THE CLIMB RATE OF A GLIDER WHEN CIRCLING WITHIN AN ISOLATED THERMAL VORTEX RING

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Presented at the XIX OSTIV Congress, Rieti, Italy (1985)

Introduction

One model for the motion of thermals well known to meteorologists, is the vortex ring: How does this phenomenon influence soaring?

Entrainment of surrounding air into the rising buoyant bubble takes place over its entire life cycle, i.e. until it reaches inversion levels. Gliders, when circling, extract energy from the thermal. Pilots understand that this gain is represented by an increase of the glider's potential energy, with respect to its height above the ground. However, GOODHART (1) was the first who pointed out that the "rate of sink (rate of climb, respectively, the author) will be materially affected when considering the effect of horizontal velocities in a radial direction on a glider circling". This notion was also applied by BETSY WOODWARD (2), to her thermal model.

As verified by a more general analysis of a glider flying in a non-stationary manner through moving air masses (3, 4), kinetic energy is gained, when the glider circles within a region where the air moves horizontally towards the centre of the circle. Keeping the speed constant will turn the kinetic power immediately into a climb rate, just like during the ascent of a propelled vehicle. The rate of energy then equals the inward directed velocity of the air times the glider's centripetal force. This adds to the glider's vertical displacement due to the vertical component of the air movement which remains, of course, the major energy source.

Most people believe that the rate of climb depends on two factors: the one is the radius of turn; circling closer to the centre of the thermal lets the glider exploit faster rising air, according to the thermal gradient. The other is the rate of sink which depends on the glider's polar curve, its speed and bank angle. The resulting climb rate is easily calculated using a given vertical velocity profile and the glider's polar curve.

But things become more complicated if one takes into account that the horizontal air movement contributes to the climb rate significantly. How shall we understand the thermal gradient now? What are the optimum banking angles? How does water ballast influence the climb. What is the optimum circling speed? The aim of this paper is to discuss these questions.

Materials and Methods

The quantitative data on isolated vortex rings as proposed by WOODWARD (5) were used. Figure 1 shows the dimensionless graph, as published; for a detailed description the reader is referred to the original paper. The bubble expands conti-

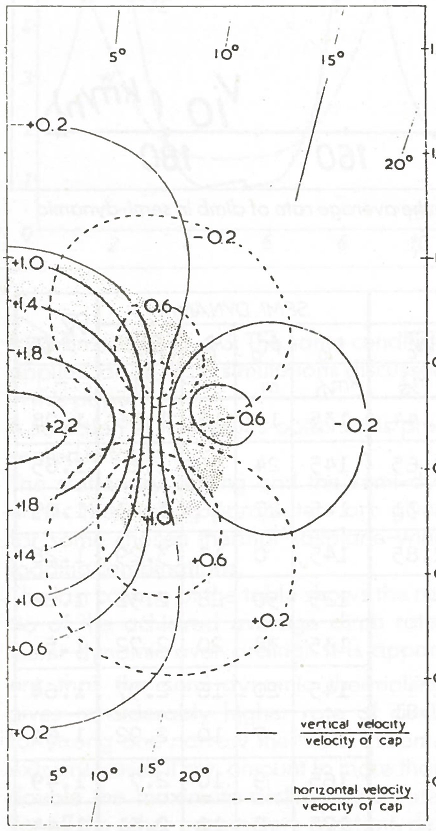


Figure 1. Cross-Section of the right hand half of a thermal showing lines of equal vertical velocities and equal horizontal velocities. From Woodward (2).

nuously upon rising, while the vertical velocity of the cap slows down with increasing height. Ideally the bubble retains its flow pattern similar to the one shown in Figure 1. In this model two parameters are to be chosen arbitrarily. These are the velocity of the thermal "cap" and its height (Z_c) above the (virtual) point of the vortex's origin. In this paper the parameters were assumed to be one meter per second and one thousand meters respectively. The corresponding real situation is characterized by a climb rate of approximately 1 m/s (as we will see) at altitudes of some hundred meters above ground. This is a relatively weak thermal. However, this creates a rather critical situation in which vortex effects on circling flight are suspected to be demonstrated more clearly.

Our particular model is now illustrated by Figure 1, where the numbers now represent "meters" and "meters per second", denoting height and radius, and velocities, instead of being dimensionless.

Isopleths for fixed values of the vertical and horizontal components of the air velocity vectors are given. Horizontals drawn at heights of 650, 700, . . ., 850 m intersect with some isopleths. The points of intersection were then plotted in a velocity-versus-radius graph, gaps being filled by interpolation. The results are shown in Figure 2. The curves which are assumed to be reasonably accurate will now represent our thermal model as it presents itself at a given point in time. It will be used to determine the energy source term.

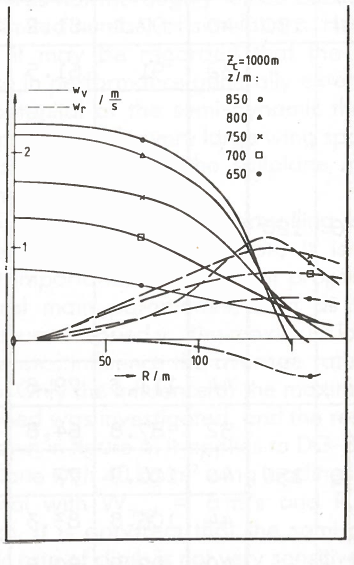
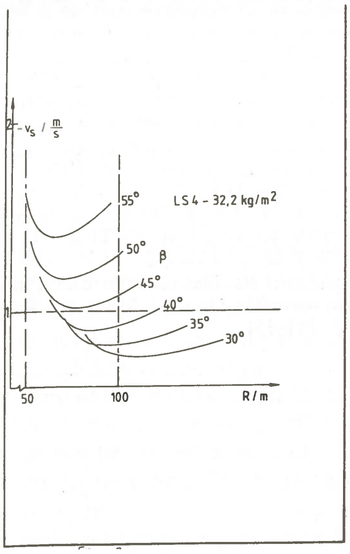


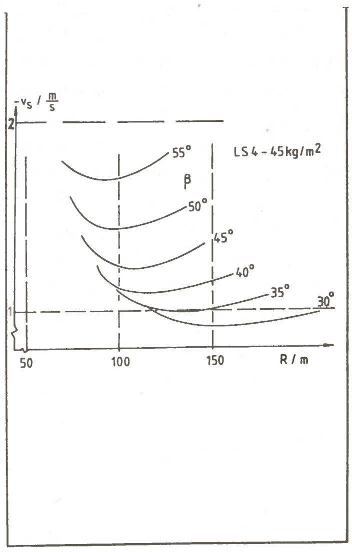
Figure 2. Vertical velocity w_v and radial velocity w_r of the air versus radius R at various height levels z. Height of the cap Z_c.

The polar curve for a LS4 glider was used. Sink rates versus circle radius were calculated for varying bank angles, in the usual manner. Two sets of curves, with and without water ballast, are shown in Figure 3. We now proceed to derive the glider's actual rate of climb.

Figure 3. Sink rates v_s versus radius R for various bank angles β



a) LS4 32.2 kg/m²



b) LS4 45 kg/m²

Results

The meteorological "climb" rate w_m is evaluated from the air velocities, according to

$$w_m(\beta) = w_v + w_r \tan\beta$$

with w_v, w_r, vertical and radial wind velocities. β is the bank angle. Tan β represents the centripetal force normalized by the glider's weight. The second term is negligible, when β is small but it becomes increasingly important when banking becomes steeper, e.g. $\tan 45° = 1$.
At an altitude of 800 m above the point source, the meteorological climb rates versus the radius for several bank angles are shown in Figure 4. Note the rather flat step-shaped profiles which pertain to moderate bank angles.
The glider's climb rate is calculated by subtracting its sink rate from the meteorological lift. This has been done for a

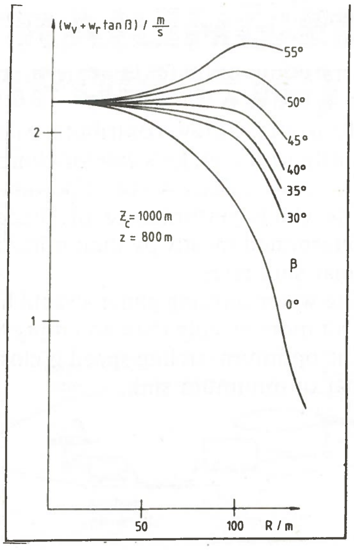


Figure 4. Net (meteorological) climb rate versus radius R dependent on the bank angle. Height z, height of the cap Z_c.

series of bank angles. Figure 5 shows the maximum achievable climb rates of the LS4 glider versus the altitude at which the glider is assumed to circle. Both configurations are compared: the sailplane with and without water ballast.

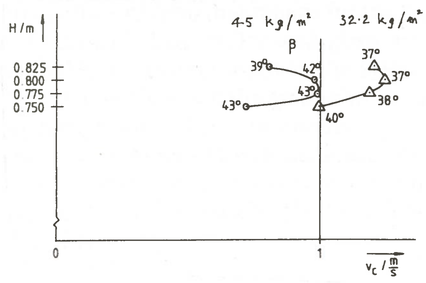


Figure 5. Maximum achievable climb rates v_c (abscissa) versus height H (ordinate) for the LS4 glider with water ballast (circles) and without water ballast (triangles). Bank angle β.

The empty glider banks at an angle of 37° whereas the heavier one executes a slightly more inclined lateral slope (43°). The former's maximum climb rate is 0.26 m/s better than that of the latter. The difference in sink rates amounts to 0.34 m/s, based on the respective flight attitudes, speed and bank.
The following table summarizes the evaluated data for the LS4-glider:

Discussion

Of course thermals change their size and velocity distribution with time. Since we have restricted our evaluation to the situation at a distinct point in time we could compare the climb rates of imaginary gliders placed within the thermal at the same instant. It remains to be evaluated how the climb rate will develop in the course of time when the glider's relative position with respect to the thermal and the velocity field change.
Isolated thermals are assumed to decelerate while rising. Pilots experience, however, is that the climb rate does not decrease with height in a significant degree. Instead, the average climb rate is known to be proportional to the height of the cloud base. In consequence, either the model is incorrect, or the vortices cannot be considered isolated. Indeed there is no reason to neglect interference effects. Why should we not believe that consecutive or adjacent thermal vortex rings upon rising merge into the strongest vortex and thereby combine their buoyant potential so that an even stronger thermal results? This can happen frequently during the life cycle of a thermal. Based on the vortex model the results are astonishing. They suggest that the radius of circling does not play a role at all. Instead, the minimum rate of sink as taken from the polar curve seems to be the important property of a glider for thermalling. Let us have a closer look: The heavy LS4 was handicapped against its light version by an excess sink rate of 34 cm/s. Finally it merely loses 26 cm/s in thermalling, even despite the fact that it circles at a larger radius (105 m versus 86 m) where the vertical air velocity is 39 cm/s lower. The explanation is that the faster moving horizontal air flow together with the stronger centripetal force both experienced by the heavier glider enhance its dynamic energy gain, according to the formula given above. This compensates for a great deal of the disadvantages due to the extra weight.
The relative importance of the polar sink rate is reflected by the finding that the optimal circling speed is the one which corresponds to the minimum sink rate. When looking for the fastest climb it does not pay to circle at a too low speed, i.e. close to stalling.

	LS4, 32.2 kg/m²	LS4, 45 kg/m²
range of bank angles	37°–40°	39°–43°
optimum	37°	43°
range of circle radii	83–89 m	95–106 m
optimum radius	86 m	105 m
maximum climb rate	1.25 m/s	0.99 m/s
sink rate due to the polar	0.84 m/s	1.18 m/s
circling altitude at which the maximum climb rate is found	800 m	775 m
vertical meteorological flow velocity at altitudes and radii given	1.79 m/s	1.40 m/s
horizontal meteorological flow velocity	0.39 m/s	0.83 m/s

Except for landing, the glider must not fly slowly, even not in thermalling. Instead, the designer should emphasize a low polar sink rate. Asking additionally for good cruising performance one would prefer large aspect ratios and comparably high wing loading which should prove useful even at mediocre thermal conditions.

In order to be able to get quantitative data, more knowledge about the kinetics of thermals must be accumulated, and the influences of the various meteorological boundary conditions analyzed. It is clear, however, that the horizontal air flow towards the centre of the thermal must not be neglected. It would be interesting to know more about the interaction of one vortex with its neighbor. A computer simulation of a glider which climbs in a thermal would be worthwhile, taking the transient behaviour of the thermal into account.

Conclusions

The most important findings are summarized as follows.

1. Horizontal inflow contributes significantly to the glider's rate of climb.
2. The circle radius is not important.
3. The climb performance of gliders is determined mostly by their minimum polar sink rates.
4. The water carrying glider should bank a bit more steeply than an empty one.
5. The optimum circling speed is close to that of minimum sink.

References

(1) *Goodhart H.C.N.*, Circling Flight in a Radial Field of Flow, Aero Revue, 6, 1958, p. 324

(2) *Woodward B.*, A Theory of Thermal Soaring, Aero Revue, 6, 1958, p. 321–324

(3) *Gorisch W.*, Energy exchange between a Sailplane and Moving Air Masses under Instationary Flight Conditions with respect to Dolphin Flight and Dynamic Soaring, Aero Revue, 11, 1976, p. 691–692, 12, 1976, p. 751–752, 3, 1977, p. 182

(4) *Gorisch W.*, Energiebilanz des Segelflugzeugs beim Kreisflug in der Thermik, Aerokurier, 4, 1980, p. 450–452

(5) *Woodward B.*, The motion in and around isolated thermals, Quart. J. Meteorol. Soc., 85, 1959, p. 144–151