CAL Upwash Worksheet Example

Sail upwind and record **WIND DIRECTION** on both tacks.	Stbd tack	Port tack	Stbd	Port
Run #1	_____	_____	230	220
Run #2	_____	_____	231	221
Run #3	_____	_____	230	220
Run #4	_____	_____	232	222
Run #5	_____	_____	231	221
Average **WIND DIRECTION** on each tack	a_____	b_____	231	221
WIND DIRECTION Difference	a-b=c_____			10
Figure change to Cal Upwash If Direction **HEADS** you when you tack, **INCREASE** Cal Upwash If Direction **LIFTS** you when you tack (example), **DECREASE** Cal Upwash Change Cal approximately 0.3° per degree of change in Wind Direction Note sign of (d) is opposite to (c)	-0.3•c=d_____			-3.0
Present **Cal Upwash**	e_____			+0.5
Set new **Cal Upwash**	d+e=f_____			-2.5

Calibration qualification

What degree of accuracy should you expect? The degree of accuracy obtainable is a function of time: the more time spent working on the calibration procedure, the closer to a perfect solution you will come. However, the bulk of the calibration accuracy is gained in your first sessions tuning your instruments be able to achieve a 5° to 7° solution, that is a 5° to 7° shift in Wind Direction when you tack or jibe, during your first calibration session. With only a reasonable amount more effort spent calibrating, you should be able to fine tune your Wind Direction solution to around 3°. Each additional degree of accuracy from this point on requires some dedicated efforts in sailing and data recording to accomplish additional gains.

Once you have reached a 3° solution, you should spend your time confirming your Wind Direction solution for different wind velocities. Use the same approach as above for heavier and lighter conditions, and this will further fine tune the Wind Direction solution. Once you are confident of a 3° solution throughout a wide range of wind velocities, you will be well on your way to a perfect solution. Refer to the Ockam instrument systems manual (section 3.4) for further information to help fine tune the Wind Direction solution. Collect your data every time you race or tune, as this will help increase the data base to further finesse your calibration accuracy.

FINE TUNING

Anemometers are not generally subject to the same variation in calibration as boatspeed transducers, because they are above most of the distortion caused by the sails. For this reason, it is usually best to start with a CAL WINDSPEED equal to the value given in Section 5.04, i.e. the manufacturers nominal calibration.

You can use your calibrated boatspeed to check the windspeed, but not to a high degree of accuracy. This is done by recording an average windspeed with the boat at rest, and then motoring directly into the wind. The windspeed should increase by your boatspeed. If Windspeed goes up by more than your boatspeed, then the CAL WINDSPEED is too high, and vice versa. You should not do this type of calibration in winds over a few knots because your resolution is poor, several tenths of windspeed against boatspeed of 5 to 8 knots. Wind speed can be better calibrated using Wind Direction (see Section 3.3).

Leeway is hard to set rationally, because it is almost impossible to measure. The usual way is to dial in a calibration that gives a "comfortable" leeway under normal conditions, ie between 2° and 4° in strong upwind conditions. You can figure out what the leeway factor is from

$$\textbf{LeewayFactor} = \textbf{Leeway} \bullet \textbf{Boatspeed}^2 / \textbf{Heel}$$

where BOATSPEED, LEEWAY and HEEL are for "standard" upwind conditions. You may also use Back Range & Bearing to calculate leeway by sailing out and back to a floating marker with a sea anchor on it. Sail by the mark on a beam reach, and reset the Back Range & Bearing. Continue out for a mile or so, and then reach back to the mark. As you pass it, note the Back Range & Bearing; the residual error. Three things can contribute to a non-zero residual; compass error, boatspeed asymmetry, and leeway. Assuming no compass error (a dangerous assumption), residuals which say that you are short or long, are due to boatspeed asymmetry. Residuals which position you at right angles are due to leeway. If the leeway calibration is too small, the Dead Reckoning puts you to weather of the mark, and vice versa.

This works because the boat points slightly toward the wind relative to its course through the water. If the CPU makes the proper amount of correction for this, your Dead Reckoning ends up where you are. Otherwise, the Dead Reckoning moves to windward [or leeward] on both the outbound and inbound legs, giving an error which accumulates in the same direction for both legs.

For systems with a compass interface, there is a way to check the accuracy of the wind, heading and boatspeed calibrations. Wind Direction and true wind speed should not correlate with the boat's maneuvers. If variations in Wind Direction consistently follow the boat, it indicates that the true wind solution is incorrect. The calibrations can be adjusted to minimize the variation in Wind Direction.

In these discussions we speak of Wind Direction as moving with or against the boat during maneuvers. "Moving with" means that the Wind Direction veers when the boat turns clockwise (Heading and Wind Direction both go to higher or lower readings). It also means that the wind appears to take a header when you tack. "Moving against" means that the Wind Direction backs when the boat turns clockwise (Heading and Wind Direction go in opposite directions). The wind appears to lift on tacking.

It is helpful to know what effect each calibration has on Wind Direction and speed. Wind Direction is composed of true wind angle and heading. True wind angle is in turn composed of boatspeed, apparent wind angle and speed, and leeway. Each of these inputs have one or more calibrations, adjustment of which will affect the solution to the true wind. Here are some rules which may help in deciding what to adjust.

- Do your fine tuning AFTER your course tuning.
- Put in some leeway (even a guess) before doing fine tuning.
- Every calibration changes the solution. Adjust the one calibration you think is least "good" first, then review things.
- Pick the calibration that has the most effect for the type of error you have.
- Fine tuning means FINE. Don't adjust anything too much.
- The closer you are to perfect, the less you should mess with things.

Boatspeed Master & Offset Calibration

The solution to the wind triangle is made from two magnitudes (boatspeed and apparent wind speed) and an angle (apparent wind angle) with garnishes of heel, leeway and upwash. The correct solution (in terms of wiggles) only requires that the ratio of boatspeed to apparent wind speed be correct. Both could be wrong in absolute terms, but by the same percentage. Given that we could tweak either boatspeed or wind speed to get a wiggle-free solution, it is better to do wind speed, because boatspeed has an absolute relationship to the navigation triangle (see the next section). In fact, the ability to get absolute boatspeed from conventional or Loran-based calibration is what establishes wind speed in absolute terms via the calibration procedure described in this section. Also, although boatspeed offset affects the wind triangle, people are very sensitive to imbalance in boatspeed from tack to tack, so this calibration is better done in the conventional way. Thus the effect of boatspeed calibrations are left out of this discussion, except for rules of thumb.

Heading Calibration (Compass Compensation)

Since Wind Direction is based directly on heading, the effect of any error in the compass reading is directly translated into that output. Analysis of a compass installation, swinging and compensation (to exact reading if possible) should be done by a QUALIFIED compass adjuster if good Wind Direction is to be expected. We have had best results by removing the built-in adjusting magnets, and relying on externally mounted ones.

Compass location also affects the quality of the output. Besides the unheeled effects of engine and wiring compensated for by the adjuster when he swings the compass, errors are often introduced when the boat is heeled, particularly if the compass is mounted asymmetrically (like outboard of the engine). Compasses almost never get swung heeled, so heeling errors don't get recognized.

Apparent Wind Angle Offset

This calibration moves the apparent wind angle to the right or left (an unsymmetrical adjustment) and therefore moves Wind Direction to the right or left. In upwind conditions, there is a large corresponding offset on Wind Direction, and downwind there is a lesser offset. Since the offset is left or right, and not in and out (like wind speed, leeway and upwash produce), there is little visible wiggle effect on Wind Direction for either tacking or jibing. The number is merely offset right or left by a greater or lesser amount.

Wind Direction wiggle caused by wind angle offset is evident only when going from upwind to downwind rather than from tack to tack, because of the decrease in the effect of apparent wind angle under the latter conditions. Apparent wind angle offset creates true wind speed wiggle fairly strongly in reach-to-reach maneuvers, and moderately in tacking.

Apparent Wind Speed

Increasing this calibration causes Wind Direction to move with the boat and also causes the upwind true wind speed to be higher than the downwind. Decreasing the calibration causes the opposite effects. Since real wind speed varies a lot, comparing upwind against downwind speeds tends to be imprecise, but over a long period, you may gradually gain the feeling that wind speed always drops [or increases] when turning downwind, which can be used as corroborative evidence of the need to change calibrations.

Upwash

Upwash calibration symmetrically increases or decreases apparent wind angle upwind but not downwind. Increasing the magnitude of apparent wind angle (positive upwash calibration) causes the Wind Direction to move against the boat upwind, and has no effect downwind. It has no significant effect on true wind speed. In terms of calibration (as opposed to aerodynamic theory), upwash should be used to trim out residual errors which remain after other calibrations are set as well as they can be.

$$\mathbf{Upwash = CalUpwash \bullet Reef^2 \bullet Flat \bullet Sin^{2.5}(0.6 \bullet (180 - Ba))}$$

Where
Ba is the measured apparent wind angle
REEF is the reefing parameter (0..1)
FLAT is the flattening parameter (0..1)
(REEF and FLAT are set by HPIL/RS232 interfaces)

Leeway

Leeway tends to be a navigation department function, set by the DR tuning. However, it does have an effect on the wind triangle. Leeway symmetrically increases true wind angle upwind but not downwind (like upwash). Therefore, increasing the leeway calibration causes the Wind Direction to move against the boat in tacking, has no effect jibing, and has a lesser effect when going from upwind to downwind. It has no effect on true wind speed wiggle.

$$\textbf{Leeway} = \textbf{CalLeeway} \bullet \textbf{Heel} / \textbf{Boatspeed}^2$$

Qualitative Rules of Thumb

All the above boils down to the following rules of thumb. These rules give the direction to turn the screws, but not how much. In general, the less you turn them, the better. Also, you should concentrate on WINDSPEED, WIND ANGLE OFFSET and UPWASH for tuning the wind triangle. Although BOATSPEED and LEEWAY have effects, they need to be used to tune the navigation triangle. However, in order to aid in determining their effect on the wind solution, in case DR tuning is also needed, the effects are shown in brackets.

If Wind Direction moves WITH you when tacking or reaching;
Increase UPWASH about 0.3° per degree of wiggle, or
Decrease WINDSPEED about 1.5% per degree of wiggle
[Increase boatspeed about 2% per degree of wiggle]
[Increase leeway about 1° per degree of wiggle]

If Wind Direction moves WITH you from port beat to port run;
Decrease WIND ANGLE OFFSET about 1° per degree of wiggle, or
Decrease UPWASH about 0.67° per degree of wiggle
[Increase LEEWAY about 2° per degree of wiggle]

If true wind speed is higher downwind;
Increase WINDSPEED about 8% per knot of wiggle

Quantitative Effects

Listed below are the perturbations (ie wiggle effect) each calibration has on Wind Direction and speed for tacking, reaching and beat-to-run for a boat that does 6.8 knots upwind. The effects are calculated by describing the effect of a small change of each calibration in a POSITIVE direction from a perfect state, and then performing the described maneuver. These conditions therefore describe the effect of calibrations that are too HIGH. Positive Wind Direction changes imply WITH type wiggle.