OPMF74 -PG TOW BACKGROUND READING

This section is intended as background reading, you will find rereading the previous sections rewarding after digesting the information contained below.

With the exception of Dick Cheney, President of UP International, who first foot launched an oak and nylon Rogallo glider in 1958, towing begat hang gliding. In 1964 an Australian water skier, John Dickenson, replaced the boat towed flat kite with the Rogallo wing. Towing done in those early days was static line towing, using a fixed length of tow line between a tow vehicle and whatever was being pulled. The use of the Rogallo wing in contrast to the flat kite was a dramatic leap in technology because the Rogallo glider is a true wing, a lifting device, distinguished by having:

- a forward glide;
- a change in that glide over a useable speed range; and
- independent control of airspeed and bank angle.

These same differences are part of what distinguishes our paragliders from parachutes, though the foundation of our technology is directly inherited from skydiving. An early example is the introduction of the Para-commander, a round canopy with stabilisers and rear slots for turn control. Modern parasailing evolved as the combination of this and other round canopies coupled to a boat by a static line. This spin-off activity has limited potential though, because it uses a drag dominated descent device which lacks an appreciable glide. Parascending was begun by towing round canopies, but has advanced with the development of the ram air canopy with a nectangular planform, commonly called squares. Mountaineers later gave birth to paragliding when they used these squares as descent vehicles.
Our modern panagliders are distinguished from skydiving or parascending by:

- being rigged with a higher angle of attack;
- using a coated impermeable fabric
- having a lower internal pressure; and
- greater aerodynamic efficiency by using....
- an elliptical plan form
- a higher aspect ratio
- more and smaller cells
- smaller cell openings relocated immediately below the front to provide a smooth leading edge profile.

As a result of these refinements, our modern paragliders require only 1/3 of the towline tension of the earlier parascending canopies, and approximately 2/3 that of earlier paragliders. Though modern lines and fabrics are strong, and certified gliders are load tested to 6-8 Gs, the skinny upper lines are much more vulnerable to abuse from abrasion and kinking than the fat “ropes” of earlier versions. This vulnerability increases the risk of “over towing”, pulling too hard and thereby stressing the lines, as well as the canopy, attachment loops and seams.

Static line towing is still in use today due to its simplicity and low cost, but the susceptibility to over-towing when using this method has made it somewhat archaic and obsolete with the current availability of new technology. Towing was popularised with the advent of the safer dynamic towline; one that changes length.

The first of the two dynamic systems, the stationary (or payin) winch, had more than just safety as motivation; namely doing it overland without a roadway, Operation of a winch begins by laying out a relatively long length of line, at least several hundred feet, and perhaps as much as a few thousand feet. Some form of power drive such as a petrol engine, in conjunction with a hydraulic or mechanical clutch, is then used to draw the towline in, temporarily creating air speed to thrust the glider to altitude.

The second system, the payout winch, reverses the dynamics by lengthening, rather than shortening the towline. This system uses a mechanical or hydraulic brake to set the line drag, much like a fishing reel. A moving vehicle such as a truck or a boat creates the thrust whilst the glider provides lift and draws the towline off the reel.
The payout winch provides a significant safety advantage over static line towing; the ability to ‘spool’ line to the glider during the tow. This is crucial because it eliminates the over-tow problem, due to thermal gusts. The clutch on a payin winch provides a similar benefit.

If hydraulic technology with an adequate pump is applied to towing, the features of a payin and payout winch can be combined into one. This offers versatility, smoothness and reliability, but the price paid is greater cost, weight, size and complexity. Whatever your budget allows, the measure of a safe tow system is its ability to provide a consistent towing tension throughout the duration of the tow. So in the interest of glider safety with respect to lines, their attachment point, the seams and canopy stretch; towline tensions should be kept to a minimum.

Many tow systems on the market today were first developed with the broader speed range of the hang glider in mind. Whilst these systems can be utilised for paraglider towing, their operational parameters of tension and speed need to be reduced and the Operator control needs to be more gentle and subtle.

Inherent in the dynamic design of both payin and payout winch systems is the large rotating mass of the spool and line. This large rotating mass has inertia; the tendency to resist speed changes and to maintain its current rotation rate, so it behaves like a flywheel. The advantage of this is that it smoothes out the delivered line tension. Another way to provide for this dampening is to use a short portion of ‘stretchy’ material, such as nylon, at the pilot end of the towline. This ‘leader’ line will be discussed further in this document when we discuss lines and their properties.

The disadvantage of the fly-wheel effect is that it slows the systems ability to prompt spool line to the glider in response to sudden changes in climb rate when entering a thermal, on from excessive pilot braking. To reduce the dynamic inertia, the weight of the notating mass should be kept to a minimum. This includes the spool, the line and the brake discs. The rotating inertia increases with the square of the distance the mass is concentrated at, so keeping the diameter of the notating mass small increases responsiveness of the system. However you’ll soon see that an excessively small reel creates a different problem.

A creative alternative for the need for the line winder and particularly for the traveller mechanism, is the use of a narrow reel. This design was originated by Brad Lindsey with his SMARTow (Self Contained Modular Automatic Rewind Tow) system, and is now used by Larry Keegan and Ed Pitman for the systems they build. The winding occurs the same as with a sewing machine bobbin. When sufficient line tension is provided during rewind, the line cannot ride over the previous wrap and pile up into a mound in the centre. Due to the tension, and the narrow spool width, the line will instead move laterally until it reaches the sidewall of the spool, which forces it to reverse direction and begin the next layer. Thus the lay of the line onto the reel is automatic, but the key is to have continuous and adequate line tension during the entire rewind process.

A synergistic means of providing this line tension is to use a retrieval kite. The kite creates resistance to keep the line tight, when simultaneously flying the line above the surface. This avoids both the abrasion wear of dragging the line over the ground, as well as the potential for snags on bushes, trees, fences etc. For boat towing, the line doesn’t have to be pulled through water, which is hard on the rewind motor, and won’t leave it vulnerable to being severed by the propellers of other boats passing across it. The retrieval kite is a fine device in theory, however it has to deploy reliably, and fly consistently to produce a tight and uniform wrap of the line of the drum.

The most critical item is the excessive change in the effective reel diameter over the entire line length. As the tow progresses and more line is payed out, the effective reel diameter, which includes the line, is diminished. This reduced radius lessons the lever length of the line with respect to the reel axle, which in turn increases the effectiveness of the hydraulic pump, with a resulting increase in the tension. What occurs operationally is that the line ceases to payout, and the tow operator must reduce the tension or increase speed to continue to feed line to the pilot.

The increased line tension is actually preferred by some hang glider pilots to ‘slingshot’ their glider to a steep tow angle and get them higher above the tow vehicle. This has value when there is a limited distance for the tow vehicle to travel, or when using a short tow line. Paragliders don’t cut through the air and penetrate as well though, and the combination of increased line tension, combined with a steeper inclination angle serve primarily to promote ‘overtowing’; excessively loading the lines and causing line stretch.

Diameter changes of approximately 25% to 30% over the entire line length are the recommended differences that can be used to prevent this automatic increase in line tension from arising. These changes in effective diameter should come close to balancing out weight and aerodynamic drag of most of the lighter types of line in the air. As noted earlier, a small diameter spool is desirable from an inertia standpoint, but the ratio of O.D. (outside diameter) to I.D. (inside diameter) should be within the above percentage and also have the capacity to accommodate a large quantity of line.

Another critical subsystem is the brake or clutch of payin and payout winches. These must be designed for repeated use to avoid excessive wear and overheating. These components should minimise the production of heat, or maximise the dissipation of heat build-up, or both, to allow them to continue to perform effectively in the presence of the heat accumulation that does occur. Also, if brakes are used, the discs or drums should be located out in the airstream to maximise their exposure to cooling airflow. Likewise, a winch clutch or the vane pump of a hydraulic system needs to have some provision for ‘keeping their cool’. Some systems have their brake drum buried within the inner diameter of the spool. This promotes brake slippage of ‘fading’ from over-heating, resulting in a reduction or loss of towline tension. In addition, the brake rotor or drum diameter should not exceed the I.D. of the spool to avoid ‘overpowering’ the inner layers during payout, and making the tow ‘jerky’.

The final major component of most winch systems is the rewind motor. It must have sufficient torque to rapidly suck the line in without over-heating or drawing an excessive amount of current that would drain the battery and/or overtax the recharging system. An automobile starter motor is often the motor employed, but it is chosen because of its low cost and availability, rather than its suitability for the job. The proper motor would also have ball bearings at both ends of the shaft for long mechanical life.

Finally, there is the control unit. It should have some provision to immediately dump pressure to allow for commencing the rewind promptly, and for emergency conditions, such as lockout. It should also have a sensitive pressure adjustment control for fine tuning the towline tension during the tow.

The most common material used for safety links is size 205 braided Dacron leech line, which is made for the sailing industry and is also used for rib tensioning on the trailing edge of hang gliders. Fishing line is also popular for this application. Whatever you chose, each newly acquired batch of material should be tested to ‘calibrate’ its load limit. This reason for this is that suppliers of line and cord monitor maximum rated workload as the criteria of quality assurance because most users want to know that the line will be strong enough for their application. This value can change with variations in the parameters of the manufacturing process, such as thread size, braiding tensions, and dye content. For our application as safety links, we are interested in the maximum breaking strength; the ultimate load at which the line will fail. This value also changes as the manufacturing process variables are adjusted. However, producers generally do not monitor or publish this value because there is not a sufficient market demand to do so. Therefore it is possible that the ultimate strength can vary from batch to batch, even if it is the same size and of the same material, and is obtained from the same supplier.

It is also critical to test the safety link in the same configuration in which it is used when towing. Use the same number of loops or strands, the same knot(s), and the same end attachments, since these all effect the failure strength.

Knotting reduces the strength of any line because of the increased tension exerted on the fibres on the outside of the bend in the line. Therefore, any type of knot, the tighter the radius of the bend in the line, the weaker the knot. That’s why a knot in a larger diameter line will be stronger beyond the proportional increase in cross-sectional area than the same knot in a smaller diameter line. Similarly, when a line is doubled, then tied, the knot will be stronger than for the same knot tied in the single line.

When using some generic ‘fineline’, a relatively small diameter towline, let’s say less than 3/ 16” (4.8mm), the safety link can be reduced in strength compared to when using a fatline’. The reason for this is additional load imposed by the added weight and the aerodynamic drag of the wider line when it is stretched out in the airstream during the tow. Both of these factors can cause the towline to sag. This penalty of ‘fatline’ is magnified when tow altitudes increase. The sag can begin to become noticeable as low as 600’ (183m) AGL with jumbo line of 3/8” (9.5mm) diameter, and can in some cases limit the tow altitude to less than 2000’ (610m) AGL. By contrast, paragliders have been towed to approximately 4000’ (1220m) AGL using a fineline.

It is important to realise that this sizing convention was derived empirically, that is through trial and error, using a hang glider safety link as a starting and reference point. The frame wings are better

suited than paragliders at handling a strong safety link because of their ability to penetrate and fly faster. Paragliders have a narrower speed range, particularly on tow, while hang gliders have a wide speed range. So the hang glider pilot can readily reduce the loading due to the tow force simply by speeding up. It is the paragliders smaller speed range, and particularly the slower top speed, that limits its ability to ‘offload’ excessive towline tension. This necessitates the weaker safety link. On the other hand, paragliders can ‘weather’ a low altitude, low airspeed safety link failure better than a hang glider. Therefore, they can be towed with a weaker safety link. If excessive towline tension breaks the safety link, canopy surging does make low altitude recovery a real danger. However, use of a stronger safety link in combination with excessive line tension can lead to low level lockout, which is even worse.

The release mechanism is what allows the pilot to separate from the towline anytime during the tow. This device must provide a means to significantly reduce the full tow-line tension to some lesser value to that holding the release pin. Otherwise it would require excessive force to activate the release. This force reduction function provides leverage, or more correctly, a mechanical advantage, much like a block and tackle system.

The release for paragliding is a variation of the three ring type used with sky-diving rigs. It allows the parachutist to ‘cutaway’ from their main canopy in the event of malfunction. For our application, fabric cords are substituted for the metal rings. This creates a 'soft' release, with three loops, or even two loops, since the leverage needed for our application is less than that needed for the higher speeds of sky-diving.

Each cord is sewn into a loop and anchored to a piece of nylon webbing, which serves as the body of the release. Each successive loop reduces the force holding the release pin in place so that only a fraction of the towline tension is required to pull the release pin. It is imperative that the release mechanism operates smoothly and flawlessly for the full range of towline tension, from full to light. It is best to have the mechanism covered to protect it from grit and dirt.

Open mechanisms have occasionally jammed and prevented separation. A 'heavy metal' release is not well suited to paragliding because of the potential hazard of the metal hitting the pilot's face if towline separation occurs while the towline tension is high. The less exposed metal the better, so the 'dust cover' mentioned above serves a secondary purpose of padding the release pin and the grommet, in the event of'slapback'.

The bridle attaches the release to the glider. To distribute the tow-line tension to each set of risers equally, the bridle must split into two legs from the release in the form of a 'V'. A short bridle is preferable to keep the release directly accessible. Optimum is about 18" (46cm) so that each leg of the 'V' is slightly longer than the distance between your risers. A short bridle will also keep the safety link well within reach, Since the safety link is the easiest component to cut with your hook knife, keeping it in close proximity will enhance the effectiveness of this emergency option. To reduce 'slapback' recoil, bridles should be made of relatively inelastic material, such as woven webbing, as opposed to a cord which is designed to stretch.

The best location for attaching the bridle for the purpose of load application is at the riser/carabiner juncture because this is where the glider is intended to be loaded; this is where you're suspended from. A short piece of cord or webbing sewn or tied into a loop and attached in a Lark's Head knot around both the riser and carabiner serves to both properly load the juncture and to anchor the carabiner from sliding into a side load position.

As an alternative, some pilots have towed from the carabiners. One problem with this attachment is that the 'biner', particularly the gate side, is not designed for this loading, and is therefore subject to failure. A worse problem that arises from towing off the carabiners is that the carabiners often become misaligned while taking up slack in the towline. This places your suspension load across the short axis of the biner. Then, during towing, you are exerting at least 1 G load across the gate of the biner, if the gate fails, you're history. By the way, when was the last time you inspected your carabiners from stress cracks at the gate hook or hinge, or for dents from such simple abuse as dropping them on a rock?

Attaching your bridle to your flying carabiners directly with another carabiner maximises the loading on both carabiners because the metal contact concentrates the load at a point, or at best on a very small area. This can cause aluminium carabiners to dent or fail. This method is only safe if all four carabiners are steel.

Towing off of the A-risers alone may cause or sustain a full frontal closure, so this is risky at best. Another poor choice for attaching the bridle is to the harness at the biner loops, usually these suspension points on the harness are designed only for an up load, not for a thrust load (forward) or down load. So unless you add some reinforcement for both forward and downward loading, you are likely to damage your harness over time. You can certainly imagine the catastrophe of having your harness fail in flight. Attaching the bridle to the harness far above or below the carabiners will tend to pivot the pilot about the carabiners, head first or feet first respectively.

It is also important to ensure that the bridle connections are symmetrical on the harness, both laterally in terms of width and vertically in terms of height. If not, you may find yourself 'crabbing' through the air sideways, or constantly countering a turn. A common cause of this error is unequal length legs on the 'V' of a home-made bridle.

As the glider climbs high and steep above the launching surface, the tow line sags as mentioned earlier and it takes the shape of a characteristic arc, known as a catenary curve. The thicker and heavier the towline, the more drag and weight respectively and the more dramatic the occurrence of this effect. It can become quite obvious on a payout system, when the towline is observed paying out horizontally from the reel. This effectively limits additional altitude gain due to the ever increasing weight and drag of the towline. To climb higher in this circumstance, the towline tension must be increased, but to do so is a strong arm answer to the problem. This is better resolved with advancements in technology.

The development of ultra high tensile strength materials has made available 'finelines' which are much smaller than commonly available 'poly ropes', and their weight is minimal. As an example, 3/32" (2.4mm) Spectra has a tensile strength of 730 lb (3.26 kN) yet weighs less than 2 lbs (0.9 kg) per 1000' (305m). Due to their extreme light weight, 'finelines' are drag dominated; their aerodynamic drag will cause the towline to sag before their weight will. But since their frontal area is so minimal, towline sag is largely eliminated because of the drag of a 4000' (1220m) towline is minimal.

'Fatlines' on the other hand require more fibres for equivalent strength and so are larger in diameter. Since they are made of relatively soft material, sometimes they are also made thicker to reduce abrasion. This make them heavy, so 'fatlines' are weight dominated; their weight will make the towline sag before their drag. This shift from being weight dominated to being drag dominated is the distinguishing characteristic of 'performance' towing.

Performance towlines are clearly more efficient, but they do cost more and because of their small size they have less wear margin for abrasion. Unless all your towing is performed in soft grassy fields, you need to consider towline abrasion. This can be avoided by using a parachute to hold the tow-line off the ground during rewind. Better yet is to use a ram-air kite to fly the towline down. Rewinding the towline while it is in the air, rather than dragging across the ground, will greatly increase the life of any towline and it is especially advantageous for costly performance tow-line.

Nylon is a Dupont branch name for Polyamine. While not recorded as a towline, it is used because of its low cost. It has elasticity and moderate U.V. resistance. Typical size would be 3/16" (4.8mm) or larger. It is most useful as a shock reducing leader line when using low stretch towlines. This application is more appropriate for towing of hang gliders to cushion the lift off loading. It's counterproductive to use Nylon as a shock reducer for paraglider towing because a firm steady pull enhances a prompt inflation and also minimises canopy surging.

Polypropylene is used as water-ski towline because it floats. It is low cost at $25 to $45 per 1000" (305m) with good U.V. resistance but is relatively heavy in the 3/16" (4.8mm) or larger size needed. It has only fair abrasion resistance.

Polyester is marketed by Dupont as Dacron. It has low stretch, with good abrasion and U.V. resistance, but does not float. It offers a good balance between cost and performance at S40 (305m). Typical (4.8mm) to ¼"
to $70 per 1000' sizes are 3/16" (6.4mm).

Polyethylene (PE) in its simplest form is produced and known in the US as Tupperware and Saran Wrap. Allied Signal markets a high tenacity modulus (HTHM) PE fibre known in the US as Spectra. In Europe, the same material in known as Dyneema. It exhibits low stretch and has good U.V. and abrasion resistance, which can be improved on with coatings. Related to Teflon, it has high lubricity, but unlike its relative, it has a low melting point so will usually melt before it wears due to abrasion. It is popular for boat tow operations because it is the only performance line which floats. It is 'pricey' at over $100 per 1000' (305m) but all regular uses feel that it is worth the extra cost. Common sizes are 3/32' (2.4mm) to 3/16(4.8mm).

Polyaramide is marketed by DuPont as Kevlar. It is very low stretch and has a very high melting point. It does not float, has fair U.V. resistance, is brittle and can be abrasive, even to itself. Silicone coatings applied during the manufacturing process can improve it handling and abrasion characteristics. It is very strong and tough and is used in tyre sidewalls, bullet proof vest, helmets and for paragliding back protectors. It costs $75 to $100 per 1000' (305m) and as a performance towline a typical size is less than 1/8" (3.2mm).

Towline is also available as a braided core material covered with a woven sheath, much like the lines on your paraglider. The core provides the strength and the external cover is for abrasion, contamination and U.V. protection. It costs more, splicing is possible though difficult, but it should last much longer. Whilst not popular in the US, some European winch builders favour it.

Hollow braided towline facilitates quick splicing out in the field without having to resort to tying a knot, which weakens the towline and creates a discontinuity for line guide systems. The preferred splicing method is the 'finger trap' because it is clean, effective, quick, and simple. The special tool required to accomplish this splice is a fid. This is typically a hollow tapered tube, closed and rounded at the narrow end, made of plastic or metal, and available in different diameters to accommodate different size lines. Fids and finger trap splicing instructions are available where hollow braid rope is sold.

Spectra is especially slippery, so when splicing this material with a finger trap, the free end of each towline should be extracted from the inside, then externally knotted from the inside. This knot does not weaken the splice because the finger trap is carrying the majority of the tension. Also it doesn't create a bulge because the knot is comparable in size to the splice. A loop in the end of a towline made with a finger trap splice of the end within itself. Alternately, doubling the towline when tying a figure-8 knot serves well for the towline end loop.