Boundaries of Safe Winch Launching

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Abstract

All UK gliding accidents from 1987-2004 have been classified by the apparent immediate cause. Accidents associated with winch launches included 18 with fatal and 38 with serious injury. The number and the severity of the accidents and corresponding hazards at each stage of a winch launch were identified. Modelling work was undertaken to establish the conditions for a stall and possible flick roll during rotation, and the combinations of airspeed, climb angle, delay before lowering the nose, recovery dive angle, and other relevant variables that would be unrecoverable after power loss. Guidance is offered for a safe transition of a winch launch from take off to the main climb and also a safe recovery in the event of power loss at a height of less than 100 ft.

Nomenclature

g	acceleration due to gravity
L/D	lift/drag ratio
V_S	stall speed
$V_{s,g=1}$	stall speed at 1g

Introduction

Over 2600 accidents and incidents were reported to the British Gliding Association in the period 1987 to 2004. They included 69 with fatal and 109 with serious injury. All have been classified by their apparent immediate cause.

Winch launches in which the glider failed to reach a normal launch height, for any reason, led to 18 fatal accidents, 38 serious injury accidents, and 157 written off or substantially damaged gliders (Table 1). In comparison with aerotow launches, the winch launch accident rate is about 50% higher, and the fatal or serious injury accident rate is over 7 times higher (Table 2).

The number and the severity of the winch accidents, and the characteristic hazards, were identified at each stage of the launch. The majority of the fatal accidents and about half the serious injury accidents were associated with a stall and spin, either during rotation while still attached to the cable, or after power loss at a height of more than 100 ft. About half the serious injury accidents were after power loss at a height of less than 100 ft (Table 3).

The purposes of this study were to determine the conditions for a stall during the rotation stage of a winch launch and to determine the combinations of airspeed, climb angle, and other variables that would be unrecoverable after power loss on a winch launch at a height of less than 100 ft. Identification of these conditions would offer guidance to pilots on how to avoid these hazards.

Winch launch hazards

The main hazards at each stage of the launch are:

1)	Ground run	Wing drop, groundloop or cartwheel.
2)	Rotation	Accelerated stall, flick roll to inverted flight *or* power loss, stall.
3)	Main climb	Power loss, spin

It is well known that accidents resulting from a wing drop on the ground can be avoided by beginning the launch with the left hand on the release and pulling the release immediately if the wings cannot be kept level.

Accidents from a stall during rotation are rare but serious. They kill or seriously injure an average of one person per year in the UK. If such a stall is to be avoided, the pilot must be aware of the conditions under which it can occur. These conditions did not seem to have been defined.

Accidents following power loss near the ground are the most common winch accident. In the 18 year period, there were only 3 accidents trying to land ahead after power loss at a height of more than 100 ft but 126 accidents after power loss at a height of less than 100 ft. The latter group included one fatal accident, 17 accidents resulting in serious injury, and 52 accidents in which gliders were written off or substantially damaged. It seems likely that some pilots do not appreciate how vulnerable they are after power loss near the ground. An assessment of vulnerability requires quantitative knowledge of recoverable combinations of airspeed, climb angle, delay before lowering the nose, and other variables. This information did not seem to be available.

It is well known that a spin after power loss in the main climb can be avoided by lowering the nose to a suitable recovery attitude and maintaining this attitude until the approach speed has been attained.

The objectives of the work reported here were to identify the conditions for stalling during rotation and to identify the circumstances in which power loss at a height of less than 100 ft would be unrecoverable.

Stall during rotation

Accidents

There were 7 fatal and 8 serious injury accidents of this kind to UK gliders in the period 1987-2004. In some instances the glider hit the ground inverted, with the cable still attached.

Mathematical models

During rotation, the glider was assumed to be a point mass subject to the forces of lift, weight, drag, and cable pull. These forces are not in equilibrium. There is both horizontal and vertical acceleration.

It was assumed that the stalling speed is proportional to the square root of the load factor and that the load factor is the sum of two elements. The first element is that which arises from assuming the lift, weight, drag, and cable pull are in equilibrium. The second element is that which arises from the vertical acceleration.

Thirteen cases were evaluated at each 5º of rotation using three airspeed profiles and five rates of rotation. The calculations were carried out manually according to procedures described elsewhere[1, 2] for the 'equilibrium' element and elementary trigonometry for the acceleration element.

This work indicated that stalling during rotation results from a low airspeed combined with a high rotation rate, and a glider with a 1g stalling speed of 34 knots will stall at about 50 knots with a rotation rate of 20º per second.

These results were discussed with Hills who then provided a more rigorous analysis and a spreadsheet with parameters that could be set by the user[3]. As with the manual analysis, the drag, the rotation rate, and the tension in the cable at the glider (the "pull") were assumed to be constant, and the cable was assumed to be horizontal at the glider throughout the rotation. Hills' tool confirmed the manual findings and permitted many new combinations of variables to be explored. Since the modelling that follows has used this tool, the details of the manual methodology are not reported here.

Main findings

The mathematical model was used to explore the effect of the following parameters on the stalling speed of a glider with a 1g stall speed of 34 knots while rotating on a winch launch with the cable horizontal at the glider and at a constant airspeed of 50 knots: glider climb angle from 10º to 40º, cable pull from 0.4 to 1.0 times the glider weight and rate of rotation from 6.3º to 20º per second.

The results are summarised in Table 4. Figure 1 is a graphical representation of Table 4. Figure 2 shows how $V_S/V_{s,g=1}$ depends on the rotation rate.

The value of $V_S/V_{s,g=1}$ during rotation is primarily controlled by the rate of rotation.

The effect of climb angle is small; the effect of drag is insignificant; variation of cable pull has a small effect; a 10% increase in airspeed increases V_S by about 2% and hence a higher airspeed increases the safety margin.

A glider with a 1g stall speed of 34 knots will stall during rotation at about 50 knots if the rotation rate is 20º per second.

Based on a steady state analysis of forces, Scull[4] suggested that a stall during rotation at 49 knots required a climb angle of 50º. This is contrary to the current work which indicates that stalling can occur at any climb angle if the rotation rate is sufficient.

Power loss at a height of less than 100ft

Accidents

Table 3 shows there were 126 accidents of this kind from 1987-2004. There was one fatal accident. Serious injury occurred in 17 accidents. In 80% of the accidents the power was lost at a height of less than 50 ft. Nearly half the accidents occurred after power loss at a height of less than 25 ft. The majority of the gliders stalled but about a quarter of them hit the ground nose first, unstalled. Forty percent of the accidents were during instructional flights. These findings suggest there are combinations of height, airspeed, and climb angle for which no safe recovery is attainable. The effects of different conditions were investigated in order to determine the boundaries for recovery to a safe landing.

Calculation of recoverability boundaries

The dependence of recoverability on height, airspeed, angle of climb, delay before lowering the nose, push over g, recovery dive angle, recovery airspeed, pull out g, and glider L/D was investigated by dividing the flight regime into 4 parts. Firstly, a climb at the angle at which power was lost, representing a reaction time. Secondly, a push over at a specified g to a specified dive angle. Thirdly, a acceleration at this dive angle to a set recovery speed. Fourthly, a pull out to level flight at a specified positive g. Using elementary Newtonian mechanics and assuming motion in a circular path during each time interval of the pushover, heights, airspeeds, and pitch angles were calculated manually at 0.5 second intervals for 18 combinations of initial airspeed, climb angle, and pushover g. Generic rules emerged, and recoverability boundaries were determined. As with rotation, this process was superseded by a facility described elsewhere[3] which confirmed the conclusions from the manual calculations and made it possible to explore many additional details.

Main findings

A safe recovery from power loss at a height of less than 100 ft requires sufficient energy, and the avoidance of a stall. The height and the airspeed control the available energy. The angle of climb, the airspeed, the delay before pushing over to the recovery dive, and the push over g determine whether the glider stalls.

The criterion for stalling is the airspeed after the pushover, at the beginning of the recovery dive, when the glider has stopped pitching down and the 1g stalling speed is restored.

Recoverability is defined as the capacity to pull out to level flight at ground level after achieving a airspeed of 45 knots in the recovery dive.

Figure 3 indicates how the speed at the beginning of the recovery dive depends on the delay before pushover.

Figure 4 indicates how the speed at the beginning of the recovery dive depends on the push over g.

Figure 5 indicates how the height required for recovery to level flight for landing after power loss depends on the steepness of the recovery dive.

Figure 6 indicates limits for recoverability after power is lost in 15º and 25º climbs. The nose is lowered after 1.5 seconds at 0g to a 10º recovery dive that continues until a speed of 45 knots or 55 knots is reached. This is followed by a pull out at 1.5g to level flight. The L/D is 25. In the 15º climb the lower line shows, in the absence of a stall, the combinations of initial airspeed and height that permit recovery at 45 knots, for example 48 knots at 7 ft. The upper line, which permits recovery at 55 knots, is 60ft higher than the lower line. The large data points indicate the glider will be at or below the 1g stalling speed of 34 knots at the beginning of the recovery dive if the speed when power is lost is 44 knots or less. In the 25º climb, the position of the lines is hardly changed but stalling in the recovery dive now occurs if the speed when power is lost is 51 knots or less.

Implications for pilots

Stall during rotation

This treatment can only be an approximation to the behaviour of a real glider because it treats the glider as a point mass subject to forces, and ignores aerodynamics. Also, rotation rates will not be constant. However, the finding that a stall during rotation arises from a low airspeed combined with a high rotation rate seems to be robust.

The dangers of a low airspeed during rotation are well known. The dangers of a high rotation rate are perhaps less well known.

A dangerous combination of airspeed and rotation rate can arise from a too rapid rotation at low airspeed, or from a rotation with an airspeed that was initially adequate but which reduces during the latter part of the rotation. At a constant pull and constant rotation rate the airspeed during rotation reaches a maximum and then declines, as noted by Riddell (personal communication, 2006).

Pilots in the UK are currently being advised to maintain a shallow climb until adequate speed is achieved (perhaps 50 knots), with continued acceleration, and to ensure the transition to the full climb is controlled and progressive, with the transition from level flight at take off to a 35º climb typically taking about 5 seconds.

Modelling indicates that this profile should provide an airspeed at least 10 knots higher than the stall speed throughout the rotation.

Power loss at a height of less than 100 ft

The glider should not be allowed to rotate from a shallow climb until the minimum launch speed is attained (e.g. 50 knots) and continued acceleration is present. The time from take off to the full climb should typically be about 5 seconds. This is the same procedure as that recommended for avoiding a stall during rotation. With good technique, and in the absence of wind gradients or other adverse conditions, this procedure should permit a safe landing after power loss.

As a guideline for instructors simulating power loss, the energy margin may be insufficient even in benign conditions unless the airspeed is at least 50 knots at a height of 50 ft.

If power is lost:

1) It is imperative to lower the nose without delay; even a 1.5 second reaction time may result in a stall
2) Pushover g should be in the range zero to 0.4
3) A recovery dive angle of 5º hardly allows acceleration but may be necessary at a few feet. For acceptable acceleration with minimum height loss the ideal recovery dive angle is about 10º to 15º. Increasing the dive angle from 15º to 30º typically consumes another 30ft.

This modelling and the accident record suggest that after power loss below about 70 ft a crash may be inevitable after a single error. Accordingly, recovery from simulated power loss below 50 ft should be by instructor demonstration only, and instructors should never surprise a student with a simulated cable break at a height of less than 100 ft.

Communication of findings

Recommendations for safe winch launching have been presented to UK gliding club chairmen and instructors. A leaflet summarising the hazards of winch launching and how to avoid or manage these hazards has been sent to all instructors and pilots. An article on safe winch launching has been published in *Sailplane and Gliding*. Work will continue under the auspices of the BGA with the objective of ensuring all UK pilots know how to conduct winch launches safely.

References

[1] Gibson J, "The Mechanics of the Winch Launch", *Winch Operators Manual, October 2002*, British Gliding Association,

[2] Riddell J.C, "The Winch Launch", *Sailplane and Gliding*, 1996, pp 220-221.

[3] Hills T, "Safety Analysis of the Winch Launch", *Technical Soaring*, this issue.

[4] Scull W, "Accidental Spins off Winch Launches", *Sailplane and Gliding*, 1991, pp 302-303.

Table 1

UK gliding accidents 1987-2004

	Personal injury			Glider damage				All accidents
	Fatal	Serious	Minor	Write off	Substantial	Minor	None	
Winch	18	38	51	45	112	205	29	391
All	69	109	279	250	704	1413	286	2653

19 people died and 42 people were seriously injured in the winch accidents

Table 2
UK winch and aerotow accident rates per 100,000 launches 1987-2004

	Fatal or serious injury	Write-off or substantial damage	All accidents
Winch	1.07	3.0	7.5
Aerotow	0.14	1.9	4.8

Table 3
UK winch accidents 1987-2004

	Accident statistics			Main hazard
	Fatal	Serious	All accidents	
Ground Roll		2	65	Groundloop or cartwheel
Rotation	7	8	18	Stall & spin while on the wire
Launch failure at a height of less than 100 ft	1	17	126	Stall, or hit ground nose first
Launch failure at a height of more than 100 ft; no recovery to controlled flight	8	8	21	Stall & spin
Launch failure at a height of more than 100 ft; controlled flight achieved		1	61	Undershoot or overshoot
Others	2	2	100	Various
Total	18	38	391	

Table 4
$V_S/V_{s,g=1}$ and Stall speed of a glider with a 1g stall speed of 34 knots while rotating on a winch launch at a constant airspeed of 50 knots with pulls of 0.4, 0.6, 0.8, and 1.0 times the weight of the glider.

Rotation Rate °/second	Climb Angle°	Pull 0.4		Pull 0.6		Pull 0.8		Pull 1.0	
		$V_S/V_{s,g=1}$	Stall Speed, knots	$V_S/V_{s,g=1}$	Stall Speed, knots	$V_S/V_{s,g=1}$	Stall Speed, knots	$V_S/V_{s,g=1}$	Stall Speed, knots
20	10	1.40	47.8	1.42	48.1	1.43	48.6	1.44	49.0
	25	1.41	48.0	1.44	49.0	1.47	50.0	1.50	50.9
	40	1.39	47.4	1.44	48.9	1.48	50.4	1.52	51.8
15	10	1.32	44.9	1.33	45.3	1.34	45.7	1.36	46.2
	25	1.33	45.1	1.36	46.2	1.39	47.2	1.42	48.2
	40	1.31	44.5	1.36	46.1	1.40	47.7	1.45	49.2
10	10	1.23	41.8	1.24	42.3	1.26	42.8	1.27	43.2
	25	1.24	42.1	1.27	43.2	1.30	44.4	1.34	45.5
	40	1.22	41.4	1.27	43.1	1.32	44.8	1.37	46.5
6.3	10	1.16	39.4	1.17	39.9	1.19	40.4	1.20	40.9
	25	1.17	39.7	1.20	40.9	1.24	42.1	1.27	43.2
	40	1.15	38.9	1.20	40.8	1.25	42.6	1.30	44.3

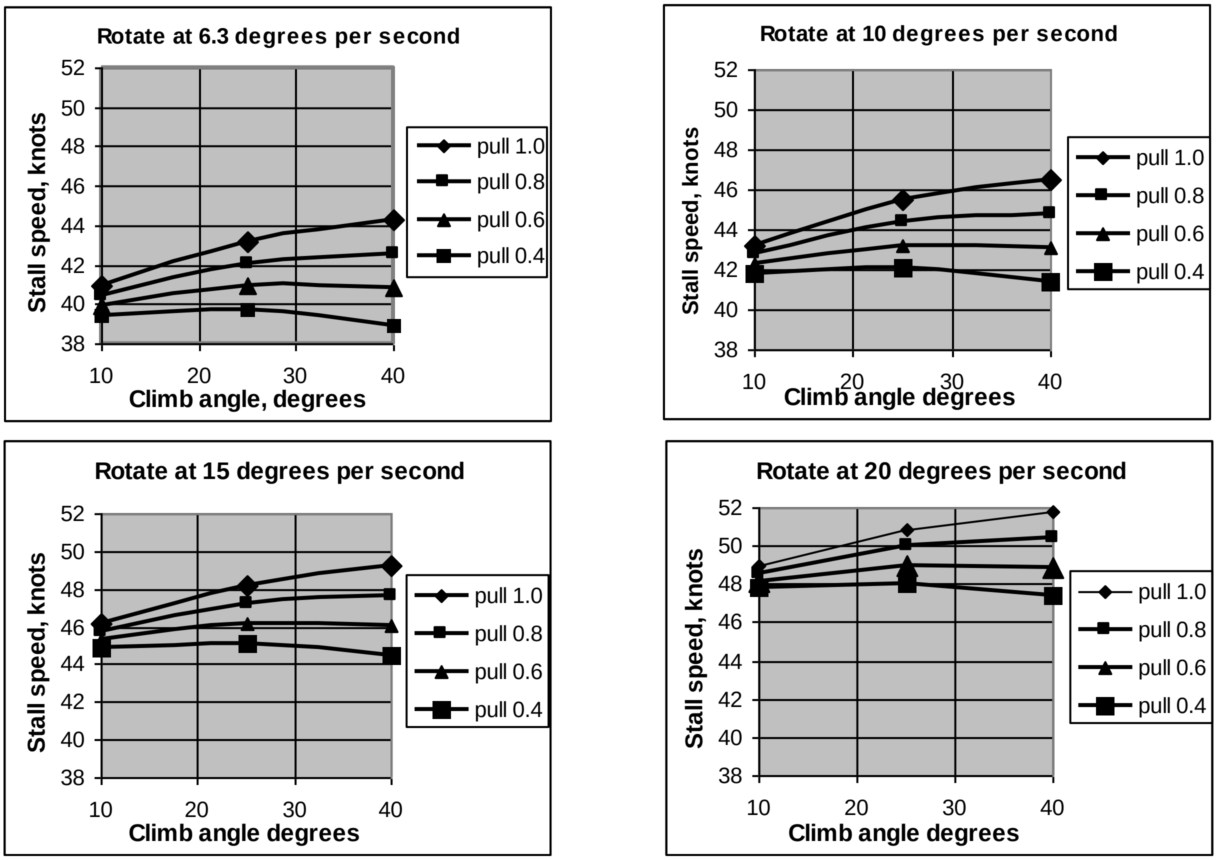

Figure 1 Stall speed of a glider with a 1g stall speed of 34 knots while rotating at a constant airspeed of 50 knots at 6.3º, 10º, 15º, 20º per second with cable pulls of 0.4, 0.6, 0.8, 1.0 times the glider weight, glider L/D 25.

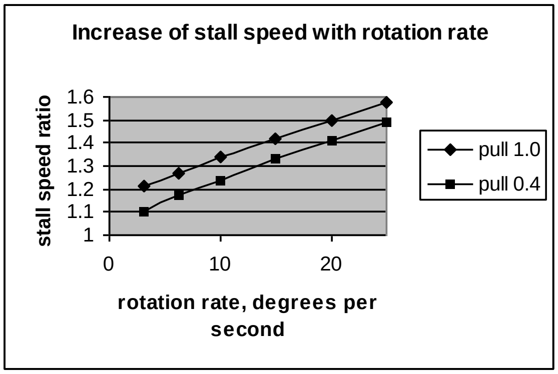

Figure 2 Ratio $V_S/V_{s,g=1}$ for a glider rotating on a winch launch at a constant airspeed of 50 knots at a climb angle of 25º.

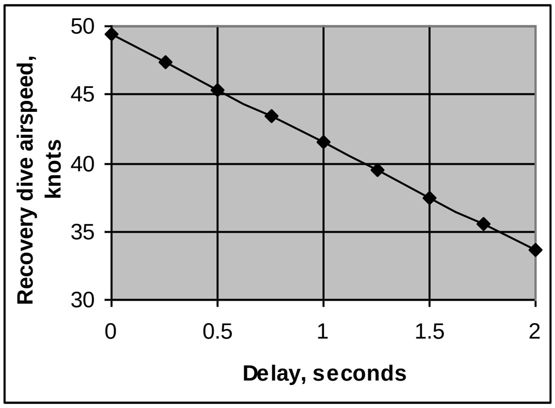

Figure 3 Airspeed at beginning of the recovery dive as a function of the delay before pushover; power loss in 25º climb at 55 knots, delay, pushover at 0g to a 10º recovery dive, glider L/D 25.

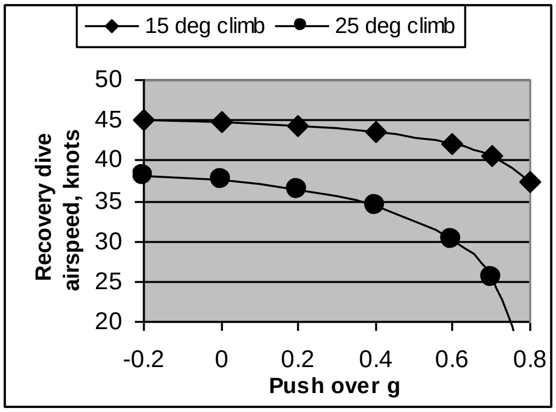

Figure 4 Airspeed at beginning of the recovery dive as a function of pushover g; power loss at 55 knots, 1.5 second delay, pushover to 10º dive, glider L/D 25.

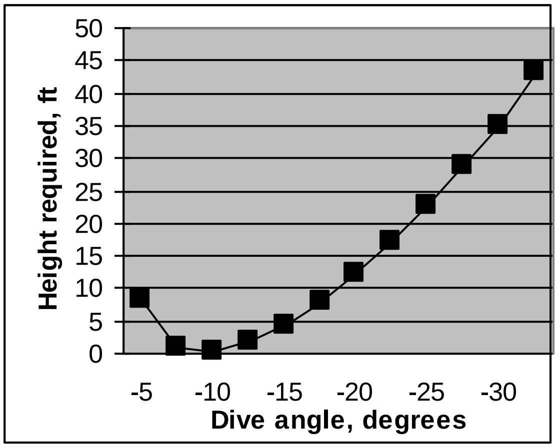

Figure 5 Height required for recovery to level flight for landing as a function of recovery dive angle; power loss at 49 knots in a 15º climb; 1.5 second delay, 0g pushover, acceleration in dive to 45 knots, pull out at 1.5g, glider L/D 25.

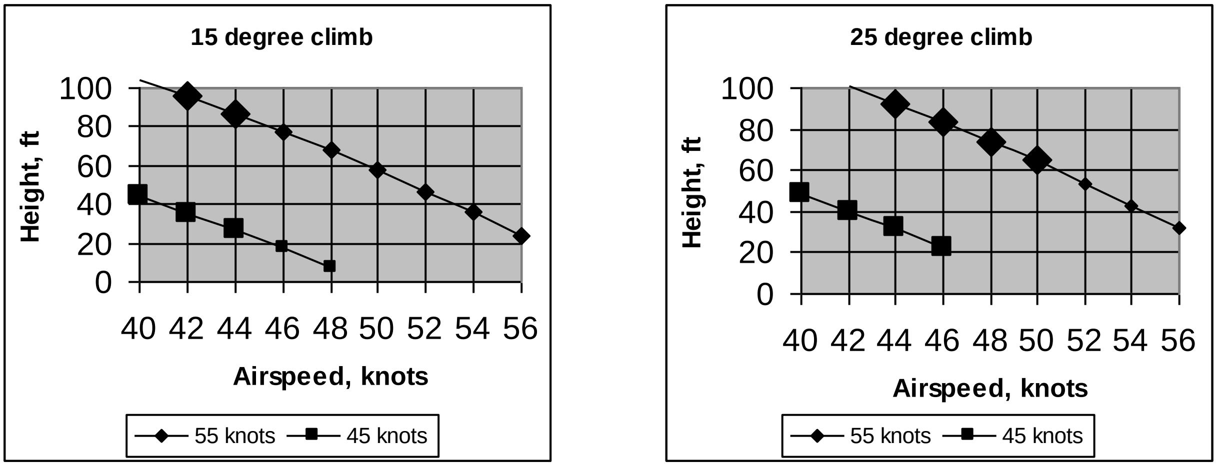

Figure 6 Airspeed/height combinations recoverable for landing after power loss; 1.5 second delay, 0g pushover to 10º dive, acceleration to 45 knots or 55 knots, pull out at 1.5g to level flight, glider L/D 25.