Water Ballast Loadings on Sailplanes

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Introduction

It is a common practice of to-day to use the water ballast for improvement of sailplane performances. The flight properties as a consequence of controllable wing loading ensure the possibility of the best avail of thermal conditions of a day or even of few hours. Quick releasing valve allows to remove the water in a short time and in the same way to lower the wing loading. It is very essential when the thermal conditions become poor.

These properties interesting in pilot's point of view create, however, some design problems concerning the loadings and in consequence the structural analysis of glider.

To obtain the significant profit of water ballast it's necessary to change the all-up weight of glider of about 12 to 15 per cent. The advantage of ballasted flight appears on speed polar (fig. 1) calculated for new Polish high performance sailplane SZD-39 Cobra 17.

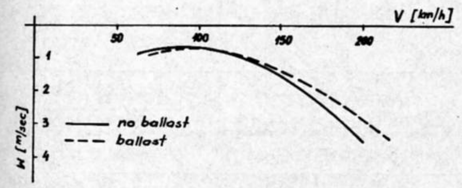

fig. 1

The main parameters for loading calculation purpose are the following:

- change of all-up weight (according to water tank capacity)
- change of inertia moments due to three main axes
- change of c.g. position and tailforce arm.

Variation of above mentioned parameters means that in design practice we have to do with two configurations of glider. The first one without and the second with water ballast. In other words all the loading calculations are to be doubled. It's a very time consuming work and in the first design approximation it would be profitable to have some directions which allow for the rough estimation of loading increment due to the water ballast.

This paper may be an approach to problem.

Load envelope (n-V diagram)

Stalling speed value is the main data for n-V diagram calculation.

It depends on wing loading:

$$w = \frac{W}{A}$$

where:

W – all-up weight of glider

A – wing area

In the ballast configuration the stalling speed increases in respect to increment of wing loading:

$$w_b = \frac{W + \Delta W}{A}$$

where:

ΔW – weight of water ballast

The manoeuvring speed follows the formula:

$$V_m = V_s \cdot \sqrt{n}$$

where:

V_s – stalling speed

n – load factor

In such a way we obtain two manoeuvring speeds V_m and V_{mb} for no-ballast and ballast configurations respectively, as a result of two various stalling speeds. We assume that the load factor n for both configurations is the same if we want to remain the glider in the same loading category for ballasted flight.

Since the wing aerofoil coefficients are independent of weight we obtain two stalling curves in respect to change of wing loading. The design diving speed in most cases is limited for strength or flutter reasons being nearly the same for no-ballast and ballast configurations.

The shape of manoeuvring envelope is shown on fig. 2, where the dotted lines concern the ballast configuration.

The loadings arising as a consequence of gusts in turbulent atmosphere are rather similar for both the configurations in respect to the value of gust alleviating factor which depends on wing loading.

In case of Cobra 17 glider all the gust load factors for ballast configuration are lower than for no-ballast flight for the same airspeed. This results from the greater inertia of ballasted glider and decreased response on gusts.

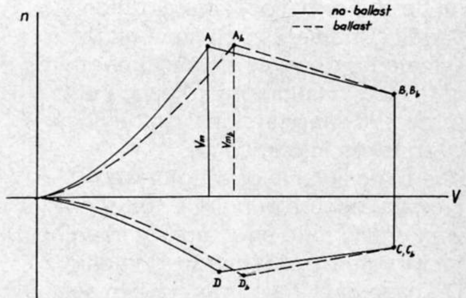

fig. 2

It's necessary to check the influence of the shape of load envelope as well as the variation of inertia moments and c.g. position on the loadings on particular glider sets.

Wing

The critical wing bending occurs in point A of manoeuvring envelope or in case of strong gust in turbulent atmosphere on airspeed established according to the Airworthiness Requirements formulas. In common practice value of this airspeed is being limited to obtain the gust load factor equal to manoeuvring one.

The water ballast tanks are placed in wing structure on front torsion box in the vicinity of fuselage. Water ballast cannot change the total value of force acting on the wing because the reducing mass force grows up proportionally to water ballast mass. The difference in bending moment of the wing in ballast configuration depends only on the discontinuity of mass distribution along the span. In ballast region we obtain the sharp mass concentration (fig. 3). This discontinuity is the reason for which the ballast flight bending moment has the greater value than for no-ballast case.

Bending moment in point A of loading envelope for Cobra 17 glider is shown

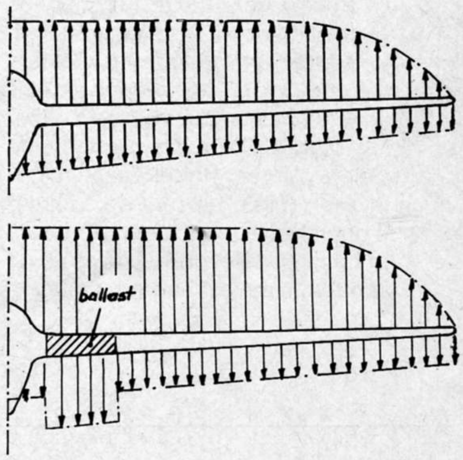

fig. 3.

on fig. 4. For ballast configuration the bending moment in plane of glider symmetry grows up about 12 per cent. In this calculation the influence of tail-force and wing torsional rigidity has been taken into account.
The critical value of wing torque moment occurs at point D for conventionally rigid structure, or in point C for structures of rather low rigidity.
On base of n-V diagram we can see that for ballast configuration the point D_b lies in region of greater airspeed and in the same way of greater dynamic pressure. Since the moment coefficient varies due to angle of attack rather in a very narrow range the torque moment for ballast configuration will be greater than for empty tank case, in respect to the increment of dynamic pressure.
Fig. 5 presents the increment of torque moment of wing calculated for Cobra 17 glider. The value of moment in plane of symmetry for ballast configuration is greater of about 11 per cent.
It's necessary to mention that the water ballast changes the distribution of wing masses having its influence on torque moment involved by mass forces. Moreover the position of elastic axis depends on the wing structure so it is rather difficult to treat the results obtained for Cobra 17 as a universal direction, when there are many structural schemes of wing.
The significant difference in bending and torque moments of wing for ballast and no-ballast configurations appears in the case of roll loading. It is, however, not a critical wing loading and in the preliminary structural analysis may be not taken into account. The rolling properties are rather interesting from pilot's point of view and depend mainly on inertia moment value.

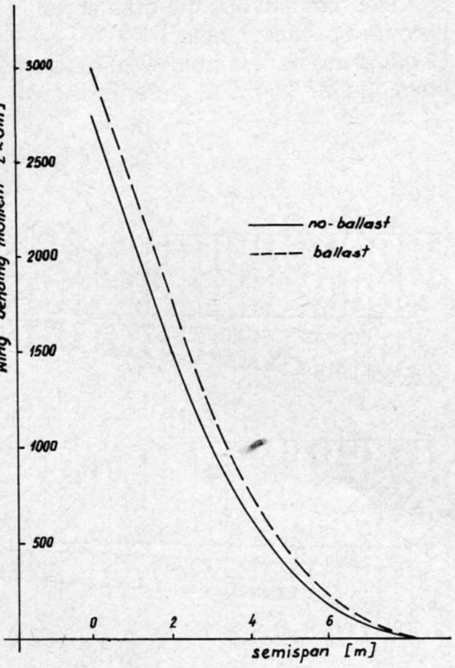

fig. 4.

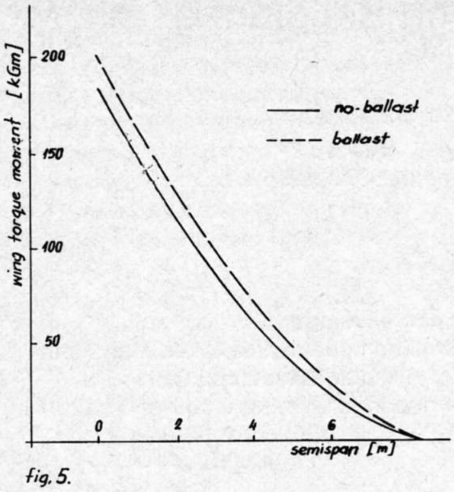

fig. 5.

Aileron

The influence of water ballast on aileron loading can be examined on base of results obtained for Cobra 17 glider (tab. 1). The pressure on aileron surface has been obtained from calculations of linearized pressure distribution along the chord. According to Polish Requirements aileron loadings have been calculated for manoeuvring speed and load factors of ½ n_A and ½ n_D for both ballast and no-ballast configurations. In each case the aileron deflection was 16° down and 34° up. The ballast pressure increment lies within 8 to 25 per cent, but for the critical case it is only 8 per cent.

Tail unit

Tailplane loadings depend as well on aerodynamic characteristics of tailplane aerofoil as on the tailless moment coefficient of the glider. The change of c.g. position due to water ballast requires the calculation of tailless moment coefficient for both configurations. Diagram of above value versus angle of attack is given on fig. 6.
Many various cases of tailplane loadings require the analysis of problem in a very vast range. The results obtained for Cobra 17 having all-moving tailplane with geared tab are gathered in tab. 2. The increment of loading due to water ballast for critical tailforce is about 15 per cent.
Fin and rudder loadings for both configurations of Cobra 17 are listed in tab. 3. The ballast loading increment for the critical case is of about 14 per cent. The main influencing factors are: the inertia moment in respect to vertical axis and greater manoeuvring speed.

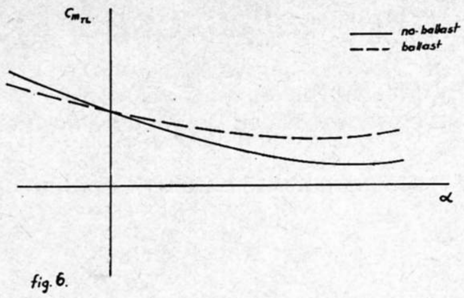

fig. 6.

Fuselage

Since the water ballast belongs to wing, all the loadings involved by accelerations (envelope load factors) are nearly the same for both configurations.
The only difference depends on various tailforces taken into account in calculations of fuselage bending moments and shearing forces.

LOADING CASE		AILERON DEFLECT.		PRESSURE ON AILERON [kG/m²]	
V	n	up	down	no-ballast	ballast
V_m	$\frac{1}{2} n_A$		16°	127,5	138
-"-	-"-	34°		-72,6	-91,2
-"-	$\frac{1}{2} n_D$		16°	84,5	96,7
-"-	-"-	34°		-116	132,1

tab. 1

LOADING CASE	TAILFORCE [kG]	
	no-ballast	ballast
Point A of envelope	-140,6	-153,1
-"- B -"- -"-	-151,4	-157
-"- C -"- -"-	-54,4	-51,4
-"- D -"- -"-	10,7	8,3
Gust on V_G U=30 m/sec	68,4	85,7
-"- -"- V_G U=-30 -"-	-175,1	-203,3
-"- -"- V_D U=4 -"-	-56,9	-56,1
-"- -"- V_D U=-4 -"-	-153	-153,8
Tailplane deflection 14° up on V_m	-239,8	-270,5
-"- -"- 7° down on V_m	83,1	94,3
Critical manoeuvre on V_D	-197,5	-203,8

tab. 2

LOADING CASE	FIN AND RUDDER FORCE [kG]	
	no ballast	ballast
Manouevring load on V_m	94,5	108,7
-"- -"- -"- V_D	91,3	92
Strong gust on V_G	161,9	184,4
Weak -"- -"- V_D	30,7	30,9

tab. 3

The envelope of fuselage bending moments in vertical plane for Cobra 17 is shown on fig. 7. The critical cases appeared: pull-up to point A of n-V diagram and nose landing.

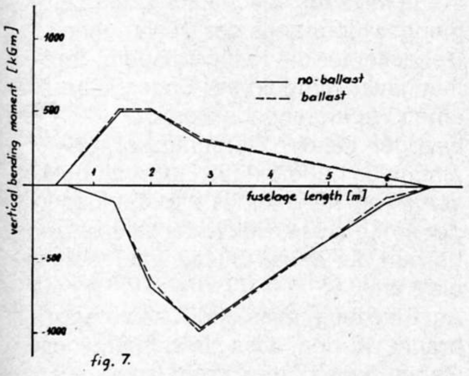

fig. 7

The bending moments of other loading cases like: towed flight, gusts in turbulent atmosphere etc. are covered by mentioned cases.
In such a way the influence of water ballast on fuselage loadings is not significant.

Landing gear
The loadings of landing gear depend on glider all-up weight. The increment of ground reactions on wheel will therefore be proportional to weight increment produced by water ballast.

Design directions
The employment of water ballast in wing structure of high performance sailplane requires the calculation of loadings for two glider configurations, namely with and without water.
This is a very time consuming work and in a simple design practice it would be profitable to have some directions concerning the influence of water ballast on the values of loadings of particular glider sets. The best way is to employ the statistics. This allows to obtain the average values of loading increment but statistic data on that subject are rather poor.
Cobra 17 being the conventional design of high performance sailplane with water ballast can give an approximate answer on above problem by means of table where there are gathered the per cent values of loading increment for the main sets of glider (tab. 4). It's necessary to note the weight of water ballast of 60 kg (maximum) and all-up weight of Cobra 17 of 445 kg (water included). The table figures can be applied to another conventional design being in first loading approach.
On base of above remarks there arises another question of practical nature. If we want to satisfy the Airworthiness Requirements it's necessary to introduce a great amount of plackars speeds. The manoeuvring speed and the limited speed in turbulent atmosphere are different for ballast and no-ballast configurations. We can say that water ballast produces some 'figure ballast' which must be remembered by pilot. There arises a suggestion to introduce the plackard speeds only for no-ballast configuration. Such a solution gives an assurance with respect to strength of structure and at the same time does not restrict the performance capabilities of sailplane. In normal competitor's practice the loadings almost never reach the critical value.
We can try to find another way of loading envelope interpretation.
Assuming only one value of manoeuvring speed V_m (plackard) for both configurations we obtain two values of load factor for point A and A_b without and with water ballast respectively (fig. 8). The load factor for ballast configuration will be lowered and in consequence the ballast envelope moves slightly down. The max. permissible speed in turbulent atmosphere for normal gust of 10 m/sec will be also lowered for ballast configuration. The decrement is shown on fig. 8 by dashed area. In case of Cobra 17 the airspeed decrement would be of $\triangle V = 10$ km/h.

CRITICAL LOADING INCREMENT DUE TO WATER BALLAST FOR "COBRA-17"	
GLIDER SET	PER CENT
Wing (bending)	12
Wing (torque)	11
Aileron	8
Tailplane	15
Fin and rudder	14
Fuselage	no signif.

tab. 4

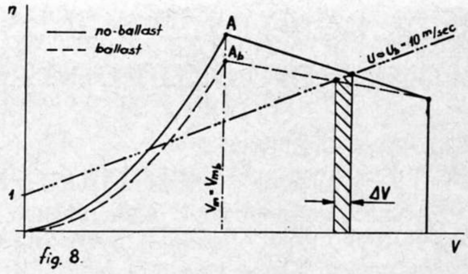

fig. 8

That means that the limited airspeed in turbulent atmosphere will be 190 km/h instead of 200 km/h. The proof load factor in point A $n=6$ obtains the value of $n=5.25$ for point A_b. The above limitations do not reduce the glider performance capabilities in a significant extent, assuming that the interthermal speeds reach the value of 200 km/h very rarely. On the other hand if we want to preserve the full range of sailplane possibilities we must take into account that the increment of loadings due to water ballast produces the strength problems. Finally we obtain more heavy aeroplane which lowers the effect of no-ballast configuration.

Conclusions
The water ballast produces an increment of loadings if the proof load factor of glider remains in the same level for ballast and no-ballast configurations it is necessary to examine the loading increment for ballast configuration in structural analysis of glider sets.
There may be applied another way of interpretation. Based on the structural analysis for no-ballast configuration it is recommended to accept the plackard values of manoeuvring speed and limited speed in turbulent atmosphere (being lower than calculated due to Airworthiness Requirements figures for increased wing loading) and to lower the value of proof load factor of point A_b as well as the limited airspeed in turbulent atmosphere. These limitations do not depreciate the sailplane in practical range of use.
The discrepancy of strict values of load factors and limited speed in turbulent atmosphere established by Airworthiness Requirements for safety reasons creates no danger providing that high performance sailplane is flown by experienced pilot who can avoid all the dangerous situations.