

Glider/Tow-Plane Upsets

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SUMMARY

Several accidents have occurred in the U.K. and elsewhere, in which a towed glider has climbed above the towplane, pulling up its tail. The towplane 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 towhooks designed to release the rope automatically when its upward angle reaches a predetermined angle. 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 released automatically when the vertical component of load at the tail of the towplane reaches some pre-determined value.

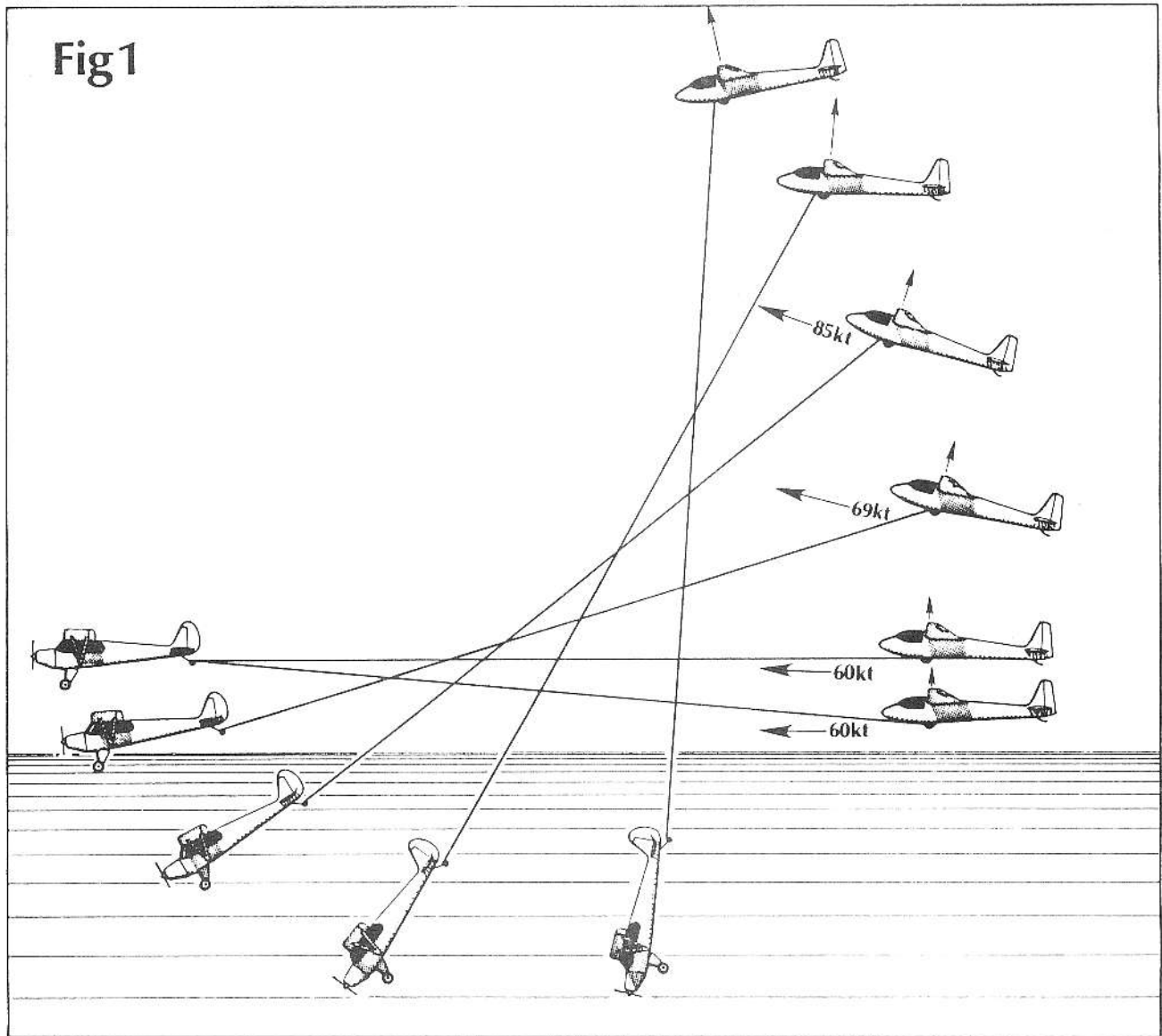
INTRODUCTION

Since 1964, there have been at least ten notified accidents in the U.K. 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 towplane pitching sharply nose-downwards. **Figure 1** illustrates the sequence of events. The consequences of such an upset, under test conditions, are described later. Clearly, recover is not normally possible if such an upset occurs near the ground.

Various causes and contributory factors for such accident 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 aerotowing, the glider trimmed tail heavy, too short a tow-rope, excessive towrope strength, and

Fig 1



difficulty in releasing one end of the other.

The purpose of this paper is not to consider the operational aspects of such accidents but rather to consider the mechanics of such upsets as a guide to devising means of avoiding them.

THE SIMPLEST ANALYSIS

The glider is assumed to climb, with its flight path inclines at Γ 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 airplane 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 general arrangement drawing. The pitching moment coefficient of the wing-plus-fuselage about its aerody-

dynamic center was estimated from the characteristics of the wing section (U.S.A. 35B) and R.Ac.S 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 I. (The maximum values of $T_{\sin\lambda}$ do not vary 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 Figure 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.

On 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 intersection 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 Figure 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 airplane to withstand it increase with speed, other things being equal.

(b) Once the tow rope 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 airplane will always be upset before a 1000-lbf or 5kN weak link load is achieved. To break the weak link requires an extremely violent maneuver 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 Γ and λ , increase the towrope load. The increment in load is negligible at high towrope angles but increases rapidly as λ decreased and the climb angle Γ in-

creases. For example, at 60 knots and $\Gamma=30^\circ$, 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. (46m) and with $\Gamma=30^\circ$, 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. (60m) rope at a towplane speed of 50 knots, the $\Gamma=30^\circ$ line is moved to roughly the position shown for $\Gamma=45^\circ$.

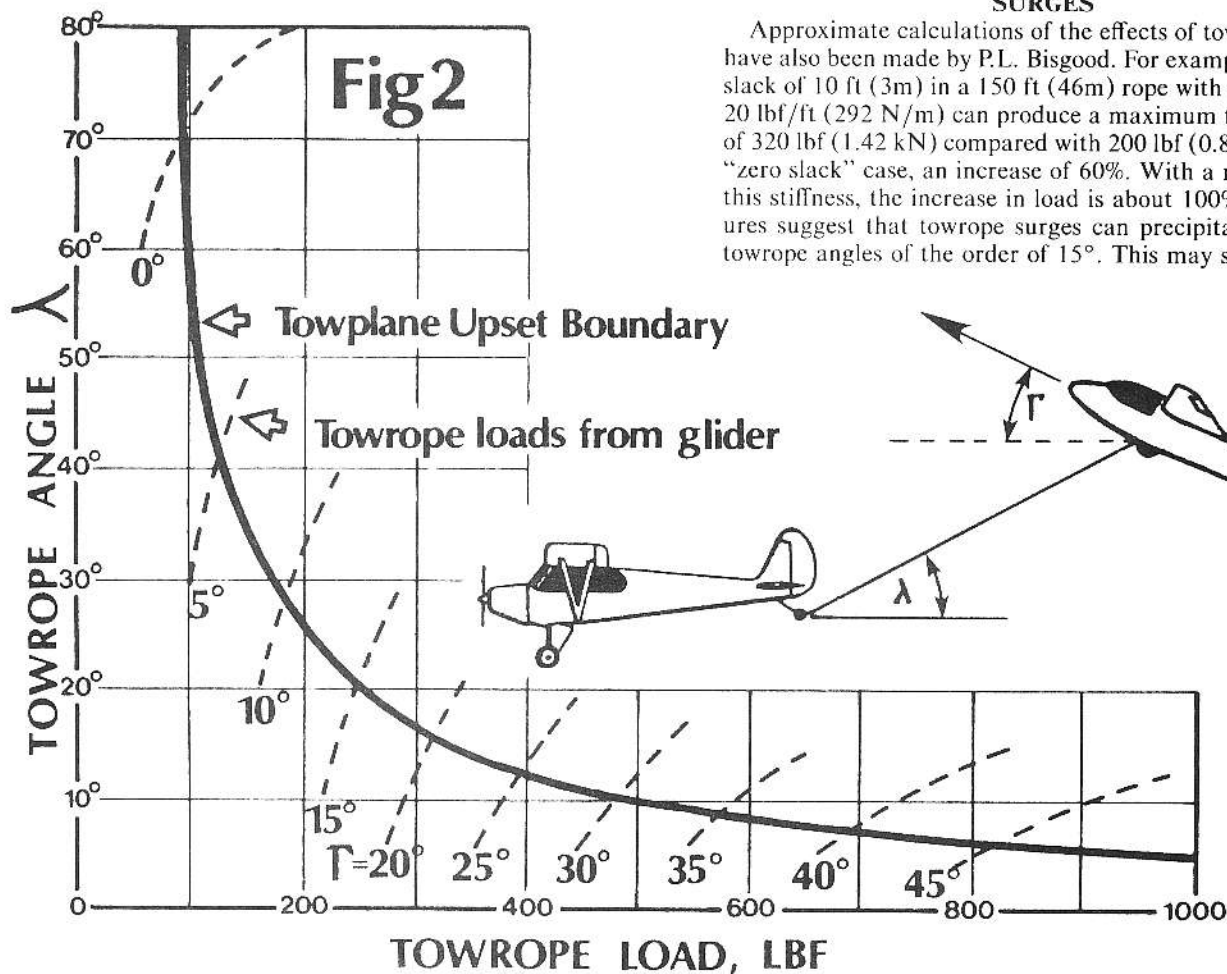
The effect of an elastic rope is that its stretch reduces the centrifugal force. If the rope has a stiffness of 20 lb/ft (292 N/m), then the load at upset in the above example is reduced from 1000 lbf (4.48 kN) to about 870 lbf (3.87 kN).

The effects of both finite length and elasticity are shown in Figure 4, for the aircraft assumed in Fig. 2 with a tug speed of 60 knots. The rope is assumed to be 150 ft (46m) long with a stiffness of 20 lb/ft (262 N/m). These effects make little difference to the upset boundaries 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.

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 (3m) in a 150 ft (46m) rope with a stiffness of 20 lb/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), and configuration which is probably no too unusual in training.

The approximate response of a glider, with fixed controls, to the surge following a 10-foot 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 U.K., being towed on the belly hook. In this case, the pitch-up produced by a combination of surge and towhook position carries the glider across the upset 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 U.K. Compared with the number of aerotow launches carried out, the rate is quite low (probably on 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

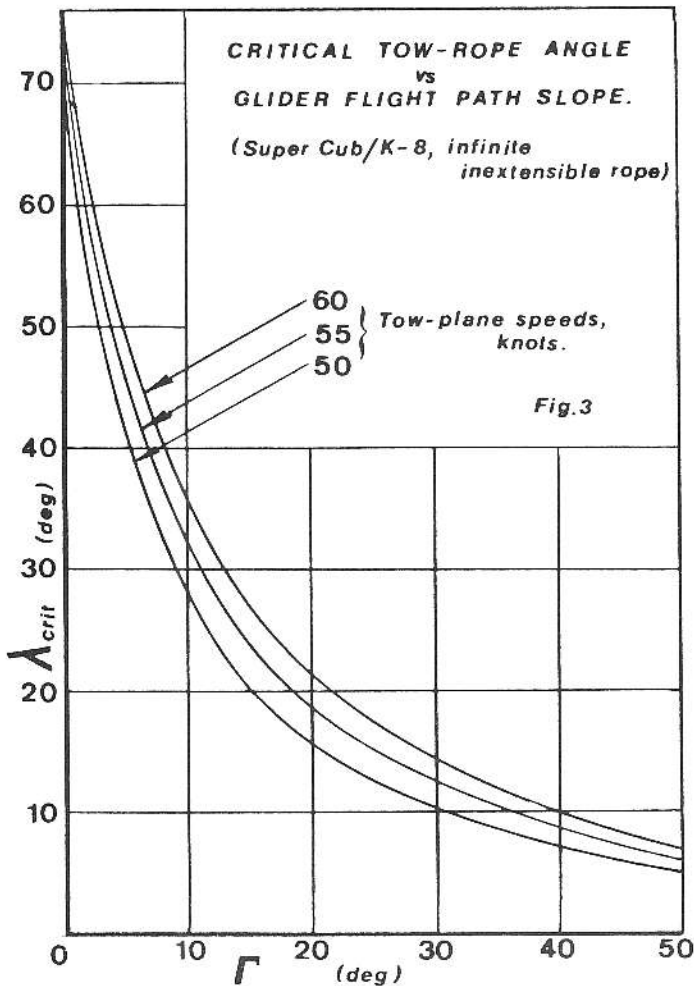


Fig. 3—Critical towrope angle vs. glider flight path slope with different towplane speeds.

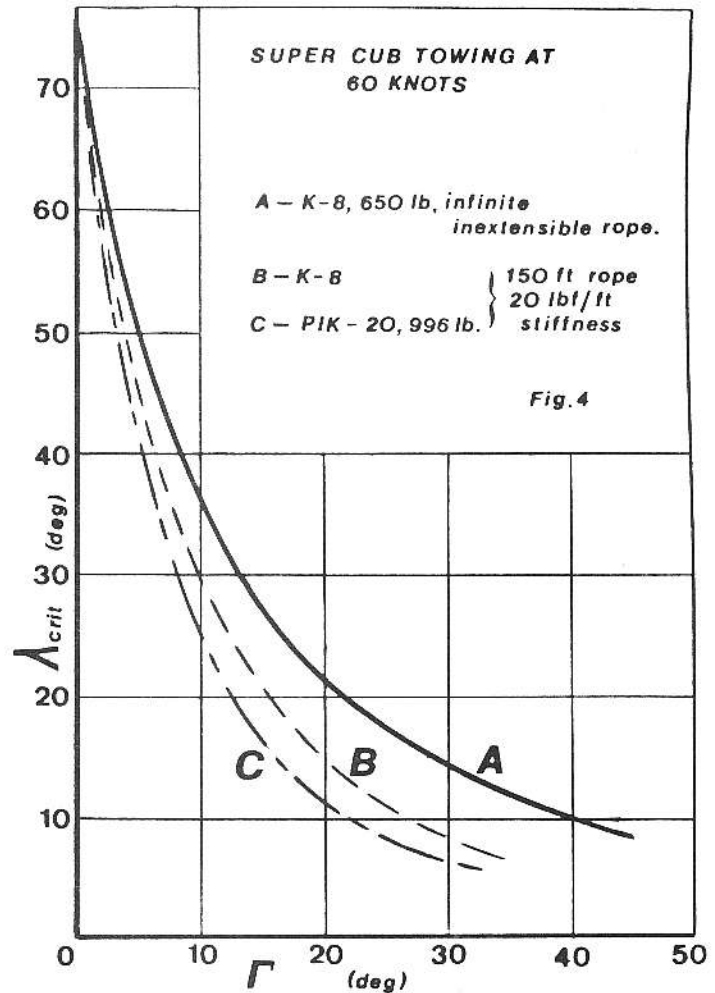


Fig. 4—Critical towrope angle vs. glider flight patch slope with different glider characteristics and constant towing speed.

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 (1.33 kN) strength 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 aerotow ropes. In the U.K., the standard figure since 1964 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 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 (61m).

(c) Towplane towhook. 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 BGS strongly recommends a modification (Ref. 4) whereby a 1-inch sealed ball race bears on the latch, replacing a plain roller. In addition, 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 negative "g". Roof-mounted releases are essential.

(d) Effects of wear on towplane and glider hooks. With "Ottfur" or "Tost" types of hook, indentation of the hook members leads to a very large increase in operating force. For example, Australian tests (Ref. 5) have shown that, if the tow rope force is 1000 lbf (4.45 kN) then the force to release a "Tost" hook in good condition is about 150N (34 lbf). The maximum JAR 22 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-center" adjustment on "Tost" hooks must be carefully adjusted. Ref. 5 shows a large increase in releasing force as the overcenter dimension is increased.

(e) Location of the glider towhook. The last two accidents in the U.K. involved Schleicher K-18 gliders which have light stick forces and a towhook mounted well aft. As Bisgood's response calculation indicates, the response of such a glider to towrope surges can be very unfavorable, 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 towplane pitched nose-down so rapidly that the engine stopped due to the negative "g" and finally it was pointed vertically downwards with an IAS of 40 knots. The pilot was unable to release the towrope, which broke, and the lowest point reached in recover was 400 to 500 ft (120-150m) 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 description of upsets.

The BGA would like to see a mandatory requirement for nose hooks to be fitted for aerotowing. The use of the expression "nose hook" is perhaps rather unfortunate: a forward-mounted hook is intended, perhaps similar to that of the AS-W 19. A modification for the K-18 now exists.

NEW EQUIPMENT

(a) Upward-releasing towhooks for towplanes. Two types of hook have been designed which were intended to release automatically when the tow-rope angle relative to the towplane reached some predetermined 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. The predictions were confirmed 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 towplanes since there may be a tendency for the hook or 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 towplane from exceeding some pre-determined value. The figures in Table 1 suggest that 65 lbf (or 300N) 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 (222-890N). He favors a system in which the body of the hook is attached to the airplane 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-center mechanism of the hook. The towrope tension then opens the hook fully.

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

CONCLUSIONS

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

Towplane 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 that theoretical prediction that they would only deal with part of the problem.

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

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

Since writing the above, it has been pointed out by B. Spreckley that violent maneuvers by the glider produce a marked deceleration of the towplane so that the upset may be due as much to the towplane stalling as to loss of elevator control.

Appendix: Symbols

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

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