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AN ANALYSIS OF THE AIRSPEEDS AND NORMAL ACCELERATIONS OF MARTIN M-130 AIRPLANES IN COMMERCIAL TRANSPORT OPERATION

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SUMMARY

Acceleration and airspeed data taken on three Martin M-130 airplanes operated on trans-Pacific routes during the prewar and wartime periods have been analyzed and the results support previous indications that airplane speed in regions of turbulent air is a significant factor in the life of airplanes. During the prewar period greater route roughness is indicated in trans-Pacific operations than in operations over transcontinental routes of the United States or over Caribbean routes.

INTRODUCTION

Acceleration and airspeed data obtained from V-G records collected during commercial transport operations (references 1 and 2) are being analyzed in some detail to determine the flight loads and operating speeds as functions of airplane, route, season, and prewar and wartime operations. References 3 and 4 used the available data for four routes and two airplane types to summarize the results of operations in the Caribbean area and to compare results of domestic operations within the United States. Results have indicated that airplane speed in rough air is a significant parameter in airplane life, that the change from prewar to wartime operation had an appreciable effect on the structural life of aircraft and that, for transcontinental routes, other factors so compensate for route roughness that route may be neglected as a significant parameter of airplane life.

V-G records taken during operations of three Martin M-130 flying boats in trans-Pacific service during the period from 1936 to 1945 have been analyzed to investigate the factors previously mentioned. The available M-130 data are summarized and the flight load results are compared with the results of analyses made in the past.

SYMBOLS

K	gust-alleviation factor
U_e	effective gust velocity, feet per second
V_L	design level-flight speed, 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 acceleration will most likely occur, miles per hour
Δn_{max}	maximum positive or negative acceleration increment on V-G record, g units
$\overline{V}_{max}$, $\overline{V}_o$, $\overline{\Delta n}_{max}$	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
P_o	probability that maximum acceleration on a record will occur in a given speed range

SCOPE

One-hundred ninety-two V-G records representing 22,374 hours of flight were available for analysis. The records, summarized in table I, were obtained during the period from 1936 when the airplanes went into service to the time when use of the airplanes on the trans-Pacific routes was discontinued. The records were supplied to the NACA with the installation and removal dates, routes flown, and flight hours per record. Supplementary information regarding unusual experiences was supplied in a few cases. No information was provided on actual operating weights.

The flight operations represent two different routes during two periods of operation. During the prewar period from 1936 to 1941, almost all flights were from Alameda, California to Hong Kong, China, via Hawaii

and the Philippine Islands; whereas operations for the war period from 1942 to 1945 were restricted to flights from Alameda, California to Hawaii. Since each record represents, in general, one round trip and since the routes were different for the two periods, the records for prewar and war operations are therefore not comparable. The results obtained are consequently in contrast to the results previously analyzed in references 3 and 4.

Table I gives a breakdown of the records taken on the three M-130 airplanes. The method of analysis requires a reasonably constant number of flight hours per record in a given group and, because of this requirement, records representing 120 to 140 hours for prewar operations and 30 to 50 hours for wartime operations were utilized in the analysis. The choices made herein conform to the requirements set forth in reference 5.

The airplane characteristics used in the evaluation and subsequent analyses of the data were obtained from the manufacturer and from the Civil Aeronautics Administration and are as follows:

Gross weight, pounds	50,000
Wing area, square feet	2,145
Wing span, feet	130
Mean aerodynamic chord, feet	17.46
Slope of lift curve, per radian	4.45
Aspect ratio	7.8
Design level-flight speed at sea level, V_L, miles per hour	168
Placard speed, miles per hour	210
Limit gust load factor, g units	2.80
Gust-alleviation factor K	1.075

In the computation of design gust load factors for airplanes of later design than the M-130, the method of computation has changed with the introduction of the gust-alleviation factor K in the gust-load-factor formula. The factors listed are based on civil airworthiness requirements (references 6 and 7) so that the results will be comparable to those of references 3 and 4. The limit gust load factor is 2.80g, which corresponds to an effective gust velocity U_e equal to 30K feet per second at a maximum level-flight speed V_L of 168 miles per hour. Since detailed information was lacking, the placard (or do-not-exceed) speed was computed from information given in reference 7 as $1.25V_L$ or 210 miles per hour. Computed values are based on the design gross weight and on the corresponding gust-alleviation factor K of 1.075.

No attempt has been made in evaluating the records to distinguish between accelerations caused by gusts and by maneuvers. In all cases, all large accelerations are assumed to be due to gusts, as experience indicates that most of the large loads imposed during normal transport operation are due to gusts.

ANALYSIS

The method of making the statistical analysis has been previously described in references 3, 4, and 5. The method utilizes five values read from each V-G record - the maximum positive and maximum negative acceleration increments Δn_{max}, the maximum speeds flown V_{max}, and the speeds V_o corresponding to maximum acceleration occurrences. The five values so selected, together with the flight miles per record (obtained by multiplying the average time per record by an assumed average cruising speed equal to $0.8V_L$), represent the flight data necessary for the statistical computations. The distribution of positive and negative accelerations is essentially symmetrical about the 1 g line, and the maximum values are therefore sorted and tabulated without regard to sign.

Real differences between probabilities are considered to exist if they differ by more than a ratio of 5:1. The 5:1 ratio for significant differences (references 3 and 4) is used herein as a level of engineering concern in connection with the spread of flight miles required to exceed the limit gust load factor and to exceed fixed effective gust velocity at probable speed.

PRECISION

The precision of the V-G recorder and the limitations of the method of analysis have been discussed in reference 3. The inherent instrument errors are assumed not to exceed $\pm 0.2g$ for acceleration nor 3 percent of the maximum airspeed range of the instrument.

The use of the design gross weight in the computations of effective gust velocities results in conservative values since, so far as is known, the M-130 airplanes were not operated at overloads.

RESULTS

The frequency distributions (defined in reference 5) of the V-G data, namely, the maximum airspeed V_{max}, maximum acceleration increment Δn_{max}, and indicated airspeed V_o at which the maximum acceleration increments are encountered are listed in table II. The average values $\overline{V}_{max}$, $\overline{\Delta n}_{max}$, and $\overline{V}_o$, the standard deviation σ, which is a measure of the dispersion of the distribution from the mean, and the coefficient of skewness α, which is a measure of deviation from symmetry of the distributions, are the statistical parameters given in the table. Pearson Type III probability curves, which are assumed to be reasonable representations of V-G data,

(reference 5) were derived from the parameters of the prewar and wartime distributions of accelerations and speeds. The probability curves, converted to average flight miles required to exceed given values of speed and acceleration, are shown, together with the cumulative data from the V-G records, in figures 1 and 2. From these curves and on the basis of the probability P_o that the maximum acceleration appearing on a record will occur in any given speed range, the flight envelopes of figures 3 and 4 were prepared to show the average flight miles required to exceed stated values of acceleration and speed for prewar and wartime operations. Composites of all available V-G records are also shown in figures 3 and 4 for comparison with the predicted envelopes of corresponding flight miles.

Figure 5 shows the flight miles required to exceed the acceleration increment due to encountering an effective gust velocity of 37.5K feet per second at the most probable speed V_p of gust encounter for the M-130 airplane compared with the airplanes reported in references 3 and 4. The change from flight hours used in references 3 and 4 to flight miles in the present analysis is based on the assumption of an average cruising speed equal to 80 percent of the high speed in level flight. The change to flight miles rather than flight hours permits a more reasonable comparison of the data from the different airplanes for miles of rough weather encountered. The results for the S-307 airplane in figure 5 are based on a maximum level-flight speed of 230 miles per hour, a slope of the lift curve of 4.42 per radian, and a computed limit load factor of 2.96g instead of the values of 250 miles per hour, lift-curve slope of 4.66, and limit load factor 3.25g used in reference 3 because, on the basis of subsequent information, the values used herein are more representative of actual operating conditions.

DISCUSSION

The results shown in figures 1 to 4 indicate that the agreement between the data and the probability curves is satisfactory. Moderate values of airspeed and acceleration were exceeded more frequently during the wartime operations than during prewar operations as shown in figures 1 and 2. The prewar data extend to the placard speed and to the limit gust load factor, but the data for the wartime period fall appreciably short of the limiting conditions because the sample of data available was very small. When the data for the wartime period are extrapolated on the basis of the Pearson Type III probability curve, indications are that the probability of encountering the limiting values are greater for the prewar period than for the wartime period; however, in view of the small quantity of the available data for the wartime period, the validity of the extrapolation is open to serious question.

Consideration of the data in figure 5 indicates that the differences in miles required to exceed the limit gust load factor for the various airplanes are large. Differences of the order of 60-to-1 and 300-to-1

exist between the M-130 airplane and the DC-3 and S-307 airplanes, respectively. Such differences when judged by the criterion of a 5:1 significance ratio are clearly of engineering concern. A previous analysis (reference 4) has indicated that these differences may be associated with differences in the ratios of probable speed of gust encounter in rough air to the design level-flight speed V_p/V_L. These ratios vary from 0.63 to 0.83 for the airplanes compared and, from figure 5, appear closely related to the probability of exceeding the limit gust load factor. The M-130 airplane was operated at a speed ratio of 0.79, and the probability that this airplane will exceed the limit load factor is relatively high. This fact seems to substantiate the conclusion of reference 4 that operating speed in turbulent air is significant in the determination of the operational life of the airplane.

In order to compare the route roughness of the several routes, the flight miles required to exceed the acceleration increment due to an effective gust velocity of 37.5K feet per second at probable speed of gust encounter V_p is shown in figure 5. Since the effect of operating speed is removed, the variation between routes is considerably reduced. For the prewar period, the frequency with which the 37.5K value is exceeded is somewhat greater for the M-130 data than for the data taken during transcontinental operations over three airlines in the United States or during Caribbean operations. The spread is of the order of about 3:1 to 11:1 between the M-130 and the other airplanes, the largest variation being with the DC-3 airplanes operated by airline A. Although the differences between the data for the M-130 and the other airplanes are not clearly significant in every case, they do indicate that the South Pacific route may have greater route roughness. This indication would appear reasonable in view of the turbulent nature of weather conditions over the western part of the route and the lack of weather information for parts of the route during the pioneering flights made by the M-130 airplanes when the trans-Pacific route was first established.

CONCLUDING REMARKS

The analysis of acceleration and airspeed data taken during trans-Pacific operations of the M-130 airplane tends to substantiate the conclusions of a previous analysis that operating speed in turbulent air is significant in the determination of the operational life of airplanes. For the prewar period, South Pacific operations indicate greater route roughness than do operations over transcontinental routes of the United States or the Caribbean.

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National Advisory Committee for Aeronautics
Langley Field, Va., May 6, 1948

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TABLE I

SUMMARY OF V-G RECORDS SUPPLIED AND USED IN ANALYSIS

Records supplied			Records used in analysis							
			Prewar				War			
Airplane	Number of records	Total flight hours	Number of records	Total flight hours	Range of record flight hours	Average flight hours per record	Number of records	Total flight hours	Range of record flight hours	Average flight hours per record
NC-14714	26	3,540	21	2,659	120 to 140	126.6	None	------	--------	---------
NC-14715	57	5,967	16	2,073	120 to 140	129.5	12	440	30 to 50	36.7
NC-14716	109	12,867	63	8,075	120 to 140	128.1	18	644	30 to 50	35.8
Total	192	22,374	100	12,807	120 to 140	128.1	30	1,084	30 to 50	36.1

TABLE II

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS OF V_{max}, Δn_{max} AND V_o FOR PREWAR AND WAR OPERATION

V_{max}			Δn_{max}			V_o		
Velocity (mph)	Frequency		Acceleration increment (g units)	Frequency		Velocity (mph)	Frequency	
	Prewar	War		Prewar	War		Prewar	War
135 to 139	1	------	0.20 to 0.29	3	----	100 to 104	3	3
140 to 144	0	------	.30 to .39	10	1	105 to 109	7	3
145 to 149	1	------	.40 to .49	31	2	110 to 114	12	0
150 to 154	3	2	.50 to .59	31	8	115 to 119	17	4
155 to 159	11	2	.60 to .69	29	13	120 to 124	23	6
160 to 164	19	3	.70 to .79	40	11	125 to 129	22	9
165 to 169	28	7	.80 to .89	20	12	130 to 134	29	10
170 to 174	11	6	.90 to .99	16	9	135 to 139	20	11
175 to 179	11	7	1.00 to 1.09	8	2	140 to 144	24	5
180 to 184	9	1	1.10 to 1.19	4	0	145 to 149	16	3
185 to 189	2	0	1.20 to 1.29	3	0	150 to 154	15	2
190 to 194	1	2	1.30 to 1.39	0	1	155 to 159	7	2
195 to 199	0	------	1.40 to 1.49	2	0	160 to 164	2	0
200 to 204	2	------	1.50 to 1.59	1	0	165 to 169	1	2
205 to 209	0	------	1.60 to 1.69	1	1	170 to 174	1	------
210 to 214	0	------	1.70 to 1.79	0	----	175 to 179	0	------
215 to 219	0	------	1.80 to 1.89	0	----	180 to 184	1	------
220 to 224	0	------	1.90 to 1.99	0	----			
225 to 229	1	------	2.00 to 2.09	0	----			
			2.10 to 2.19	0	----			
			2.20 to 2.29	0	----			
			2.30 to 2.39	1	----			
Total	100	30	Total	200	60	Total	200	60
$\overline{V}_{max}$	169.45	170.84	$\overline{\Delta n}_{max}$	0.71	0.77	$\overline{V}_o$	133.20	132.17
σ_V	11.85	9.52	$\sigma_{\Delta n}$	0.27	0.20	σ_o	14.15	14.30
α_V	1.41	0.19	$\alpha_{\Delta n}$	1.77	1.36	α_o	0.22	0.08

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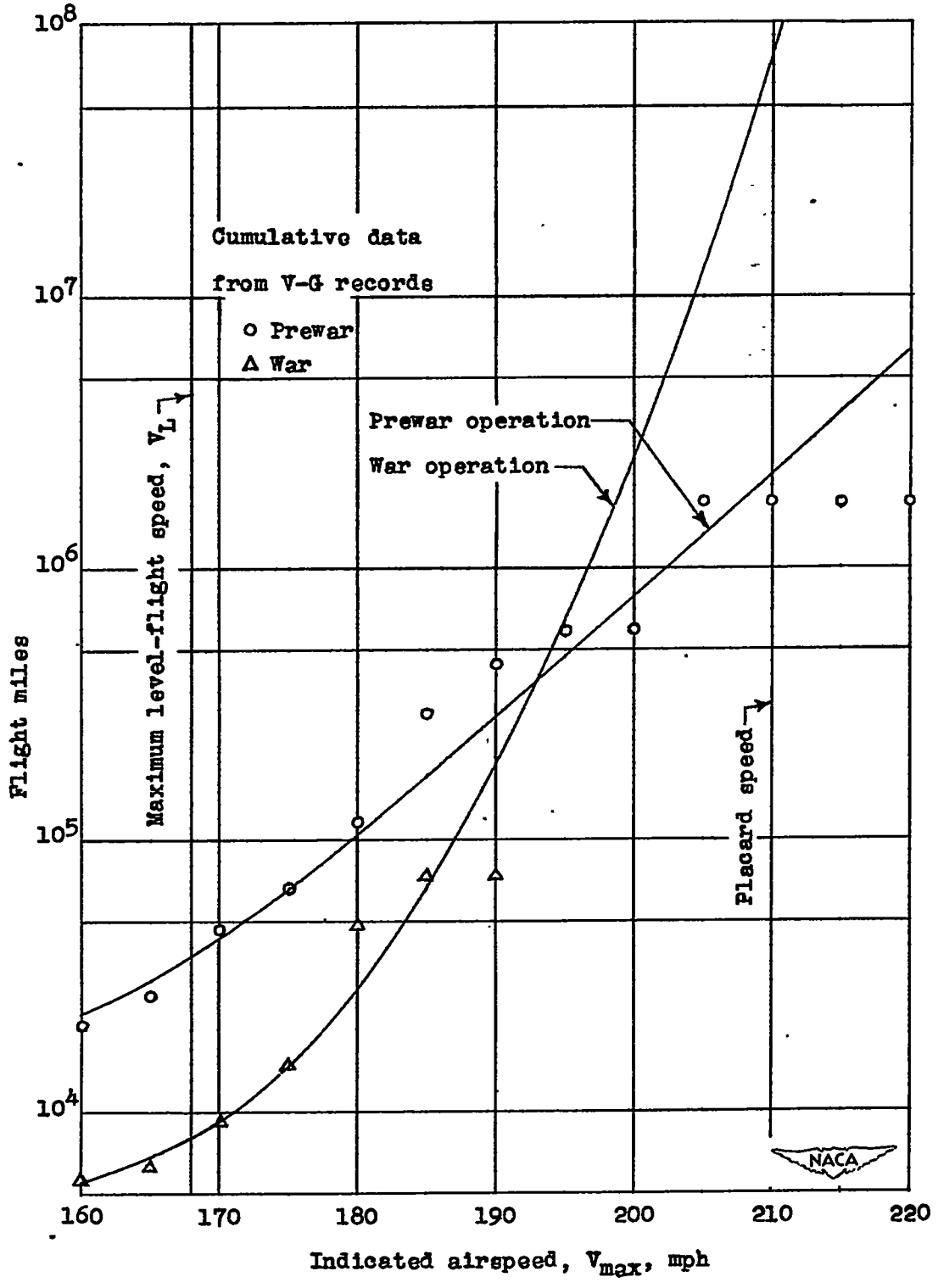

Figure 1.- Average flight miles required to exceed a given value of airspeed for prewar and war operation.

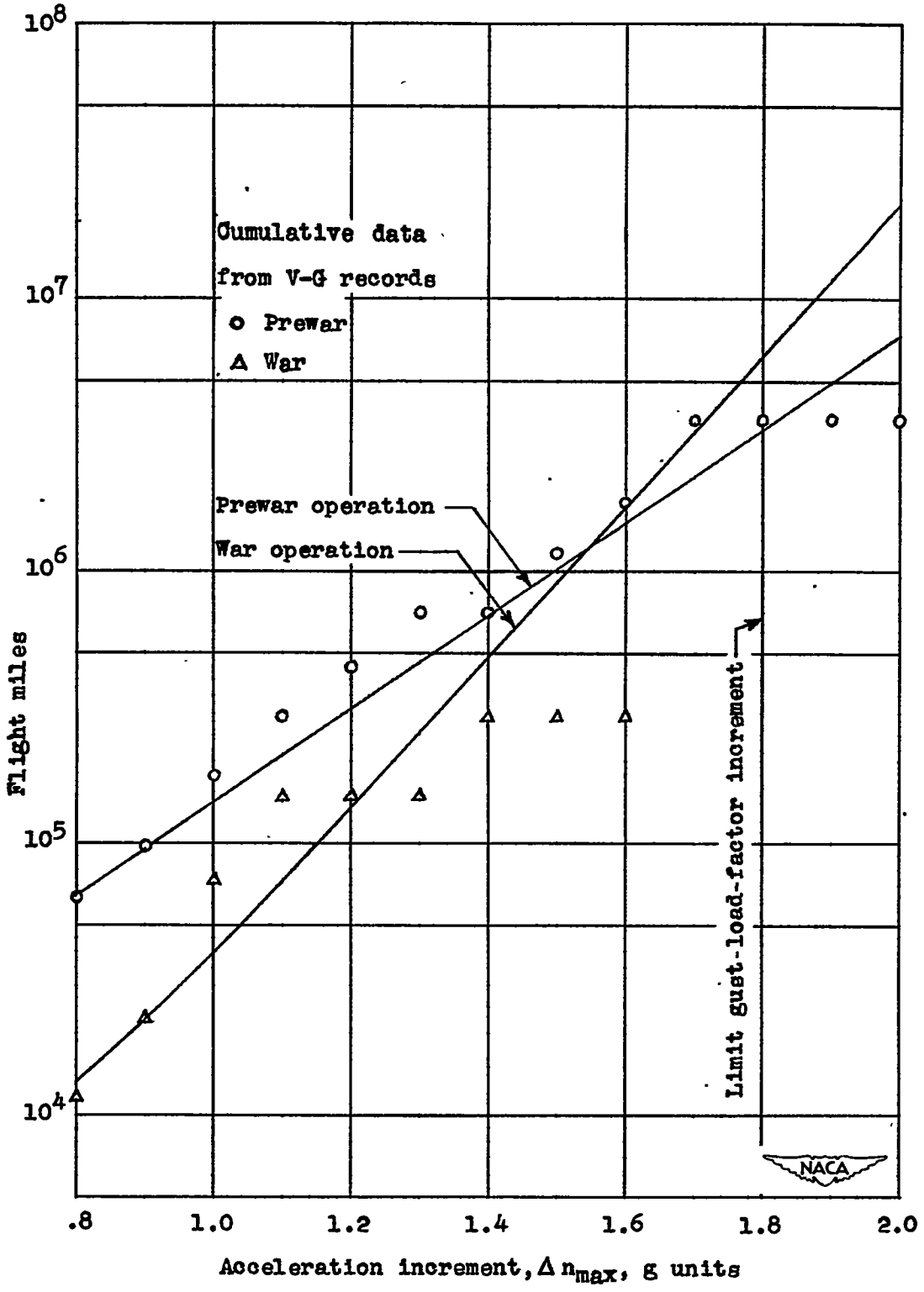

Figure 2.- Average flight miles required to exceed a given acceleration increment for prewar and war operation.

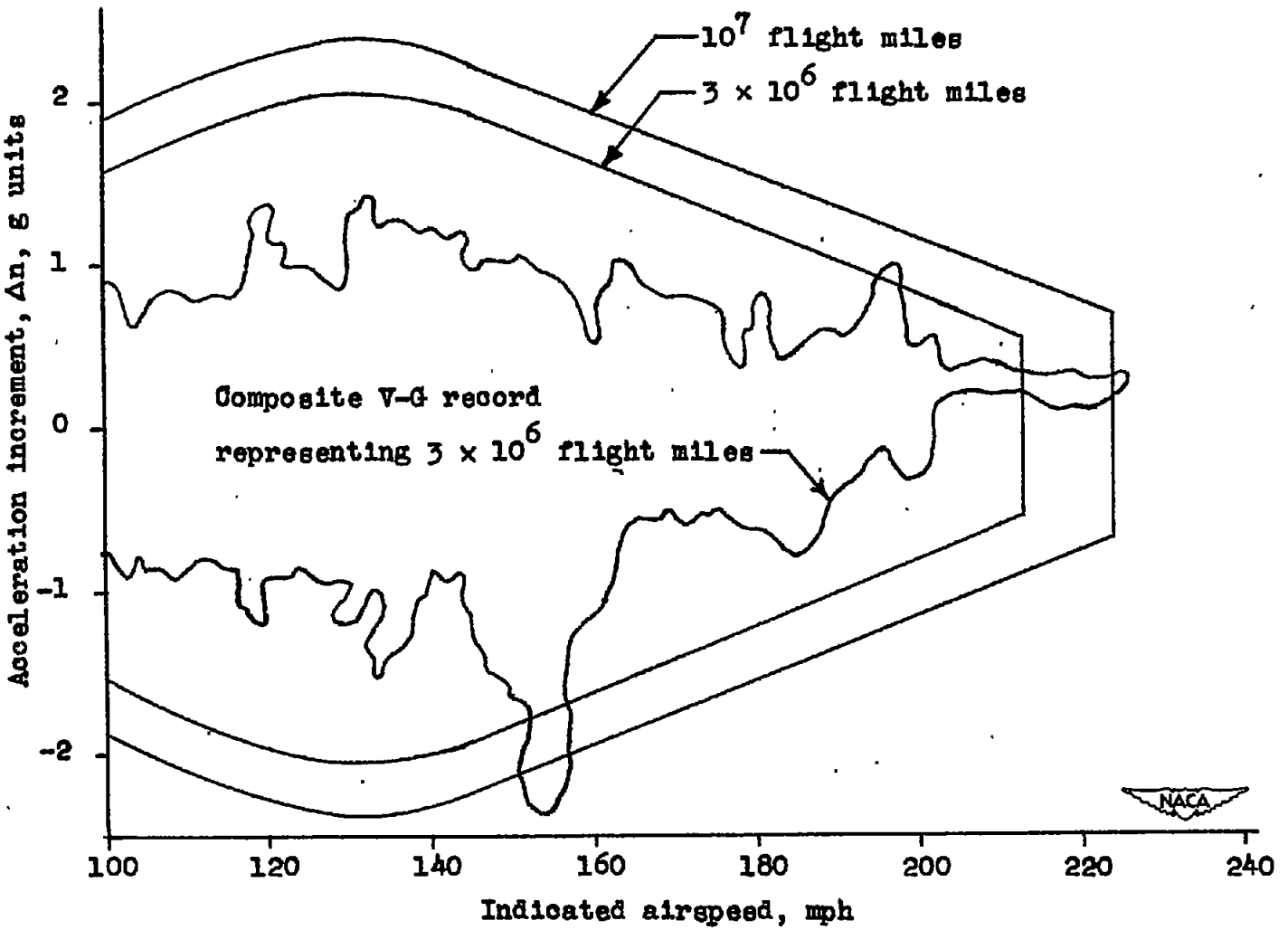

Figure 3.- Comparison of calculated flight envelopes with the composite V-G record for the prewar period.

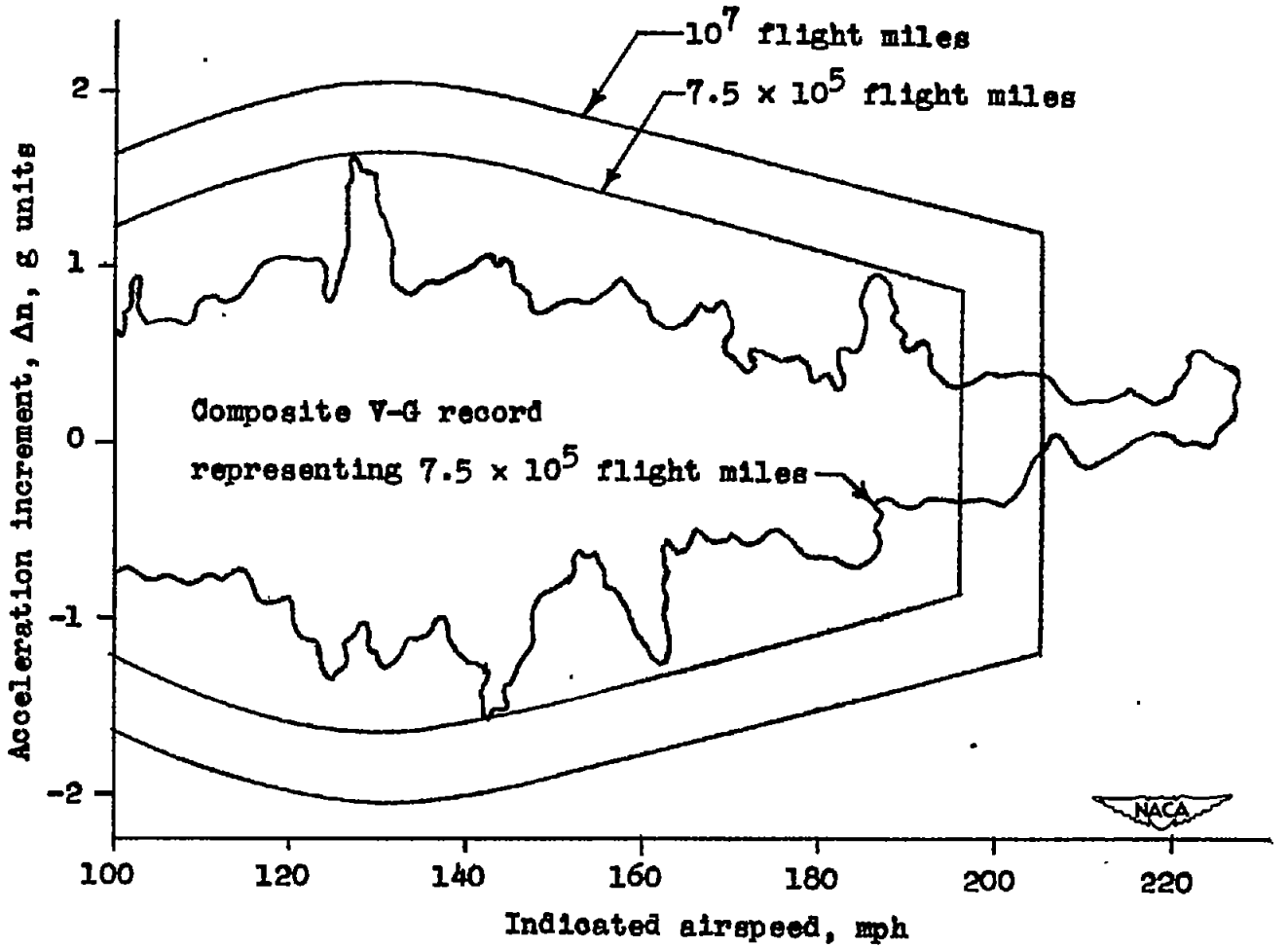

Figure 4.- Comparison of calculated flight envelopes with the composite V-G record for the war period.

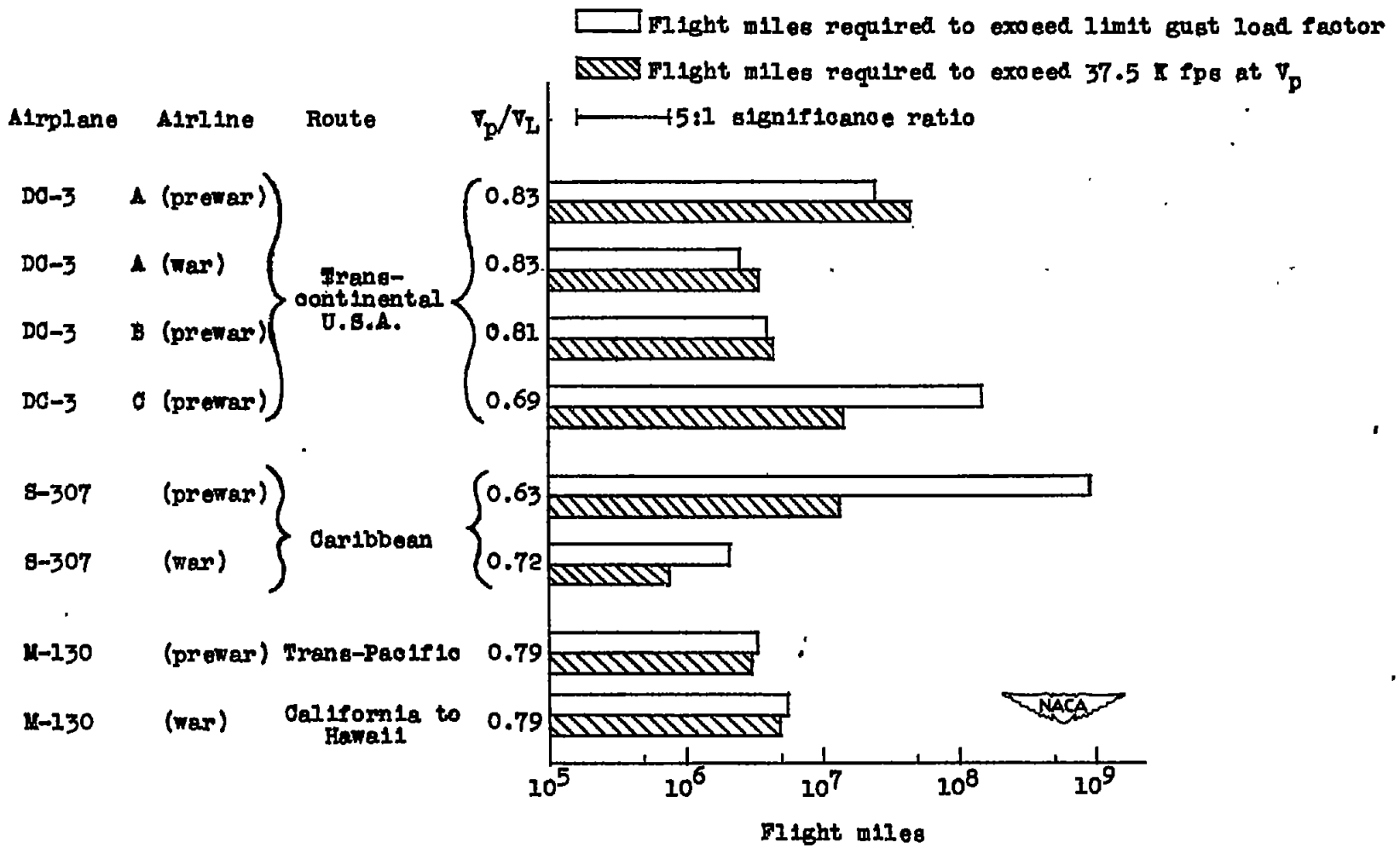

Figure 5.- Comparison of average flight miles required to exceed limit gust load factor and to exceed fixed effective gust velocity at probable speed V_p of gust encounter.