NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2625

SUMMARY OF ACCELERATION AND AIRSPEED DATA FROM COMMERCIAL TRANSPORT AIRPLANES DURING THE PERIOD FROM 1933 TO 1945

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Washington
February 1952

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SUMMARY

Normal acceleration and airspeed data collected with NACA V-G recorders in transport airline operations from 1933 to 1945 are summarized and analyzed with respect to gusts and gust loads. The accelerations experienced in most operations equaled or exceeded the limit-gust-load-factor increment, on the average, twice (once positive and once negative) in 10^7 flight miles. The gusts experienced in most operations exceeded 33 feet per second, on the average, twice (once positive and once negative) in 10^7 flight miles. The loads experienced for several operations varied appreciably from average conditions. A predominating factor causing the variations in the load experience was the difference in the gust experience, with operating speeds in rough air being a secondary contributing or moderating factor.

INTRODUCTION

Records of normal acceleration and airspeed for use in connection with the study of applied gust loads have been obtained with the NACA V-G recorder in commercial transport airplanes during a period of 18 years. Six hundred and fifty-four suitable records representing more than 90,000 flight hours of operations on six types of transport airplanes were collected and evaluated from 1933 to 1945. Analyses of these records for the gust loads experienced by each airplane type are presented in references 1 to 6. Estimates of the frequency of equaling or exceeding stated limit values of acceleration and airspeed were obtained by utilizing statistical methods of analysis. The major implications as to the effects of route, speed, and other associated conditions on the gust loads were considered.

Further study was made of the V-G data collected from 1933 to 1945 to correlate the gust loads and the gusts experienced during the operational lives of the airplanes. A method of statistical analysis (reference 7), which appeared more logical in application to these data than past procedures and which provided a measure of reliability of the derived estimates, was applied. This paper presents a summary of the imposed accelerations, the effective gust velocities, and the airspeeds flown. The statistical method applied gives some measure of sampling reliability to determine the significance of observed differences in the results. The influences of various operating parameters such as flight airspeed are analyzed with respect to the accelerations experienced. Differences in the observed accelerations that could be attributed to differences in route and period of operation are also examined.

SYMBOLS

A	aspect ratio (b^2/S)
b	span, feet
$\bar{c}$	mean geometric chord, feet
K	gust-alleviation factor (reference 8, p. 11)
m	slope of lift curve per radian
W	gross weight, pounds
S	wing area, square feet
ρ_o	mass density of air at sea level, slugs per cubic foot
Δn	normal-acceleration increment, g units
Δn_{LLF}	design limit-gust-load-factor increment, g units
U_e	effective gust velocity, feet per second
V	airspeed, miles per hour
V_L	design maximum level-flight speed, miles per hour
V_{NE}	never-exceed speed, miles per hour (reference 8, p. 36)

V_o	indicated airspeed at which maximum positive or negative acceleration increment or effective gust velocity occurs on a V-G record, miles per hour
V_p	most probable indicated airspeed at which maximum acceleration increment or maximum effective gust velocity occurs in a sample of V-G data, miles per hour
τ	average flight time per V-G record, hours
N	total number of observations
P	probability that maximum value on a V-G record will equal or exceed a given value
u	expected largest value in a specified distribution of extreme values (reference 7)
α	parameter specifying rate of increase of maximum value of variable with increasing sample size (reference 7)
σ_V, σ_o	standard deviations of distributions of V_{max} and V_o, respectively (reference 9, p. 73)
k_V, k_o	coefficients of skewness of distributions of V_{max} and V_o, respectively (reference 9, pp. 74-75)
s	best small sample estimate of the standard deviations of Δn_{max} and $U_{e_{max}}$ computed by $\sqrt{\frac{\sum (x - \bar{x})^2}{N - 1}}$ (reference 7)
x	random variable

Subscripts:

max	maximum value read from V-G record
30	denotes an effective gust velocity of 30 feet per second

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

SCOPE AND EVALUATION OF RECORDS

The scope of the V-G records collected is summarized in table I according to routes flown, dates of operation, number of V-G records evaluated, average hours per record, and total record hours for a given operation. The 654 records summarized in table I comprise most of the flight acceleration and airspeed measurements suited for evaluating the gust loads experienced by American commercial transport airplanes during domestic and overseas operations from 1933 to 1945. In addition to the data of table I, information regarding unusual acceleration or airspeed occurrences was supplied in some cases and was of appreciable help in evaluating the records. No information was provided on actual operating weights. All faulty records and records that could not be regarded as typical of normal transport operation, such as records having large accelerations caused by maneuvers in pilot check flights, were not included in the analysis.

Since the years during which these data were taken included a wartime period and since marked changes in operating techniques and airspeed practices in rough air during the pressure of this emergency could have appreciably influenced the gust loads, the data in table I are divided into two groups to study the effects of the different periods. Period I (prewar period) contains the data collected from 1933 to 1941 and period II (wartime period) represents the 1941 to 1945 data. The letters A, B, E, and F identify landplanes while C and D identify flying boats. Combinations such as A-I and B-II are used to identify airplane and airline operations for the routes shown in table I.

Table II gives the airplane characteristics used in the evaluation of the data. These values were obtained either from the Civil Aeronautics Administration and the design data of the airplane manufacturer or the values were computed in accordance with the present Civil Aeronautics Administration design requirements (reference 8). The two Δn_{LLF} values shown in table II for each airplane were computed on the basis of the design lift-curve slopes to conform with references 1 to 6 and on the basis of computed lift-curve slopes to place all the data herein on a common basis. The computed lift-curve slopes were obtained from the relation $\frac{6A}{A + 2}$, as recommended in reference 10, and are shown in the table together with the design values. The placard never-exceed speed V_{NE} is defined herein as $1.25V_L$. This speed value lies within the permissible never-exceed speed range specified in reference 8.

In evaluating the V-G records, all large accelerations at airspeeds above 100 miles per hour were assumed to be due to gusts since experience has indicated that most of the maneuver accelerations during normal transport airline operations are small. Accelerations occurring at speeds less than 100 miles per hour were assumed to be due to landing shocks and, therefore, were not read.

The values read from the V-G records for the analysis were the maximum positive and negative acceleration increments Δn_{max}, their corresponding indicated airspeed values V_o, and the maximum indicated airspeed V_{max}. The maximum positive and negative effective gust velocities were computed from the positive and negative Δn values and their corresponding V_o values by using the sharp-edge-gust formula (see reference 11)

$$U_{e_{max}} = \frac{2 \Delta n \frac{W}{S}}{1.47 \rho_o m K V_o}$$

The actual weight of the airplane was not known at the time of gust encounter. Eighty-five percent of gross weight, which past experience has indicated is a reasonable estimate, and the K value corresponding to this weight were used for evaluating the effective gust velocity.

ANALYSIS AND RESULTS

The statistical theory of extreme values was applied to the Δn_{max} and $U_{e_{max}}$ values in the present analysis. An application of this theory in reference 7 indicated that the estimates of the frequency of encountering the larger gust loads and gust velocities are more consistent with the data and more reliable than the estimates obtained by applying the methods used heretofore. Inasmuch as past investigations have indicated that the theory of extreme values was not applicable to the distributions of airspeeds, the Pearson Type III distribution curves were utilized to estimate the probabilities of large airspeed occurrences in the same manner as in references 1 to 6.

Table III gives the observed frequency distributions and statistical parameters of Δn_{max}, $U_{e_{max}}$, V_{max}, and V_o used in the analysis. The basic distributions are the same as those used in references 1 to 6. For the extreme-value method, however, the parameters given in these tables differ in some cases from the corresponding values given in references 1 to 6. In the present data where the number of observed values are greater than 75, the parameters were obtained by the method of moments (reference 7). For the distributions where the number of values are less than 75, the method of least squares was applied. With the use of these values and the procedures outlined in reference 7, distributions of extreme values were fitted to the observed distributions of tables III(a) and III(b) to obtain estimates of the probability P of equaling or exceeding given values of Δn_{max} or $U_{e_{max}}$.

If it is assumed that the airplanes were flown at an average speed of $0.8V_L$, the average miles the airplanes would have to fly to equal or exceed given values of Δn_{max} or $U_{e_{max}}$ were obtained by using the relation

$$\text{Flight miles} = \frac{0.8V_L T}{P}$$

Figures 1(a) and 1(b) present the curves of average flight miles to equal or exceed given values of $\Delta n_{max}/\Delta n_{LLF}$ twice (once positive and once negative) for periods I and II, respectively. The curves of average flight miles to equal or exceed given values of $U_{e_{max}}/U_{e_{30}}$ twice for periods I and II are shown in figures 2(a) and 2(b), respectively. The abscissa scales in these figures are nondimensional ratios to permit direct comparison of the accelerations and gust velocities for different operations. For those samples of data which did not extend to the values used in design, the probability curves were extrapolated to obtain the estimates at the design limits. The extrapolated portions of the curves are shown in the figures as dashed lines. These extrapolations appear justified by past experience, provided the estimates are used only as an indication of the order of magnitude.

The curves of figures 3(a) and 3(b) show the average flight miles to equal or exceed given values of V_{max}/V_L for periods I and II, respectively. The airspeeds are given as nondimensional ratios to facilitate direct comparison of different operations.

In order to obtain a measure of the average operating airspeeds in rough air, the most probable speeds at which the largest accelerations were experienced were computed from the parameters of the V_o distributions of tables III(d) and III(e) with the relation

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

which can be derived from reference 12, page 92. For comparing the different operations discussed herein, these probable speeds are given in table IV in the form of the airspeed ratio V_p/V_L. Also shown in table IV are the average flight miles to equal or exceed Δn_{LLF}, V_{NE}, and $U_{e_{30}}$ as taken from figures 1 to 3 for comparing gust-load, gust, and maximum-airspeed occurrences.

For comparing the accelerations experienced by the airplane as indicated by the extreme-value and Pearson Type III methods, table V shows the $\Delta n_{max}/\Delta n_{LLF}$ values for 10^7 flight miles as obtained by the two methods. For the extreme-value method, two sets of values are given in the table to indicate the effect, on the accelerations experienced, of basing the ratios on the computed and the design values of the lift-curve slopes.

One of the problems in a statistical analysis containing limited data samples, such as the Δn and U_e values presented herein, is the question of the reliability of the estimated probability of equaling or exceeding the larger and extrapolated values. In connection with this problem, a method of obtaining confidence bands based on the distribution of the sampling estimates of u and α was derived by Kimball in reference 13. These confidence bands can be taken as a measure of the range within which, for a given probability level, the true value may be expected to lie. The width of these confidence bands at a given value of the distribution is a function of the sample size and the parameter representing the scatter of the data about the mean.

Figures 4 and 5 show the width of the confidence bands derived about the Δn and U_e values from figures 1 and 2 at 10^7 flight miles. These confidence bands were obtained for a probability level of 95 percent. Observed differences between given values of any two samples in figures 4 and 5 are considered significant if each value is not enclosed by the confidence band of the other value. Although this procedure is not rigorous, it appears to be a reasonable basis for judging real differences between the present samples of data.

PRECISION

The precision of the NACA V-G recorder has been discussed in reference 1. The inherent errors in the instrument are assumed not to exceed either a maximum value of ±0.2g or 3 percent of the maximum-airspeed range. For the large number of V-G recorders used in obtaining the present data, random positive and negative errors would tend to reduce the error of the final results.

Reading errors which occurred during the evaluation of the data are believed to be random and largely to balance out. Sampling errors may be large depending on the sample size and have already been considered in terms of the confidence bands.

Although it is recognized that dynamic response of the airplane structure can have a significant effect on the accelerations measured at the center of gravity, the effect of dynamic response on the accelerations analyzed herein is unknown.

DISCUSSION

Factors of primary importance in this analysis are the estimates of the average values of Δn_{max} and $U_{e_{max}}$ experienced during the operational lives of the airplanes. The largest values of Δn_{max} and $U_{e_{max}}$ generally approached the limit-gust-load-factor increment Δn_{LLF} and an effective gust velocity U_{e30} in the neighborhood of 10^7 flight miles. The 10^7 flight miles level, therefore, appears reasonable for comparing the results. This level is equivalent to about 50,000 flight hours or more than 15 years operation of the airplanes. The V_{max} experiences are compared at a level roughly equivalent to the placard never-exceed speed V_{NE}.

Acceleration Experience

Figure 1 indicates that the acceleration experiences for most operations equaled or exceeded Δn_{LLF}, on the average, twice (once positive and once negative) in 10^7 flight miles. Although the over-all spread of $\Delta n_{max}/\Delta n_{LLF}$ is from approximately 0.8 to 1.24, most values at 10^7 flight miles are closely grouped about a value of 1. The value of 1 for $\Delta n_{max}/\Delta n_{LLF}$, therefore, is considered as the group average during the operational lives of these airplanes.

Inspection of figure 4 indicates that the acceleration experiences of all operations except four are not significantly different from the group average. It is considered, therefore, that the acceleration experiences of most of these operations were generally in close agreement insofar as the limit-load-factor increment is concerned.

In regard to the four exceptions noted, figure 4 indicates that for the E-I and F-III routes the accelerations experienced during period II operations were significantly larger than during period I operations. Inasmuch as the routes remained the same during the two different periods in these two cases, the reason for the generally larger accelerations during period II than during period I might be attributed to the fact that period II covered wartime operations. In addition to this difference between the two periods, some operations over different routes also varied significantly during the same period as indicated by a comparison of the acceleration experiences of A-I and F-III period I operations in figure 4. These differences will be discussed in more detail subsequently.

It is of interest to note that the acceleration experiences for the flying boats, the C-III and D-IV operations, are not significantly different from the group average.

Before considering the factors which affect the acceleration experiences, it is appropriate to mention the differences obtained between the results of this analysis and those of references 1 to 6. Any differences in the results may be attributed to two causes: first, the use of the extreme-value method instead of the Pearson Type III method in estimating the frequency of occurrence of the larger accelerations; and, second, the use of a computed slope of the lift curve for obtaining limit load factors instead of using the design limit load factors. Table V shows that each of these changes had a rather marked effect on the acceleration ratios. The effect of using the computed lift-curve slope and the extreme-value method generally was to yield larger values of $\Delta n_{max}/\Delta n_{LLF}$ at 10^7 flight miles than the corresponding values obtained by using the Pearson Type III method and the airplane characteristics of references 1 to 6. The relations of the acceleration experiences among the different operations, however, remained about the same in most cases regardless of the particular statistical method used. The changes introduced by the analytical techniques are, therefore, believed to be of minor importance with respect to the comparisons between the airplane experiences although the predicted load levels were appreciably increased.

Since the acceleration experiences are principally a function of gust experiences, operating airspeeds, and operating weights, the data were studied to learn to what extent these parameters would influence the acceleration experiences.

Gust Experience

Figure 2 indicates that the effective gust experiences for all operations exceeded $U_{e_{30}}$, on the average, twice in 10^7 flight miles. Most of these operations are grouped in the neighborhood of $\frac{U_{e_{max}}}{U_{e_{30}}} = 1.1$ at 10^7 flight miles. This value, which corresponds to an effective gust velocity of 33 feet per second, is accordingly taken as the group average.

In comparing the gust experiences of the various operations in figure 5 with the acceleration experiences in figure 4, it will be noted that the gust experience in each case appears directly reflected in the acceleration experience. In the case of the F-III period I operations, however, the average gust experience in figure 5 and the acceleration experience in figure 4 that is significantly lower than average will be considered with respect to the effect of operating speed in the subsequent discussion. It is concluded from a comparison of figures 4 and 5 that the level of the gust experiences are directly reflected in the acceleration experiences of most of the operations considered.

When the gust experiences are considered with respect to different periods, figure 5 shows that the gust experiences during period II tend to be higher than during period I, the differences for the E-I and F-III operations being clearly significant. These differences are believed to be attributable to changed operational techniques between the two periods, with the more urgent nature of the wartime operations and the use of improved navigational facilities allowing more flights under conditions likely to be turbulent.

Comparison of the operations of different airplanes during different periods where the routes and operating airline remained the same shows that (see fig. 5) the A-I gust experience is significantly more severe than the E-I (period I) gust experience. In fact, the A-I gust experience is approximately the same as the gust experience during E-I (period II) wartime operations. Some clue regarding this fact is indicated in table I which shows that A-I was the first transcontinental operation where V-G data were collected. It is quite possible that the lack of a background of experience in avoiding severe turbulence during this earliest A-I operation might partly account for the larger than average gusts encountered.

Since the gust experience is approximately the same for all operations in a given period, it is concluded that the gust experiences during these operations were largely independent of route, airplane, and operator; changes in operating techniques and practices for different periods probably accounted in most part for the different gust experiences indicated.

Probable Airspeed

When considering the probable airspeeds at the maximum gust occurrences, table IV shows that the values of the ratio V_p/V_L at $U_{e_{max}}$ are in most cases lower than 0.7. Inasmuch as the average operating speed under normal conditions is usually taken as $0.8V_L$, some tendency to reduce speed when turbulent air was encountered might be inferred.

The relative contributions of variations in operating speeds and variations in gust experience to the acceleration experience may be inferred from the data of table IV and figures 4 and 5. The variations from average values are summarized in the following table:

Operation	Period	Variation from average value, percent		
		V_p/V_L at Δn_{max}	$U_{e_{max}}/U_{e_{30}}$ at 10^7 flight miles	$\Delta n_{max}/\Delta n_{LLF}$ at 10^7 flight miles
A-I	I	10	27	24
E-I	II	6	45	20
E-V	I	-4	16	10
F-III	II	-11	31	7
F-III	I	-19	-1	-21

The table indicates that, in the first four operations, the major contributing factor causing unusually high acceleration experience was the variations in the gust experience.

For the A-I and the E-I (period II) operations, operating speed apparently contributed to the high acceleration experience while for the E-V and the F-III (period II) operations, operating speed was a moderating factor on the acceleration experience. In one case, the F-III (period I) operation, the gust experience did not depart appreciably from average but a 21-percent reduction in acceleration experience was achieved by flying at appreciably lower airspeeds in rough air. It is consequently concluded that the gust experience was the predominating factor involved in the variation of the acceleration experiences from the average acceleration experience. Operating speeds in rough air in general were a secondary contributing factor causing smaller variations in the acceleration experiences.

Maximum Airspeeds

Examination of figure 3 indicates that the spread in flight miles to equal or exceed the placard never-exceed speed V_{NE} varies from about 10^6 flight miles, equivalent to about 7,000 flight hours, for A-I to more than 10^9 flight miles in five other cases. Comparison of the flight miles during different periods for the E-I and the F-III operations indicates a small decrease in flight miles to equal V_{NE} during period II operations.

Inspection of the records indicated that the high speeds were attained during the times the airplanes were experiencing low turbulence. A comparison of the flight miles to equal V_{NE} with the flight miles to equal Δn_{LLF} or to equal $U_{e_{30}}$ indicated no relation between the quantities for either period I or period II operations.

CONCLUSIONS

The analysis of the acceleration and airspeed data obtained on six types of airplanes in commercial transport airline operations during the period from 1933 to 1945 indicates the following results:

1. The accelerations experienced in most operations equaled or exceeded the limit-gust-load-factor increment Δn_{LLF}, on the average, twice (once positive and once negative) in 10^7 flight miles. The gusts experienced in most operations exceeded 33 feet per second, on the average, twice (once positive and once negative) in 10^7 flight miles.

2. The loads experienced for several operations varied appreciably from average conditions. A predominating factor causing the variations in the load experience was the differences in the gust experience, with operating speeds in rough air being a secondary contributing or moderating factor.

3. The gust experiences during the operations of these airplanes were largely independent of route, airplane, and operator; the changes in operating techniques for different periods accounted in most part for the significantly different gust experiences indicated.

4. Flights were made through turbulence of greater severity during period II (wartime period) than during period I (prewar period).

5. The miles to exceed the placard never-exceed speed V_{NE} varied considerably for the present data and were apparently not related to the miles to exceed the limit-load-factor increment Δn_{LLF} or effective gust velocity of 30 feet per second $U_{e_{30}}$.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., August 20, 1951

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TABLE I

SCOPE OF V-G DATA COLLECTED IN AIRLINE OPERATIONS FROM 1933 to 1945

Airplane	Airline	Routes flown	Dates of operation	Number of records evaluated	Average flight hours per record, τ	Total record hours
			Period I operations			
A	I	Newark-Seattle-Oakland	July 1933 to April 1937	30	305	9,168
B	II	Miami-Newark-Boston	June 1935 to Dec. 1940	18	367.5	6,615
C	III	Miami-Buenos Aires	April 1936 to Dec. 1939	117	95.1	11,124
D	IV	San Francisco-Hawaii-Hong Kong	June 1936 to Dec. 1941	100	128.1	12,807
E	I	Newark-Seattle-Oakland	July 1937 to Dec. 1941	15	645	9,691
E	V	Boston-Newark-Los Angeles	Feb. 1937 to Oct. 1939	37	275	10,187
E	VI	Newark-Kansas City-Los Angeles	Sept. 1938 to Oct. 1940	11	295	3,232
F	III	Caribbean region and northern part of South America	April 1940 to Dec. 1941	83	29	2,386
			Period II operations			
F	III	Caribbean region and northern part of South America	Dec. 1941 to Sept. 1944	193	53	10,261
E	I	Newark-Seattle-Oakland	Dec. 1941 to Dec. 1944	20	695	13,911
D	IV	San Francisco-Hawaii	Dec. 1941 to Jan. 1945	30	36.1	1,084

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TABLE II

AIRPLANE CHARACTERISTICS

Airplane	Design gross weight, W (lb)	Wing area, S (sq ft)	Wing span, b (ft)	Mean geometric chord, $\bar{c}$ (ft)	Aspect ratio, A	Gust-alleviation factor K for -		Design maximum level-flight speed (mph)		Placard never-exceed speed, V_{NE} (mph)	Slope of lift curve, m (per radian)		Limit-gust-load factor increment, Δn_{LLF} (g units)	
						W	0.85W	V_L	$0.8V_L$		Design value	Computed value	Design value	Computed value
A	13,400	836	74	11.3	6.6	1.000	0.960	180	144	225	4.22	4.60	2.48	2.70
B	18,560	939	85	11.0	7.7	1.045	1.008	215	172	269	4.65	4.76	2.77	2.83
C	41,000	1340	118.2	11.3	10.4	1.130	1.098	181	145	226	4.54	5.04	1.59	1.76
D	50,000	2145	130	16.5	7.9	1.084	1.045	168	134	210	4.45	4.78	1.82	1.95
E	25,200	987	95	10.4	9.1	1.100	1.064	211	169	263	4.79	4.92	2.28	2.34
F	45,000	1486	107.3	13.9	7.8	1.128	1.097	230	184	288	4.42	4.78	1.98	2.14

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TABLE III

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS

(a) Δn_{max}

Δn_{max} (g units)	Period I operations								Period II operations		
	A-I	B-II	C-III	D-IV	E-I	E-V	E-VI	F-III	F-III	E-I	D-IV
0.2 to 0.3	----	----	2	3	----	----	----	----	----	----	----
.3 to .4	----	----	11	10	----	----	1	12	3	----	1
.4 to .5	----	----	14	31	----	----	2	41	7	----	2
.5 to .6	----	----	24	31	----	1	2	30	27	----	8
.6 to .7	1	1	57	29	1	3	1	35	51	----	13
.7 to .8	0	4	57	40	1	1	3	21	64	2	11
.8 to .9	0	4	31	20	2	9	3	12	61	0	12
.9 to 1.0	2	4	19	16	2	6	2	7	57	2	9
1.0 to 1.1	2	3	9	8	4	8	3	5	44	5	2
1.1 to 1.2	1	4	3	4	4	14	2	2	22	2	0
1.2 to 1.3	2	2	4	3	6	9	0	1	23	5	0
1.3 to 1.4	3	4	1	0	4	6	0	----	8	4	1
1.4 to 1.5	2	2	2	2	2	5	3	----	7	5	0
1.5 to 1.6	5	1	----	1	0	3	----	----	1	1	0
1.6 to 1.7	6	2	----	1	0	2	----	----	3	4	1
1.7 to 1.8	10	2	----	0	3	2	----	----	4	1	----
1.8 to 1.9	9	1	----	0	0	2	----	----	1	3	----
1.9 to 2.0	1	2	----	0	1	0	----	----	1	3	----
2.0 to 2.1	4	----	----	0	----	1	----	----	1	1	----
2.1 to 2.2	3	----	----	0	----	2	----	----	0	0	----
2.2 to 2.3	5	----	----	0	----	----	----	----	0	0	----
2.3 to 2.4	1	----	----	1	----	----	----	----	1	1	----
2.4 to 2.5	2	----	----	----	----	----	----	----	----	1	----
2.5 to 2.6	1	----	----	----	----	----	----	----	----	----	----
Total, N	60	36	234	200	30	74	22	166	386	40	60
$\overline{\Delta n}$	1.71	1.23	0.73	0.71	1.22	1.20	0.88	0.63	0.92	1.44	0.75
s	0.34	0.40	0.20	0.28	0.31	0.34	0.32	0.20	0.28	0.41	0.21
α	2.96	2.88	6.30	4.64	3.62	3.54	3.47	6.52	4.63	2.85	5.67
u	1.53	1.04	0.64	0.58	1.07	1.04	0.73	0.55	0.80	1.25	0.66

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TABLE III - Continued

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS - Continued

(b) $U_{e_{max}}$

$U_{e_{max}}$ (fps)	Period I operations								Period II operations		
	A-1	B-II	C-III	D-IV	E-I	E-V	E-VI	F-III	F-III	E-I	D-IV
4 to 6	----	----	2	2	----	----	----	1	1	----	1
6 to 8	----	----	5	23	----	----	1	10	2	----	1
8 to 10	1	----	12	30	----	----	2	29	9	----	4
10 to 12	1	5	36	46	2	3	2	41	36	1	18
12 to 14	1	8	38	33	1	7	5	25	42	1	13
14 to 16	7	8	67	40	5	17	2	36	80	8	15
16 to 18	8	5	32	15	3	7	5	12	58	4	5
18 to 20	7	4	20	3	6	8	2	5	70	6	1
20 to 22	13	3	15	3	8	16	2	2	36	7	0
22 to 24	4	1	1	0	3	8	0	3	19	4	1
24 to 26	5	0	2	4	1	3	1	2	15	3	0
26 to 28	9	1	1	0	1	2	----	----	4	0	0
28 to 30	1	1	3	0	----	0	----	----	2	0	1
30 to 32	3	----	----	0	----	1	----	----	5	3	----
32 to 34	----	----	----	0	----	2	----	----	1	1	----
34 to 36	----	----	----	1	----	----	----	----	2	0	----
36 to 38	----	----	----	----	----	----	----	----	0	0	----
38 to 40	----	----	----	----	----	----	----	----	1	0	----
40 to 42	----	----	----	----	----	----	----	----	3	0	----
42 to 44	----	----	----	----	----	----	----	----	----	1	----
44 to 46	----	----	----	----	----	----	----	----	----	0	----
46 to 48	----	----	----	----	----	----	----	----	----	0	----
48 to 50	----	----	----	----	----	----	----	----	----	0	----
50 to 52	----	----	----	----	----	----	----	----	----	1	----
Total, N	60	36	234	200	30	74	22	166	386	40	60
$\bar{U}_e$, fps	20.87	16.05	14.85	12.43	18.71	18.68	14.76	12.72	17.39	21.43	13.09
s	5.10	4.48	3.96	4.08	3.83	4.88	4.45	3.71	5.21	7.88	3.70
α	0.23	0.26	0.32	0.31	0.30	0.25	0.25	0.35	0.25	0.15	0.32
u	18.50	13.95	13.06	10.59	16.89	16.42	12.63	11.05	15.05	17.72	11.37

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TABLE III - Continued

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS - Continued

(c) V_{max}

V_{max} (mph)	Period I operations								Period II operations		
	A-I	B-II	C-III	D-IV	E-I	E-V	E-VI	F-III	F-III	E-I	D-IV
135 to 140	—	—	—	1	—	—	—	—	—	—	—
140 to 145	—	—	—	0	—	—	—	—	—	—	—
145 to 150	—	—	—	1	—	—	—	—	—	—	—
150 to 155	—	—	12	3	—	—	—	—	—	—	2
155 to 160	—	—	18	11	—	—	—	—	—	—	2
160 to 165	—	—	22	19	—	—	—	—	—	—	3
165 to 170	—	—	23	28	—	—	—	—	—	—	7
170 to 175	—	—	17	11	—	—	—	—	—	—	6
175 to 180	1	—	16	11	—	—	—	—	—	—	7
180 to 185	1	—	6	9	—	—	—	—	—	—	1
185 to 190	2	—	0	2	—	—	—	3	—	—	0
190 to 195	1	—	1	1	—	—	1	7	—	—	2
195 to 200	5	3	2	0	—	—	1	17	1	—	—
200 to 205	7	3	—	2	—	4	3	15	3	—	—
205 to 210	1	10	—	0	—	7	3	13	12	1	—
210 to 215	4	1	—	0	—	6	2	12	25	3	—
215 to 220	2	0	—	0	1	13	0	10	44	1	—
220 to 225	6	1	—	0	4	3	0	2	27	4	—
225 to 230	—	—	—	1	3	1	1	2	35	2	—
230 to 235	—	—	—	—	4	1	—	2	24	5	—
235 to 240	—	—	—	—	2	1	—	—	13	2	—
240 to 245	—	—	—	—	0	0	—	—	5	0	—
245 to 250	—	—	—	—	0	0	—	—	2	1	—
250 to 255	—	—	—	—	1	0	—	—	2	0	—
255 to 260	—	—	—	—	—	1	—	—	—	0	—
260 to 265	—	—	—	—	—	—	—	—	—	1	—
Total, N	30	18	117	100	15	37	11	83	193	20	30
$\bar{V}_{max}$, mph	205.3	206.1	167.1	169.5	229.8	215.7	206.6	205.7	223.0	227.8	170.8
σ_V	12.72	5.70	9.60	11.85	8.30	9.90	8.70	10.00	10.06	12.70	9.52
k_V	-0.17	0.79	0.58	1.41	1.04	1.48	0.79	0.44	0.31	0.77	0.19

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TABLE III - Continued

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS - Continued

(d) V_o at Δn_{max}

V_o at Δn_{max} (mph)	Period I operations								Period II operations		
	A-I	B-II	C-III	D-IV	E-I	E-V	E-VI	F-III	F-III	E-I	D-IV
100 to 110	1	----	1	10	----	1	----	2	1	3	6
110 to 120	3	2	14	29	1	4	----	14	4	3	4
120 to 130	5	2	36	45	0	6	3	23	22	0	15
130 to 140	5	3	76	49	1	8	2	18	32	2	21
140 to 150	8	2	65	40	3	5	8	25	45	1	8
150 to 160	14	3	30	22	3	13	4	25	64	3	4
160 to 170	7	8	8	3	4	9	3	24	70	5	2
170 to 180	8	10	3	1	6	13	1	21	59	6	----
180 to 190	5	6	0	1	7	8	0	11	41	6	----
190 to 200	3	----	1	----	2	5	1	2	29	4	----
200 to 210	1	----	----	----	3	2	----	1	17	7	----
210 to 220	----	----	----	----	----	----	----	----	0	----	----
220 to 230	----	----	----	----	----	----	----	----	1	----	----
230 to 240	----	----	----	----	----	----	----	----	1	----	----
Total, N	60	36	234	200	30	74	22	166	386	40	60
$\bar{V}_o$, mph	156.0	161.7	139.2	133.2	172.0	158.9	149.5	149.6	163.8	168.5	132.2
σ_o	22.24	20.40	13.00	14.15	21.20	24.20	16.40	22.24	21.60	30.90	14.30
k_o	-0.15	-0.90	0.40	0.22	-0.57	-0.22	0.73	0.07	0.09	-0.75	0.08
V_p, mph	157.7	170.9	136.6	131.6	178.0	161.6	143.5	148.8	162.8	180.1	131.6

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TABLE III - Concluded

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS - Concluded

(e) V_o at $U_{e_{max}}$

V_o at $U_{e_{max}}$ (mph)	Period I operations								Period II operations		
	A-I	B-II	C-III	D-IV	E-I	E-V	E-VI	F-III	F-III	E-I	D-IV
100 to 105	-----	2	5	14	-----	-----	-----	2	8	-----	6
105 to 110	4	4	25	27	2	3	1	16	41	3	3
110 to 115	9	1	16	25	6	2	2	23	31	3	6
115 to 120	3	1	19	22	0	3	2	13	19	4	5
120 to 125	4	2	34	32	1	5	1	18	31	0	4
125 to 130	5	1	23	19	2	12	4	18	27	1	8
130 to 135	4	3	36	22	1	7	2	10	25	0	10
135 to 140	5	1	32	9	0	5	2	6	22	5	11
140 to 145	5	2	17	13	3	2	1	14	25	2	2
145 to 150	2	5	13	7	2	6	2	10	28	1	1
150 to 155	2	2	8	6	1	8	1	13	30	4	1
155 to 160	4	0	4	3	1	4	1	8	18	4	1
160 to 165	6	1	1	0	1	5	1	4	22	1	1
165 to 170	0	3	1	0	2	3	1	3	17	4	1
170 to 175	1	0	-----	1	1	3	1	3	10	0	-----
175 to 180	3	5	-----	-----	2	2	-----	1	10	3	-----
180 to 185	0	1	-----	-----	3	1	-----	1	7	1	-----
185 to 190	3	2	-----	-----	0	1	-----	2	8	1	-----
190 to 195	-----	-----	-----	-----	0	1	-----	1	1	0	-----
195 to 200	-----	-----	-----	-----	1	0	-----	-----	2	0	-----
200 to 205	-----	-----	-----	-----	1	1	-----	-----	1	3	-----
205 to 210	-----	-----	-----	-----	-----	-----	-----	-----	3	-----	-----
Total, N	60	36	234	200	30	74	22	166	386	40	60
$\overline{V}_o$, mph	138.8	144.7	128.3	123.4	146.8	143.7	135.9	132.5	139.2	149.0	127.0
σ_o	22.91	26.44	13.69	14.22	28.89	21.24	18.05	20.00	23.92	27.32	14.96
k_o	0.46	-0.02	0.13	0.60	0.19	0.48	0.13	0.69	0.44	0.18	0.26
V_p, mph	133.5	145.0	127.4	119.1	144.1	138.6	134.7	125.6	133.9	146.5	125.0

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TABLE IV

SUMMARY OF GUST LOADS AND OPERATING AIRSPEEDS IN ROUGH AIR

Airplane	Airline	V_p/V_L at Δn_{max}	Average flight miles to equal or exceed -			V_p/V_L at $U_{e_{max}}$
			Δn_{LLF} (twice)	V_{NE} (once)	$U_{e_{30}}$ (twice)	
Period I operations						
A	I	0.88	1.5×10^6	0.94×10^6	0.66×10^6	0.74
B	II	.79	11.0	>1,000	3.9	.67
C	III	.75	16.4	>1,000	3.3	.70
D	IV	.78	9.7	2.1	7.6	.71
E	I	.84	10.9	80.0	5.2	.68
E	V	.77	4.6	30.0	1.3	.66
E	VI	.68	13.4	>1,000	3.6	.64
F	III	.65	173.3	>1,000	3.8	.55
Period II operations						
F	III	0.71	4.9×10^6	$>1,000 \times 10^6$	0.39×10^6	0.58
E	I	.85	2.7	15.5	.77	.69
D	IV	.78	7.5	82.0	1.9	.74

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TABLE V

COMPARISON OF ACCELERATION EXPERIENCES BASED

ON DIFFERENT METHODS OF ANALYSIS

Airplane	Airline	$\Delta n_{max}/\Delta n_{LLF}$ at 10^7 flight miles		
		Extreme value		Pearson Type III
		Using computed value of m (see figs. 1 and 2)	Using design value of m	Curve of references 1 to 6: m = Design
Period I operations				
A	I	1.24	1.35	1.06
B	II	.99	1.01	.82
C	III	.95	1.06	.93
D	IV	1.00	1.07	1.15
E	I	.99	1.02	.88
E	V	1.10	1.12	1.02
E	VI	.96	.99	.78
F	III	.79	.86	.76
Period II operations				
F	III	1.07	1.16	1.15
E	I	1.20	1.23	1.07
D	IV	1.03	1.10	1.04

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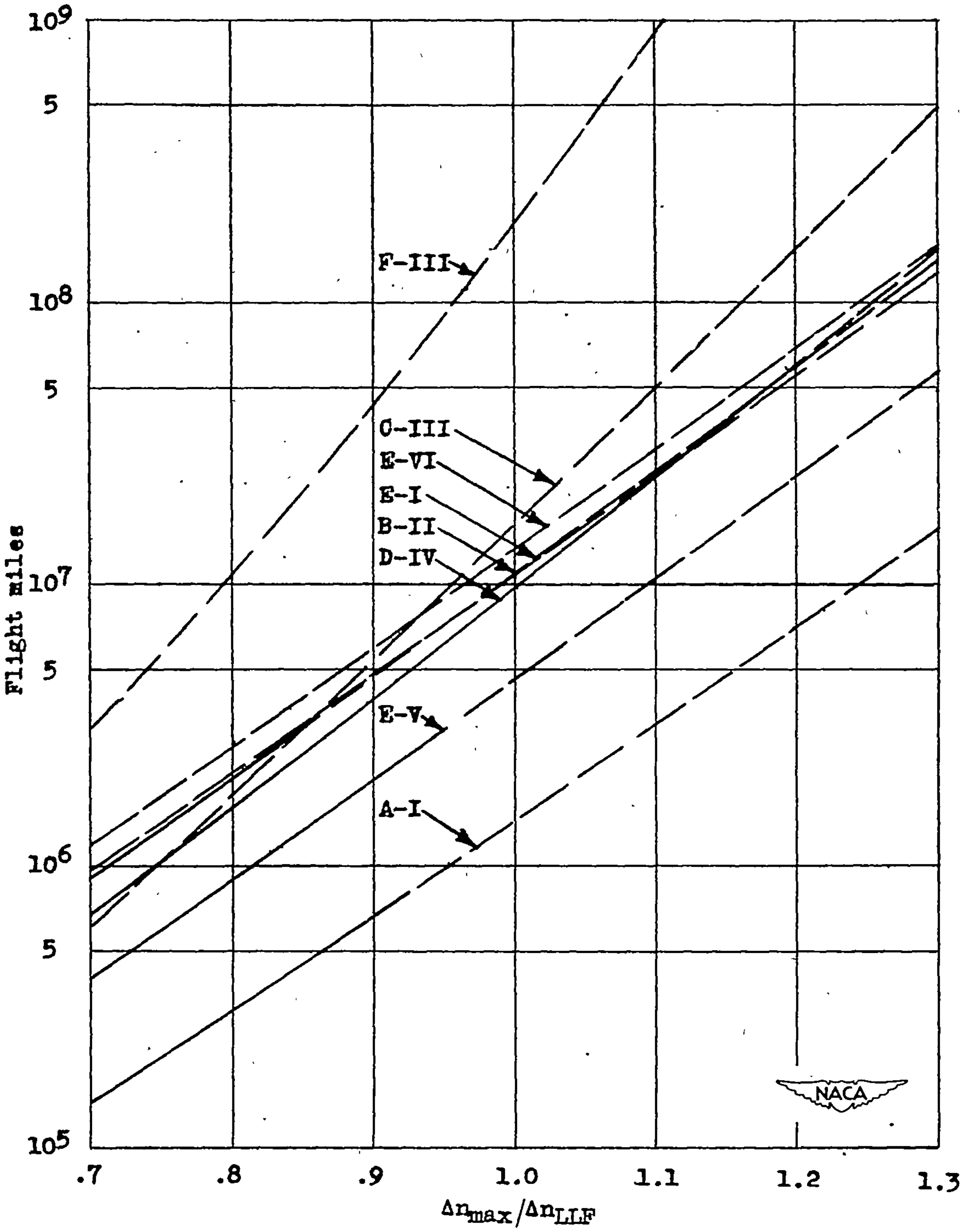
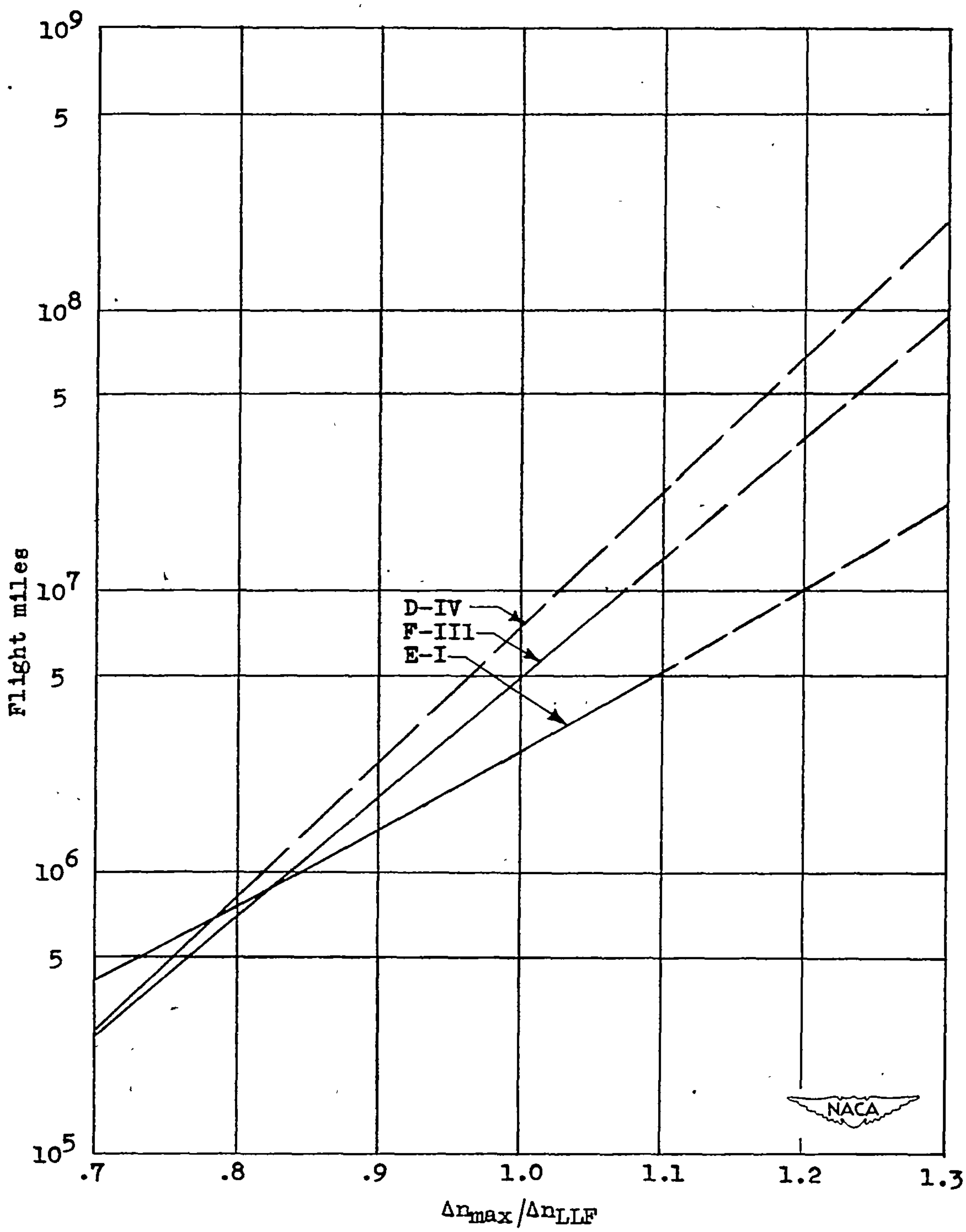


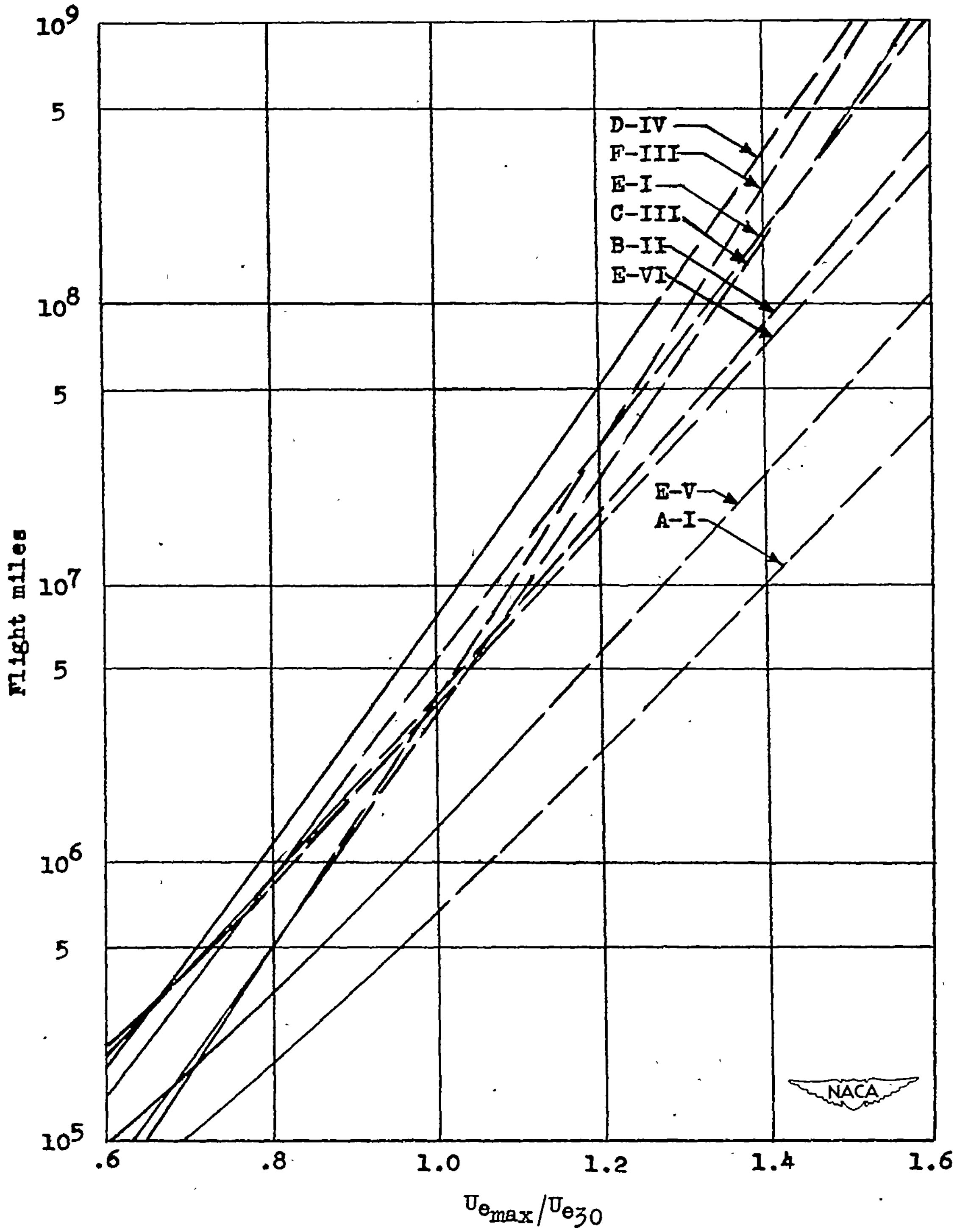
(a) Period I operation.

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



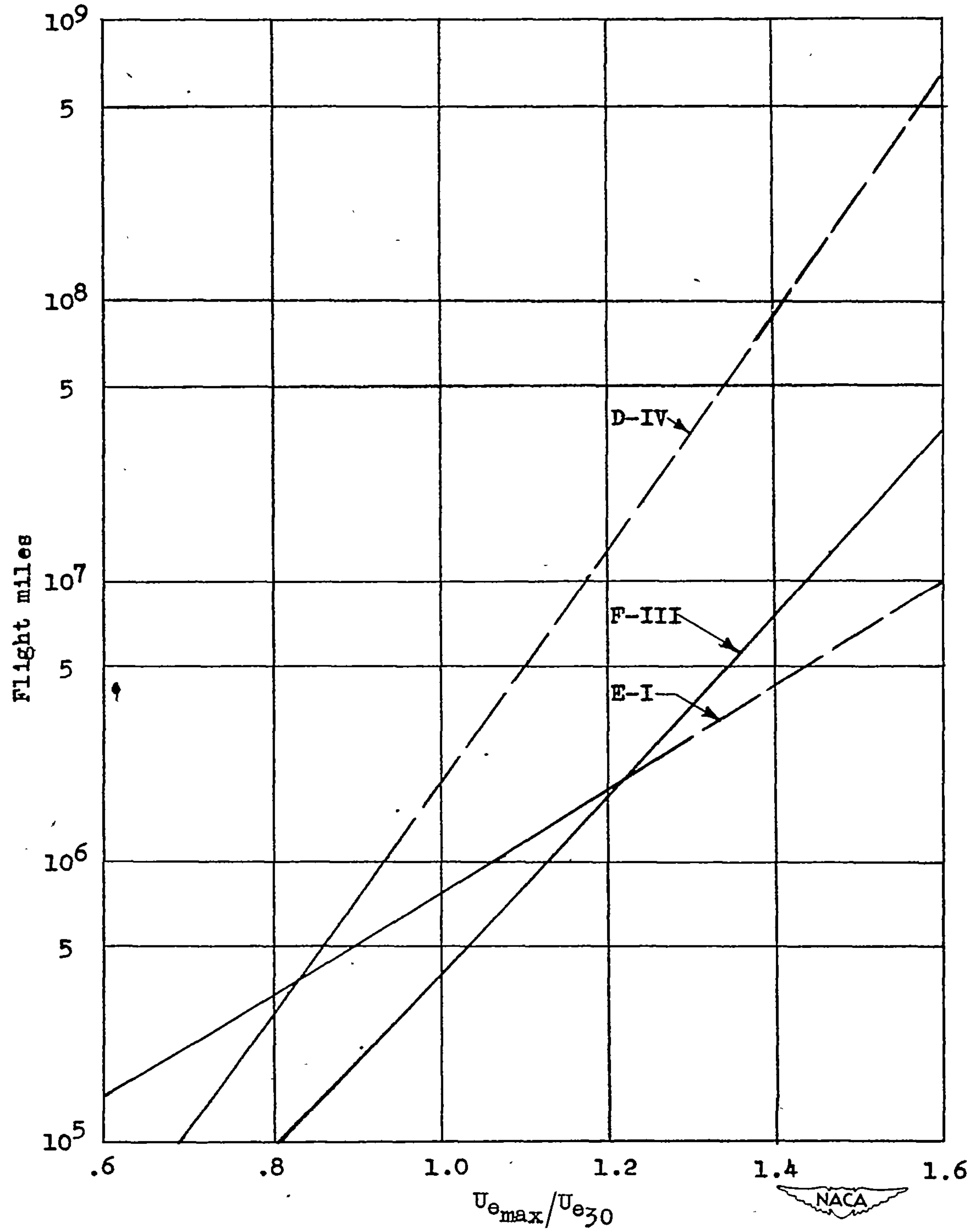
(b) Period II operation.

Figure 1.- Concluded.



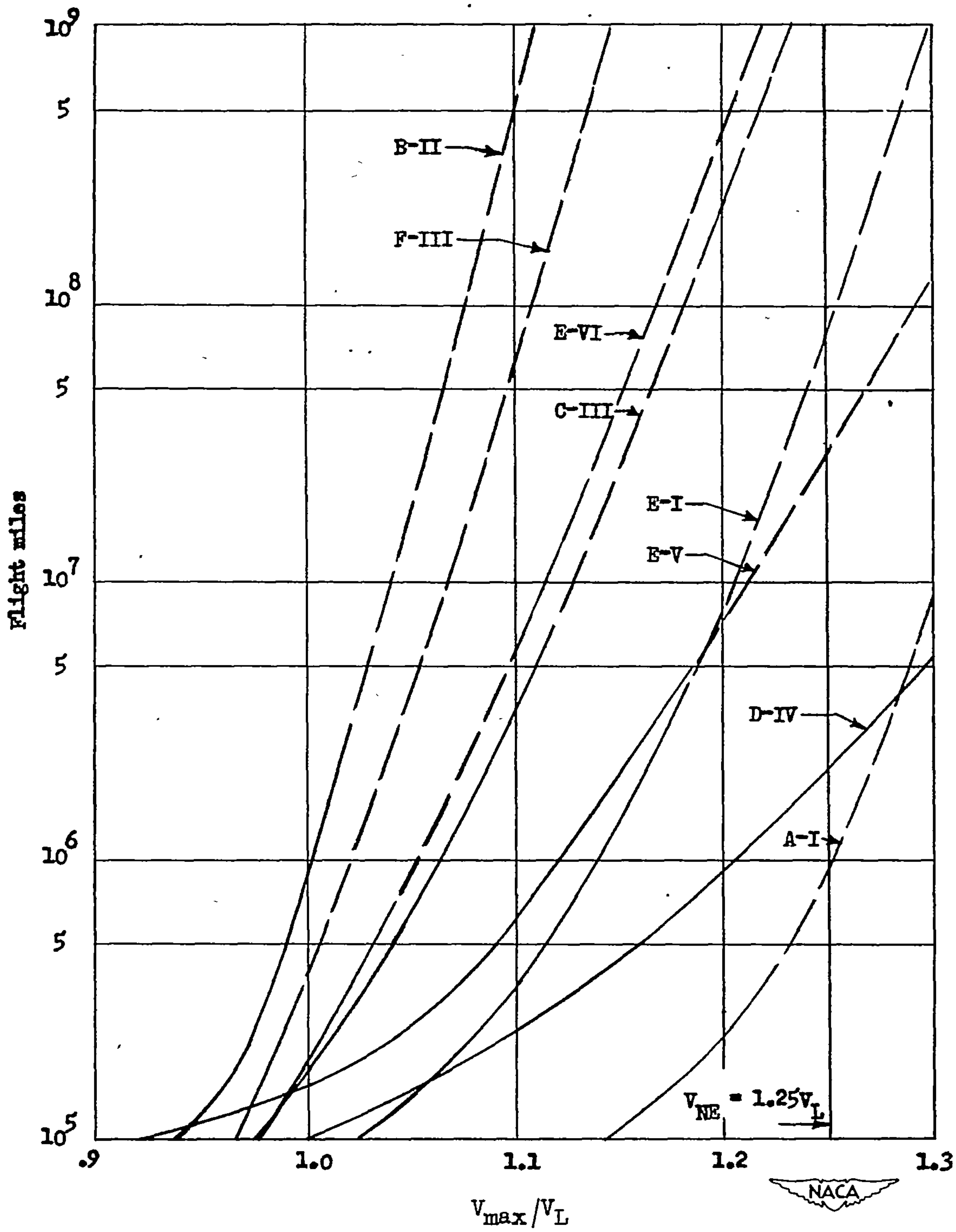
(a) Period I operation.

Figure 2.- Average flight miles for maximum positive and negative effective-gust-velocity ratio to equal or exceed a given value.



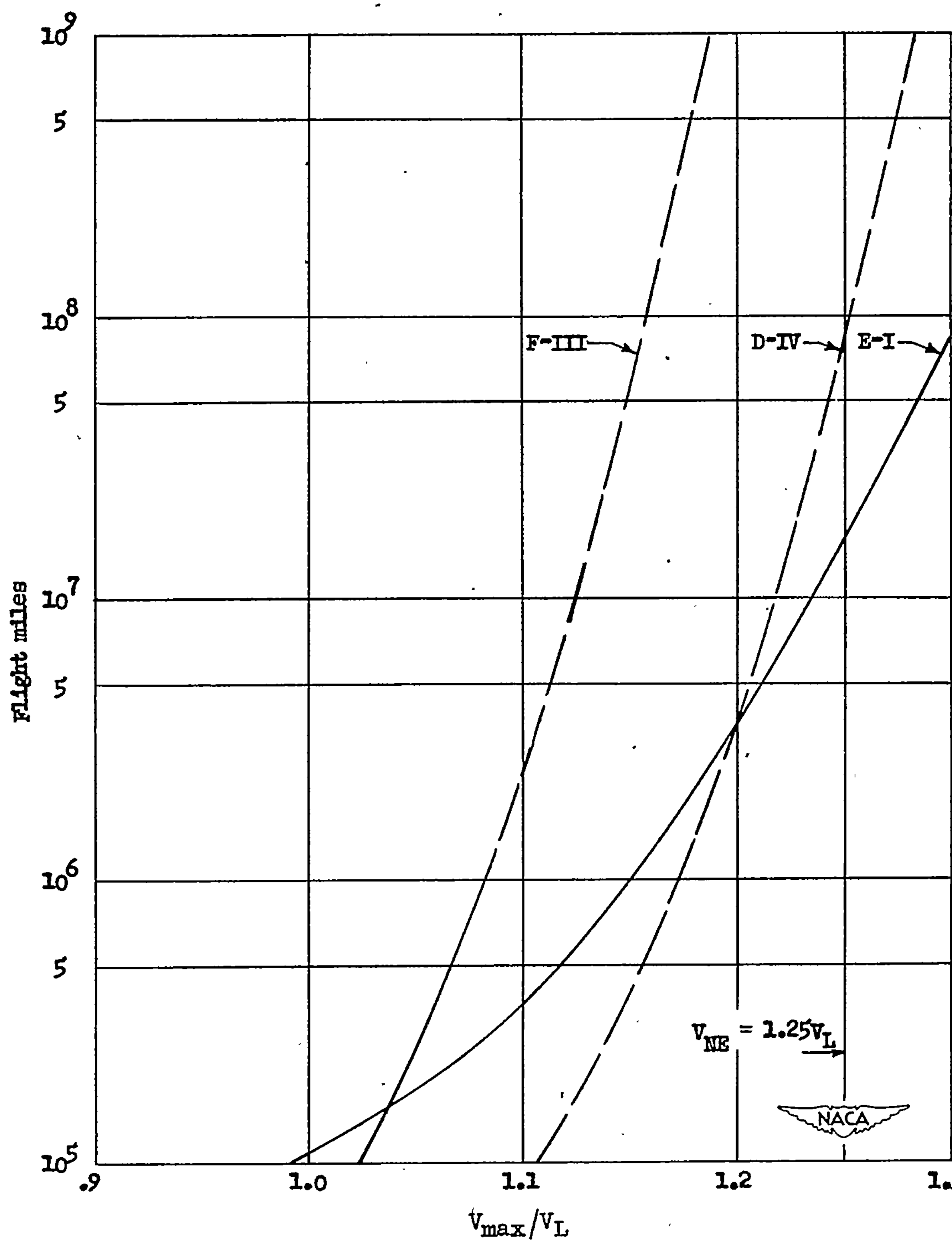
(b) Period II operation.

Figure 2.- Concluded.



(a) Period I operation.

Figure 3.- Average flight miles for maximum-indicated-airspeed ratio to equal or exceed a given value.



(b) Period II operation.

Figure 3.- Concluded.

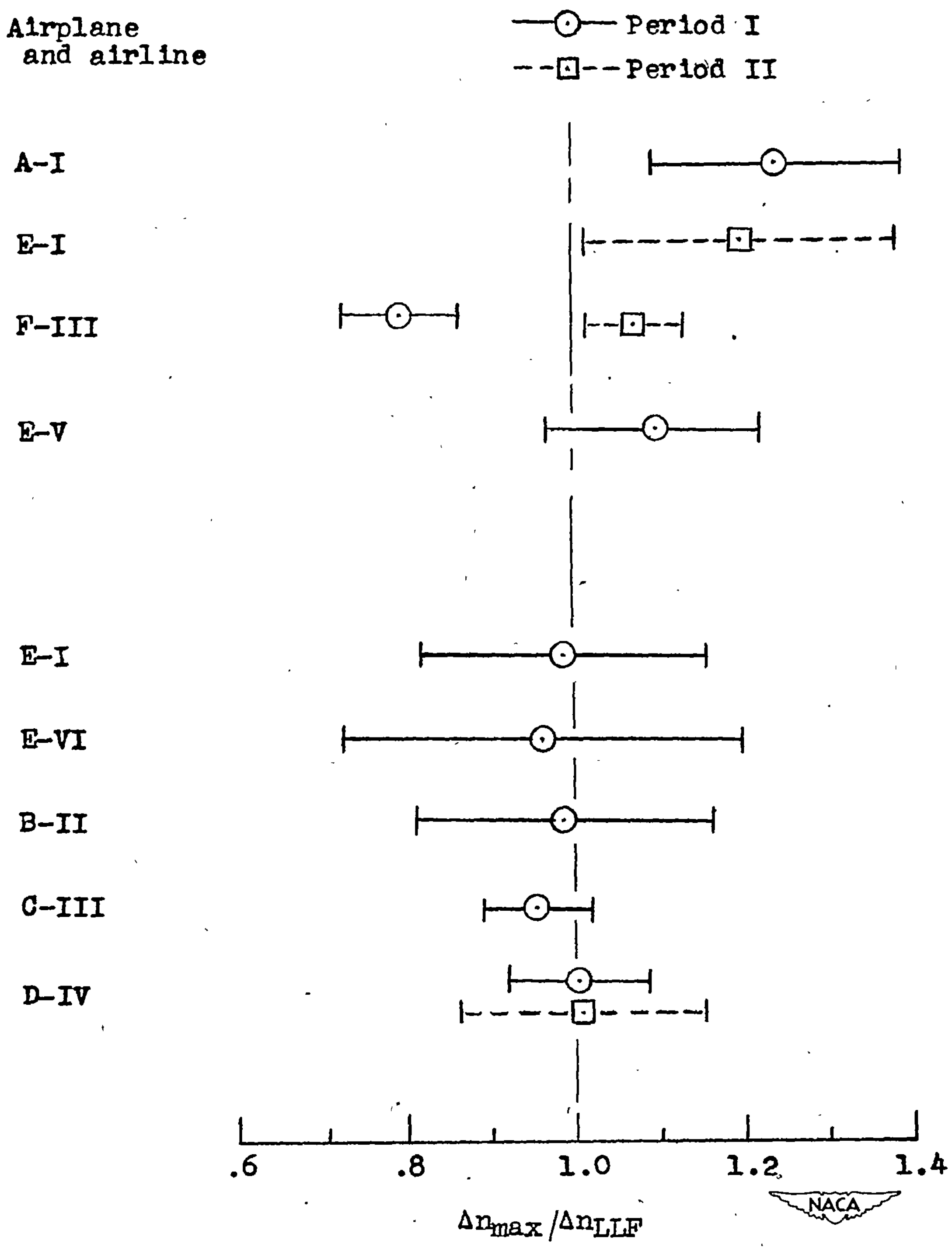


Figure 4.- Values of acceleration-increment ratio at 10^7 flight miles and the width of the 95-percent confidence bands about the values.

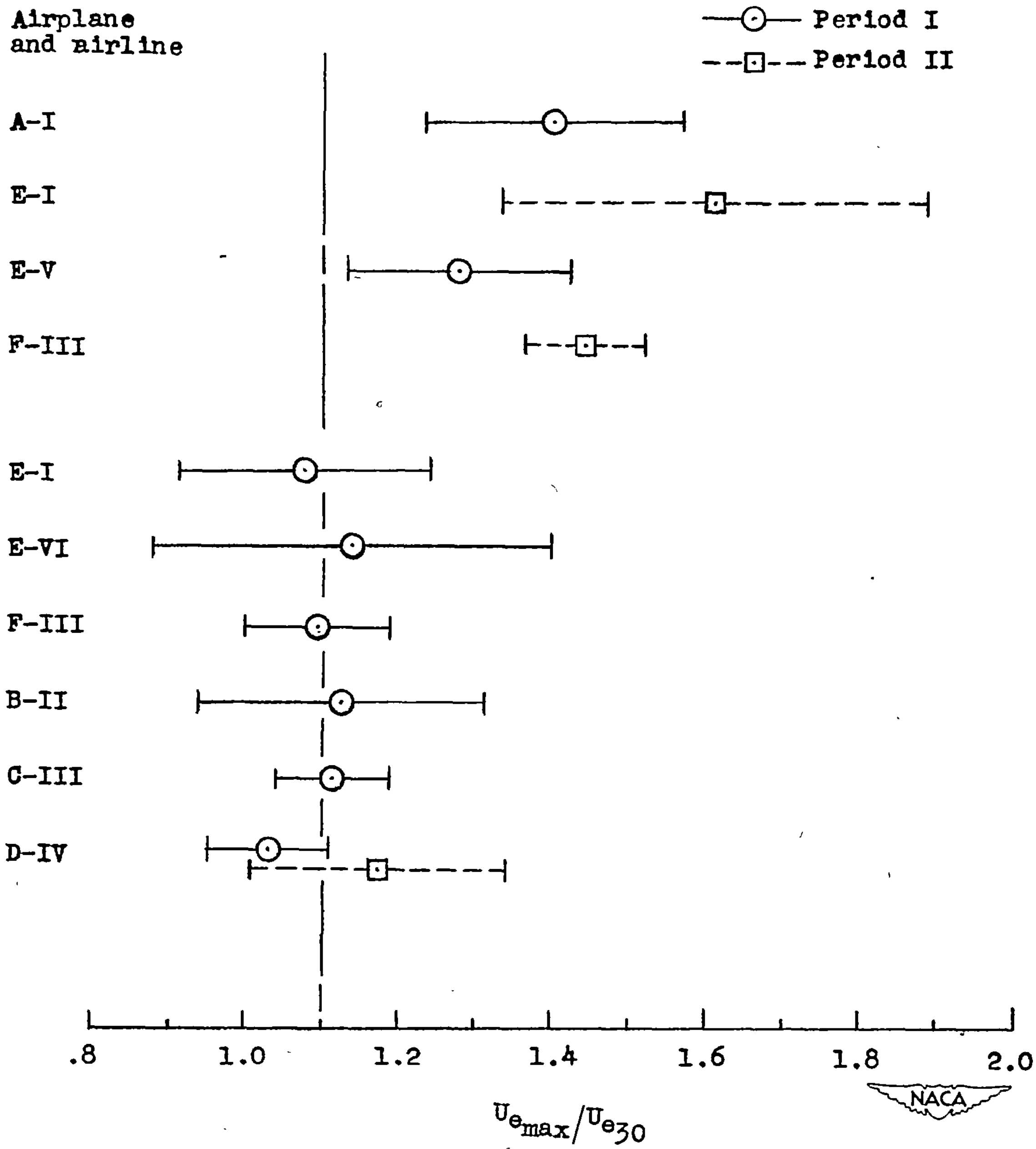


Figure 5.- Values of effective-gust-velocity ratio at 10^7 flight miles and the width of the 95-percent confidence bands about the values.

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