THE CHOICE OF LIMITATIONS FOR WINCH LAUNCHING

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INTRODUCTION

The Operating Limitations for winch launching a particular type of sailplane are the maximum weak link strength Q_{nom} and the maximum winch launching speed V_w. The first of these quantities is prescribed in JAR 22.581(b)(2) and OSTIVAS 3.612; the second in JAR 22.335(e), 22.1518(b) and OSTIVAS 7.37. While the wordings of JAR-22[(1)] and OSTIVAS[(2)] differ slightly, the intentions are generally similar. Briefly, Q_{nom} must not be less than 1.3Mg, where M is the Design Maximum Mass of the sailplane, nor less than 5 kN. For stressing purposes, a load of 1.2 Q_{nom} is to be considered. The maximum winch launch speed V_w must not exceed the speed for which the structure has been proved in accordance with the paragraphs relating to the stressing conditions, or the speed demonstrated in flight tests, whichever is the lower. V_w must not be less than 110 km/h. These definitions of Q_{nom} and V_w are slight paraphrases of the OSTIV wording which, in this context, seems the more straightforward.

In this paper, we examine the consequences of these definitions, on the assumption that the minimum available values have been chosen. We then consider whether more suitable values could be chosen, both from the design point of view and perhaps as a guide to future revisions of OSTIVAS. The main basis for the analysis and discussion is Reference 3.

Some relevant considerations are:

(1) Generally similar sailplanes should use the same strength of weak link.

(2) If the weak link is very strong, it may be possible to achieve very high wing-root bending moments during the launch; also, attempts to climb more steeply will tend to result in a stall rather than breakage of the weak link.

(3) If the weak link is too weak, it will frequently fail, leading to inefficient operation and some element of needless risk.

(4) If the max, winch launch speed V_w is too low, it will frequently be exceeded in practice.

(5) If V_w is very high, it will be possible to generate loads exceeding those of the maneuvering envelope.

A reasonable compromise would seem to involve arranging for the max. attainable loads (in particular, the wing-root bending moment) to be somewhat less than those of the maneuvering envelope and that V_w should be as high as is then possible. There should be a reasonable margin between the "Recommended Wing Launch Speed" (see below) and V_w.

ASSUMPTIONS

These are stated in full in Reference 3. The most important ones are:

- At any instant, the sailplane is supposed to be in equilibrium under the influence of the aerodynamic forces, the weight and the cable force. Accelerations, whether due to speed changes or curvature of the flight path, are therefore negligible. Intuitively, this would seem to be reasonable, except at the start of the launch.
- Hence we are also assuming that the balance of moments acting on the sailplane need not be considered, as if the forces all act through the center of mass, as in Figure 1. The effect of tail loads was investigated and found not to be significant.
- The maximum lift coefficient of the sailplane is assumed to be constant, having the same value as in

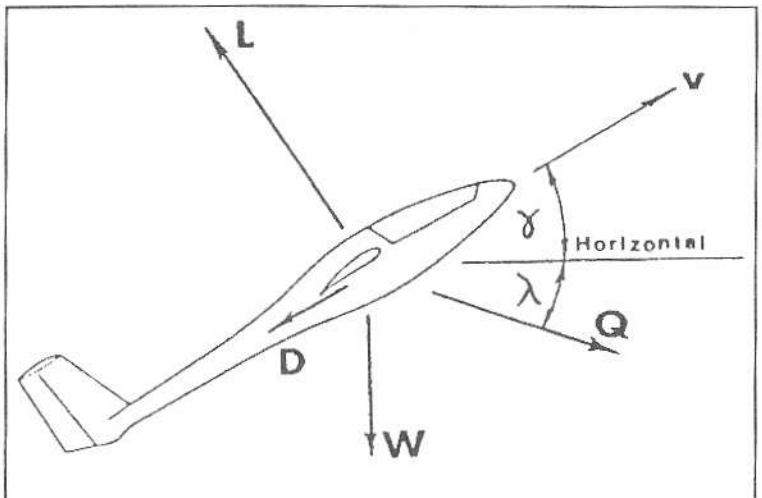

FIGURE 1. The sailplane is assumed to be in equilibrium under the action of the forces L, Q, W and D.

free flight. The stalling speed will then be proportional to the square root of the load factor, L/W.

- An important quantity is the ratio of the wing-root bending moment to its value in free 1g flight. This is greater than the value of the load factor because the downward bending due to the wing weight is not scaled by the load factor, as in free flight maneuvers. On the contrary, it may be diminished as a result of the flight path slope.

All speeds are "equivalent."

Flight Path Boundaries

It was shown in Reference 3 that for a given sailplane, subject to the above assumptions, flight path slope can be plotted against speed for a given cable angle. Figure 2 shows such a plot for a cable angle of 45°, the sailplane being approximately an ASW-19. Line SS is the stalling boundary: attempts to operate above and to the left of SS result in a stall. Line WW is the weak link failure boundary: attempts to operate above this line, to climb more steeply, result in breakage of the weak link. Operation to the right of the right-hand line is forbidden, since this line represents the max. permitted winch launch speed, V_w. In Reference 3, the speed at the intersection of SS and WW was denoted by $V_{s\ crit}$. As the cable angle increases, the diagram contracts and $V_{s\ crit}$ increases as in Figure 3, which corresponds to a cable angle of 75°, the steepest considered in JAR-22 and OSTIVAS. The speeds in Figures 2 and 3 are in knots because the original computer program only dealt with English units. If the launch is conducted at a speed greater than the $V_{s\ crit}$ corresponding to a cable angle of 75°, it will never be possible to stall during the launch. It has now been proposed to the Sailplane Development Panel that this speed, [viz., $V_{s1}(1+ Q_{nom}/W)^{1/2}$ from Equn. 21 of Reference 3], should be known as the "Recommended Winch Launching Speed," symbol V_{wr}, and should appear on the cockpit placard. It would seem sensible to provide a reasonable margin between V_{WR} and V_w.

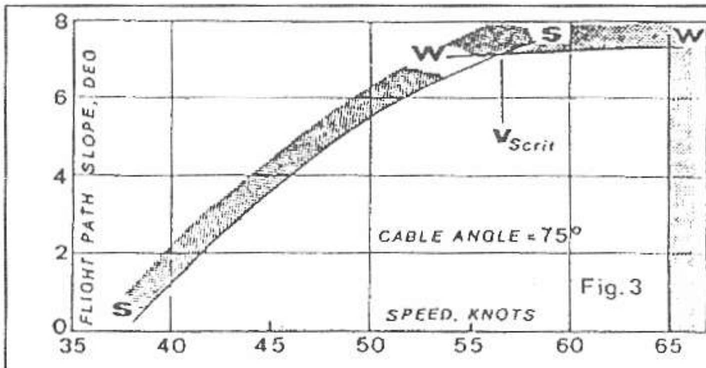

FIGURE 3. Flight path boundaries for a cable angle of 75°.

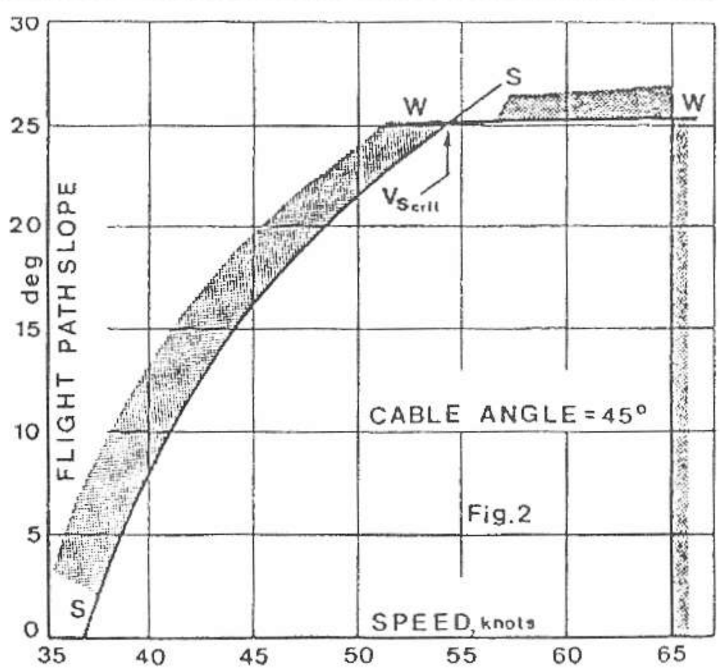

FIGURE 2. Flight path boundaries for a cable angle of 45°.

Weak Link Strengths

If a plot is made, as in Figure 4, a line can be drawn as shown representing the condition $Q_{nom} = 1.3Mg$. To satisfy JAR-22 and OSTIVAS, weak link strengths must lie on or above the line. In what follows, the ratio Q_{nom}/Mg is termed "the weak link factor" and its value will generally exceed 1.3.

In practice, only a finite number of weak link strengths are available to the operator. The Tost series, widely used in Europe, is as follows:

No.	Color	Strength, kN
1	Black	10.0
2	Brown	8.5
3	Red	7.5
4	Blue	6.0
5	White	5.0

The weak link strengths would be represented by a series of horizontal lines in Figure 4. In order to use them, while just satisfying JAR-22 and OSTIVAS, for a series of sailplanes of increasing mass, one would have to proceed along a series of steps, ABCDEFGHIJ. Inevitably, the factor of 1.3 would be exceeded in most cases.

Plotting the weak link factors corresponding to the steps of Figure 4 gives a saw-tooth plot as in Figure 5. The maximum values of the factor mostly lie between 1.47 and 1.62, but higher values would be achieved by sailplanes of less than about 315kg if 5 kN is retained as the weakest weak link. Also shown is the variation of the ratio V_{WR}/V_{S1} as defined by Equation 21 of Reference 3. V_{S1} is the stalling speed in free flight at n=1 in the winch launch configuration. The values of this ratio generally lie between 1.52 and 1.62, but higher values would apply to light sailplanes.

Assuming that the sailplane has sufficient strength, increasing the weak link rating moves the line WW upwards in diagrams such as Figures 2 and 3. On the one hand, fewer weak link failures are to be expected: on the other hand, attempts to climb steeply are more likely to result in a stall.

Maximum Weak Link Strength

An obvious limit to the strength of the weak link is the ratio of the wing root bending moment to that in free 1g flight, M_R. This ratio will be greatest with the steepest cable angle to be considered (75°) and can be calculated from Equn. 12 of Reference 3. It seems desirable that this ratio should not exceed those corresponding to the boundaries of the maneuvering envelope. This is obviously not the only stressing consideration, but seems likely to be the most important.

Here, it is convenient to consider some simple expressions which, as shown in Reference 3, are nevertheless quite accurate. Near the top of the launch, the approximate load factor will be:

$$n = 1 + Q/W. \qquad (1)$$

The approximate wing root bending moment ratio, from Equn. 12 of Reference 3 will be:

$$M_R = (n - W_R Y_{GR})/(1 - W_R Y_{GR}). \qquad (2)$$

It then follows that, denoting $W_R Y_{GR}$ by M_W,

$$M_R = 1 + [\,(Q/W)/(1 - M_W)]. \qquad (3)$$

If M_W has the typical value of 1/3, Equn. 3 finally becomes

$$M_R = 1 + 1.5\,(Q/W). \qquad (4)$$

If $Q = 1.2Q_{nom}$ and $M_R = 5.3$, then $Q_{nom}/W = 2.39$, or 2.4 in round figures. This corresponds approximately to the case of JAR 22.583(b)(1) or OSTIVAS 3.621 with the wing-root bending moment corresponding to Point A of the maneuvering envelope. The case in which the cable load suddenly increases from the level-flight equilibrium value to $1.2Q_{nom}$ does not normally seem to be significant.

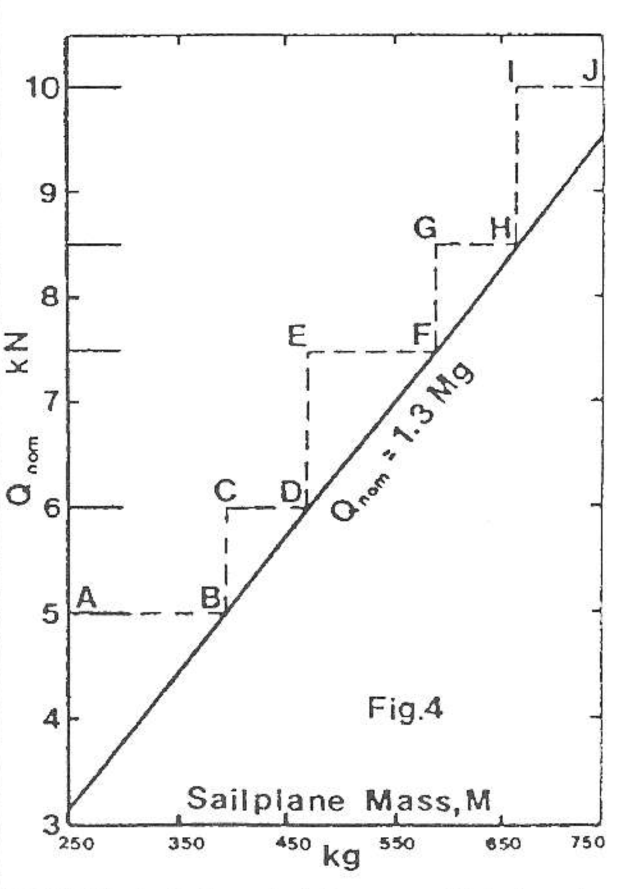

FIGURE 4. Available and minimum weak link strengths.

Under these conditions, from Equn. (2), the load factor will be 3.87 and the corresponding stalling speed will be $1.97V_{s1}$.

To summarize this paragraph, if the maximum wing-root bending moment ratio is not to exceed 5.3, if M_W is 1/3, and if the various initial assumptions apply, then Q_{nom}/W must not be greater than 2.4 and the corresponding load factor and stalling speed will be as above.

Speeds

Since the wing-root bending moment ratio calculated above is 5.3 just as the weak link breaks at $1.2Q_{nom}$, and this figure is independent of speed, it would seem that V_W could be as high as V_A, about $2.3V_{s1}$. The recommended winch launching speed V_{WR}, from Equn. (21) of Reference 3 with the cable load equal to Q_{nom}, is then $1.84V_{s1}$. The margin between V_{WR} and V_W becomes $0.46V_{s1}$ or typically about 30 km/h.

An extreme but feasible choice of wing launching limitations would therefore consist of having a weak link of strength 2.4W and a max. winching speed equal to V_A. This, of course, is a very simplified concept and assumes, in particular, that tail loads are not a consideration.

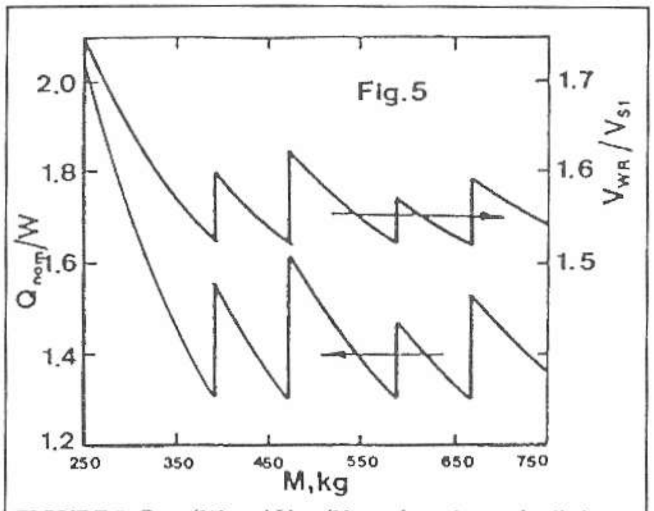

FIGURE 5. Q_{nom}/W and V_{WR}/V_{s1} as functions of sailplane mass.

Further considerations

The above calculations assume that, when the cable applies a load of $1.2Q_{nom}$, the wing root bending moment ratio will be 5.3. This represents a "snatch" case: more commonly, the max. cable load would be Q_{nom} and the wing root bending moment ratio would then be 4.6. Even this figure is rather high, being equivalent to $0.87n_1$. It would seem undesirable to apply loads as high as this at possibly frequent intervals particularly since the pilot has very little indication of the loads being imposed near the top of a wing launch, whereas in maneuvers he is well aware of them.

In the present case, I would propose that the wing root bending moment ratio should not exceed 4.0 with a cable load equal to Q_{nom}. Then Q_{nom} would be approximately 2W and V_{WR} would be $1.73V_{s1}$. If V_W remained equal to V_A, then the margin between these figures would be about $0.57V_{s1}$, or perhaps about 38 km/h (20 knots). With a cable load of $1.2Q_{nom}$, the wing root bending moment ratio becomes 4.6. Similar calculations can be made for other weak link strengths, including the minimum value of 1.3W and the value of 1.62W which appears in Figure 5. These results are summarized in Figure 6.

Q_{nom}/W	V_{WR}/V_{S1}	$\frac{V_A-V_{WR}}{V_{S1}}$	M_R	$1.2Q_{nom}/W$	M_R
1.3	1.52	0.78	2.95	1.56	3.34
1.6	1.61	0.69	3.40	1.92	3.88
1.62	1.62	0.68	3.43	1.94	3.91
2.0	1.73	0.57	4.00	2.40	4.60
2.4	1.84	0.46	4.60	2.88	5.32

FIGURE 6. Effect of weak link strength on V_{WR}, the margin betweeen V_{WR} and V_A, and the wing root bending moment ratio.

Consequences of the proposal

As noted above, weak links have five standard strengths and it would therefore be impossible to satisfy Q_{nom} = 2Mg for all sailplane masses. We also need to choose a minimum value of the weak link factor so that a diagram similar to Figure 4 can be derived. If this factor is taken to be 1.6, as opposed to the present 1.3, then the diagram of weak link strengths as a function of sailplane mass is shown in Figure 7. It will be seen that it is possible to choose a weak link for almost any sailplane mass such that the weak link factor always lies between 1.6 and 2.0. Sailplanes with masses above 637 kg represent the exception. Either weak links of say 1200 daN would have to be provided or it must be accepted that lower weak link factors will apply to heavy sailplanes.

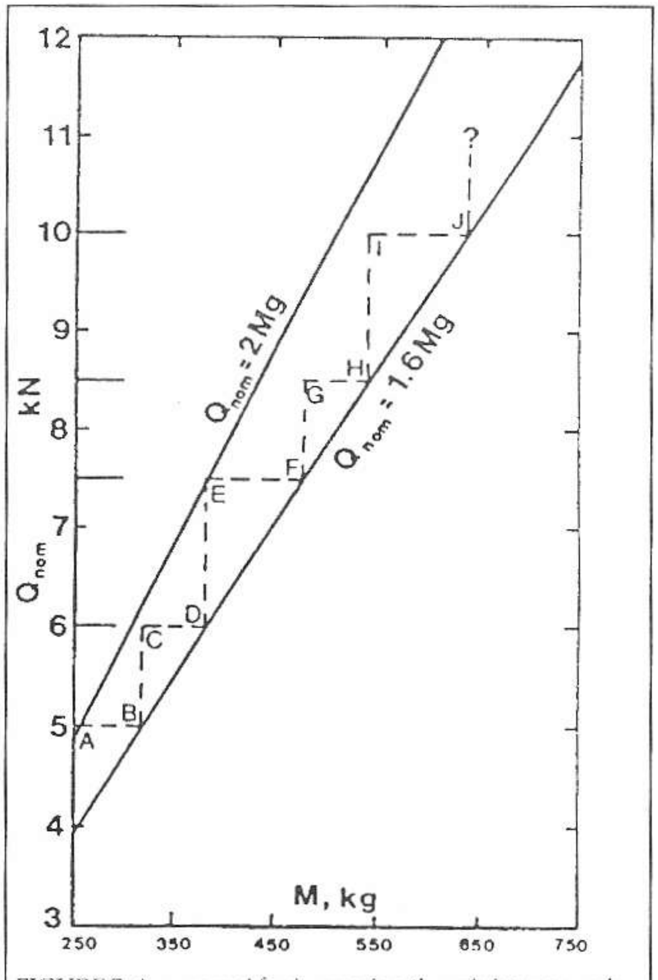

FIGURE 7. A proposal for increasing the minimum weak link strength to 1.6W.

Recommendations and conclusions

1. It is recommended that the minimum value of Q_{nom}/W be taken as 1.6 instead of the usual 1.3. If this value is used in conjunction with the standard range of weak links, the achieved values of Q_{nom}/W will always lie between 1.6 and 2.0. The maximum wing

root bending moment ratio would then be 4.0, or 4.6 with a cable load of $1.2Q_{nom}$.

2. The max. winch launch speed V_W should be as close as possible to V_A. The present value of 110 km/h seems to be too low for current designs. It would be more logical to relate V_W to V_{s1} (or to V_A, which amounts to much the same thing). There would then be a reasonable margin between V_{WR} and V_W.

Some of the figures quoted above are based on calculations relating to a typical Standard Class sailplane without water ballast. While most of the analysis is quite general (subject to the initial assumptions) some figures, such as those relating to wing root bending moment ratios, assume specific values of the ratio of wing weight to total weight and of the spanwise location of the wing's center of mass. These quantities will probably not vary greatly between different designs of unballasted Standard Class sailplanes, but the figures relating to the more extreme Open Class machines or to any ballasted sailplanes may be considerably different and would require individual attention. The object of this paper is not so much to provide precise figures but rather to attempt to extract some general ideas.

References

1. Joint Airworthiness Requirements. "JAR-22: Sailplanes and Powered Sailplanes." Airworthiness Authorities Steering Committee.
2. "OSTIV Airworthiness Standards for Sailplanes," October, 1986, May, 1989 and June, 1992.
3. Irving, F.G.: "Speed and Flight Path Boundaries for Winch Launching." Technical Soaring, Vol. 16, No. 4, October, 1992.

LIST OF SYMBOLS

b Wing span.

C_D Drag coefficient of the sailplane.

C_L Lift coefficient of the sailplane.

g Acceleration due to gravity.

L Total lift of the sailplane.

M Laden mass of the sailplane.

M_R Ratio of the wing root bending moment to that in free flight at n=1.

M_W $W_R Y_{GR}$.

n Load factor, L/W.

Q Cable tension.

Q_{nom} Nominal weak link breaking load.

V_A The maneuvering speed.

V_{s1} Stalling speed in free flight at n=1 in the launch configuration.

$V_{s\,crit}$ The speed at the intersection of the stalling and weak link failure boundaries.

V_W Maximum permitted winch launching speed.

V_{WR} Recommended winch launching speed, equal to $V_{s\,crit}$ at a cable angle of 75°.

W Weight of the sailplane, Mg.

W_R Ratio of the wing weight to the total laden weight of the sailplane.

Y_G The spanwise location of the center of mass of one wing.

Y_{GR} A dimensionless measure of the spanwise location of the center of mass of one wing, defined as $(^3/_4)(2Y_G/b)$.

Note that all speeds are "equivalent."