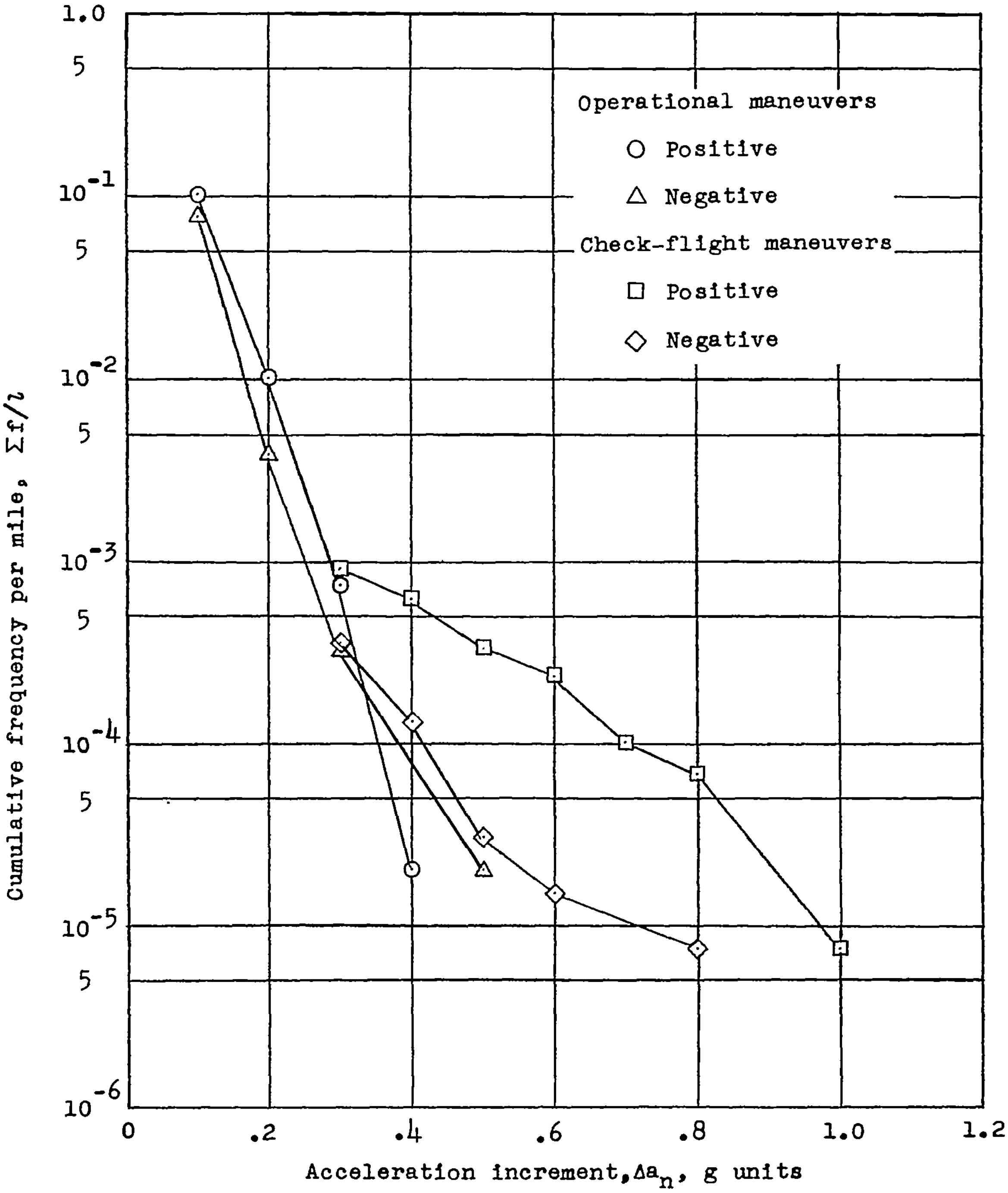
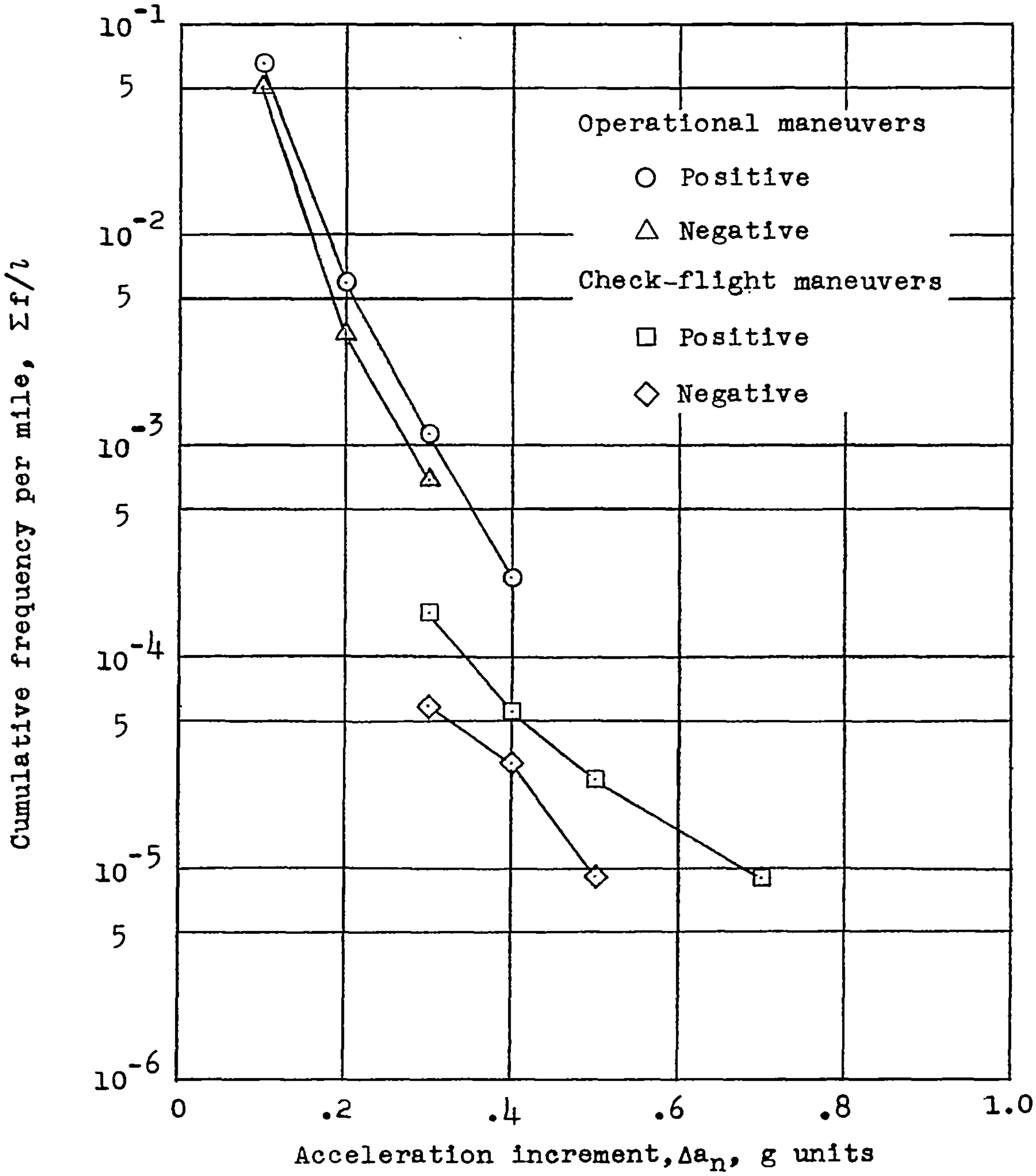


Figure 3.- Comparison of acceleration increments caused by check-flight maneuvers on five airplanes.



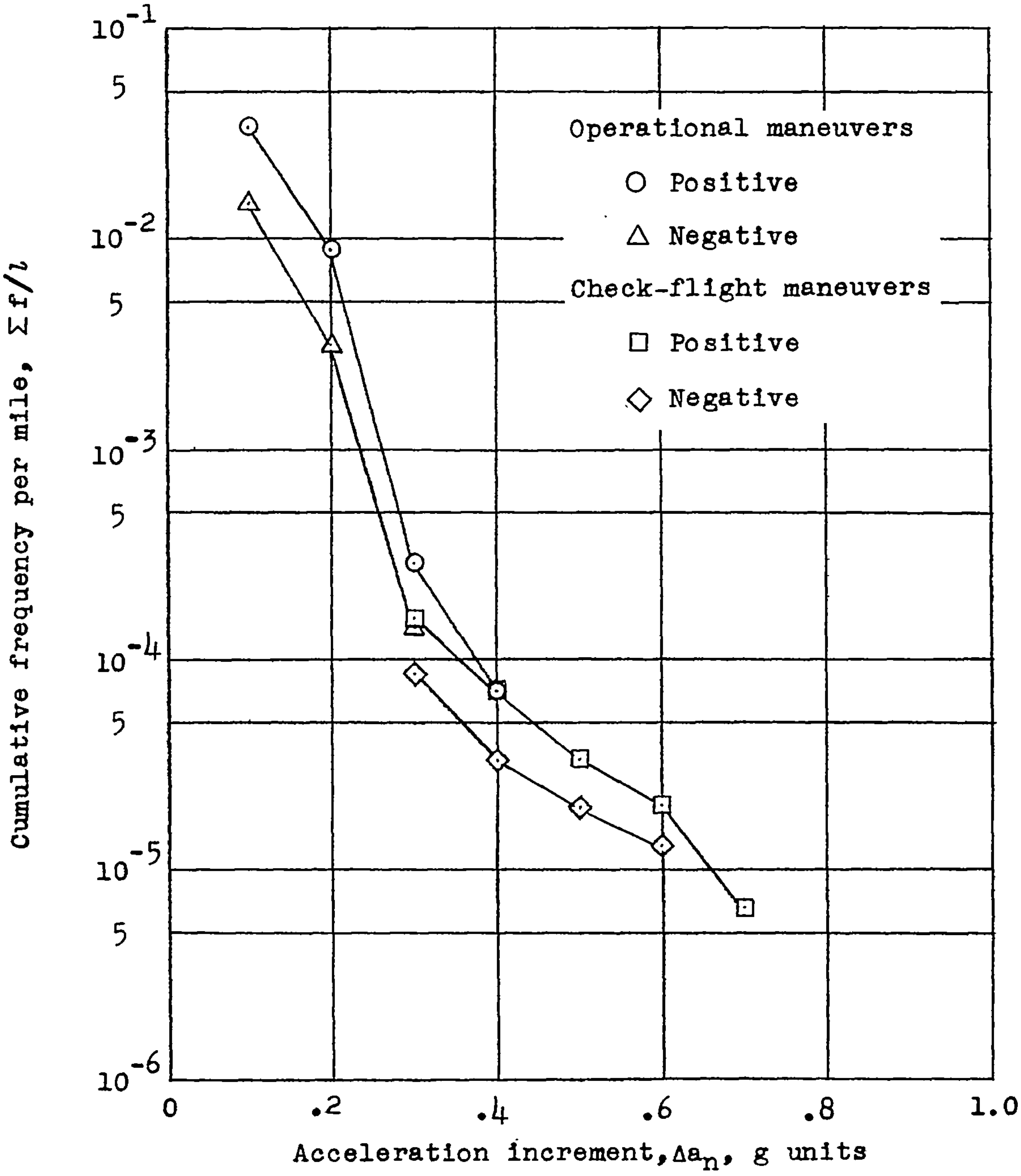
(a) Airplane A.

Figure 4.- Comparison of acceleration increments caused by operational and check-flight maneuvers.



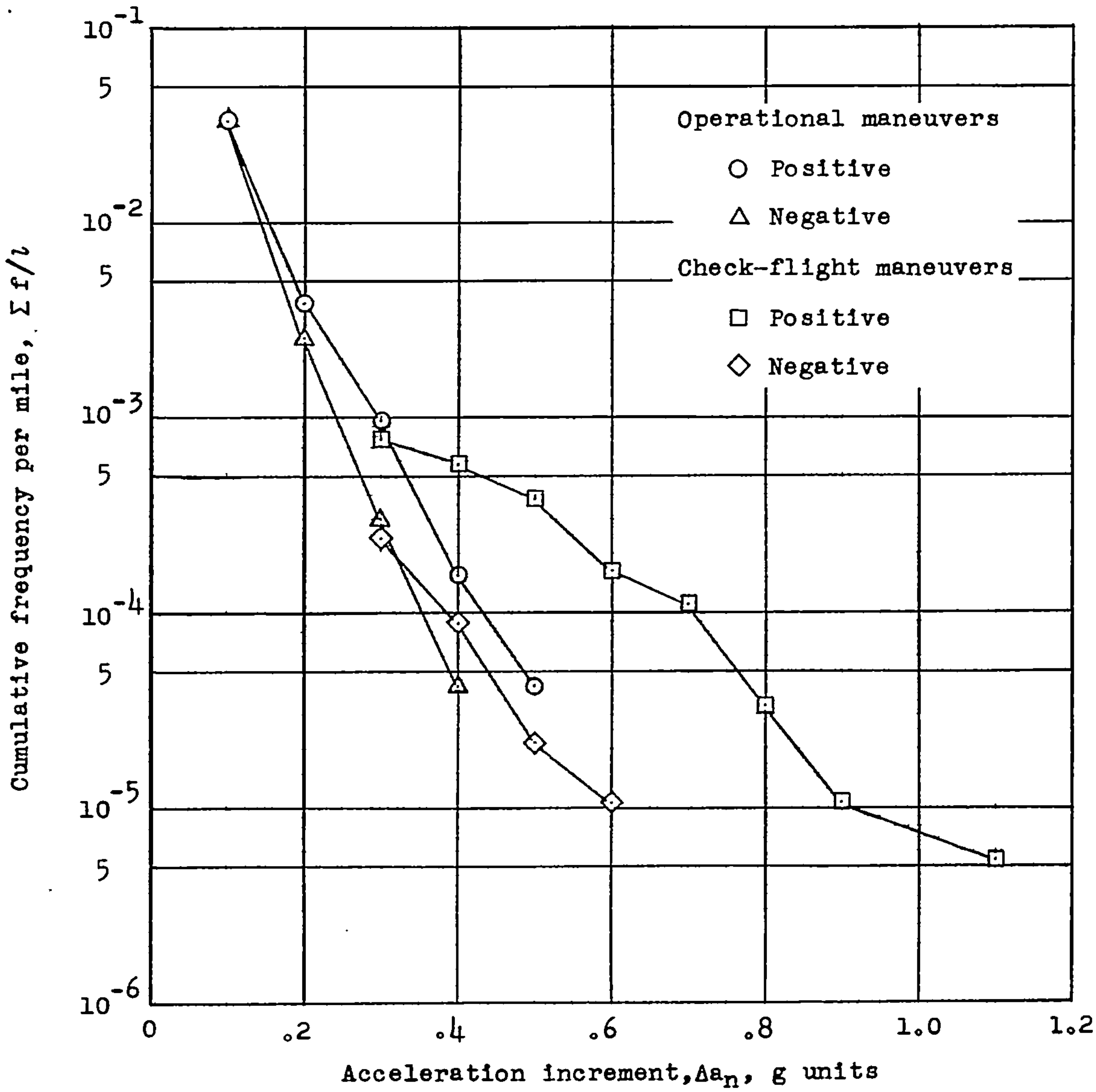
(b) Airplane B.

Figure 4.- Continued.



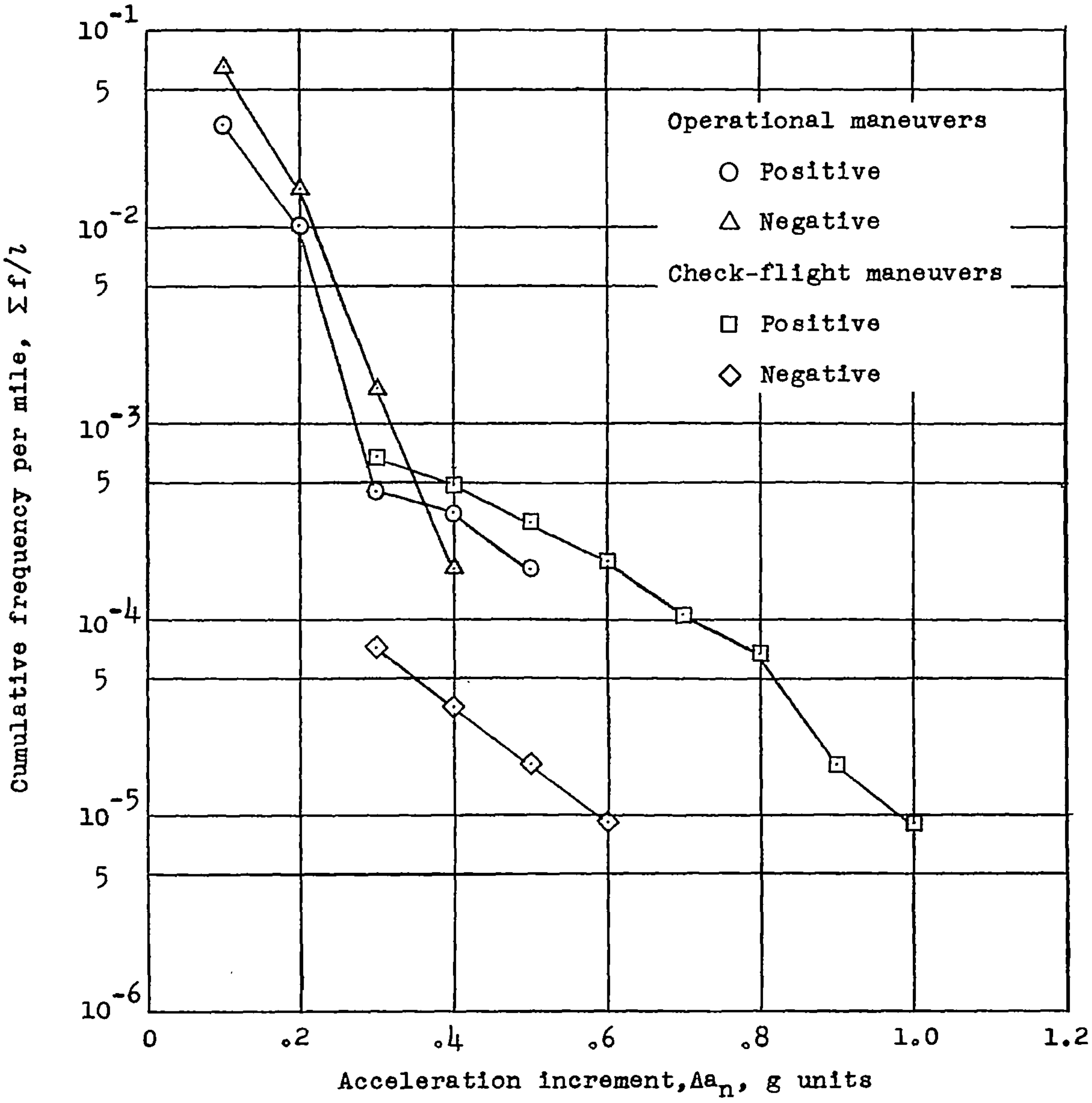
(c) Airplane C.

Figure 4.- Continued.



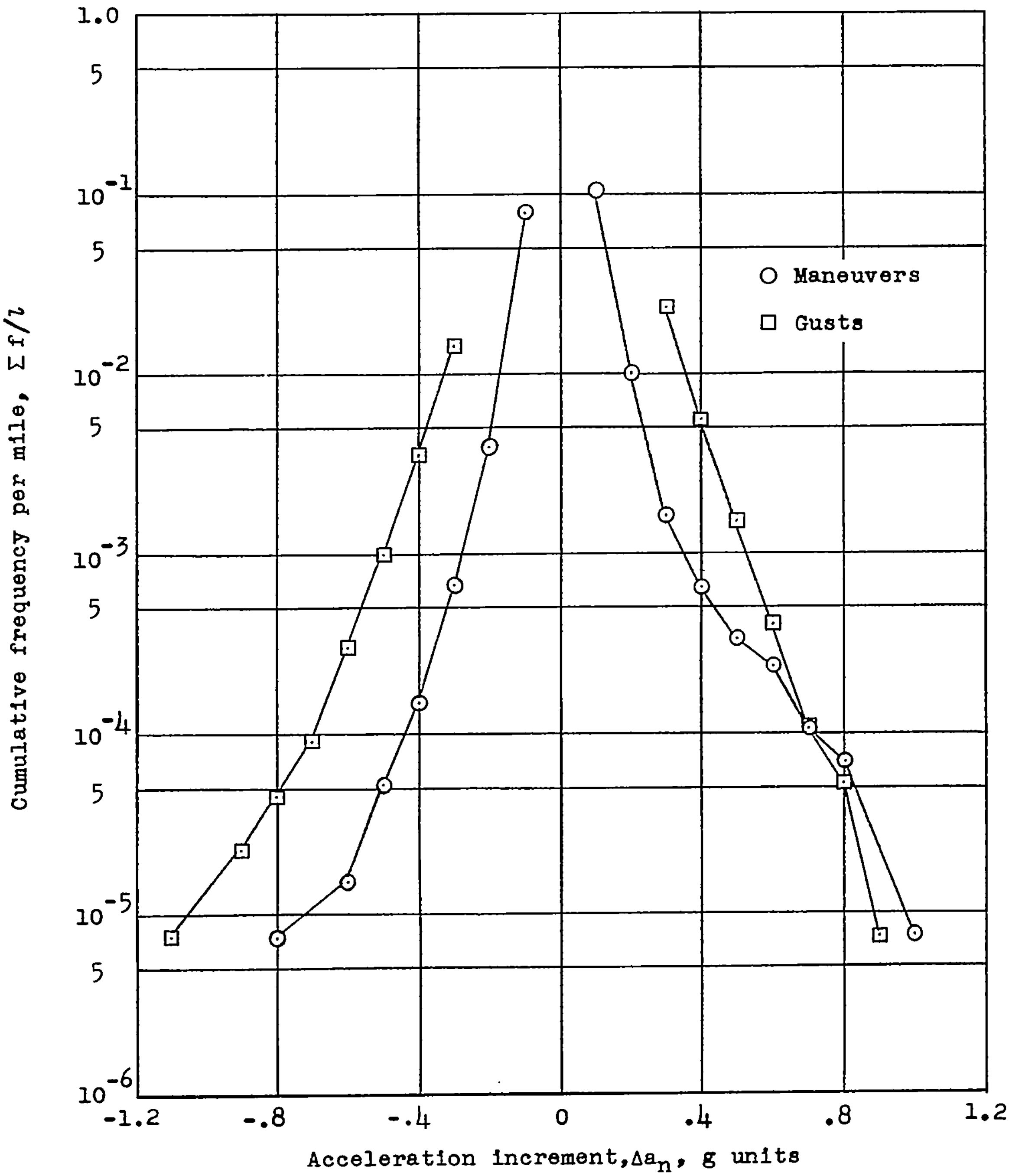
(d) Airplane D.

Figure 4.- Continued.



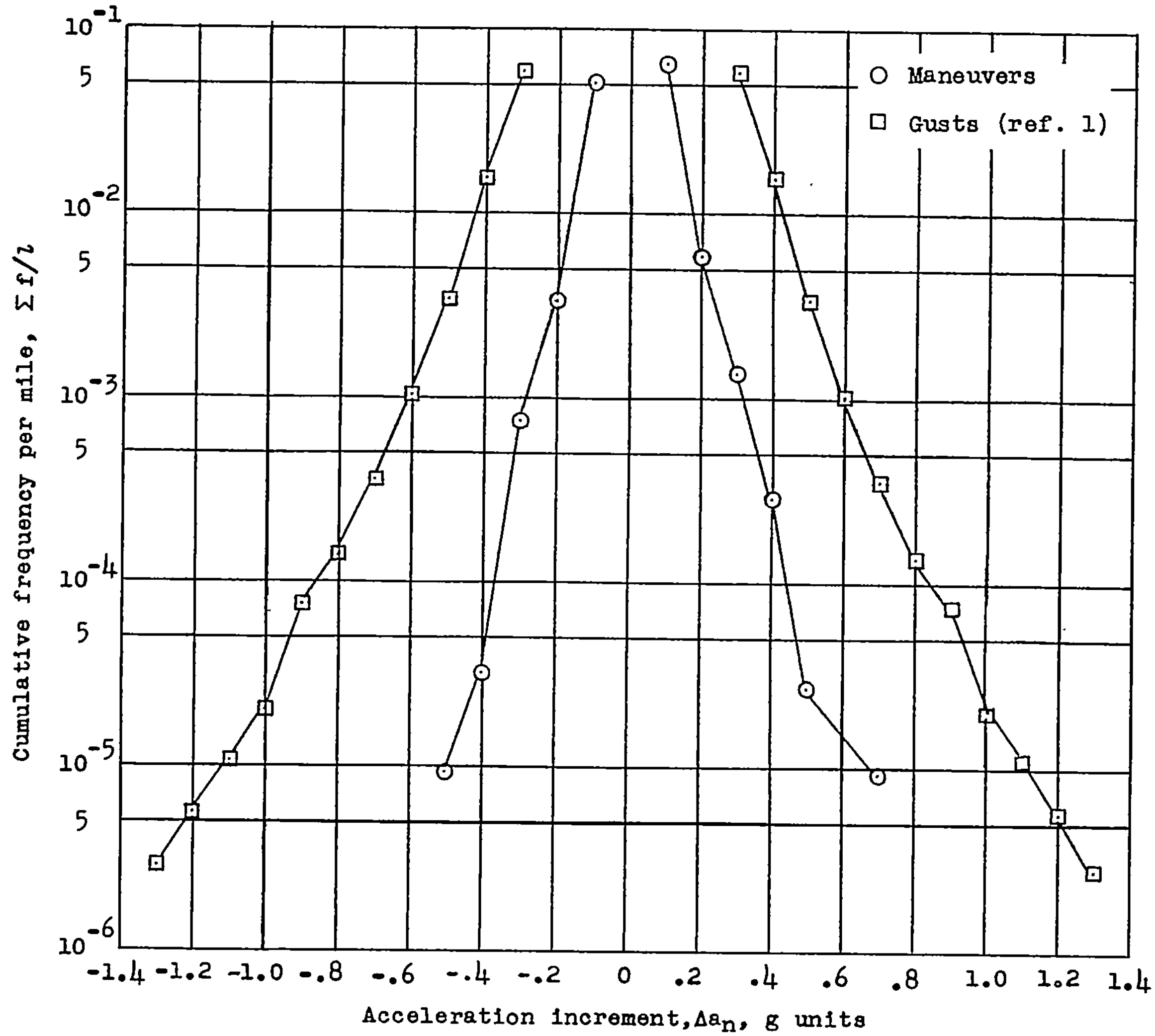
(e) Airplane E.

Figure 4.- Concluded.



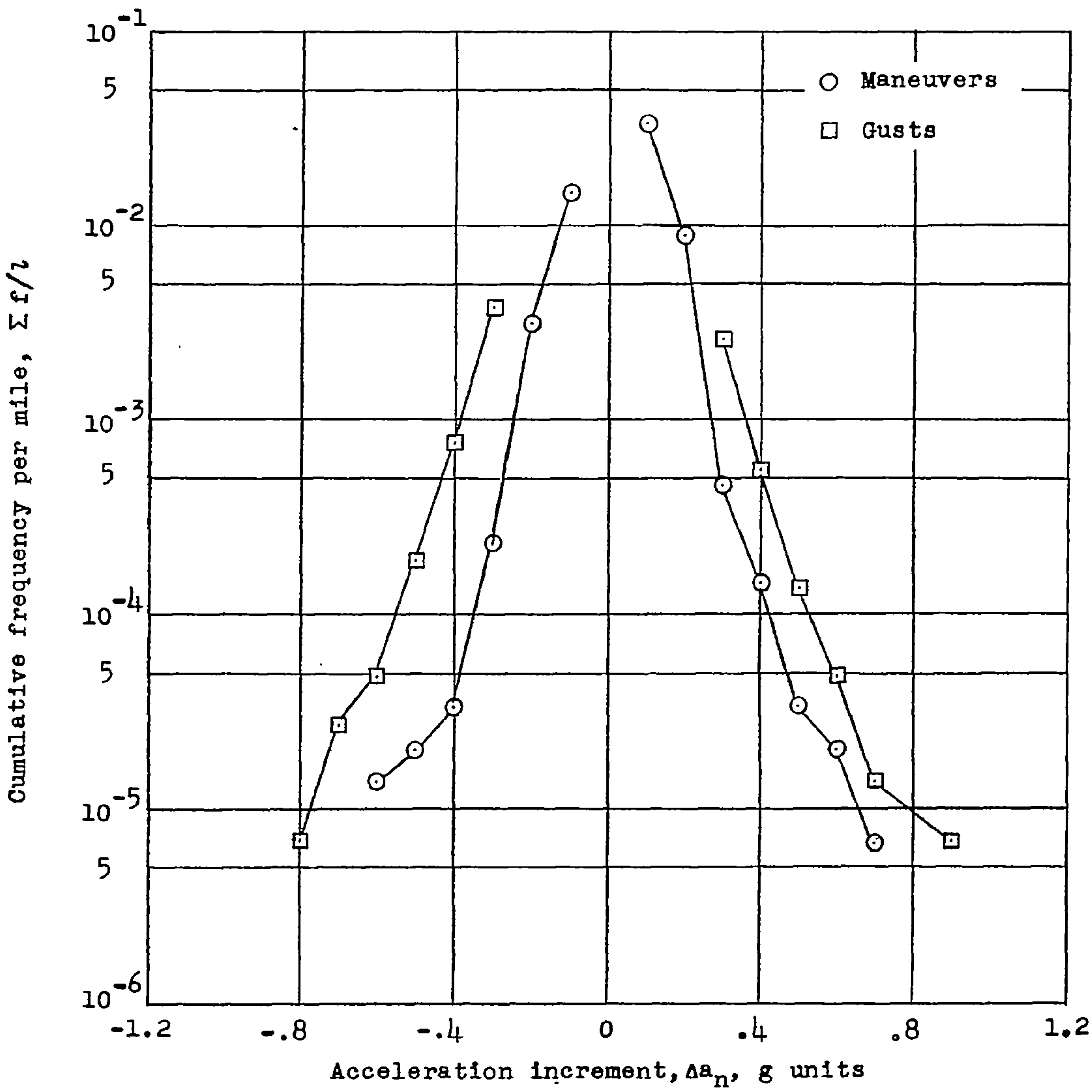
(a) Airplane A.

Figure 5.- Comparison of acceleration increments caused by combined check-flight and operational maneuvers and gusts.



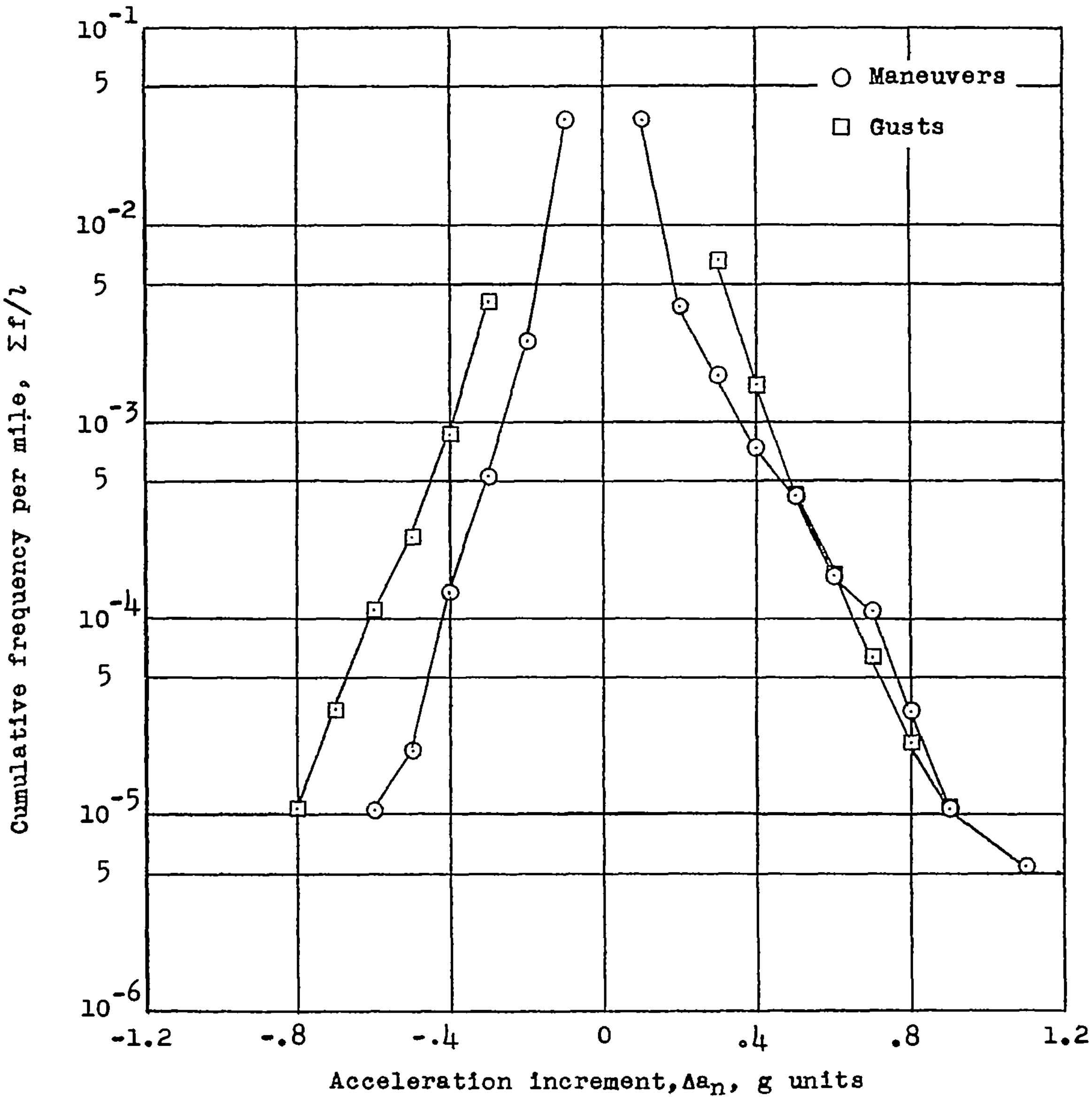
(b) Airplane B.

Figure 5.- Continued.



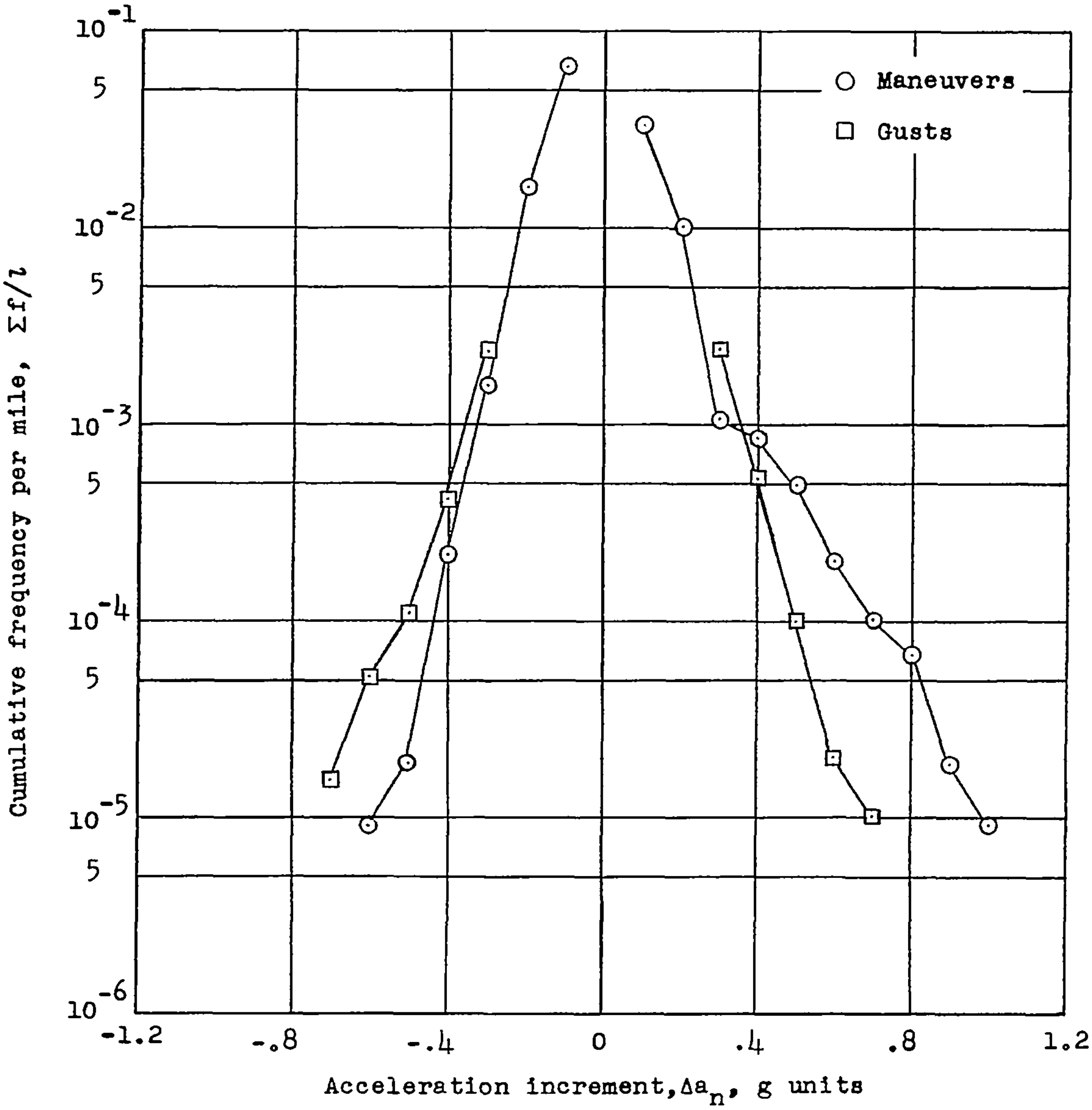
(c) Airplane C.

Figure 5.- Continued.



(d) Airplane D.

Figure 5.- Continued.



(e) Airplane E.

Figure 5.- Concluded.

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