THE MECHANICS OF THE WINCH LAUNCH

John Gibson

References:

1. "A look at winch launching", J. Gibson, Sailplane and Gliding, Aug/Sept. 1985
2. "Understanding the winch launch", J. Gibson, Sailplane and Gliding, Feb/March 1987
3. "Towards optimisation of ground-powered glider launch", J.V. Byrne, 10th OSTIV Congress, 1965
4. "Accidental spins off winch launches", W.G. Scull, Sailplane and Gliding, Dec.'91/Jan.'92
5. "Speed and flight path boundaries for winch launching", F.G. Irving, OSTIV Sailplane Development Panel paper.
6. "Notes on winch-launching cases in the OSTIV airworthiness requirements for Standard Class sailplanes", C.W.A. Oyens, 9th OSTIV Congress, 1963
7. "The design of a glider winch", J.D. Brouwer, 9th OSTIV Congress, 1963
8. "Flight on the winch", P.J. Goulthorpe, Sailplane and Gliding, June/July 1996
9. "Wire launching", Instructors' Manual preview, Sailplane and Gliding, Feb/March 1987
10. "Power winching without tears", J. Gibson, Sailplane and Gliding, June/July 1996

Although very powerful winches, used for years on the Continent, have become more common in the U.K., the ability to handle their power has sometimes been hard won. Historically, each substantially increased step in power from the 70 BHP of 40 years ago to the 340 BHP available today has been claimed by some to be dangerous in the hands of amateur drivers. Clearly, such an opinion might well be generated by an unhappy experience, but the explanation for this can be laid at the door of general confusion about the mechanics of the winch launch, that is the control of the winch itself, the source of the loads on the glider, and the pilot's management of the launch.

This article explores the several elements that go together to make up the launch.

1. The need for high power.

It used to be a common misconception that diesels made ideal winch engines "because they have lots of torque". They can indeed be good but only if they have enough BHP as well. Torque provides the cable pull, and BHP is effectively pull times speed or the rate of work done. The 70 BHP of some early winches could have provided a pull of 1500 lbs but only at 15 knots. At 40 knots the available pull is only 570 lbs, enough to get a T-21 off the ground but not to provide a steep climb in zero wind, although its far forward hook would have prevented this in any case. Even so, respectable launch heights could be achieved with the aid of a long runway and some wind, as discussed below, and of course the light and slow single-seaters such as the Olympia 2 launched quite well.

Later, with heavier and faster gliders, many underpowered amateur-built diesel winches resulted from lack of BHP or wrong gearing, providing a good pull but insufficient cable speed for take-off, or alternatively enough speed but insufficient pull for a decent launch. (Ref.1.)

The basic BHP used is found from the glider weight and its climb rate. In the early launch at low altitude, a 1500 lb two-seater climbing at 60 knots at 45 degrees consumes 196 BHP. Only about 16 BHP more is needed to drag it through the air. Thus the cable, moving at about 38 knots or less, must supply 212 BHP, that is a pull of about 1800 lbs. Assuming a flat engine torque curve, a constant gearing ratio, and a top cable speed of 60 knots to ensure safe take-off in all conditions, the engine would need a rated power (i.e. the maximum power available flat out) of about 330 BHP without accounting for efficiency losses in the transmission etc.

At 60 knots it takes half a minute to pull the cable to the ground from a 3000 foot launch, a height not commonly achieved but not unknown either. Although it is normally preferable to fly the cable parachute more sedately in to the winch, a wet, muddy parachute can fall remarkably fast, depositing loose cable on the field if the winch cannot keep up, and crosswind drift may force a fast recovery on a narrow field. A higher top speed, say 70 knots, might be arranged. On the previous assumptions the rated power required would be 385 BHP.

In actual fact the torque curve is seldom flat. The torque reduces towards maximum rpm, bringing the rated power down but to a value that is still well over 300 BHP. Other considerations apply. As the launch progresses, the climb rate and cable speed are greatly reduced, reducing the BHP consumed, but the cable pull needed does not change much. Whether the engine can then provide the same pull at the correspondingly reduced speed depends on its torque and transmission characteristics. These include the various effects such as hydraulic coupling slip, torque converter or automatic gearbox ratios, etc. (Refs.1 and 7).

Refs 3 and 7 advocated a minimum of 200 BHP over 30 years ago, before the era of fast and heavy two-seaters, and at a time when 100 to 120 BHP was generally considered to be adequate in the U.K. A major influence on the choice of power for a given site is the type of two-seaters to be launched and to a lesser extent the length of the winch run. General experience together with rough calculations of the sort discussed here indicate that with a properly matched transmission, as little as 220 BHP can give satisfactory launches in a majority of cases, but that over 300 BHP would not be excessive where more stringent conditions apply.

Concerns about the risk in using such brute power to launch a slow and light single seater are usually misdirected. Overspeeding is the most intractable problem, often experienced even with older winches of less than 100 BHP, but this does not necessarily lead to severe structural loading. A possibly unconsidered but very real advantage of high power winches is that they can provide all gliders with similar launches, eliminating the confusion caused to pupils on their first solo single seater flights by a vastly different take-off performance.

2. The basic launch loads on the glider.

Although everybody knows that a kite can rise upwards while tethered to a point below it, it may not be clear how a glider can climb while apparently being pulled downwards by a strong cable tension as well as gravity. Figure 1 leads up to the launch by first considering the familiar forces in an unpowered glide and the possibly less familiar ones in a powered climb.

A body set in motion along some path will continue steadily so long as the forces on it are in equilibrium. This simply means that all the forces cancel each other out. If one force changes, the motion will change. Any individual force can be resolved into two components in different directions, or two forces can be resolved into one resultant. Here all the forces are also assumed to act through the centre of gravity.

- In the glide, Figure 1a, the well known result is that the aerodynamic forces of lift and drag are resolved into a vertical aerodynamic resultant force Ra, equal and opposite to the vertical force Rw exerted by gravity, the weight. The gliding angle is the same as the ratio of lift to drag. For reasonably small glide angles the lift is near enough equal to the weight, though it is always less.
- With an engine added for a powered climb, Figure 1b, the opposing thrust and drag are first resolved into a single thrust-minus-drag force, then further resolved with the lift into a vertical aerodynamic resultant force Ra, equal and opposite to the vertical force Rw exerted by gravity. The climb angle and speed settle to that at which this balance is achieved. The lift is always less than the weight and is directly related to the climb angle, becoming zero in a vertical climb.
- In the winch launch, Figure 1c, there are two external forces below the glider, the cable pull and gravity, which can be resolved into a single resultant Rw to balance the

aerodynamic resultant Ra of the lift and drag. This does not look anything like the normal powered climb system, but has the exact appearance of the glide system rotated in a nose-up direction. A line drawn at right angles to Rw through the CG (the "false horizontal" in Ref.1) has the same significance as the true horizontal in Figure 1a, the flight path being angled below it by the lift/drag ratio. It is the line along which the glider would fly if it had no drag.

In Figure 1c the cable pull from the hook passes through the CG, a reasonably close approximation to most modern gliders early in the launch. For many older gliders with the hook further forward, and all gliders higher up the launch, the cable pull exerts a nose down moment which has to be resisted by more up elevator. In this basic presentation of launching loads, the effect is ignored. The glider drag is represented by a constant lift/drag ratio equal to a 2 degree glide angle. As glider's "gliding angle" in the launch is unlikely to lie outside a range of 1 to 3 degrees, or about 60:1 to 20:1, this assumption is accurate to within a degree.

3. A universal force diagram.

Similar pictures can be drawn for any combination of flight path and cable angle, from which the required wing lift, cable pull and the stalling airspeed are obtained. Calculation is an easier option and Figure 2 shows the result (Refs.1, 2). The loads are expressed as ratios of the cable pull and the wing lift to the weight of the glider, and so they apply to gliders of any weight. The stalling speed is expressed relative to the normal 1g stall speed.

A 45 degree climb with the cable 5 degrees below the horizontal, Figure 1c, requires a cable pull of 1·2 and a lift of 1·63 times the weight. The only significant effect of airspeed on the basic launch forces is that there must be enough of it to generate the required lift with some margin, which in this case requires more than 1·3 times the normal stall speed. Otherwise, speed affects the drag and therefore the lift/drag ratio, which as shown has a negligible effect on the climb angle, but does not change the lift. Speed does have other implications which are discussed further below.

A number of basic facts can be seen from Figure 2.

- For any constant value of cable tension, the highest wing load occurs at the top of the launch, and is least at the beginning of the launch.
- For any constant value of wing lift, the highest cable tension occurs at the start of the launch, reducing as the launch progresses.
- The steepest climb angle is achievable at the start of the launch, where a five degree difference in climb angle has the least effect on cable tension.
- There is negligible climb at the end of the launch, where a five degree difference in climb angle has a large effect on the cable tension.

Practical limitations on the steepness of the flight path can be deduced. An initial flight path angle of 55 degrees (or more than 60 degrees fuselage attitude because of the added angle of attack required) will break the weak link of most gliders almost at once. If it did not, it would typically require something like the placard limit speed of many older gliders simply to avoid stalling, though the limit on modern gliders is relatively much higher.

Such numbers are exceedingly approximate because of the infinite variations between glider types in the ratio of weak link and placard speed to the weight and stall speed, but there is obviously a generally sensible upper limit of about 45 degrees path angle, or say 50 degrees glider attitude. Figure 2 shows (by following a line vertically at this climb angle across the lines of increasing cable pull and steepening cable angle) that excessive enthusiasm to maintain even a 45 degree path merely postpones the weak link failure to a height of a few hundred feet, a familiar experience for pole-benders in the old days of the U.K. 1000 lb weak link.

4. Control of speed and flight path.

In all three cases in Figure 1, the lift acts at right angles to the flight path and plays no part in moving the aircraft along it. If any force can be said to "pull the aircraft along", it must act forwards along the flight path, though it actually does no more than just balance the rearwards force exactly. In the powered climb, the engine provides the forwards thrust that balances both the drag and the large component of the gravity force Rw (71% of the weight in this example) acting rearwards. The only force than can do this on a glider is a component of the external resultant force Rw. In both the glide and the winch launch, Rw acts at just less (by the glide angle or lift drag ratio) than a right angle forward of the path. Its small forward component exactly equals the drag, and that is all that keeps the launch going at constant airspeed.

If the forces are to remain in balance and the speed remain constant, there is only one possible climb angle for each cable angle and pull force as shown in Figure 2. Alternatively, at any given position along the launch path, the cable pull necessary to sustain a steady launch speed is determined by the flight path angle and the angle of the cable. It has been noted also that airspeed has almost no effect provided there is enough of it, but it has to be controlled within some limits. The only action open to the pilot is to raise or lower the nose. The results of this depend on the winch characteristics.

4.1 The constant torque winch.

In some diesel engines the fuel bar delivering fuel to the cylinder injectors is directly controlled. This provides a torque and therefore a cable pull proportional to the power lever position, but the driver has no control whatever of the cable speed. Except for an upper engine RPM limit, the speed will increase if the load is less than the demanded pull, remain constant when the load equals the pull, and decrease if the load is greater.

Figure 3a shows the Figure 1(c) example, a steady 45° climb early in the launch with the cable angle of 5° (equivalent to a height of 250 feet or so), a pull of 1·2 times the weight, opposing resultants Rw and Ra of 1·63 times the weight, and a lift also essentially 1·63 times the weight. At other climb angles the cable pull is unchanged and so the forces become unbalanced, as can be seen by resolving Rw into its components along and at right angles to the new flight path. These of course still represent the individual cable pull and the weight.

If the pilot steepens the climb to 55° (Figure 3b), Rw remains the same size and direction as before. The lift required to balance Rwz, the component of Rw at right angles to the new flight path, decreases by 2%. Rwx, the component of Rw along the flight path acting rearwards with the drag, causes a deceleration of 5½ knots per second at this point.

If the pilot flattens the climb to 25° (Figure 3c), Rw again remains as before. The lift required to balance Rwz, the component of Rw at right angles to the new flight path, decreases by 8%. Rwx, the component of Rw along the new flight path acting forwards against the drag, causes an acceleration of 10 knots per second.

The pilot thus has a very effective control over speed changes by temporarily adjusting the attitude, but has no choice over the climb angle that produces a steady speed. It may be surprising to find that the lift hardly changes between 25 and 55 degrees of climb angle, that it decreases for steeper climbs than the nominal as well as for shallower ones, and that in the latter it is still 92% of the nominal. The explanation is simply that the lift can never be greater than the constant Rw, and must decrease when directed either forwards or aft of the line of action of Rw.

These results are for steady conditions, as there is obviously a temporary lift increase when first pulling up to to a steeper climb. For this winch type, assuming selection of the correct cable pull by the driver, pulling up is absolutely the correct pilot response to excess launch speed.

4.2 The constant speed winch.

In the traditional large diesel engine, an engine rpm proportional to the power lever setting is achieved by a governor which adjusts the fuel bar and torque as necessary. Assuming a "rigid" transmission with no slip or variable gearing and enough surplus torque, the cable speed remains constant regardless of how hard the glider pulls. In this case the lift and cable forces change to retain a balanced state.

Figure 4a shows again the Figure 1c case. A triangle of velocities is superimposed to show that for a glider speed of 60 knots, the cable speed is 38·2 knots.

If the pilot steepens the climb to 55° (Figure 4b), the airspeed must increase to 77·2 knots to close the velocity triangle with constant cable speed. The lift increases by 29% from 1·63 to 2·1 times the weight. The stall margin increases because of the extra speed, or in other words the angle of attack is decreased. The cable pull increases by 50% from 1·2 to 1·8 times the weight.

If the pilot flattens the climb to 25° (Figure 4c), the airspeed decreases to 44 knots, the lift decreases to 1·18 times the weight. The stall margin decreases, a higher angle of attack being needed. The cable pull decreases to 0·55 times the weight.

These results are very different from those in §4.1. The pilot has direct control over the airspeed by adjusting the climb angle. This affects the airframe loads in the direction one would expect, though by less than 2 to 1 over this 32 knot speed and 30° climb angle range, and proportionally considerably less than the 3 to 1 changes in cable pull.

The numbers given in here and in §4.1 will differ considerably for other positions along the launch path. There is little point in working out a whole series of them. The principles remain the same, and some idea of their values can be picked off the plot in Figure 2.

4.3 Mixed engine effects.

A petrol or LPG-converted engine is something of a mixture of the above types. (Torque governed diesels were introduced in response to driver demands for a more car-like behaviour, in fact.) Their torque is not so explicitly controlled as in a diesel, but it is reasonably proportional to throttle opening, more of which is needed at a given speed for heavier gliders. On the other hand, the RPM is limited by the air intake throttling. The speed increases but will not "run away" to the maximum if the glider does not match the supplied pull.

An RPM-governed diesel winch can only act as one if there is enough torque to supply any demand. When there is not, as with many medium powered winches launching two-seat gliders, or sometimes even single-seat gliders, the wide-open fuel bar effectively turns the engine into a constant torque type. The pilot can then control the airspeed through the climb attitude, slowing down in a steeper climb. Lighter gliders demanding less than the maximum torque have their speed basically controlled by the winch driver, and will speed up in a steeper climb. This dual character can lead to confusion in training methods.

4.4 Transmission system effects.

The dry plate clutch, usually with a manual gearbox, was common for many decades. It required considerable driver skill in clutch-slipping to get the glider into the air, often in top gear. While the general principles of §4.2 applied theoretically, the engines were prone to being stalled by the later heavier and faster gliders some way up the launch, due to the low power customarily available. Prompt action in lowering the nose would usually keep things going, necessitating close monitoring of the ASI for a sudden drop in airspeed.

The hydraulic coupling is the absolute minimum standard desirable today. This allows slip between the engine and drive shaft at low RPM and progressively locks up as speed increases, making it impossible to stall the engine. It does not alter the output torque, other than for some losses due to inefficiency. One example on a Gardner diesel winch allowed 800 RPM at full throttle with the cable drum locked, but was effectively locked up at 1200 RPM or 36 knots cable speed. This coupling type is necessary to take full advantage of torque-controlled winches which require the driver to set a known cable tension.

The torque convertor is a hydraulic coupling that allows the engine to rotate faster than the drive shaft at low RPM through a more complex variable ratio rotor and stator system, multiplying the output torque, but again locking up at some higher RPM. Figure 5 shows a typical plot of one used with a 220 BHP petrol engine, from Reference 7. A torque convertor tends to reduce the cable speed in response to a demanded increase in cable pull, so that pulling up into a steeper climb can result in less speed increase than is suggested in §4.2. Some winches use an automatic gearbox as well.

4.5 The effect of wind.

A steady wind does not alter the loads and flight path through the air, but it obviously affects the launch. A headwind is like having the winch moving away from the glider and winding in the cable more slowly, which reduces the BHP but not the torque required. The launch height increases because more time is available for the climb and the cable length is greater at the finish.

The tailwind launch is doubly penalised, with the winch effectively moving towards the glider. Not only is the cable being wound in more quickly but the extra cable speed needs more BHP to provide the same torque. If the winch has not got it then the climb attitude has to be reduced giving an even lower height.

Figure 6a shows the effect of a 20 knot wind on the Figure 1c case. The attitude, loads and flight path through the air are the same as in no wind, but the flight path relative to the ground is steeper and the cable speed is halved. The effect is even more marked at lower launch speeds suitable for many older gliders, Figures 6b and 6c. A glider with a stall speed in the upper 20's can launch safely at 45 knots, where it can produce lift more than 2½ times it weight. If it could sustain an early 55 degree climb, it could virtually "kite" with negligible cable speed.

The full potential climb performance available to low speed gliders in a wind seems to be seldom realised, however, because few winch drivers are able to believe how low the cable speed should be once the glider has achieved the full climb angle. Many pilots of such gliders, accustomed to being launched at much higher speeds than necessary, are similarly inhibited by lower though sufficient speeds. On the other hand, it is not unusual for cautious pilots, who won't pull back hard when the speed is high, to achieve lower launch heights in a stiff wind than in a lighter wind when the speed is lower.

5. Take-off and climb entry.

The maximum launch height is obviously achieved by minimising the horizontal distance taken up in the transition from the stationary beginning to the full climb. Common sense and self-preservation dictates that the prudent pilot does not reduce this to the minimum that is physically possible. The fact that high powered winches make it possible to pull straight off the ground into a steep climb does not make it a safe practice. However, the old dictum that the climb must be shallow until 200 feet is reached was imposed by the need to maintain adequate margins of speed, attitude and altitude with low powered winches. A safe compromise between these extremes results naturally from the basic mechanics of the launch process itself, requiring that the pilot intervenes only as needed to maintain it.

5.1 The idealised process, Figure 7.

A fallacious assumption is made by many pilots that the stick must be pulled back to initiate the climb. This would be true if the nose were to be initially held down in level flight while the glider accelerates to the desired full launch speed before any climb is started, but that is not a very sensible technique. The lift will increase with the angle of attack held constant as the speed increases, which it does at the beginning of the launch. An aeroplane with sufficient power to accelerate in the same manner would continue pitching up and over in a loop, since its lift requirement actually reduces in a climb. A glider stops the pitching process when the lift, weight and cable pull force are in balance.

The angle of attack at which the glider will just fly off the ground at a little above the stall speed will also provide all the lift required for the climb when the speed has increased to an appropriate value. Most gliders are probably not quite stalled in the tail-down ground attitude. If the tail skid is held off the ground before take-off occurs, the glider cannot become airborne at much less than about 15% above the stall speed. At 30% above take-off speed, the lift will be 69% greater than the weight, which Figure 2 shows is about what is needed to support an early climb angle of 45°. At the resulting climb speed of at least 50% above the stall, the potential maximum lift is 2¼ times the weight. This is 38% more than the lift required, a margin achieved in principle without pulling the stick back.

5.2 The practical process.

The stick position needed to get the glider on to the mainwheel for a level lift-off depends on wheel position, that is the tail may have to be raised or the nose lifted. The cable pull will itself tend to raise the nose, by an amount depending on how far the hook is below the centre of gravity and at what level the acceleration continues once flying speed has been reached. Given sensible winch driving, it can be expected that the desired level lift-off can be achieved to a sufficient approximation in almost any glider. In some cases, this same stick position will see the basic rotation through without adjustment. A further increase in climb angle can then be initiated if the airspeed, weak link and pilot can stand it.

In many other cases, it will be necessary to alter the stick position to a lesser or greater extent, because of the changing line of action and the strength of the cable pull with climb attitude. The cable pitching effect can vary from remaining markedly nose up, reducing to zero, or changing to strongly nose down, depending on the hook vertical and fore-and-aft location. This can cause a departure from the idealised case, the glider pitching up too steeply or too little if left to its own devices. To counter this the stick can be moved smoothly and progressively to the extent necessary to arrive at the desired initial climb attitude at a safe speed and height.

The aim should be produce an elegantly smooth rotation in which the safety margins are never in doubt. The task boils down simply to stopping the nose from coming up too quickly, but not unnecessarily holding it down either. To the experienced pilot, this comes as second nature. The angle of attack is kept comfortably less than the stall, the attitude cannot become very steep too close to the ground, and there is always adequate speed to push over safely if the cable breaks or the winch fails. However, the elegance depends to an extent on the winch driver too, who should understand the ideal take-off profile and always attempt to provide it.

6. Speed effects on the airframe.

Many years ago, pilots were expected to release the cable if the airspeed exceeded the placard limit by even one knot, regardless of the circumstances, lest some amazing force came along and destroyed the airframe. Although, and perhaps unfortunately because, the situation is now better understood, respect for the placard has diminished to judge by its widely experienced exceedance. Yet no structurally sound glider has ever been damaged by air loads in a winch launch in the U.K. as far as is known. How can this be?

The placard limit Vw is the speed at which the structural strength requirements are shown to be met. OSTIV and JAR-22 require Vw to be not less than 60 knots, and the old U.K. BCAR Section E advises this, but many older gliders have lower limits. The glider is assumed to be in level flight at Vw with the cable load either at 20% above the nominal weak link strength, or at the maximum value achieved at the wing stall or that can held with full up elevator. In the latter cases, the cable load is then assumed to increase suddenly to break the weak link, again at 20% above its nominal value. The additional loads are considered to be reacted by linear and rotational inertial forces in the airframe, not by a rebalance of the aerodynamic loads.

Although the case has to be considered with all cable angles between horizontal and 75° below the horizontal, covering all conditions from take-off onwards, the largest cable angle is of most concern because it produces the largest lift loads. Figure 8 shows the seven forces acting on the airframe in this condition. The relative lengths of L, W and C are arbitrarily taken from Figure 2 for the 75° cable angle and cable pull of 1·2 times the weight, the assumption being that full up elevator is unable to react a larger pull than this.

Note that while the vertical forces and the moments are balanced, the forward component of the cable pull is not in balance because level flight is assumed instead of the 6 or 7 degrees climb shown in Figure 2. The consequence is that the glider is accelerating, but the rearward inertial force on the wings is the same as they would experience in a steady climb at constant speed with this cable pull. This rather theoretical design case is therefore an instantaneous snapshot and no account is taken of the higher speed that would occur immediately afterwards.

Five of the forces in Figure 8 are effectively independent of the airspeed. These are the weight, cable pull, basic wing lift, and the two tail lift components T1 and T3 that balance the lift and cable pull. These are determined principally by the launch geometry and a very little by the drag effects of speed. The two remaining forces vary directly with the square of the airspeed, but neither is related to the launch geometry. They are the wing pitching moment (due to the aerofoil camber shape plus a small fuselage effect) and the tail lift component T2 that balances it. The actual wing lift is greater than the basic value discussed earlier by the total tail download, and so it is slightly influenced by speed to the extent that T2 changes.

Wing torsion.

The maximum design wing torsion due to camber occurs at negative g at the design diving speed Vd. Positive lift reduces the torsion, acting at the aerodynamic centre ahead of the wing structure shear centre. At a winch launch placard speed typically about half Vd, the wing torsion is significantly less than 25% of the design value. With a typical overshoot of 10 knots this would still be less than 35% or so. Even this small torsion would be reduced again by the increased lift generated by the full up elevator of the design case, now able to pull the nose up against the cable to a higher angle of attack. There is no possibility of wing damage due to torsion, therefore.

Tail loads.

The maximum tail design download is given by instantaneously applying full elevator at the manoeuvring speed Vm, or one third full elevator at Vd, both in level flight. As the overall angle of attack subsequently increases, the download decreases. Even if the launch speed increases to Vm, which may be 30% to 50% higher than Vw, full up elevator cannot give the same download because it is applied at a higher angle of attack with corresponding relief. Although this shows there is no possibility of tail damage except in an exceedingly gross speed exceedance, the loads can be considerably higher than the nominal winch design case.

Wing lift loads.

Reference 6 showed that at a nominal Vw of 54 knots, the Ka-6 could balance a cable load of only 1·4W with full elevator, or just over 1·5W at wing stall if the elevator had more power. At a launch speed of 64 knots, only 10 knots higher, a cable load of 2W could be balanced with full elevator, or 2·4W at wing stall with more elevator power. Hence the loading conditions when the weak link breaks would differ greatly at the two speeds. At 54 knots a substantial part of the wing load is inertial bending upwards as the glider is accelerated downwards by the cable surge load applied at the fuselage, but at 64 knots the wing load is almost entirely due to lift distributed along the wing with little or no extra inertial load.

The wing bending loads in the launch are greater than is suggested by the wing lift balancing the weight and cable load shown in Figure 2. In free flight, the normal acceleration or g resulting from excess lift relieves the spar bending stress by pulling downwards along the wing. In the winch launch design case, the spar stress is relieved only by the normal 1g due to gravity, and is therefore substantially greater at a given wing lift than in free flight.

Figure 8 includes an approximate expression to calculate the "equivalent g" imposed by a given cable load. This is based on the assumption that the wing bending stress in level flight is directly proportional to the unsupported load of the fuselage, and that the wing weight generates no stress because its spanwise distribution is the same as that of the proportion of the total lift supporting it. Typically the weight of a fuselage and payload is about 65% of the total. Adding the cable load to this then increases the wing bending loads in proportion.

A weak link nominally breaking at about 2·3W would do so at a wing lift of about 3·3W, but would produce a bending load equivalent to 4·5g. With the 1·2 factor on this strength assumed for certification, the design case would be considered to reach the actual limit load for current gliders of 5·3g. Any weak link of lower strength will prevent overstressing of the wing in bending, essentially independent of speed. Typical weak link values range from about 1·5W to 1·8W, and a few are as high as 2W, though only the greater of 1·3W or 500 daN is formally required.

Gust effects.

For winching, only the old U.K. BCAR Section E and the earlier OSTIV documents specified a gust case. OSTIV and JAR-22 assume that in a gust the wing can dynamically develop 25% more lift than the normal static maximum. With the glider restrained by the cable, the lift induced is not alleviated by inertial relief. However, if the weak link breaks, free flight is resumed and normal loading occurs. This is not normally critical, since the maximum design gust is much larger and occurs at the much higher manoeuvre speed Vm at least. Presumably that is the reason for removal of the winch gust case from later OSTIV and JAR-22 requirements. Nevertheless, the loads in a severe gust will be greater than normal above Vw.

7. Safety implications for speed control.

Piloting considerations are discussed at length in the BGA "Instructors' Manual", essentially the same as Reference 9. This section deals with a few matters in more detail.

Caution is necessary in discussing the control actions, the over-riding factor being the stick positioning. Terms such as pull or push are imprecise and relative because the actual stick force depends on individual preferences in setting the trimmer, a choice usually more relevant to flight after cable release. A rearwards movement could be either an increasing pull or a relaxation of a push, and it is most important that the pilot is not confused by this. Usually the action is a case of allowing the nose to rise at a sensible and natural rate, which could require a gradual forward movement of the stick if the hook is well aft. It could alternatively require the nose to be assisted upwards as the rotation progresses especially with the hook well forward on older gliders. It should not be primarily thought of as "pulling the nose up into the climb".

The nose may rise unexpectedly rapidly for a number of reasons. One is simply a driver mistake in opening the throttle too rapidly or far, though the high initial acceleration should identify this easily enough. Another is having the stick too far back, which could actually mean neutral or even a position well forward of this, so that the glider pitches straight into the full climb right off the ground. The extreme version of this is deliberately holding the tail on to the ground so that the rotation takes place around the tail skid or wheel, an exceedingly dangerous practice though one observed here and there. A third is a rotation normal at a site but unexpectedly fast for a visiting pilot accustomed to a lower power winch, an essential subject for a site check.

7.1 Dealing with insufficient speed.

The speed numbers given in §5.1 are of course just an idealised indication of typical speeds in a practical launch. It is impossible to check off a precise speed versus height and attitude schedule, and even if it were possible there would often not be time. It cannot be emphasised too strongly that after leaving the ground, the nose normally wants to rise without assistance at a rate depending on the increase in speed, giving an excellent and continuous cue that the speed is indeed increasing. Despite this the pilot should maintain awareness of the speed, particularly its trend, by rapid glances at the ASI.

A failure of the nose to rise as expected should set off a loud mental warning bell that the speed may be too low, and that the nose must not be forcibly raised unless the actual airspeed is confirmed to be sufficient. Pilots who truly understand the launch will never be tempted. Pilots who do not fully understand are at risk not only in a failing or incorrectly driven launch, but in an unprepared conversion from an accustomed high power winch to a low power one, the temptation being to impose a fast rotation where a slow one, or none at all, is necessary. The need for continuous speed awareness extends all the way up the launch, a gradual power failure being particularly insidious because it is hard to detect other than by a decreasing ASI reading.

7.2 Dealing with excessive speed.

The traditional scenario is a launch, well-regulated initially and already at a normal climb attitude, that steadily becomes too fast because the driver fails to back off the power adequately. Although a minimum Vw and weak link strength are specified in the regulations, the designer often chooses higher values. The result is a considerable variation in the design case conditions for different glider types, exacerbated further by the differences in relative hook positions and elevator power. The pilot cannot guess either what the design conditions are or what maximum loads and their distribution *could* be imposed at speeds in excess of Vw. The idea was to release before exceeding Vw. However, exceeding this placard limit is not a reason to panic or to act precipitately.

A common experience encountered in more recent years is a launch which is immediately too fast, even before the climb is established. The nose may be kept low immediately after take-off because the pilot holds the stick too far forward for fear of the glider "rearing up", and/or is so alarmed by a proper but largely uninformed concern about the structural implications of excess speed that the nose is allowed to rise only a little or not at all. This is likely to produce still more speed as the winch driver responds to what appears to be the recognised signal for "too slow", or as a torque controlled winch responds to the lack of cable load by accelerating. Holding the nose low is therefore counterproductive and brings a risk infinitely greater than the effects of the excess speed on the glider structure, which are easily kept to a moderate level.

If the pilot releases the cable and lowers the nose while in a fast shallow climb, there is a highly significant risk of flying underneath the cable parachute. The cable may then fall over the glider. If the winch driver, who is not usually in a good position to see exactly what is going when the glider is at low altitude, opens the throttle in an attempt to keep the parachute out of the glider's way, then the cable could pull the glider round and into the ground. (This has happened.) The safest driver option is to operate the guillotine, which immediately removes all possible power from the cable, but as this is commonly associated with a cable hang-up at the end of the launch, a more likely response is to cut the power and apply the brakes.

The safest pilot option in the above examples is to put the glider into, or keep it in, a reasonably normal but not excessively steep climb, and especially not pulling back hard on the stick, giving the normal "too-fast" signal. For example, climbing at 45° attitude means a flight path angle of about 40°, generating very moderate values of lift and cable load as Figure 2 shows. For most gliders, a large tail download is not required because the cable load is directed close to the centre of gravity. Excess speed beyond Vw generates the required lift at a lower than normal angle of attack so that less aft stick is needed, ensuring that tail loads do not become excessive.

This generally benign situation persists up to cable angles of at least 15° to the horizontal, representing an altitude of several hundred feet, giving time to see if the launch slows down as the load increases or the driver wakes up to a "too-fast" yawing signal. Without the stick being hard back, flick-rolling as a result of this signal is not a possibility. Continuing the climb to a safe circuit height of several hundred feet allows the cable to be released while it is under tension and pointing well below the glider. It is then likely to pull away immediately to give space to pitch over, though this should not be too abrupt so as to avoid flying into the parachute if it is temporarily hovering nearby. That has happened, though it is probably unlikely with today's customarily longer shock ropes between glider and parachute.

Towards the end of the launch, where small flight path changes strongly affect the loads which are also greatest for a given cable pull, a moderately loaded condition is impossible to judge directly. Continuing to apply full up elevator will certainly take the glider into loading conditions that have not been calculated for certification. It may also take the glider so close to the stall that a too-fast yaw signal risks a flick-roll, though this depends on the relationships between weak link strength, placard limit, hook position and elevator power. As noted above, however, only the tail load is likely to reach much larger values than intended. This is easily prevented simply by moving the stick towards a normal cruising position, which will also ensure safe signalling. While the result may well be a further increase in speed and even a slightly downwards flight path, it gives a breathing space until the cable can be released.

8. Operating margins.

Clearly there are three principal aims in a launch. These are to obtain the highest launch possible, maintain a safe margin from the stall, and keep the weak link unbroken. From the above discussion it can be seen that these are a function of the ratio of the launch speed to the 1g stall speed, and of the ratio of cable pull to the weight. These parameters are variously under the control of the pilot, the winch driver, or both, depending on the winch type and sometimes on the glider weight, and always of the designer's whim.

The maximum achievable launch height has been examined in References 3 and 8. The latter introduced the concept of the "idealised launch" by equating the work done on the cable to the potential energy gained by the glider. If the ratio of cable pull to weight is C, then the height gained is ideally C/(1 + C) times the distance between the initial point at full climb and the winch. For C = 1·2, as used to illustrate the present paper, the ideal height would be 54% of the launch length. The height gained is reduced by drag and by the sag and weight of the cable, for which simple rules of thumb are given, but one might expect about 45% to 50% in zero wind.

8.1 Launch analysis.

Reference 2 suggested that a launch speed of 1·5 times the stall speed is generally sufficient and that much more than this is unnecessary. For some gliders this is close to the placard limit anyway. The subject is elaborated in References 4 and 5, from which Figure 9 is derived. Their original calculations for a specific glider type have been generalised to cover all types by expressing speed and cable pull as ratios to the 1g stall speed and weight. Conditions are shown for cable angles of 5° representing the start of the full climb, 45° at typically more than 80% of the final height, and 80° representing the last sensible point for release near the winch.

The plots show the flight path climb angles at which the glider will stall at a given airspeed, and the critical speed above which the weak link breaks first. The operating case for a speed of 1·5 to 1·6 times stall speed with C = 1·2 is also shown for the three launch positions. At the start of the launch, the climb angle of 45° gives comfortably large margins. Provided this speed is maintained, no stall is possible and the weak link can break only if C increases to equal the link strength, requiring a very steep climb unless the relative link strength is very low. At this point, too, the wing loads when the link breaks are lower than at any later point in the launch.

In the next example at 45° cable angle, both the climb angle and speed margin from the stall have halved. Only a small increase in climb angle is required to break the weak link, though the percentage increase in cable load to reach this is the same as before. Because the cable angle relative to the glider has steepened by 17°, it is pulling the nose down, but there is less elevator available to counteract it because more wing lift and therefore angle of attack is required, unless the speed has increased. If the glider requires full back stick to achieve the initial nominal launch, it will be impossible to maintain the nominal conditions shown here.

At the final 80° cable angle, the glider would in principle stall before breaking the weak link unless the speed has increased substantially, and the climb angle margin from the stall is negligible. If the speed decreases only slightly, the glider would stall at the nominal climb angle. In practice, with the cable pulling down at almost 90° to the glider, many gliders could not keep the nose up sufficiently, for similar but even more pronounced reasons than in the second case, so that the nose would be lower and the speed would increase.

With a powerful elevator and a well-aft hook, the possibility to drive the speed down and enter a stall with no guiding visual cues from the climb angle is at its greatest at the top of the launch. Allowing the speed to increase sufficiently to ensure a weak link break before stalling would probably result in a high speed stall when the link does break. Such gliders need to be treated with circumspection. However, the winch power should have been backed off well before the glider comes close to reaching this position.

Probably all gliders could stall if rotated too quickly into a steep climb with insufficient speed in the first half of a launch, but here the protective cues are obvious and compelling when clearly understood. These are the matching of appropriate speed and attitude in a controlled rotation into the early climb, and the limiting of the full climb angle in the earlier parts of the launch while maintaining sufficient speed. (There is a tale from many years ago of a Grunau Baby performing a complete autorotation roll on the wire and going on to finish the launch.)

Figures 2 and 9 give clues to explain the famous launch performance of the Ka-8. It has a placard limit Vw that is twice its 1g stall speed, and a weak link strength of about twice its weight. Operated at 55 knots near Vw, it is above its weak link critical speed for the entire launch with a huge stall margin, and so could not be stalled while still on the wire. To break the link requires an exceptionally steep and unlikely attitude in the early climb (a weary link excepted, of course!), though maintaining a 45° climb to several hundred feet would in principle produce the required condition. This seems unattainable in practice at this speed due to insufficient elevator to balance a sufficiently steep relative cable angle on the well-placed hook. At 45 to 50 knots, about 60% to 80% above 1g stall, full elevator applied when established at a safe height in the full climb results in a wonderfully peaceful and relaxed launch, still with excellent performance. Operations where link breakage is regularly experienced (as opposed to being mentally prepared for by the pilot in every launch) are clearly launching Ka-8s well outside these conditions.

8.2 Optimum cable loads.

There is a dearth of information about what cable pull can be applied comfortably to different glider types. Some information has actually been obtained on an instrumented torque control Supacat, though it remains unpublished. Trials (in a strong wind) demonstrated that a Ka-13 could just about manage a 1500lb pull, which is approximately 1·4W. It appears that 1300lbs or about 1·2W is a more acceptable limit which avoids pulling the nose down too much at the end of the launch. The Ka-8 was shown to be able to accept a 900lb pull, which is about 1·4W. A pull of 770lbs or 1·15W gave an excellent launch to an SD3.

Clearly such information is invaluable to drivers of torque control winches, enabling the optimum launch to be pre-set. With most winches this would not be useful to know, since it is not measured, and a routine is developed (or should be!) that provides an acceptable speed and climb angle. An initial climb angle of 45° or less is commonly observed, from which it can be deduced that a cable pull not greater than about 1·2W is being delivered. The Ka-8 can certainly climb more steeply, a 50° climb indicating a cable pull of 1·4W. These deductions made from the initial climb angle alone are consistent with the measured results.

Approximate support to these figures is given by application of the Reference 8 formula, which agrees well with the actual zero-wind launch height achieved by a K-13 in a test of power settings on a Skylaunch winch. A gain of 1200 feet from the 850 yard run indicates a practical average cable pull of about 1·2W, and is commensurate with the estimated initial climb angle. It required a determined though acceptably comfortable effort to stay within Vw, a sign that more power and pull would have been becoming excessive. The same height gain and therefore relative cable pull was found with a Ka-8 launched at 47 knots. The greater pull of 1·4W noted above appears to require a higher launch speed, though the formula shows that the extra height gained in zero wind amounts to only 4%. In a wind, the lower speed wins as noted in §4.5.

9. Winch driving considerations.

Many examples of poor driving technique were discussed in Reference 10, often associated with the more recent (at least in the U.K.) high power winches. With sufficient driver cues to the required power settings and an understanding of how these influence the launch, such winches are not difficult to drive reasonably well even by the inexperienced. With all winches, launch performance depends on cooperation between the driver and pilot to a varying extent.

The first essential for uncomplaining pilots and airframes is to appreciate the effects of the initial acceleration. With many gliders that sit on the nose skid, abrupt throttle opening smashes the tail skid down, which is bad for the fuselage, the hook, the weak link, the cable, and the pilot's temper, and makes no practical difference to the launch height whatever. Even when the tail sits on the ground, a severe jerk may also shift an inadequately restrained pilot to the rear of the cockpit, with potentially serious degradation of precise controllability.

The mark of a caring driver is the ability to ease the tail skid to the ground by a progressive application of power. The best throttle technique to use depends on the winch power unit and transmission characteristics. In practice, local opinions as to acceptable performance will hold sway and so the techniques may well differ from site to site, but the general principles apply to any winch.

For most winches, it is sufficient to open the throttle smoothly to the initial climb power setting over a period of some two to three seconds, taking particular care in the first second not to jerk the throttle into the motion.

For high power torque controlled winches, immediate application of the full cable pull may cause an over-speed which continues unabated to the maximum winch speed unless the glider rotates very rapidly into the climb. An alternative to progressive application over two or three seconds is to apply a lesser amount, quickly but smoothly to avoid the tail skid smash, and then apply the remainder as the glider nose rises into the climb.

On some winches the initial acceleration leaves a lot to be desired, particularly with heavier gliders. Even here the initial throttle application should be smooth, and not jerked in a misguided attempt to improve the take-off performance. It doesn't work!

There is an inevitable small delay until the winch driver has seen and reacted to the change in signal to "all out". It is tempting to reduce this delay by starting the "all out" process before the cable has fully pulled up tight. The pilot, to whom any bow or slack in the cable is fully visible, was unlikely to initiate the signal too soon. Now that the process is controlled by a person outside the cockpit and well to one side of the cable line, carelessness can lead to the signal being given while there is still a considerable bow. If this is combined by a too-eager winch driver, the result can be an exceptionally vicious snatch. Obviously no signal should be given until the cable is visibly tightening at the hook. A prudent pilot would release the cable before the snatch, but it is not easy to monitor simultaneously the cable ahead and the signaller to one side.

With the operating margins steadily reducing as shown from the beginning to the end of the launch, and because so little height can be gained from the last segment of the launch path, there is no point in sustaining high winch power to the bitter end. The more likely result of doing so is the familiar experience of a rapid speed increase and a descending flight path in a usually unsuccessful attempt to release the cable with no tension in it. What is actually required is that the cable speed should reduce to a very low value as the glider approaches an overhead position.

The driver input to achieve this is so dependent on the glider being launched and on the winch power and transmission characteristics that it cannot be described other than to say the power should be backed off appropriately. Only practice will get this right every time. The one gauge that would give the driver completely meaningful guidance would be a cable speed indicator, which of course is almost unheard of, but an RPM gauge is a useful substitute.

Figure 10, sketched from an instrumented winch print-out, shows the typical cable speed profile needed. Here the speed changes from 36 knots to 4 knots with no change in driver input, an advantage of the torque control principle. The steady cable pull is equal to 1·15W, equivalent to a nominal 22 knots per second initial acceleration. As the power demand was applied over about 5 seconds, with the pull lagging a little behind and reaching its full value only as the glider reached the full climb attitude, the initial acceleration actually averaged only 14 knots per second. Despite this the lift-off was reached in under two seconds in the 20 knot wind. The plot also shows a rapid speed reduction as the pilot pulled up to correct an initial over-speed.

Figure 11 is a reconstruction of the end of a 100 knot launch, drawn to convince sceptical drivers who did not believe it to be possible. In a 20 knot wind, the initial climb speed increased beyond the placard limit and then so rapidly that the yaw signal was considered to be inadvisable. The nose was lowered but the acceleration continued to 100 knots, and the cable was released at 800 feet when it was felt certain that it could not fly up in front of the glider. The sketch showed from the rate of cable shortening that at this point its speed must have been about 35 knots, equal to more than half the maximum RPM and much too fast even for the early climb in such a wind. The driver failed to notice both the glider attitude and the large rpm indicator.

> Ideally, drivers and pilots should understand the mechanics of the winch launch to the same depth as expected for actually flying the glider. This state is seldom achieved.

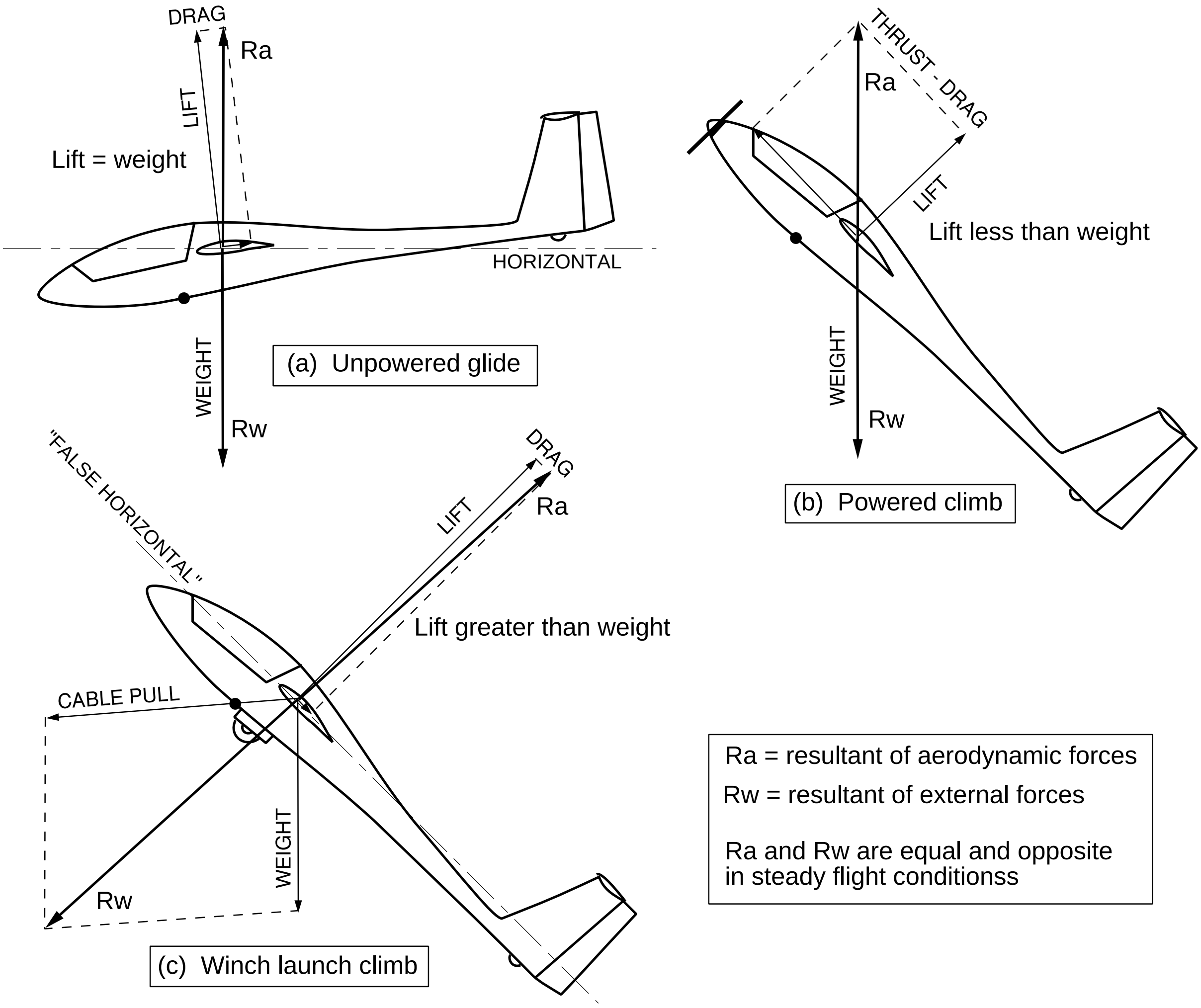

Figure 1 The basic equilibrium of forces

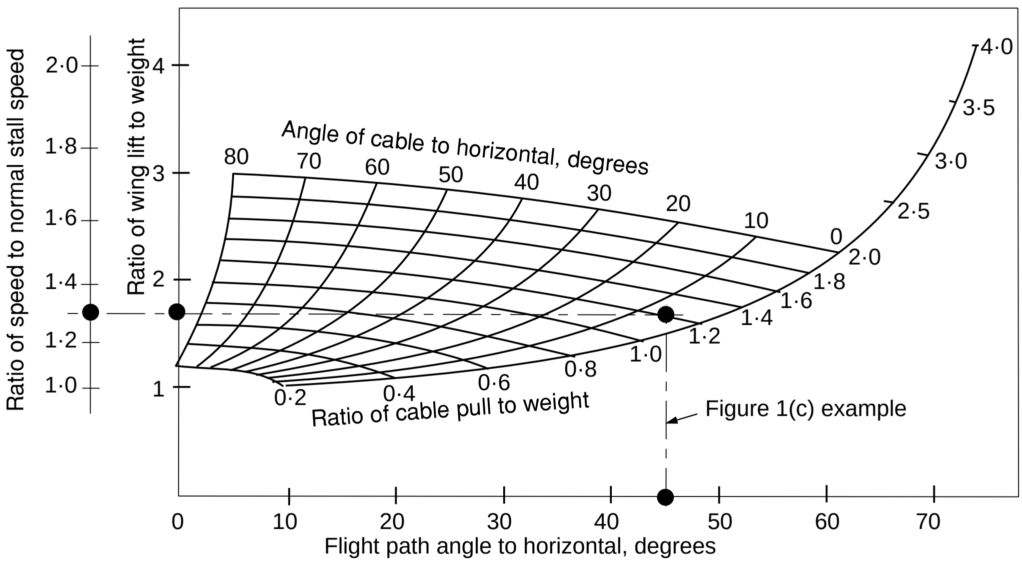

Figure 2 The universal force diagram

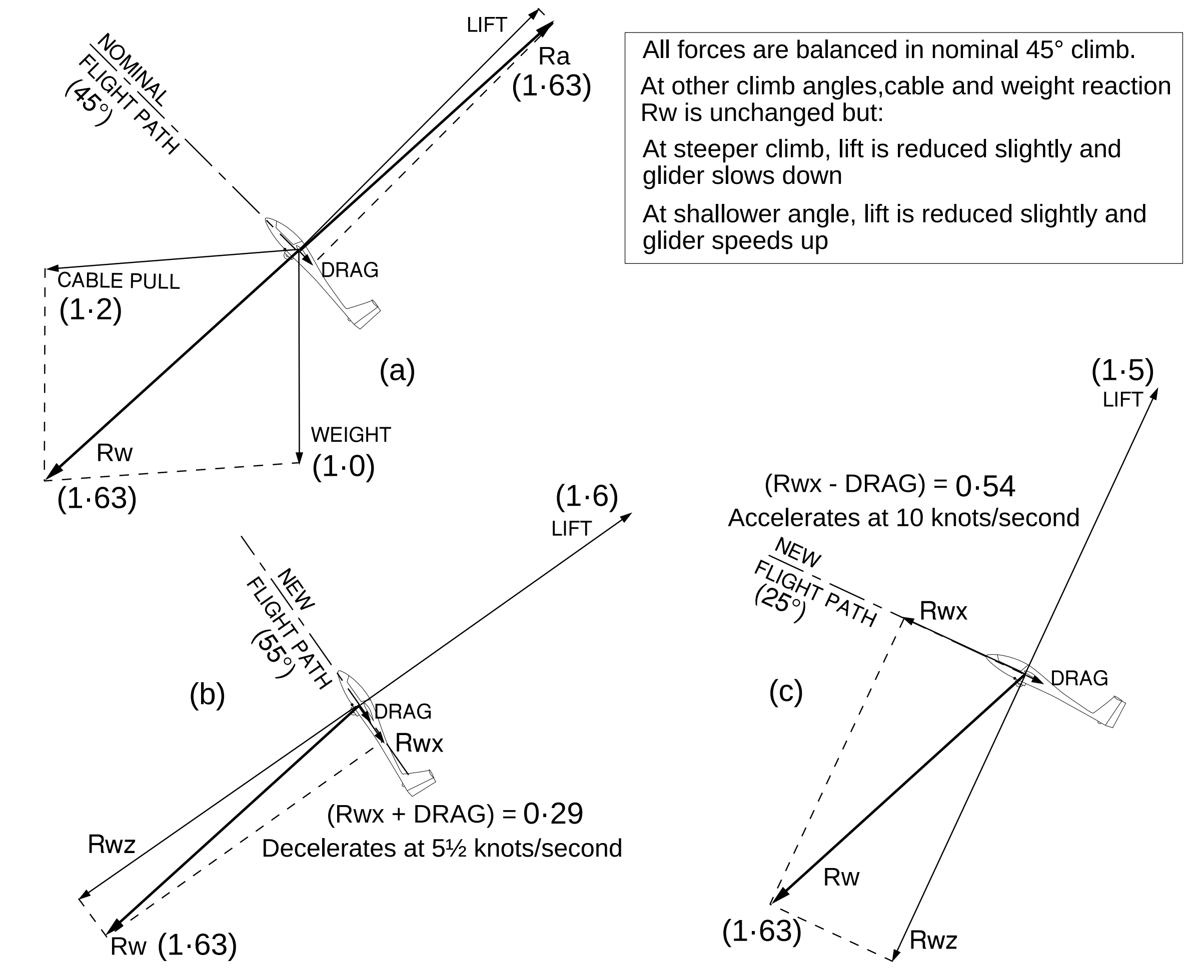

Figure 3 Speed control with constant torque winch

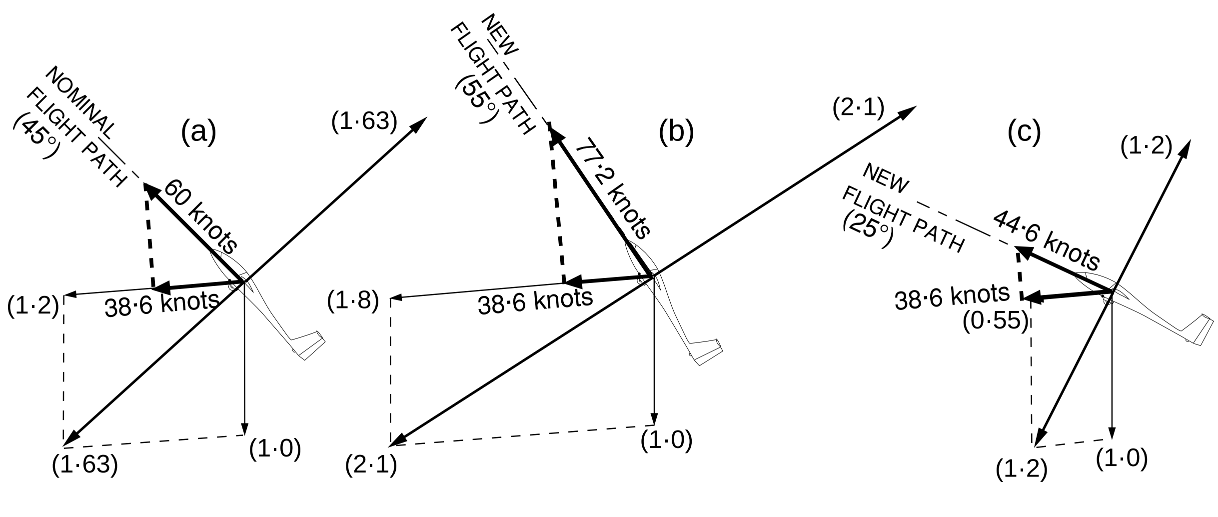

Figure 4 Speed control with constant speed winch

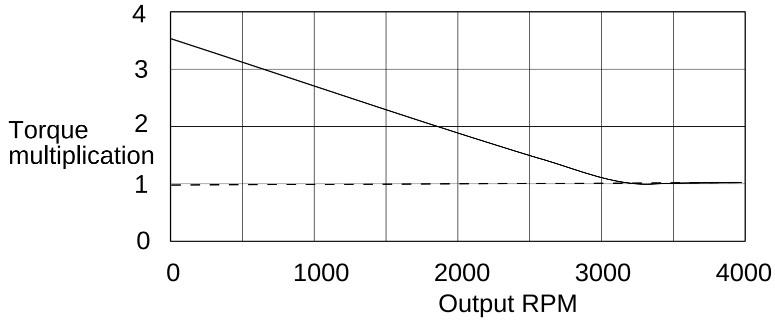

Figure 5 Typical torque converter characteristic

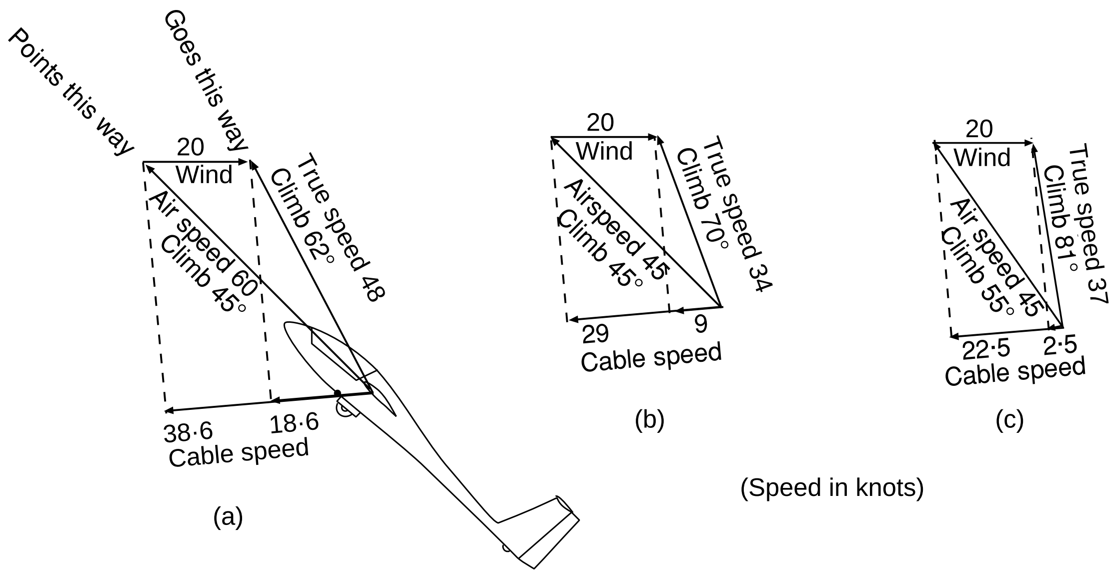

Figure 6 Effect of wind at various speeds and climb angles

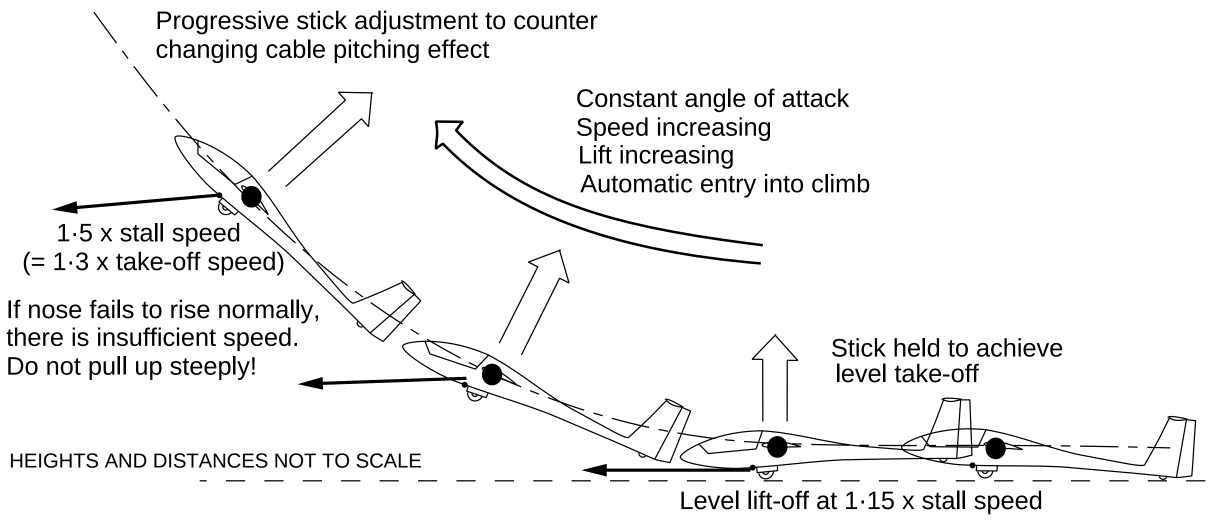

Figure 7 Ideal take-off and climb entry

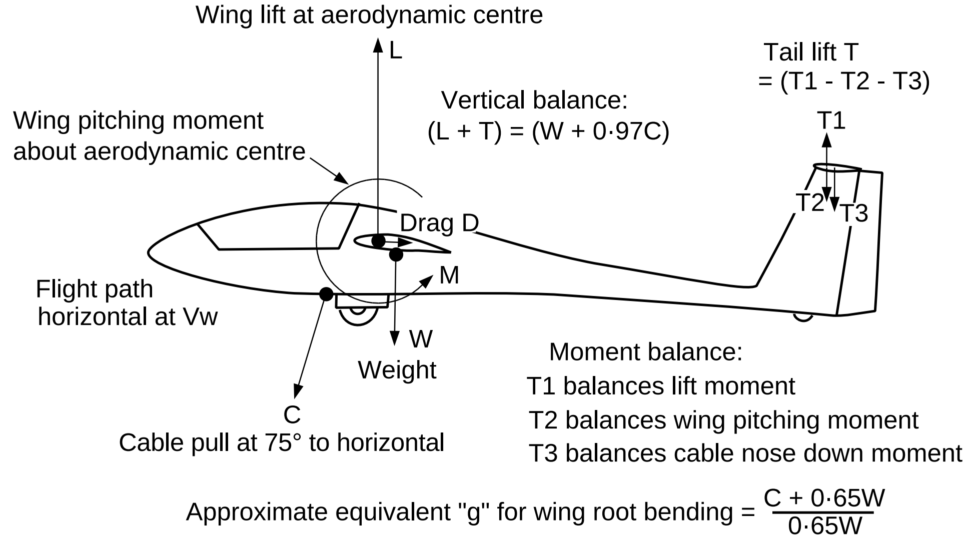

Figure 8 Nominal winch launch design case

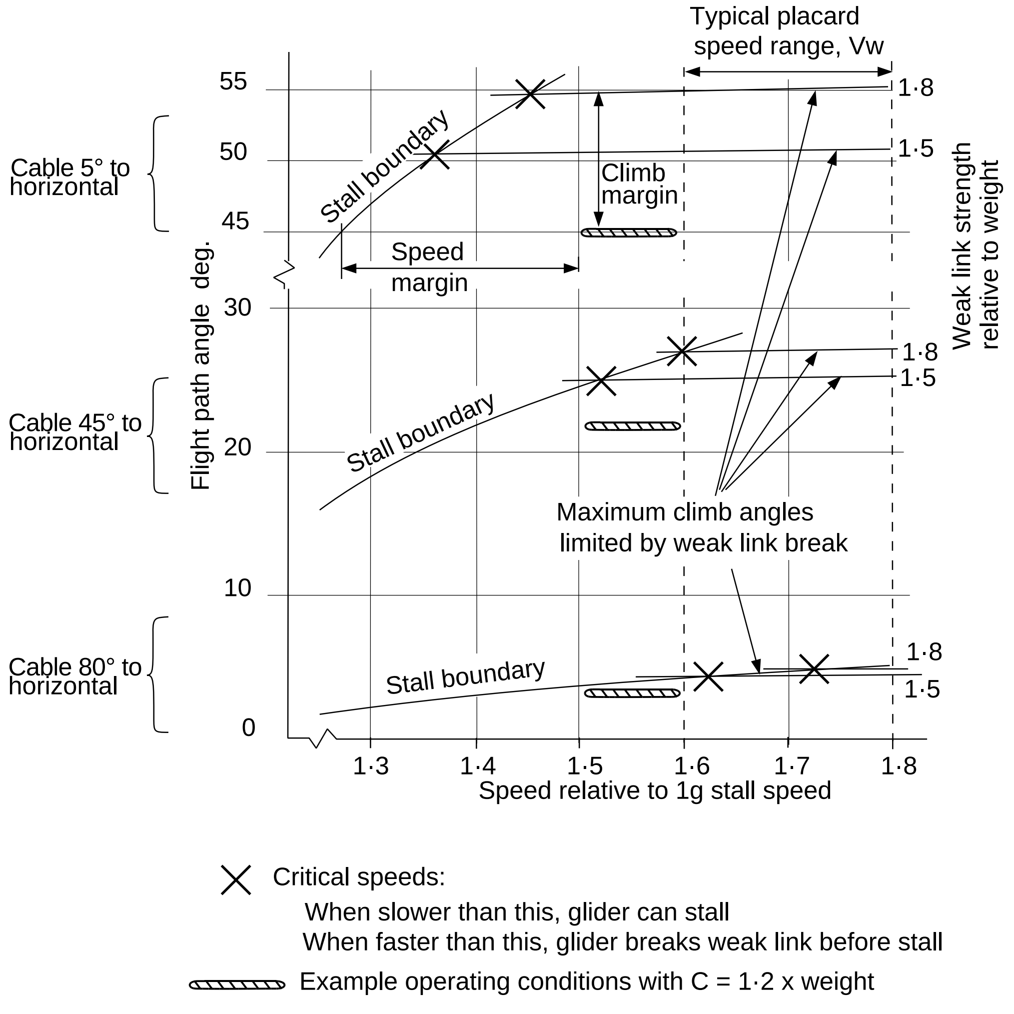

Figure 9 Stall and cable break margins

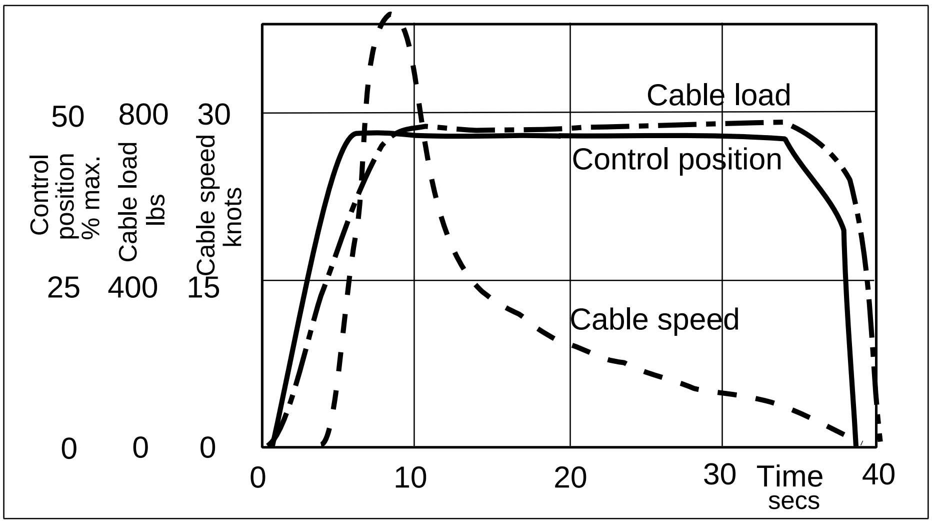

Figure 10 Torque-controlled winch launch

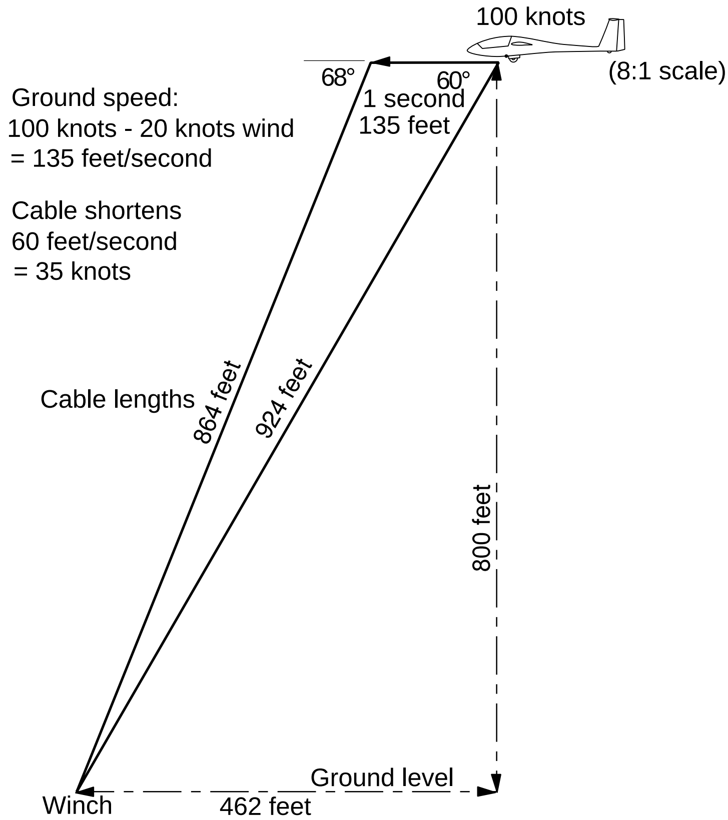

Figure 11 Anatomy of a 100 knot launch