Research in frequencies and natural oscillation modes in sporting gliders

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Presented at the 11th OSTIV Congress at Leszno

I. Testing Technique

Frequencies of natural oscillations in sporting gliders are determined by resonance testing. When recording frequencies and modes of natural (to be more exact, resonant) oscillations in an aircraft one should at the same time register its convergent oscillations. Convergent oscillations of an easily induced frequency usually present no difficult problem as far as their recording is concerned.

If we induce oscillations of a higher frequency into a structure and then instantly remove the disturbing force, they will quickly turn into oscillations of a lower frequency that are easier to induce. It is very seldom that convergent oscillations of several different frequencies may be induced into the same structure. However, one of the strutures tested yielded easily enough vibro-records of convergent oscillations of the four frequencies of 97 osc/min,/120 osc/min, 128 osc/min and 182 osc/min. To produce vibro-records for convergent oscillations of as many frequencies as possible must represent one of the aims of the tests.

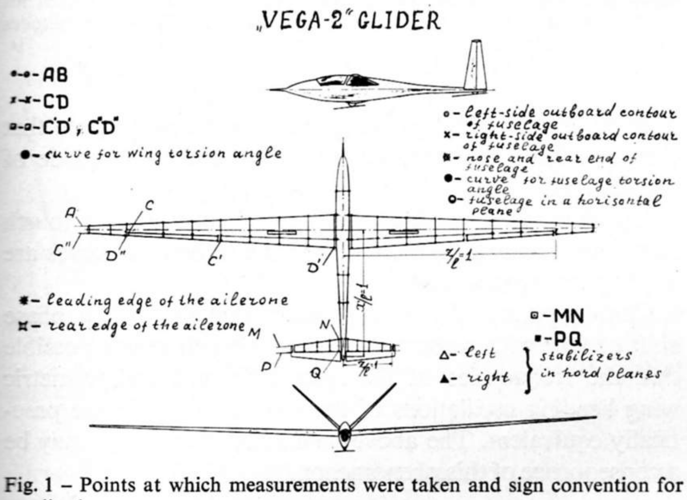

Fig. 1 – Points at which measurements were taken and sign convention for amplitude curves

A glider under test should be placed on an elastic suspension so that the frequency of its natural oscillations along the vertical axis is as low as possible. The same stipulation is valid and can be easily complied with in respect to the remaining five frequencies of natural oscillations in a glider as a suspended solid. Sporting gliders due to their small weight can do with a simpliest form of suspension, i.e. shock-absorber cord. In this case the frequency of the natural oscillations may be brought down to 40 osc/min.

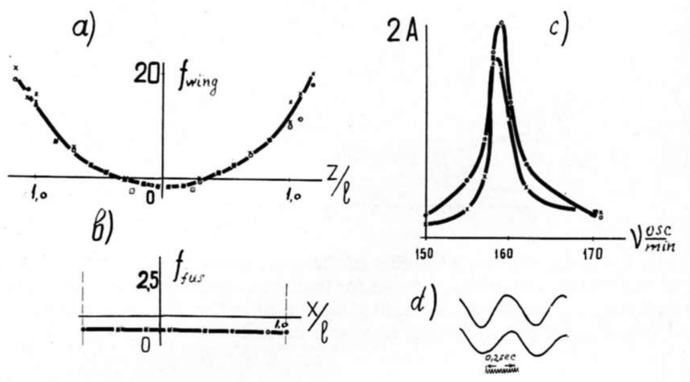

Fig. 2 – Symmetric wing fundamental bending, $\upsilon = 158$ osc/min: a) curve for wing amplitudes and stabilizer tip amplitudes (in mm, as in all other diagrams); b) fuselage amplitude curve; c) wingtip resonnance curves; d) oscillogram for wingtip points

II. Glider oscillation modes

1. Specific features of glider oscillation modes

Frequency characteristics of sporting gliders are distinguished by a number of specific features.

Of special interest are oscillation modes occurring in butterfly tail gliders. Under certain conditions the tail oscillates in and perpendicular to chord planes simultaneously. It is as if the resulting oscillations in each half of such a tail were formed of oscillations that would occur in the projections of this half on a horizontal plane and a vertical plane

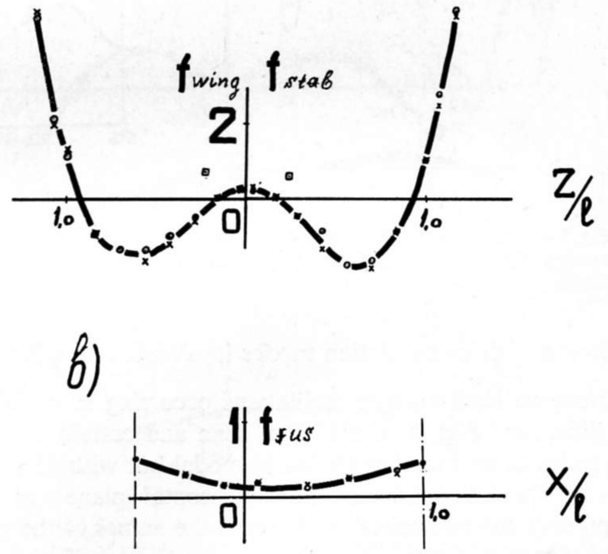

Fig. 3 – Symmetric wing bending of the second harmonic, $\upsilon = 535$ osc/min: a) curve for wing and stabilizer tip amplitudes, b) fuselage amplitude curve

of the outboard fuselage contour line along which the tail is fixed. Thus, antisymmetric wing bending oscillations of the second tone in «VEGA-2» glider with the wingspan of

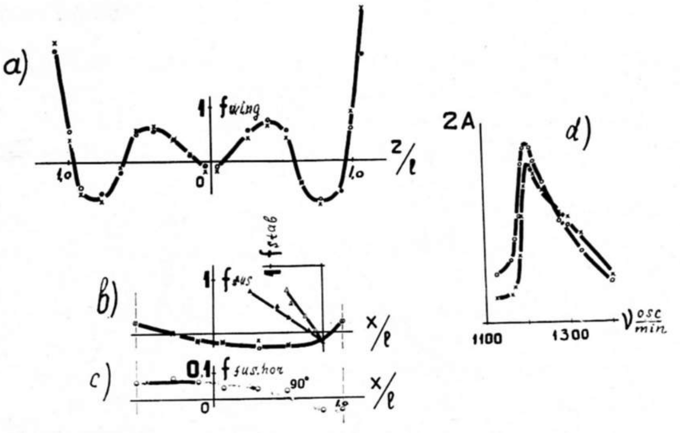

Fig. 4 – Symmetric wing bending of the third harmonic, υ=1210 osc/min: a) wing amplitude curve; b) curves for fuselage amplitudes in a vertical plane and stabilizer amplitudes in chord planes; c) curve for fuselage amplitudes in a horizontal plane; d) wingtip resonance curves.

17.5 m (see Fig. 7) result in both halves of the tail oscillating in their planes in phase opposition to each other and perpendicular to chord planes.

Identical tail oscillations but of a much higher frequency were registered in the same glider with the wingspan of 15 m when its wings experienced antisymmetric bending oscillations of the second harmonic (see Fig. 8).

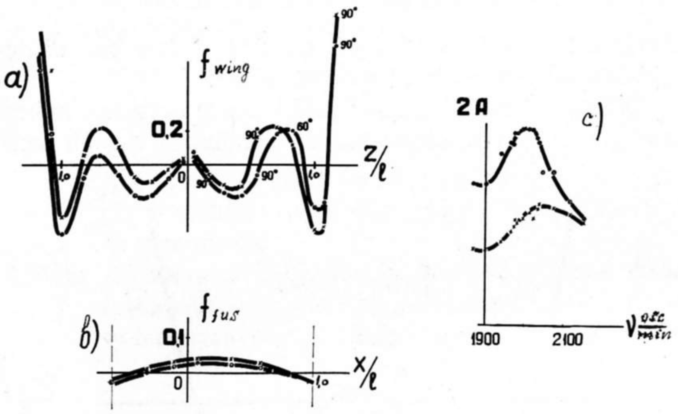

Fig. 5 – Symmetric wing bending of the fourth harmonic, υ=2010 osc/min: a) wing amplitude curves; b) fuselage amplitude curves; c) wingtip resonance curves

2. Analysis of oscillation modes in «VEGA-2» glider

Now we shall analyse oscillations occurring in «VEGA-2» glider (see Fig. 1) with 17.5 m span and certain oscillation modes to be found in the same model but with 15 m span.

If oscillations occur in a horizontal plane (or chord planes) due references are made in the names of the respective modes. Otherwise, it is assumed that oscillations take place in vertical direction (or perpendicular to chord planes).

Symmetric wing bending oscillations of the fundamental (see Fig. 2) are characterized by the fact that the fuselage and tail oscillate as absolutely rigid structures. Wings would probably oscillate with the same frequency and in the same mode if the entire mass of the fuselage and tail were concentrated at the centreplane part of the body.

Under symmetric wing bending oscillations of the second harmonic (see Fig. 3), the fuselage undergoes certain deformation though still following the centreplane parts of the wings. This points to the fact that the frequency of vertical fuselage bending oscillations is higher than the frequency of the mode discussed. Tail tips follow the end of the fuselage, thus revealing that the frequency of their bending oscillations is also higher than the one discussed.

Under symmetric wing bending oscillations of the third harmonic at 1210 osc/min (see Fig. 4), the ends of the fuselage start lagging behind the centreplane parts of the wings. This indicates that the frequency of vertical fuselage bending oscillations must lie below 1210 osc/min. Reson-

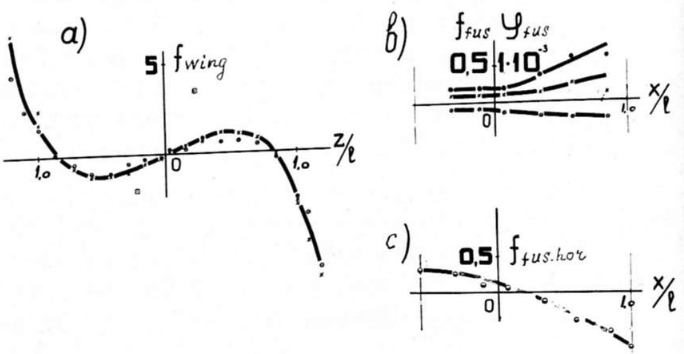

Fig. 6 – Antisymmetric wing fundamental bending, υ=350 osc/min: a) curve for wing amplitudes and stabilizer tip amplitudes; b) curves for amplitudes and angles of fuselage torsion; c) curve for fuselage amplitudes in a horizontal plane

ance curves for wingtips are given here to demonstrate that they still have well-pronounced peaks under this mode of oscillations.

Under symmetric wing bending oscillation of the fourth harmonic (see Fig. 5), the peaks in the resonance curves are already less pronounced.

Certain points of the right wing oscillate with a phase shift of 90 ° with respect to the left wing. It seems possible that the frequencies of the symmetric and antisymmetric wing bending oscillations of the fourth harmonic are practically equivalent. The above-mentioned phase shift may be a consequence of this phenomenon.

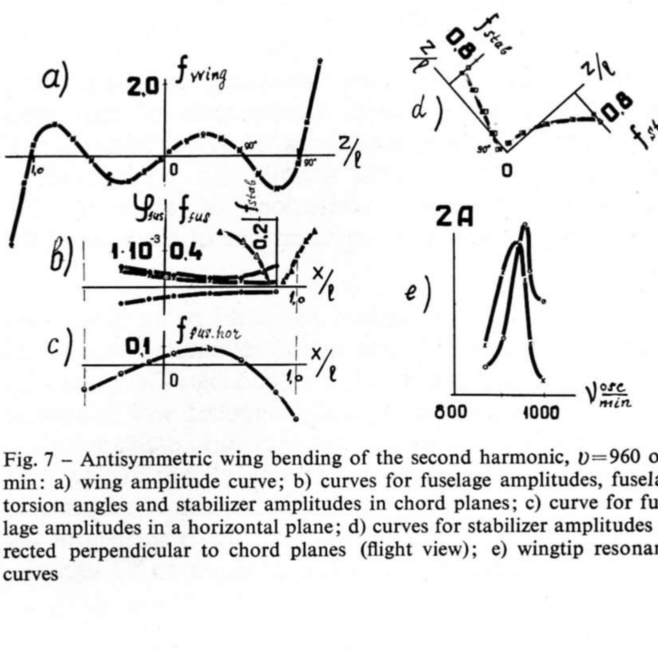

Fig. 7 – Antisymmetric wing bending of the second harmonic, υ=960 osc/min: a) wing amplitude curve; b) curves for fuselage amplitudes, fuselage torsion angles and stabilizer amplitudes in chord planes; c) curve for fuselage amplitudes in a horizontal plane; d) curves for stabilizer amplitudes directed perpendicular to chord planes (flight view); e) wingtip resonance curves

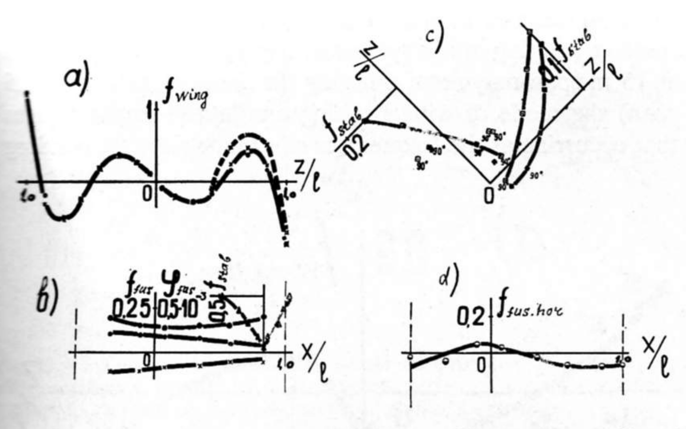

Fig. 8 – Antisymmetric wing bending of the second harmonic, $\upsilon=1320$ osc/min ($l=15$ m): a) wing and aileron amplitude curves; b) curves for fuselage amplitudes, fuselage torsion angles and stabilizer amplitudes in chord planes c) curves for stabilizer amplitudes directed perpendicular to chord planes flight view); d) curve for fuselage amplitudes in a horizontal plane

Fig. 6 shows curves for antisymmetric wing bending oscillations of the fundamental. Judging by the mode of the fuselage oscillations it may be assumed that the frequencies of antisymmetric wing bending oscillations and fuselage torsional oscillations are equal or almost equal.

Fig. 7 presents curves for antisymmetric wing bending oscillations of the second harmonic at 960 osc/min. In fact, there were two resonances present — 940 osc/min for the right wing and 960 osc/min for the left wing (see resonance

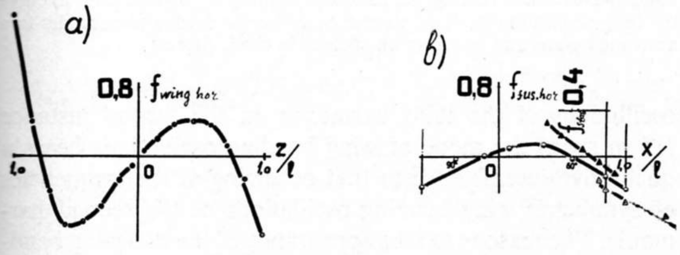

Fig. 9 – Antisymmetric wing bending of the second harmonic in chord planes, $\upsilon=1680$ osc/min ($l=15$ m): a) curves for wing amplitudes in chord planes; b) curves for fuselage amplitudes in a horizontal plane and stabilizer amplitudes in chord planes

curves in Fig. 7). Judging by the rather great amplitudes of stabilizer oscillations in chord planes, it may be assumed that the frequency of the antisymmetric stabilizer oscillations in chord planes is close to that of the mode discussed. The stabilizers oscillate in chord planes with a phase shift of 90 ° with respect to the wings and fuselage. The fuselage oscillates in a horizontal plane with a phase shift of 90 ° with respect to the wings.

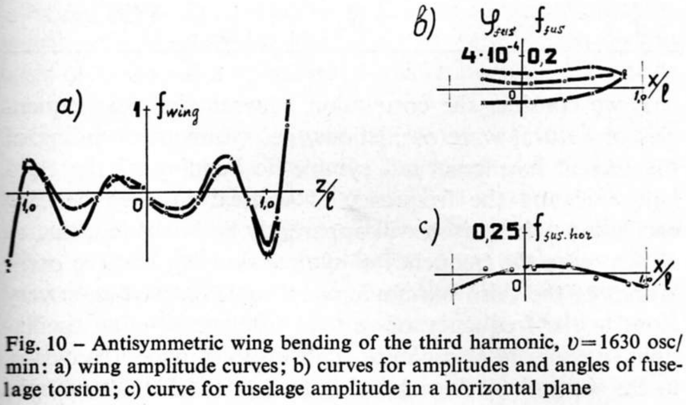

Fig. 10 – Antisymmetric wing bending of the third harmonic, $\upsilon=1630$ osc/min: a) wing amplitude curves; b) curves for amplitudes and angles of fuselage torsion; c) curve for fuselage amplitude in a horizontal plane

Antisymmetric wing bending oscillations of the second harmonic in «VEGA-2» glider with 15 m span bring about exactly the same phase shift in stabilizer and fuselage oscillations (see Fig. 8).

Fig. 9 contains curves for antisymmetric wing bending oscillations of the second harmonic in a horizontal plane at

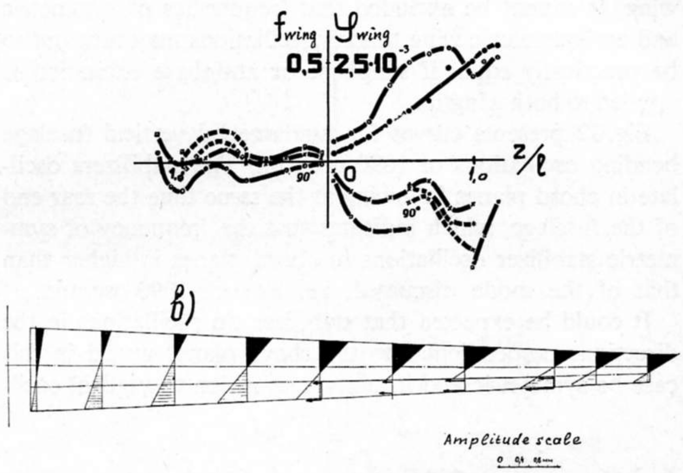

Fig. 11 – Right wing fundamental torsion, $\upsilon=2500$ osc/min: a) curves for wing amplitudes, aileron amplitudes and right-wing torsion angles; b) amplitude diagram for the right wing and aileron

1680 osc/min in «VEGA-2» glider with 15 m span. In this case, oscillations in stabilizer tips are phase shifted by 180 ° with respect to the rear end of the fuselage which oscillates in a horizontal plane (see Fig. 9b), i.e. the stabilizers lag behind the fuselage. This shows that antisymmetric stabilizer

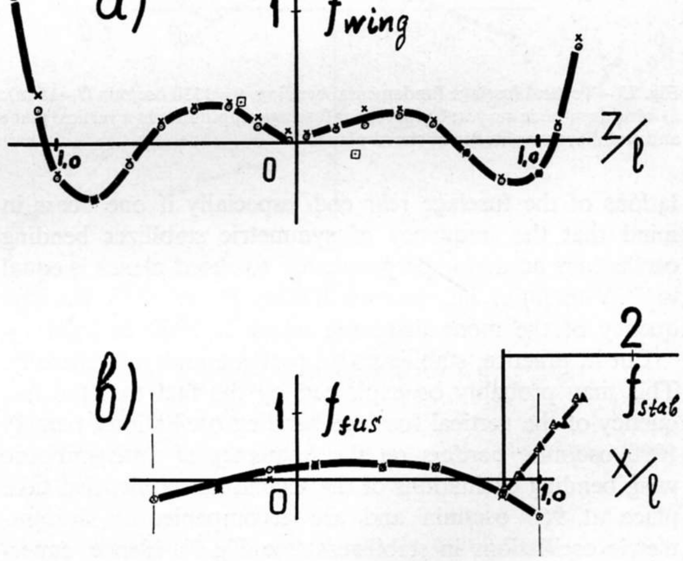

Fig. 12 – Vertical fuselage fundamental bending, $\upsilon=1090$ osc/min: a) wing amplitude curve; b) curves for fuselage amplitudes in a vertical plane and stabilizer amplitudes in chord planes

oscillations in chord planes must be of lower frequency as compared with the mode discussed, i.e. below 1680 osc/min.

As to symmetric stabilizer oscillations in chord planes, their frequency probably lies within the 1260—1350 osc/

min bracket, for it is exactly within this range that large-amplitude oscillations of different frequencies were registered for the left and right stabilizers. It cannot be excluded that symmetric stabilizer oscillations in chord planes take place at various resonant frequencies for the left and right stabilizers.

Fig. 10 bears curves for antisymmetric wing bending oscillations of the third harmonic.

Fig. 11 shows curves for torsional oscillations in the right wing. It cannot be excluded that frequencies of symmetric and antisymmetric wing torsion oscillations may turn out to be practically equal if synphase or antiphase excitation is applied to both wingtips.

Fig. 12 presents curves for fundamental vertical fuselage bending oscillations of 1090 osc/min. The stabilizers oscillate in chord planes following at the same time the rear end of the fuselage, which indicates that the frequency of symmetric stabilizer oscillations in chord planes is higher than that of the mode discussed, i.e. exceeds 1090 osc/min.

It could be expected that stabilizer tip oscillations in the directions perpendicular to the chord planes would in this case be symmetric and in phase opposition to vertical oscillations of the fuselage rear end, especially if one bears in mind that the frequency of symmetric stabilizer bending oscillations occurring perpendicular to chord planes is equal to 775 osc/min, i.e. is considerably lower than the frequency of the mode discussed which is 1090 osc/min.

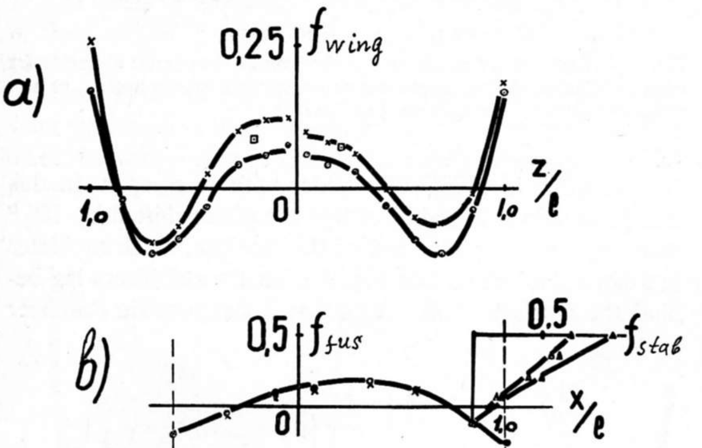

Fig. 13 – Vertical fuselage fundamental bending, $\upsilon = 1130$ osc/min ($l = 15$ m): a) wing amplitude curves; b) curves for fuselage amplitudes in a vertical plane and stabilizer amplitudes in chord planes

But in practice, stabilizer tips oscillate antisymmetrically. This may probably be explained by the fact that the frequency of the vertical fuselage bending oscillations, namely 1090 osc/min, borders on the frequency of antisymmetric wing bending oscillations of the second harmonic, that take place at 960 osc/min and are accompanied by antisymmetric oscillations in stabilizers (see Fig. 7). Hence, superimposed antisymmetric oscillations might lead to distortion of the symmetric oscillation mode in stabilizers.

Reverting to the symmetric stabilizer oscillations in chord planes, we can assert that the natural frequency of these oscillations also exceeds 1130 osc/min. The assertion is proved right by Fig. 13 which illustrates modes of fundamental vertical fuselage bending oscillations in the glider with 15 m span, when the stabilizers oscillate in chord planes following at the same time the rear end of the fuselage.

The difference in wing oscillation modes under vertical fuselage bending oscillations at 17.5 m span (see Fig. 12) and at 15 m span may seem puzzling. In the first instance (17.5 span) the mode of wing bending oscillations approximates that occurring at the frequencies of symmetric wing bending

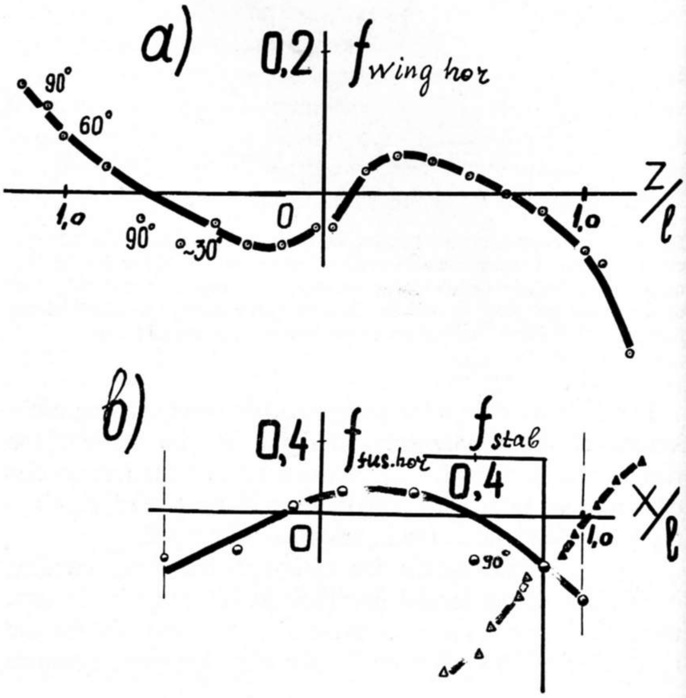

Fig. 14 – Horizontal fuselage fundamental bending, $\upsilon = 890$ osc/min: a) curve for wing amplitudes in chord planes; b) curves for fuselage amplitudes in a horizontal plane and stabilizer amplitudes in chord planes

oscillations of the third harmonic. In the second instance (15 m span) the mode of wing bending oscillations bears a qualitative resemblance to that occurring at the frequencies of symmetric wing bending oscillations of the second harmonic. The reasons for the appearance of the two wing bending modes may become clear from the following frequencies table:

	Oscillation Frequency, osc/min		
Wingspan, m	*Symmetric wing bending of the second harmonic*	*Vertical fuselage bending*	*Symmetric wing bending of the third harmonic*
17,5	535	1090	1210
15	730	1130	1810 right 1850 left

If we consider the correlation between the two frequencies of natural wing oscillations, i.e. symmetric bending of the second harmonic and symmetric bending of the third harmonic and the frequency of vertical fuselage bending oscillations, the reason will apparently lie in the fact that at 17.5 m span the frequency of symmetric wing bending oscillations of the third harmonic equal to 1210 osc/min is very close to the frequency of vertical fuselage bending oscillations, namely 1090 osc/min, while at 15 m span, the closest to the vertical fuselage bending frequency of 1130 osc/min

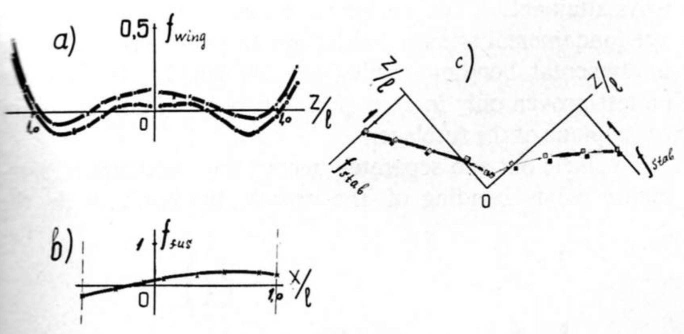

Fig. 15 – Symmetric stabilizer fundamental bending, $\upsilon = 775$ osc/min: a) wing amplitude curves; b) fuselage amplitude curve; c) curves for stabilizer amplitudes directed perpendicular to chord planes (flight view)

is the frequency of symmetric wing bending oscillations of the second harmonic, equal to 730 osc/min.

Fig. 14 shows curves for horizontal fuselage fundamental bending oscillations with the frequency of 890 osc/min. The stabilizers oscillate in chord planes following the fuselage in its horizontal oscillations. This indicates that the natural frequency of antisymmetric stabilizer oscillations in chord planes is higher than the frequency of the mode discussed, i.e. exceeds 890 osc/min.

Fig. 15 contains curves for symmetric stabilizer oscillations perpendicular to chord planes.

Fig. 16 presents curves for antisymmetric stabilizer oscillations perpendicular to chord planes at 640 osc/min. In

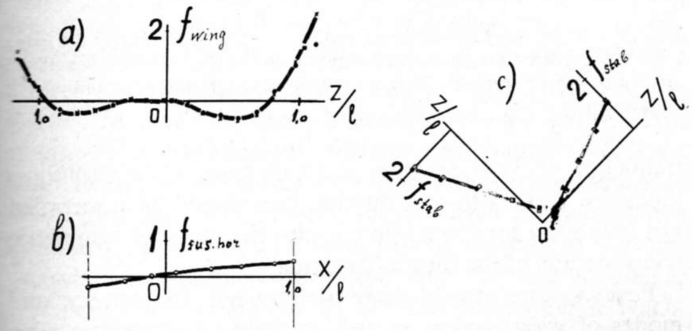

Fig. 16 – Antisymmetric stabilizer fundamental bending, $\upsilon = 640$ osc/min: a) wing amplitude curve; b) curve for fuselage amplitudes in a horizontal plane; c) curves for stabilizer amplitudes directed perpendicular to chord planes (flight view).

this case the wings do not oscillate antisymmetrically which is probably explained by the fact that the frequency in question lies very close to the frequency of symmetric wing bending oscillations of the second harmonic, equal to 535 osc/min, and superposition of the latter could distort the antisymmetric wing mode.

Fig. 17 is an illustration to horizontal fundamental symmetric wing oscillations. The diagrams were plotted on the basis of measured amplitudes of oscillations in the wingtips and fuselage nose.

Fig. 18 contains a diagram of horizontal fundamental antisymmetric wing oscillations. The wings also experience large-amplitude vertical oscillations. The arrows show amplitudes of vertical wingtip oscillations to the same scale as the horizontal oscillation amplitudes. A vertical wing oscillation component relates to the fact that the frequency discussed, i.e. 385 osc/min, lies close to the frequency of fundamental antisymmetric wing bending oscillations, i.e. 350 osc/min, occurring in the vertical direction (see Fig. 6).

Fig. 19 shows curves for horizontal antisymmetric wing bending oscillations of the second harmonic at 1180 osc/min (right wing resonance) and 1240 osc/min (left wing resonance).

It seems possible that the frequency of horizontal symmetric wing bending oscillations of the second harmonic lies

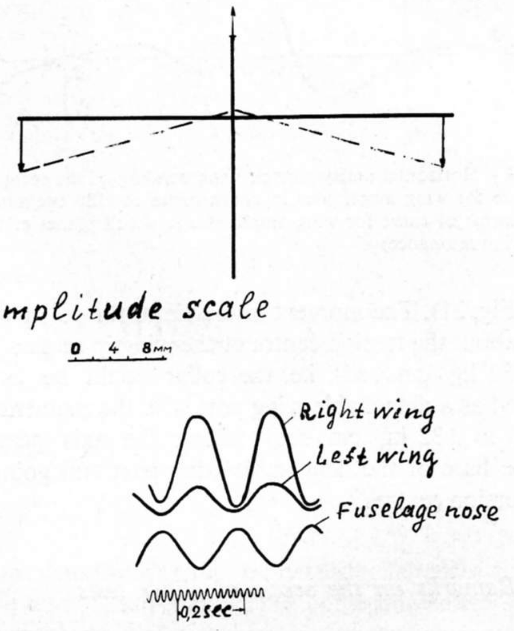

Fig. 17 – Horizontal symmetric fundamental wing oscillations, $\upsilon = 300$ osc/min

somewhere close to the frequency discussed. The tests of «VEGA-2» glider with 15 m span reveal that the frequencies of the two above-mentioned oscillation modes are very close to each other. The frequency of the symmetric oscillations of the second harmonic turned out to be 1780 osc/

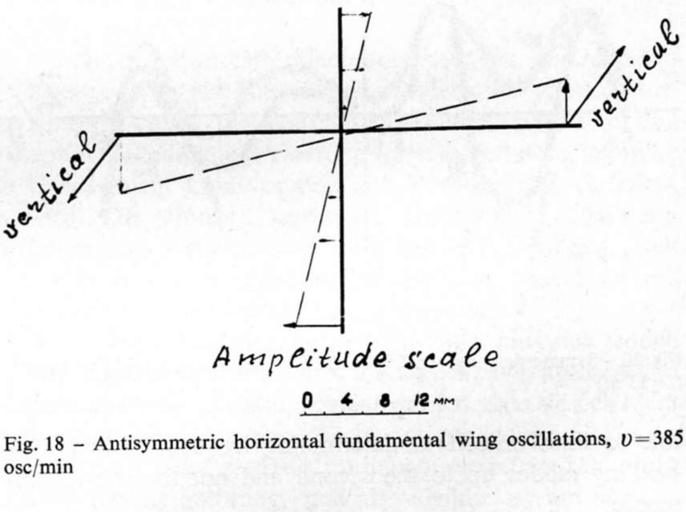

Fig. 18 – Antisymmetric horizontal fundamental wing oscillations, $\upsilon = 385$ osc/min

min, while that of the antisymmetric oscillations of the second harmonic was equal to 1680 osc/min.

Tests of the glider with 15 m span did not reveal any wing torsion oscillations below the frequency of 4000 osc/min. We registered wing oscillations with the frequency of 3150 osc/min (see Fig. 20) which could be classified as a form of symmetric wing bending oscillations of the fourth harmonic. It was assumed that the frequency of wing torsion oscillations concurred with the frequency of symmetric wing bending of the fourth harmonic.

When a load was applied to the right wingtip by means of a collar with two vibrators, the right wing experienced torsional oscillations with the frequency of 2540 osc/min

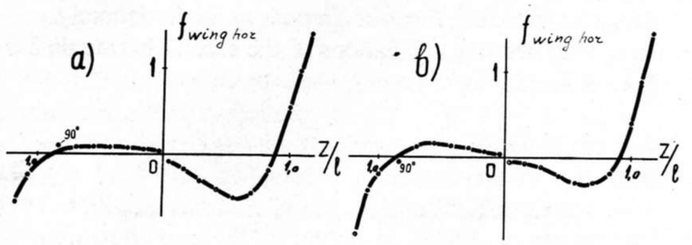

Fig. 19 – Horizontal antisymmetric wing bending of the second harmonic: a) curve for wing amplitudes in chord panes et 1180 osc/min (right-wing resonance); b) curve for wing amplitudes in chord planes et 1240 osc/min (left-wing resonance)

(see Fig. 21). The moment of inertia of the collar with vibrators about the torsion centre of the wingtip section was equal to 0.32 $kg \cdot cm \cdot sec^2$, i.e. the collar could be as well regarded as a detachable wing part with the moment of inertia equal to 0.32 $kg \cdot cm \cdot sec^2$ (along the axis perpendicular to the base of the detachable wing part and going through the torsion centre).

III. Remarks on the scope of glider tests

One may wonder what reasoning was employed for determining the scope of the tests, the results of which are discussed above. If the aims of the experiment were to compare test data with theoretical flutter calculations or to supervise the construction of a dynamic model, was it poss-

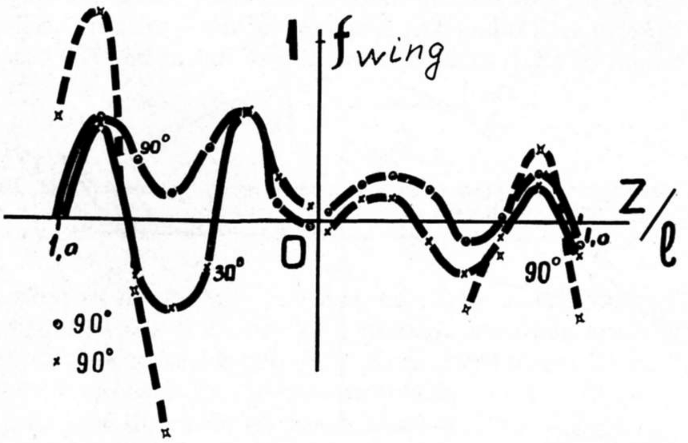

Fig. 20 – Symmetric wing bending of the fourth harmonic, $\upsilon = 3150$ osc/min ($l = 15$ m)

ible to limit oneself to determining frequencies and wing bending modes up to the second and not the fourth harmonic?

Frequencies and modes of antisymmetric wing bending of the third harmonic and symmetric wing bending of the fourth harmonic had to be determined, for they precede the frequencies of wing torsion oscillations which are rated among the most essential experimental data to be found out during glider frequency testing. During the tests discussed, resonant frequencies beyond 4000 osc/min were observed but neglected.

There is usually a tendency to limit the scope of tests to a certain minimum volume, but even this volume is not always attainable. Thus, an assertion that frequencies of fuselage fundamental torsion oscillations and antisymmetric wing fundamental bending oscillations are juxtapositioned can be test-proven only in case of rigid attachment of the entire centreplane of the fuselage.

To single out and separately record the resonance of symmetric wing bending of the fourth harmonic with the

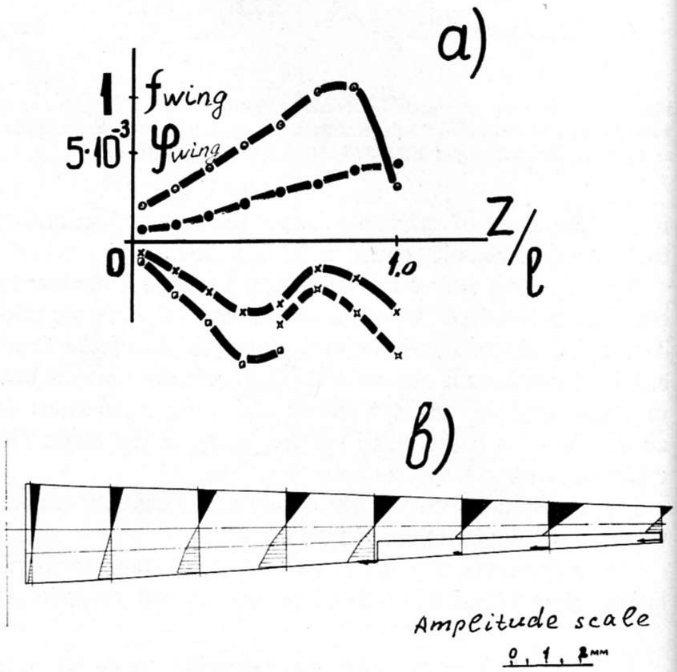

Fig. 21 – Right wing fundamental torsion ($l = 15$ m): a) curves for wing amplitudes, aileron amplitudes and wing torsion angles with additional load applied to the wingtip, $\upsilon = 2540$ osc/min; b) diagram for wing and aileron amplitudes

frequency of 3150 osc/min at 15 m span when additional loads are applied to the wingtips, one should have recorded not only wing torsion mode but also the mode of symmetric wing bending of the fourth harmonic.

Besides, one should have determined frequencies and modes of wing torsion as well as those of symmetric wing bending of the fourth harmonic at, at least, two more values of the moment of inertia, both of which should have been less than 0.32 $kg \cdot cm \cdot sec^2$.

Along with determining the basic frequencies and oscillation modes during frequency tests on gliders, special attention must be paid to modes of easily induced oscillations that occur in different parts of the structure. For instance, one of the structures under test revealed a certain mode of horizontal oscillations in the ailerons along their rotation axes. These were found to be bending oscillations in a horizontal plane taking place in the aileron suspension brackets, against which the entire mass of the ailerons rested.

The oscillations could be easily induced by forces applied to various points of the structure to excite other oscillation modes. Even a vertically directed disturbing force applied to the wing or fuselage could at certain frequencies induce great amplitude aileron oscillations in a horizontal plane.

Hence, it could be expected that the oscillation mode discussed might be easily induced by certain impulses at take-off and landing (even if only in the form of slow convergent oscillations) and eventually lead to a sudden destruction of the brackets. The observation resulted in a recommendation to increase the horizontal rigidity of the brackets.