Angles And Forces While Turning On Tow

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To quote D. Piggot (Sailplane & Gliding, Dec. 1972) aerotowing is one of the more difficult aspects of gliding to teach. Because of this there are also many different philosophies on how to fly on tow. It seems that part of the difficulty comes from the unusual combination of forces acting on the glider - aerodynamic forces plus the pull of the rope connecting it to the towplane. I would like to discuss one aspect of this - the forces acting on the glider while turning on tow, and how these forces affect the attitude of the glider. The results are not revolutionary, but might help some pilots to improve their flying. At least they will know what they and the glider should ideally do.

The towplane and the glider fly formation. They therefore fly along circles with the same center but not necessarily the same radius. Since the rope is attached to the tail of the towplane, but fairly close to the center of mass of the glider, it is recommended the rope be kept in line with the fuselage of the plane (Fig. 1). In this alignment, no sideways force acts on the tail of the towplane; such a force would have to be counteracted by rudder, an action towpilots do not like. We see from Fig. 1 that the glider then flies a larger circle than the towplane.

For v_{plane} = 100 km/h, angle of bank $\beta_{plane} = 20^o$, we get from the well-known equation (see Fig. 2)

$$tg\beta = \frac{L_h}{L_v} = \frac{mv\omega}{mg} = \frac{v\omega}{g} \qquad (1)$$

that the angular velocity $\omega = v/R$ is 0.128 Rad/sec and that R_{plane} = 217 m. If we now assume 60 m separation between the c.m.'s of plane and glider, we calculate that:

$$R_{glider} = \sqrt{217^2 = 60^2} = 225 \text{ m.}$$

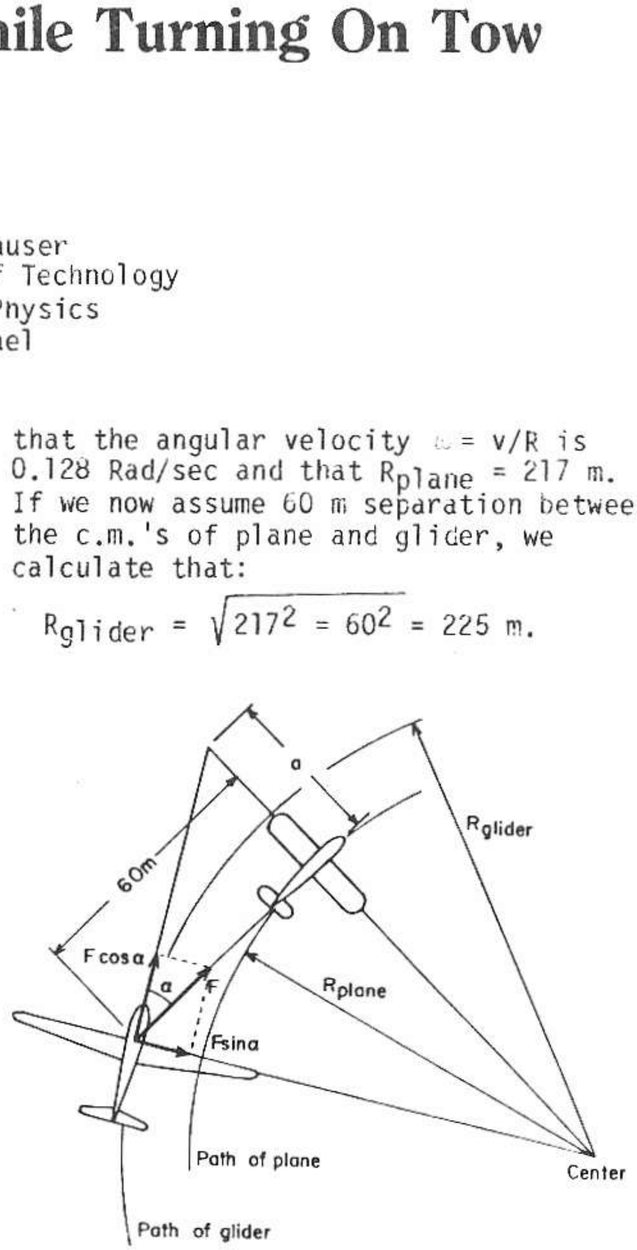

Fig. 1

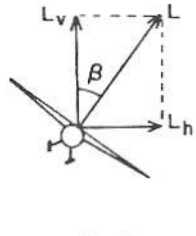

Fig. 2

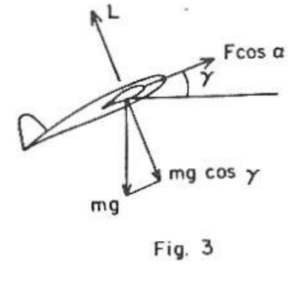

Fig. 3

Where should the nose of the glider point? This depends again on the radius of the circle, i.e. the steepness of the turn. We see from Fig. 1 that the wing should point towards the center, otherwise the glider will be slipping or skidding. The nose should therefore point at an angle α to the left of the towplane. The longer the rope and the steeper the turn, the larger α. For the values we assumed above, we get $\alpha = 15^{\circ}$ and a = 16 m (see Fig. 1). Many instructors recommend keeping the nose pointing towards the outer wing tip of the plane. This is probably a good approximation for medium turns using a medium length rope, but should not be taken too literally in all situations.

What about the angle of bank of the glider? The glider flies a larger circle that the plane but with the same angular velocity ω. Its speed, v, is therefore higher than that of the towplane and so is $v\omega$, the acceleration acting towards the center. Let us suppose for a moment that the towrope is not there (glider in a level turn with zero drag, happy thought!), then for both planes Eq. 1 holds, and the larger $v\omega$ implies a larger angle of bank for the glider. For our numerical values we get $\beta_{glider} = 20.7^{\circ}$, compared with $\beta_{plane} = 20^{\circ}$, i.e. the difference is very small.

Now we have to take the force F of the towrope into account. Let us first assume that it acts on the center of mass, as shown in Fig. 1. This is certainly closer to the truth for the glider than for the plane and is the reason why we want to keep the rope aligned with the towplane rather than with the glider. The forward component $F\cos\alpha$ counteracts the drag of the glider and also pulls the glider up a plane inclined at an angle γ (see Fig. 3; remember, we are climbing behind a towplane). We have to a good approximation*

$$F\cos\alpha = mg\sin\gamma + mg(D/L) \qquad (2)$$

The sideways component of F is $F\sin\alpha$ and acts towards the center of the circle, i.e. in the same direction as L_h in Fig. 2. We have therefore to reduce the bank somewhat to a new value β' because we now have a sideways force already without banking. Instead of Eq. 1, we now have

$$\frac{L_h + mg\left(\sin\gamma + D/L\right)tg\alpha}{L_v} = \frac{v\omega}{g} \qquad (3)$$

but, since $L_v = mg$ amd $L_h = L_v tg\beta'$, we get

$$tg\,\beta' + (\sin\gamma + \frac{D}{L})\,tg\alpha = \frac{v\omega}{g} = tg\beta \quad (4)$$

Let us take $\sin\gamma = 0.1^{\circ}$ (this gives a reasonable climb of 3 m/s) and $D/L = 0.04$. We get $tg\beta' = tg\beta - 0.037$, i.e. with $\beta = 20.7^{\circ}$, $\beta' = 18.8^{\circ}$. The force of the towrope therefore requires a slight reduction of bank compared with free flight.

Lastly, we should consider that the rope acts forward of the c.m. and tries to tighten the turn of the glider. We need some rudder to counteract this turning moment. The force acting on the rudder points toward the center and adds to $F\sin\alpha$. As a result, the necessary bank is once more reduced very slightly.

In sum, to fly a glider correctly on tow, in a turn, we have to point its nose somewhat outside the circle and, in theory, maintain a very slightly smaller bank than the towplane. The sample calculation shows that the difference in bank is usually negligible, i.e. for correct flying keep the wings parallel to those of the towplane.

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*Actually,

$$F\cos\alpha = mg\sin\gamma + mg\,\frac{\cos\gamma}{\cos\beta}\,\frac{D}{L}$$

but the cosines are close to 1.0 for our values.