NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3621

GUST-LOAD AND AIRSPEED DATA FROM ONE TYPE OF TWO-ENGINE AIRPLANE ON SIX CIVIL AIRLINE ROUTES FROM 1947 TO 1955

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SUMMARY

Approximately 70,000 hours of V-G data from one type of two-engine transport airplane were analyzed to determine the severity and frequency of occurrence of the gust loads and gusts. The data were obtained during routine feeder-line and short-haul commercial operations on six different routes from 1947 to 1955. The results obtained indicate that normal accelerations corresponding to the calculated value of limit-gust-load-factor increment may be exceeded, on the average, twice (once positive and once negative) within the range of 3.6×10^6 to 106.0×10^6 flight miles for the various operations. A derived gust velocity of 50 feet per second may be exceeded twice within the range of 0.8×10^6 to 23.5×10^6 flight miles. There were sizable variations among the different operations with regard to the loads, gust velocities, and operating airspeeds, but, in general, these quantities were of the same order of magnitude as those experienced in past operations of the same type of airplane.

INTRODUCTION

As a part of the general investigation that has been conducted for a number of years by the National Advisory Committee for Aeronautics for determining the severity and frequency of the gust loads experienced in routine transport operations (see, for example, refs. 1 to 4), V-G records representing more than 70,000 operating hours were collected from one type of two-engine transport airplane. These records represent feeder-line and short-haul operations and were obtained on six different civil airline routes during the period from 1947 to 1955. An evaluation of these records has yielded the magnitudes and frequencies of occurrence of given values of normal acceleration, airspeed, and derived gust velocity; and the results are presented herein.

Probability distributions were fitted to the observed distributions to determine the frequency of exceeding the larger values of the airspeeds, gusts, and gust loads. These results of the present investigation are also briefly compared with the results from past operations of the same type of airplane. Together these data represent a continuous sample of measurements for this airplane covering a total of more than 130,000 hours of flight over 18 years of operations.

In addition, V-G data, when combined with time-history data (VGH), can be used to define the overall gust and load histories experienced in routine operations. The results thus obtained can be used in refined analyses involving power-spectral techniques, as indicated in reference 5.

SYMBOLS

a_n	normal acceleration, g units
$a_{n,LLF}$	normal acceleration corresponding to the design limit-gust-load-factor increment, g units
A	aspect ratio, b^2/S
b	wing span, ft
c	mean geometric chord, ft
g	acceleration due to gravity, ft/sec^2
K	gust alleviation factor (function of wing loading, ref. 6, p. 12)
K_g	gust factor (function of mass ratio μ_g, ref. 3, fig. 2)
m'	slope of wing lift curve per radian
n	design limit gust load factor (ref. 6, p. 12)
S	wing area, sq ft
U_{de}	derived gust velocity, $\frac{2a_nW}{m\rho_oSV_eK_g}$, fps
V_e	equivalent airspeed for derived gust velocity from V-G record, fps

V_{max}	maximum indicated airspeed on V-G record, mph
V_B	design speed for maximum gust intensity, mph (ref. 6, p. 4)
V_C	design cruising speed, mph (ref. 6, p. 4)
V_D	design diving speed, mph (ref. 6, p. 4)
V_L	design maximum level-flight speed, mph
V_{NE}	never-exceed speed, mph (ref. 6, p. 4)
V_o	indicated airspeed at which maximum positive or negative acceleration occurs on V-G record, mph
V_p	most probable operating speed at which maximum acceleration occurs in a sample of V-G data, mph
W	airplane weight, lb
k_V, k_o	coefficients of skewness of distributions of V_{max} and V_o, respectively (ref. 4, appendix B)
σ_V, σ_o	standard deviations of distributions of V_{max} and V_o, respectively (ref. 4, appendix B)
u	location parameter of distribution of extreme values (ref. 7, p. 2)
α	scale parameter of distribution of extreme values (ref. 7, p. 2)
ρ	mass density of air, slugs/cu ft
ρ_o	mass density of air at sea level, slugs/cu ft
μ_g	airplane mass ratio, $2W/\rho mgcS$

Subscript:

max	maximum value of the variable

A bar over a symbol indicates the mean value of the variable for a given set of observations.

APPARATUS AND SCOPE OF DATA

The V-G records were collected by means of NACA oil-damped V-G recorders (see ref. 8) which were installed close to the center of gravity of each of 20 civil transport airplanes sampled in the six operations. The airplane characteristics pertinent to the evaluation of the V-G records are given in table I.

The scope of the present V-G data is summarized in table II for the different operations designated as A, B, C, D, E, and F. A considerable variation existed in the individual record times for the data of each operation. Inasmuch as past studies (see ref. 4) have indicated the desirability of restricting the analysis to records of fairly uniform record times, some record monitoring appeared to be required. As a consequence, for samples B, C, and D, in which a large number of records were available, only those records covering the flight times indicated in table II were retained for analysis purposes. Because of the much smaller number of records available for operations A, E, and F, all the records were used even though in some cases wide differences in record times were involved.

EVALUATION OF RECORDS

The V-G records were evaluated in accordance with the procedures outlined in reference 4. Routine details of the method of evaluation and the analytical procedures used are given in the appendix. The data obtained from the records for the analysis are listed in table III as frequency distributions of the maximum normal acceleration $a_{n,max}$, the associated indicated airspeed V_o, the maximum indicated airspeed V_{max}, and the maximum derived gust velocity $U_{de,max}$ for the six operations.

RESULTS

Distribution of Acceleration, Gust Velocity, and Airspeed

Figures 1 to 3 present the results in terms of the average flight miles to exceed given values of acceleration, gust velocity, and airspeed. The curves in figures 1 and 2 were obtained by fitting extreme-value distributions (see ref. 7) to the observed acceleration and gust velocity data of table III. On the other hand, past experience had indicated that Pearson type III distributions (see ref. 1, p. 5) yield more reasonable representations of airspeeds and, therefore, these were fitted to the

airspeed data in figure 3. The dashed portions of the curves in figures 1 to 3 are extrapolations of the calculated distributions beyond the limits of the data.

The pertinent results from figures 1 to 3 and corresponding results from past operations of this type of airplane are summarized in table IV as the average flight miles to exceed: (1) the value of acceleration $a_{n,LLF}$ of 2.34g, (2) value of the derived gust velocity $U_{de,max}$ of 50 feet per second (roughly equivalent to the current Civil Aeronautics Administration design value of 30 feet per second for the effective gust velocity at V_C), and (3) the never-exceed speed V_{NE} of 257 miles per hour. The values of the most probable operating speed V_p at which maximum acceleration occurs in a sample of V-G data are also given in table IV.

Confidence Bands

As a measure of the reliability of the estimates of flight miles to exceed given values of $a_{n,max}$ and $U_{de,max}$, 95-percent confidence bands were determined for the normal-acceleration and gust-velocity distributions of table III by the procedures given in reference 9. The true value of the distribution may be expected to lie within such confidence bands 95 percent of the time. Figures 4 and 5, respectively, show the confidence bands derived on this basis for the flight miles to exceed the values of $a_{n,LLF}$ of 2.34g and $U_{de,max}$ of 50 feet per second. In assessing the significance of the observed differences between two values, a useful rule of thumb is to consider a difference between two values to be statistically significant if the respective confidence bands for each of the values do not enclose the other value.

Acceleration and Gust Velocity Envelopes

A design acceleration diagram for the present airplane was computed according to current CAA requirements for the gross-weight condition and is shown in figure 6. In order to compare the present test data with this design envelope, flight envelopes were calculated for the acceleration data for an arbitrary flight distance of 10^7 miles. For this comparison, the acceleration values of the calculated envelopes have been multiplied by 85/100 (the ratio of the assumed average operating weight to the airplane gross weight) in order to approximate the equivalent loading history for the gross-weight condition. These adjusted calculated envelopes for the acceleration are shown in figure 6 and should be directly comparable to the design diagram which also applies to the gross-weight condition. The acceleration envelopes for the past operations of the same type of airplane are also given in figure 6 for

comparison. Figure 7 shows the gust-velocity envelopes computed for the present and past operations. These envelopes are for the gust data that were determined initially on the basis of an assumed average weight of 85 percent of the airplane gross weight.

SUMMARY OF RESULTS

Since the pattern of presentation of material of this type has been well established, a detailed discussion of the present results was not felt to be needed. Instead, an itemized summary of the principal indications of the present study is included in order to pinpoint the salient features.

An analysis of 70,000 hours of V-G records from routine feeder-line and short-haul operations for one type of two-engine airplane operated on six civil airline routes from 1947 to 1955 has indicated the following results:

Accelerations

1. The distances to exceed the acceleration corresponding to the design limit-gust-load-factor increment (2.34g) range from 3.6×10^6 to 106.0×10^6 flight miles for the present operations (fig. 1).

2. Although there were considerable differences in the average flight miles to reach the stated level of accelerations experienced among the present operations, the average flight miles are generally somewhat greater than those of the past operations (fig. 4).

Gusts

1. The distances to exceed the derived gust velocity of 50 feet per second range from 0.8×10^6 to 23.5×10^6 flight miles for the present operations (fig. 2).

2. The gusts encountered in the present operations were generally of about the same intensity as those encountered in past operations (fig. 5).

Airspeeds

1. The ratios of V_p/V_C range from 0.70 to 0.87 for the present operations and cover approximately the same range as that indicated for the past operations (table IV).

2. The distances to exceed the never-exceed speed V_{NE} of 257 miles per hour range from 15×10^6 to considerably more than 10^9 flight miles for the present operations (fig. 3).

3. The likelihood of exceeding V_{NE} is indicated as somewhat less for most present operations than that for most past operations (table IV and figs. 6 and 7).

Acceleration and Gust-Velocity Envelopes

1. The calculated acceleration envelopes for 10^7 flight miles do not exceed the design gust-load diagram with the exception of a portion of the envelope for operation B. At high speeds the differences between these calculated envelopes and the design diagram is quite large (fig. 6).

2. The acceleration envelopes for the present operations were generally in the same range or somewhat smaller than the envelopes of the past operations (fig. 6).

3. The gust velocity envelopes of the present operations agree fairly well with the envelopes of the past operations, except for a portion of the envelope for operation B (fig. 7).

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 28, 1955.

APPENDIX

DETAILS OF METHOD OF EVALUATION AND ANALYSIS OF RECORDS

Record Evaluation

The values read from each V-G record were the maximum positive and negative accelerations $a_{n,max}$ which occurred at speeds above 120 miles per hour, the associated values of indicated airspeed V_o, and the maximum indicated airspeed V_{max}. In addition, the largest a_n values in each 20-mile-per-hour speed bracket were read from each record.

The maximum positive and negative derived gust velocities $U_{de,max}$ were computed for each record by use of the revised gust-load formula (see ref. 3):

$$U_{de,max} = \frac{2a_n W}{m\rho_o S V_e K_g} \tag{1}$$

where

$U_{de,max}$ maximum derived gust velocity, fps

a_n normal acceleration on V-G record, g units (corresponds to Δn used in refs. 1, 2, and 4)

V_e equivalent airspeed for derived gust velocity from V-G record, fps

m slope of lift curve per radian (see table I)

ρ_o mass density of air at sea level, slugs/cu ft

K_g gust factor (obtained from fig. 2, ref. 3)

W airplane gross weight, lb

S wing area, sq ft

Inasmuch as the actual operating weights and altitudes at the times the maximum gusts were encountered were not known, the gust velocities $U_{de,max}$ were computed for an assumed average operating weight of 85 percent airplane gross weight and an assumed operating altitude of 5,000 feet.

Curve Fitting

The parameter values given in table III for the acceleration and gust-velocity distributions are: the mean value of the variable $\bar{a}_{n,max}$ and $\bar{U}_{de,max}$, the location parameter u, and the scale parameter α, which were calculated from the observed frequencies by application of the procedures outlined in reference 7. Extreme-value distributions (ref. 7) were fitted to the observed distributions of $a_{n,max}$ and $U_{de,max}$ by use of the parameter values and the method of reference 7 in order to obtain the probabilities P of equaling or exceeding given values of the respective variables.

The parameter values given in table III for the airspeed distributions are: the mean values $\bar{V}_o$ and $\bar{V}_{max}$, the standard deviations σ_o and σ_v, and the coefficients of skewness k_o and k_v, which were obtained by applying the statistical procedures given in reference 10.

A measure of the most probable operating airspeed V_p at which the maximum acceleration occurs in a sample of V-G data was computed from the parameters of the V_o distributions by using the equation (see ref. 11)

$$V_p = \bar{V}_o - \frac{\sigma_o k_o}{2} \tag{2}$$

The V_p values calculated by using this equation are given in table III(b).

The fitted probability distributions obtained for the $a_{n,max}$, $U_{de,max}$, and V_{max} data were used to obtain the average flight miles to equal or exceed given values of the respective variables by using the equation (see ref. 4)

$$\text{Flight miles} = \frac{0.8V_C\tau}{P} \tag{3}$$

where

P probability of equaling or exceeding given values of the variable

τ average flight hours per V-G record

$0.8V_C$ assumed average operating speed

Envelopes

The gust-load and gust-velocity envelopes were calculated from the observed distributions of normal accelerations and derived gust velocities obtained from the data for the 20-mile-per-hour speed brackets of the records analyzed. In order to calculate the envelope in each case for a value of 10^7 flight miles, a probability value was obtained for this value of flight miles by the use of equation (3). Values of a_n or U_{de} for each 20-mile-per-hour speed bracket (positive and negative values were treated separately) corresponding to this probability were calculated by use of the extreme-value method and the parameters of the speed-bracket distributions. These a_n or U_{de} values were plotted at the midpoint speed value of each speed bracket and a curve was faired through these points. In order to complete the envelope from the last speed bracket to the highest speed flown, the product probability method outlined in reference 2 was used. From envelopes calculated on this basis it is expected that, for the given value of flight miles, an average of one positive and one negative acceleration (or gust velocity) will exceed the envelope in each speed bracket and one maximum airspeed will occur above the maximum speed of the calculated envelope.

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TABLE I.- AIRPLANE CHARACTERISTICS[1]

Gross weight, W, lb	25,200
Wing area, S, sq ft	987
Mean geometric chord, c, ft	10.4
Aspect ratio, A	9.1
Slope of lift curve, m, per radian $\left(\text{computed from } \frac{6A}{A+2}\right)$	4.92
Gust factor, K_g (function of mass ratio μ_g, see ref. 3)	0.621
Gust alleviation factor, K (function of wing loading, see ref. 6)	1.100
Design limit gust load factor, n (computed according to ref. 6)	3.34
Design speed for maximum gust intensity, V_B, mph	138
Design cruising speed, V_C (also manufacturer's design maximum level-flight speed, V_L), mph	211
Design diving speed, V_D, mph	286
Never-exceed speed, V_{NE}, mph	257

[1]The values listed were obtained from the manufacturer's design data or were computed according to current design requirements given in reference 6.

TABLE II.- SCOPE OF V-G DATA FOR OPERATIONS FROM 1947 TO 1955

Operation	Service	Routes flown	Dates of operation	Number of airplanes supplying records	Records evaluated		Records analyzed				
					Number	Total hours	Number	Total hours	Range of record hours	Average hours per record	Equivalent flight miles
A	Short-haul	New York - Los Angeles - Seattle	Apr. 1947 to Oct. 1949	2	10	9,829	10	9,829	800 to 1,100	983	1.7×10^6
B	Short-haul	Chicago - New Orleans	Apr. 1950 to Apr. 1953	3	41	19,503	30	10,409	200 to 610	347	1.8×10^6
C	Feeder-line	Billings - El Paso	Mar. 1953 to Oct. 1954	5	73	14,123	58	11,276	150 to 360	194	1.9×10^6
D	Feeder-line	Cincinnati - Norfolk - Myrtle Beach	Jan. 1953 to Feb. 1955	5	81	24,439	78	23,239	200 to 400	298	3.9×10^6
E	Feeder-line	Milwaukee - Wichita - Nashville	Oct. 1953 to Apr. 1955	3	19	7,534	19	7,534	113 to 992	397	1.3×10^6
F	Feeder-line	New Orleans - Memphis - Jacksonville - Charlotte	July 1953 to Apr. 1955	2	7	4,862	7	4,862	170 to 1,508	695	0.8×10^6

TABLE III.- FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS FOR DATA SAMPLES ANALYZED

(a) Maximum normal accelerations $a_{n,max}$

Maximum normal accelerations, $a_{n,max}$, g units	Number of observations for operation -					
	A	B	C	D	E	F
0.4 to 0.5	--	1	---	---	--	--
.5 to .6	--	3	---	1	--	--
.6 to .7	1	2	5	0	3	--
.7 to .8	2	5	8	10	3	3
.8 to .9	1	4	18	11	7	1
.9 to 1.0	2	5	17	21	2	0
1.0 to 1.1	1	7	24	29	2	2
1.1 to 1.2	7	6	20	28	6	3
1.2 to 1.3	1	4	11	22	4	2
1.3 to 1.4	2	4	4	12	1	1
1.4 to 1.5	1	4	2	11	3	0
1.5 to 1.6	0	3	6	5	3	2
1.6 to 1.7	1	2	1	3	1	--
1.7 to 1.8	1	3	---	1	1	--
1.8 to 1.9	--	4	---	1	2	--
1.9 to 2.0	--	1	---	1	--	--
2.0 to 2.1	--	2	---	---	--	--
Total	20	60	116	156	38	14
$\bar{a}_{n,max}$, g units	1.14	1.21	1.05	1.14	1.15	1.11
$\underline{u}$	1.01	1.02	0.95	1.03	1.00	0.99
α	4.45	3.10	5.81	5.38	3.73	4.41

TABLE III.- FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS FOR DATA SAMPLES ANALYZED - Continued

(b) Indicated airspeeds V_o for $a_{n,max}$

Airspeed, V_o, mph	Number of observations for operation -					
	A	B	C	D	E	F
120 to 130	--	7	10	3	3	2
130 to 140	6	12	13	4	7	1
140 to 150	5	12	29	11	2	3
150 to 160	2	5	31	10	3	0
160 to 170	3	7	17	22	6	5
170 to 180	1	10	13	26	5	1
180 to 190	2	6	3	26	6	0
190 to 200	1	1	---	24	1	2
200 to 210	--	--	---	19	4	--
210 to 220	--	--	---	9	0	--
220 to 230	--	--	---	1	1	--
230 to 240	--	--	---	1	--	--
Total	20	60	116	156	38	14
$\bar{V}_o$, mph	154.0	153.7	152.2	179.6	165.5	157.9
σ_o	18.70	19.95	14.90	22.14	26.15	21.52
k_o	0.74	0.24	0.06	-0.27	0.01	0.14
V_p, mph	147.1	151.3	151.7	182.6	165.4	156.4

TABLE III.- FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS FOR DATA SAMPLES ANALYZED - Continued

(c) Maximum indicated airspeeds V_{max}

Airspeed, V_{max}, mph	Number of observations for operation -					
	A	B	C	D	E	F
175 to 180	--	--	1	--	--	--
180 to 185	1	--	4	--	--	--
185 to 190	1	--	10	--	--	--
190 to 195	1	--	22	--	--	--
195 to 200	0	2	10	--	1	1
200 to 205	3	10	7	--	1	1
205 to 210	2	7	1	1	3	0
210 to 215	2	4	2	2	2	2
215 to 220	--	1	0	14	3	1
220 to 225	--	4	1	12	2	1
225 to 230	--	1	--	14	3	1
230 to 235	--	1	--	12	1	--
235 to 240	--	--	--	15	3	--
240 to 245	--	--	--	5	--	--
245 to 250	--	--	--	2	--	--
250 to 255	--	--	--	0	--	--
255 to 260	--	--	--	1	--	--
Total	10	30	58	78	19	7
$\bar{V}_{max}$, mph	201.0	209.7	194.2	228.9	219.6	213.2
σ_V	9.76	9.00	7.85	9.50	11.84	9.79
k_V	-0.62	0.88	0.97	0.26	-0.03	-0.20

TABLE III.- FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS FOR DATA SAMPLES ANALYZED - Concluded

(d) Maximum derived gust velocities $U_{de,max}$

Gust velocity, $U_{de,max}$, fps	Number of observations for operation -					
	A	B	C	D	E	F
12 to 16	--	1	---	1	--	--
16 to 20	1	4	6	12	7	--
20 to 24	2	7	23	38	5	3
24 to 28	3	6	25	33	7	4
28 to 32	6	9	28	30	6	3
32 to 36	3	8	18	23	2	2
36 to 40	2	8	9	12	3	2
40 to 44	1	5	5	6	5	--
44 to 48	1	6	1	1	1	--
48 to 52	1	4	0	---	1	--
52 to 56	--	1	1	---	0	--
56 to 60	--	1	---	---	1	--
Total	20	60	116	156	38	14
$\bar{U}_{de,max}$, fps	31.80	34.00	29.04	27.95	30.10	29.56
u	28.18	29.36	26.07	25.02	25.69	27.15
α	0.16	0.13	0.19	0.20	0.13	0.23

TABLE IV.- COMPARISON OF ACCELERATIONS, GUSTS, AND AIRSPEEDS FOR THE PRESENT AND PAST OPERATIONS

Operation	Dates of operation	V_p, mph	V_p/V_C	Average flight miles to exceed -		
				$a_{n,LLF}$ twice	$U_{de,max}$ of 50 fps twice	V_{NE} once
A (present)	1947 to 1955	147	0.70	63.2×10^6	5.5×10^6	$> 1,000 \times 10^6$
B (present)		151	.71	3.6	0.8	267
C (present)		152	.72	106.0	3.5	> 1,000
D (present)		183	.87	56.9	6.9	15
E (present)		165	.78	10.0	1.5	105
F (present)		156	.74	45.4	23.5	> 1,000
E-I (ref. 1)	1937 to 1941	178	.84	10.9	[a]5.2	80
E-V (ref. 1)		162	.77	4.6	1.0	30
E-VI (ref. 1)		144	.68	13.4	7.0	> 1,000
E-I (ref. 1)	1941 to 1944	180	.85	2.7	[a]0.9	15.5
------ (ref. 2) E-VII (ref. 3)	1948 to 1950	158	.75	2.8	[a]0.6	> 1,000

[a]The $U_{de,max}$ values shown for the past operations were obtained from reference 3.

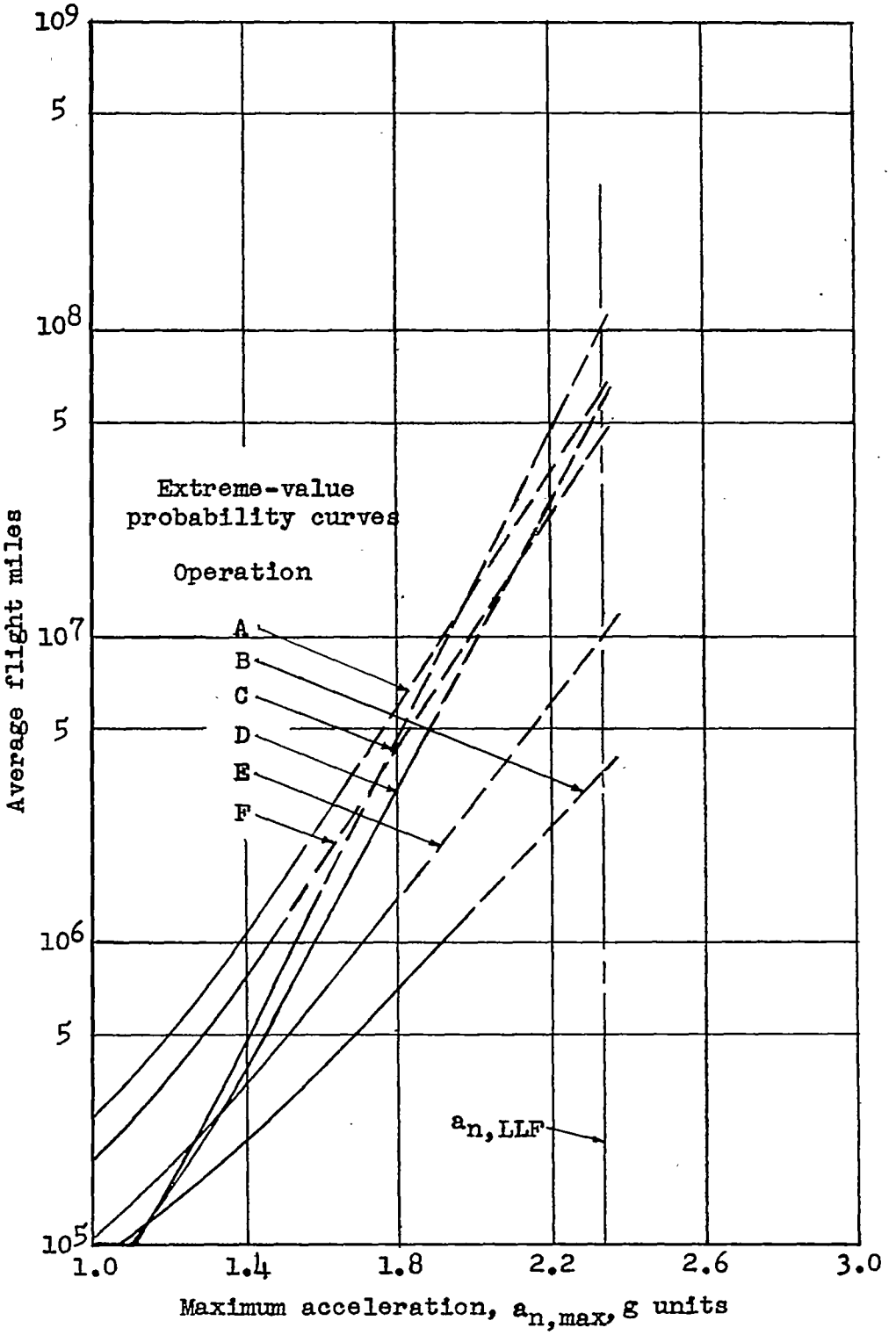

Figure 1.- Average flight miles for a maximum positive and negative acceleration to exceed a given value.

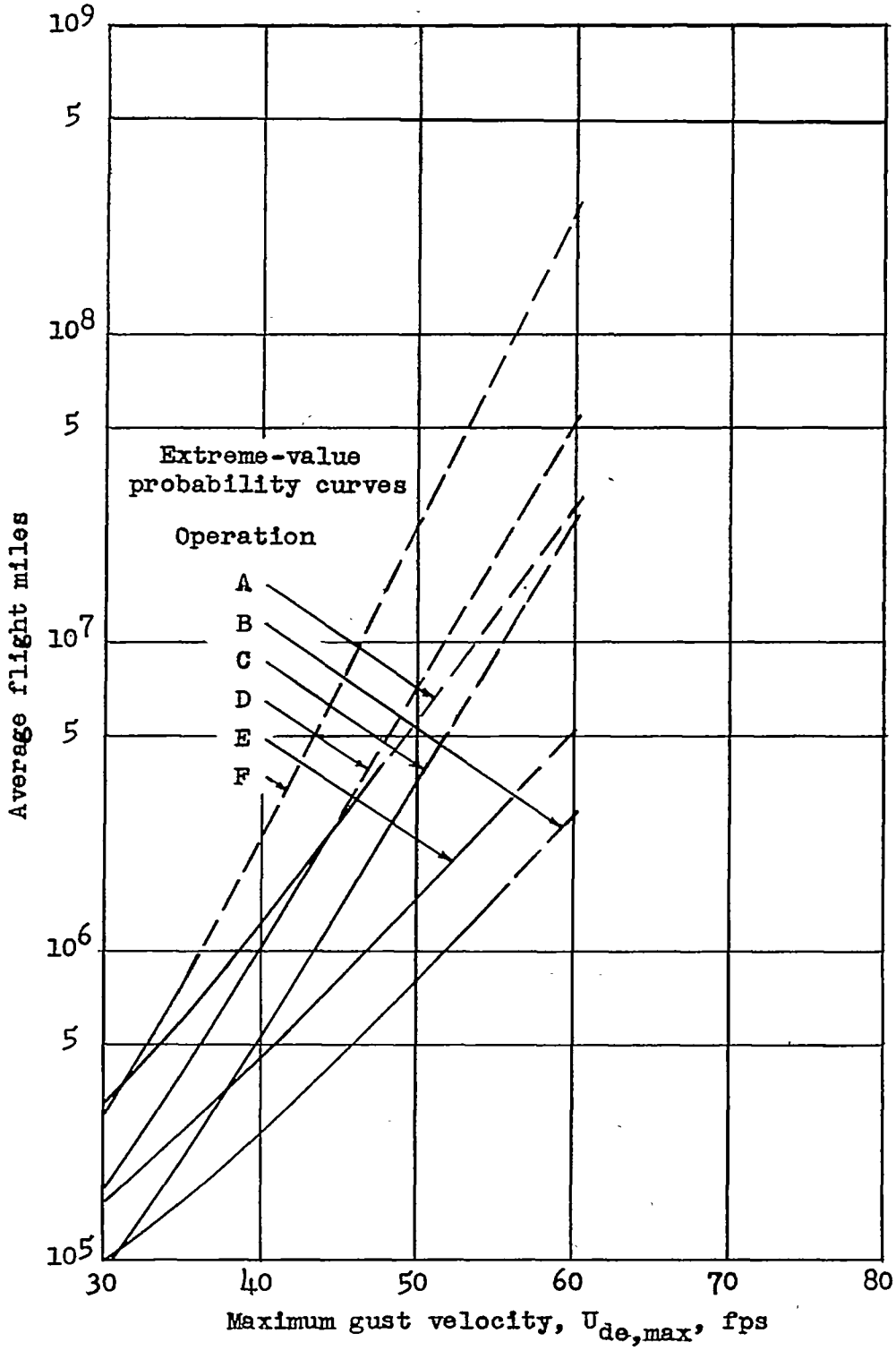

Figure 2.- Average flight miles for a maximum positive and negative derived gust velocity to exceed a given value.

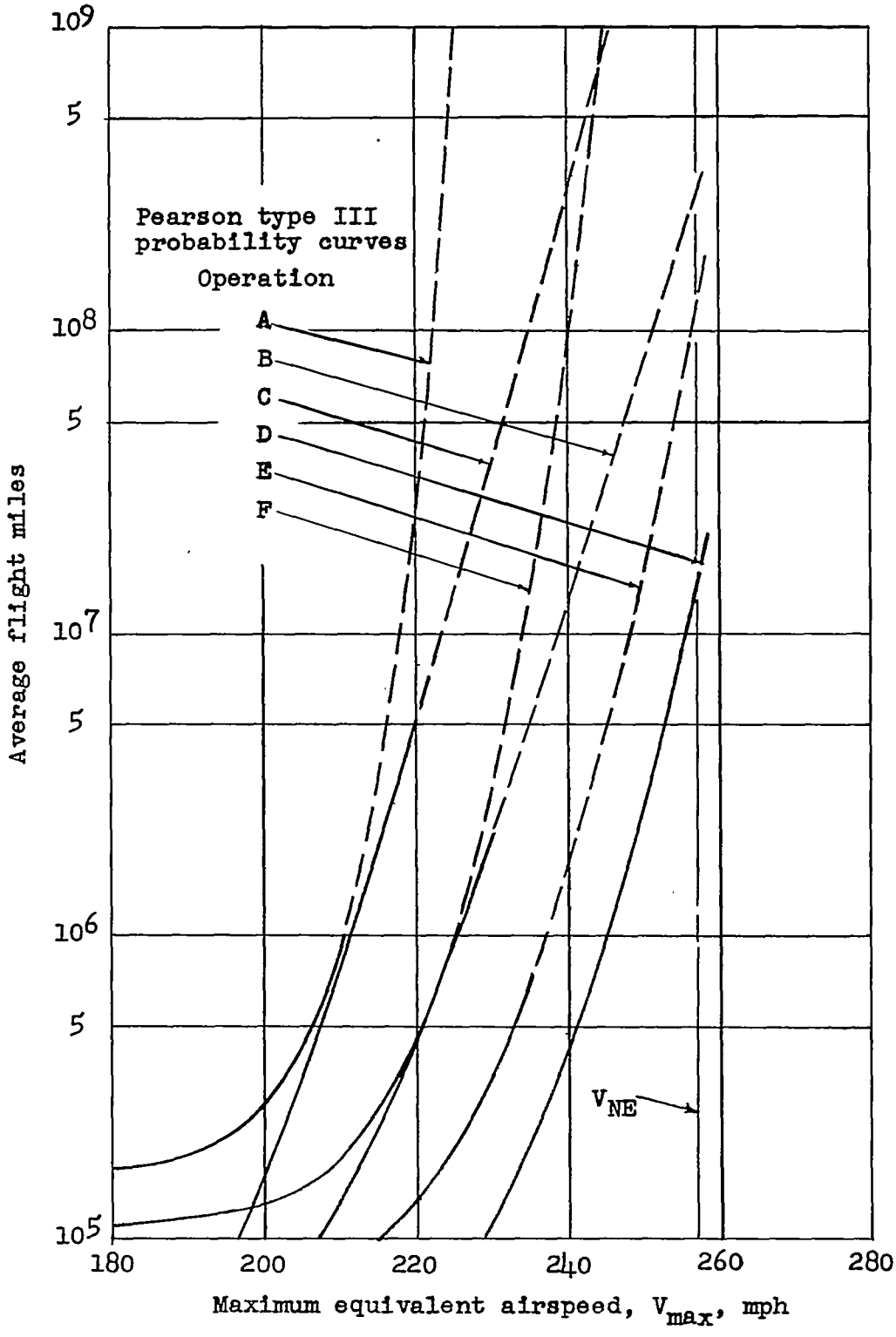

Figure 3.- Average flight miles for maximum equivalent airspeed to exceed a given value.

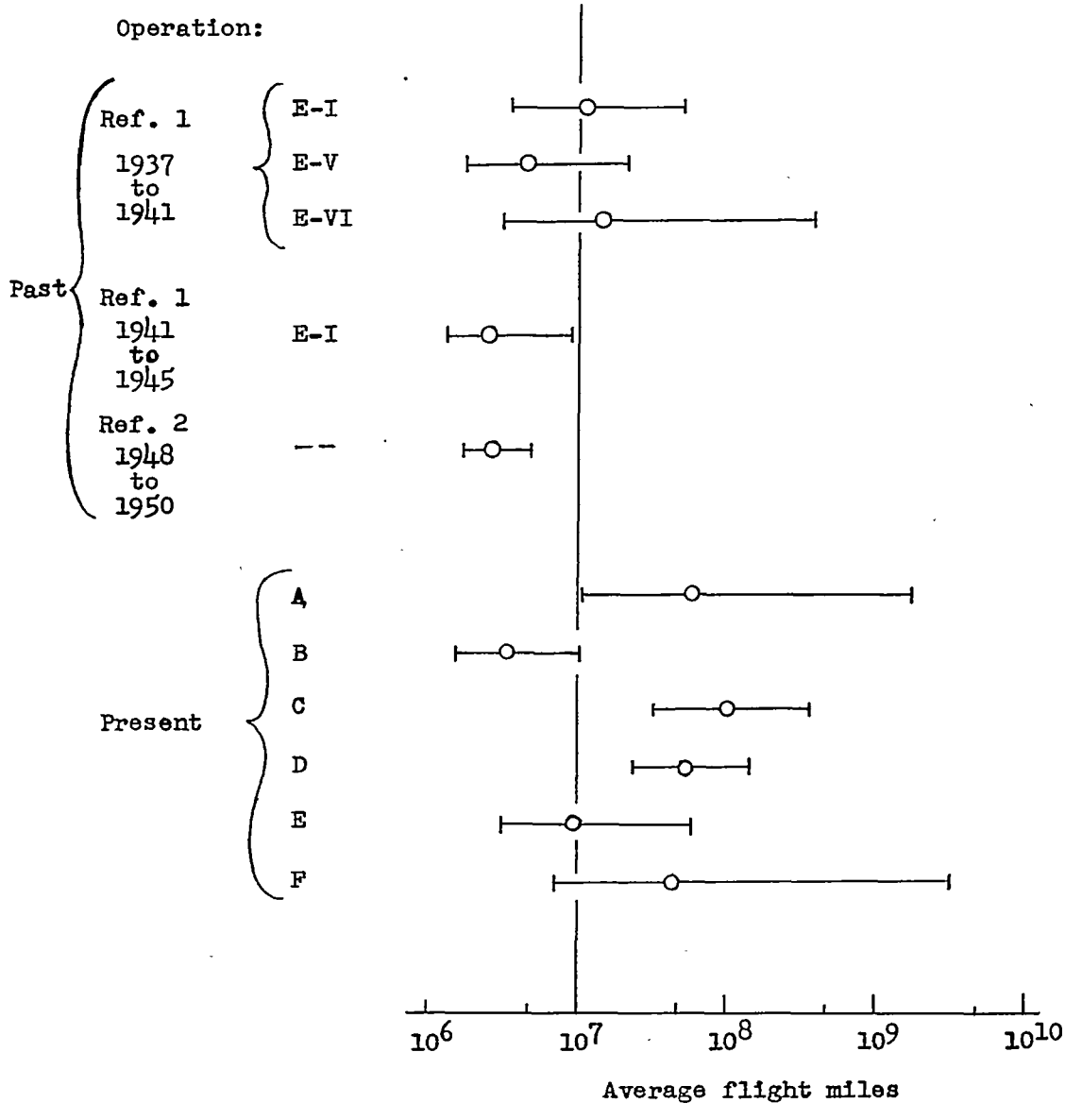

Figure 4.- Average flight miles to exceed $a_{n,LLF}$ twice and the 95-percent confidence bands.

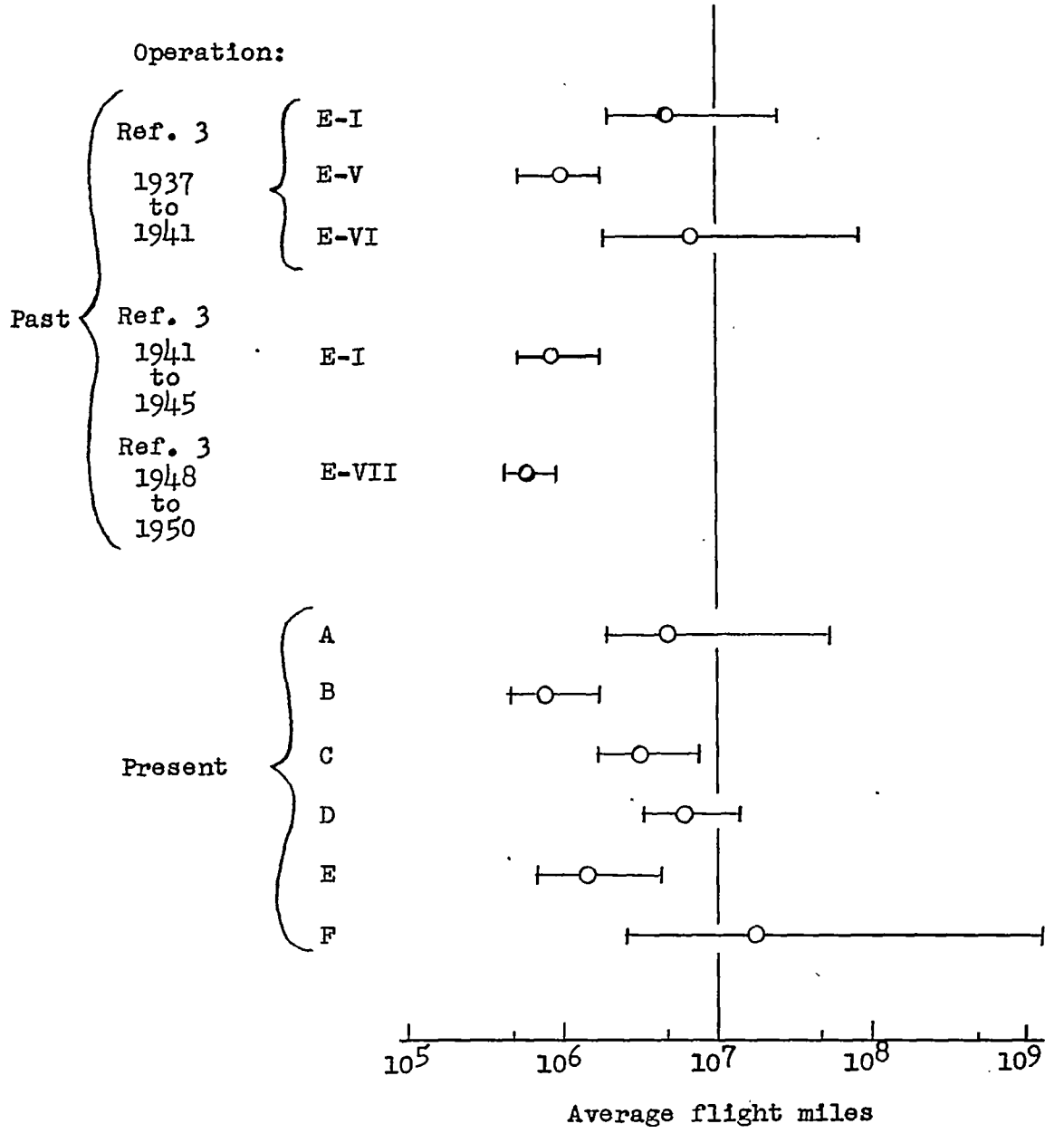

Figure 5.- Average flight miles to exceed $U_{de,max}$ of 50 feet per second twice and the 95-percent confidence bands.

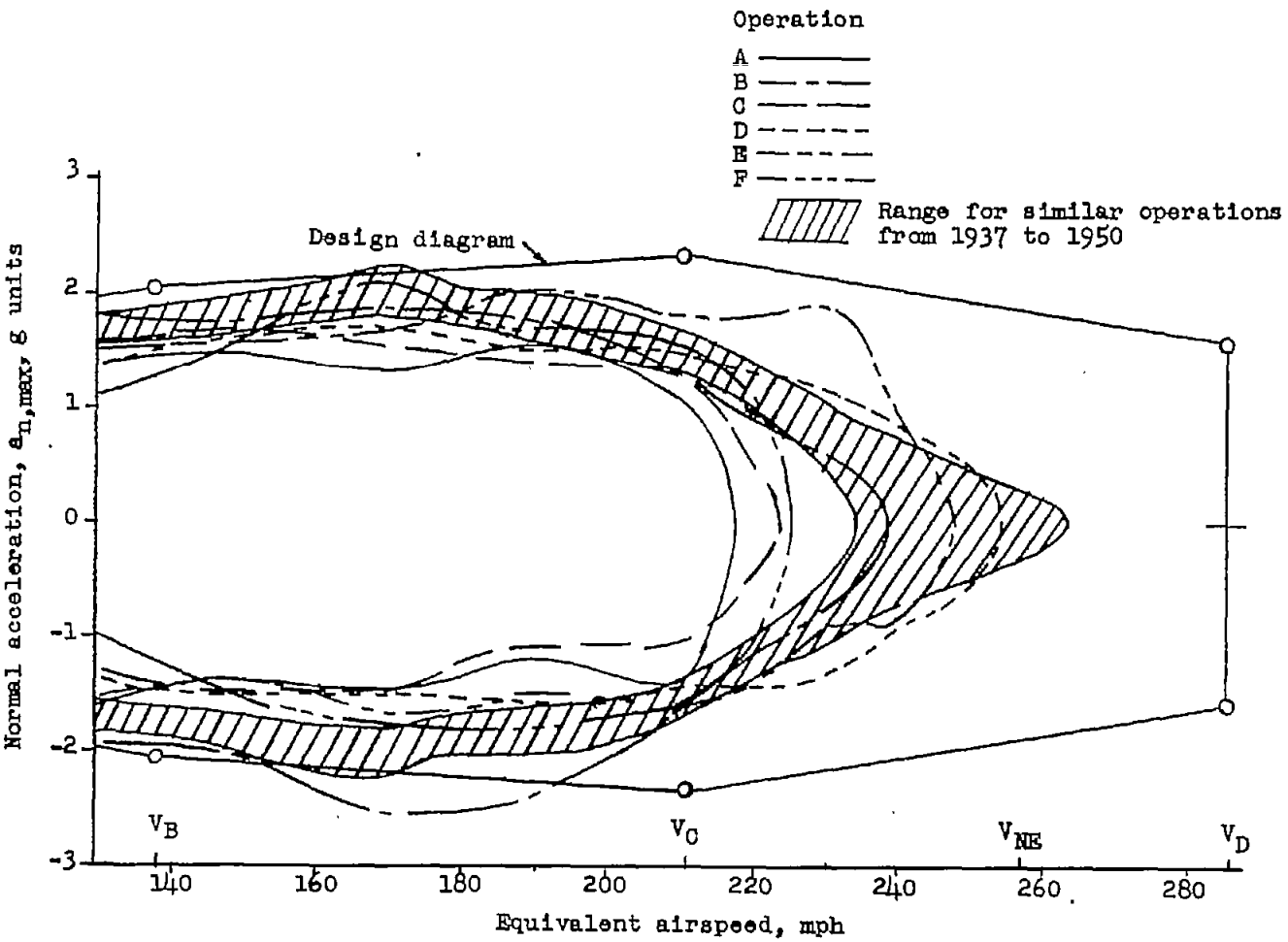

Figure 6.- Calculated gust-load envelopes for 10^7 flight miles of operations of the two-engine transport airplane on each of six different routes, the range for similar airplanes in other transport operations from references 1 to 3, and a design gust-load diagram.

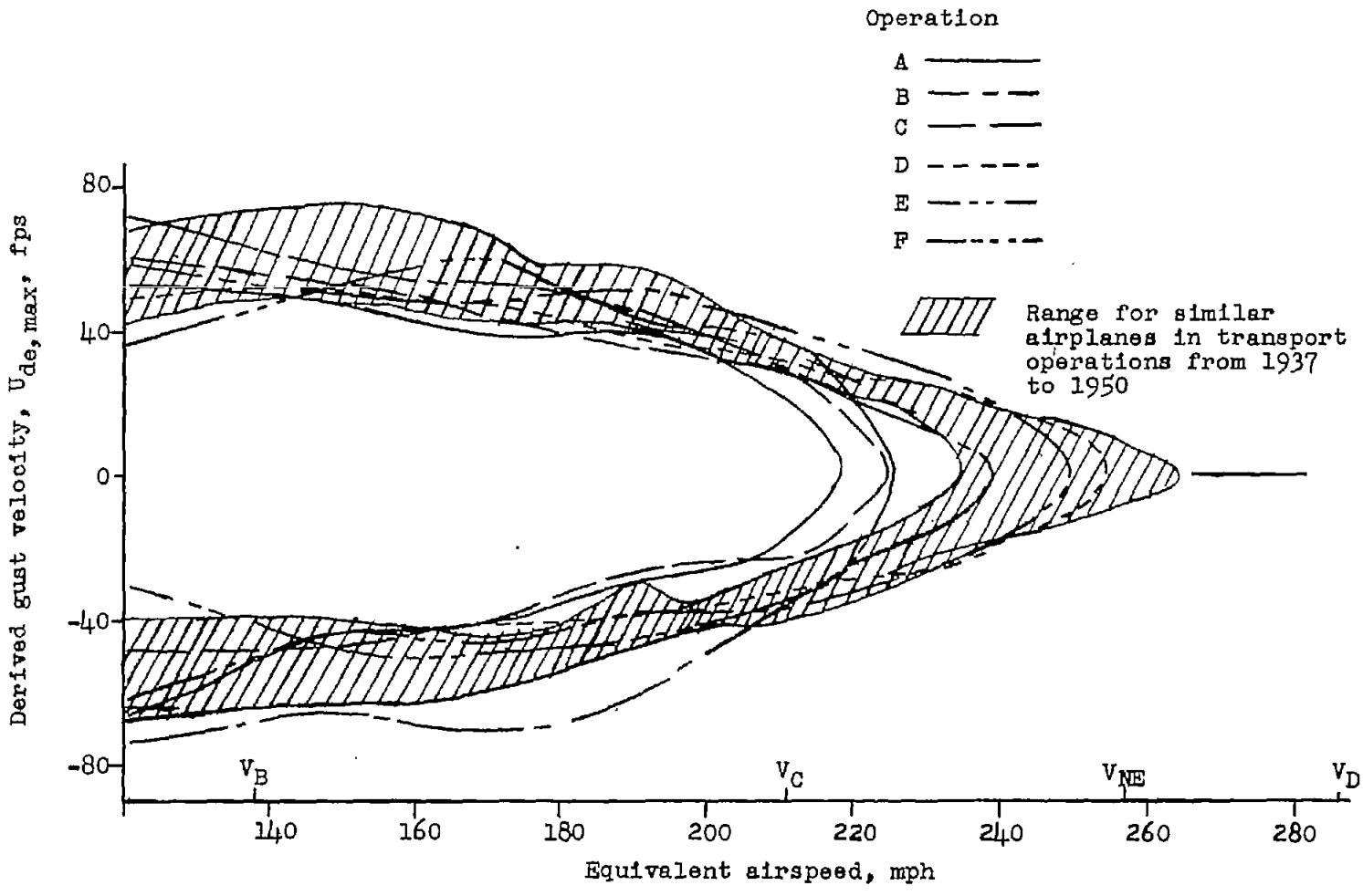

Figure 7.- Calculated gust-velocity envelopes for 10^7 flight miles of operations of the two-engine transport airplane on each of six different routes and the range for similar airplanes in other transport operations from references 1 to 3.