Flight Measured Load Factors

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Introduction

Among the glider parameters measurable in flight the most interesting for design purposes are acceleration and airspeed versus time. In Poland many flight tests have been made of gliders equipped with the SFIM multirecorder, which enables suitable parameters for such tests to be recorded.

This paper gives results obtained on four Polish gliders: SZD-30 PIRAT, SZD-35 BEKAS, SZD-36 COBRA and SZD-43 ORION. These aircraft represent a wide range of designs. The PIRAT is a popular-performance and training single seater, the COBRA and ORION are high-performance competition sailplanes, while the BEKAS is a two-seater school and training glider. All the aircraft have wings of modern Wortmann sections. With the exception of BEKAS all have «T» tails.

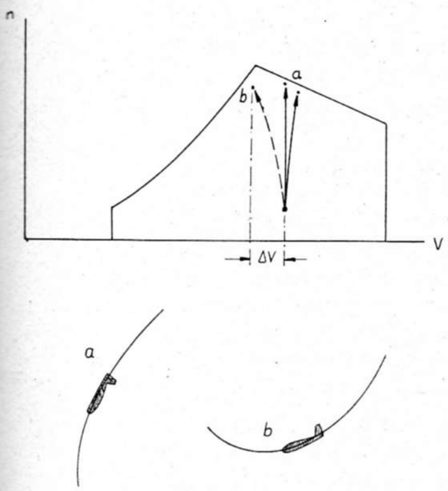

Fig. 1

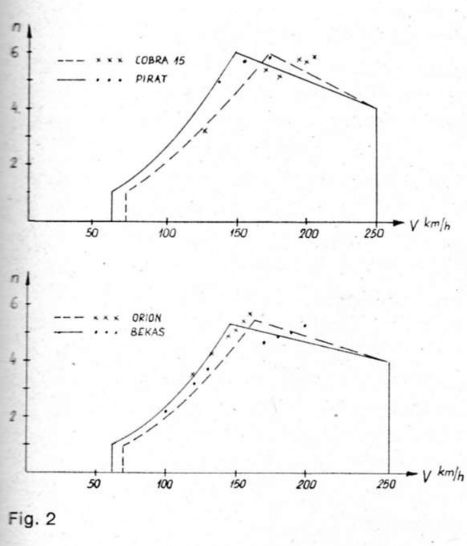

Fig. 2

The SFIM recorder registers on phototapes the flight parameters appropriate to the test under consideration. The recorded data permit investigation of the values of the parameters of interest and also their time histories. In other words we obtain the information on the intensity and frequency of loadings to be expected in the carrying out of particular manoeuvres of the glider, as discussed in this paper.

Pull-Out Manoeuvre

The pull-out manoeuvre can generally be performed in two ways. The first one initiated at the top of a loop in the inverted position (fig. 1a) and the second as a normal recovery action from diving flight. In the first case the increment of load factor is combined with constant or even slightly increasing airspeed. The second kind of pull-out manoeuvre shows the simultaneous increment of load factor and decrement of airspeed (fig. 1b).

Both procedures have been realized during the tests. In the case «a» the load factor grows up rapidly, while in case «b» the maximum load factor is obtained after a few seconds of recovery action from diving. The points of the load factor «n» (fig. 2) in the vicinity of stalling line have been reached using the «b» procedure, while the points for the airspeed greater than V_M (manoeuvring speed) have been reached rather by means of the «a» method. The latter points lie outside the design loading envelope and seem to show some danger to the glider structure. It is necessary to note that the «a» pull-out manoeuvres were made by the test pilots with the intention of reaching the maximum load factor, and in the normal use of the glider there can be expected rather the «b» kind of manoeuvres.

It can be seen from fig. 2 that the points realized for ORION tend to lie above the calculated stalling line. This suggests that the theoretical wing C_{Lmax} assumed by the designer was too pessimistic.

Investigation of the record tapes permits the plotting of a diagram of airspeed decrement as a function of the maximum load factor reached (fig. 3). For each aircraft there are two lines, one of which represents the initial airspeed of the manoeuvre and the second the airspeed at which the maximum load factor was reached. At the

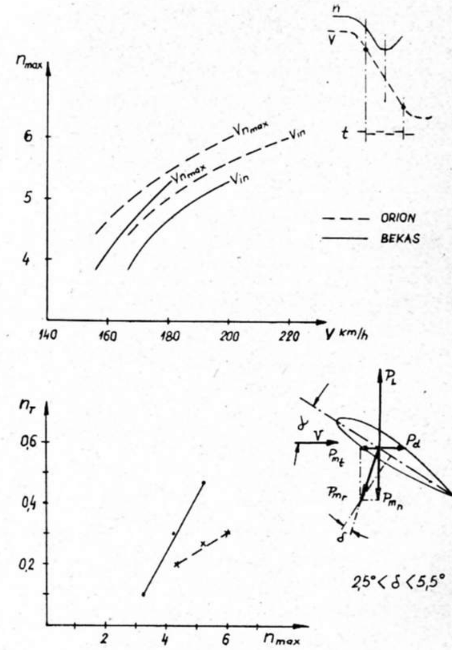

Fig. 3

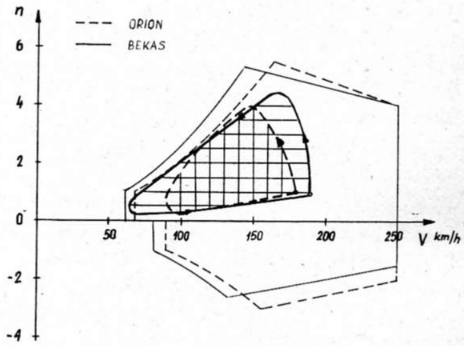

Fig. 4

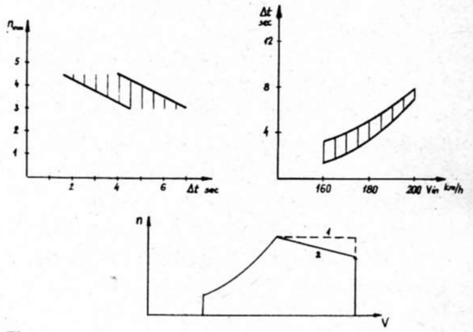

Fig. 5

top right corner of the diagram is shown a portion of tape record. The increment of the line «n» (normal acceleration) is accompanied by the airspeed decrement (line «V») which is nearly constant in the vicinity of «n_{max}». This permits the calculation of the negative acceleration of the glider along the flight path. Dividing this value by the acceleration due to gravity «g» we obtain the load factor «n_T» tangential to the flying path. This procedure allows us to find the normal and tangent components of the inertia forces acting on the glider's components. The value of the tangent load factor «n_T» is a function on the normal load factor (see lower diagram on fig. 3).

Here appears an important conclusion

for the designer. The tangential bending moment of the wing, based only on the values of aerodynamic coefficients C_L and C_D in the pull-out, is reduced by the tangential moment produced by the inertia forces of the wing. The values of load factors «n_T» and «n_N» so determined allow us to find the components of mass forces P_{mn} and P_{mt} and hence their resultant P_{mr}. This resultant can be projected on the chord line of the wing. It is only necessary to know the value of the angle between the normal to the chord and the resultant mass force P_{mr}. Investigation of the records for the above-mentioned gliders showed this angle to be 2.5° to 5.5° (see sketch on fig. 3). The lower value of 2.5° applies to the ORION sailplane and the upper value of 5.5° to the BEKAS. The value depends on the aerodynamic condition of the aircraft; nevertheless angles such as those quoted can help the designer in preliminary structural analysis.

Looping
The representative load factor time histories for the gliders ORION and BEKAS superimposed on the design manoeuvring envelopes are shown on fig. 4. The shaded area represents the range of load factors reached in several loop manoeuvres. The maximum and minimum load factors in the loop lie in the range of 4.5–0.2. They seem to be the real values of load factor which can be used in determining the program of looping simulation in the ground fatigue tests of the wing.
The investigation of the history of loading increment during the loop manoeuvre permits the relation between the maximum load factor reached and the time necessary for it to be plotted. This time depends also on the initial airspeed of the manoeuvre (fig. 5). The shaded area of both diagrams represents the scatter of the measured points. As would be expected, the shorter the time of looping, the greater is the value of load factor achieved. The time taken to perform the loop is greater for the greater values of initial airspeed. In another words the looping manoeuvre is similar to the pull-out of kind «b». The diagram confirms the philosophy of the manoeuvring envelope shape which in many national airworthiness requirements is defined as a straight line with a slope towards the V_D line (line 2 on fig. 5). The horizontal line between manoeuvring speed V_M and diving speed V_D (dotted line 1 on fig. 5) represents the «a» kind of pull-out and corresponds to the aerobatic gliders only.

Stall Turn
Representative stall-turn load factor time-histories are shown on fig. 6. The limit values of load factor lie between 4.5 and 0. These values can be used in preparing the programme for the fatigue ground tests of the wing. The shaded areas of the loading variation lie very close to the stalling line, but in considering the airspeed in this manoeuvre we must be very careful because of the airspeed indicator error at the top point of the manoeuvre path.

Spiral
The value of the load factor achieved in the spiral depends on the airspeed of the manoeuvre. The correlation between these two values is shown on fig. 7. The greater the indicated airspeed the greater is the load factor. The representation of the spiral in ground tests requires the use of load factors in the range of 4 to 2.

Spin
The investigation of the spin is really troublesome. There are many parameters defining this manoeuvre, e.g. rate of rotation, angle of inclination of main glider axes, descent velocity, configuration of controls etc.

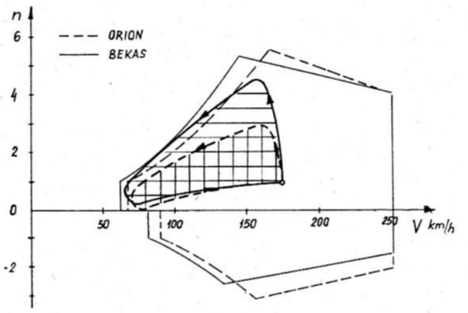

Fig. 6

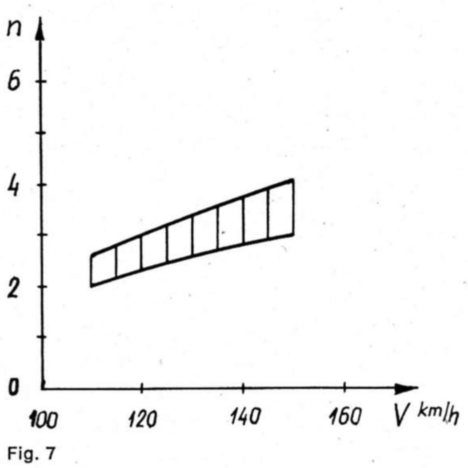

Fig. 7

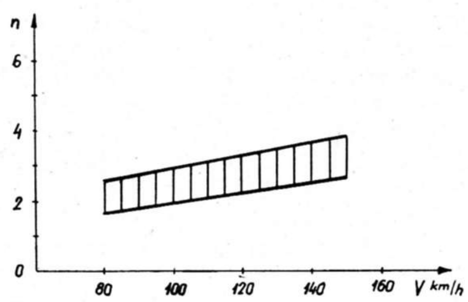

Fig. 8

To analyse the value of load factor we have chosen indicated airspeed as the basic parameter, to be consistent with the other manoeuvres. It is however necessary to note that a pressure head mounted on the wing tip by means of an extended tube or bar will be reflecting the resultant airflow produced by the very complex movement of the glider wing tip and in no way corresponds to the true value of the airspeed of the glider as a whole. The indicated airspeed is treated here only as a comparative parameter for the gliders under consideration.
The values of load factor against wing-tip-recorded airspeed are shown on fig. 8. The values of the load factor increase with airspeed. The limit values of load factor in the spin vary between 4 and 1.5. The scatter of points, represented by the shaded area, depends on the many other parameters as discussed above.

Landing
The load factors produced during landing depend mainly on the shock-absorbing qualities of the undercarriage. Therefore gliders with and without shock-absorbers must be considered separately. The present tests were restricted to two gliders, the PIRAT and BEKAS, on which the only energy absorption elements were the tyres. The test pilots introduced deliberate mishandling, to simulate landings by inexperienced pilots.
Peak values of load factor were extracted for each landing from the first touch-down until the glider came to rest. Here, «peak» means both maximum and minimum values, and only distinct well-defined pecks were selected. The values are classified in five groups of 0, 1, 2, 3, and 4 g.
0 g means from 0 g to 0.5 g
1 g means from 0.5 g to 1.5 g
2 g means from 1.5 g to 2.5 g
3 g means from 2.5 g to 3.5 g
4 g means from 3.5 g to 4 g.
There were no values below 0 g or above 4 g.
The table shows the percentage of peak loads occurring in each group for the following four cases:
drop landing, nose-down landing, sideslip landing and landing with the wheel-brake applied. The figures in the last column indicate (to the nearest 5) the lowest and highest number of peaks in any one landing.
The results confirm the value of load factor 4 prescribed in the airworthiness requirements as the maximum for undercarriages without shock absorbing elements. The values collected for the various landing cases give the statistical material which can be used in determining the loads for ground fatigue test.

Final Remarks

All the test results, on which the conclusions of this paper are based, have been obtained during flight tests of the sailplanes in which the collection of statistical material for loading and design considerations, was not the primary aim. Therefore the data obtained are only fragmentary. There are also many other interesting manoeuvres such as for example the rolling condition and the inverted flight cases. The collecting of the loading data for all possible manoeuvres would require a great number of flight test hours.

Therefore the conclusions and statistical material reported here cover a limited range of manoeuvres only. The main object of this paper is to draw attention to the fact that flight tests of instrumented gliders can supply the designer with very useful information, especially for preparing the static and dynamic ground tests of the sailplane under the very early stage of design process.

The instrumentation of the gliders under test is now becoming more extensive. It is possible to equip the aircraft with two or more SFIM recorders, and so obtain the simultaneous records of a wide range of parameters. In this way the flight testing yields not only the handling qualities of the glider but also provides the statistical loading data on which the airworthiness requirements may be based. The collaboration between the designer and the test pilot becomes closer and more fruitful.

Zusammenfassung

Messungen der Normalbeschleunigung und der Fluggeschwindigkeit wurden unter Benutzung eines Vielfachschreibers mit dem PIRAT, BEKAS, COBRA und ORION in verschiedenen Arten von Flugmanövern gemacht.

Zwei Methoden der Durchführung von Abfangfällen und den entsprechenden Typen im n-V-Diagramm sind in Figur 1 gezeigt und einige gemessene Ergebnisse in Figur 2. Einige der Werte lassen erkennen, dass die Schätzung des $C_{L\ max}$ durch den Entwurfs-Ingenieur pessimistisch war. Der Zeitablauf erlaubt auch eine Bestimmung der Tangentialbeschleunigung, von der einige Ergebnisse in Figur 3 angegeben sind. Die Ergebnisse von Ueberschlägen (Loopings) sind in Figur 4 und 5 gezeigt; hochgezogene Kehrtkurven in Figur 6, Spiralen in Figur 7, Trudeln in Figur 8, Landungen in Figur 9.

KIND OF LANDING		LOAD AMPLITUDE 0g	1g	2g	3g	4g	TOTAL AMOUNT OF LOADING CYCLES
DROP LANDING	PER CENT OF LOADING PEAKS	20	57	11	7	5	60 - 85
NOSE LANDING	PER CENT OF LOADING PEAKS	22	52	20	6	0	60 - 80
SIDE SLIP LANDING	PER CENT OF LOADING PEAKS	25	50	12	11	2	60 - 75
LANDING WITH BRAKED WHEEL	PER CENT OF LOADING PEAKS	26	35	30	5	4	65 - 80

Fig. 9

Die hier gezeigten Ergebnisse bilden nur einen Teil derjenigen, die im ganzen Testprogramm erhalten wurden, in einem Programm, das andere Manöver wie z. B. Rollen und Rückenflug einschloss. Der Gegenstand dieses Berichtes ist, auf die Daten aufmerksam zu machen, die im Flugversuch mit einem Schreibersystem gewonnen werden können; die Werte sind nützlich nicht nur für das Prüfen der statischen Beschleunigung, sondern auch für die Bestimmung des Programmes der dynamischen Bodenversuche.

Résumé

L'accélération normale et la vitesse ont été enregistrées, grâce à un enregistreur multivoies, au cours de différentes sortes de manœuvres effectuées avec les planeurs PIRAT, BEKAS, COBRA et ORION.

Deux méthodes d'exécution des ressources et les diagrammes n(V) correspondants sont montrés sur la fig. 1; la fig. 2 donne le résultat des mesures. L'examen des valeurs obtenue laisse à penser que l'estimation du Cz max. a été pessimiste. L'enregistrement en fonction du temps permet aussi de déterminer l'accélération tangentielle et des résultats sont donnés sur la fig. 3. Des résultats concernant les loopings sont donnés fig. 4 et 5, les décrochages en virage fig. 6, les spirales fig. 7, les vrilles fig. 8 et les atterrissages en fig. 9.

Les résultats donnés dans cet article ne représentent qu'une partie de ceux obtenus au cours de la campagne d'essais, qui comportait d'autres manœuvres telles que le tonneau et le vol inversé. Le but de cet article est d'attirer l'attention sur les résultats que l'on peut obtenir au cours d'essais en vol grâce à l'utilisation d'un enregistreur. Les données sont utiles non seulement pour contrôler les accélérations statiques mais aussi pour établir le programme des essais dynamiques (vibrations) au sol.