AUTOMATIC ADJUSTMENT OF THE MACCREADY RING

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Presented at the XX OSTIV Congress, Benalla, Australia (1987)

Maximising cross-country speed

To maximise the speed in a cross-country soaring flight using thermals, one must follow three rules:

(i) Adopt a critical rate of climb, CC

(ii) Circle if, and only if, the rate of climb exceeds the critical rate of climb (Edwards Threshold theorem)

(iii) Cruise at speeds V_G, such that

$$V_G = (CC + V_S)/(dV_S/dV_G)$$

where V_S is the glider sink rate (MacCready Theorem)

A MacCready Ring gives continuous advice for rule (iii) and indicates decision points for rule (ii). Speed directors do the same more effectively, but some of them neglect rule (ii).

There is no instrument for advising on rule (i), although the selection of a critical rate of climb is complex. It is a function of thermal strength, thermal spacing, wind speed, wing loading, and altitude. This paper describes an instrument that computes critical rate of climb.

Rules for determining the critical rate of climb

Determining the critical rate of climb depends on a published rule for leaving a thermal (Speight, 1984):

"When thermaling, as soon as it becomes almost certain that one can reach a stronger thermal or the finish line by cruising towards it with a ring setting equal to the present rate of climb, leave the thermal and fly to that ring setting."

This rule can be generalized to the form:

Rule I. Adopt a critical rate of climb such that one can almost certainly reach either a thermal that exceeds it, or the finish line.

This is a "Survival" rule to be applied when there is a significant risk of outlanding. Arbitrarily, a significant risk is defined to exist when the number of thermals remaining above minimum height (H_M) is more likely to be one than two. The maximum thermal strength that one can almost certainly reach is defined as that exceeded by 99% of the thermal population.

When there is no significant risk of outlanding the following "Racing" rule applies:

Rule II. Adopt a critical rate of climb such that there is an even chance of reaching a thermal that exceeds it before the risk of outlanding becomes significant.

This rule expresses the idea that one should move on whenever to do so is more likely to increase the cross country speed than to decrease it.

CC a function of thermals to go

By rules I and II the critical rate of climb is made a function of the number of thermals estimated to remain on the glide path ahead above the minimum height, H_M.

A log-normal distribution of the central velocities of thermals in the sky at any time is fitted to barograph data. The probablistic relation of critical rate of climb for the 'N'th thermal to N is approximated by the function:

$$CC_N = \lfloor a(N-b)^c . V_T \rfloor - V_c$$

where a, b, c are constants, V_T is the central velocity of the mean thermal at the time, and V_C is the sink rate of the ballasted glider while thermaling. The nominal rate of climb to be set on the MacCready knob is $NC = V_T - V_C$. NC is the average rate of climb available from all significant thermals, including those not used for circling.

Thermal spacing

The mean spacing of thermals is taken to be proportional to the thickness of the convective layer extending from H_M to the top at H_C. The factor P, for "Prospects" is subjectively estimated by the pilot, giving a range of values from 2.5 to 10.0. The spacing is $P(H_C - H_M)$.

Altitude

The height loss in each increment of distance equal to the mean thermal spacing can be calculated from the polar and the relevant value of CC, taking into account the wind. The value is:

$$h = P(H_C - H_M)\,\frac{V_T}{V_W}\left[\frac{1}{\frac{V_G}{V_S}\cdot\frac{V_T}{V_W} - 1}\right]$$

The total altitude when there are N thermals remaining on the glide path is:

$$H = H_M + P(H_C - H_M)\left(\frac{NC+V_C}{V_W}\right)\sum_{n=0}^{N}\left[\frac{1}{\frac{V_G(NC+V_C)}{V_S V_W} - 1}\right]$$

Thus, both altitude H and critical rate of climb CC are expressed in terms of N, the number of thermals estimated to remain on the glide path above minimum height. CC can therefore be expressed as a function of H.

Implementation

The instrument is linked to a Borgelt system with a B21 variometer, a B24 speed director, a B25 "NAV" glide computer, and a digital electric altimeter. Nearly all of the inputs come from the existing system: altitude H; polar curve including "bug" factor and ballast; nominal rate of climb NC from the MacCready knob; headwind/tailwind speed V_W; and minimum height H_M.

Additional pilot inputs are the height of the top of convection H_C, and the "Prospects" P, both entered by knobs. The value of the critical rate of climb CC is shown on a digital display adjacent to the achieved (average) rate of climb. These are arranged in the same sense as the "critical height" of the final glide calculator and the "achieved height" of the digital altimeter.

A switch allows the system to be changed from "automatic" to "manual," for the case of the final glide, when the critical rate of climb should remain constant.

The critical rate of climb is displayed merely for reassurance. Its main function is to modify the vario and speed director audio signals so that they give correct advice on speed to fly and thermals to accept or reject. Every half-hour or so, and on each leg of the task, the pilot must up-date the various inputs: prospects, height of convection, minimum height, wind, nominal rate of climb, ballast and bugs. The instrument will then see to it that he stays air-borne and gets the best speed out of the thermals that he finds.