Optimized Sailing Trajectories: Team SailTrim

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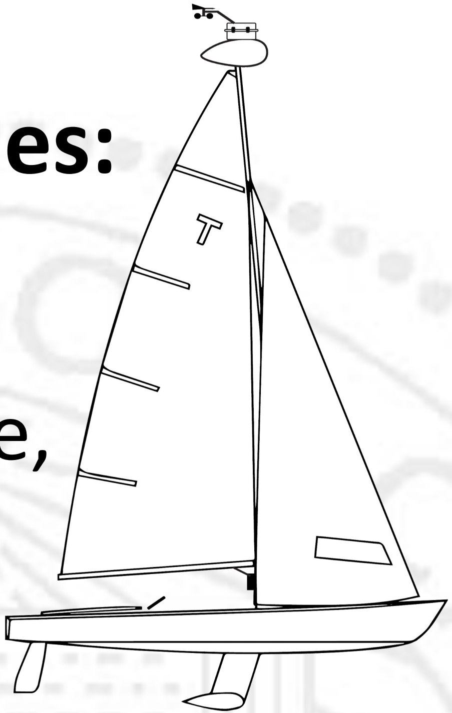
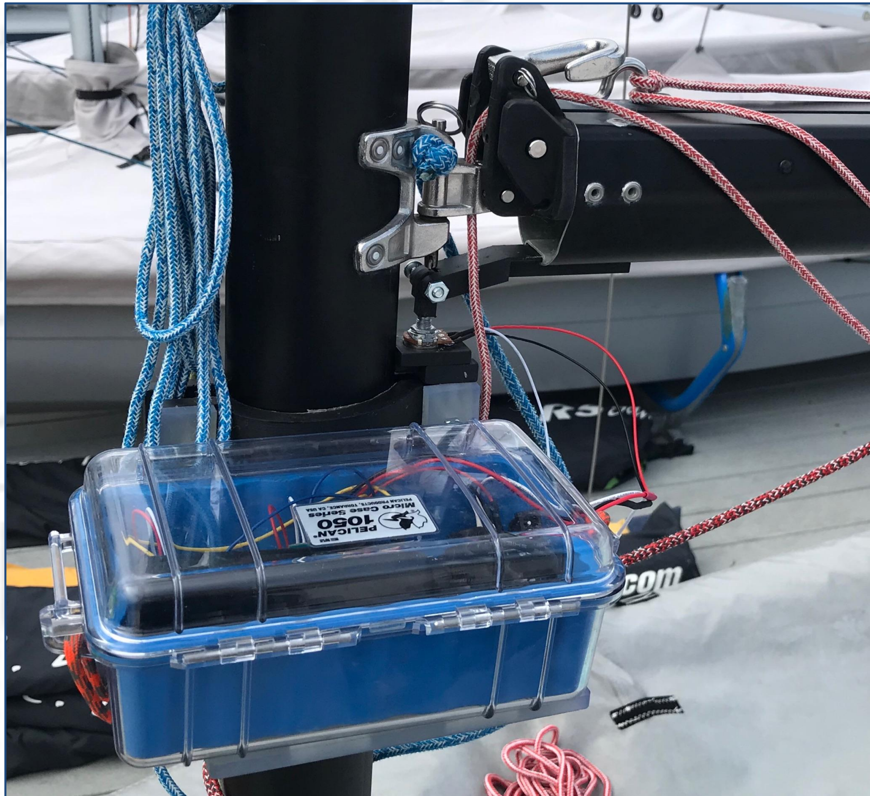


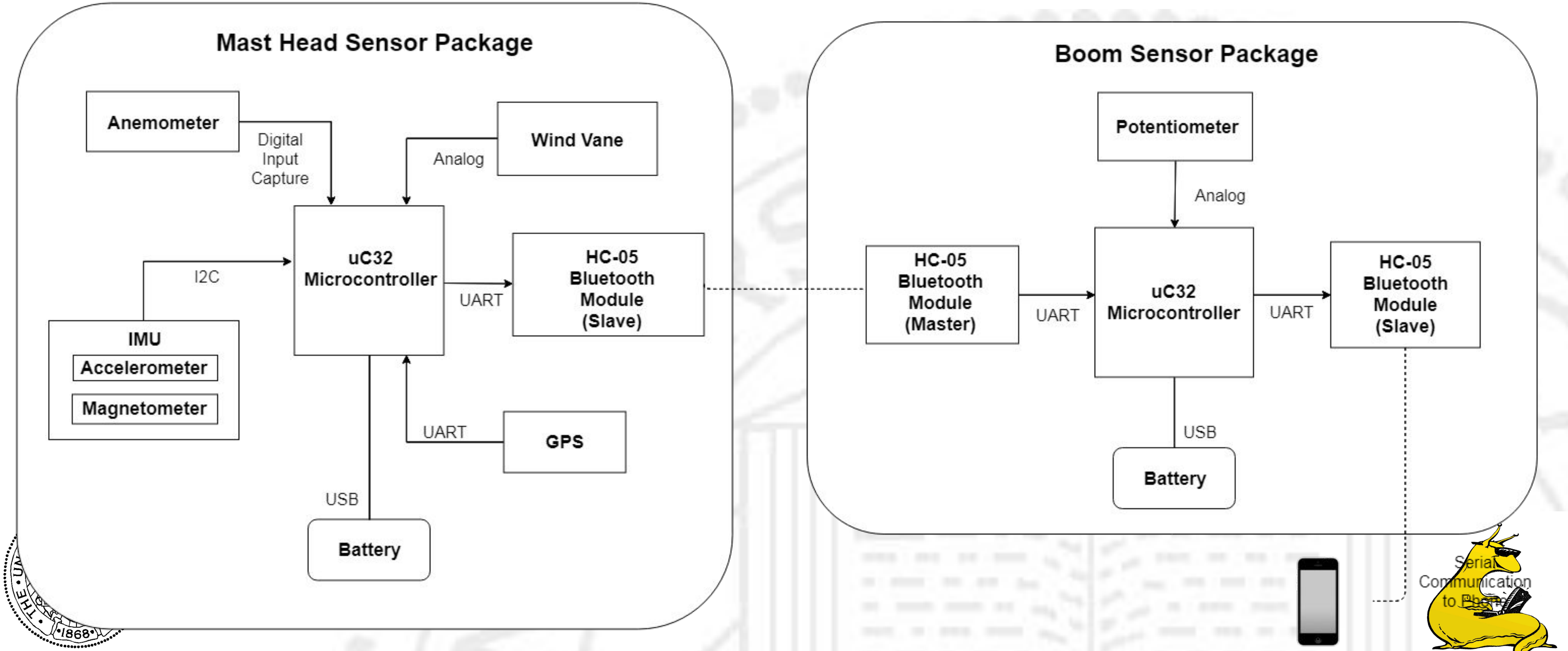
CMPE 129 – Capstone Design

Mast Sensor Package

Boom Sensor Package

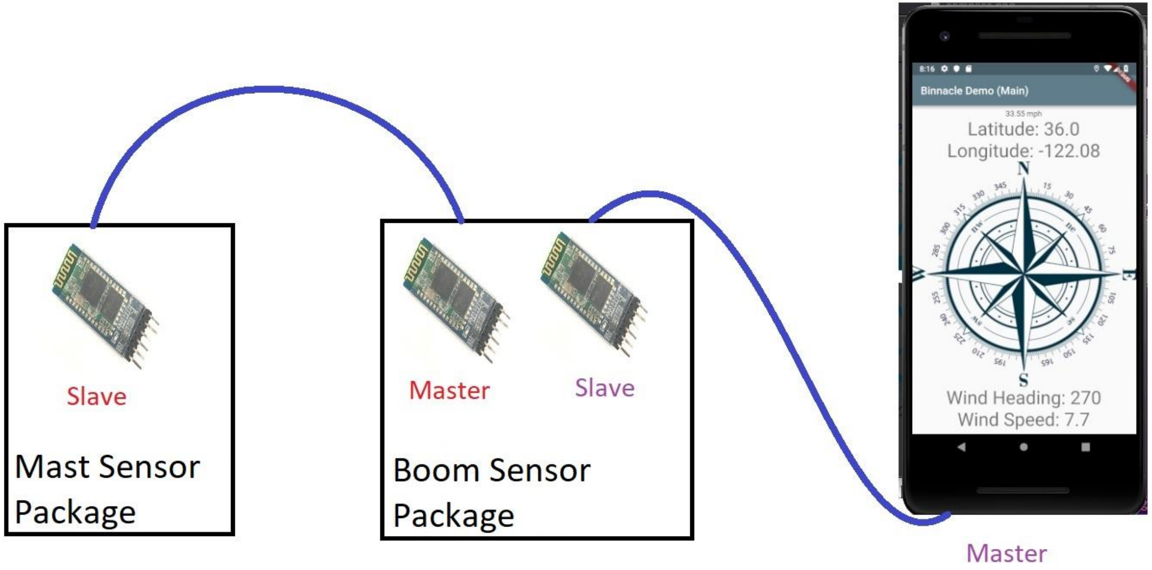


System Overview



Bluetooth: Network Config

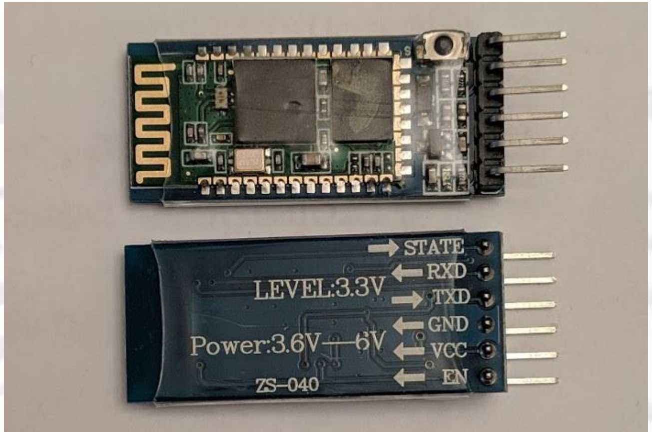
- Three Bluetooth modules, one phone
  - HC-05’s (BT 2.0): 1 Slaves, 1 Master
  - SH-HC-08 (BLE): 1 Slave



Bluetooth: Serial UART

- Max’s serial.c modified to support UART2 as well
- Our serialcomm.c built on this to support NMEA use

- Also used to configure HC-05 and SH-HC-08 modules w/ AT commands



State - Error checking (unused)
RXD - TX on uC32 UART 1 or 2
TXD - RX on uC32 UART 1 or 2
GND - GND from uC32
VCC - 5V from uC32
EN - Triggers AT command mode

Bluetooth: Data Format

- Our custom NMEA based packet:

$GNOST,(filtered?),(lat),(long),(wind speed),(wind dir),(gps speed),(gps direction),(boom angle),(compass heading),(timestamp),(checksum)\r\n*

Example Custom Packet:

$GNOST,1,3658.0442,-12200.2109,3.31,13.00,0.30,261.81,2.10,213,204122*57

- Uses same parser as the GPS data

Bluetooth 4.0 vs 2.0

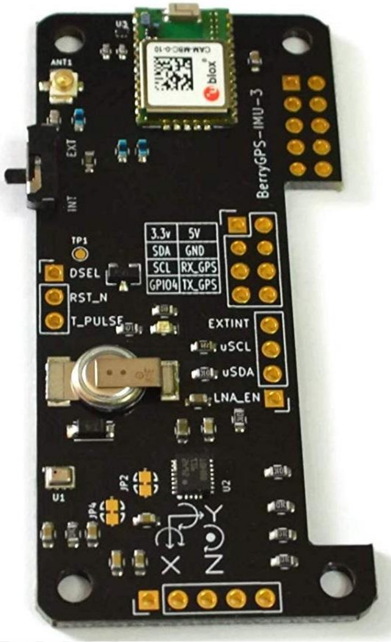
- Bluetooth 4.0 (BLE) required by iOS
- BLE sends at a much lower frequency than 2.0
- To maintain high speed processing, BT 2.0 used between sensor packages, while BLE is used to talk to phone app

RESULTS: 12Hz communication between packages

1Hz communication to phone

GPS: Hardware

- BerryGPS-IMUv3 has CAM-M8 (uBlox)
- Uses a serial UART connection



3.3v	5v
SDA (I2C)	GND
SCL (I2C)	RX_GPS
	TX_GPS

GPS: Data Parsing

- Information sent with NMEA data format
- Various packets send wide range of info, we pick and choose what parts we care about

Example:

*$GPRMC,123519,A,4807.38,N,01131.000,E,022.4,230394,003.1,W*6A*

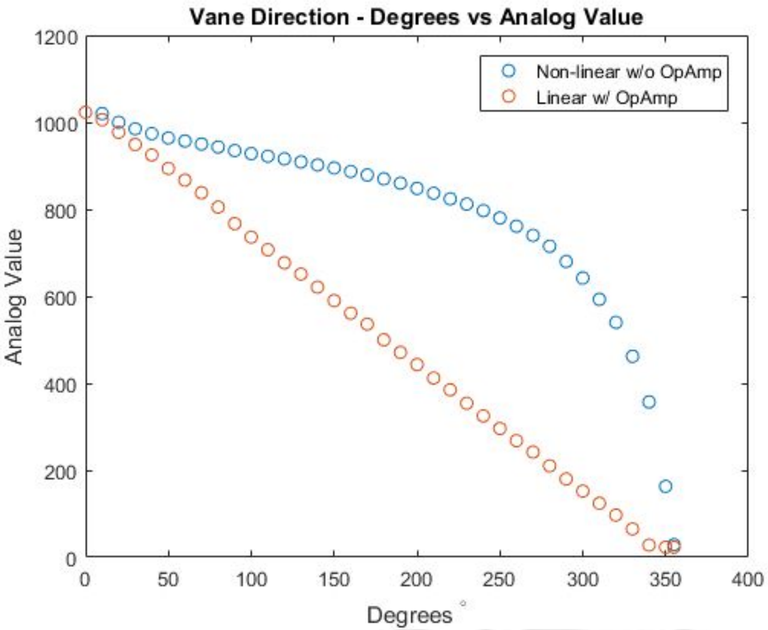
*$HEADER,hh:mm:ss,status,lat,N/S,long,E/W,speed,angle,date,mag. var., *checksum*

Anemometer and Wind Vane

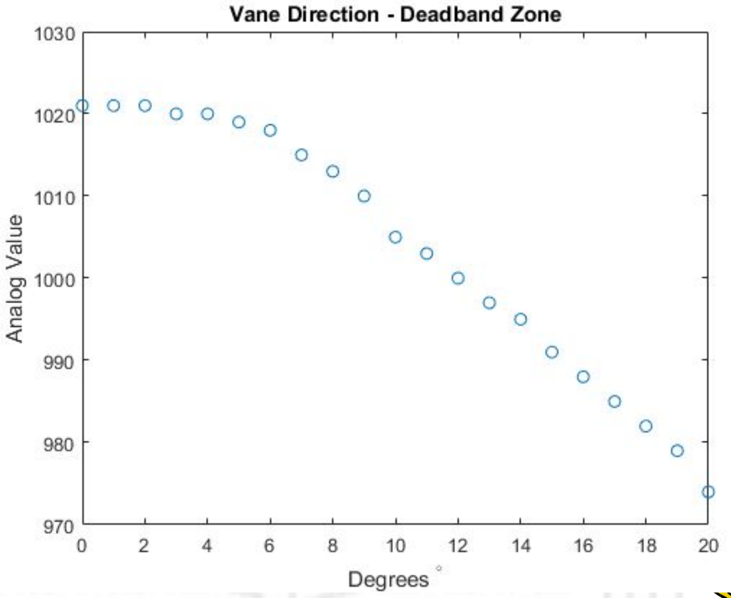
- Davis 7911
  - Wind vane - wind direction
  - Anemometer - wind speed

Wind Vane Circuit

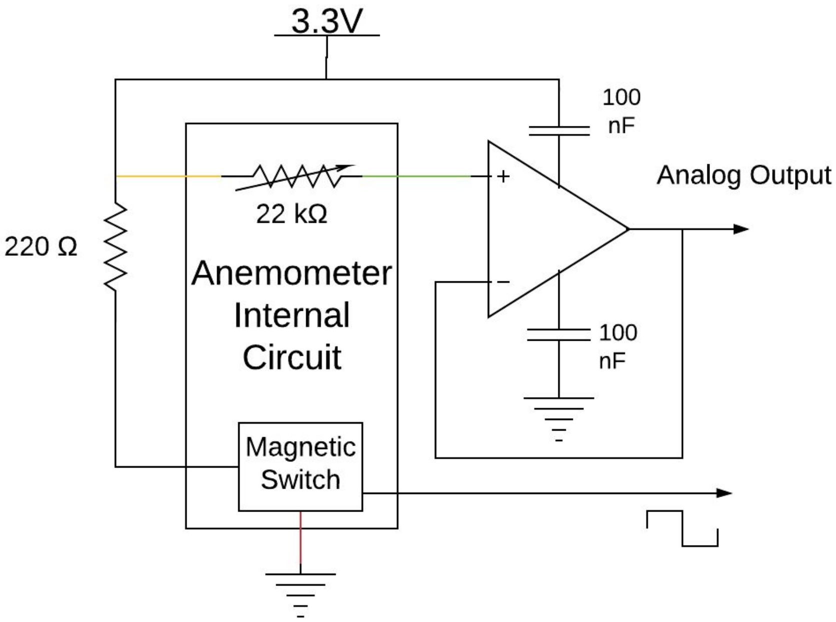
- uC impedance caused disturbance to linearity



- Linear uC readings with small deadzone (345°-10°)



Davis 7911 Circuit



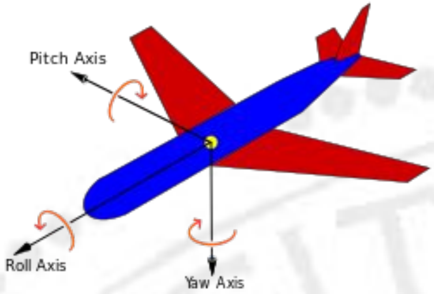
- Fit function excludes deadzone
- Wind vane mounted to have dead zone aligned with dead down wind
- Accuracy ± 1 ° within (7° -349°)

Anemometer: Data Collection

- Square wave signal with falling edge triggers
- Input Capture
  - 40 MHz PCBCLK, 1:256 prescalar, 32 bit timer
- Rollover period of 7.6 hrs
- Required mapping of freq/period to speed

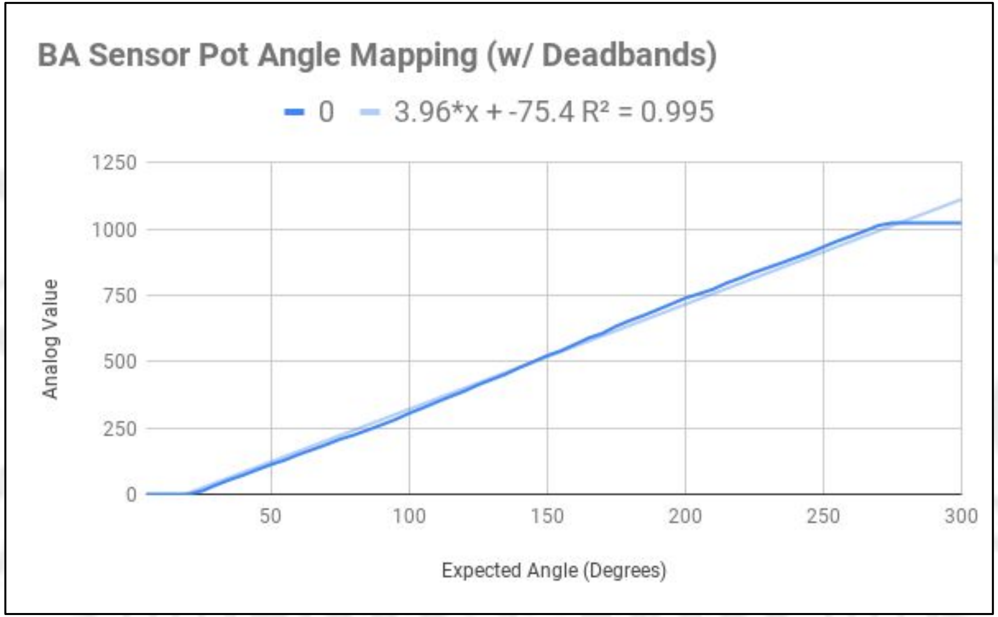
Boom Angle Sensor System Ideation

- Translate rotation of boom into readable signal
- Mount circuit on mast
- Boom offset from hinge by 2 inches
- Boom pitch range =(-30°, 15°)



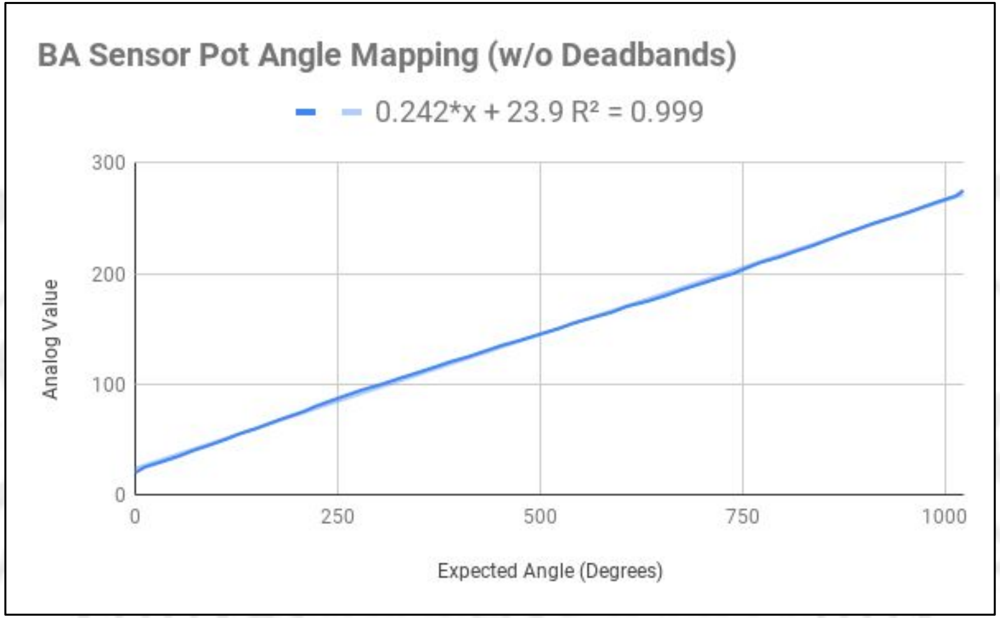
Boom Angle Sensor Library, Calibration

- Inverse fit function:
  3.96*x + -75.4
- Pot dead band: (0°->24°), (210°->270°)
- Place dead band outside of active zone (120 deg)

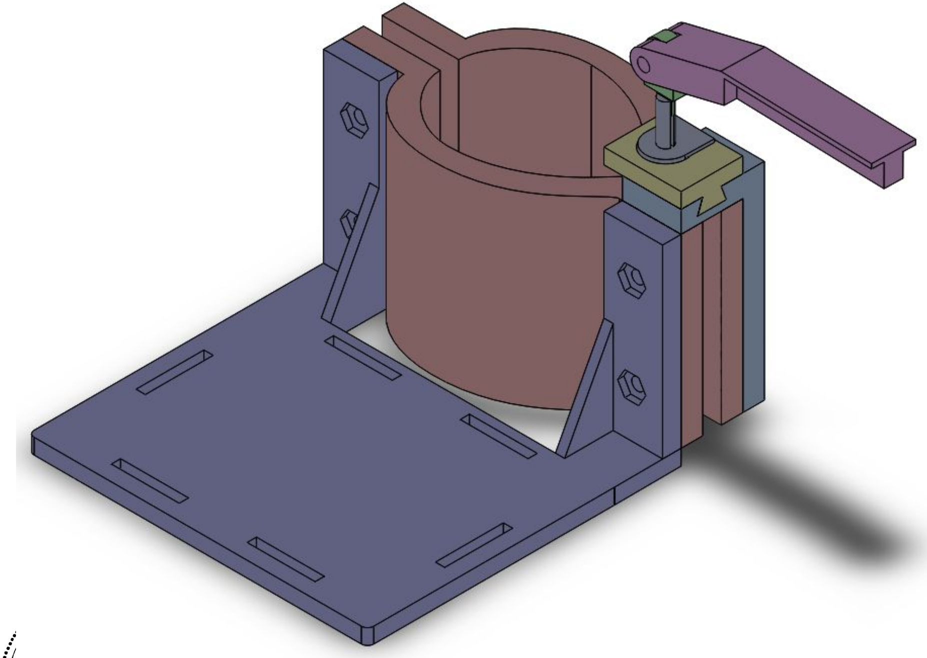


Boom Angle Sensor Calibration (Cont.)

- Least squares error: 0.999
- Piecewise fit function to improve accuracy inside active zone
- Total angle range: ~270
- Centering offset: 111
- New fit function: 270-(0.242*x + 24)-111

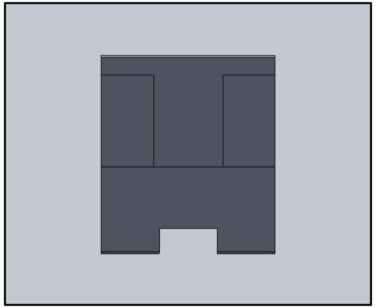


Boom Angle Sensor Mechanical System

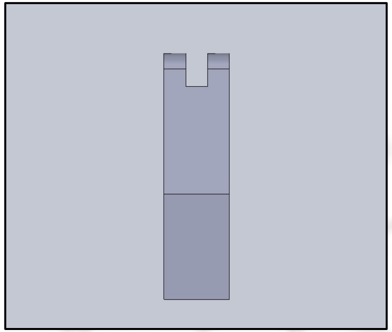


- Hinge joint in linkage to compensate for offset
- Slider and bracket to adjust pot position
- Platform to hold box
- Mount to connect to mast
- Parts drafted in Solidworks, easy to transfer to .stl for 3D printing and rapid prototyping

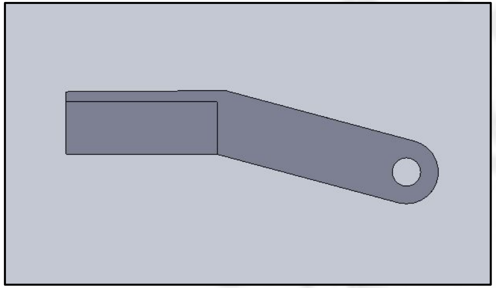
Mechanical System: Boom Slider



Front View: facing T-section



Top View: slot added
for pot turner

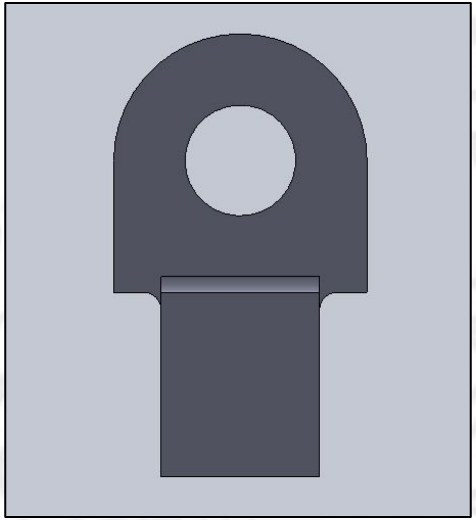


Side View

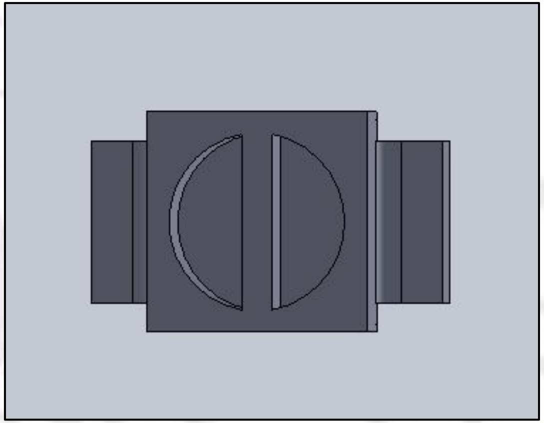
- Horizontal link slides into boom slot 0.5 in
- Issues with binding: slider was too long
- Shorten and taper T-section
- Lubricate to reduce friction

Mechanical System: Pot Turner

- New pot had different cross-section
- Piece slides on top of pot, fastened to boom slider

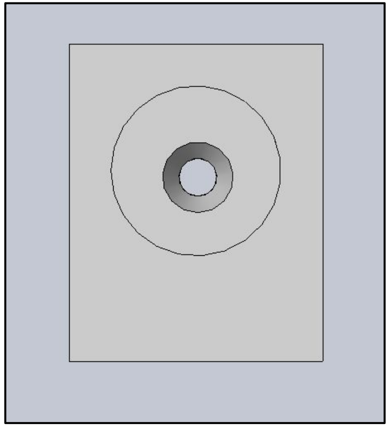


Side View: hole for screw

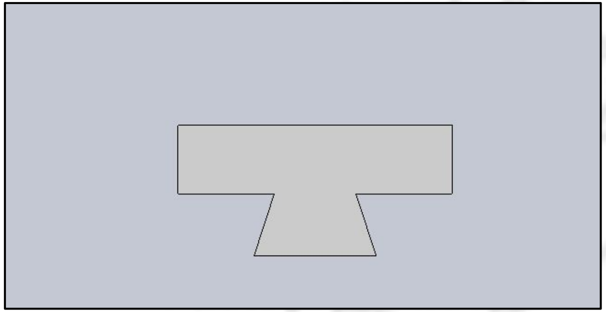


Bottom View: indented to sink onto pot

Mechanical System: Pot Slider



Top View: hole re-tapped on left side



Front View

- User error in setting pot: position may be off
- Slider moves in bracket, allow user to put pot under hinge
- Set screw to lock good position
- Tolerances too tight, sanded piece down, lubricate
- Set screw hole placed at side, screw interferes with position of pot

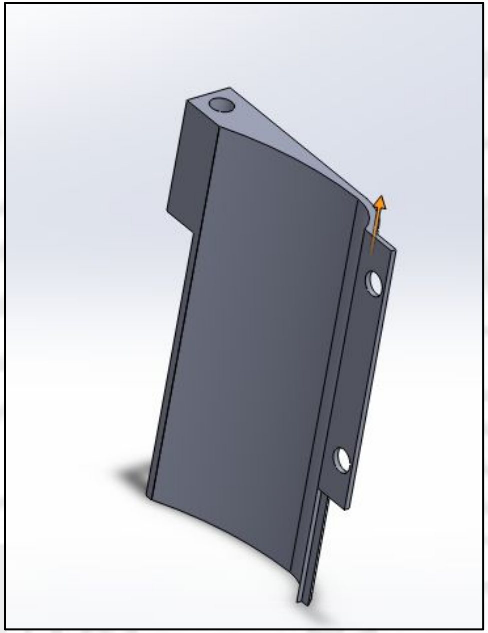
Boom Angle Sensor Measurements

- Few measurements in RS Quest manual, collect them in person at harbor
- Wrap tape along arc length of mast, mark and measure

-Mast has airfoil shape, difficult to obtain arc length

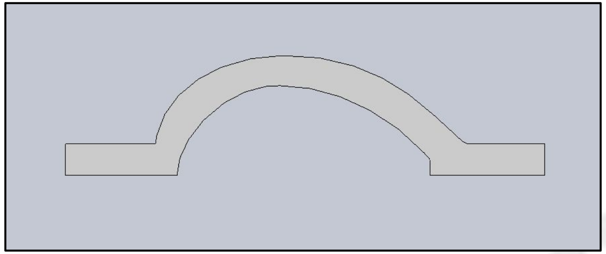
CAD Mast Draft, Developments

- First drafts did not match shape of mast
- Use modeling clay to wrap around mast and hold shape, create fiberglass mount

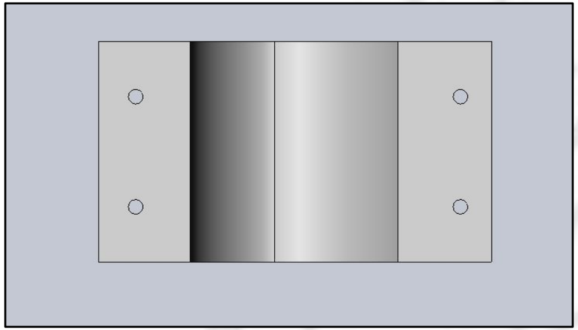


-First Draft of Mast Mount

Mast Mount: Final Developments



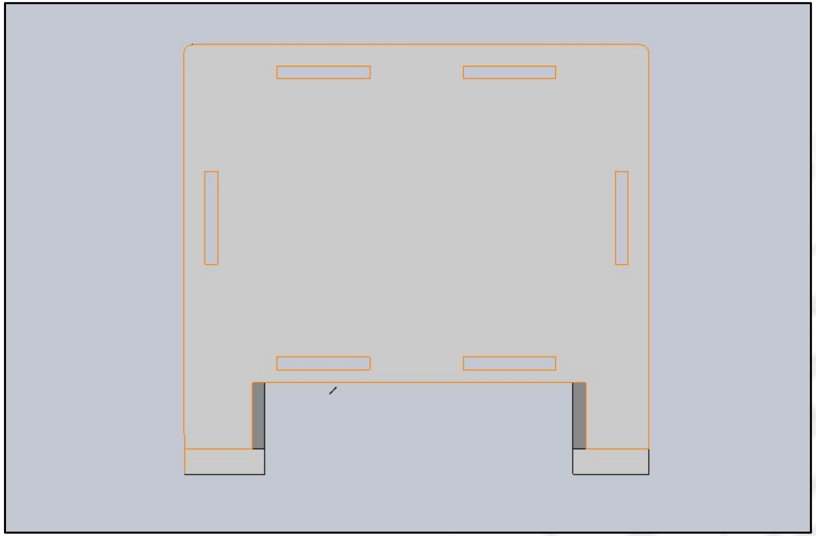
Top View



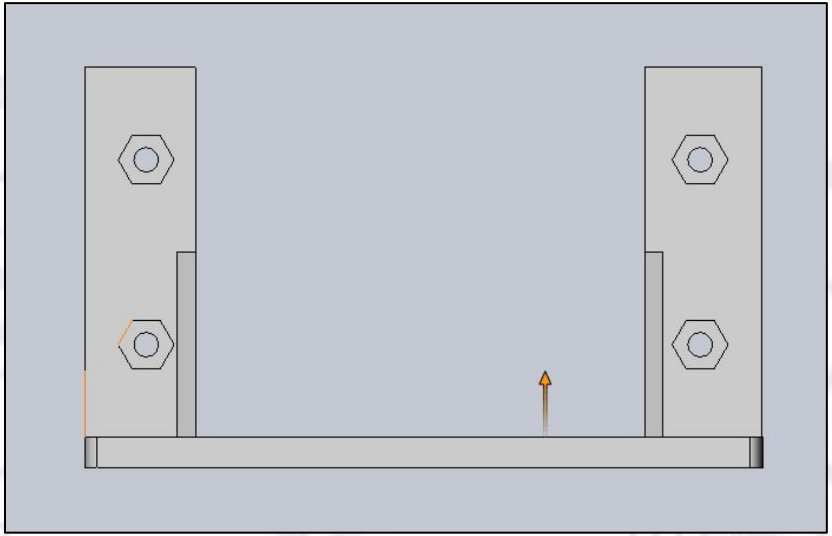
Side/Inside View

- Used cross-section of mast to revise mast mount
- Duct tape in curved section to protect mast
- Hex holes for nuts, screws
- Slots in platform to tie box down

Mast Mount: Final Developments (cont.)



Bottom View



Front View

IMU Attitude Estimation/Issues

- IMU Used: MPU9250
- Motion of boat affects wind vane, anemometer data
- Find roll and pitch, remove their effect
- Initially used closed-loop controller: integrate gyro rates, correct w/ accel and mag, get angles from DCM
- Switched to accel-based attitude estimation, low-pass filtering

IMU Attitude Estimation/Issues (Cont.)

- Axes of accel and mag not aligned
- Tumble device, collect data, find scale factors, null shifts, misalignment matrix
- Left-handed coord frame, not right-handed
- Fix: make z neg. for accel and gyro, x and z neg. for mag

Results

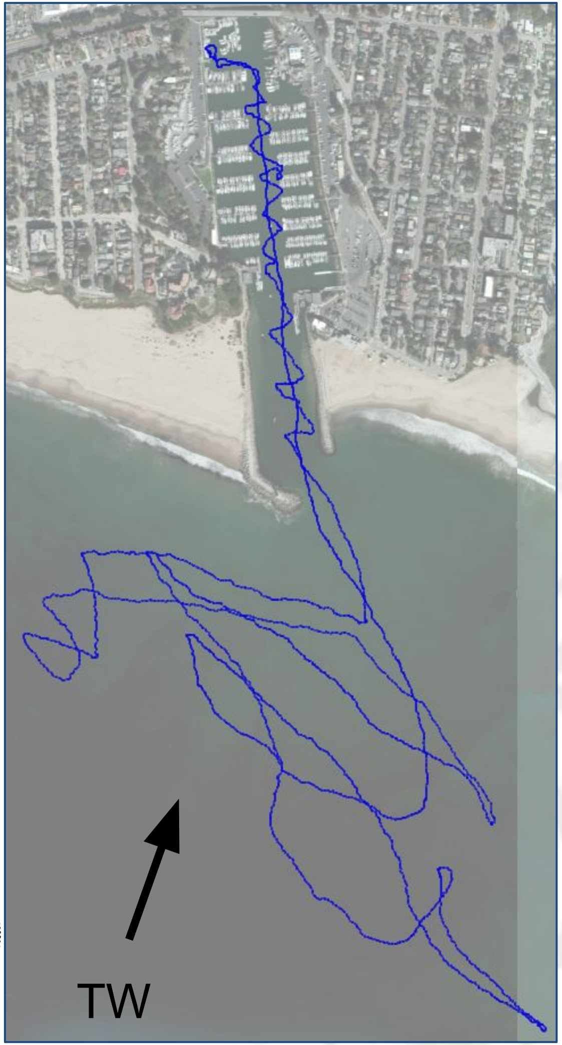
Data Collection

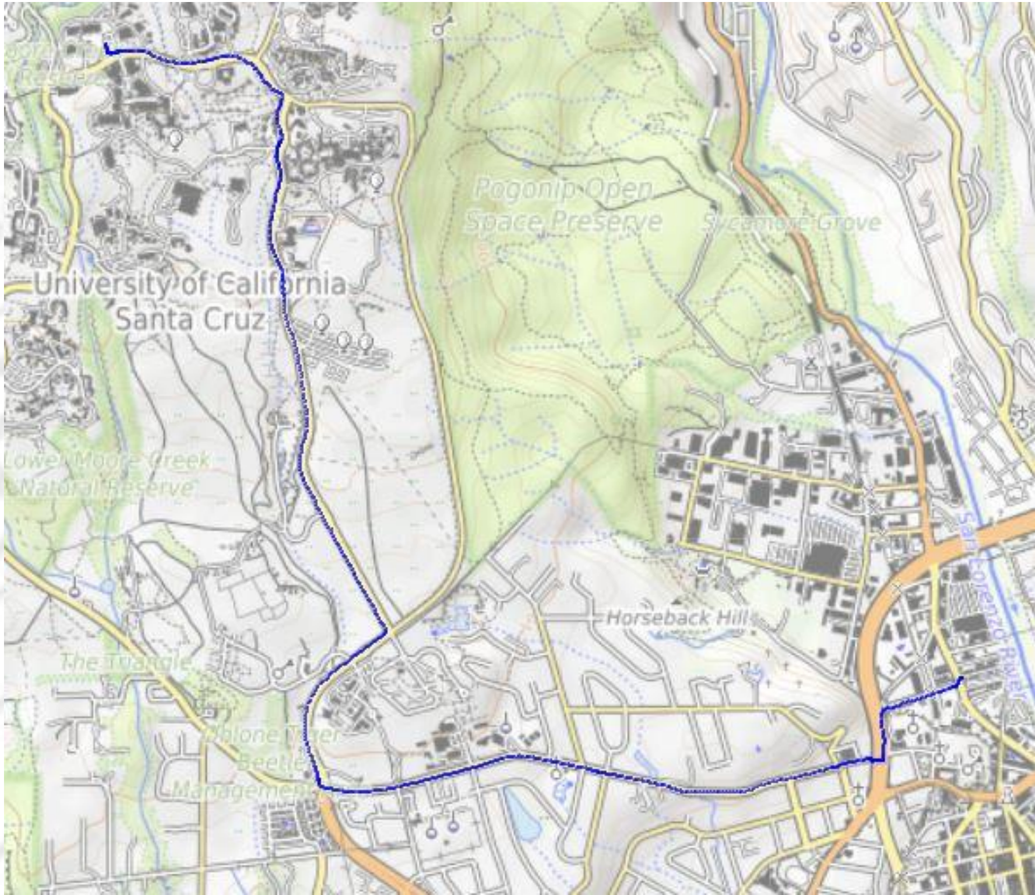
- GPS Location, Heading, Speed
- Apparent Wind Speed & Direction

Post Processing (mimic phone processing)

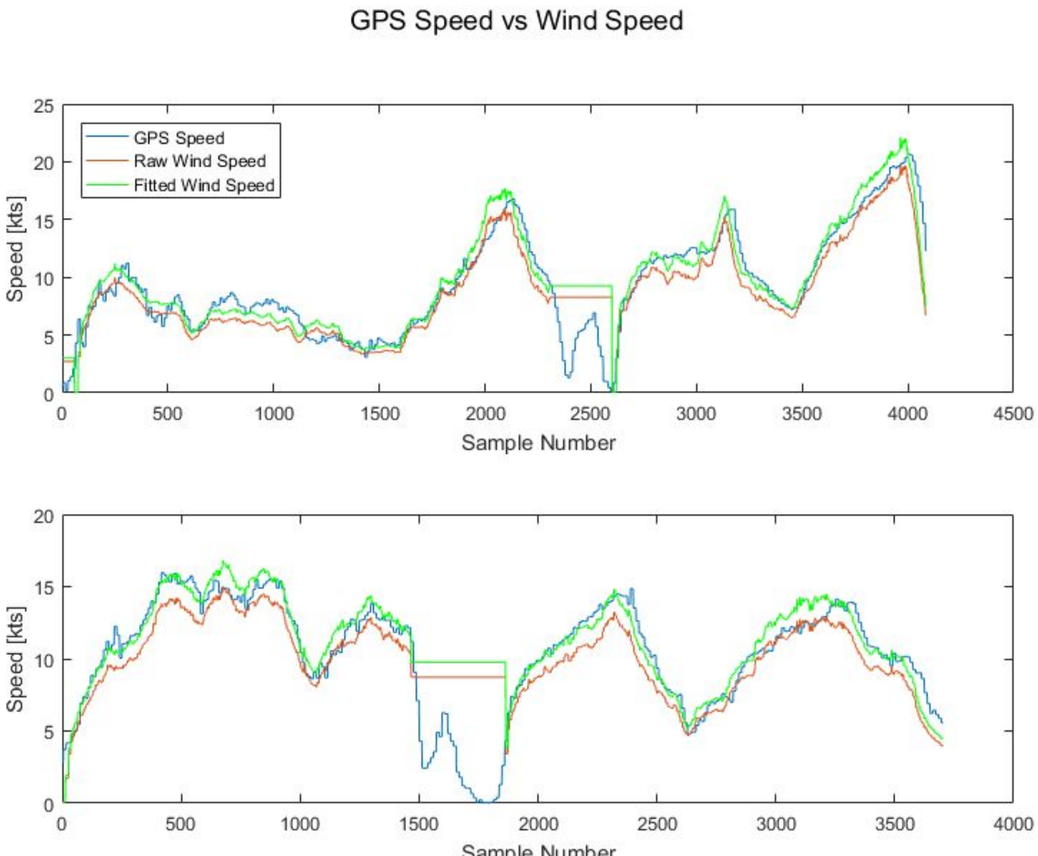
- Wind Vector Triad
- Polar Speed Plots

GPS Plotting



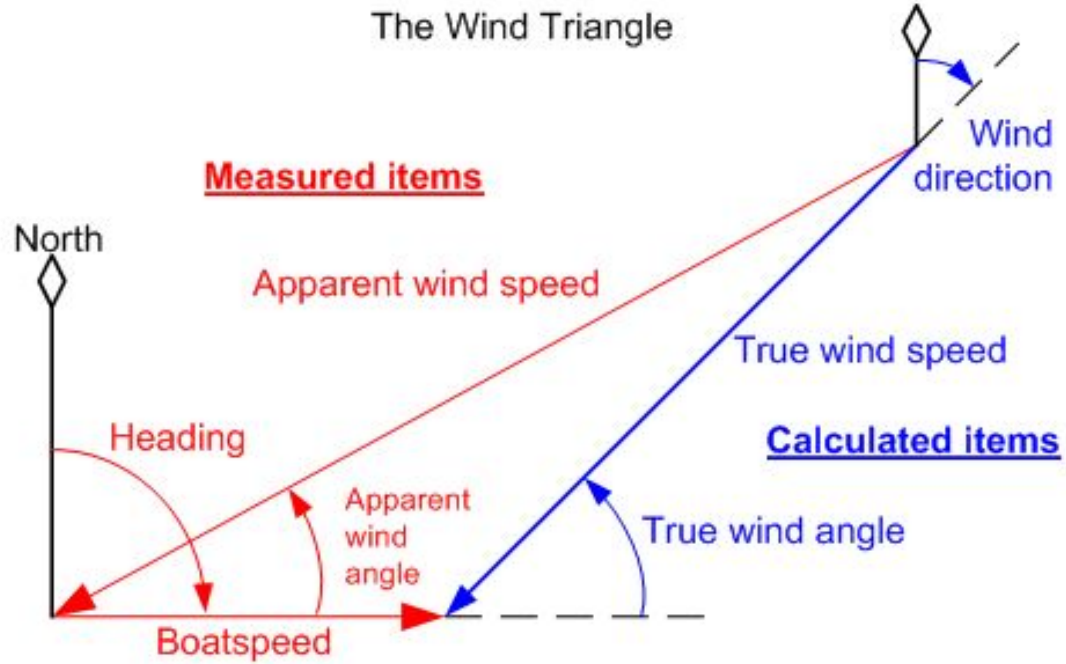


GPS/Anemometer: Data Run



- Initial Results:
  - max error: 2.74 knots
  - avg error: 1.06 knots
- Python Script to minimize error
- Good Agreement
  - max error: 1.96 knots
  - avg error: 0.38 knots
- Current Fit
  - 2.46 Hz per 1 knot

Triad of Wind Vectors

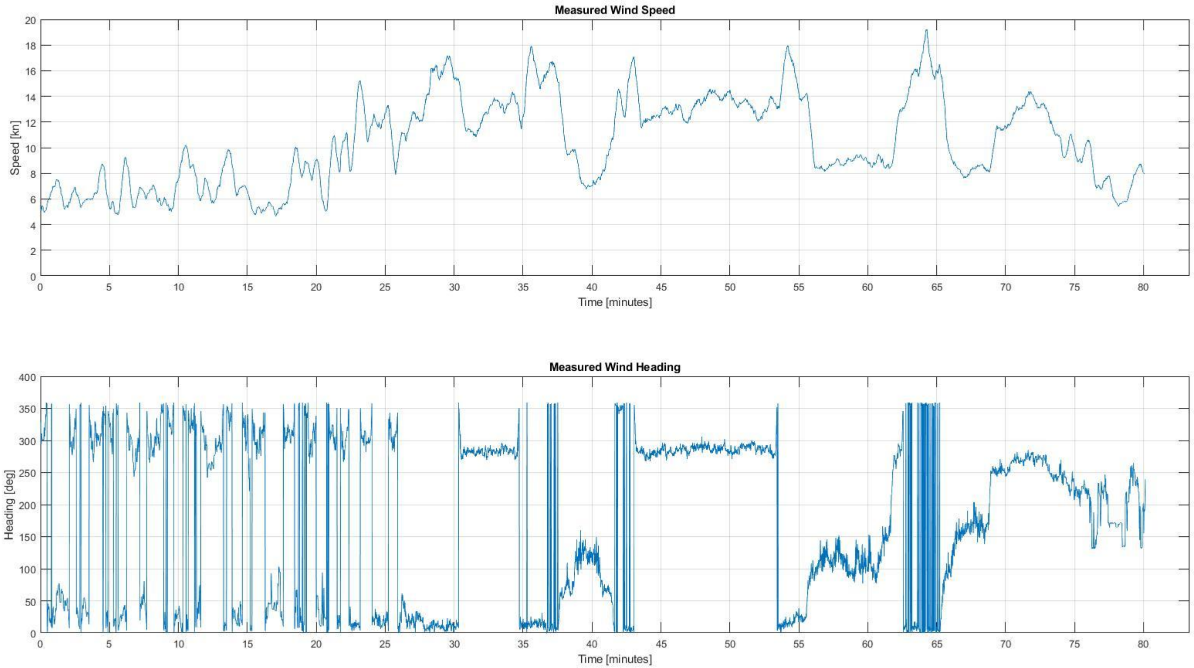


[1]

B + T = A   or   T = A - B

Measured Wind

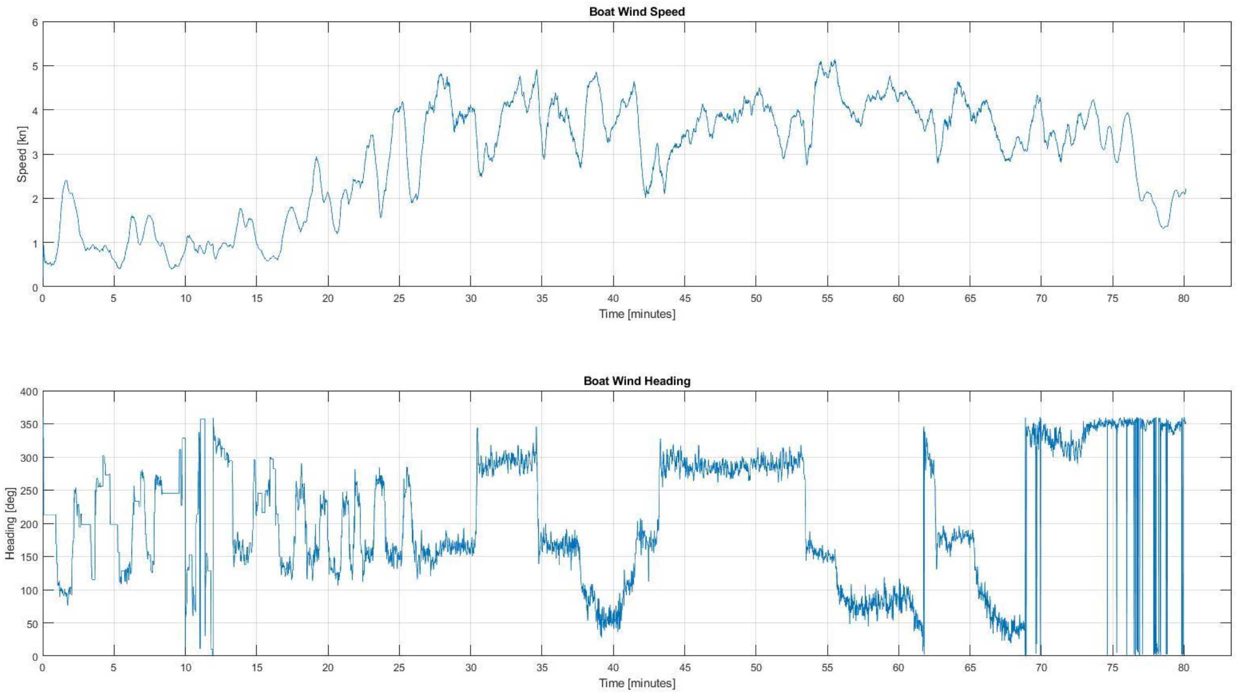
- The wind vector measured by our sensors is a combination of true wind and motion-induced wind



stone Design

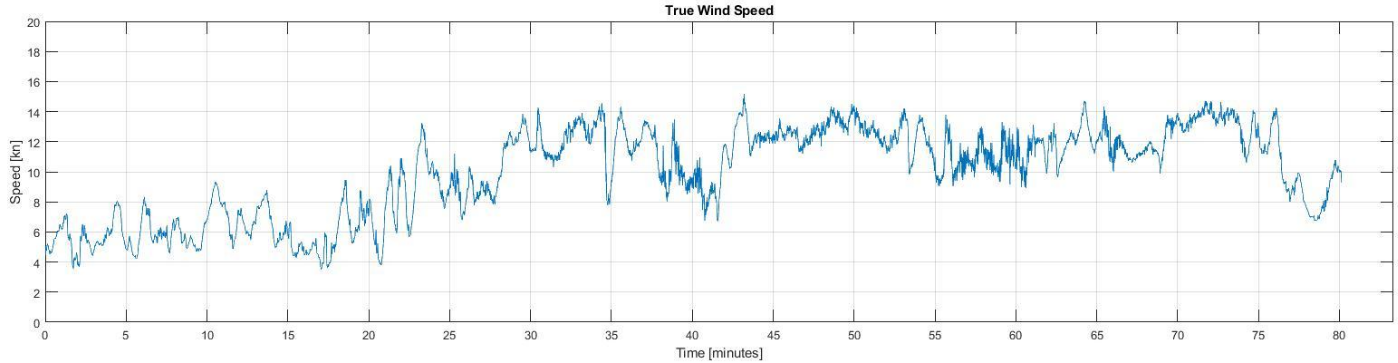
Boat Wind

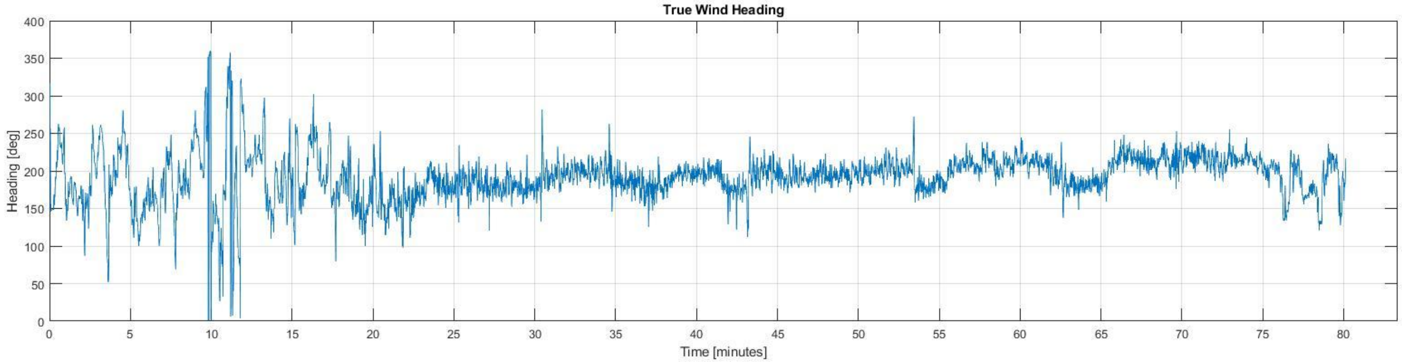
- Using GPS speed and track, we have access to a vector of wind induced by the motion of the boat

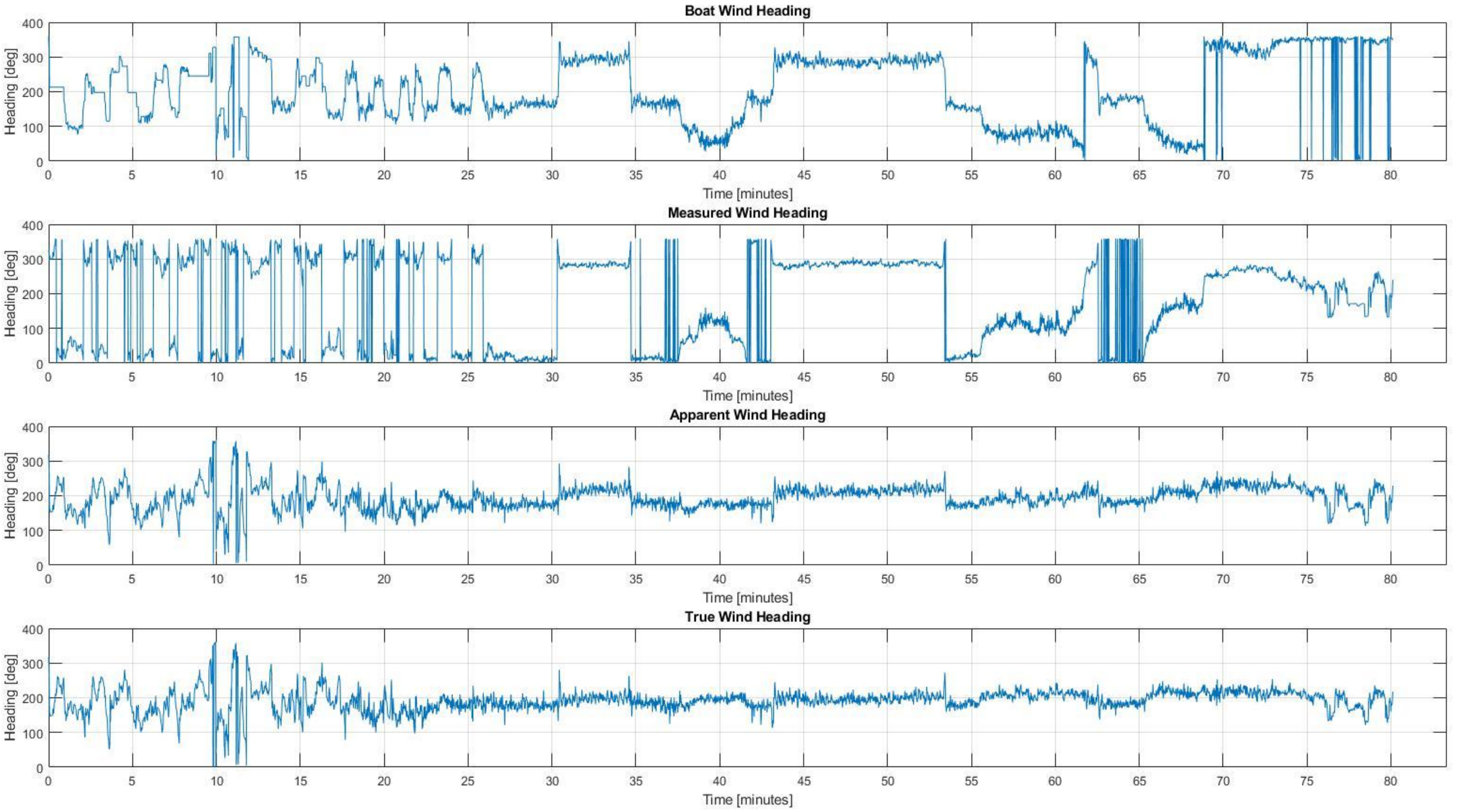


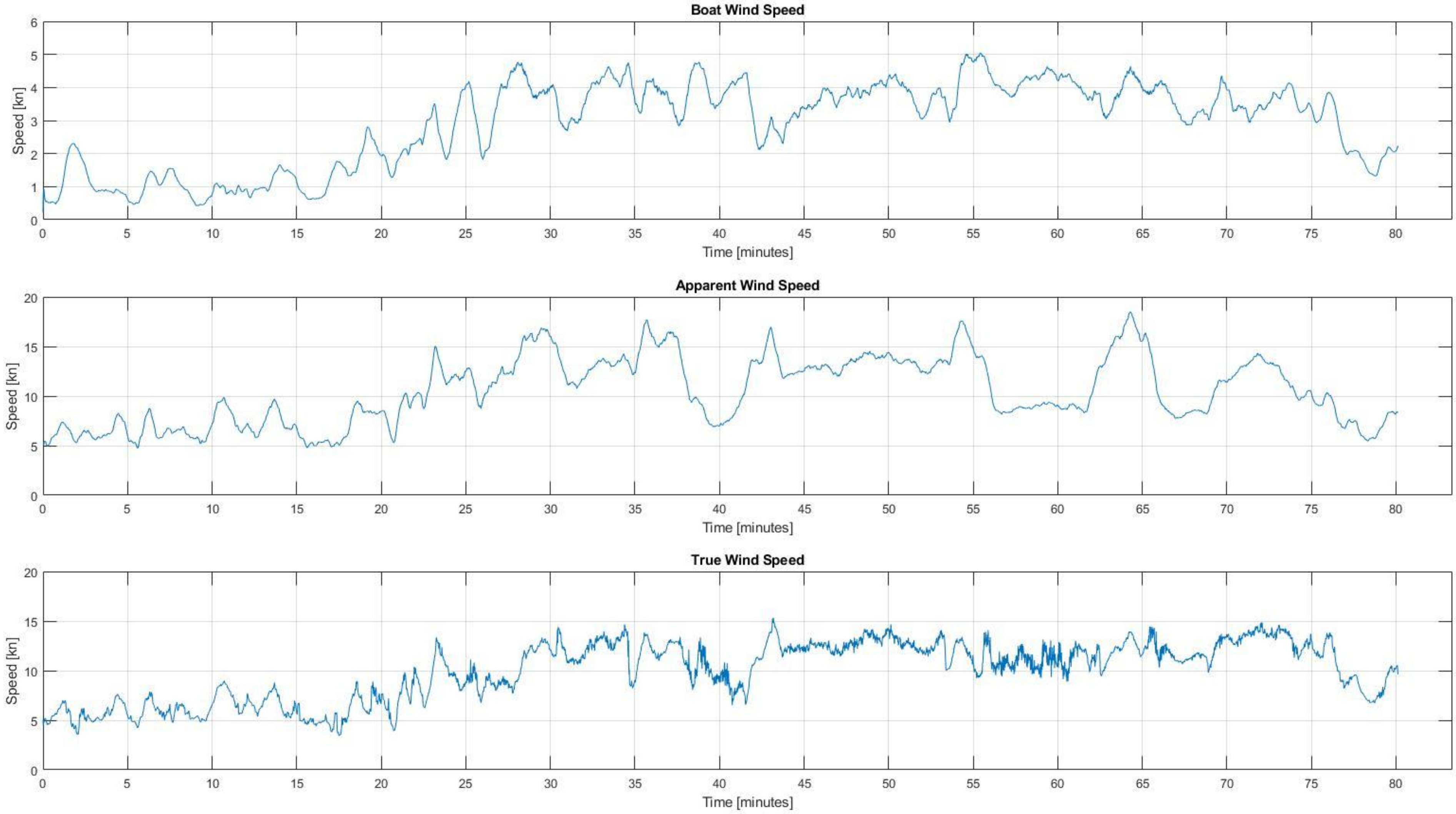
stone Design

True Wind Results



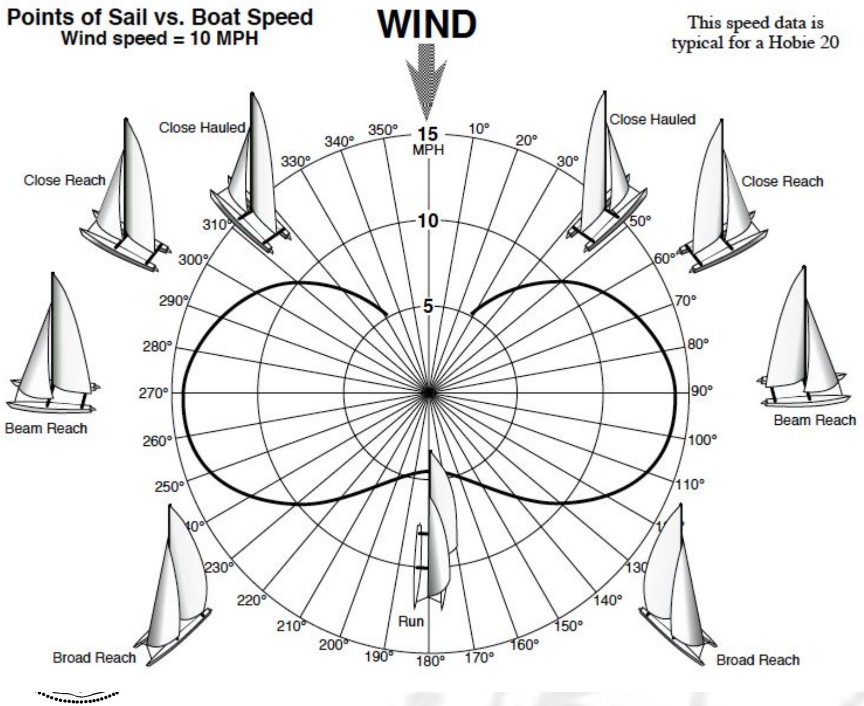



Boat Wind Heading
Heading [deg]
Time [minutes]
Measured Wind Heading
Heading [deg]
Time [minutes]
Apparent Wind Heading
Heading [deg]
Time [minutes]
True Wind Heading
Heading [deg]
Time [minutes]



Boat Wind Speed
Speed [kn]
Time [minutes]
Apparent Wind Speed
Speed [kn]
Time [minutes]
True Wind Speed
Speed [kn]
Time [minutes]

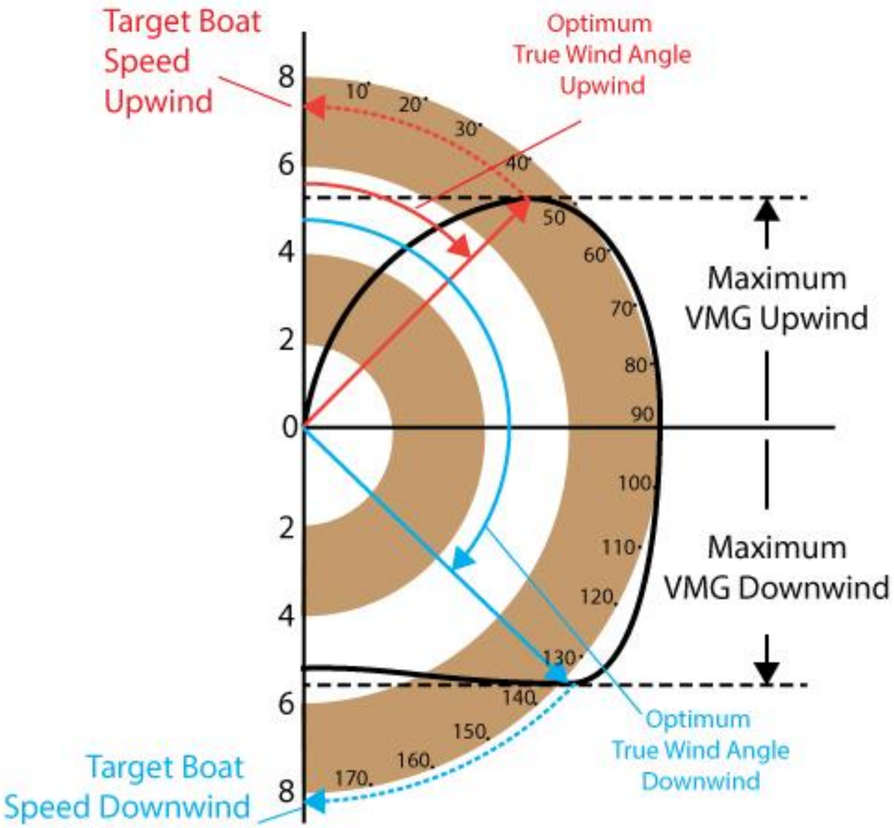
Polar Speeds of Points of Sail



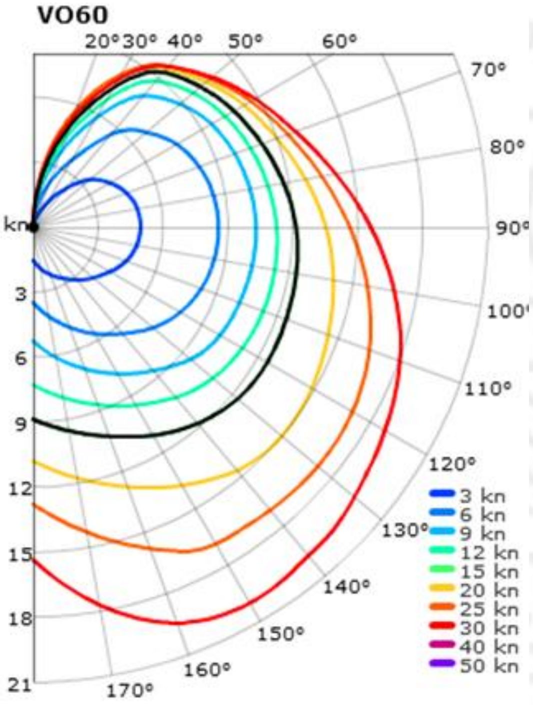
[2]

- **P**oint **O**f **S**ail **-** boat's direction relative to true wind direction
- **V**elocity **M**ade **G**ood - speed of boat upwind or downwind

Polar Speed Plot Examples

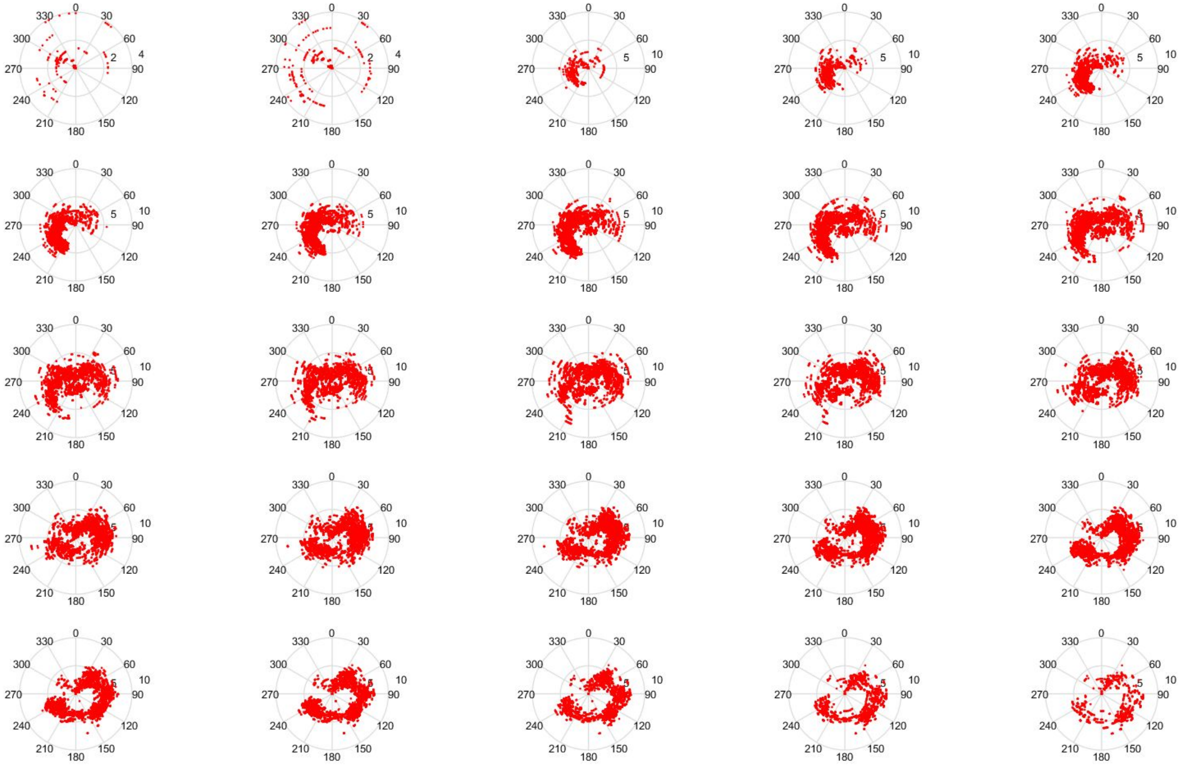


[3]



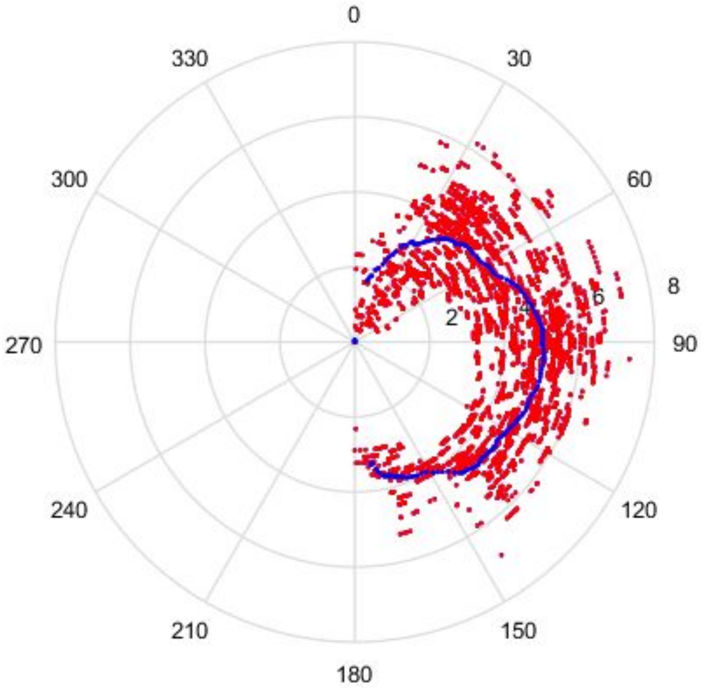
[2]

Polar Speed Analysis



- Wind Speeds grouped around Δ threshold
- Corresponding speeds plotted vs POS headings

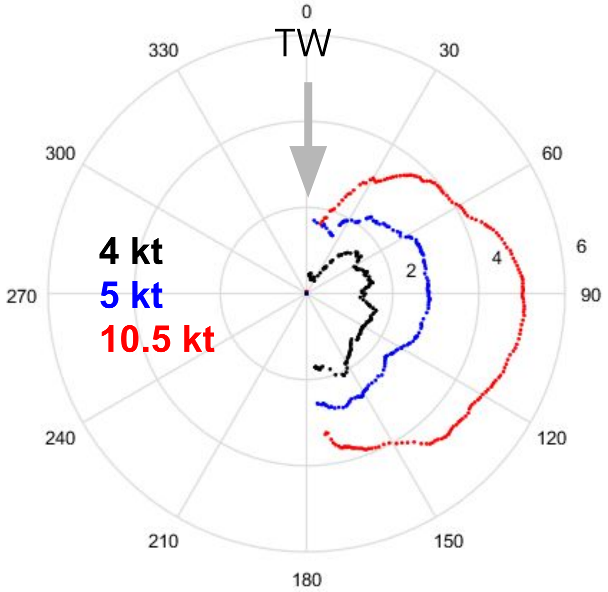
Polar Speed Results



- Chosen group of data based on wind speed conditions and likeness to common polar plot form

- Corresponding **True Wind Speed** = 10.48 kt

Polar Speed Results



10.5 kt Results:

- SOG max = 5.1kts at Beam Reach 95°
- VMG Upwind 2.75 kts at 41°
- VMG Downwind 3.63 kts at 159°

Future Work

- Refine IMU roll/pitch data correction
- Obtain reliable tilt-compensated magnetic heading
- Review and refine mobile application's optimal trajectory methods
- Condense sensor packages into marketable product

Questions?

References

1. http://www.ockam.com/2013/05/15/true-wind/
2. https://www.nauticed.org/sailing-blog/sailboat-speed-versus-sailing-angle/
3. https://www.nauticed.org/sailing-blog/how-do-polar-plots-work-on-a-sailboat/