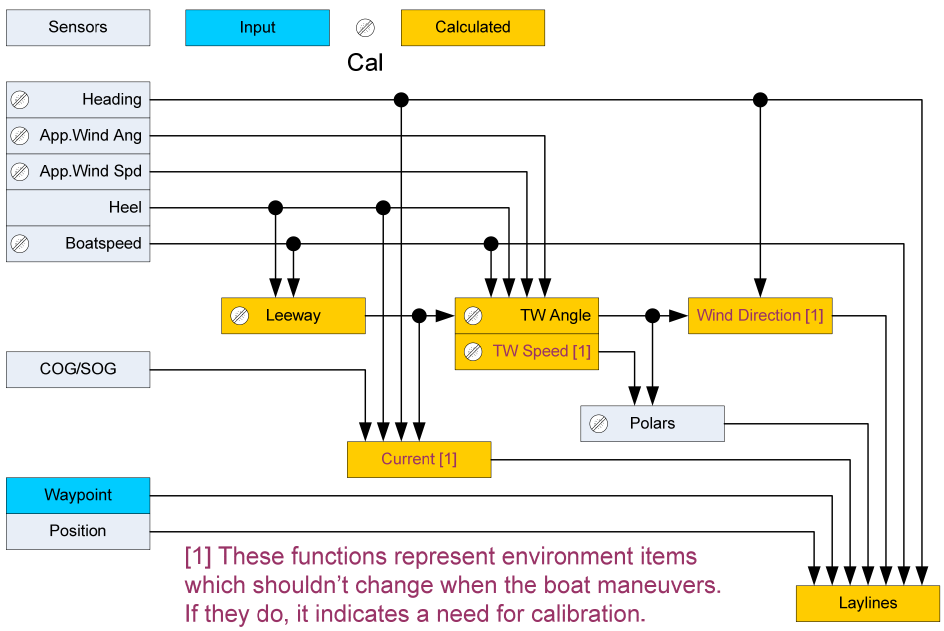
How Ockam Calculates Things

Proper math, accurate sensors and diligent calibration are important for a true wind instrument system. This paper explains the math part – i.e. how we get from paddle clicks to wind direction. It's all high school math, but there is a lot of detail.



Basic inputs

Everything begins with accurately determining the various primary inputs.

Boatspeed

The current technology is paddlewheels, although sonic sensors are trying for viability, and COG/SOG is available if needed. Paddles are pulse generators producing a frequency roughly proportional to boatspeed.

Why not COG/SOG over paddles or sonic? The reason is that the vector is earth-relative, so the wind solution would be too. The boat senses what the water is doing (with its keel), so boatspeed should be relative to the water. If COG/SOG were used, it would throw off the symmetry that sailors love so much. Nevertheless, the Ockam system can substitute SOG for boatspeed if necessary.

Now for the details.

1. $Speed = Offset + Cal \bullet PulseRate$

   Ockam supports one or two paddle installations, and does a complete boatspeed calculation for both of them. *Offset* is a table lookup and *Cal* is combination of switch setting and T2 screw cal *g* or calibration command K1. Boatspeed cal is also adjustable by AutoCal.

2. If two paddles are installed, the leeward boatspeed is selected. Then differential calibration is applied. Port and starboard boatspeeds are offset from the median by T2 screw cal *f* or calibration command K2.
3. If a correction table is installed, it is then applied.
4. This unaveraged value is used internally.
5. The displayed boatspeed is an average value set by average command A0.

Heading

The compass is experiencing the most innovation of all the boat sensors save GPS. Heading is used for wind direction and current calculation. The accuracy of heading is very important – a 2º error throws wind direction off by 2º, and messes up current by 0.2 knots.

All compasses, even card compasses, measure the <u>horizontal</u> component of the earth's magnetic field. This means they need to know where <u>down</u> is – not that easy on a sailboat.

We classify compasses as follows:

- 2D compass (older technology). This compass senses vertical by mounting two magnetometers on a pendulum. Pendulum swing is a problem with these types. Output is heading only.
- 3D compass (current technology). The MEMS revolution has allowed affordable compasses with no moving parts. Three mutually perpendicular magnetometers measure the earth's field while tilt sensors measure pitch and roll. The compass does the math and outputs heading, pitch and roll.
- Rate compass (current technology). The next step is to add rate gyros to the 3D compass to correct for short-term errors caused by horizontal acceleration perturbing the tilt sensors.
- AHRS (aerospace technology). An **A**ttitude and **H**eading **R**eference **S**ystem is a rate compass on steroids. It has really good tilt sensors, rate gyros and magnetometers in all three dimensions. These things were originally designed for aircraft, but the MEMS revolution has brought the price down to a couple of thousand dollars.

The Ockam system can use any of these types, and two fringe technologies – the gyro compass and the GPS compass (which may actually win the compass race eventually).

Now for the details:

1. If a correction table is installed, it is applied.

2. Software correction via Options 17-19 are applied.
   $Correction = Option17 + Option18 \bullet Sin(Heading + Option19)$
3. If the compass is not outputting turn rate, a linear fit to 2 seocnds of heading is done, extracting turn rate.
4. The unaveraged value is used internally.
5. The displayed heading is averaged by averaging command A23.

Heel, pitch and leeway

Heel narrows measured apparent wind angle by $\frac{1}{Cos(Heel)}$. Upwind, with a 30º heel, apparent wind is narrowed about 3.5º or 13%. Ockam systems have always measured heel by means of a heel sensor in the wind interface rather than relying on an estimate.

3D compasses provide heel and pitch as a byproduct of their operation. If such a compass is attached, the Ockam system overrides its built-in sensor and uses the compass' values instead.

Heel and pitch rates also induce wind at the masthead. This effect is compensated for during calculation of apparent wind.

Leeway is the angle between heading and boatspeed and is used in both wind and current calculations. It is calculated from
$Leeway = -CalK3 \bullet \frac{Heel}{Boatspeed^2}$.
CalK3 is set by T2 screw cal *d* or calibration command K3. Leeway cal is also adjustable by AutoCal.

Apparent wind angle and speed

Most masthead sensors use analog cup and vane technology. The vane moves a rotary encoder that produces 3 voltages, S1 thru S3. The apparent windspeed is a pulse generator driven by the cups. Cup anemometers have two disadvantages. The cups are slow to respond to changes in windspeed, and they have bearings that limit their low wind sensitivity.

A new technology is now becoming viable – the sonic masthead. These sensors use sound and time-of-flight to measure windspeed in two or three angles, and output their results digitally. Because of changes in the speed of sound in air, these sensors measure temperature and barometric pressure, which they also output. There are no bearings to stick, and the response time is very fast.

Now for the details – analog mastheads:

1. $Speed = Offset + Cal \bullet PulseRate$
   Offset is a table lookup, and *Cal* is a combination of switch setting

and T2 screw cal *j* or Calibration command K5. Windspeed cal is also adjustable by AutoCal.

2. Angle is determined from the three voltages.

Both analog and sonic:

1. If correction tables are installed, they are applied.
2. Wind angle offset is applied by T2 screw cal *k* or calibration command K4. This corrects for installation misalignment.
3. Upwash corrects for the bending of the wind by the sails. T2 screw cals *h* and *i* (or cal commands K6 and K9), and options 5, 6 and 21 control how much upwash correction is applied (see the system manual for details). Upwash cal is also adjustable by AutoCal.
4. Roll and pitch rate are compensated for. This requires mast height as entered by option 8, and rates as measured by the T2 heel sensor, a 3D compass or an AHRS. This compensates for the wind created at the masthead by boat slosh.
5. The unaveraged values are used internally.
6. The displayed angle and speed averages are set by averaging commands A2 and A1. Note that the displayed values are still the heeled values, but corrected for sensor correction tables, upwash and pitch/roll rates.

True wind

Now that we have the basics, we can start on the calculated functions.

True wind angle & speed

These operations use unaveraged values.

1. Break the apparent wind into longitudinal and athwartship components.
2. Stretch the athwart component by $\frac{1}{Cos(Heel)}$ to correct for heel angle.
3. Subtract boatspeed from the longitudinal component.
4. Recombine the components to give raw true wind angle and speed.
5. Apply the true wind angle corrections:
   - True wind angle offset (option 4). This is deprecated.
   - AutoCal Bt lookup table.
   - QuikCal (Unlift/Unhead, calibration commands K11 & 12).
   The sum of these adjustments is output on tag “e”, TWcorr. Calibrators should check this number before twiddling cals.
6. Apply the true wind speed corrections:
   - AutoCal Vt lookup table.
   - QuikCal (calibration commands K13 & 14).

7. The unaveraged values are used internally.
8. The displayed true wind angle and speed averages are set by averaging commands A5 and A4.

Wind direction

1. Add true wind angle to heading.
2. Add in turn rate compensation (Option 28 – see http://www.ockam.com/docs/MtPerturbation.pdf.

Retro-apparent

Retro-apparent is our name for back-calculating apparent wind from true. This slimy hack was invented by Graeme Wynn (of WTP fame) in his formative years. The B&G instruments of the day had no apparent cals, unbelievable as that is. Instead, true wind was munged with an adjustment table. In order to get reasonable apparent wind after this 'adjustment', he came up with retro-apparent. Some English majors think it's cool, so we can do it too if you insist (yuck). Here's how we do it.

1. During the measurement of apparent, the outputs are inhibited.
2. Starting with true wind angle and speed and boatspeed, do the wind triangle backwards:
   - Break the true wind into athwart and longitudinal components.
   - Add boatspeed to the longitudinal part.
   - Shrink the athwart by $Cos(Heel)$.
   - Put them back together for apparent wind angle and speed.

To commit this atrocity on an Ockam system, set bit 2 of Option 21. Don't call us.

The current triangle