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SUMMARY OF V-G RECORDS TAKEN ON TRANSPORT

AIRPLANES FROM 1932 TO 1942

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SUMMARY

Since the preparation of the last report on gust loads a large number of records have been obtained from V-G recorders installed in airplanes flying on the domestic and transoceanic transport air lines of the United States. Records totaling more than 134,000 flying hours have been received and evaluated in order to bring up to date the V-G recorder data. The analysis of these records is contained in this report.

The results indicate that the maximum effective gust velocities for both the land transport airplanes and the flying boats have approached values of ±40 feet per second. This value is discussed with reference to the present design gust load factor and it is concluded that the present design factor is adequate when all the factors affecting the maximum effective gust velocities are considered.

INTRODUCTION

Since the preparation in 1937 of reference 1, the number of V-G recorder flight hours has been increased from about 20,000 hours to more than 134,000 hours. At the same time several new types of airplane have been placed in regular service on the air lines. These airplanes are much larger and, in some cases, have higher wing loading values than the old types they have replaced. In 1937 the ratio of flight time accumulated on land transports to that of flying boats was about 6 to 1, whereas at the present time the ratio is very near unity. Likewise the wing loadings of the landplanes and the flying boats are more nearly equal at the present time than in 1937. The approach toward parity of these quantities permits at the present time a more reasonable comparison between the records taken on the landplanes and on the flying boats than was possible in 1937.

The transport air lines of the United States have been very cooperative with the NACA by installing V-G recorders in transport airplanes and periodically returning the records obtained on these airplanes with the pertinent data required to evaluate the records. This procedure has made it possible to obtain a large amount of V-G recorder data from transport airplanes.

METHOD AND RESULTS

Scope of measurements.- The scope of the V-G data obtained to date is presented in table I in terms of the type of airplane in which the V-G recorders have been installed and the total number of flying hours for each type of airplane.

Figure 1 shows the monthly distribution of flying time from October 1932 to April 1942. The chart shows a total of over 134,000 flying hours for this period of time.

Composite V-G diagrams.- The results of the evaluated V-G records are given as composite plots for the different types of landplane in figure 2 and for the different flying boats in figure 3. Normal acceleration values in terms of g are plotted against indicated airspeed; envelopes of the maximum g values are shown for all the V-G records taken on each type of airplane.

These composite plots are based on the analysis and the evaluation of hundreds of separate V-G records obtained over a long period of time. In the analysis of the data, some individual records had to be rejected because the instrument operation was obviously faulty. In all cases in which the question arose as to whether a large acceleration appearing on the record was due to a maneuver rather than to an atmospheric gust, the acceleration in question was thrown out. As a result all the accelerations that make up the maximum outline on the composite plots of figures 2 and 3 are gust accelerations.

For cases in which definite evidence indicated that severe storm conditions existed during the time any given V-G record was taken the data have been included on the plots in dashed outline. The record for the DC-2 airplane (fig. 2), when a storm was encountered between Richmond, Va. and Washington, D.C., was described in detail in reference 1 as a unique V-G record; the record for the M-130 airplane (fig. 3) was obtained under storm conditions on a flight from Alameda, Calif. to Hong Kong, China. This procedure has been followed because it is believed that these storm conditions should be considered exceptional cases and should be treated separately.

Composite U_e diagrams.- The plots of figures 2 and 3 have been converted, as was explained in reference 1, into the form of maximum effective gust velocities U_e plotted against a speed ratio V/V_L and are presented in figures 4 and 5. The ratio V/V_L is the ratio of the indicated airspeed at which the gust was encountered to the maximum indicated airspeed in level flight for the particular type of airplane under consideration. The conversion of the g values into terms of U_e has been accomplished by use of the following relation:

$$U_e = \frac{2\Delta nW}{\rho mVS}$$

in which

U_e effective gust velocity, feet per second

Δn increment of load factor from 1g

W gross weight of the airplane, pounds

S wing area, square feet

ρ air density at sea level

m slope of wing lift curve per radian

V indicated airspeed of airplane, feet per second

The foregoing formula is based upon the assumption of a "sharp-edged" gust, this assumption being that an airplane flying in calm air suddenly encounters a vertical gust which is sharply defined relative to the surrounding atmosphere. All the data have been given using the assumption of a sharp-edged gust. The discussion of the theoretical relationships involved is contained in references 2 and 3.

Certain assumptions must be made in order to evaluate the sharp-edged-gust equation. The actual values of the wing loadings and the slopes of the lift curves of the various airplanes at the time the gusts were encountered are not known. For this reason the gross weights of the different types of airplane and a value of the slope of the lift curve of 4.5 have been used in the determination of the gust velocities from which figures 4 and 5 have been prepared.

Table II presents data of basic airplane characteristics that have been used in the computations made in this report. The speed ratio V/V_L is used in the converted plots to reduce the V-G data for all the different types of airplane to a common basis for comparison. The values of maximum indicated airspeed V_L, the source of the data in each case, and the maximum values of the V/V_L ratio, as obtained from figures 4 and 5 or from calculations, are given in table II.

In figure 6 the effective gust velocities for all the land transport airplanes have been combined to form one composite gust velocity envelope and the same thing has been done for the flying boats. In this manner a comparison between the effective gust velocities occurring on the land transports and on the flying boats is possible.

The effects of variation of the wing loading and the slope of the lift curve on the calculated values of gust velocity are shown in table III. Two values of wing loading have been chosen for each type of airplane, the value that corresponds to full gross weight and the value that corresponds to weight empty. The $U_{e_{max}}$ and $U_{e_{min}}$ values obtained under the conditions described are tabulated. The values of Δn and V chosen for use in these computations are taken from figures 2 and 3 and are the values that give the highest values of calculated effective gust velocity. The other factors in the equation have been held constant.

The values of the lift-curve slopes are not the same for all the airplanes used in collecting the V-G records. A value of 4.5 has been used for computing the data for all airplanes. The actual values for the lift-curve slopes on particular airplanes should approximate the calculated values given in table III. These values have been calculated using equation (88) of reference 4:

$$\frac{dC_L}{d\alpha} = \frac{n}{10(n + 1.8)}$$

where

$\frac{dC_L}{d\alpha}$ slope of the lift curve

C_L lift coefficient

α angle of attack

n aspect ratio

The values calculated by this formula are converted to radian measure for use in the gust equation. The equation for $\frac{dC_L}{d\alpha}$ gives an approximate value of the slope for a thickness-to-chord ratio of 0.12. For the purpose of this report the calculated values of the slopes are sufficiently accurate. A set of computations for the gust velocities are given in table III for the maximum wing-loading conditions and using the lift-curve slopes calculated by the equation.

The values of the design gust velocity for each type of airplane are shown in table III. The values of the gust factor K used to obtain the design gust values given in the table were taken from figure 11a of reference 5.

DISCUSSION

A comparison of the results of the present tests with similar results contained in reference 1 indicates that not only have the composite gust velocity curves for the landplanes and the flying boats (fig. 6) approached each other but also that, in general, the values of U_e are somewhat higher than in reference 1. It is reasonable to expect that the curves for the landplanes and the flying boats considered in this report would approach each other inasmuch as the chords and wing loadings are approximately the same and inasmuch as the flying times recorded for each type are nearly equal. The gust velocities should be higher in value in this report than they were in reference 1 because of the great amount of data accumulated during the ensuing period of time. The assumption that the gust-velocity envelope will gradually increase with times is logical because the chances of encountering large gusts increase with time. An interesting point is that the composite outlines for the landplanes and the flying boats that have comparable characteristics are approaching each other, although the operating conditions are not similar.

The altitudes at which the various airplanes in this report encountered any given gusts are unknown and all the records have been evaluated for sea-level conditions. The results contained in reference 6 show that, for practical purposes, the maximum effective (indicated) gust velocity is independent of altitude up to about 34,000 feet. For this reason, the conclusion is reached that the effect of altitude on the results contained in this paper may be neglected.

The most troublesome factor in the determination of the effective gust velocity is the value of the wing loading, which properly should be taken as that existing during the application of the gust load. Because this value is not known, the practice has been to take the value of wing loading corresponding to maximum gross weight. Such a practice is conservative if the values of U_e derived as a result are ultimately used as design values. As has been seen in table III the maximum values of U_e, in all but one case, are in excess of the design values for the airplanes listed. From this result one should not conclude that present design practice is unconservative, because the most probable values of the wing loadings at the times the gusts were recorded were substantially less than those based on maximum gross weight. The minimum values of U_e based on weight empty are, however, unduly low. A fair guess is that the most probable value of wing loading is about 85 percent of the maximum value. With such an assumption, the effective gust velocities determined from the records agree remarkably well with the design values, which are therefore considered to be adequate.

CONCLUSIONS

The analysis of the V-G recorder data based on a total of more than 134,000 flight hours and the comparison of the results obtained with present design values indicate the following conclusions:

1. The maximum effective gust velocities obtained from V-G records to date and based on maximum wing loading are approximately ±40 feet per second at all useful operational airspeed values.

2. The effective gust velocities of approximately 40 feet per second obtained from V-G data exceed the values of 30 feet per second multiplied by the gust factor used for design purposes. The difference may be largely accounted for by the use of the maximum wing loading. If the more probable wing loading of about 85 percent of the maximum values is used, the effective gust velocities are in good agreement with design values.

3. When a sufficiently large amount of data have been accumulated, the composite plots of the gust velocities for the land transport airplanes and the flying boats will probably agree very closely for types that have approximately the same wing loadings, the same wing chords, and the same operational speeds.

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TRANSPORT V-G RECORDER DATA TO APRIL 1942

Airplane	Air line	Routes flown	Period	Total air hours
		Landplanes		
Boeing 247	United	Whole system - coast to coast Newark - Seattle - Oakland	Oct. 1933 to Nov. 1935	6,907
Boeing 247-D	United	Whole system - coast to coast Newark - Seattle - Oakland	April 1935 to April 1937	7,170
Boeing 247-D	Pennsylvania Central	Milwaukee - Detroit - Pittsburgh - Cleveland - Washington, D. C.	Sept. 1938 to Oct. 1938	348
				Total 14,425
Douglas DC-2	Eastern	Miami - Newark - Boston	May 1936 to Jan. 1941	10,781
Douglas DC-2	TWA	Whole system - coast to coast Newark - Los Angeles	April 1936 to Feb. 1938	1,884
Douglas DC-2	Pan-American Grace	Buenos Aires, Argentine - Santiago, Chile	July 1935 to July 1937	1,037
				Total 13,702
Douglas DC-3	United	Whole system - coast to coast Newark - Seattle - Oakland	July 1937 to Jan. 1942	19,111
Douglas DC-3	American	Whole system - coast to coast Boston - Newark - Los Angeles	Feb. 1937 to Oct. 1939	12,835
Douglas DC-3	TWA	Whole system - coast to coast Newark - Los Angeles	Sept. 1938 to Oct. 1940	4,455
				Total 36,401
Boeing SA-307	TWA	Whole system - coast to coast Newark - Los Angeles	July 1940 to April 1941	2,073
Boeing S-307	PAA Latin America	Miami - San Juan - Port of Spain - Belem	April 1940 to April 1942	3,455
				Total 5,528
Lockheed 12A	Continental	Denver - El Paso	Aug. 1938 to March 1939	535
Ford 5AT-C	Pan-American Grace	Buenos Aires, Argentine - Santiago, Chile	Dec. 1932 to Dec. 1936	2,831
Fairchild FC-2W2	Pan-American Grace	Buenos Aires, Argentine - Santiago, Chile	Dec. 1932 to Nov. 1934	306
Fokker F10-A	American	Cleveland - Dallas	Oct. 1932 to Jan. 1933	300
			Landplane total	74,028
		Flying boats		
Boeing 314	Pan-American Atlantic Division	New York - Europe	March 1939 to April 1942	12,515
Boeing 314	Pan-American Pacific Division	San Francisco - Hawaii - Orient	April 1939 to April 1942	7,410
				Total 19,925
Martin 130	Pan-American Pacific Division	San Francisco - Hawaii - Orient	June 1936 to April 1942	18,272
Sikorsky S-42	Pan-American Grace	Miami - Buenos Aires	Aug. 1935 to Dec. 1935	490
Sikorsky S-42A	Pan-American Grace	Miami - Buenos Aires	April 1936 to Nov. 1939	15,902
Sikorsky S-42B	Pan-American Grace	Miami - Buenos Aires	June 1937 to March 1940	5,391
Sikorsky S-43	Pan-American Grace	Miami - Cristobal, Canal Zone	July 1936 to Oct. 1936	349
				Total 22,132
			Flying-boat total	60,329

AIRPLANE CHARACTERISTICS

Airplane	Gross weight, W (lb)	Wing loading, W/S (lb/sq ft)	Power loading, W/P (lb/hp)	Maximum indicated airspeed, V_L (mph)	Altitude at V_L (ft)	V/V_L	Source of data
Landplanes							
Boeing 247	13,100	15.67	12.48	169	5,000	1.31	Boeing Aircraft Co.
Boeing 247-D	13,650	16.32	12.41	177.5	8,000	1.31	Boeing Aircraft Co.
Douglas DC-2	18,200	19.4	12.2	215	8,000	1.11	Douglas Aircraft Company, Inc.
Douglas DC-3	24,000	24.3	13.3	213	7,000	1.13	Aviation, April 1937
Boeing S-307	45,000	30.2	12.5	250	16,200	.94	Aviation, Feb. 1942
Lockheed 12A	8,650	23.8	10.82	225	5,000	.93	Aviation, Feb. 1942
Ford 5AT-C	14,000	16.8	11.0	148	Sea level	1.27	Ford Motor Company
Fairchild FC-2W2	4,500	13.4	10.6	137	Sea level	1.21	NACA
Fokker F10-A	13,100	15.4	10.9	140	Sea level	1.08	Aviation, Aug. 1929
Flying boats							
Boeing 314	84,000	29.3	13.12	210	Sea level	1.01	Aviation, Feb. 1942
Martin 130	52,000	22.9	15.65	160	8,000	1.33	The Glenn L. Martin Co.
Sikorsky S-42	40,000	29.9	13.4	171	7,000	1.00	Sikorsky Aircraft (Division of United Aircraft Corp.)
Sikorsky S-42A	40,000	29.9	13.3	171	7,000	1.14	Aviation, March 1936
Sikorsky S-42B	42,000	31.3	14.0	188	7,000	1.09	Aviation, April 1937
Sikorsky S-43	19,000	24.3	12.7	175	7,000	1.06	Aviation, March 1936

TABLE III

EFFECT OF AIRPLANE CHARACTERISTICS ON THE CALCULATED EFFECTIVE GUST VELOCITIES

Airplane	Average chord (ft)	Aspect ratio	$\frac{dC_L}{d\alpha}$	$(W/S)_{max}$ (lb/sq ft)	$(W/S)_{min}$ (lb/sq ft)	Δn	V (mph)	V/V_L	$U_{e_{max}}$ $(W/S)_{max}$ at $m=4.5$	$U_{e_{max}}$ $(W/S)_{max}$ at $m=\frac{dC_L}{d\alpha}$	$U_{e_{min}}$ $(W/S)_{min}$ at $m=4.5$	$U_{e_{design}}$ 30K at $V/V_L=1.0$
Landplanes												
B-247-D	11.0	6.7	4.52	16.3	10.8	±2.5	140	0.79	37.2	37.0	24.6	[a]30.0
DC-2	11.0	7.7	4.65	19.4	12.6	-1.8	140	.65	31.9	30.9	20.7	31.2
DC-3	10.4	9.1	4.79	24.3	16.2	-2.1	162	.76	40.2	37.8	26.8	32.4
S-307	13.9	7.8	4.66	30.2	20.2	-2.0	190	.76	40.6	39.2	27.2	33.6
Flying boats												
B-314	17.7	8.1	4.69	29.3	17.2	1.4	128	0.61	41.0	39.3	24.0	33.6
M-130	16.7	7.8	4.66	22.9	14.4	-1.7	146	.91	34.0	32.9	21.4	31.5

[a]Reference airplane. K = 1.0.

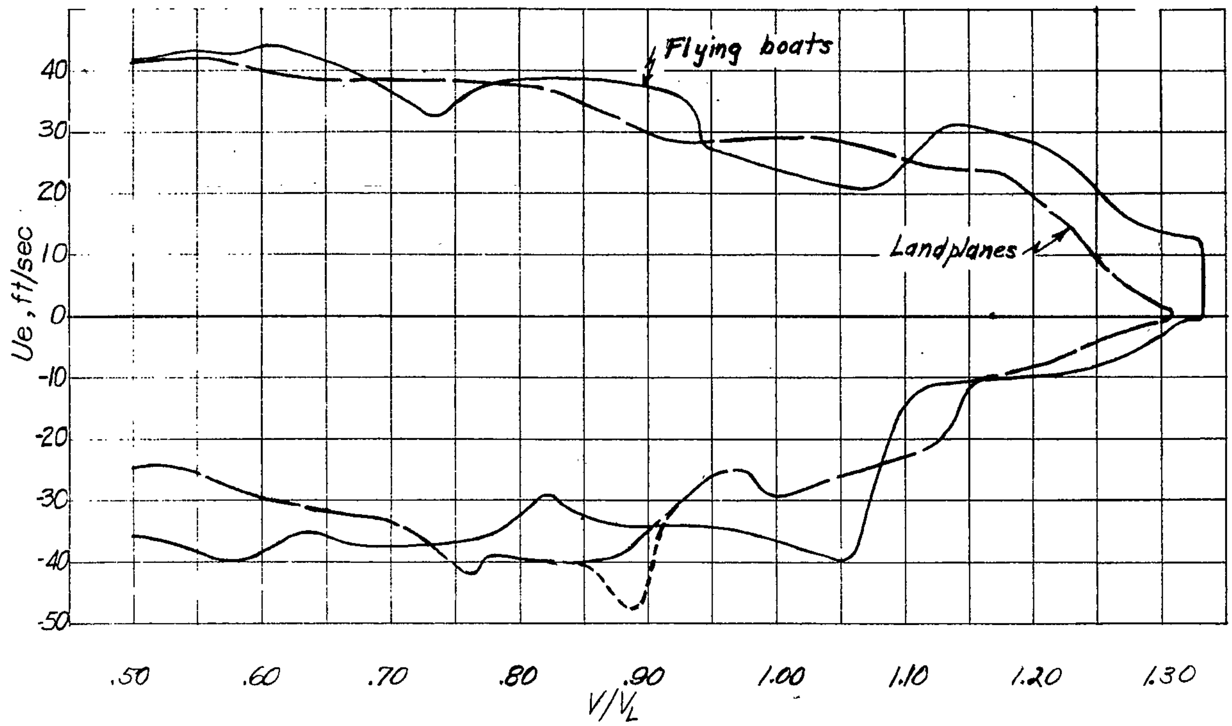

Figure 6.– Effective gust velocities from V-G records.

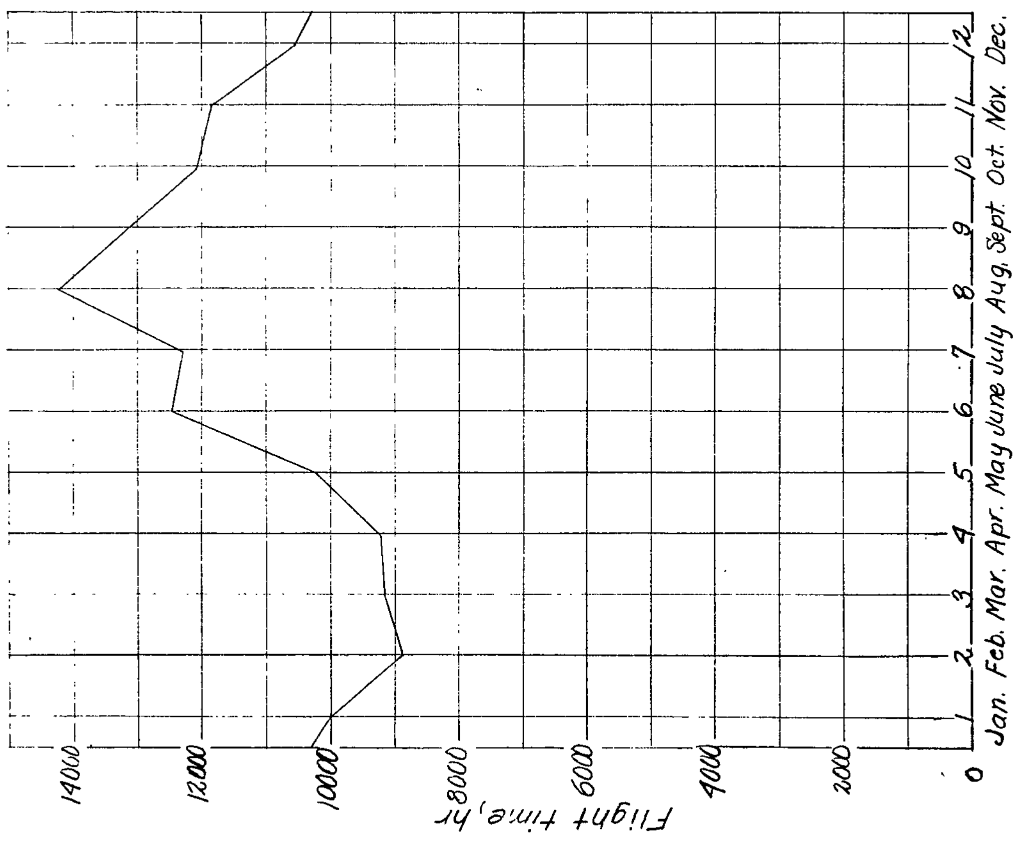

Figure 1.– Monthly distribution of total V-G flight time from October 1932 to April 1942.

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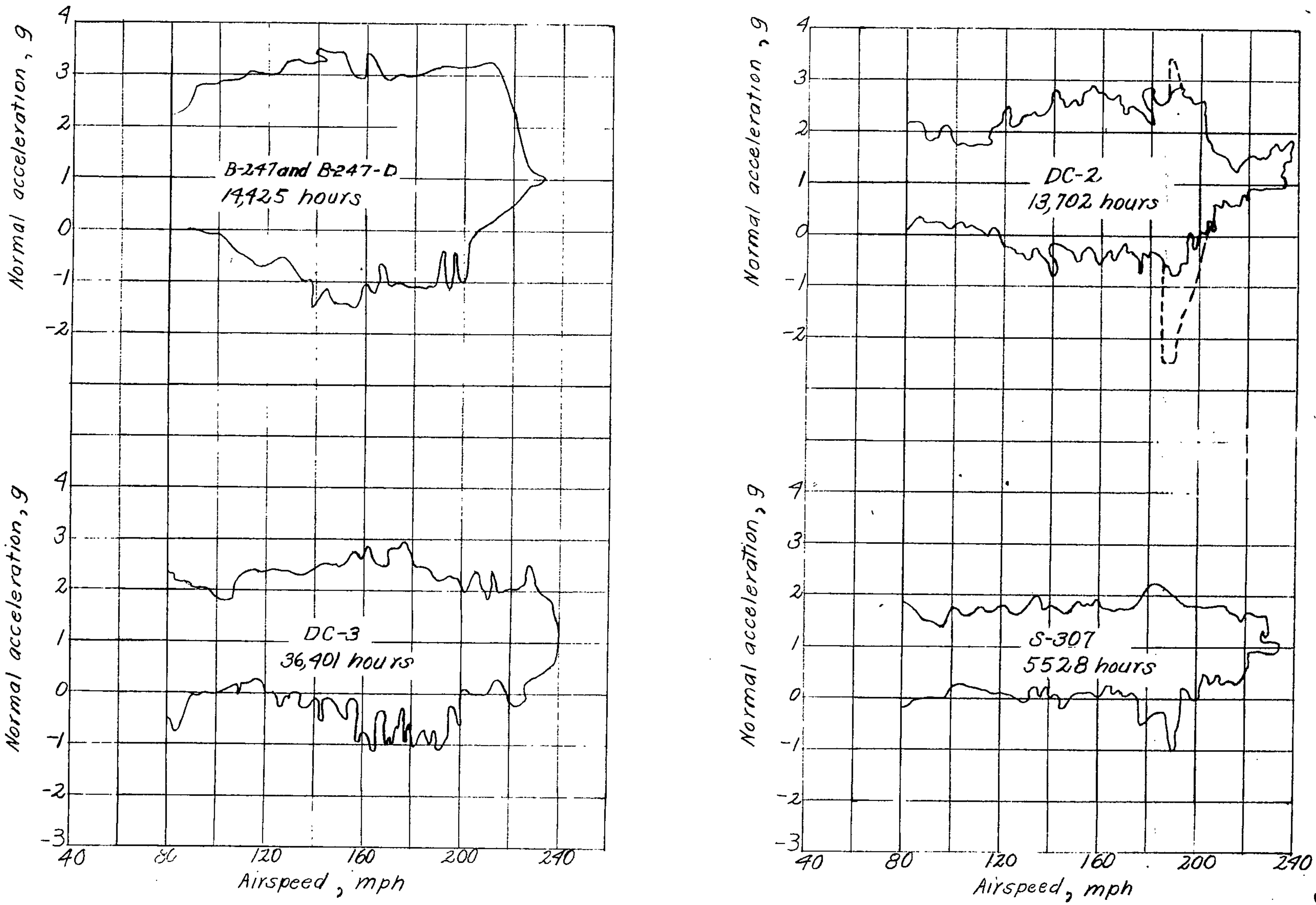

Figure 2.– Composite V-G envelopes for landplanes to April 1942.

Fig. 2

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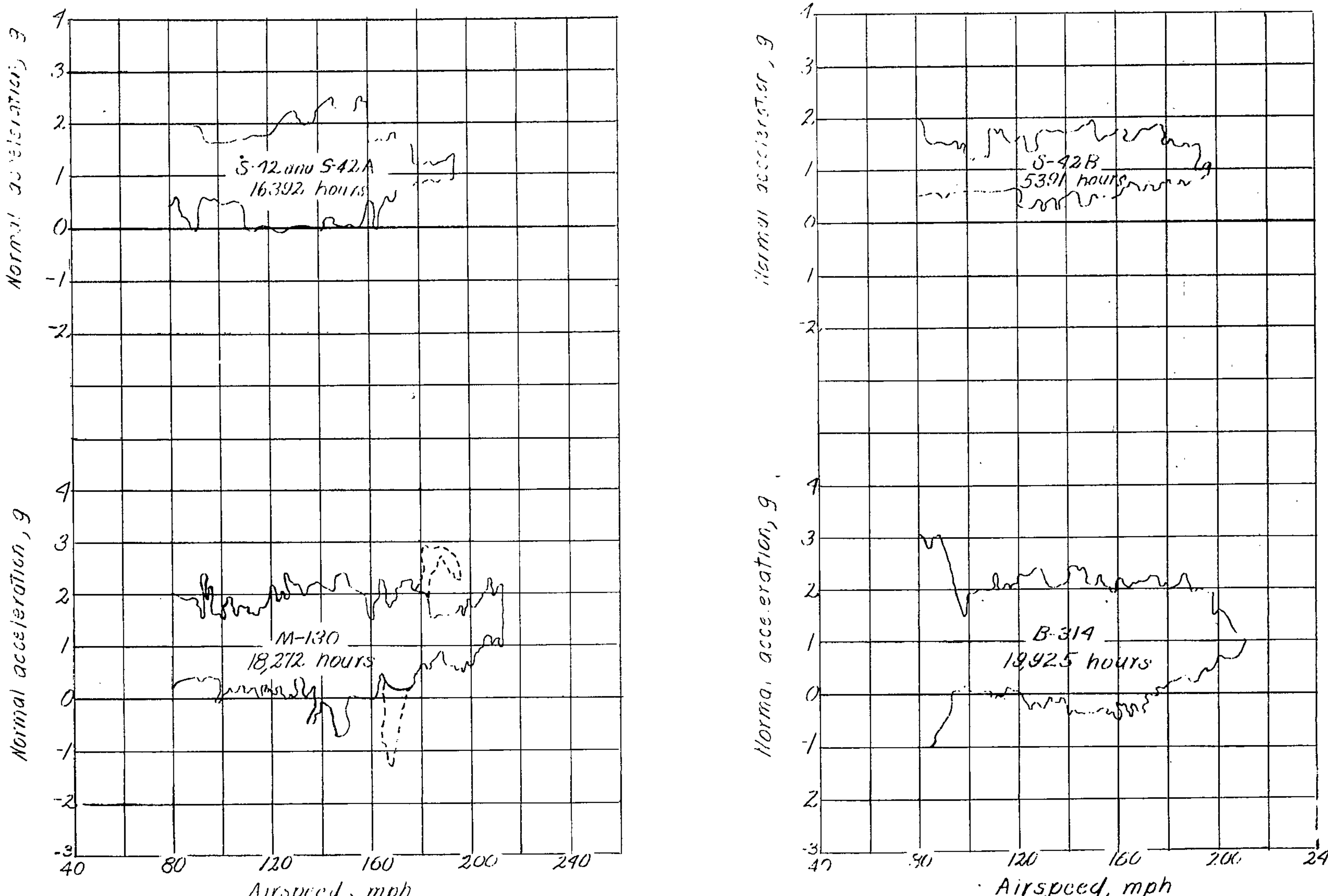

Figure 3.- Composite V-G envelopes for flying boats to April 1942.

Fig. 3

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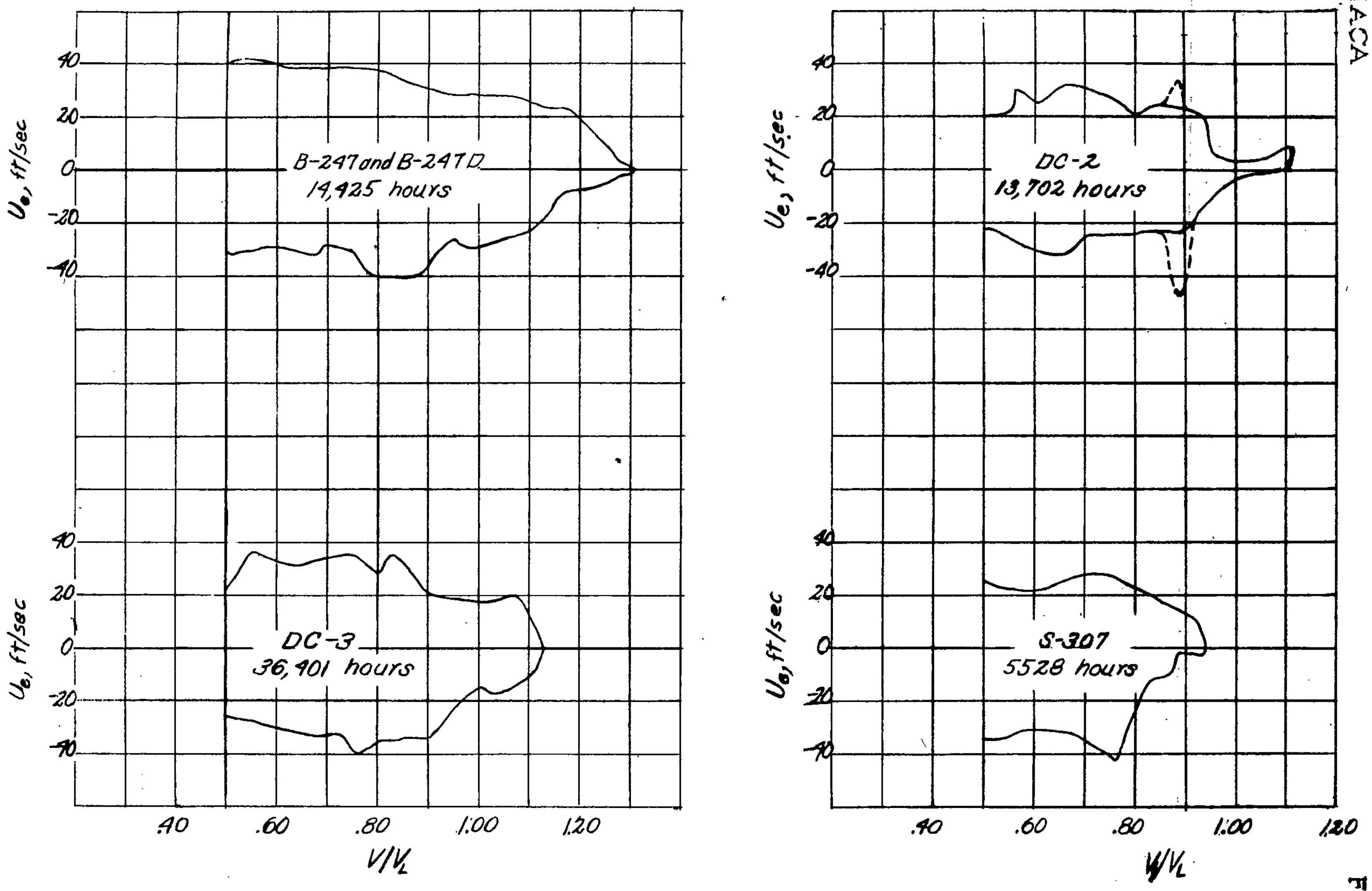

Figure 4.– Maximum effective gust velocities from V-G records for landplanes.

Fig. 4

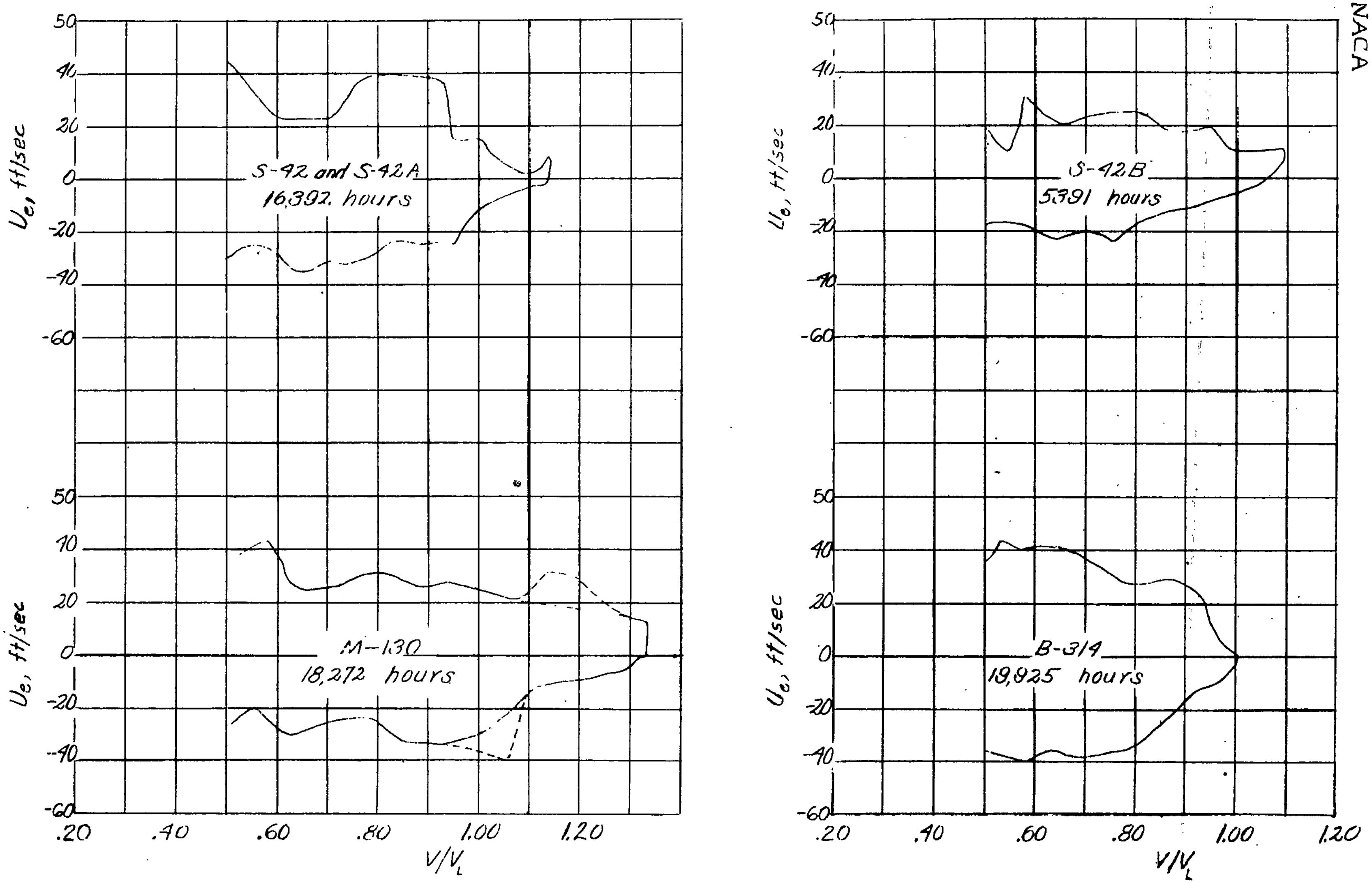

Figure 5.– Maximum effective gust velocities from V-G records for flying-boats.