Sailing Vehicles

ArduRover now supports sailing vehicles. Only sail boats have been tested so far, although there is no reason land based vehicles wouldn't work. It is recommended that the user familiarises themselves with the basic principles and terminology of sailing and sailboats.

https://www.youtube.com/watch?v=zoNLZ-xE-_0

NOTE

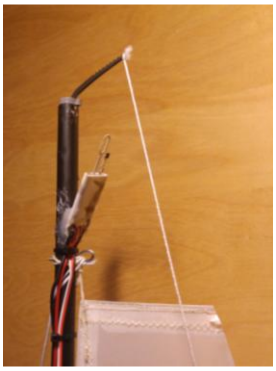
Sailboat support is new to ROVER 3.5.xxx. Please bear in mind that the new code may still have some issues. The more people try out and test sailing support the faster the bugs can be found and fixed.

Hardware setup

Sailing vehicles require a rudder for boats or movable wheel/ wheels for land vehicles. This is setup in the normal way by assigning a servo output channel to function 26 – Ground Steering.

Sailing vehicles also require a method of controlling the sails. The servo must pull in and let out the sails in a symmetrical way. I.e. no change of servo position should be required to set the sails at the same angle on a new tack. This is typically achieved through the use of a sail winch servo with a main sheet system. The sail winch is servo output function – 89.

Although not absolutely required for best results a wind vane should be fitted to allow the vehicle to sense the wind direction. A further improvement can be gained by fitting a wind speed sensor, the faster your vehicle goes relative to the wind speed the more important this is. See optional hardware – wind vane.

Sailing vehicles are supported by any flight controller, however if a wind vane is to be fitted one analogue ADC input must be available. On newer beta-flight style controllers this is typically labelled as RSSI. In order to fit a hot wire type wind speed sensor two more analogue inputs are required, although just a single additional input can be used with a small loss in accuracy. Alternatively a pressure based airspeed sensor can be used (link to optional hardware airspeed). Ideally a sail vehicle flight controller would have three analogue inputs. Pixhawk1 and the CUBE both fit this criteria.

What to expect in different control modes

This outlines the differences in sailboat behaviour over the standard Rover mode.

- Manual

Sail position is directly controlled by throttle position. Minimum throttle is sail fully in, maximum throttle is sail fully released. You may find the controller disarms when tacking to the left travelling upwind with the sails tight. If this is an issue disable stick disarming with the rudder arming parameter.

- ACRO

The Sail is automatically trimmed to the wind direction using the wind vane. A tack can be triggered from an aux switch; the vehicle will match its current angle to the true wind on the new tack.

- Hold

The sail is released and the vehicle steers directly into the wind to reduce its speed.

https://youtu.be/k_uv4jtqh70?t=3m32s

- Loiter

The vehicle will keep moving within the loiter area.

https://youtu.be/NCUF66rQXFg

- RLT

The vehicle will tack upwind back to the home location if required.

- AUTO

The vehicle will tack upwind to reach the next waypoint if required. Note that if the vehicle has to tack it will not stay on the line between waypoints. While traveling upwind a tack can be triggered from an aux switch or a full rudder input in the correct direction.

https://www.youtube.com/watch?v=zoNLZ-xE-_0

Configuration

The vehicle steering output channel should be set to servo function 26 – Ground steering. The sail output channel should be set to servo function 89 - mainsail sheet.

All sailing parameters can be found by searching for the prefix SAIL_ (link to parameter list), the sailing code relies heavily on getting correct information on the wind direction and strength from the wind vane (link to optional hard ware windvane).

Setting up sail range

This can be tested by arming in manual mode; the throttle will directly control the sail position. Throttle stick down (towards you) should result in the sail being sheeted in towards the centre line. If the sail is sheeted out the servo should be reversed. The servo min and max parameters can then be used to set up the range of travel. The min and max values should be set such that the boom is brought in towards the centre line of the boat but not pulled down tightly. The boom should be able to be let out until it reaches the shrouds; if no shrouds are fitted the boom shouldn't go too far past 90 degrees to the boat centre line.

The sail angle min and max parameters should be set to the angle to boom is to the centre line at each extreme of its travel. This allows the angle of the boom to be calculated at any point between.

The ideal sail angle to the wind should then be set. This defines the angle between the boom and the wind direction as reported by the wind vane. An angle of zero here would result in the boom staying parallel to the wind vane. The boom will keep this angle to the wind until it reaches either its minimum or maximum limit. If the sails are too loose this number should be increased. This can be tested in ACRO mode.

Other parameters

SAIL_NO_GO_ANGLE defines the no go zone into witch the sailing vehicle cannot travel. In auto heading modes the vehicle will tack at this angle into the true wind If the desired heading is within the no go zone. Note: this angle will be used whatever the wind strength and should be set with that in mind.

SAIL_MAX_XTRACK defines the maximum cross track error in auto mode that is allowed before the vehicle will tack. This keeps the vehicle within a corridor of width 2* SAIL_MAX_XTRACK. If set to zero the vehicle will ignore the cross track error and only tack once it can reach its destination.

SAIL_MAX_ST_RT defines the maximum turn rate of the vehicle when sailing upwind but not tacking. This can be used to reduce the aggressiveness with which the vehicle will change is heading to react to a change in wind direction.

PIVOT_TURN_RATE defines the maximum rate used for tacking, a lower value will result in slower tack. This should be reduced if the vehicle is tacking too sharply and losing momentum while tacking.

SAIL_LOITER_RAD defines the radius from the loiter point the vehicle will try and stay within, the vehicle will keep moving and tack back towards the loiter point once it reaches this radius.

SAIL_HEEL_MAX defines the angle at which the sail heel control PID controller is enabled. If the heel is larger than this angle the PID controller will target this angle however if the heel is less the controller will not try and reach it. i.e. only sheet out, don't sheet in.

SAIL_GCS_TRU_WND parameter controls if true or apparent wind speed and direction are reported to the ground control station. This is particularly useful for correctly setting up the wind vane.

Heel control PIDs values are set using (link to param set) paramiters. The effect of changing the value can be seen in ACRO mode by manually heeling the vehicle. Most control should be do using the P and I terms. D gain is usually too quick for the relatively slow response of the sail winch servos so should be left at zero.

Tacking in ACRO and AUTO mode while traveling upwind can be triggered through the use of an aux switch. This can be setup by setting the RCxOption parameter to function 60 – sailboat tack.

Tuning

The steering rate and navigation should be tuned in the usual way. Care should be taken that the final parameters work well on all points of sail and at range of wind speeds. For tuning the navigation controller it is recommended that a simple two point mission is run. The mission should be set up such that the boat travels at 90 degrees to the wind. This can be run indefinitely using a do_jump waypoint. Note that the L1 controller is only used when the vehicle is not tacking close to the wind.

If the vehicle aggressively responds to changes in wind direction when traveling upwind either the wind vane direction filter frequency can be reduced or the maximum straight line rate reduced. Reducing the filter frequency will also slow the response of the sails whereas reducing the rate only effects the steering.

The heel angle controller can be setup in two ways. A low I term can be used with a low max heel angle. In this case the controller will never hold at the max heel angle but will progressively sheet out as heel is increased. Alternatively the heel angle can be set at the actual maximum desired heel and then higher gains used to more aggressively let the sails out. In this case larger I and I max values should be used. Unlike the P and I terms the D term is always active however due to the slow response of typical sail winch servos it is unlikely to prove useful, vehicles with faster servos may benefit from a small amount of D gain.

Feedback

Sailing support is new to Ardurover and we need your feedback to continue improving the code, join the discussion here and let us know how you got on:

https://discuss.ardupilot.org/t/sailboat-support/32060

If you have found a bug or other issue with the code please fill in an issue report here:

https://github.com/ArduPilot/ardupilot/issues/

Optional hardware - Wind vane

A wind vane is used to sense both the wind speed and direction of the apparent wind; this can then be used to calculate the true wind speed and direction. Wind vanes are only supported for Rover sailing vehicles.

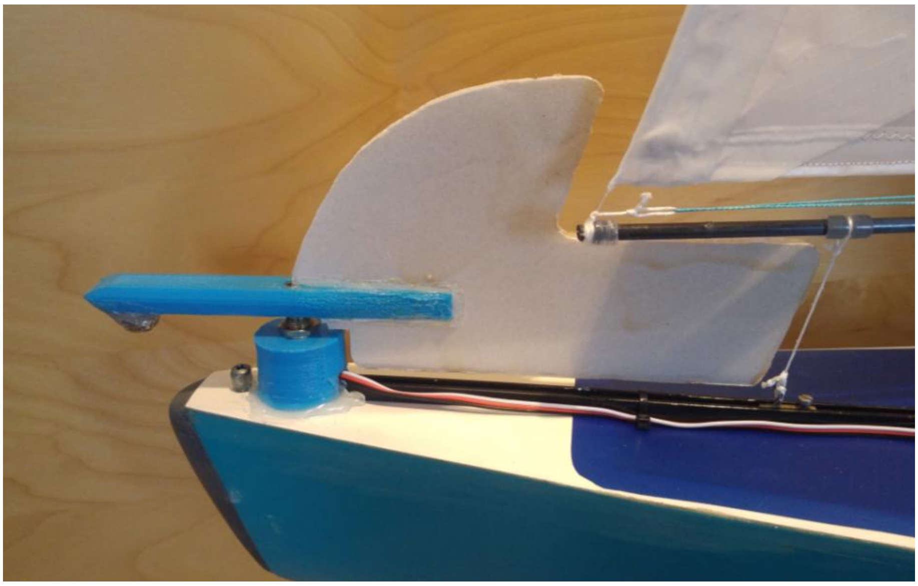
Sensing wind direction

Wind direction can only be directly sensed through the use of an analogue voltage from a 360 degree rotation potentiometer at this time. Two other methods can be used to give the code information about the wind direction. The wind vane type can be selected with WNDVN_TYPE.

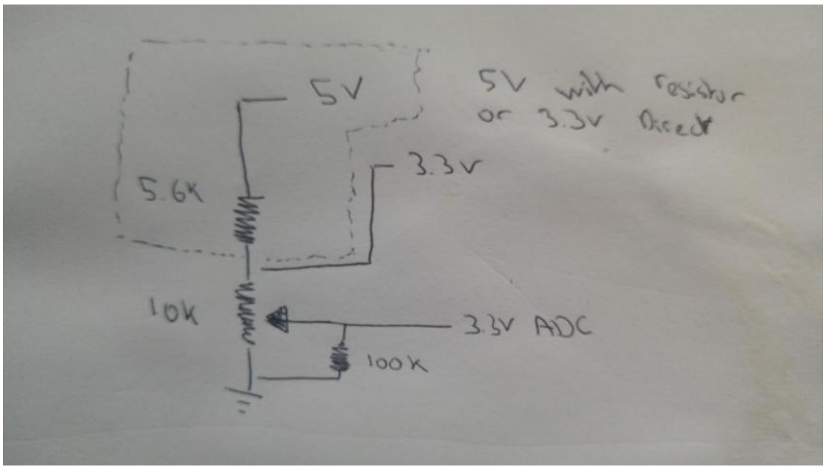
Home heading wind direction

The wind vane library can assume the wind is coming from the direction the vehicle was pointing when armed. This method is slightly improved upon by type 2 allowing this initial wind direction to be offset +- 45 degrees by a RC input channel defined by WNDVN_RC_IN_NO. These methods do not directly sense the wind but just assume it is coming from a constant direction so they shouldn't be used in shifty wind conditions or for longer missions. They are however a good method to test sailing support before a proper wind vane can be fitted.

Potentiometer wind vane



This wind vane relies on the reading voltage from a 360 degree rotation potentiometer. A Bourns 6630S0D-C28-A103 has been used with success and is easy to get hold of. However it takes quite a large force to rotate. A more free-turning one would provide better results. If you find a better one please tell us! The outer pins of the potentiometer should be wired to a voltage less than the voltage rating of the ADC pin you plan on using. If using a 6.6V ADC the potentiometer can be wired to 5V and ground. If using a 3.3V ADC the potentiometer can be wired to 3.3V if available or for the Bourns 10k potentiometer a 5.6k resistor can be used to drop 5V down to less than 3.3V. As the potentiometer passes from maximum to minimum output voltage the wiper pin is briefly floating, it is recommended to use a high value pull down resistor of around 100k. The outer pins of the potentiometer should be connected in such a way that rotating the potentiometer clockwise will result in an increasing voltage.



Neater version of this

The analogue pin the potentiometer is connected to is defined by WNDVN_ANA_PIN. The maximum and minimum voltage should be set. This can be done by manually setting WNDVN_ANA_V_MIN and WNDVN_ANA_V_MAX but it is recommended that a automatic calibration is used. To trigger this the WNDVN_CAL parameter should be set to one. A message will appear saying "WindVane: Analogue input calibrating" the vane should then be slowly rotated for 30 seconds until "WindVane: Analogue input calibration complete" is seen. Changing SAIL_GCS_TRU_WND to one will report the apparent wind speed and direction to the GCS. This can be viewed by double clicking on one of the numbers in the quick tab of mission planner and selecting wind_dir and wind_vel. If the wind vane is set up correctly you should see the wind direction value increase as you turn the van clockwise, it should reach both zero and 359 degrees. If this is not the case double check the potentiometer is wired such that a clockwise movement provides a increasing voltage and check the min and max voltage parameters are sensible. Now the vane can be set such that it points to the front of the vehicle as if it was head to wind. The negative of wind_dir value should then be set to the WNDVN_ANA_OF_HD parameter. The wind_dir value should now be zero and read 90 degrees when turned 90 degrees clockwise and read 270 degrees when turned 90 degrees anticlockwise.

Note: in testing so far it has been found that the potentiometer is not very accurate. An accuracy of +- 20 degrees around the circle is acceptable. The potentiometer should however be repeatable. If your potentiometer has a large dead zone where it passes from maximum to minimum voltage some improvement may be gained by setting WNDVN_ANA_DZ to a suitable angle, a dead zone value may be provided in the data sheet for your potentiometer.

If a wind speed sensor is also fitted the WNDVN_CUTOFF speed can be set. At wind speeds less than this the vane will be ignored. Keep in mind that if the wind is consistently less than this value the vehicle will have no information about wind direction.

The wind speed is low pass filtered at a frequency defined by WNDVN_VANE_FLT. If the wind direction is oscillating this frequency can be reduced. This will reduce the effect of fast oscillating wind shifts but will also reduce the response time to a change in wind direction.

It is hoped that more accurate sensors for reading the angle of the wind vane will be supported in the future.

Wind vane construction

A wind vane should be constructed to provide the maximum force to turn the potentiometer. A larger wind vane will be more effective in lighter winds than a smaller one. It is recommended to mount the vane as high as possible so that it is in clear wind. The vane must be balanced about the pivot point so that any heel angle of the craft does not change the reading. The weight of a well balanced vane has little effect; it can be directly mounted to the shaft of the potentiometer.

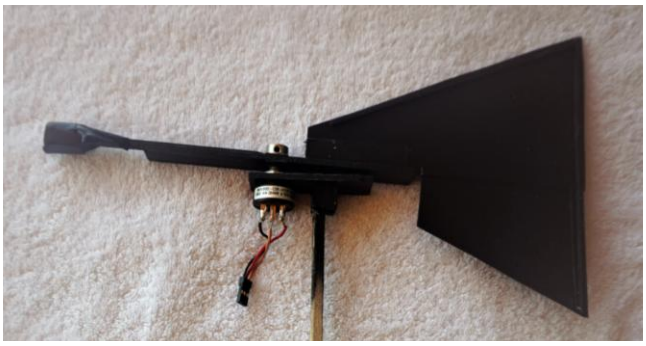


Photo - David Boulanger

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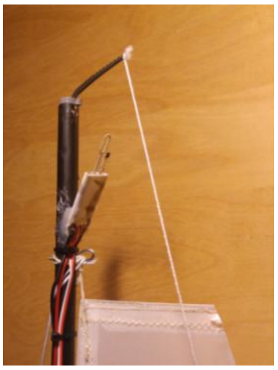
Sensing wind speed

A wind speed sensor is not absolutely required to get a sailing vehicle to work well. If one is not fitted apparent wind effects are ignored, for vehicles that move slowly in comparison to the wind speed this will have little effect however If possible it is always better to have a wind speed sensor.

The wind speed can be sensed in two ways, the wind speed sensor type can be change with WNDVN_SPEED_TYPE. The first is to read the speed from the airspeed library. This allows any pitot tube type airspeed sensor to be used. It is important not to the ARSPD_USE and ARSPD_AUTOCAL parameters are left at zero, they enable features designed for aircraft that will not work with Rover.

It may also be desirable to disable start up calibration with ARSPD_SKIP_CAL. If left enabled the airspeed sensor will be zeroed at boot. This recalibration requires the sensor is sheltered from the wind, this may be hard on a sailing craft. Pitot tube airspeed sensors require to be pointed directly into the wind, in this case that would require mounting the sensor to the wind vane. Due to this mechanical complexity other methods of sensing wind speed might be more convenient.

Hot Wire Anemometer



A hot wire anemometer can be used to sense the wind speed from any direction so can be mounted directly to the vehicle. So far only the modern devices wind sensor Rev. P is supported.

https://moderndevice.com/product/wind-sensor-rev-p/

This should be wired to between 10V and 12V the OUT and TMP pins are then connected to two 3.3V ADC pins. As with the wind vane the sensor should be mounted as high as possible.

Wiring diagram here

The speed output pin labelled OUT should connected to the flight controller ADC pin defined by WNDVN_SPEED_PIN1. The TMP pin of the sensor should be connected to the flight controller ADC pin defined by WNDVN_SPEED_PIN2. If only a single ADC pin is available the TMP output can be omitted, WNDVN_SPEED_PIN2 should be set to -1 in this case. The code will then assume room temperature; this will reduce the accuracy of the wind speed reading. The WNDVN_SPEED_OFST parameter should be increased until there is a small wind speed read in zero actual wind speed, it can then be reduced again until it reaches zero. This should be set using the apparent wind value sent to the GCS using SAIL_GCS_TRU_WND equal to one.

The wind speed is filtered using a low pass filter, the frequency of this filter can be set using WNDVN_SPEED_FLT.