RESEARCH MEMORANDUM

AN ANALYSIS OF THE NORMAL ACCELERATIONS AND AIRSPEEDS OF SEVERAL LOCKHEED CONSTELLATION L-649 AIRPLANES IN POSTWAR COMMERCIAL TRANSPORT OPERATIONS OVER THE EASTERN PART OF THE UNITED STATES

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SUMMARY

An analysis of the first postwar sample of acceleration and airspeed data from commercial transport operations of L-649 airplanes on a single airline indicated that, on the average, the positive and negative limit gust load factor increments may be exceeded once in about 5.8×10^5 flight miles and the never-exceed speed may be exceeded once in about 5.0×10^5 flight miles. The frequency of exceeding the never-exceed speed was found to be in good agreement with the results of a previous analysis of flight analyzer records. To the extent that the present results can be taken as representative of the postwar period, a trend is indicated toward higher imposed flight loads and increased apparent gust experience for postwar commercial transport airplanes.

INTRODUCTION

Previous analyses of acceleration and airspeed data have yielded information regarding the imposed flight loads, operating speed, and gust experience of commercial transport airplanes during the prewar and wartime periods. This information has in the past formed the basis for gust-load design requirements. With the introduction of new airplane types during the postwar period and changes observed in operating practices, considerable doubt arose that the postwar flight experiences could be predicted on the basis of the prewar and wartime data. An expanded V-G program was initiated, therefore, to obtain data on the imposed flight loads, operating speeds, and gust experience of postwar commercial transport airplanes.

To date, sufficient records to warrant an analysis have been obtained from only a single airplane type. This paper presents the analysis of these records with the aim of indicating in a preliminary manner the trend of the imposed flight loads, operating speeds, and gust experience of postwar commercial transport airplanes. A comparison is made of the frequency of exceeding the never-exceed speed as indicated by the present results and the results of a previous statistical analysis of flight analyzer records (reference 1).

SYMBOLS

K	gust-alleviation factor
U_e	effective gust velocity, feet per second
V_L	design maximum level-flight speed, (indicated) miles per hour
V_{max}	maximum indicated airspeed on V-G record, miles per hour
V_o	indicated airspeed at which maximum positive or negative acceleration increment occurs on V-G record, miles per hour
V_p	probable airspeed at which maximum recorded acceleration can be expected to occur
Δn_{max}	maximum positive or negative acceleration increment on V-G record, g units
$\overline{V}_{max}$, $\overline{V}_o$, $\Delta\overline{n}_{max}$	average values of distributions of V_{max}, V_o, and Δn_{max}, respectively
σ_V, σ_o, $\sigma_{\Delta n}$	standard deviations of distributions of V_{max}, V_o, and Δn_{max}, respectively
α_V, α_o, $\alpha_{\Delta n}$	coefficients of skewness of distributions of V_{max}, V_o, and Δn_{max}, respectively
τ	average flight time per record, hours

P_V probability that maximum indicated airspeed for a record will exceed a given value

$P_{\Delta n}$ probability that maximum acceleration increment for a record will exceed a given value

APPARATUS AND SCOPE OF DATA

The data were obtained from V-G records taken on six Lockheed Constellation L-649 airplanes. Characteristics of the airplane which were used in the analysis are given in table I. The slope of the lift curve and the gross weight were obtained from the manufacturers' design data and the operator, respectively. The limit gust load factor of 2.4g was computed with the gust-load-factor formula of reference 2 and is based on gross weight and on an effective gust velocity U_e of 30K feet per second at the maximum speed in level flight V_L of 271 miles per hour. Although the limit gust load factor was calculated to be 2.4g, the airplane was actually designed for the slightly higher maneuver load factor 2.5g. The maximum CAA approved never-exceed speed for this airplane is 324 miles per hour; the airline, however, operates the airplane with an approved never-exceed speed of 300 miles per hour. Information supplied by the airline did not include the altitudes at which the airplanes were flown, but it is estimated that about 70 percent of the operating time is between 14,000 and 24,000 feet.

Thirty-nine V-G records, representing a total of 9375 flight hours on six airplanes, were available for analysis. Table II gives a breakdown of the records by airplane. The analysis utilized 38 records representing between 200 and 250 flight hours each. In order to keep the range of flight hours per record small, one record representing 50 flight hours was not included in the analysis. Also, a maximum indicated airspeed of 356 miles per hour from another record was not used in the analysis of the statistical parameters since, according to information furnished by the airline, it occurred during an unusual emergency descent. Figure 1 gives a breakdown of the records by months. On the basis of available information, it is estimated that approximately 90 percent of the records were obtained from flight operations over the United States east of the Mississippi River.

Analysis and Results

The analytical procedures used in the analysis are described in reference 3. From each V-G record the following values were read: the maximum positive and negative acceleration increments Δn_{max}, the speeds corresponding to the maximum acceleration occurrences V_o, and the maximum speed recorded V_{max}. Table III gives the frequency distributions of these variables with the statistical parameters of each distribution; namely, the average values indicated by a bar over the variable, the standard deviation σ, and the coefficient of skewness α. Pearson Type III probability curves (reference 4), which in the past have given reasonable representations of this type data, were fitted to the observed distributions by use of the statistical parameters. The results obtained are shown in figures 2 to 4 for the Δn_{max}, V_{max}, and V_o distributions, respectively.

The probability curves fitted to the distributions of Δn_{max} and V_{max} were then transformed to curves of average flight miles required to equal or exceed given values of acceleration increment and airspeed by multiplying $1/P_{\Delta n}$ and $1/P_v$ by an assumed cruising speed of $0.8V_L$ and the average flight hours per record τ of 245 hours. The upper part of the transformed curves is shown in figures 5 and 6. The limitations of transforming the Δn_{max} and V_{max} probability curve to curves of average flight miles to equal or exceed given values will be discussed at a later point.

The most probable speed V_p for maximum acceleration increment shown in figure 4 was calculated from the statistical parameters for the V_o distribution (table III) to be 222 miles per hour. Since the value of V_p can have an important bearing on the flight loads imposed on the airplane, it is used herein as representative of the speed that can be expected during operations in rough air.

In order to compare the gust experience of the present airplane with the gust experience of the airplanes reported in reference 5, the flight miles required to exceed the acceleration due to an effective gust velocity of 37.5K feet per second at V_p are shown in table IV. The use of V_p as a representative airspeed for each airplane allows the reduction of acceleration data to apparent gust data and permits an evaluation of an apparent gust experience which is unaffected by the flight speed. The particular value of 37.5K feet per second for the effective gust velocity was chosen so that the resulting acceleration would equal the limit gust load factor if the airplane were flown at $0.8V_L$. Included in table IV are the average flight miles required to exceed the limit gust load factor for the present airplane and the airplanes reported in reference 5.

PRECISION

The precision of the V-G recorder and the limitations of the method of analysis are discussed in reference 6. It is assumed that the inherent instrument errors do not exceed ±0.2g for acceleration nor 3 percent of the maximum airspeed range of the instrument. The errors in the reading of the records are small and tend to average out in a statistical analysis of the type used in this paper.

The adequacy of accelerometer measurements at the center-of-gravity position for measuring gust loads on modern transport airplanes may be open to some question. Whereas in the past, dynamic response effects on accelerometer measurements have been considered unimportant, recent trends toward higher speeds, larger size and increased weight concentrations in the wing sections have made dynamic response effects of increasing concern. Theoretical analyses to date have been unable to yield absolute results for the dynamic effects of gusts on wing loads and on fuselage acceleration, although simple considerations indicate that for the modern airplane the dynamic effects on wing stresses and fuselage accelerations may be considerable in some cases. Until experimental or analytical investigations can resolve the dynamic response effects on accelerometer measurements at the center of gravity, the full significance of the present results may be subject to some question.

On the basis that the curves fitted to the observed data were not extrapolated and that they fit the data well, it is felt that the flight miles to exceed the limit gust load factor and never-exceed speed are reliable within a range extending from one-third to three times the values quoted.

DISCUSSION

Examination of figure 5 indicates that, for the present airplane and route, the limit gust load factor increment may be exceeded twice (once positive and once negative) in about 5.8×10^5 flight miles. The ratio of the frequency of exceeding the limit gust load factor in the present airplane to the other airplanes shown in table IV varies from about 4:1

for the S-307 airplane (war) to about 1600:1 for the S-307 airplane (prewar). The analysis indicates, therefore, that the load experience as measured by the frequency of exceeding the limit gust load factor is appreciably more severe for the present data than for any previous sample.

In order to obtain some estimate of the actual loads applied to the airplane structure, information on the operating weight of the airplane is needed. Although the operating weights at the times of encountering the accelerations are not known, available information obtained from the airlines indicates that average operating weight was about 85 percent of design gross weight. This weight appears to correspond roughly with the available information on the prewar operating weights. If the maximum acceleration increments are assumed to have occurred at average weight conditions, the estimate for exceeding loads the equivalent of the limit gust load factor at design gross weight becomes about 2×10^6 flight miles. Since past analyses, as summarized in table IV, have assumed operations at gross weight, this number is not directly comparable to those given therein.

As shown in figure 6 the never-exceed speed of 324 miles per hour may be exceeded, on the average, once in about 5×10^5 flight miles, or converting to a time basis, once in about 2300 flight hours. This value substantiates the result obtained earlier from flight analyzer records and reported in reference 1 to be one exceedance of the never-exceed speed in about 1000 flight hours. The never-exceed speed used by the airline, 300 miles per hour, was exceeded on 31 of the 37 records included in the airspeed analysis.

The ratio of the most-probable speed of gust encounter to the design maximum level-flight speed V_p/V_L for the present data is 0.82 as shown in table IV. The ratios for the other sets of data shown in the table range from 0.63 to 0.83. The relatively high V_p/V_L ratio appears instrumental in producing the high frequency of exceeding the limit gust load factor.

The comparison of the flight miles to exceed the acceleration increment due to an effective gust velocity of 37.5K feet per second at V_p, table IV, indicates more severe gust experience for this set of data than for any previous set. The reasons for the increase in apparent gust experience are not known, but a possible explanation may be that the better navigational aids and safety devices used in the postwar period permit more flight operations under adverse weather conditions. It also may be due in part to the limited scope of the data which, as shown in figure 1, cover less than a complete year of operations. Dynamic response may also be a factor.

Some concern has been expressed concerning the validity of transforming the Δn_{max} and V_{max} probability distributions, figures 2 and 3, to a mileage basis such as shown in figures 5 and 6. Inasmuch as only the maximum values are read from each V-G record, the total frequency of occurrence of all values of Δn and V except the largest is greater than indicated by the distribution of maximum values. Consequently, the transformation of the distribution of maximum values to a mileage basis yields estimates of the average flight miles required to exceed given values that are overestimated for all values except the largest observed value. Work in the past has indicated that in the neighborhood of the largest observed value estimates of the flight miles to exceed given values based on the distribution of maximums are fairly close to estimates based on the total distributions. It is felt, therefore, that estimates of the flight miles to exceed given values based on the observed maximum distribution are not seriously in error, provided that the values used are in the neighborhood of the largest observed values.

On the basis of the foregoing, the estimates obtained in the present analysis for the flight miles to exceed the limit gust load factor increment and the never-exceed speed appear reasonable, although there remains some tendency toward overestimation. Consideration of the total frequency with which the foregoing limit values are exceeded would result in somewhat lower estimates for the required flight miles to exceed these values.

CONCLUDING REMARKS

Analysis of the first postwar sample of acceleration and airspeed data from commercial transport operations of L-649 airplanes on a single airline indicates that the limit gust load factor increment may be exceeded, on the average, twice (once positive and once negative) in about 5.8×10^5 flight miles and the never-exceed speed may be exceeded once in about 5×10^5 flight miles. The frequency of exceeding the never-exceed speed as shown by the present results is in good agreement with the results obtained from flight analyzer records and reported in reference 1. If it can be assumed that the present results are representative of the postwar period, a trend is indicated toward more severe imposed flight loads and increased apparent gust experience for postwar commercial transport airplanes. The increase in the imposed flight loads appears to be partly due to the comparatively high speed at which the airplanes were operated in rough air. The reason for the increase in apparent gust experience is not known, but a partial explanation may be that better postwar navigational aids and safety devices permit more flight operations through adverse weather conditions than in the prewar and wartime period. Dynamic response may also be a factor.

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TABLE I

AIRPLANE CHARACTERISTICS

Gross weight, pounds	94,000
Wing area, square feet	1,650
Wing span, feet	123
Mean aerodynamic chord, feet	14.67
Slope of lift curve, per radian (value used in design)	4.67
Aspect ratio	9.17
Design maximum level-flight speed at sea level V_L, miles per hour	271
Limit gust-load factor, g units (computed)	2.40
Gust-alleviation factor, K	1.204
Never-exceed speed, miles per hour (CAA)	324

TABLE II

SUMMARY OF V-G RECORDS SUPPLIED AND USED IN ANALYSIS

Airplane	Records available for analysis		Records used in analysis			
	Number of records	Total flight hours	Number of records	Total flight hours	Average flight hours per record T	Range of record flight hours
A	11	2700	11	2700	245	200 to 250
B	7[a]	1700	7	1700	243	200 to 250
C	8	1950	8	1950	244	200 to 250
D	2[b]	300	1	250	250	250
E	7	1725	7	1725	247	225 to 250
F	4	1000	4	1000	250	250
Total	39	9375	38	9325	245	200 to 250

[a] Maximum airspeed from one record not used in analysis.

[b] One record representing 50 flight hours not used in analysis.

TABLE III

FREQUENCY DISTRIBUTION AND STATISTICAL PARAMETERS

OF V_{max}, Δn_{max}, and V_o

Δn_{max}		V_{max}		V_o	
Acceleration increment (g units)	Frequency	Velocity (mph)	Frequency	Velocity (mph)	Frequency
0.30 to 0.40	1	290 to 295	2	150 to 160	1
.40 to .50	2	295 to 300	4	160 to 170	1
.50 to .60	10	300 to 305	3	170 to 180	5
.60 to .70	6	305 to 310	5	180 to 190	1
.70 to .80	6	310 to 315	13	190 to 200	9
.80 to .90	10	315 60 320	3	200 to 210	9
.90 to 1.00	11	320 to 325	4	210 to 220	10
1.00 to 1.10	12	325 to 330	1	220 to 230	10
1.10 to 1.20	2	330 to 335	1	230 to 240	9
1.20 to 1.30	5	335 to 340	1	240 to 250	6
1.30 to 1.40	5			250 to 260	10
1.40 to 1.50	3			260 to 270	3
1.50 to 1.60	1			270 to 280	1
1.60 to 1.70	0			280 to 290	0
1.70 to 1.80	1			290 to 300	1
1.80 to 1.90	0				
1.90 to 2.00	0				
2.00 to 2.10	0				
2.10 to 2.20	1				
Total	76	Total	37	Total	76
$\overline{\Delta n}_{max}$	0.94	$\overline{V}_{max}$	311.42	$\overline{V}_o$	222.11
$\sigma_{\Delta n}$	.32	σ_v	10.14	σ_o	27.90
$\alpha_{\Delta n}$	.82	α_v	.276	α_o	-.043

TABLE IV

COMPARISON OF LOAD AND APPARENT GUST EXPERIENCE FOR PREWAR, WAR, AND POSTWAR OPERATIONS

Airplane	Route number	Route	Flight miles to exceed: Limit gust load factor twice (positive and negative)	Flight miles to exceed: Acceleration due to 37.5k fps gust at V_p	V_p/V_L
Prewar					
DC-3	I	Transcontinental	23×10^6	43×10^6	0.83
DC-3	II	Transcontinental	3.8	4.2	.81
DC-3	III	Transcontinental	140	14	.69
S-307	IV	Caribbean	920	12	.63
M-130	V	Trans-Pacific	3.4	3.1	.79
War					
DC-3	I	Transcontinental	2.5×10^6	3.4×10^6	.83
S-307	IV	Caribbean	2.2	.72	.72
M-130	V	California to Hawaii	5.6	5	.79
Postwar					
L-649	VI	Eastern part U.S.A.	$.58 \times 10^6$	$.66 \times 10^6$	.82

NACA

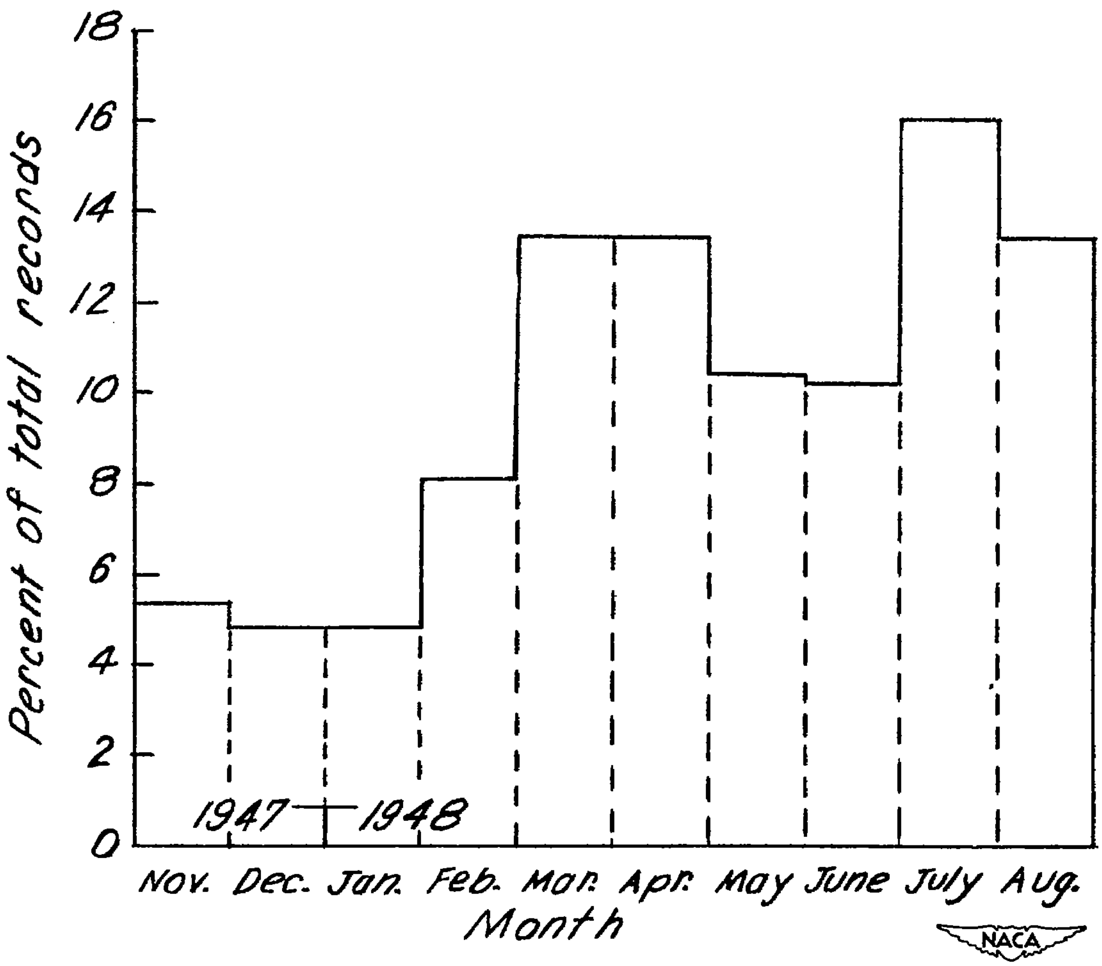

Figure 1.- Monthly distribution of records analyzed.

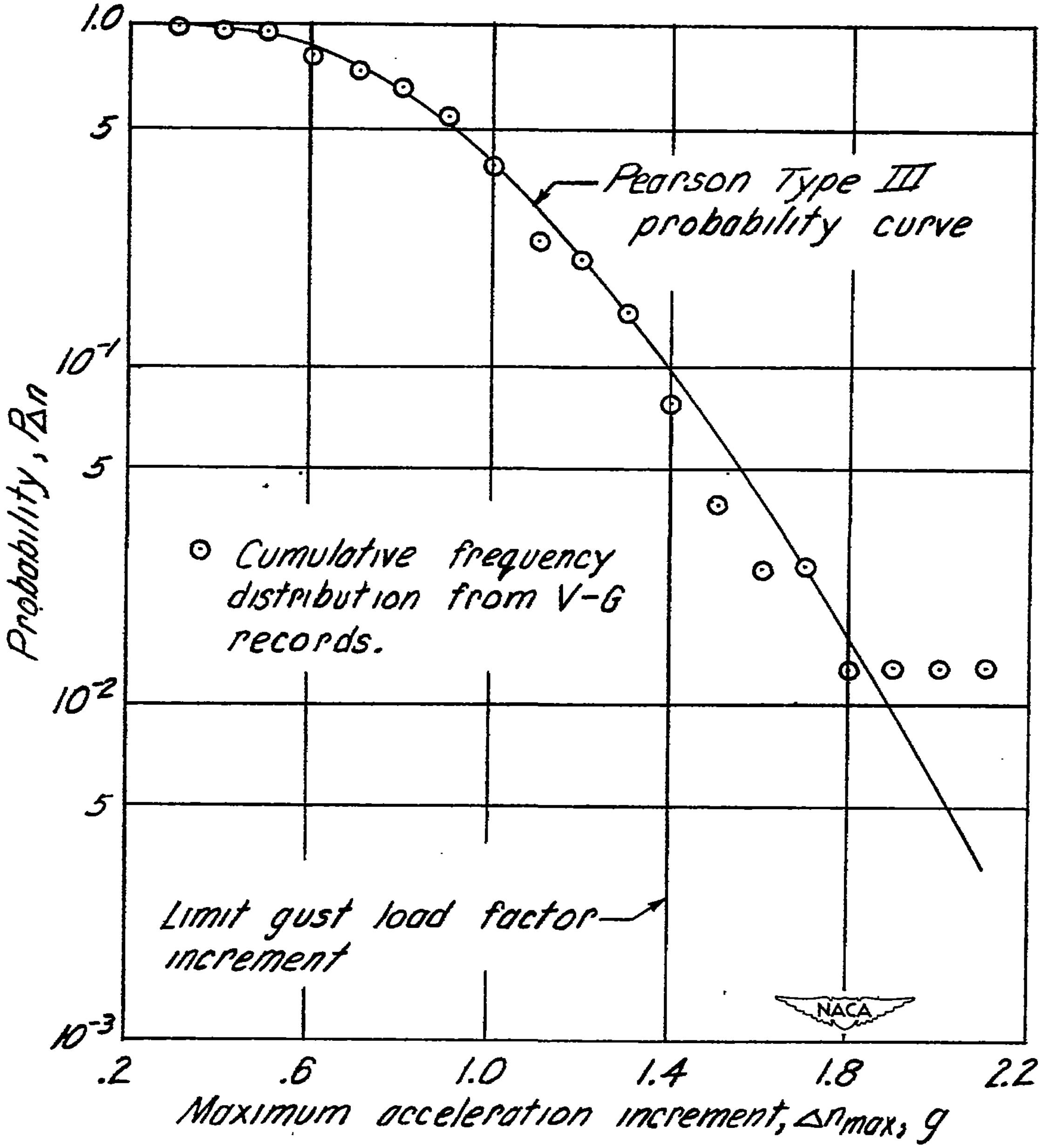

Figure 2.- Probability that maximum positive or negative acceleration increment on a record will equal or exceed a given value.

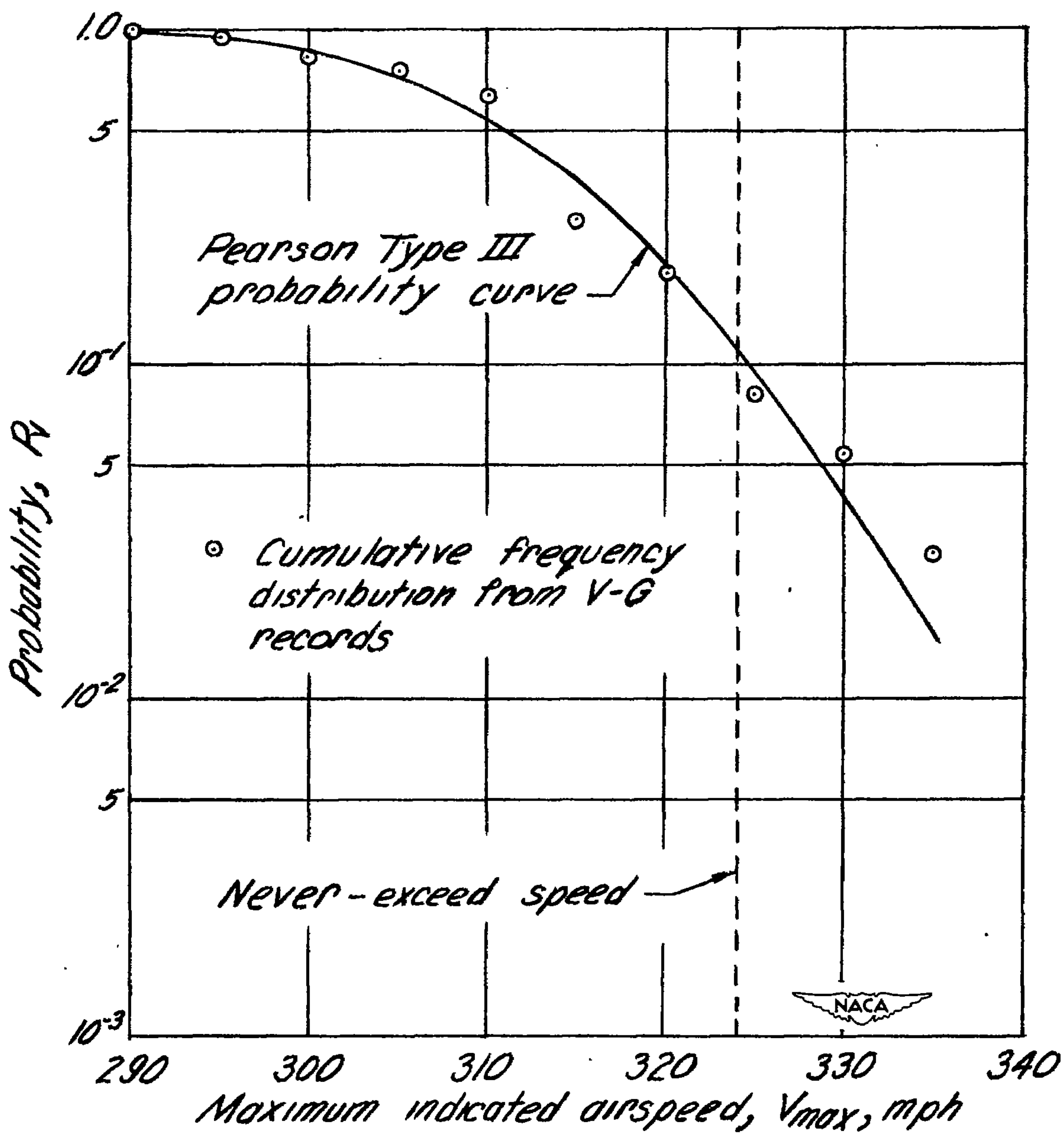

Figure 3.- Probability that maximum indicated airspeed on a record will equal or exceed a given value.

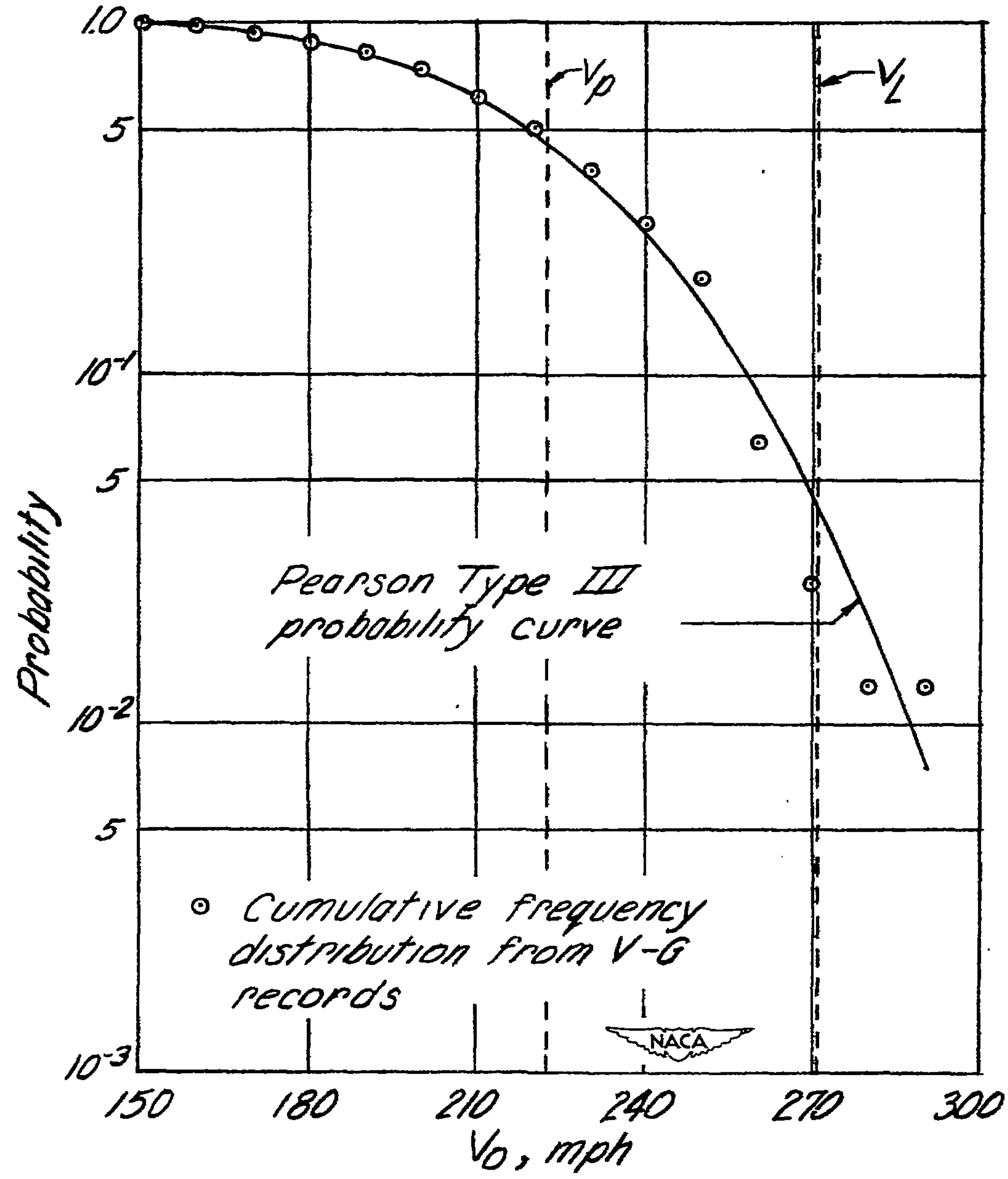

Figure 4.- Probability that indicated airspeed at which maximum acceleration increment is experienced will equal or exceed a given value.

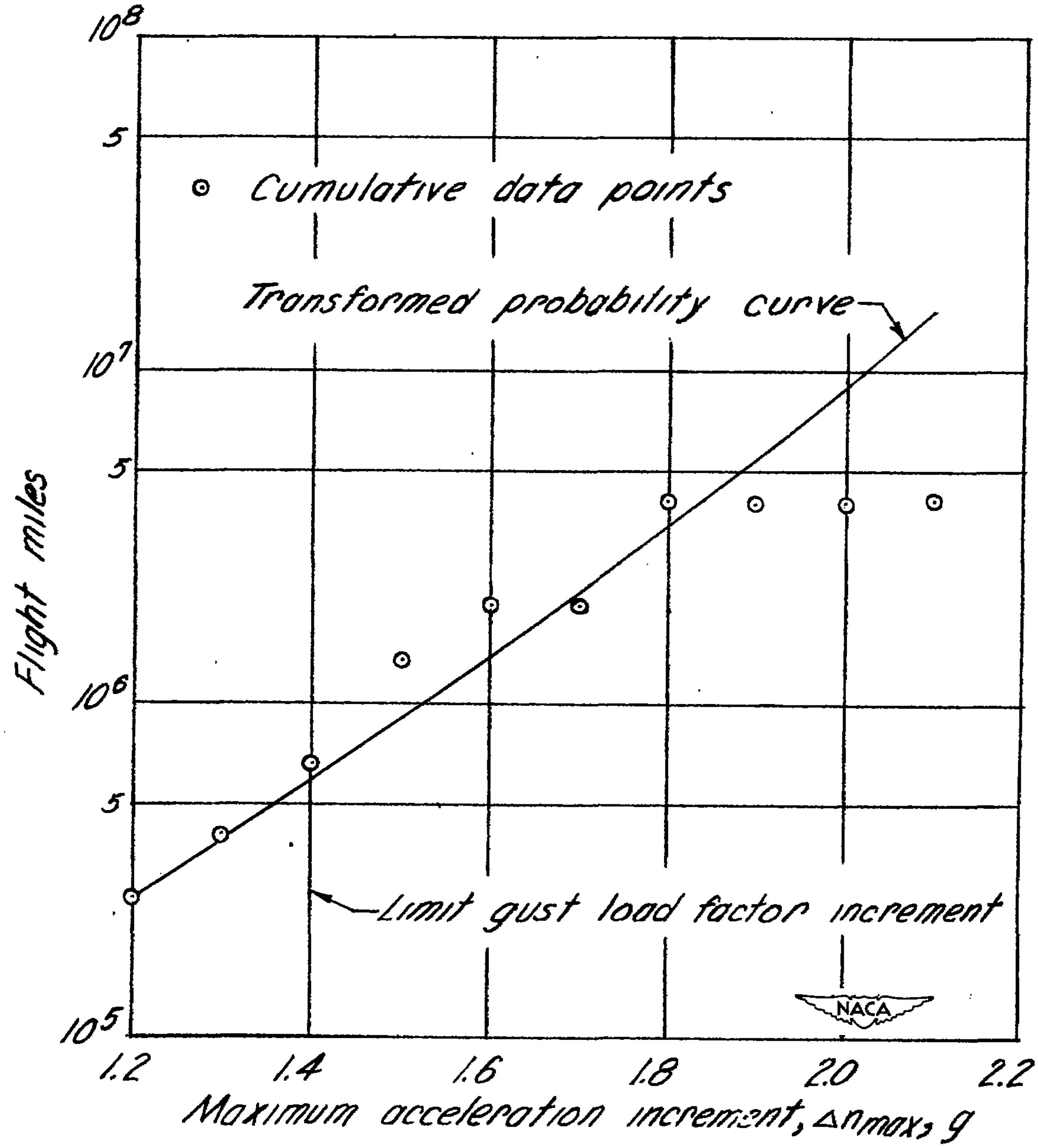

Figure 5.- Average flight miles required for a maximum positive and negative acceleration increment to equal or exceed a given value.

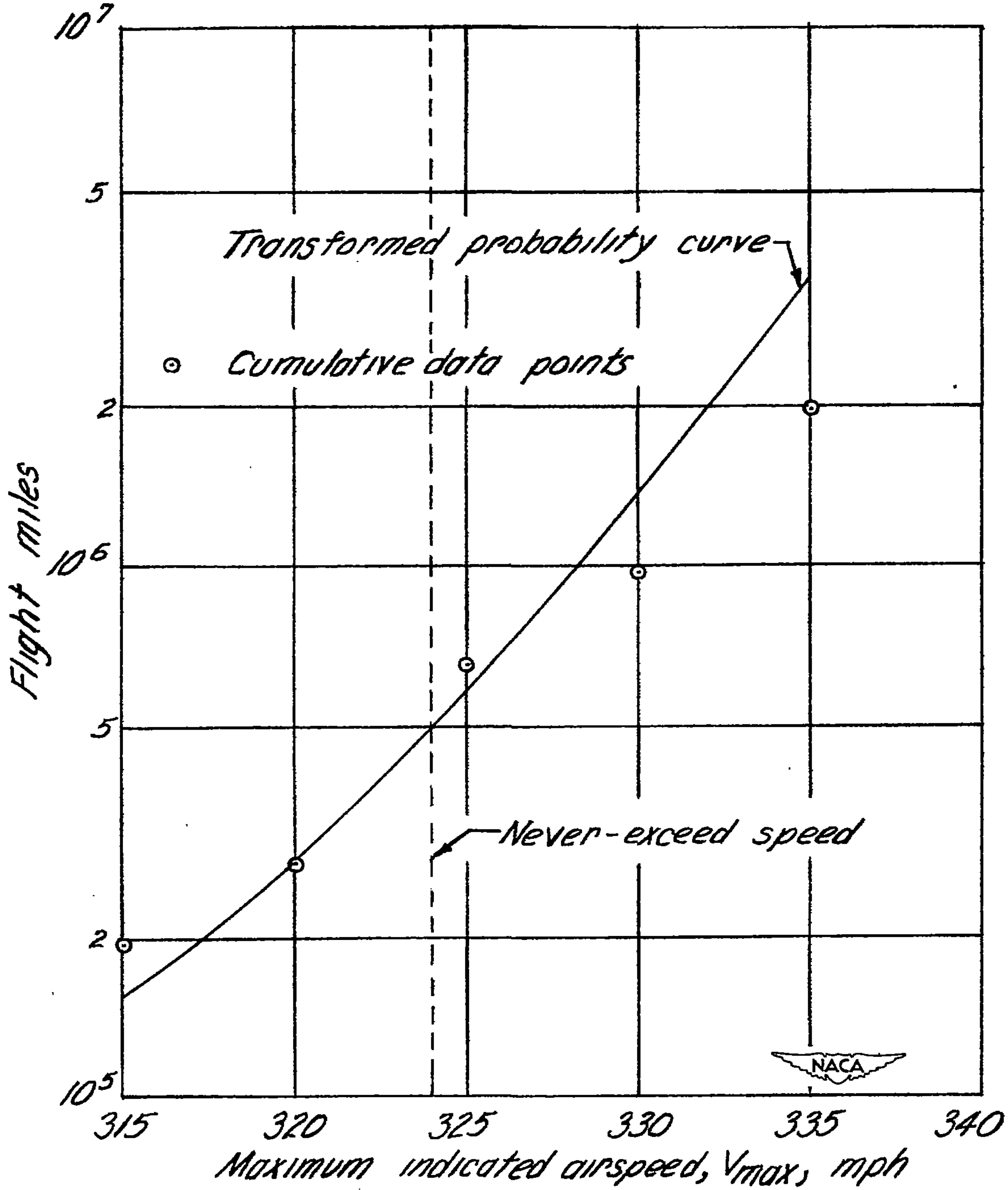

Figure 6.– Average flight miles required for the maximum indicated airspeed on a record to equal or exceed a given value.