GUST LOADS ON GLIDERS TAKING INTO ACCOUNT THEIR FLEXIBILITY

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INTRODUCTION

The paper presents both the theoretical and the experimental results derived in (Ref. 1) concerning the flexibility effects on the loads of elements of given construction under the assumption of the random character of their excitations.

Here we are interested in the aeronautical aspects of these problems (precisely: sailplane aspects). Certain general problems were extended and described in (Ref. 2), nevertheless, it would be seen that we should give here some results of (Ref. 2).

THE CHANGES OF SAMPLE FUNCTIONS

The structural flexibility leads to the important changes in the load sample functions. The last one describes load history (in time or in space) at a given point in the structure. These effects are seen clearly if we compare either loads acting on the same element of the "flexible version" and "rigid version" of the glider (it's so called "global pair") or loads acting on two elements of the "flexible version" - called "local pair" - of the glider.

What are the differences between the two sample functions? Broadly speaking, we can see (fig. 1):

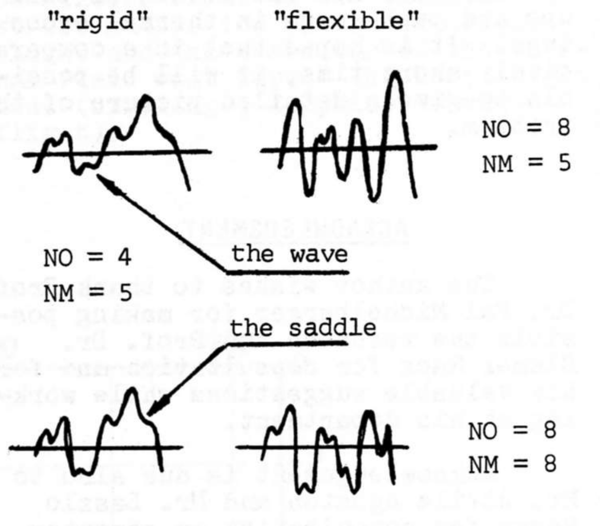

Figure 1

(1) changing scale of ordinate and
(2) changing scale of abscissa, which constitute a change in quantity;
(3) changing smoothness, which is a change in quality.

The pairs of the numerical characteristics σ , NO i.e. the variance σ and the mean value of number of zeros NO are involved in measuring the quantity effects.

The smooth sample function, as a function with neither wave nor saddle will be understood from fig. 1. Roughly speaking, it follows that every two zeros are united with a single peak. Thus, the other pair of the numerical characteristics - NO, NM (where: NO is the number of zeros as previously, and NM the number of peaks) as a measure of the smoothness of the sample function is valuable; for another measure see: (Ref. 2)).

The gust loads under consideration are described in a unique way by the one-dimentional stationary and gaussian random function (see (Ref.(3), (Ref. 6)). It is easy to see that every mean value which was introduced follows from $\Psi_2(k)$ the power spectrum of the random function considered (see (Ref. 4)).

Thus, the variance of the random function is given by:

$$\sigma_2 = \int_0^\infty \Psi_j(k)\, dk \tag{1}$$

where: k a frequency the mean number of zeros by:

$$NO_2 = \frac{1}{\pi}\left(\frac{\int_0^\infty k^2\Psi_j(k)\, dk}{\sigma_j}\right)^{\frac{1}{2}} \tag{2}$$

and the mean number of peaks by:

$$NM_2 = \frac{1}{2\pi}\left(\frac{\int_0^\infty k^4\Psi_j(k)\, dk}{\int_0^\infty k^2\Psi_j(k)\, dk}\right)^{\frac{1}{2}} \tag{3}$$

It is well known that the power spectrum of gusts $\emptyset$ (k) and the transfer function of the j-th point of the glider $T_j(ik)$ are sufficient to define of the power spectrum of loads $\Psi_j(k)$ by:

$$\Psi_j(k) = \phi(k)\,|T_j(ik)|^2 \tag{4}$$

The power spectrum of gusts $\emptyset$ (k) contains all the information about the random function of the vertical atmospheric gusts; on the other hand, the transfer function $T_j(ik)$ contains all the information about the dynamic properties of the flexible construction. The latter is very laborious and difficult to determine and it had to be obtained by use of the digital computer.

Finally, numerical characteristics as given by formulas (1), (2), and (3) were computed (see Tab. 1) for the "Foka" and "Zefir" sailplanes.

On the base of the numerical results derived the following conclusions might be possible.

Two kinds of change were observed -

<u>the strong changes</u>: we could see great numerical values and a monotone character (a decrease as well as an increase is possible);

<u>the weak changes</u>: we could see a comparatively smaller values and nonmonotonic character (a decrease as well as an increase is possible).

It should be emphasized that the global pairs in the presented analysis of the effects of flexibility play the main role.

For the local pairs it can be noted, that in general, the observable changes form a weak version of the effects which we can see within the global pairs. In a set of global pairs, strong changes as well as weak are possible.

<u>The strong changes within global pairs</u>:

(a) the change of zeros

TABLE 1

	A Centre of Grav.				A Middle of Half-Span			
	Foka		Zefir		Foka		Zefir	
	rigid	flexible	rigid	flexible	rigid	flexible	rigid	flexible
NO	4.1	9.8	3.0	10.5	4.1	20.5	3.0	22.9
NM	14.8	20.0	16.0	17.7	15.9	19.5	16.0	29.0

The data concerned to about 20 km flight's path.

the change in direction from "rigid version" to "flexible version" is great - we can see an increase of zeros up to about 7-times;

(b) the change of the smoothness measured by the ratio of the number of peaks to the number of zeros

the observable ratio is great too - and we can see the values equal to about 5.

The weak changes within global pairs contain the variance change. In comparison with the values applicable to the "rigid version", every value of variance which is obtained for the "flexible version" belongs to the interval (-13%, 85%), however, the root mean square variations belong to the interval (-8%, 35%).

THE CHANGE OF LOAD STATISTICS

The words "load statistics" are used as a shorter synonym of the mean number of crossings of the given values of the load with a positive slope.

Where the function is derived by experiment (see: (Ref. 5), (Ref. 3)) it is denoted by $M^e(a)$, and where it is found by use of the theoretical tools (see: (Ref. 3), (Ref. 7) it is denoted as $M^t(a)$.

The change of the load statistics within a global pair as well as a local pair is apparent. We consider the flexibility effects to be the unique source of this change.

We will see that the change of the load statistics is uniquely determined by the change of the numerical characteristics which were defined by (1) and (2). Therefore, below we will give the expression, which determined the theoretical load statistics in this way.

We suppose, that σ_j the variance, and NO_j the number of zeros of j-th point of the glider, and $M^e_j(a)$ the experimental load statistic connected with j-th point are given; and in addition, let σ_r and NO_r be given (they are playing a similar role for the r-th point of the same or of the other glider). Then, $M^t_r(a)$ i.e. the theoretical load statistic of the r-th point follows from the formula:

$$M^t_r(a) = \frac{NO_r}{NO_j} M^e_j\left(\left(\frac{\sigma_j}{\sigma_r}\right)^{\frac{1}{2}}\right) \qquad (5)$$

The changes of the load statistics follow uniquely from the previous discussion of the change of the sample function.

The changes within the global pairs

It was shown above that we have both, the strong change (of the number of zeros), and the weak change (of the variance). It follows that two different types of the changes of the load statistics are possible as shown on the fig. 2:

case "a" we see an increase in the number of zeros and the variance,

case "b" the increasing number of zeros is accompanied by decreasing variance.

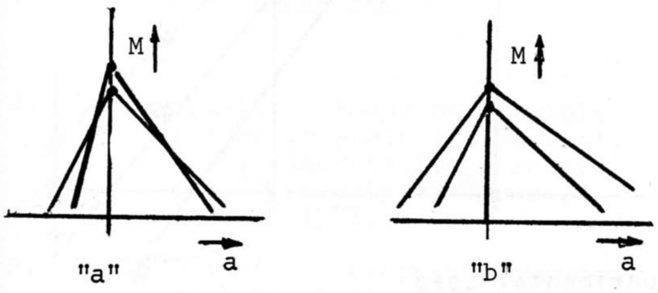

Figure 2

The changes within the local pairs

Comparing the data obtained for the points at the middle of the half span of the "Foka" and "Zefir" sailplanes with the data for the c.g., it can be seen that for both gliders

> the number of zeros increased by about 200%, and the variance increased by from 20% to 80% - thus we can see that this case is like case "a" on fig. 2 (see: (Ref.7)).

EXPERIMENTAL AND THEORETICAL RESULTS

The Department of Flight Mechanics at the Technical University of Warsaw in the years 1956-64 has been occupied with collecting experimental data concerning flight loads on gliders, first of all in thermal flights under clouds. The material has been published currently (see: (Ref. 5), (Ref. 3). The results which were obtained at that time were reevaluated and included in (Ref. 1). One of these results is given in fig. 3 and shows the experimental load statistics of three types of glider. It was obtained on the basis of a rather small number of recording hours (for comparison the results were converted to 100 hours of flight). It is easy to see (compare (Ref. 3) - for example) that the scatter of the data may be larger than the differences between the values for the three types of glider. This tends to weaken the argument under discussion.

In fig. 4 are shown, together, $M^e(a)$ the experimental load statistics at the c.g. of the "Foka" and the theoretical load statistics for the c.g. of the "Zefir" $M^t_1(a)$ and for the point at the middle of the half-span of the "Foka" $M^t_2(a)$. They were obtained on the basis of the foregoing considerations and the previously mentioned numerical results.

Thus, the theoretical load statistics shown on fig. 4 tend to support the doubtful experimental results shown on fig. 3.

CONCLUSION

The discussion and results under consideration may be applied briefly to the fatigue life problems which are always present in practice. We know that the part played by gust loads in the overall picture of the loads acting on any sailplane is great (see: (Ref..8)).

The methods considered may be easily extended to analysis and computation of ground loads which occur during the take-offs and landings.

In these two cases, given a knowledge of the deterministic model

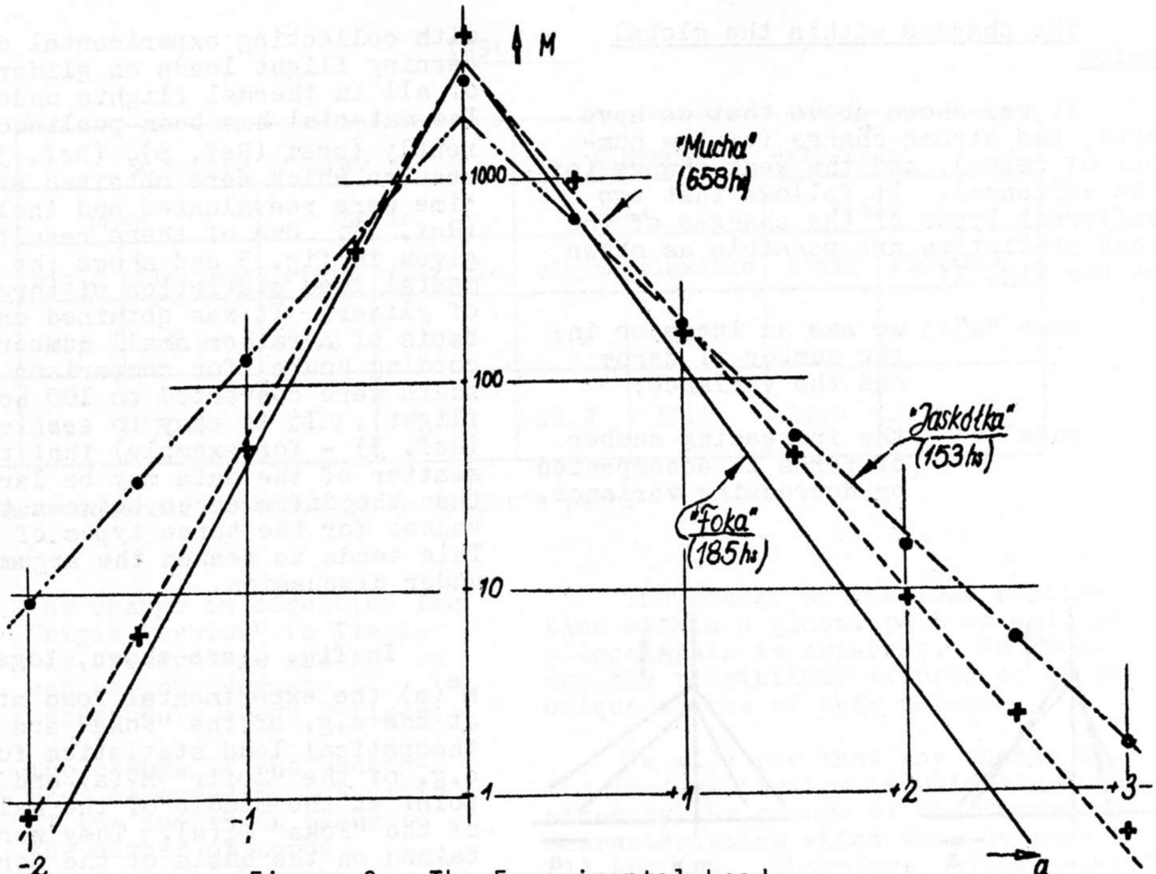

Figure 3. The Experimental Load Statistics (for c.g.)

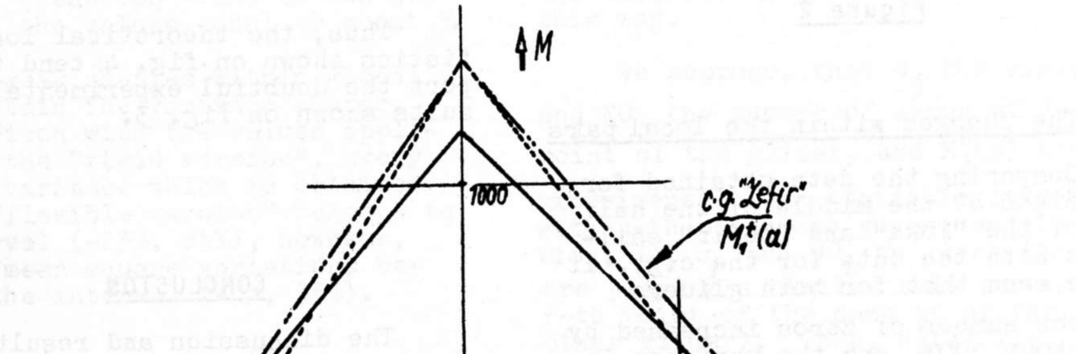

Figure 4. The Theoretical Load Statistics

of the dynamic properties of the glider design, we should have a realistic model of the influences. Fortunately, they have a universal character, but, unfortunately, we are still a long way from the moment when they have been collected.

This work could be fruitfully continued in the direction of the possibility of determining load sample functions by the use of the digital computer. In turn these might be used as an input to the machine programming the fatigue loads.

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