

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1142

AN ANALYSIS OF THE AIRSPEEDS AND NORMAL ACCELERATIONS
OF DOUGLAS DC-3 AIRPLANES IN COMMERCIAL
TRANSPORT OPERATION

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SUMMARY

Acceleration and airspeed data in the form of V-G records from Douglas DC-3 airplanes operated over three transcontinental routes in the United States have been analyzed to determine the influences of route, forecasting and dispatching practices, and operating speed on the applied loads experienced during commercial transport operation. The operational life of airplanes was found to be directly related to the operating speeds maintained in regions of turbulence and to the forecasting facilities and dispatching practices of the airline. During a given period of operation, however, for transcontinental operation in the United States, differences in route roughness appear to be so compensated for by the forecasting and dispatching practices of the airlines that route, as a significant parameter in airplane life, may be neglected.

INTRODUCTION

The present report is the second prepared to give the results of an analysis of V-G data from commercial transport airplanes. The first report (reference 1) dealt with data obtained from Boeing S-307 airplanes flying in the Caribbean region. The present report is concerned with an analysis of data obtained with Douglas DC-3 airplanes flying over three transcontinental routes in the United States. The data have been analyzed in accordance with the method of reference 2 to indicate the influences on airplane life of route, dispatching and forecasting practices, and operating speed.

SCOPE AND EVALUATION OF DATA

A total of 133 V-G records representing 54,210 hours of flight were available for the present analysis. These records were obtained with the NACA V-G recorder (reference 3) from DC-3 airplanes operated by three of the principal airlines of the United States during the period from 1937 to 1944. The records were supplied to the Langley Memorial Aeronautical Laboratory of the NACA by the airlines together with the dates of installation and removal, the number of flight hours per record, the routes flown during the time that the record was installed in the airplane, and occasional supplementary remarks regarding unusual atmospheric conditions or operating practices. Since no information was made available by the airlines on the operating weight and other characteristics of the airplanes pertinent to the present report, the design values as obtained from references 4 to 6 have been used. These values are presented in table I. The limit load factor of 3.11g was determined from the other airplane characteristics on the basis of the requirements set forth in reference 7. This value represents the acceleration that would result from an effective gust velocity of 30K feet per second encountered at maximum level-flight speed where K is the gust alleviation factor (reference 7). On the basis of the design gross weight of the DC-3 airplane, a value of K of 1.07 has been used in the present report.

A summary of the records supplied for analysis by each of the airlines (referred to hereinafter as airlines A, B, and C) is given in table II. Records were supplied by airline A from 1937 to 1944 and these records have been separated in table II according to prewar (before World War II) or war (during World War II) operation. Airlines B and C supplied records during only the prewar period. Inasmuch as the flight hours per record for each airline covered a fairly wide range, and since the method of analysis which has been employed requires that the flight time per record be held reasonably uniform, it was necessary to restrict the analysis to smaller groups of records for which the ranges of flight hours were not too great. The ranges of flight hours that were selected for each group of records are shown in table II together with a summary of the records that corresponded to these ranges. The choice of a suitable range of flight hours is somewhat arbitrary. The present choices, however,

conform to the statement given in reference 2 of the ranges that are desirable in the application of the present method of analysis.

No attempt has been made in the present analysis to classify acceleration peaks as due to gusts, gust maneuvers, or maneuvers. As in reference 1, the assumption has been made that all large accelerations in flight are due to gusts.

METHOD OF ANALYSIS AND RESULTS

The method of analysis of the data obtained with the DC-3 airplanes is exactly the same as the method used for the data obtained with the S-307 airplanes (reference 1). Six values are read from each record: the flight time, the maximum indicated airspeed V_{max} , the maximum positive and negative acceleration increments Δn_{max} , and the indicated airspeeds V_0 at which these maximum accelerations are experienced. The frequency distributions of V_{max} , Δn_{max} , and V_0 for each of the airlines are shown in tables III, IV, and V, respectively. Because of the essential symmetry of positive and negative acceleration increments, values of Δn_{max} were combined without regard to sign.

With the aid of the computed mean value \bar{V}_{max} , $\bar{\Delta n}_{max}$ or \bar{V}_0 , and the computed values of the standard deviation σ and the coefficient of skewness α , Pearson Type III probability curves (reference 2) can be fitted to each of the frequency distributions so that estimates may be made of the probability of exceeding given values of airspeed and acceleration. By means of these probability curves and the values of the average record time τ in table II, the average number of hours required for each of airlines A, B, and C to exceed different values of airspeed and acceleration has been computed in the manner outlined in reference 1. The results for airspeed and acceleration are shown in figures 1 and 2, respectively. The curves of figures 1 and 2 are merely Pearson Type III probability curves referred to a time scale. Values taken from figures 1 and 2 at the placard speed (nine-tenths of the maximum gliding speed) of 257 miles per hour and at the

limit-load-factor increment of $2.14g$ of the DC-3 airplane are summarized in figures 3 and 4.

By the procedure in reference 2, "flight envelopes" have been constructed from the data for each of the airlines. These envelopes predict that, in a given number of flight hours, an average of one airspeed will exceed the envelope, and an average of one positive and one negative acceleration increment will exceed the envelope with equal probability of being experienced at any airspeed. For comparison with other data, the flight envelopes corresponding to 10,000, 20,000, and 50,000 hours of flight by airline A during the prewar and war periods and by airlines B and C during the prewar period, are shown in figures 5, 6, 7, and 8, respectively. The composite V-G envelopes representing all the data supplied by each of the airlines are also shown in figures 5 to 8. For purposes of comparison the 5000-hour flight envelope has been included in figure 8, inasmuch as only 4485 hours of records were supplied by airline C. On several of the individual V-G records the flight-acceleration peaks at low speeds (100 to 120 miles per hour) were expunged by traces on the records caused by landing shocks. The landing shocks so exhibited on these records were not included in the composite V-G envelopes of figures 5 to 8.

The flight envelopes have been converted, by means of the sharp-edged-gust formula (reference 3), to gust-velocity envelopes which predict that in a stated number of flight hours, an average of one up gust and one down gust will exceed the envelope with equal probability of being encountered at any airspeed. The 50,000-hour effective-gust-velocity envelopes corresponding to the 50,000-hour flight envelopes of figures 5 to 8 are presented in figure 9.

PRECISION

The precision of the NACA V-G recorder and the limitations of the method of analysis employed have been discussed in reference 1. The inherent errors in the V-G recorder should not exceed $\pm 0.2g$ for acceleration and 3 percent of the full-scale value for airspeed.

The use of the design gross weight in the calculation of effective gust velocities undoubtedly results in conservative gust velocities since, so far as is known, the DC-3 airplanes were not operated at weights greater than their gross weights. Scheduled operating times that were supplied by the airlines have been used as the basis of a rough calculation of the average gross weight of the airplane in flight and, on the average, the effective gust velocity appears to be conservative by about 5 percent.

DISCUSSION

Application of the methods of reference 2 to the data obtained with the DC-3 airplanes has indicated certain trends with regard to the influences of route, forecasting and dispatching practices, and operating speed on the life expectancy of commercial transport airplanes.

For the analysis it is necessary to determine what constitutes a significant difference between two probabilities. The criterion adopted in reference 1 is employed herein; namely, if one probability is greater than the other by a ratio of more than 5 to 1, the difference between the probabilities may be regarded as significant.

Route, forecasting, and dispatching. - The combined effects on airplane life of route and of forecasting and dispatching practices, as contrasted with the separate effect of operating speed, may be determined by eliminating, so far as possible, the influences on the data of differences in operating speed. This determination may be made by selecting a representative airspeed for each airline and reducing the data to a common basis in terms of these representative speeds. The speed selected for each airline is the "probable speed" V_p (reference 1), which is the speed that corresponds to the maximum acceleration increment on the calculated envelopes of figures 5 to 8. The probable speed is the speed at which the maximum acceleration increments will most probably be experienced.

The influences of route and of dispatching and forecasting practices are expressed in terms of the average number of flight hours required to exceed the acceleration that would be experienced as the result of encountering a gust of given effective velocity at probable speed. The effective gust velocity chosen for this purpose is $37.5K$ feet per second, where K is the gust alleviation factor (reference 7). This particular value of gust velocity was selected so that the time required to exceed the resulting accelerations would be roughly comparable to the time required to exceed the limit load factor. The average time required to exceed the acceleration increment produced by a gust velocity of $37.5K$ feet per second at probable speed for each of airlines A, B, and C, as determined from figure 2, is shown in figure 3. Since the time scale on this figure is logarithmic, the 5-to-1 criterion for significant differences may be represented by a constant length and is included in the figure for purposes of comparison. It will be noted that the differences among the airlines for prewar operations are not significant on the basis of the 5-to-1 criterion. Thus, at least for transcontinental operation in the United States, differences in route roughness appear to be so compensated for by variations in the forecasting and dispatching practices of the airlines that route, as a significant parameter of airplane life, may be neglected.

Forecasting and dispatching over a given route.-

The fact that data from airline A are available for both prewar and war periods affords an opportunity to determine the effect on airplane life of changes in forecasting and dispatching techniques over a given route. During the war period, either because less adequate facilities for forecasting were available or because dispatching techniques were deliberately relaxed, the airplanes were flown through turbulent air that would have caused flight cancellation in the prewar period. A direct evaluation of the effect of these changes may be made from the times required to exceed an effective gust velocity of $37.5K$ feet per second at probable speed (fig. 3). In fact, figure 3 indicates that the average time required for airline A to exceed this value was decreased by a factor of 10 during the war period. Since the probable speed for airline A is the same

for both periods, so that a general similarity of over-all operating speeds for the two periods may be inferred, the indicated decrease in time may be attributed directly to the greater turbulence experienced during the war period as a result of either less adequate forecasting facilities or relaxed dispatching practices. Thus, forecasting and dispatching practices over a given route are of appreciable importance in determining airplane life.

Operating speed.- Since the parameters of route, forecasting, and dispatching have been shown to have had no significant influence on airplane life during the prewar period, whatever differences exist among the operational lives for the three airlines must be attributed to other factors. The operational lives may be determined directly from figure 3 in terms of the average flight time required for each airline to exceed the limit load factor. Although the values given for airlines A and B are in essential agreement, the operational life for airline C is significantly higher than the others. In fact, airline C exceeds the limit load factor only about one-tenth as often as do airlines A and B. The values of probable speed in figure 3 show that the difference is due to the fact that the airplanes of airline C are flown at low speeds in regions of turbulence. Whereas airlines A and B have probable speeds of 175 miles per hour and 170 miles per hour, respectively, with resulting operational lives of about equal magnitude, the probable speed of airline C is only 145 miles per hour. Thus operating speed in turbulent air is apparently of primary importance in the determination of the operational life of airplanes.

Excessive speed.- The results shown in figure 4, in which the time required to exceed the limit load factor in figure 2 and the time required to exceed placard speed in figure 1 are summarized, indicate a direct relationship between these factors. Such a relationship might be expected if, as can be reasonably assumed, transport airplanes are never intentionally flown at excessively high speeds and these speeds are attained only as a result of the loss of control in turbulent air.

CONCLUSIONS

An analysis was made of the V-G records obtained from Douglas DC-3 airplanes during commercial transport operation over three transcontinental routes in the United States to determine the effects of route, forecasting and dispatching practices, and operating speed on the applied loads experienced during commercial transport operation. The analysis indicated the following conclusions:

1. For transcontinental operation in the United States, differences in route roughness are so compensated for by variations in the forecasting and dispatching practices of the airlines that route, as a significant parameter in airplane life, may be neglected.
2. Forecasting and dispatching practices over a given route, as reflected in differences between prewar and war operation, are of appreciable importance in determining airplane life.
3. Operating speed in regions of turbulence is of primary importance in the determination of the operational life of airplanes.
4. The average time required to exceed the placard speed seems to be directly related to the average time required to exceed the limit load factor.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., April 16, 1946

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6. Anon.: Private and Commercial Aircraft. Aero Digest, vol. 38, no. 3, March 1941, p. 138.
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TABLE I

CHARACTERISTICS OF DOUGLAS DC-3 AIRPLANES

Gross weight, lb	25,200
Wing area, sq ft	987
Wing span, ft	95
Mean aerodynamic chord, ft	11.5
Slope of lift curve, per radian	4.79
Aspect ratio	9.1
Maximum level-flight speed, mph	211
Placard speed, mph	257
Limit load factor, g	3.14

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TABLE II
SUMMARY OF V-G RECORDS SUPPLIED FOR ANALYSIS

Operator	Records supplied		Ranges of flight hours used in analysis	Records used in analysis		
	Number of records	Total flight hours		Number of records	Total flight hours	Average flight hours per record, \bar{r}
A (prewar)	35	17,675	575 to 800	15	9,691	645
A (war)	33	20,002	600 to 800	20	13,911	695
B (prewar)	52	12,048	200 to 400	37	10,187	275
C (prewar)	13	4,485	150 to 450	11	3,232	295

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TABLE III

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS OF V_{max}

Velocity (mph)	Frequency for airline A, prewar	Frequency for airline A, war	Frequency for airline B, prewar	Frequency for airline C, prewar
190 to 194				1
195 to 199				1
200 to 204			4	3
205 to 209		1	7	3
210 to 214		3	6	2
215 to 219	1	1	13	
220 to 224	4	4	3	
225 to 229	3	2	1	1
230 to 234	4	5	1	
235 to 239	2	2	1	
240 to 244				
245 to 249		1		
250 to 254	1			
255 to 259			1	
260 to 264		1		
Total	15	20	37	11
\bar{V}_{max}	229.8	227.8	215.7	206.6
σ	8.3	12.7	9.9	8.7
α	1.04	0.77	1.48	0.79

TABLE IV

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS OF $\bar{A}_{n_{max}}$

Acceleration increment (g units)	Frequency for airline A, prewar	Frequency for airline A, war	Frequency for airline B, prewar	Frequency for airline C, prewar
0.30 to 0.39				1
0.40 to 0.49				2
0.50 to 0.59			1	2
0.60 to 0.69	1		3	1
0.70 to 0.79	1	2	1	3
0.80 to 0.89	2		9	3
0.90 to 0.99	2	2	6	2
1.00 to 1.09	4	5	8	3
1.10 to 1.19	4	2	14	2
1.20 to 1.29	6	5	9	
1.30 to 1.39	4	4	6	
1.40 to 1.49	2	5	5	3
1.50 to 1.59		1	3	
1.60 to 1.69		4	2	
1.70 to 1.79	3	1	2	
1.80 to 1.89		3	2	
1.90 to 1.99	1	3		
2.00 to 2.09		1	1	
2.10 to 2.19			2	
2.20 to 2.29				
2.30 to 2.39		1		
2.40 to 2.49		1		
Total	30	40	74	22
$\bar{A}_{n_{max}}$	1.23	1.45	1.21	0.89
σ	0.30	0.39	0.34	0.32
α	0.46	0.48	0.74	0.25

TABLE V

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS OF V_0

Velocity (mph)	Frequency for airline A, prewar	Frequency for airline A, war	Frequency for airline B, prewar	Frequency for airline C, prewar
100 to 109		3	1	
110 to 119	1	3	4	
120 to 129			6	3
130 to 139	1	2	8	2
140 to 149	3	1	5	8
150 to 159	3	3	13	4
160 to 169	4	5	9	3
170 to 179	6	6	13	1
180 to 189	7	6	8	
190 to 199	2	4	5	1
200 to 209	3	7	2	
Total	30	40	74	22
\bar{V}_0	172.0	168.5	158.9	149.5
σ	21.2	30.9	24.2	16.4
α	-0.57	-0.75	-0.22	0.73

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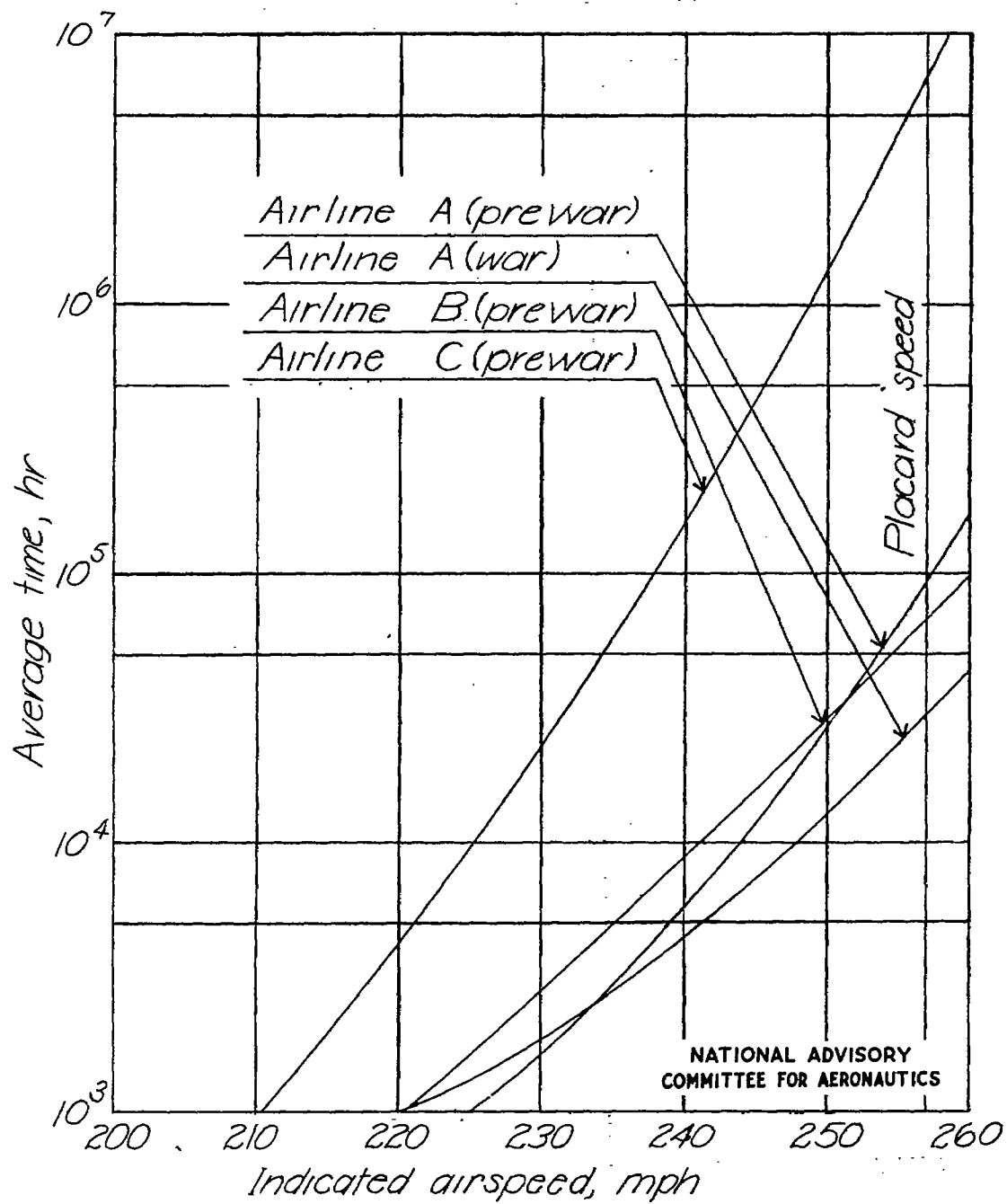


Figure 1.—Average time required to exceed a given value of airspeed.

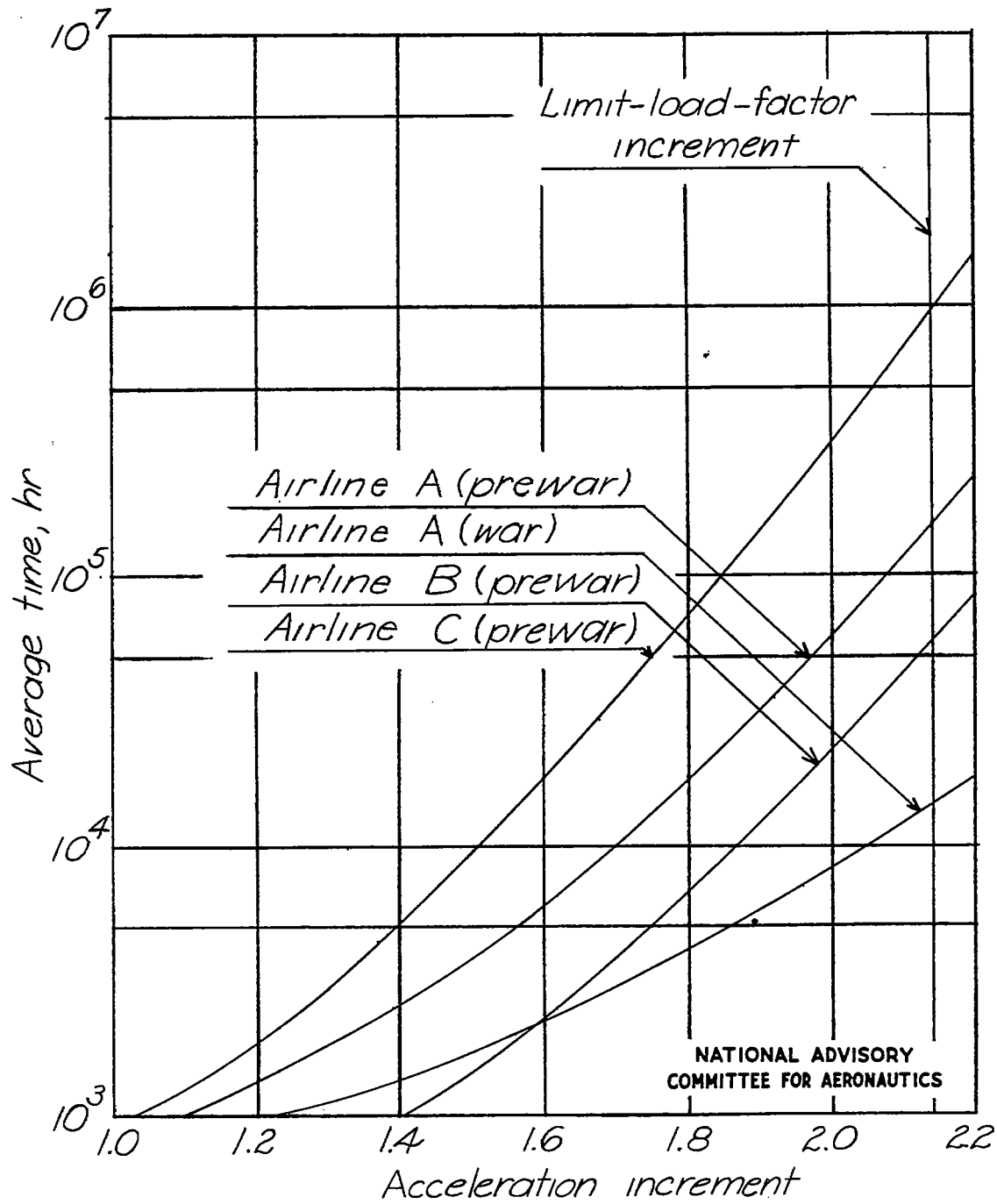


Figure 2.—Average time required to exceed a given acceleration increment.

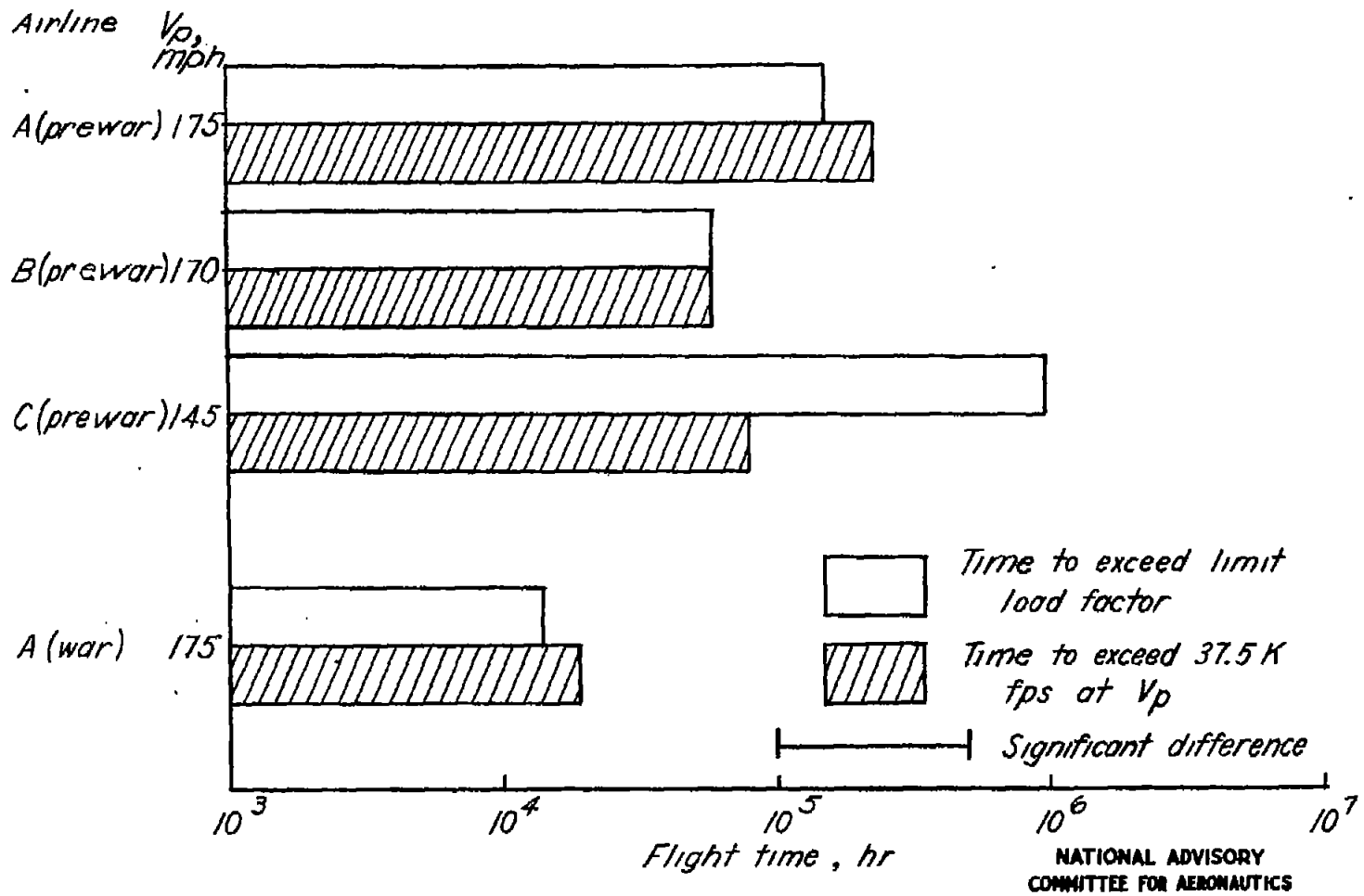
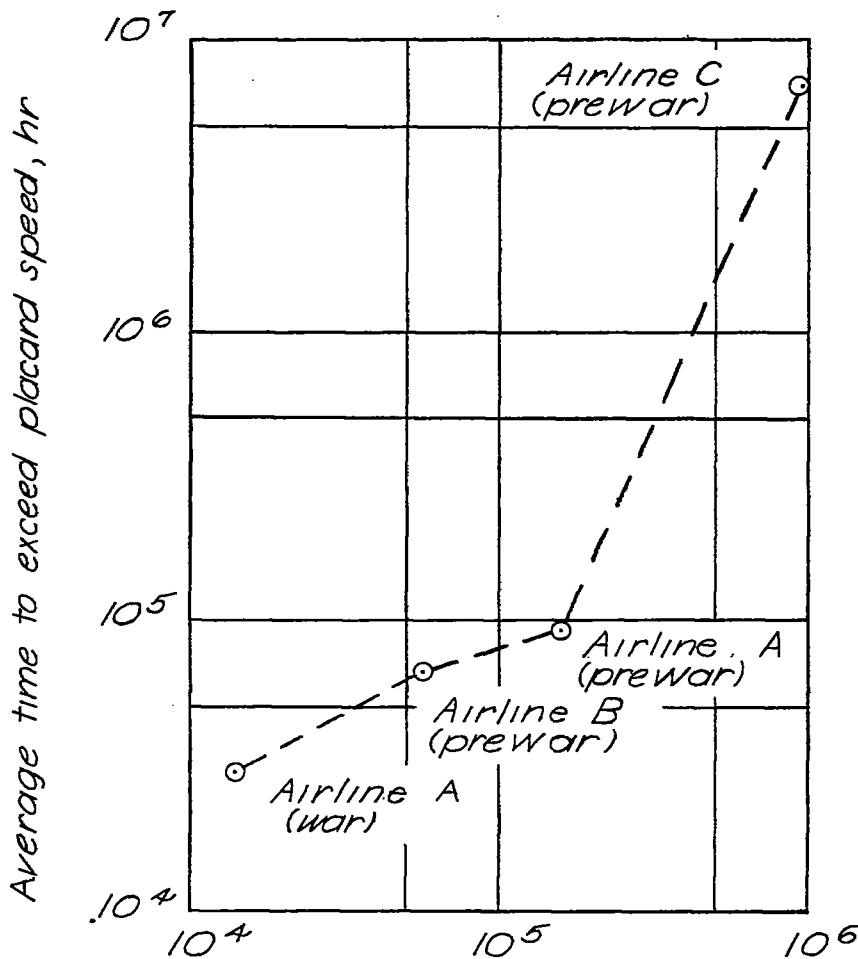


Figure 3.-Average time required to exceed limit load factor and to exceed fixed effective gust velocity at probable speed.



Average time to exceed limit-load-factor increment, hr

Figure 4.—Relation between average time required to exceed limit-load-factor increment and average time required to exceed placard speed.

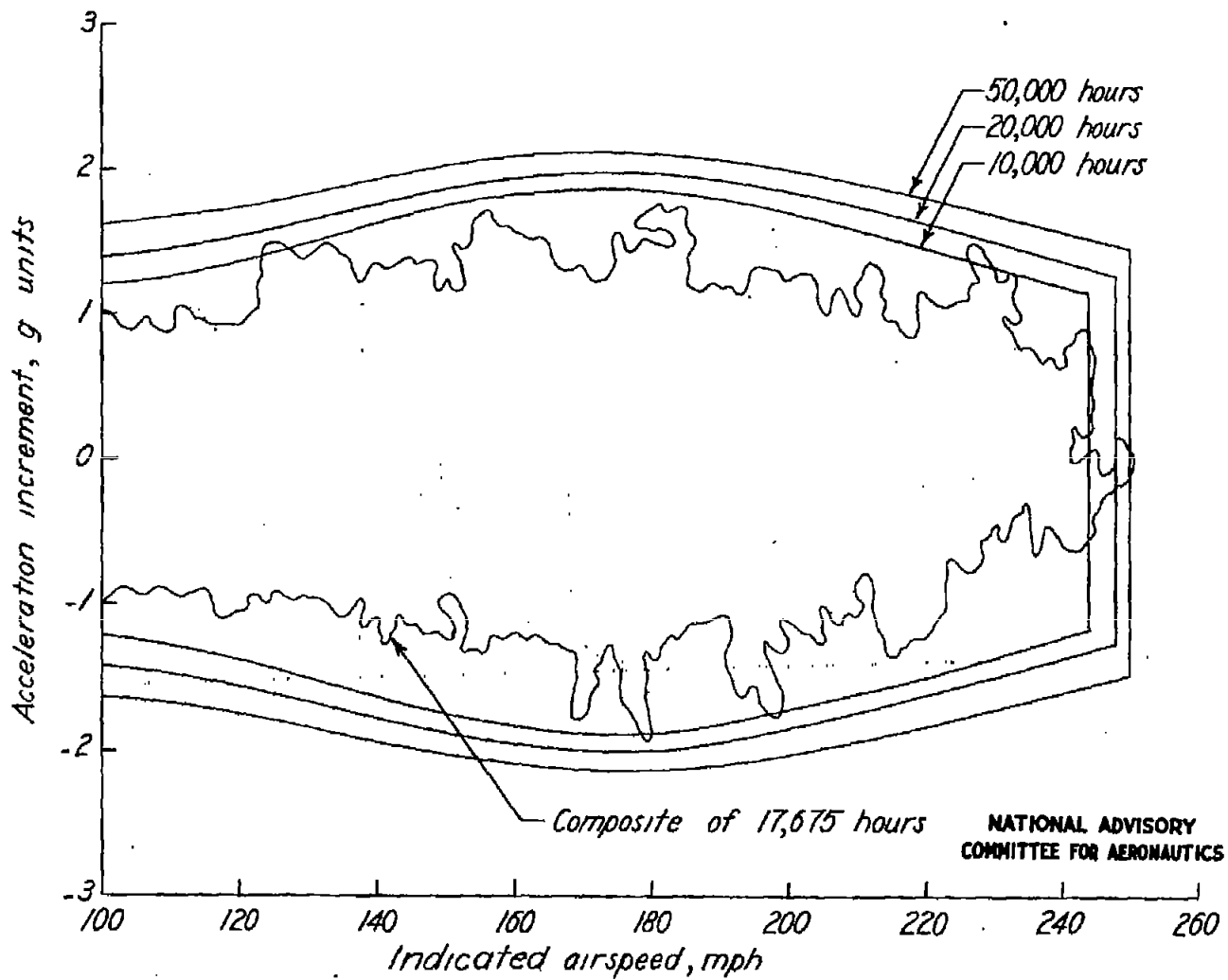


Figure 5.-Comparison of calculated flight envelopes with composite of V-G envelopes obtained by airline A during prewar operation.

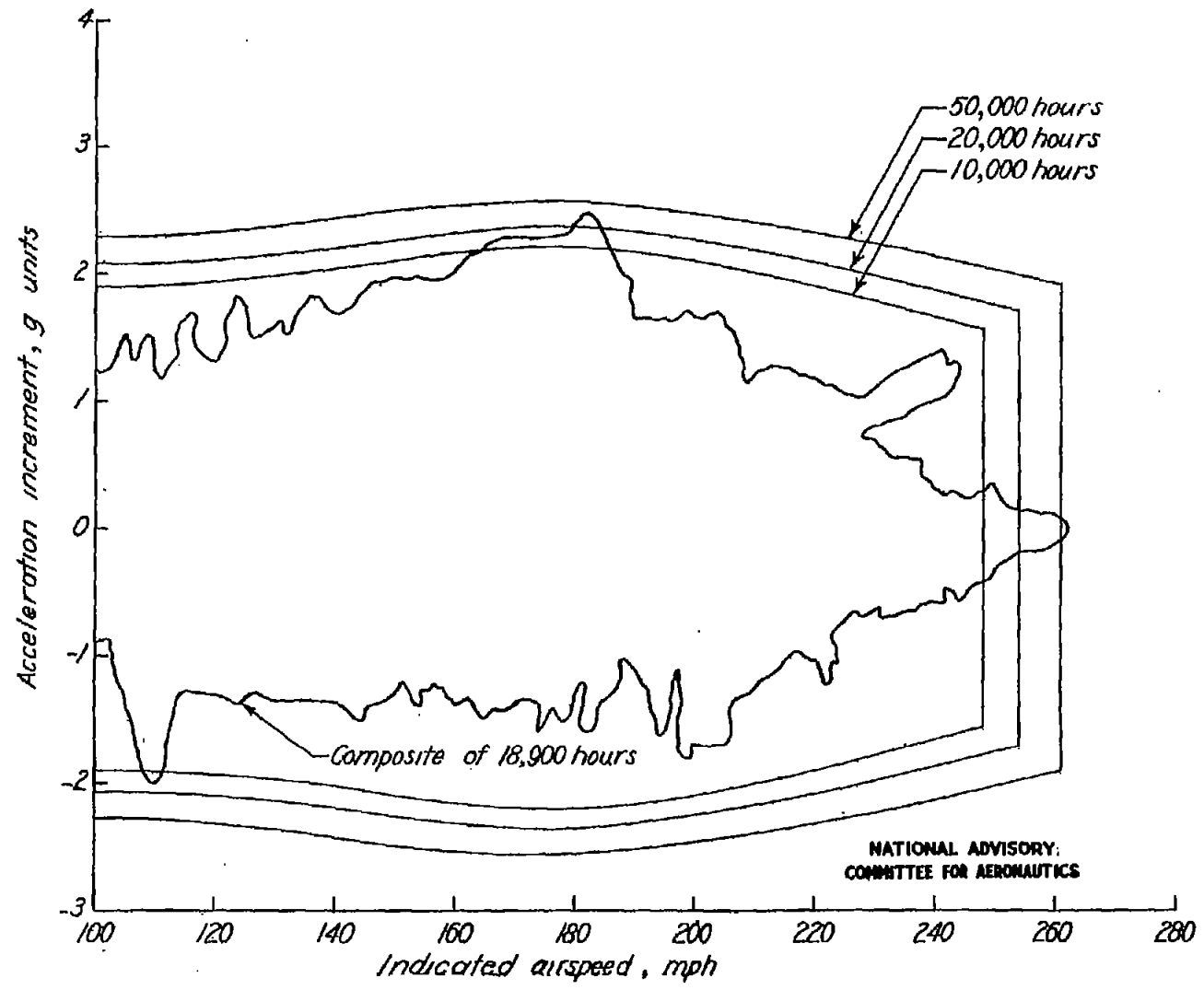


Figure 6.- Comparison of calculated flight envelopes with composite of V-G envelopes obtained by airline A during war operation.

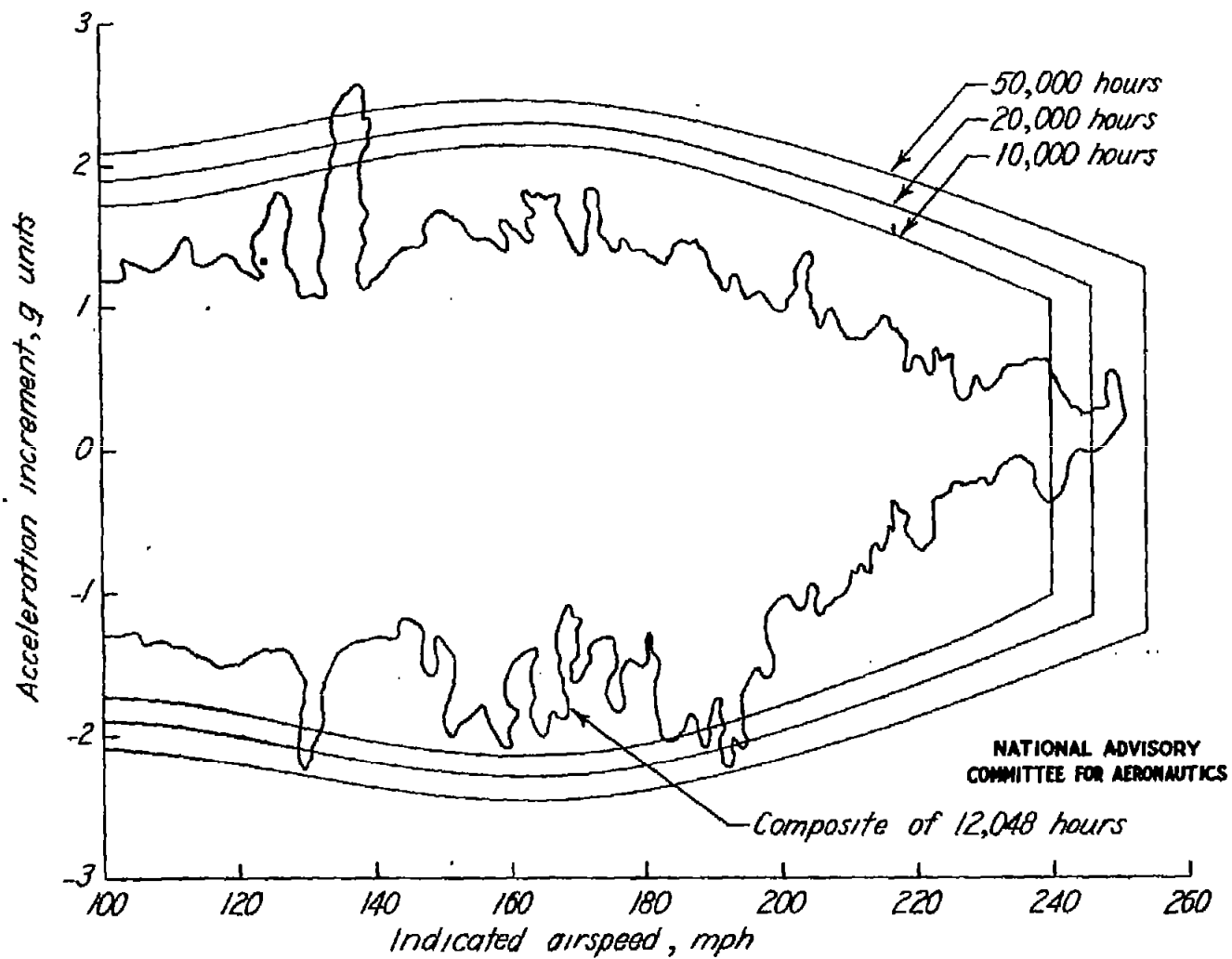


Figure 7.—Comparison of calculated flight envelopes with composite of V-G envelopes obtained by airline B during prewar operation.

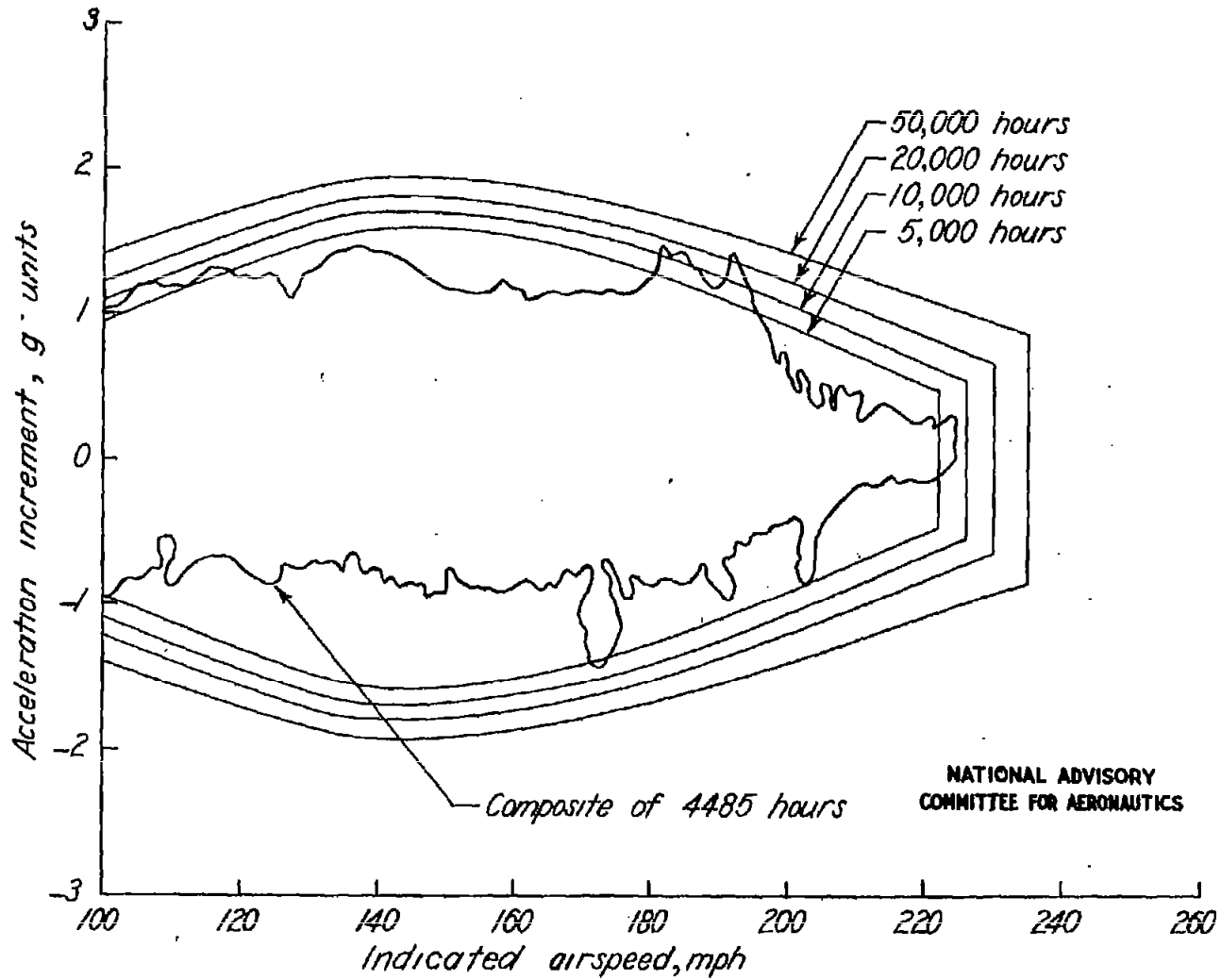


Figure 8.—Comparison of calculated flight envelopes with composite of V-G envelopes obtained by airline C during prewar operation.

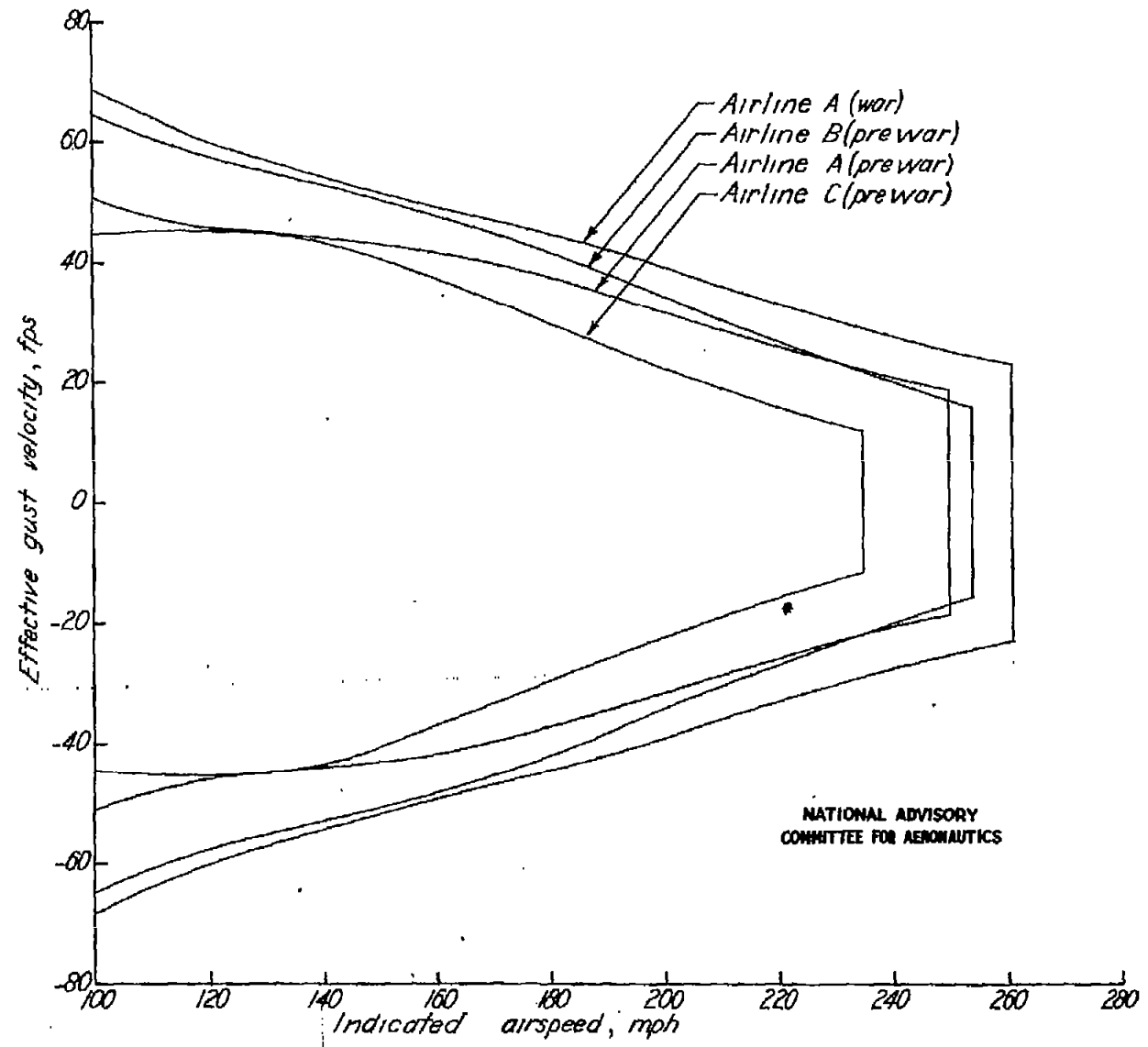


Figure 9.-Effective-gust-velocity envelopes for 50,000 hours of operation.