Glider/Tow-Plane Upsets

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Summary

Several accidents have occurred in the UK and elsewhere, in which a towed glider has climbed above the tow-plane, pulling up its tail. The tow-plane pilot has lost control, resulting in a sharp nose-down pitch. If the upset takes place near the ground, the results are often fatal.
Calculations by F.G. Irving and P.L. Bisgood have indicated dangerous combinations of glider flight path slope and towrope angle. Various gliders were considered, towed by a 180-HP Super Cub. Surging loads can induce upsets at quite modest towrope angles—about 15°—particularly, if the glider pilot allows a nose-up pitch to develop. Flight tests confirm these findings.
Various technical measures to reduce the likelihood of such upsets are mentioned. Tests have been made of tow-hooks designed to release the rope automatically when its upwards angle reaches a predetermined value. They have not worked particularly well and have confirmed the theoretical prediction that they would only deal with part of the problem. A more promising approach is a proposal for a hook which releases automatically when the vertical component of load at the tail of the tow-plane reaches some pre-determined value.

Introduction

Since 1964, there have been at least ten notified accidents in the UK due to the tail of a tow-plane being pulled up by the glider. Of these, six were fatal, resulting in the deaths of five tug pilots and one glider pilot. Similar occurrences have been reported in other countries: for example, there was a particularly serious accident in Tasmania in 1984 when all three occupants of a Pawnee and a Blanik were killed.
In all of these accidents, the glider achieved a high position behind the tug and the tug pilot applied up-elevator to maintain his attitude. Eventually, the tug pilot lost control and was unable to prevent the tow-plane pitching sharply nose-downwards. *Fig. 1* illustrates the sequence of events. The consequences of such an upset, under test conditions, are described later. Clearly, recovery is not normally possible if such an upset occurs near the ground.

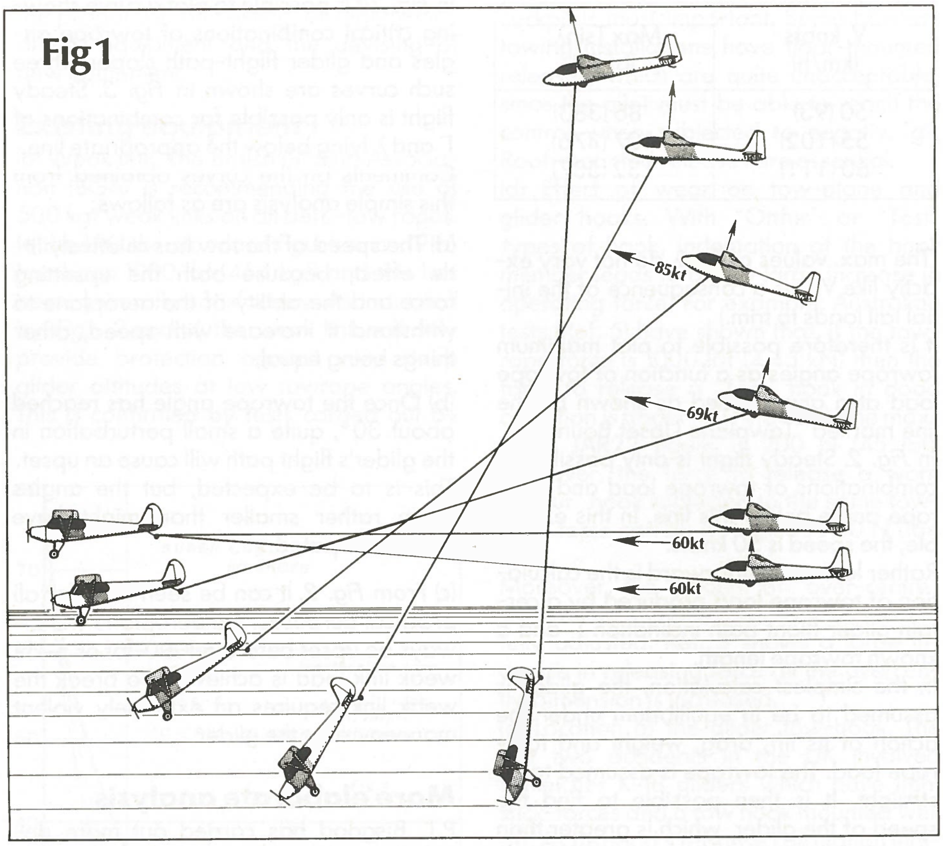

Fig. 1 Sequence of events during a glider/tow-plane upset.

Various causes and contributory factors for such accidents have been suggested, including poor instructional methods, taking-off into the blinding evening sun, a sudden climb due to wind gradient, low longitudinal stability of the glider, the use of belly-hooks for aero-towing, the glider trimmed tail-heavy, too short a towrope, excessive towrope strength, and difficulty in releasing one end or the other.
The purpose of this paper is not to consider the operational aspects of such accidents but rather to consider the mechanics of the upsets as a guide to devising means of avoiding them.

Appendix: Symbols

T	Load in the towrope (lbf or N)
V	Equivalent airspeed of the tow-plane (knotsa or km/h)
Γ	Slope of the flight path of the glider
λ	Angle of the towrope relative to the flight path of the tow-plane

The Simplest Analysis

The glider is assumed to climb, with its flight path inclined at to the horizontal, whilst being towed by a tug which is itself in level flight. The towrope angle to the horizontal is λ. It is assumed that control of the tug is lost when the tailplane attains the extreme negative lift coefficient available at the prevailing tail incidence (approx. zero) and with the elevator fully up. There is some evidence (Ref. 1) that a likely figure would be about −0.6. In order to calculate the corresponding curves of critical towrope angle against towrope load at various speeds, the aeroplane was assumed to be a 180-HP Super Cub. It was assumed to be flown by a 170-lb pilot and to be half-full of fuel. Dimensions and weights were taken from the flight manual and some further dimensions were estimated from the GA drawing. The pitching moment coefficient of the wing-plus-fuselage about its aerodynamic centre was estimated from the characteristics of the wing section (USA 35B) and RAeS data sheets. It is therefore possible to find the limiting value of the vertical component of the towrope load at a given airspeed with the tail at the extreme negative lift coefficient. Some values are given in *Table 1.*

V, knots (km/h)	Max Tsinλ, lbf (N)
50 (93)	86 (383)
55 (102)	107 (476)
60 (111)	132 (587)

(The max. values of Tsinλ do not vary exactly like V^2, as a consequence of the initial tail loads to trim.)
It is therefore possible to plot maximum towrope angles as a function of towrope load at a given speed as shown by the line marked "Towplane Upset Boundary" in *Fig. 2.* Steady flight is only possible at combinations of towrope load and towrope angle below this line. In this example, the speed is 50 knots.
Rather less straightforward is the calculation of towrope load produced by a certain glider flight path inclination Γ and a known towrope length.
In the simplest calculation, the glider is assumed to be in equilibrium under the action of its lift, drag, weight and towrope load. The towrope is assumed to be straight. It is then possible to find the speed of the glider, which is greater than that of the towplane, its load factor, its drag and finally the towrope load. The equilibrium hypothesis is equivalent to assuming a rigid towrope of infinite length, since accelerations are neglected.

This method was used to derive the lines labelled "Towrope loads from the glider" in *Fig. 2.* These correspond to a glider with roughly the characteristics of the K-8. From the intersections of the curves in *Fig. 2* it is possible to plot a curve showing critical combinations of towrope angles and glider flight-path slopes. Three such curves are shown in *Fig. 3.* Steady flight is only possible for combinations of Γ and λ lying below the appropriate line. Comments on the curves obtained from this simple analysis are as follows:

(a) The speed of the tow has relatively little effect, because both the upsetting force and the ability of the aeroplane to withstand it increase with speed, other things being equal.

(b) Once the towrope angle has reached about 30°, quite a small perturbation in the glider's flight path will cause an upset. This is to be expected, but the angles seem rather smaller than might have been anticipated.

(c) From *Fig. 2,* it can be seen that, for all practical purposes, the aeroplane will always be upset before a 1000-lbf or 5-kN weak link load is achieved. To break the weak link requires an extremely violent manoeuvre by the glider.

More elaborate analysis

P.L. Bisgood has carried out more detailed analyses to include towropes of finite length and stiffness (Ref. 2). The effect of finite length is to introduce centrifugal forces which, for given values of λ and Γ, increase the towrope load. The increment

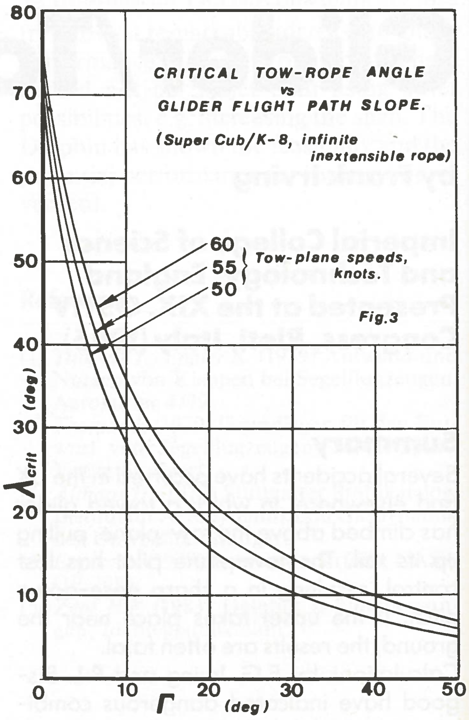

Fig. 3 Critical towrope angle vs glider flight path slope with different towplane speeds.

in load is negligible at high towrope angles but increases rapidly as λ decreases and the climb angle Γ increases. For example, at 60 knots and Γ = 30°, the towrope load at upset according to the simplest analysis would be 535 lb (2.38 kN). With a rigid rope of length 150 ft (46 m) and with Γ = 30°, upset would occur at a load of about 1000 lb (4.48 kN) and a correspondingly smaller towrope angle. It is evident that the effect of finite rope length is very great and renders upsets more likely than *Fig. 2* would suggest. In *Fig. 2,* the effect is to move the "Towrope load" lines increasingly to the right as Γ increases. For a 200-ft (60 m) rope at a towplane speed of 50 knots, the Γ = 35° line is moved to roughly the position shown for Γ = 45°.
The effect of an elastic rope is that its stretch reduces the centrifugal force. If the rope has a stiffness of 20 lbf/ft (292 N/m), then the load at upset in the above example is reduced from 1000 lbf (4.48 kN) to about 870 lbf (3.87 kN).
The effects of both finite length and elasticity are shown in *Fig. 4,* for the aircraft assumed in *Fig. 2* with a tug speed of 60 knots. The rope is assumed to be 150 ft (46 m) long with a stiffness of 20 lbf/ft (292 N/m). These effects make little difference to the upset boundary at low values of Γ and high values of λ but the effect at lower values of λ is considerable. For example, if λ is 15°, the critical flight path angle Γ is reduced from 30° to 20°. An upset is markedly easier to achieve than one might expect from *Fig. 2.*

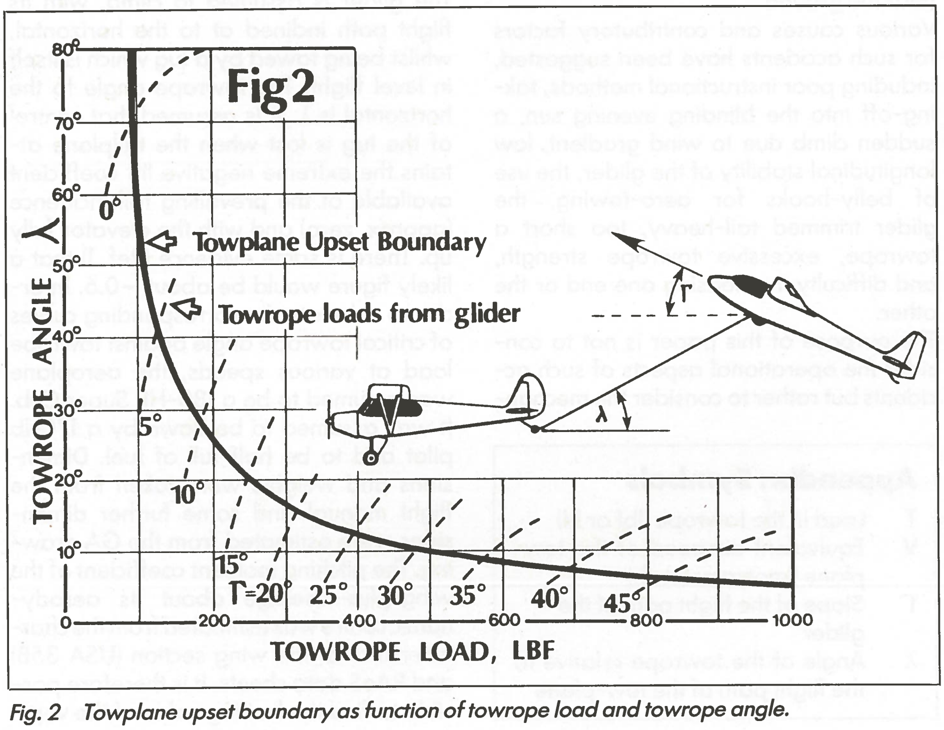

Fig. 2 Towplane upset boundary as function of towrope load and towrope angle.

Also shown in *Fig. 4* is a similar curve for a PIK-20 to illustrate the effects of better performance and higher weight. The former effects are fairly small and predominate at high λ whilst the latter are significant at high Γ. Upsets would appear to be more likely when towing such a glider: in practice this is not so, doubtless due to the greater pilot skill.

Surges

Approximate calculations of the effects of towrope surges have also been made by P. L. Bisgood. For example, an initial slack of 10 ft (3 m) in a 150-ft (46 m) rope with a stiffness of 20 lbf/ft (292 N/m) can produce a maximum towrope load of 320 lbf (1.42 kN) compared with 200 lbf (0.89 kN) in the "zero slack" case, an increase of 60%. With a rope of twice this stiffness, the increase in load is about 100%. These figures suggest that towrope surges can precipitate upsets at towrope angles of the order of 15°. This may seem a fairly large angle, but the glider is only slightly more than one towplane span above the towplane (assuming the latter to be in horizontal flight), a configuration which is probably not too unusual in training.
The approximate response of a glider, with fixed controls, to the surge following a 10-ft slack in the rope has also been considered. The glider was assumed to be a K-18, the type involved in the two most recent accidents in the UK, being towed on the belly-hook. In this case, the pitch-up produced by a combination of surge and tow-hook position quickly carries the glider across the uset boundary. This analysis assumed that the towplane was initially climbing at 6° to the horizontal and that the initial towrope angle, relative to the towplane's flight path, was 10°. Speeds of 50 and 60 knots were considered. So, upsets can occur even when the glider is not greatly above a normal towing position. In real life, it is unlikely that the glider pilot would hold the controls fixed but this example serves to illustrate what might happen if he were slow to respond.

Prevention of upsets

On the average, there is one upset accident every other year in the UK. Compared with the number of aero-tow launches carried out, the rate is quite low (probably of the order of one per 100,000 tows) but since such accidents are very often fatal, every effort should be made to prevent them. It may well be that the primary cause of such accidents is associated with poor instructional or operational techniques but any mechanical measures which might obviate them should obviously be considered. Such measures should not, of course, introduce other hazards: for example, using a weak link of only 300 lbf strength (1.33 kN) might eliminate some upsets but at the expense of frequent rope breaks. "Mechanical measures" comprise both the proper use of existing, or slightly modified, equipment and the devising of new equipment.

Existing equipment

(a) Weak link. The British Gliding Association (BGA) is recommending the use of 500 kgf weak links on all aero-tow ropes. In the UK, the standard figure since 1946 has been 1000 lbf (454 kgf) and this has been generally satisfactory. As indicated by *Figs. 2* and *4*, the weak link will only provide protection against very steep glider attitudes at low towrope angles. This is confirmed by tests carried out by

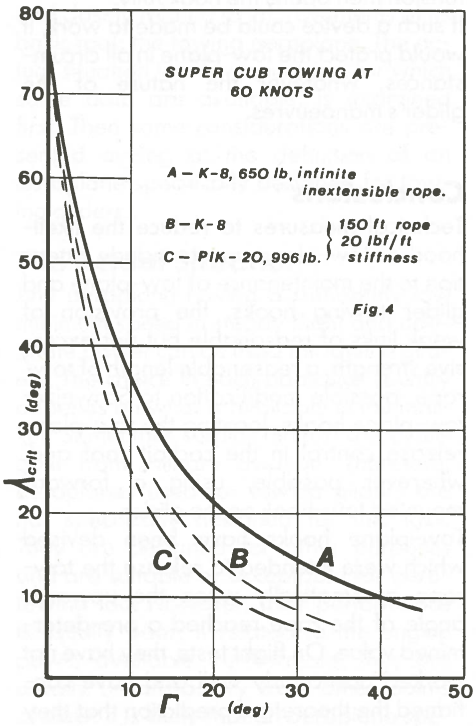

Fig. 4 Critical towrope angle vs glider flight path slope with different glider characteristics at constant towing speed.

the Booker Gliding Club (Ref. 3), when the weak link broke on every occasion that a rapid climb by the glider was initiated, producing only a slight nose-down pitching motion of the tug. Clearly, a weak link is essential.
(b) Towrope length. For obvious reasons, upsets are less likely with longer towropes. The BGA currently recommends a length of 200 ft (61 m).
(c) Tow-plane tow hook. Many towplanes, particularly Piper Cubs and Pawnees, are fitted with the Schweizer hook. This cannot be made to release under severe loads even with a 190-lb (86 kg) adult pulling as hard as possible (Ref. 3). The BGA strongly recommends a moditication (Ref. 4) whereby a 1-inch sealed ball race bears on the latch, replacing a plain roller.
The location of the release control in the cockpit is most important. Some banner-towing installations have floor-mounted releases, which are quite unacceptable, since the pilot must be able to reach the control when subjected to negativ "g". Roof-mounted releases are essential.
(d) Effect of wear on tow-plane and glider hooks. With "Ottfur" or "Tost" types of hook, indentation of the hook member leads to a very large increase in operating force. For example, Australian tests (Ref. 5) have shown that, if the towrope force is 1000 lbf (4.45 kN) then the force to release a "Tost" hook in good condition is about 150 N (34 lbf). The maximum JAR22 figure is 200 N (45 lbf). However, the force to release a worn "Ottfur" hook subjected to the same towrope force can be as high as 730 N (164 lbf).
Moreover, the amount of "over-centre" adjustment on "Tost" hooks must be carefully adjusted. Ref. 5 shows a large increase in releasing force as the overcentre dimension is increased.
(e) Location of the glider tow-hook. The last two accidents in the UK involved Schleicher K-18 gliders which have light stick-forces and a tow hook mounted well aft. As Bisgood's reponse calculation indicates, the response of such a glider to towrope surges can be very unfavourable, even at modest towrope angles. The tests at Booker (Ref. 3), in which a K-8 was towed on the belly hook, produced spectacular results. The glider was put into a climb at about the same rate as at the beginning of an auto-tow launch, whereupon it was almost impossible to stop it. Full forward stick only reduced the rate at which the pitch-up increased. The tow-plane pitched nose-down so rapidly that the engine stopped due to the negative "g" and finally it was pointing vertically downwards with an IAS of 40 knots. The pilot was unable to release the towrope, which broke, and the lowest point reached in recovery was 400 to 500 ft (120–150 m) below the initial height.
Of course, large amounts of aero-towing have been done without any trouble using belly-hooks, and a skilled pilot would not expect to get into trouble. But it is clear that once things start to go wrong, the situation can get out of hand very rapidly. See also Ref. 6 for further descriptions of upsets.
The BGA would like to see a mandatory requirement for "nose hooks" to be fitted for aero-towing. The use of the expression "nose hook" is perhaps rather unfortunate: a forward-mounted hook is in-

tended, perhaps similar to that of the ASW-19. A modification for the K-18 now exists.

New Equipment

(a) Upward-releasing hooks for tow-planes. Two types of hook have been designed which were intended to release automatically when the towrope angle relative to the tow-plane reached some pre-determined value. Tests (Ref. 3) have been made on one type which, on static test with no significant towrope load, released at towrope angles of 15° and 12°. It is apparent, from *Figs. 2* and *4*, that such a hook would only deal with part of the problem, when the angle of climb of the glider was fairly small. These predictions were confirmend by the tests. The towrope angle at release was typically 30° for the nominal 15° hook. This type of hook may be difficult to install on some tow-planes since there may be a tendency for the hook or the rope to foul the rudder. A more compact design was totally unsuccessful.

Another type of hook based on the automatic-releasing Ottfur/Tost principle has also been tested without success. Some calculations by L. Welch (Ref. 7) show that the effects of friction defeat such an arrangement.

(b) Load-sensing hooks. The preceding analysis indicates that the fundamental solution consists of preventing the vertical component of load applied to the tow-plane from exceeding some predetermined value. The figures in *Table 1* suggest that 65 lbf (or 300 N) might be a reasonable value, subject to confirmation by flight trials. L. Welch has written a specification (Ref. 7) proposing that the load should be adjustable over the range 50–200 lbf (222–890 N). He favours a system in which the body of the hook is attached to the aeroplane by means of a pivot but is restrained by a strong spring. A vertical load causes the hook body to move relative to its attachments and a striker then trips the over-dead-centre mechanism of the hook. The tow-cable tension then opens the hook fully.

If such a device could be made to work, it would protect the tow-plane in all circumstances, whatever the nature of the glider's manoeuvres.

Conclusions

Technical measures to reduce the likelihood of tow-plane upsets include attention to the maintenance of tow-plane and glider towing hooks, the provision of weak links of reasonable but not excessive strength, a reasonable length of towrope, possible modification to Schweizer tow-plane hooks, locating the tow-plane release control in the cockpit roof and, wherever possible, using a forward mounted tow-hook on the glider.

Tow-plane hooks have been devised which were intended to release the towrope automatically when the upwards angle of the rope reached a pre-determined value. On flight tests, they have not worked particularly well and have confirmed the theoretical prediction that they would only deal with part of the problem.

A proposal has been made for a tow-hook which releases automatically when the vertical component of load at the tail of the tow-plane reaches some pre-determined value. If such a device could be made to work, it would protect the tow-plane in all circumstances, whatever the nature of the glider's manoeuvres.

Finally, the theoretical figures quoted in this paper are all rather approximate but should serve as a reasonable guide to further developments.

Since the above was written, is has been pointed out by B. Spreckley that violent manoeuvres by the glider produce a marked deceleration of the tow-plane so that the upset may be due as much to the tow-plane stalling as to loss of elevator control.

Deutsche Zusammenfassung

«Das Übersteigen des Schleppflugzeuges durch das Segelflugzeug» von Frank G. Irving.

In Grossbritannien sowie in anderen Ländern haben sich verschiedentlich Unfälle ereignet, bei denen ein Segelflugzeug das Schleppflugzeug während des Schlepps überstiegen hat und dabei den Schwanz des Schleppflugzeuges hochgezogen hat.

Berechnungen von F.G. Irving und P.L. Bisgood geben näheren Aufschluss über die gefährlichen Kombinationen von Flugbahnanstieg des Segelflugzeugs und Schleppseilwinkel. Verschiedene Segelflugzeuge werden dabei betrachtet, die jeweils von einer 180-PS-Super-Cub geschleppt werden. Anschwellende Last kann ein Übersteigen schon bei sehr geringen Seilwinkeln, etwas bei 15°, verursachen, vor allem, wenn der Segelflugzeugpilot es zulässt, dass das Segelflugzeug in eine hohe Anstellwinkellage gerät. Flugversuche haben dieses Verhalten bestätigt.

Verschiedene technische Abschätzungen zur Verringerung der Wahrscheinlichkeit solchen Übersteigens werden angestellt. Es wurden auch Versuche mit Schleppkupplungen gemacht, die speziell dazu entworfen waren, das Seil automatisch auszuklinken, wenn der Aufwärts-Winkel einen vorgegebenen Wert erreicht. Diese Kupplungen haben nicht sonderlich gut gearbeitet und haben bestätigt, dass damit nur ein Teil des Problems gelöst war. Eine bessere Lösung scheint ein Vorschlag für eine Schleppkupplung zu sein, bei der das Ausklinken automatisch dann erfolgt, wenn die Vertikalkomponente der Kraft am Rumpfende des Schleppflugzeuges einen vorgegebenen Wert erreicht.

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