

Results of research in the field of structural strength limits for sporting gliders

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Introduction

Limits of structural strength for sporting gliders published in 1960 and worked out on the basis of Limits for structural strength for aircraft, 1947, do not meet existing requirements. Consequently, a series of theoretical and experimental investigations in the field of structural strength and its limits in the case of sporting gliders is being carried out.

This article gives a short summary of results obtained in the research that is under way.

Statistical research on g-loadings and atmospheric turbulence in case of sporting gliders

This report gives an account of statistical research in the field of peak g-loadings registered during routine flights of A-11, A-13, KAI-12 "Primorets" and L-13 "Blanik" gliders performed in 1962 during 970 flying hours.

A high probability of surpassing the limits of operational g-loadings by sporting gliders was registered in 1961. In some cases gliders were on the verge of destruction. These were mainly the results of flagrant violations of the existing flying technique regulations, which led to taking certain measures aimed to possible improvement of operational flying technique of sporting soaring pilots.

As a direct consequence of these measures, in 1962 the KAI-12 "Primorets" gliders surpassed the limits of operational g-loadings once in 525 flying hours, while in 1961 it had averaged once in 200 flying hours, and in case of the L-13 "Blanik" glider once in every 90 flying hours.

| | | | | | | | | | |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0,1 | 0,2 | 0,3 | 0,4 | 0,5 | 0,6 | 0,7 | 0,8 | 0,9 | 1,0 |
| 29 | 29 | 8 | 5 | 2 | 3 | 0 | 1 | 1 | 0 |
| 48 | 44 | 22 | 14 | 7 | 3 | 2 | 1 | 0 | 0 |
| - | 5 | 8 | 20 | 14 | 6 | 2 | 1 | 0 | 0 |

Table 2. Number of gusts with gradients of given values.

Gradient W^0 (line 1)
Data of TAGE (line 2)
Data of NACA (line 3)
Data of this paper (line 4)

Thus, the principal conclusion of the research is that probability of exposure to high g-loadings in case of sporting gliders sharply dropped down in 1962 as compared with 1961.

Besides that, the research resulted in finding ratios between the speed of a vertical air gust and its gradient distance:

$$\frac{W}{\dot{\delta}} = W^{\dot{\delta}} \quad (1)$$

Table 3. Frequency of up- and down-gusts (H_t = number per hour; H_L = number per 100 km). Experimental data of 1963 comprising 54.5 flying hours and 2546 route km.

| L_{max} [m] W_{max} [%/сек] | 200 ÷ 400 | | 400 ÷ 500 | | 600 ÷ 800 | | 800 ÷ 1000 | | 1000 ÷ 1200 | | 1200 ÷ 1400 | | 1400 ÷ 16000 | |
|--|-----------|-------|-----------|-------|-----------|-------|------------|-------|-------------|-------|-------------|-------|--------------|-------|
| | H_t | H_L | H_t | H_L | H_t | H_L | H_t | H_L | H_t | H_L | H_t | H_L | H_t | H_L |
| 3,5 ÷ 3,0 | 0,991 | 2,12 | 0,697 | 1,49 | 0,459 | 0,982 | 0,202 | 0,432 | 0,092 | 0,197 | 0,037 | 0,079 | 0,018 | 0,039 |
| 3,0 ÷ 2,5 | 1,40 | 2,98 | 1,01 | 2,16 | 0,660 | 1,41 | 0,385 | 0,825 | 0,220 | 0,471 | 0,129 | 0,275 | 0,073 | 0,157 |
| 2,5 ÷ 2,0 | 4,44 | 9,50 | 2,75 | 5,89 | 1,63 | 3,50 | 0,697 | 1,49 | 0,238 | 0,510 | 0,129 | 0,275 | 0,110 | 0,236 |
| 2,0 ÷ 1,5 | 8,12 | 17,4 | 4,35 | 9,30 | 2,20 | 4,71 | 0,752 | 1,61 | 0,294 | 0,628 | 0,165 | 0,354 | 0,129 | 0,275 |
| 1,5 ÷ 1,0 | 13,1 | 28,1 | 4,90 | 10,5 | 1,87 | 4,00 | 0,579 | 1,45 | 0,404 | 0,864 | 0,220 | 0,471 | 0,073 | 0,157 |
| -1,0 ÷ -1,5 | 10,5 | 22,5 | 3,45 | 7,38 | 1,47 | 3,14 | 0,624 | 1,34 | 0,202 | 0,432 | 0,165 | 0,354 | 0,092 | 0,197 |
| -1,5 ÷ -2,0 | 4,62 | 9,90 | 2,59 | 5,54 | 1,23 | 2,63 | 0,660 | 1,41 | 0,275 | 0,589 | 0,073 | 0,157 | 0,037 | 0,079 |
| -2,0 ÷ -2,5 | 2,20 | 4,71 | 1,23 | 2,63 | 0,770 | 1,65 | 0,422 | 0,903 | 0,220 | 0,471 | 0,092 | 0,197 | 0,037 | 0,079 |
| -2,5 ÷ -3,0 | 0,789 | 1,69 | 0,642 | 1,38 | 0,404 | 0,864 | 0,220 | 0,471 | 0,129 | 0,275 | 0,055 | 0,118 | 0,037 | 0,079 |
| -3,0 ÷ -3,5 | 0,422 | 0,903 | 0,257 | 0,550 | 0,165 | 0,354 | 0,110 | 0,236 | 0,073 | 0,157 | 0,037 | 0,079 | 0,018 | 0,039 |

It is well known that peak g-loading increment resulting from a glider's entry into an up-going vertical gust may be, with precision sufficient for structural strength limits requirements, expressed by the following dependence:

$$\Delta n_{y \max} = W \delta \frac{V}{g} \quad (2)$$

This clearly shows the importance of $W\delta$. Peak $W\delta$ values referred to in this report were theoretically calculated for four different types of gliders.

But the results should be regarded with due caution as it is likely that g-loadings taken as a basis for $W\delta_{\max}$ calculations included a manoeuvre increment.

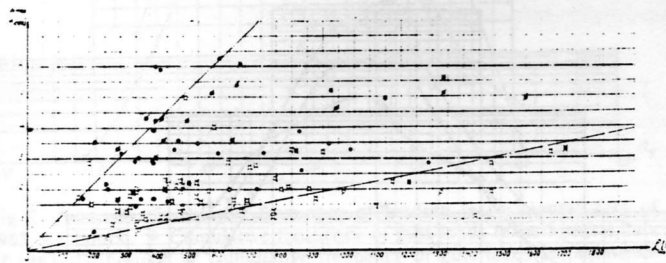


Fig. 1. Flights: ○ 4.9.62. ◐ 5.9.62. ◑ 6.9.62. ● 7.9.62. ◐ 13.9.62. ◑ 14.9.62. Absc.: Gust length (m); Ord.: W_{\max} (m/sec).

Values are presented in Table 1.

Table 1

| Glider | $W\delta_{\max}$ |
|--------------------|------------------|
| A-11 | 0.6 |
| A-13 | 0.93 |
| KAI-12 "Primorets" | 1.25 |
| L-13 "Blanik" | 0.8 |

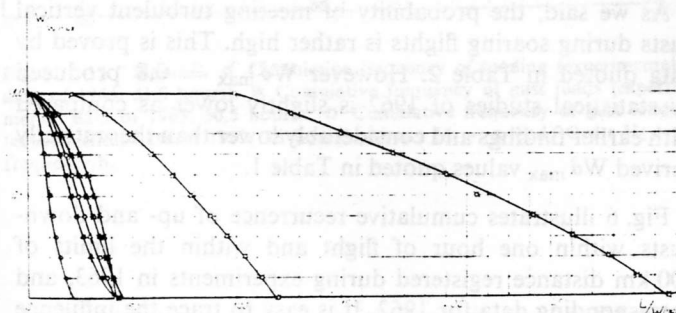


Fig. 2. Data of this paper: ○ narrow gusts; ◐ normal gusts; ◑ broad gusts. Carmichael thermals: ● strong thermals, $W_{\max} = 6.2$ m/sec; ● weak thermals, $W_{\max} = 3.1$ m/sec; ◐ wide thermals, $W_{\max} = 4.6$ m/sec. Results of Polish research: ×, $W_{\max} = 3$ m/sec. Absc.: L/W_{\max} ; Ord.: W/W_{\max} .

Study of g-loadings affecting a glider within up-gusts and structural strength limits for sporting gliders

Studies of up-going air gusts and their influence on glider's g-loadings were conducted in the years of 1962-1963 with A-11 and L-13 "Blanik" gliders. The research was aimed at working out recommendations as to optimum structural strength limits for sporting gliders and the technique of soaring flights.

The results are given in the two main parts of the present report accounting for two principal fields of studies.

Study of thermal up-gusts and their structure

In September 1962 there was conducted a flight experiment during which 250 up-gusts were studied with 114 of them thoroughly analyzed later.

Fig. 1 illustrates so-called peak characteristics of up-gusts: their maximum vertical speed W_{\max} and their full distance L_{\max} . As expected, dependence between them was not simple. This led to classifying all up-gusts into

- narrow gusts ($L_{\max}/W_{\max} \leq 100$);
- normal width gusts ($100 < L_{\max}/W_{\max} < 500$);
- broad gusts ($L_{\max}/W_{\max} \geq 500$).

General characteristics of distribution of vertical velocity within a gust section were ascertained. The findings confirm (statistically, of course) a hypothesis of axial symmetry of up-gusts. Besides, we discovered the existence of cores in up-gusts, i. e. the central part of a gust having (excluding slight pulsations) constant vertical velocity equal to W_{\max} .

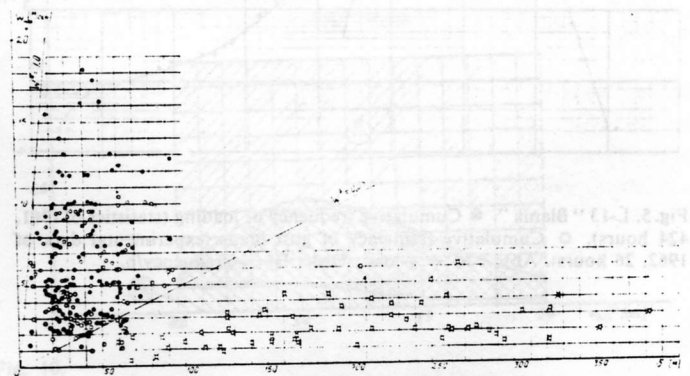


Fig. 3. ○ TAGE experiments; ● NACA experiments; ◑ experiments here reported. Absc.: δ (m); Ord.: W_{\max} (m/sec).

Fig. 2 presents relative values of these general characteristics for vertical velocity distribution (due to symmetry, only half is shown) as compared with data of US and Polish researchers. It can be seen that gusts studied by us were much broader (only our narrow gusts correspond to

the foreign data quoted), but the basic law for the distribution of velocity outside the core seems to be in compliance with US findings. Neither US nor Polish research discovered the existence of the core which was probably due to insufficient width of gusts taken for analysis.

However, it should be noted that, as we shall see further, the probability of meeting turbulent vertical gusts during soaring flights is rather high.

Statistics of routine operation

Statistical data on up- and down-gusts and g-loadings affecting gliders within then were recorded in April–September 1962 and in June–August 1963.

The recurrence of purely “air-bump” g-loadings is of great significance for working out structural strength limits for sporting gliders.

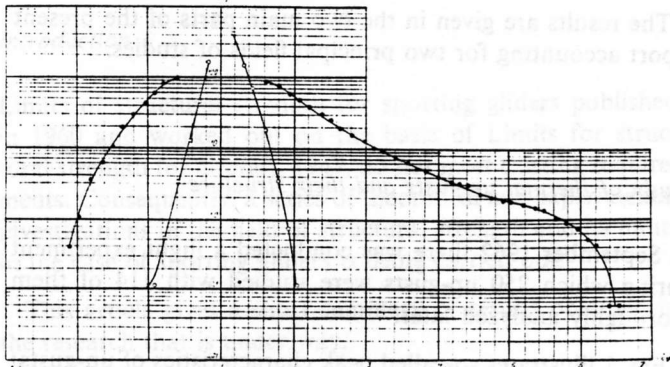


Fig. 4. A-11. ● Cumulative frequency of loading (statistics of 1961, 15,5 hours). ○ Cumulative frequency of gust loads (experimental data of 1962, 19 hours). Absc.: M = g-load; Ord.: H_t = frequency/h.

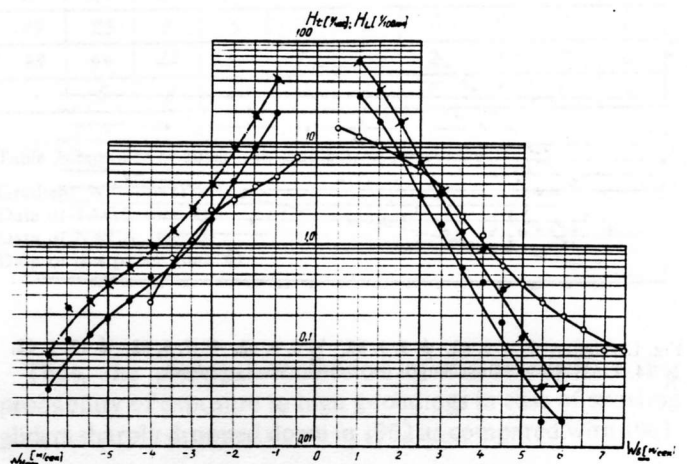


Fig. 6. ● Frequency of gusts per 100 km flown (experimental data of 1962, 2546 km). ● Frequency of gusts per hour of flight (experimental data of 1963, 54,5 hours). ○ Frequency of gusts per hour of flight (experimental data of 1962, 45,0 hours). Absc.: W_{max} (m/sec); Ord.: H_t = frequency/h, H_L = frequency/100 km.

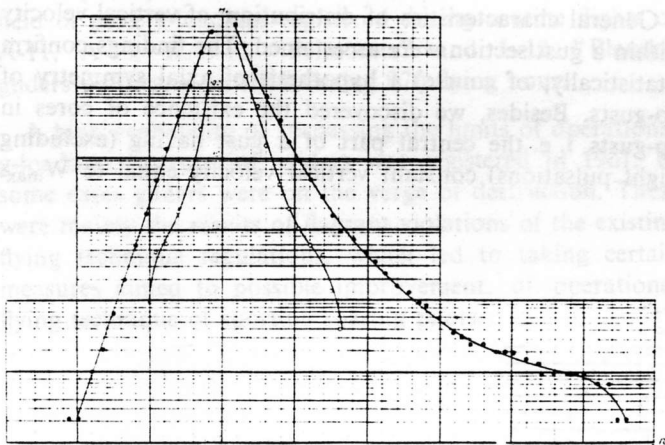


Fig. 5. L-13 “Blanik”. ● Cumulative frequency of loading (statistics of 1961, 424 hours). ○ Cumulative frequency of gust loads (experimental data of 1962, 26 hours). Absc.: M = g-load; Ord.: H_t = frequency/h.

The described up-gusts, being large scale vertical displacement of air masses, that are used by gliding pilots to gain altitude, are of almost no practical interest as far as structural strength limits of sporting gliders are concerned. This assertion is proved by Fig. 3 citing our findings as compared with NACA experimental data. NACA gives $W\delta_{\max} = 1$, our findings produce the result of $W\delta_{\max} = 0.05$.

Considering expression 2, we notice that thermal up-gusts used by gliding pilots to gain altitude result in g-loadings that are considerably lower than in the case of turbulent gusts.

Fig. 4 presents cumulative recurrence of these “pure air-bump” g-loadings as compared with general cumulative recurrence of g-loadings for A-11 gliders during the statistical research carried out in 1961. Fig. 5 presents the same values in case with the L-13 “Blanik” glider.

As we said, the probability of meeting turbulent vertical gusts during soaring flights is rather high. This is proved by data quoted in Table 2. However $W\delta_{\max} = 0.8$ produced by statistical studies of 1962 is slightly lower as compared with earlier findings and considerably lower than theoretically derived $W\delta_{\max}$ values quoted in Table 1.

Fig. 6 illustrates cumulative recurrence of up- and down-gusts within one hour of flight and within the limits of 100 km distance registered during experiments in 1963, and corresponding data for 1962. It is easy to trace the influence of subjective factors on the picture of these recurrences. More experienced pilots who took part in 1962 experiments assured asymmetrical recurrences in favour of up-gusts, while the data for 1963 give an approximately symmetrical picture of up- and downward gusts.

However, we are much more interested in this recurrence from the point of view of gust peak characteristics (maximum vertical velocity and full gust distance). This can be ascertained on the basis of 1963 studies. Table 3 shows cumulative recurrences of both peak characteristics commonly met with in up- and downward gusts which were registered during one hour of flight and within 100 km distance.

Studies of landing loads affecting a glider with regard to more precise structural strength limits

This report studies the landing shock and distribution of its energy between a glider's structural elements. The research was carried out theoretically by means of integration of simultaneous differential equations illustrating vibrations in different structural elements of a glider at landing. Generally speaking, the equations are non-linear, though in this case they are linearized as the studies were conducted from the

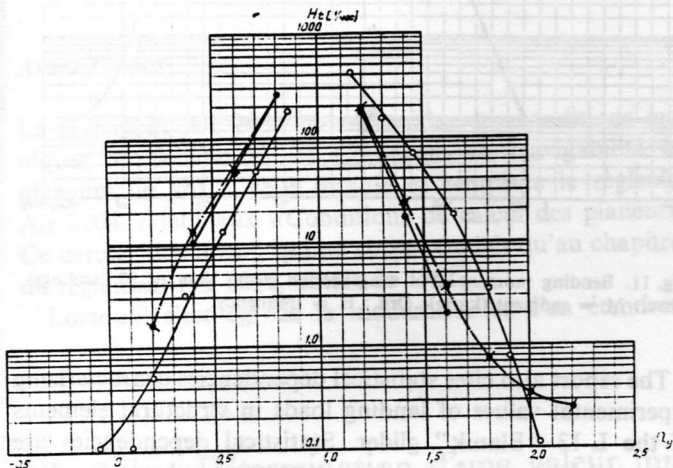


Fig. 7. A-11. ● Cumulative frequency of loading (experimental data of 1963, 4.1 hours). ● Cumulative frequency of gust loads (experimental data of 1963, 4.0 hours). ○ Cumulative frequency of gust loads (experimental data of 1962, 19.0 hours). Absc.: M = g-load; Ord.: Ht = frequency/h.

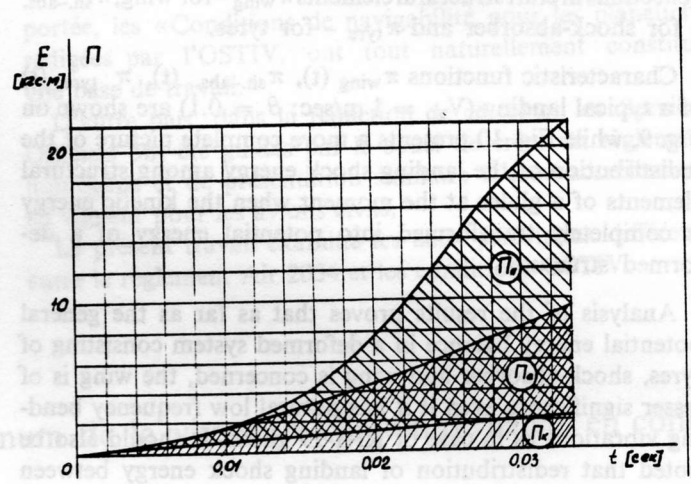


Fig. 9. L-13 "Blanik". $V_{y0} = 1 \text{ m/sec}$; $\beta = 0.1$. t (secs); E (kg. metres). Standard E. $\bar{\pi}_{\text{fl}} = \bar{\pi}_{\text{eye}}$; $\bar{\pi}_a = \bar{\pi}_{\text{sh. abs.}}$; $\bar{\pi}_k = \bar{\pi}_{\text{wing}}$. Absc.: t (sec); Ord.: E (kg. m)

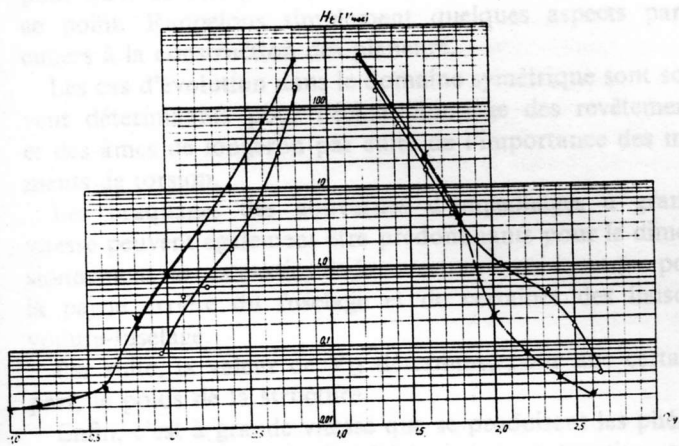


Fig. 8. L-13 "Blanik". ● Cumulative frequency of loading (experimental data of 1963, 51.0 hours). ● Cumulative frequency of gust loads (experimental data of 1963, 50.5 hours). ○ Cumulative frequency of gust loads (experimental data of 1962, 26 hours). Absc.: M = g-load; Ord.: Ht = frequency/h.

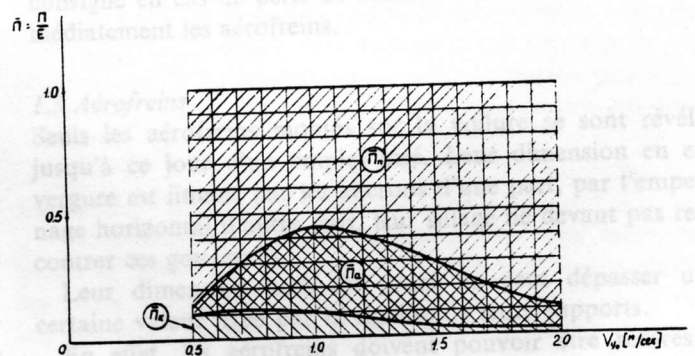


Fig. 10. L-13 "Blanik". $\beta = 0.1$. $\bar{\pi}_{\text{fl}} = \bar{\pi}_{\text{eye}}$; $\bar{\pi}_a = \bar{\pi}_{\text{sh. abs.}}$; $\bar{\pi}_k = \bar{\pi}_{\text{wing}}$. Absc.: V_g (m/sec); Ord.: $\bar{\pi} = \frac{\pi}{E}$

The 1963 studies went on with analysis of g-loadings in up- and downward gusts. Cumulative recurrences recorded in 1963 experiments and the corresponding data from 1962 are illustrated by Fig. 7 and 8 for A-11 and L-13 "Blanik" gliders respectively.

point of view of statistical analysis aimed to improve the precision of structural strength limits for sporting gliders. Linearization of the equation makes it possible to represent their solution in quadratures. They are solved by the operational method.

Variable parameters (vertical velocity at touchdown V_{y0} , and load coefficient β) used for the calculations were ascertained during landing load tests with sporting gliders. The experiments were conducted within the framework of the present report. The results show that both pancake and fast landings are a daily routine, and that vertical velocity at touchdown does not exceed the values prescribed by the structural strength limits for sporting gliders.

Calculations on the basis of L-13 "Blanik" and KAI-19 gliders defined characteristic changes of potential energy of deflections in craft structural elements π_{wing} - for wing, $\pi_{sh.-abs.}$ - for shock-absorber and π_{tyre} - for tyres.

Characteristic functions $\pi_{wing}(t)$, $\pi_{sh.-abs.}(t)$, $\pi_{tyre}(t)$ of a typical landing ($V_{y0} = 1$ m/sec; $\beta = 0.1$) are shown on Fig. 9, while Fig. 10 presents a more complete picture of the redistribution of the landing shock energy among structural elements of a glider at the moment when the kinetic energy is completely transformed into potential energy of a deformed structure.

Analysis of the results proves that as far as the general potential energy balance in a deformed system consisting of tyres, shock-absorber and wing is concerned, the wing is of lesser significance even if it has natural low frequency bending vibrations as in case of KAI-19 glider. It should also be noted that redistribution of landing shock energy between tyres and shock-absorber at the moment when the kinetic energy is completely transformed into potential energy of a deformed system, is greatly dependent on V_{y0} and β values. The dependence is not simple.

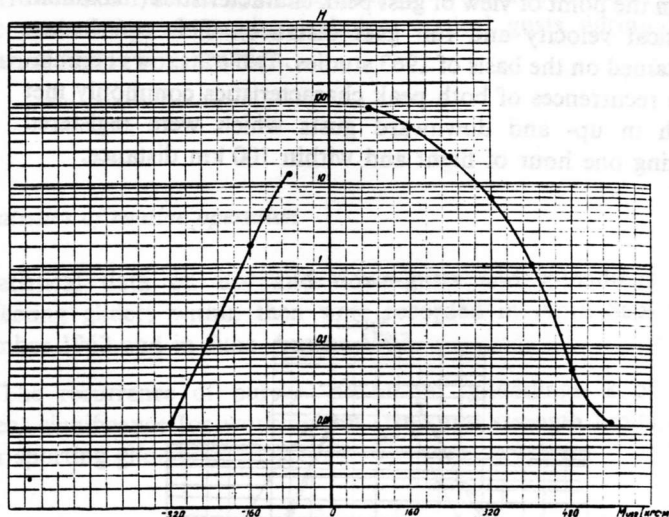


Fig. 11. Bending moment at a wing section (from data of 92 landings). Absc.: $M =$ moment (kg/m); Ord.: $H =$ frequency.

The report also cites statistical dependencies characterizing experimental values of landing loads in structural elements of the L-13 "Blanik" glider. Statistical dependencies are presented in form of cumulative recurrence charts for peak bending moment values for three wing sections and forces affecting a shock-absorber strut (see Fig. 11).

The mentioned dependencies can be used as basic data for determining the resources of L-13 "Blanik" glider.

(Swiss Aero-Revue 3/1966)