Handicapping Weight Adjustment Proposal for US Soaring Competition

Introduction

Handicapped scoring is broadly used in soaring competition in the US and around the world. The objective of handicapping is to permit pilots to fly in competition using available sailplanes of varying performance by compensating for the variation in performance attributable to the glider itself such that it doesn’t unduly factor into the overall results. A well-designed handicapping system can allow for larger combined classes than would otherwise be possible on an equitable basis, thereby increasing the overall competitiveness of soaring contests with diverse glider types competing.

In the US, handicapping is used in three circumstances:

1) Sports Class – A class that allows any glider to compete and does not permit water ballast. Because of variations in pilot and equipment weight, installation of motors and/or second pilots in two-seaters, potentially significant variations in flying weight need to be accounted for. This necessitates setting a base handicap at a specific reference weight and varying the handicap with weight variations.

2) Club Class – Similar to Sports Class, but permitting only gliders in a relatively narrow base handicap range. No ballast, motors or two-seaters are permitted, resulting in relatively small handicap adjustments based on flying weight.

3) FAI Classes – Primarily used to combine two or more FAI classes to meet a minimum threshold number of competitors. FAI classes permit the use of water ballast and handicapping typically use small fixed handicaps between two class types (combined Std/15M or 15M/18M and Flapped/Unflapped 20M, 2-seat), but can also use glider-specific handicaps with significant weight adjustments (e.g. Region 11 FAI contest at Truckee).

Problem Statement

US handicap adjustments for flying weight, as described above, can lead to significant competitive inequities if the formula for adjusting handicaps for weight isn’t consistent with the actual effects of weight on glider performance. Small variations in weight are less sensitive to inaccuracies in the way the formula predicts performance, but as weight changes get larger, these effects can grow significantly and the fidelity of the weight adjustment formula becomes more important. The following analysis lays out the theoretical relationship between flying weight and cross-country performance and suggests a new formula to adjust handicaps based on weight. It also compares the proposed formula to the current formula used in US rules.

Approach and Analytical Considerations

The following is a “from scratch” analysis based on the sailplane performance analytical methods described in “Cross-Country Soaring” by Helmut Reichmann and are based on quadratic-fit curves of available polars for several sailplanes: JS3-18, Arcus-M, ASW-27 and LS-4.

When this paper mentions thermal strength across multiple wingloading conditions and across gliders, it will show graphs for thermal strengths in 1-knot increments rounded to the nearest even number. Comparisons across wing loadings and across gliders will represent the same lift conditions, which means MacCready values will vary to the extent that minimum sink rates vary. Heavier flying weights and lower performance gliders achieve slightly lower climb rates in the same lift conditions. These are the appropriate comparisons to make when calculating achieved cross-country speed for any given lift condition.

A consideration in making weight adjustments to handicaps is that gliders with significant amounts of fixed ballast in the form of a motor or second pilot cannot dump the extra weight. On weak days – particularly with tight thermals – these heavier gliders may experience a significant percentage degradation in climb rate and therefore a degradation in cross-country speeds achieved. Given that the mathematical relationships governing achieved cross-country speed are increasingly non-linear at slow climb rates and glider sink rates are increasingly non-linear as thermal radius gets smaller, there can be a set of conditions where the combined effects of heavy gliders and weak thermals (particularly with small radii) will be particularly challenging to account for with a simple handicap adjustment model based only on glider weight rather than also accounting for the lift conditions.

Lastly, the following analysis is for classical McCready theory. No account is taken for wind effects, streeting/convergence/energy lines or ridge-running, though analysis of these effects is ongoing.
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Analysis

First, we need to set up equations representing the performance of a glider in terms of a speed polar that includes the effect of flying weight (W) as a function of the reference weight at which the polar was measured (Wref). We start with a base polar for a glider by fitting three pairs of gliding and sinking speeds to a quadratic of the form:

\[ V_s = aV^2 + bV + c \]

Without going into the full derivation, we can create a new polar for any new flying weight by dividing and multiplying the first and last coefficients (a and c) respectively by the square root of the overload multiple \((W/Wref)\). The new polar equation is:

\[ V_s' = a'V^2 + bV + c' \]

Where:

\[ a' = \frac{a}{\sqrt{(W/W_{ref})}} \]

\[ c' = c\frac{W}{W_{ref}} \]

The resulting set of polars (calculated for a Jonker JS3-18 at wing loadings from 8.4 to 12.3 lbs/sf) are shown below.

Again, without going through the derivation, we can use these polars to calculate sustained cross-country speeds for a glider at any arbitrary weight for any average climb rate (Mc) by substituting the appropriate values for Mc, \(a'\), \(b\) and \(c'\) into the equation:

\[ V_{xc} = \frac{Mc\sqrt{(c' - Mc)/a'}}{2(Mc - c') - b\sqrt{(c' - Mc)/a'}} \]

The resulting cross-country speed curves look like the following:
As previously mentioned, the above curves assume a single thermal strength across flying weights but climb rates (and resulting Mc values) used to calculate each Vxc at each weight will vary slightly based on the increasing minimum sink as flying weight goes up. In addition, achieved climb rates can vary based on weight for a variety of reasons that don’t figure into the simple MacCready theory: 1) glider polars close to minimum sink speed can vary from the quadratic polar fit due to the vagaries of low-speed aerodynamics and 2) sink rate can go up significantly as turning bank angle increases. Tight thermals can alter achieved climb rates by several tenths of a knot, which can be particularly influential on Vxc for climb rates below 3 knots. 3) altitudes vary, resulting in changes in true airspeed for minimum sink, which will require a different bank angle for a given thermal radius, resulting a different minimum sink rate.

The effect of a 500-foot thermal radius on cross-country speed is shown below (for a glider flying at 6000 feet MSL):

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**Handicapping**

The goal of a handicap weight adjustment is to adjust for the achieved cross-country speed difference between gliders with the same polars due to flying at different weights. Handicap formulas will generally be more robust if generated in terms that are consistent with the underlying performance relationships. Therefore, it makes sense to start by calculating how big that advantage is and how the magnitude of the advantage varies with different inputs (particularly flying weight and lift conditions).

Below is a summary of the achieved cross-country speed as a percentage of speed achieved at reference weight (V/Vref) versus overload ratio (W/Wref) for a variety of lift conditions. As described above, W/Wref is the weight adjustment variable in quadratic glider speed polars and MacCready cross country speed formulas. The curves for lift conditions above 3-knots are gently arced and fairly close together with slightly different slopes. In contrast, there is a substantial falling off in performance improvement with wing loading for Mc<3 knots and the relationships show a significant amount of curvature with increasing weight. The same analysis for narrow (500’ radius) thermals shows even more performance deviation for weak lift conditions to
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the point that cross-country speed performance actually decreases with increasing \( W/W_{\text{ref}} \). A single-factor handicap based only on flying weight \( W/W_{\text{ref}} \) won’t be able to fully account for all lift conditions — particularly on the very weak side. A handicap weight adjustment system that accounts for key performance factors would need to include average climb rate - or more realistically something that can be easily measured in a contest environment that represents the speed potential of the day.

For Sports Class a typical motor and/or second pilot weight variation can easily be 200-350 lbs. For mixed FAI classes with ballast the weight variations can also be quite large, depending on what ballast variations might be permitted (at R11 Truckee pilots may declare any weight up to MTOW). For very weak days with 2-knot and below average climbs in tight thermals, heavy motorgliders and two-seat gliders could be at a disadvantage under a handicap system that is based solely on \( W/W_{\text{ref}} \) (and also works for other lift conditions) because they cannot get rid of very much (if any) weight.

Let’s assume for now that we don’t want to do get into a multi-factor handicap system. If we want to pick a \( M_c \) value that minimizes the error in handicaps on most days (this is called minimizing the mean-squared error) the handicap based on \( W/W_{\text{ref}} \) ought to be set for a \( M_c \) value around 3 knots. This has been the historical target \( M_c \) design point for handicapping.

Handicap Weight Adjustment Formulas — Current versus Proposed

The objective of a handicap weight adjustment formula is to adjust the base handicap to compensate for the change in cross-country speed attributable to the change in weight. Ideally this is simply the inverse of the \( V/V_{\text{ref}} \) curves above to exactly cancel out the incremental cross-country speed attributable to glider performance.

The following is a comparison of 1) the current RC rule (HCrc) and, 2) the handicap committee recommendation to modify the current RC rule (HChc):

1) \[
HCrc = H_{\text{ref}} \times (1 - 0.0002 \times (W - W_{\text{ref}}))
\]

2) \[
HChc = H_{\text{ref}} \times (1.3 - 0.4 \times (W/W_{\text{ref}}) + 0.1 \times (W/W_{\text{ref}})^2)
\]

Where: \( W = \) Competition Weight
\( W_{\text{ref}} = \) Handicap Reference Weight

One challenge with the current formula (HCrc) is that it is based on a linear relationship using change in weight in pounds \( (W - W_{\text{ref}}) \). However, as shown above, glider cross-country speed is determined by a non-linear relationship based on percent change in weight \( (W/W_{\text{ref}}) \). This creates two problems: 1) the fit of the handicap to weight change is only good for a narrow weight band as the linear and non-linear curves diverge at higher values of \( W/W_{\text{ref}} \) and 2) the fit of the handicap line varies with the starting weight of the glider. For example: a 150 lb change in a 1500 lb glider is a 10% change in \( W/W_{\text{ref}} \) compared to 20% for a 750 lb glider. A weight adjustment formula designed to properly adjust for 750 lb glider is way too aggressive for a glider that weights 1500 lbs. This means that for a weight adjustment to work well over a range of weight changes it can’t be a
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simple linear relationship with weight change, it needs to be non-linear and based on W/Wref. This is what the HChc formula does.

Below is a comparison of each weight adjustment HC formula as a function of W/Wref along with the HCbase/(V/Vref) “theoretically perfect” handicaps across various Mc values overlaid for reference. The first comparison is for a JS3-18 based on the factory-published polar. The HChc curve follows the Mc=3 curve (the small variation is due to rounding to single significant digits in the formula), while the HCrc curve over-compensates by ~1% as W/Wref increases. The second comparison is for a much heavier Arcus-M. The reference weight for the Arcus-M includes a motor and two pilots, so it is possible for flying weight to be significantly below, as well as above, Wref. Here the effect of the Arcus’ relatively high reference weight shows a pronounced over-correction at weights both above and below Wref.

Below is a comparison of HCrc and HChc plus 1/(V/Vref) for a variety of Mc values for an ASW-27B and an LS-4A. As previously mentioned, because these gliders have slightly higher minimum sink rates, the curves reflect slightly different Mc values for the same lift conditions.

Because the Vxc and HChc are both based on quadratics, it is possible to set HChc to track V/Vref for any Mc value with zero error versus theory. However, because each Mc value generates a different V/Vref curve the HC formula will differ from theory at all other Mc values. In the table below “errors” versus theory are shown for HChc formulas centered on Mc=3, Mc=4 and Mc=3.5. Highly loaded gliders in very weak and very strong conditions are over- and under-handicapped respectively by 2-3%, with the model fit to Mc=3 showing the most symmetrical behavior in error versus “theoretically perfect” handicaps. This is why Mc=3 has been selected as the best compromise value for handicap weight adjustment.
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There are many factors that can affect cross-country speeds beyond base handicap plus weight adjustment (e.g. lift conditions, flaps/no flaps or other polar variations with speed, tight thermals and streeting) that are challenging to account for by even the most elaborate handicapping system. Nevertheless, a base handicap plus weight adjustment formula for \( Mc \approx 3 \) keeps glider performance variation to <1% for the majority of flying conditions. A winner’s speed adjustment could reduce the remaining variation by \( \frac{1}{2} \) to \( \frac{2}{3} \) but at the cost of complexity and reduced scoring transparency.