Notes on Winch-Launching Cases in the OSTIV Airworthiness Requirements for Standard Class Sailplanes

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1. Introduction

Sailplanes, in contrast with other aircraft, require for taking off the aid of external means. These external means usually take the shape of either a towplane or a stationary winch.

For the stress-analyst the winch launch in particular represents a very special loading condition. Airworthiness requirements for sailplanes, therefore, have to include rules for the calculation of the loads occurring during this condition. Different nations have adopted different sets of rules.

The OSTIV requirements for standard class sailplanes, in their attempt to standardize and to find a solution acceptable to all countries, originally included a set of regulations which was largely a copy of the existing British requirements. Following some criticism in earlier OSTIV meetings these regulations have been rewritten in an attempt to provide a more precise definition of the various loading cases. In their revised form the rules have been included in the July 1962 edition of the OSTIV requirements.

Closer study of the new rules leaves some doubt as to the question whether the prescribed loading cases actually represent the most severe conditions occurring during the winch-launching sequence. In order to obtain a clearer picture of what actually can be expected in various stages of the launch, an analysis has been made of a given case, namely that of the Schleicher Ka-6 standard class sailplane, of which a strength calculation was available to the authors. The results of this analysis will be discussed in the following paragraphs. It will be shown that the OSTIV loading cases need not necessarily be the critical cases occurring during a winch launch. To correct this, some modifications are proposed.

2. Basic flying condition

The typical flying condition on which the OSTIV winch-launching requirements are based has also been taken as the starting point for the present study. It is defined as follows (Fig. 1). The sailplane is assumed to be in horizontal flight at speed V_w with a cable load Q acting forward from the towing hook in the plane of symmetry at an angle Θ from the horizontal. The speed V_w should not be less than 100 km/h. The maximum value of the load Q is defined as the nominal strength of the winch cable or weak link incorporated in that cable, multiplied by a safety factor of 1.2. A lower value of Q may be assumed only when the tailplane with fully deflected elevator is incapable of holding this maximum value in balance.

Examination of figure 1 shows that, at a given value of Θ and with $Q = Q_{max}$, there are only two unknowns, viz. the air load acting on the wing and fuselage (resolved into its components L and D), and the tail load L_T. If L_T, with maximum deflection of the elevator, cannot be made sufficiently large to balance Q_{max}, L_T assumes a fixed value and Q, in turn, changes into an unknown. With three equilibrium equations and only two unknowns, the structure is in an unstable condition; to make up for this, a third unknown is introduced in the shape of the force I, a horizontal inertia force. The assumption of such a force is not illogical; it presupposes an acceleration of the sailplane under the influence of the high load Q.

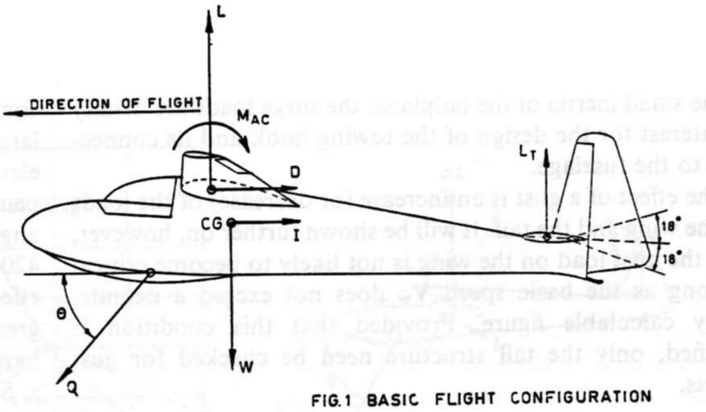


FIG. 1 BASIC FLIGHT CONFIGURATION

3. Discussion of basic assumptions

The basic configuration described above is, in itself, sound. Although during the greater part of the launch the aircraft will be in climbing flight, not in horizontal flight, this only means that the component of the airplane weight perpendicular to the wing will be smaller. This results in a smaller load on the wing. Thus the case of horizontal flight may be considered to be the most critical position the sailplane can assume.

A greater problem is contained in the definition of the maximum cable load. As stated above, this is defined as 1.2 times the nominal strength of the cable, the latter being selected by the designer. The cable strength in this expression *may* be replaced by the strength of a weak link but only if such a weak link is being employed. In the opinion of the authors, this definition of Q_{max} is inadequate, and exposes a sailplane calculated on the basis of an average cable strength to the danger of severe overloading in cases where heavier cables are used. Also in the interest of standardization the authors are of the opinion that the OSTIV strength regulations should include a definite *requirement* for the use of a weak link during winch-launching. A reasonable value for the strength of this link would appear to be 600 kg, which is about twice the weight of the average standard class sailplane and about 40 percent of the strength of a new 4.2 mm (5/32″) winch cable. The maximum value of Q would then be in all cases: 1.2 × 600 = 720 kg.

4. Further loading cases

To complete the picture, on the basic loading configuration discussed in the previous paragraphs, loads of an instantaneous nature are superimposed. They are divided into gust loads and surge loads. These 'dynamic' loads induce changes in the cable load, and also give rise to both linear and rotational accelerations. In the strength analysis equilibrium is obtained by the introduction of linear and rotational inertia forces.

It is obvious that the assumption of the cable load suddenly surging to its maximum value Q_{max} has only then sense when this value has not yet been reached in the basic flying condition discussed before. It will be shown later that this can be the case in the early stages and in the last part of the launch when L_T, being at its maximum, limits Q. But even then, due to the small inertia of the tailplane, the surge loads are mainly of interest for the design of the towing hook and its connection to the fuselage.

The effect of a gust is an increase (or decrease) of the loads on the wing and the tail. It will be shown further on, however, that the gust load on the wing is not likely to become critical so long as the basic speed V_w does not exceed a definite, easily calculable figure. Provided that this condition is satisfied, only the tail structure need be checked for gust effects.

5. Limitations of basic flying condition

We now proceed to a more detailed investigation of the basic loading case represented in figure 1. The sailplane to which the following figures and the various diagrams apply is the well-known Schleicher Ka-6. The principal data of this type are the following:

Design Maximum Weight	W	$= 300$	kg
Wing Weight	W_W	$= 110$	kg
Wing Span	b	$= 15$	m
Wing Area	S	$= 12.4$	m^2
Horizontal Tail Area	S_T	$= 1.61$	m^2
Aspect Ratio	A	$= 18.2$	
Stalling Speed	V_s	$= 61$	km/h

Two different positions of the centre of gravity were investigated, a forward position (CG at 0.17 m aft of wing leading edge) and a rearward position (CG at 0.35 m aft of leading edge). These two values are the extreme CG limits permitted in the Dutch Certificate of Airworthiness.

Furthermore, the calculations were carried out for two different launching speeds, viz. V_w = 100 km/h and the rather higher speed V_w = 118 km/h.

The maximum cable load was taken as 720 kg according to the considerations put forward in paragraph 3.

Firstly, for different values of cable angle and cable load the required elevator force was derived from the equilibrium equations, and from this the required elevator angle was calculated. The results are shown in figure 2.

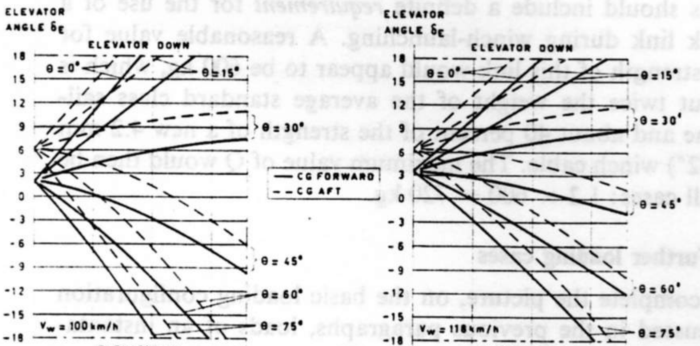


FIG. 2 ELEVATOR ANGLE δ_E AS A FUNCTION OF CABLE LOAD Q AND TOWING ANGLE θ

It is seen that, due to the low position of the launching hook, at small cable angles (up to about 40°) the cable moment is tailheavy and is balanced by an upward force on the tail resulting from a downward (positive) elevator deflection. With larger cable angles the moment is noseheavy and the elevator deflection is upward.

The limited deflection of the elevator (± 18 degrees in the case of the Ka-6) places a distinct restriction on possible combinations of Θ and Q. At a speed of 100 km/h, the largest horizontal cable load that can be balanced with elevator fully down, lies between 270 kg and 350 kg, depending on the CG position. At the same speed and a cable angle of 75°, the largest possible cable load lies between 420 kg and 490 kg. With the larger speed of 118 km/h the effectiveness of the elevator naturally increases so that greater cable loads can be supported, as shown in the right-hand half of the diagram.

So far, only the restrictions resulting from limited elevator movement have been investigated. A restriction of a different nature is imposed by the maximum value of the lift coefficient. At a given speed, the value of $C_{L\max}$ limits the magnitude of the upward force on the wing and, as a consequence, also that of the downward component of the cable load.

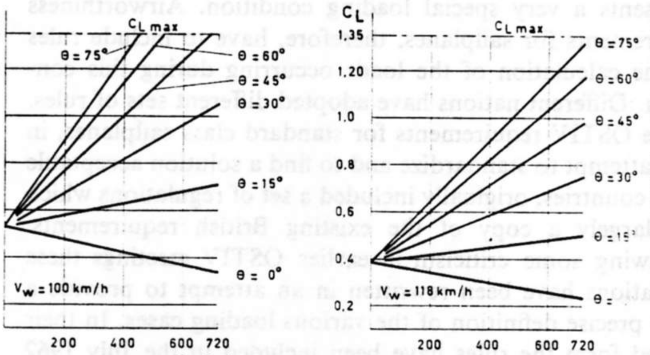


FIG. 3 C_L AS A FUNCTION OF CABLE LOAD Q AND TOWING ANGLE θ

For the Ka-6, the effect of this restriction is illustrated in figure 3. At the launching speed of 100 km/h, the maximum cable load of 720 kg can only be balanced by wing lift as long as the cable angle does not exceed 43°. With larger angles, the possible cable load drops off, until at 75° a value of 450 kg is reached.

On the other hand, when the speed is raised to 118 km/h, as shown in the right-hand half of the figure, this limiting effect from $C_{L\max}$ disappears, meaning that now sufficient lift can be developed for all possible combinations of cable angle and cable load.

In figure 4, the results of the previous calculations have been combined for one particular case: speed of 100 km/h and forward position of the CG. The diagram shows that the full cable load of 720 kg can be developed only within a very restricted area of cable angles, viz. between 21° and 43°. Outside this area the possible cable load drops off rapidly, due to restrictions imposed either by the lifting power of the wing or by the elevator deflection. For example, at $\Theta = 0$, the possible cable load is not more than 350 kg, one-half of the maximum value. At this stage it may be noted already that the case specified in para. 2.2.1. of the latest OSTIV winch-launching requirements ($\Theta = 0°$, $Q = Q_{\max}$) is, at least for the sailplane under consideration, incompatible with the actual characteristics of the aircraft. (Apart from the fact that this case would require a power output from the winch of not less than $\dfrac{100 \times 720}{3.6 \times 75} = 267$ hp!)

6. Critical loads

After the above survey of the possible combinations of cable angles and loads in the basic winch-launching condition, we

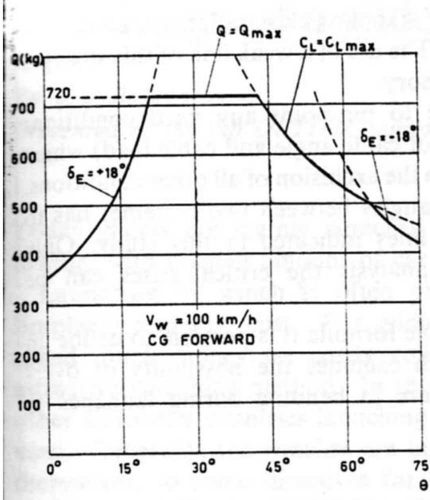


FIG 4 POSSIBLE COMBINATIONS OF Q AND θ

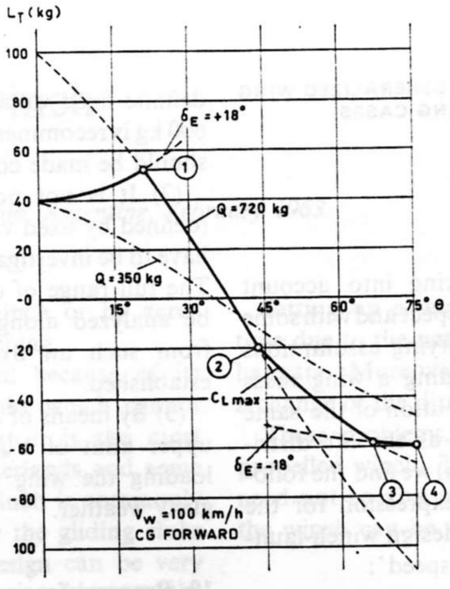


FIG 5 TAIL LOAD L_T AS A FUNCTION OF CABLE ANGLE θ

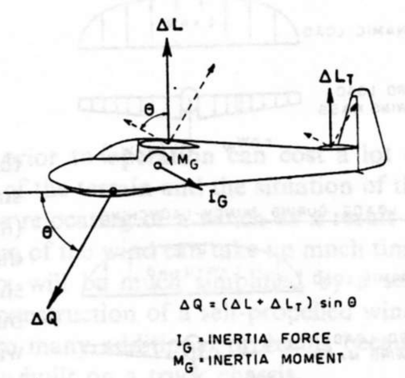


FIG 6 EQUILIBRIUM OF INCREMENT LOADS DUE TO AN UPWARD GUST

now turn to the question which of these combinations are critical. In a winch launch, there are three main critical areas in the sailplane structure: (i) the cable hook and its attachments to the surrounding fuselage structure; (ii) the wing, and (iii) the tailplane. As for the *hook*, this must be capable of carrying the maximum cable load at all possible cable angles, whether this load occurs in the basic equilibrium condition or is caused by surging. In practice, it is sufficient to investigate the extreme cases of $\Theta = 0°$ and $\Theta = 75°$, both combined with Q_{max}.

The load on the *wing* is not likely to become critical in the basic condition as long as the speed V_w is kept sufficiently far below the design manoeuvring speed V_M. In the case of the Ka-6 with a stalling speed of 61 km/h, $V_M = 61 \sqrt{5.3} = 140$ km/h. On the contrary, the positive gust case may be critical for the wing structure, as will be explained further on.

The variation of the load on the *tailplane* as a function of the cable angle is shown in figure 5. It is seen that the maximum positive (upward) tail load occurs at $\Theta = 22°$, Q being 720 kg (point 1). Maximum negative tail load is reached at point 4 with $\Theta = 75°$ and Q = 500 kg. The portion of the curve between points 2 and 3 indicates the range where the wing load is at its maximum, C_L having reached C_{Lmax}. Obviously, maximum wing load does not coincide with maximum tail load.

7. Gust cases

The effect of a gust is an increase or a decrease of the aerodynamic loads on the wing and on the tailplane.

Considering first the case of an upward gust, the increase of the loads on the wing and the tailplane causes an increase of the cable load and, at the same time, linear and rotational accelerations of the aircraft. It seems reasonable to assume that the cable load increment equals the sum of the components parallel to the cable of the lift increments:

$$\Delta Q = (\Delta L + \Delta L_T) \sin \Theta$$

The force system will then be as shown in figure 6. An inertia force I_G and an inertia couple M_G have been introduced to achieve equilibrium.

The existing OSTIV regulations already implicate that an increase of the cable load to its breaking strength will cause the sailplane to regain free flight, a situation which from the strength standpoint is not critical provided the launching speed V_w does not exceed the design manoeuvring speed V_M. In algebraic terms, only those cases need be investigated where $Q + \Delta Q < Q_{max}$.

In trying to assess the actual magnitude of ΔQ, we have to consider the fact that in gust cases the lifting capacity of wing and tailplane is greater than in unaccelerated flight, being limited by the value of C_{Lmax} (dynamic) for the surface in question. In the OSTIV requirements this is assumed to be $1.25 \times C_{Lmax}$ (static), hence for the Ka-6 wing amounts to $1.25 \times 1.35 \cong 1.7$. A rough calculation indicates that with the required gust strength of 10 m/s this figure is likely to be exceeded, or at least very closely approached, at all cable angles within the range under consideration.

It may be concluded that in winch-launching the upward gust case can be a critical case only when at one or more values of the cable angle the cable is capable of sustaining, without breaking, an increase of the wing lift coefficient to C_{Lmax} (dynamic) and a corresponding simultaneous increase of the tail lift.

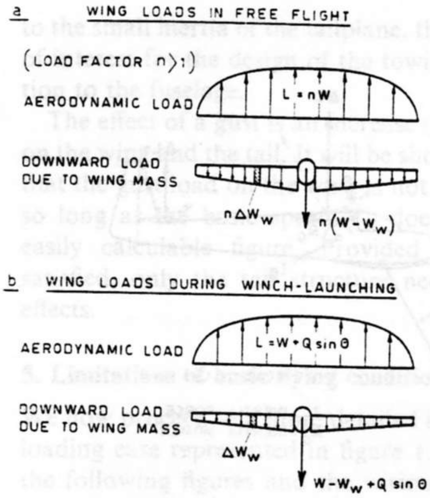
Examination of figure 5 shows that for the Ka-6 this condition is fulfilled at $\Theta = 0°$ ($Q = 350$ kg, $\sin \Theta = 0$ hence $\Delta Q = 0$) and at point 3, where $\Theta = 66°$. For this latter point the figures are as follows, assuming for the tailplane 90 per-cent of the aerodynamic efficiency of the wing:

$$\begin{aligned}\Delta L + \Delta L_T &= q\,S\,(1 + 0.9\,S_T/S) \times 0.25\,C_{Lmax}\,(\text{stat})\\ &= 48 \times 12.4\,(1 + 0.9 \times 0.13) \times 0.25 \times 1.35\\ &= 224 \text{ kg}\end{aligned}$$

$$\Delta Q = 224 \sin 66° = 205 \text{ kg}$$

$$Q + \Delta Q = 500 + 205 = 705 \text{ kg} < Q_{max}.$$

At this point the question arises whether it would be possible to define an upper limit to the winch-launching speed V_w (similar to V_M in free flight) that would exclude any possibility of an upward gust becoming critical to the wing structure. On tackling this question it must be kept in mind that when equal amounts of aerodynamic lift are developed in a winch launch and in free manoeuvring flight, wing bending moments will be higher in the first case due to the relieving effect from the wing mass being smaller (1 g in unaccelerated flight against n g). This effect is illustrated in figure 7.



◀ FIG 7 GENERALIZED WING LOADING CASES

Taking into account this aspect and with some simplifying assumptions (including a wing mass distribution of the same shape as the lift distribution) we find the following expression for the 'safe design winch-launching speed':

$$V_{w1} = V_M \sqrt{\frac{C_{L\,max}\,(stat)}{C_{L\,max}\,(dyn)}} \sqrt{1 - \frac{n_1 - 1}{n_1}\,\frac{W_w}{W}}$$

If the design speed does not exceed the value V_{w1} given above, there is no danger of a gust causing critical bending loads in the wing structure during any stage of the launch. For the Ka-6, V_{w1} is 105 km/h.

The effect of the upward gust on the tailplane must be investigated separately. The critical condition for this surface under positive gust loads obviously occurs when the sum total of the basic aerodynamic load, the load increment from the gust, and inertia loads from I_G and M_G (Fig. 6), attains a maximum with the cable load being just under Q_{max}. The critical case is found by trial and error; for the Ka-6 it is due to occur within the cable angle range between 0° and 22° where high basic tail loads are developed.

So far, only the case of an upward gust has been discussed. However, there are two reasons why a downward gust is not likely to be critical for the structure of a sailplane in a winch launch. Firstly, with normal values of the design launching speed and a downward gust of the required strength of —10 m/s, the resulting load on the wing is due to be relatively small. Secondly, under the influence of a down gust the cable will slacken so that temporarily the aircraft will be in a free flight condition where it can withstand gusts of much higher strength.

8. Surge cases

We have observed already that surging loads are mainly of importance for the launching hook and its attachment to the surrounding fuselage structure.

Furthermore, surging gives rise to linear inertia loads that usually subtract from the basic 'static' tail load, and to rotational inertia forces that always add up to the basic load. Consequently, in those cases where surging is possible (Q having not yet reached its maximum value in the basic condition) these inertia effects have to be investigated. For the Ka-6, this investigation can be restricted to the case represented by point 4 of figure 5.

9. Conclusions

The most important conclusions to be drawn from the above study are the following:

(1) The choice of the nominal cable force Q_{nom} should not be left to the designer but should be set, once and for all, at a definite fixed value. For standard class sailplanes a value of 600 kg is recommended. The use of a weak link of this strength should be made compulsory.

(2) It is not possible to pin-point any fixed conditions (defined by fixed values of cable angle and cable load) which have to be investigated to the exclusion of all other conditions. The full range of cable angles between two extremes has to be analyzed along the lines indicated in this study. Only from such an overall analysis the critical cases can be established.

(3) By means of a simple formula it is possible to define an upper limit of V_w which excludes the possibility of overloading the wing structure in bending during launches in gusty weather.

10. Proposal for new wording of OSTIV winch-launching requirements

2. *Winch-launching*

2.1. The sailplane shall have proof and ultimate factors of not less than 1.0 and 1.5 respectively under the loads arising from the conditions prescribed below.

2.2. *Cable Loads.* The sailplane is initially assumed to be in horizontal flight at speed V_w with a cable load Q acting forward from the towing hook in the plane of symmetry and at an angle Θ from the horizontal. Equilibrium shall be achieved by the introduction of a horizontal inertia force.

2.2.1. The speed V_w shall be chosen by the designer but shall not be less than 100 km/h EAS.

2.2.2. The cable load Q shall be the lesser of 1.2 Q_{nom} and that value for which equilibrium is achieved with either the elevator fully deflected or the wing at its maximum lift value. *Note:* Q_{nom} shall be taken as 600 kg, and a weak link of this strength or less shall be employed during winch-launching.

2.2.3. The whole range of cable angles between Θ = 0° and Θ = 75° shall be investigated.

2.3. *Gust Loads.* In the conditions of para. 2.2. the sailplane encounters up and down gusts normal to the flight path of maximum velocity ± 10 m/s.

Note (i): The load increments due to gusts shall be determined according to Chapter 3-1. para. 2.

Note (ii): The load increments due to gusts shall be balanced by linear and rotational inertia forces; with upward gusts also by an increase of the cable load. When Q attains 1.2 Q_{nom}, the cable will break and the sailplane regain free flight. Provided that V_w does not exceed V_M, this case is not critical.

For downward gusts it shall be assumed that the cable load temporarily reduces to zero.

2.4. *Surge Loads.* In the conditions of para. 2.2., at those cable angles where the cable load Q is below 1.2 Q_{nom}, the cable load suddenly increases to the latter value. The increment loads shall be balanced by linear and rotational inertia forces.

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