Safety Analysis of the Winch Launch

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Abstract

In 2004 the British Gliding Association (BGA) formed a Safety Initiative Team to determine actions to improve the gliding accident rate in the UK. Analysis of the accident record from 1987 to 2004 showed that there was scope for action to reduce the hazards associated with incomplete winch launches. It was evident from the accident data that many of the most serious winch launch accidents—those resulting in either fatal or serious injury—can be divided into two classes: stall during rotation into the climb; and power loss at low level. This paper describes two simple modelling tools which were created to assist Browning and others to assess the important factors which can lead to dangerous conditions in each of these cases. To permit the user easily to assess 'what-if' cases the tools were constructed using a readily available spreadsheet program (Microsoft Excel), which also allowed immediate graphing of the results. In addition the Appendix gives consideration to what is meant by the pilot's perception of normal acceleration judged by the force exerted by the glider seat.

Nomenclature—see also definition sketch (Fig. 1)

Symbol	Meaning	Unit
θ	Flight path angle above horizontal	radians
β	Angle of cable pull below horizontal	radians
D	Magnitude of drag force	N
L	Magnitude of lift force	N
W	Magnitude of weight force	N
P	Magnitude of cable tension at the glider	N
n	Load factor ($= L/W$)	'g'
g	Acceleration due to gravity	$m\ s^{-2}$
u_1 , u_2	Horizontal and vertical components of glider's velocity	$m\ s^{-1}$
v	Magnitude of glider's velocity	$m\ s^{-1}$
U_0	Initial value of u_1	$m\ s^{-1}$
x , y	Horizontal and vertical position of glider	m

Note that equation symbols in bold text represent vector quantities.

Introduction—the tools in general

In 2004 the British Gliding Association (BGA) formed a Safety Initiative Team to determine actions to improve the gliding accident rate in the UK. Analysis of the accident record from 1987 to 2004 showed that there was scope for action to reduce the hazards associated with incomplete winch launches[1]. It was clear that the lessons of the articles by Gibson on the subject[2,3] were being forgotten.

It was evident from the accident data that many of the most serious winch launch accidents—those resulting in either fatal or serious injury—can be divided into two classes:

- stall during rotation into the climb; and
- power loss at low level.

This paper describes two simple modelling tools which were created to assist Browning and others to assess the important factors which can lead to dangerous conditions in each of these cases. To permit the user easily to assess 'what-if' cases the tools were constructed using a readily available spreadsheet program (Microsoft Excel), which also allowed immediate graphing of the results, and cells can be highlighted according to the conditions found (such as a stalled state).

The tools are simplified as much as possible to basic dynamics and kinematics, and contain no aerodynamics. The glider is treated as a point mass subject to the forces of weight, lift, drag and cable pull (see Figure 1). The load factor n is calculated as the ratio of the lift to the weight of the glider, and the condition for a stall is diagnosed when the speed of the glider falls below the 1g stalling speed multiplied by the square root of the load factor. No attempt is made to account for the effects of a wind gradient.

Forces are resolved in two orthogonal directions in the vertical plane containing the motion, and the resulting differential equations of motion are solved using a simple centred difference scheme; a time step of 0·05 seconds was found to be suitable.

In each of the two cases there are many parameters controlling the behaviour of the glider, some of which are under the control of the pilot. These and others can be set by the user of the tools so as to examine which combinations result in hazardous conditions. It is also possible to step automatically through ranges of parameter values and build up tables of a particular output measure of interest such as glider speed ÷ stall speed (i.e. the margin above stall). Figure 2 is drawn from tables constructed in this way.

Rotation into the climb

The principal motivation behind examining this phase of the winch launch in detail was the appreciation that the loading on the wing (and hence the propensity to stall) depends not only on the static pull exerted by the cable[5], but also the dynamic force required to provide the vertical acceleration of the glider in these early stages[4].

Baseline case

Simple assumptions were made in the baseline case assessed. These were:

- Drag was assumed to be constant: a fixed fraction (which could be set by the user) of the weight.
- The tension in the cable at the glider (which we call the "pull") was assumed constant.
- The pilot rotates at a constant rate (i.e. $\dot{\theta}$ is constant).
- The cable was assumed to be horizontal at the glider throughout the rotation.

Other cases considered

In order to assess the sensitivity of the results to these assumptions, the following excursions were considered:

A. Other drag cases:
   Zero drag (just a special case of the first baseline assumption above); and
   A simple representation of polar drag as the sum of terms in v^2 and v^{-2}.
B. The speed of the cable being constant. This was not pursued to any great extent as it seemed contrary to common experience.
C. The pilot rotates at a rate which linearly increases from a pre-set value to a maximum (set by the user) and then linearly decreases to the starting value at the same rate. This manner of behaviour was suggested by Goulthorpe[4].
D. Cable at a small downward angle to the horizontal.

Equations of motion

We aim to calculate:

1. L/W and $v = \left(u_1^2 + u_2^2\right)^{1/2}$. Then we can determine whether the glider is stalled.
2. P/W to determine whether the weak link breaks.

Kinematically:

$$\tan\theta = \frac{u_2}{u_1}$$

Resolving forces horizontally and vertically:

$$P\cos\beta - L\sin\theta - D\cos\theta = \frac{W}{g}\dot{u}_1$$

$$-W - P\sin\beta + L\cos\theta - D\sin\theta = \frac{W}{g}\dot{u}_2$$

For a range of conditions it is straightforward to solve these numerically (for example using an Excel workbook). This was done using centred differences in time, with a forward difference step to start.

As a check, they can be solved analytically if certain simplifications are made:

1. $D = 0$.
2. Rotation is at a constant rate so that $\theta = kt$ for a constant value of k.
3. $P = P_0$ a constant.
4. $\beta = 0$ (which is in the baseline case anyway).

Then

$$\frac{L}{W} = \frac{kU_0}{g} + \frac{2P_0}{W}\sin\theta + 2\cos\theta - 1$$

and $$v = U_0 + \frac{gP_0}{kW}\sin\theta + \frac{g}{k}\left(\cos\theta - 1\right)$$

These quantities were calculated alongside the numerical results for the equivalent cases and good agreement was obtained.

Results

Although the purpose of this paper is to describe the tools used by Browning and others, rather than to present detailed results, it is appropriate to outline the main lessons identified.

The two main things under the control of the pilot are the initial speed at the start of rotation, and the rotation rate. So for ranges of these values the margin above stall was tabulated several times, each table for a different value of cable pull (in principle under control of the winch driver). The curves in Fig. 2 show the combination of values of initial speed and rotation rate which *just* result in a stall at some time during rotation. These show that the stall regime is insensitive to the cable pull unless the pull is small, but if the pull is too small the stall regime expands. It is clear that low speed at the start of rotation combined with a quick rotation is a recipe for a stall, whatever the cable pull. It was found that for a small pull the stall can occur at the end of the rotation rather than the beginning (Figure 3). So the advice to pilots is:

- Delay rotation until adequate speed is seen and continuing acceleration is present.
- Ensure the transition from level flight at take-off to the full climb is controlled, progressive and the rotation rate is not excessive.

The key is to ensure the airspeed increases quickly enough to outpace the increase in stall speed as the load factor increases. This is made easier if the pilot starts by demanding a steadily increasing rotation rate and backs off as the desired climb angle is approached[4]. This provided the motivation for trying excursion C above. Because the curve representing airspeed against time is generally found to be concave upwards, this variation was indeed found to assist in avoiding stalling during rotation but the effect was small.

Under the conditions of interest changing the formulation of drag (excursions A) made little difference of significance.

Setting the cable at a small downward angle to the horizontal (excursion D) also made only a small difference to the results, in this case increasing the likelihood of a stall by a small amount.

Low-level power failure

We now consider the other tool which allows investigation of the recovery to steady level flight following a sudden launch failure at low level.

In these calculations the recovery is broken down into four stages numbered 0 to 3:

0. A delay following power failure during which the pilot does not react to recover (although it is assumed that control inputs are applied to maintain the climbing flight path). The duration of this delay can be set by the user, as can the initial flight path angle and speed.
1. A push-over manoeuvre in which the pilot maintains a constant reduced perceived 'g' value, set by the user.
2. A straight dive during which the pilot waits for speed to build up. The flight-path descent angle and the target speed can be set by the user.
3. A pull-out manoeuvre in which the pilot maintains a constant perceived 'g' value greater than unity, set by the user. This is maintained until the flight-path is horizontal.

Symbols for low-level power failure—see also definition sketch (Fig. 4)

	Symbol	Meaning	Unit
	θ	Flight path angle above horizontal	radians
→	θ_0	Initial flight path angle above horizontal	radians
→	β	Flight path angle below horizontal after push-over	radians
→	T_0	Delay after power failure before pilot starts push-over	s
→	n_1	Load factor* during push-over	'*g*'
→	n_2	Load factor* during pull-out	'*g*'
⇒	v_0	Magnitude of glider's velocity at time of power failure	$m\ s^{-1}$
	v_1	Magnitude of glider's velocity at start of push-over	$m\ s^{-1}$
	v_2	Magnitude of glider's velocity at end of push-over	$m\ s^{-1}$
→	v_3	Magnitude of glider's velocity at start of pull-out	$m\ s^{-1}$

Notes on table of symbols

Symbols marked thus → are under the pilot's control and can be set by the user of the tool. In addition, the user can set the initial speed of the glider marked as ⇒. Unmarked quantities are calculated by the tool.

* It is worth considering in more detail what is meant by the pilot's perception of normal acceleration judged by the force exerted by the glider seat. See Appendix.

Solution

In stages 1 and 3 the equations of motion are formed by resolving forces horizontally and vertically, just as in modelling the rotation into the climb. Stages 0 and 2 are simpler and are solved by resolving along the flight path which can be treated as an inclined plane. The solution at the beginning of one stage is matched to that at the end of the previous one.

Discussion

Once again the purpose of this paper is to describe the tools rather than to present detailed results. Browning[1] reports the results of many runs of the tool, varying initial airspeed and climb angle, and pilot reaction delay to determine the stall boundaries, and varying these, recovery angle and target airspeed following recovery to evaluate the height lost. The tool reports when it diagnoses a stall and if this happens the subsequent calculations should be disregarded. An example is illustrated in Figure 5.

Conclusions

Determining the boundaries of a safe rotation into a winch launch and a safe recovery from a power failure at low level requires the variation of many parameters, and so needs tools which enable the investigator to try different values and get immediate feedback on their effect. This was achieved using spreadsheet solutions to the simplified equations of motion, with the added benefit of dynamic graphs giving further insight.

References

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3 Gibson, J.C., "The mechanics of the winch launch", *BGA winch driver's manual*, 2002.

4 Goulthorpe, P.J., "The first few seconds", *Sailplane & Gliding*, June/July 1997, pp. 138–140 and BGA winch driver's manual.

[5] Scull, W., “Accidental spins off winch launches”, *Sailplane & Gliding*, December 1991/January 1992, pp. 302–303.

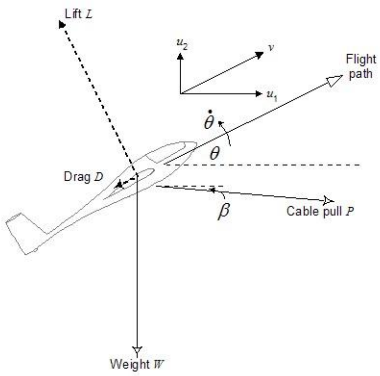

Figure 1 Force definition sketch during rotation.

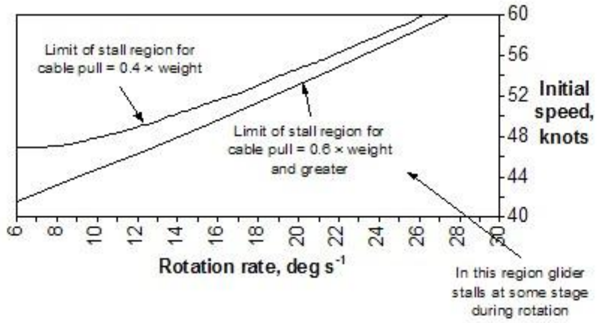

Figure 2 Example of stall regions for different values of cable pull. Plotted for glider L/D = 45 and 1g stall speed of 38 knots.

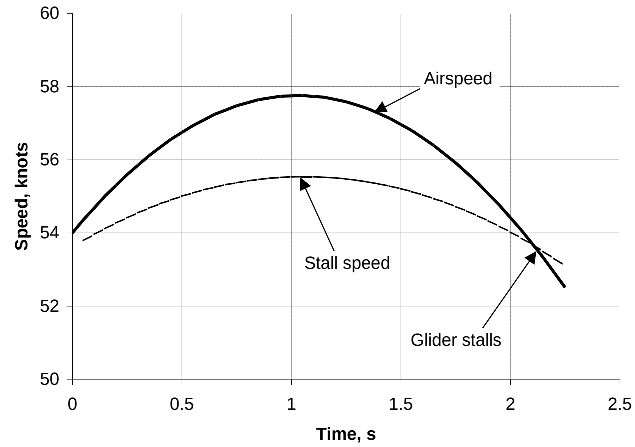

Figure 3 Airspeed and stall speed during rotation for an example case of small cable pull (0·4W), a rotation rate of 20° per second and the same glider parameters as for Fig

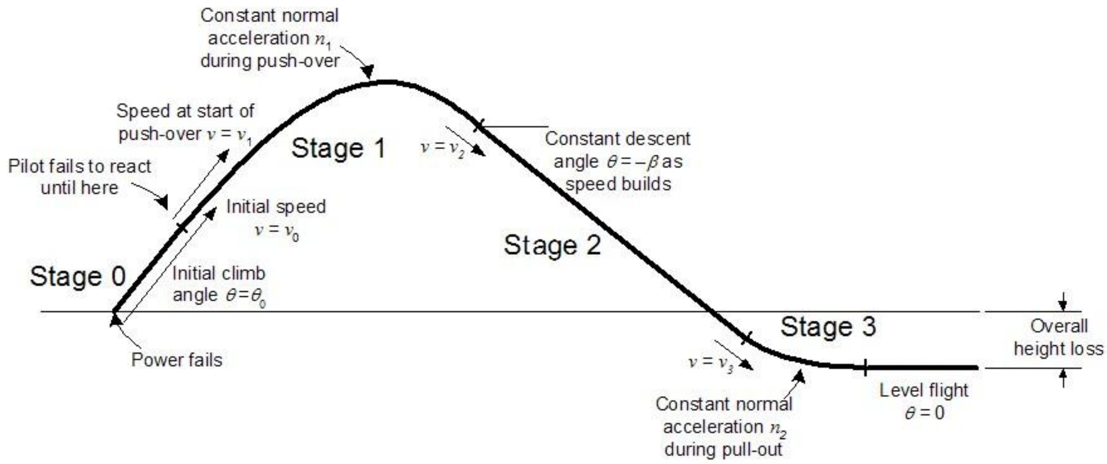

Figure 4 Definition sketch for the recovery after power failure.

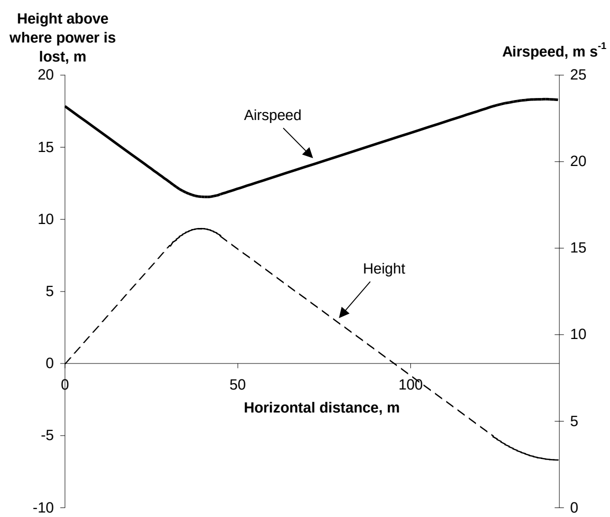

Figure 5 Example of airspeed and flight profile for the case of a glider with L/D = 25 starting at speed 23·2 ms^{-1} (45 knots), initial climb angle 15 degrees and a pilot delay of 1·5 seconds. The push-over to a 10 degree dive angle is at zero 'g' and the target airspeed before pulling out is also 23·2 ms^{-1} (45 knots). The height lost from the point of power failure is 6·7 m.

Appendix—Pilot's perception of acceleration

In giving advice to pilots about the manoeuvres for recovery in Stages 1 and 3 we need to say something about the normal acceleration or 'g' to be achieved. This begs the question concerning the pilot's perception of this—the force on the pilot exerted by the seat.

The starting point for the analysis is noting that the pilot and the glider have identical accelerations so the vector sum of the forces on the glider divided by its mass,

$(\boldsymbol{W} + \boldsymbol{P} + \boldsymbol{L} + \boldsymbol{D})/(M + m) = \boldsymbol{a}$

where $\boldsymbol{a}$ is the acceleration

M is the mass of the (empty) glider, and

m is the mass of the pilot

is the same as the vector sum of the forces on the pilot divided by the mass of the pilot:

$$(\boldsymbol{F} + \boldsymbol{w})/m = \boldsymbol{a}$$

From this we can deduce that during a steady climb (with P present) $\boldsymbol{a} = \boldsymbol{0}$ and so the seat force is equal to the weight of the pilot and acts vertically upward, the pilot experiencing 1g. Note that this is different from what would be deduced from the reading of an accelerometer fixed to the panel. This would read the component of $\boldsymbol{F}/m$ resolved in the direction of the glider's normal axis—in this case $w\cos\theta/m$ which equals $g\cos\theta$. Following a cable break, after P is removed and the angle of climb maintained, the seat force is $(\boldsymbol{L} + \boldsymbol{D})\dfrac{m}{M + m} = (\boldsymbol{L} + \boldsymbol{D})w/W$ and for small D the pilot therefore experiences approximately L/W units of 'g'. In other words, in the absence of the cable force P the load factor n can be approximated by the pilot's perception of 'g'.