

# Autopilots – Care & Feeding

## SHTP 2014



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# Autopilot near Full Time Operation are Key

## Priorities:

- Reliability & Robustness
- Redundancy
- Performance
- Power consumption



# AP Failure Mechanism's

- Tiller pilots
  - Water intrusion at the push rod seal. COVER – simple sleeve is all you need.
  - Condensation from cold, moist air drips onto internal components within the case
- Tiller wands (X5):
  - Water intrusion (see above).
  - Spring clip failure (Red Sky, Wet Su, others) causes pushrod to fall out and can be lost overboard. Tension threaded rod daily. Before departure take it apart and confirm spring clip is in good shape.
  - Motor brush failures
- Tiller attachment pins can break or pull out of wood tillers, welded pins can snap.
  - Attach two pins to tiller. Bring spares. Shorten pin by building up with epoxy or Welding pins.
- Below deck units: 100's of lbs of force are generated for up to 2 million rudder cycles (est).
  - A type 1 hydraulic pump can generate ~700 PSI on a 1 sq inch cylinder.
  - Attachment points delaminate from fiber glassed regions of hull. Consider thru bolted mounts.
  - Mounting brackets work loose or crack and fail.
  - Attachment point: Thin hull regions can oil can under load: Secure to structural features of hull or stiffen area.
  - Drive motor/pump fails due to bad brushes. (~ 9000 ocean miles on RM Type 1 pump prior to fail).
  - Linear Drives – motor and gears that disintegrate.

# Failure Mechanism's (cont)

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    - Linear Drives – motor and gears that disintegrate.
- Control head failures
- Compass failures – Raymarine often reported.
- Computer failures
- Electrical connection failures.

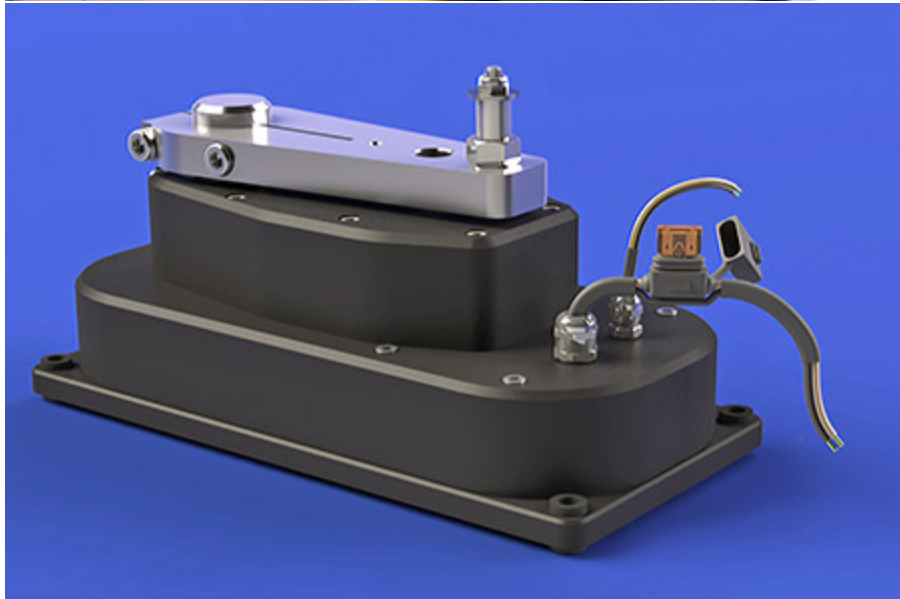
# Redundancy

- Different Styles:
  - Flight Risk: French to port / English to starboard (NKE & B&G).
  - Green Buffalo: Two Alpha's, one as parts.
  - 101: B&G and ST 2000
  - Redsky: X5 & DIY Brains, Hydraulics, Tiller Drive, two ST2000's, a BMW car window winder motor.
  - Slacker: X5, ST2000.
  - Windvane + tracker saved the unmanned Bella Bartok
  - Many other variants driven by cost and instrument family.

# Rudder Drive System and Load

- An autopilot is no better than the response time of the helm – choose the appropriate drive.
  - Hydraulics are very robust and fast if properly sized.
  - Electrics can achieve similar results with good actuator design.
- Low dynamic boats (long keel) don't require as much rudder response as high dynamic vessels (fin keel)
- Boats with large rudder loads should consider up sizing the drive from the recommendations. Express 27's not so much.
- Pick a solution that can drive your rudder 30 deg in less than 4 secs in moderate conditions with a kite up. This is what most AP electronics are expecting.

# Above and Below deck Drives



# Fluxgate Compass Modules

- Mechanical Gimbal swings a electromagnetic toroid in 2 axis (pitch and roll).
- Small signals are decoded at the brain box to determine compass heading.
- Gimbal is slow to react to motion and results in brief heading error.
- Insensitive to vibration, temperature.



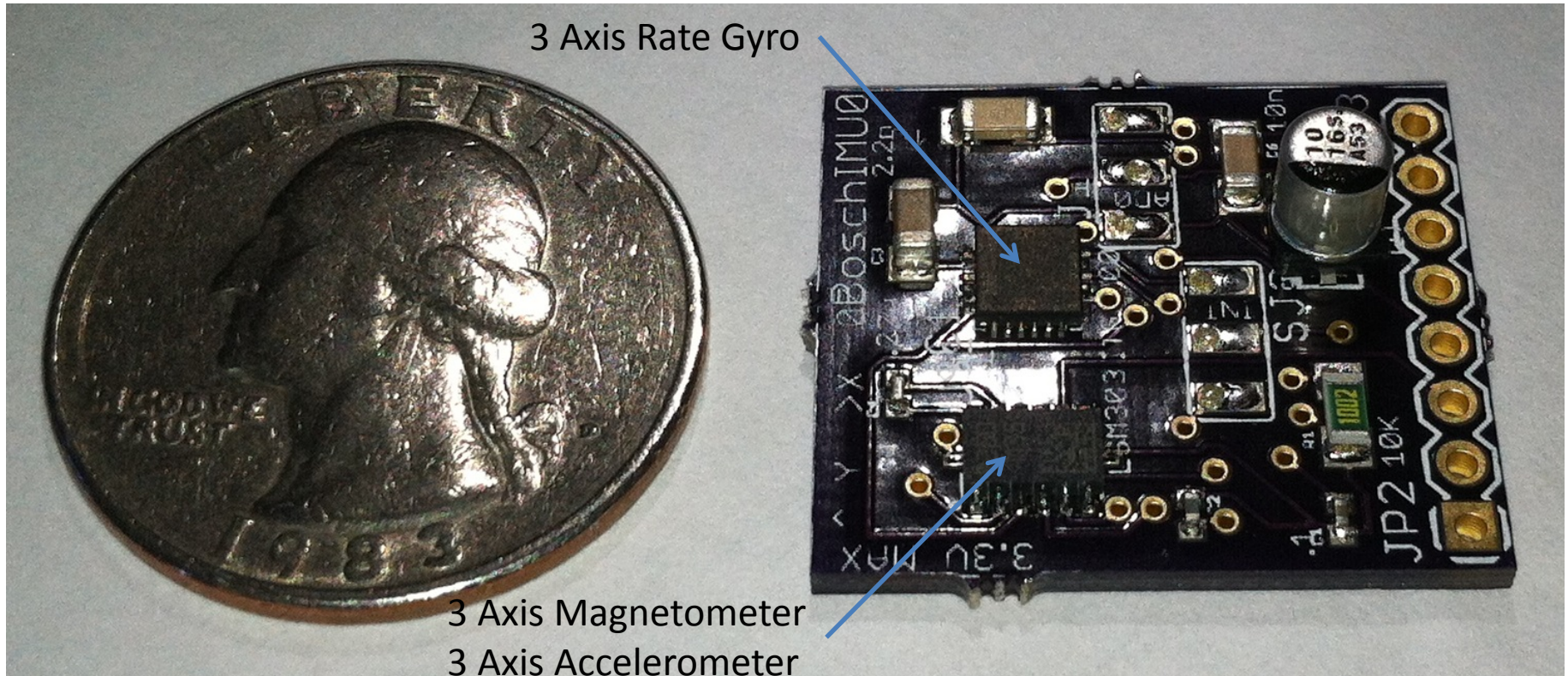
Gimbaled fluxgate  
(RayMarine)





# Micro Sensor (MEMS) based Compass & Gyro

- Use micro vibrating elements etched in silicon integrated circuits.
- Vibration sensitivity results in delay in heading computation.
- Rate gyros, low noise but drift and are temperature sensitive.
- Used together in concert with a computation engine a fast compass can be implemented



# Rate Gyro vs Compass Only (ST4000 vs X5 in RayM Terms)

Issue	No Gyro	Rate Gyro
Gust/Wave Turns Boat	Compass slowly reacts to course	Detects near instantaneous bow turn (yaw).
Course Recovery	Degrades with increasing course error as size of disturbance grows.	Course is corrected much sooner. Degrades in more extreme conditions.
Rudder Responsiveness	Limits rate of recovery	Limits rate of recovery
Rudder Sensor	Mandatory	Optional in some cases

Rudder Sensors, depending on the AP software design, even if optional can enhance the performance. In the RM design rudder stalls, which cause the AP to go offline, will be Minimized.

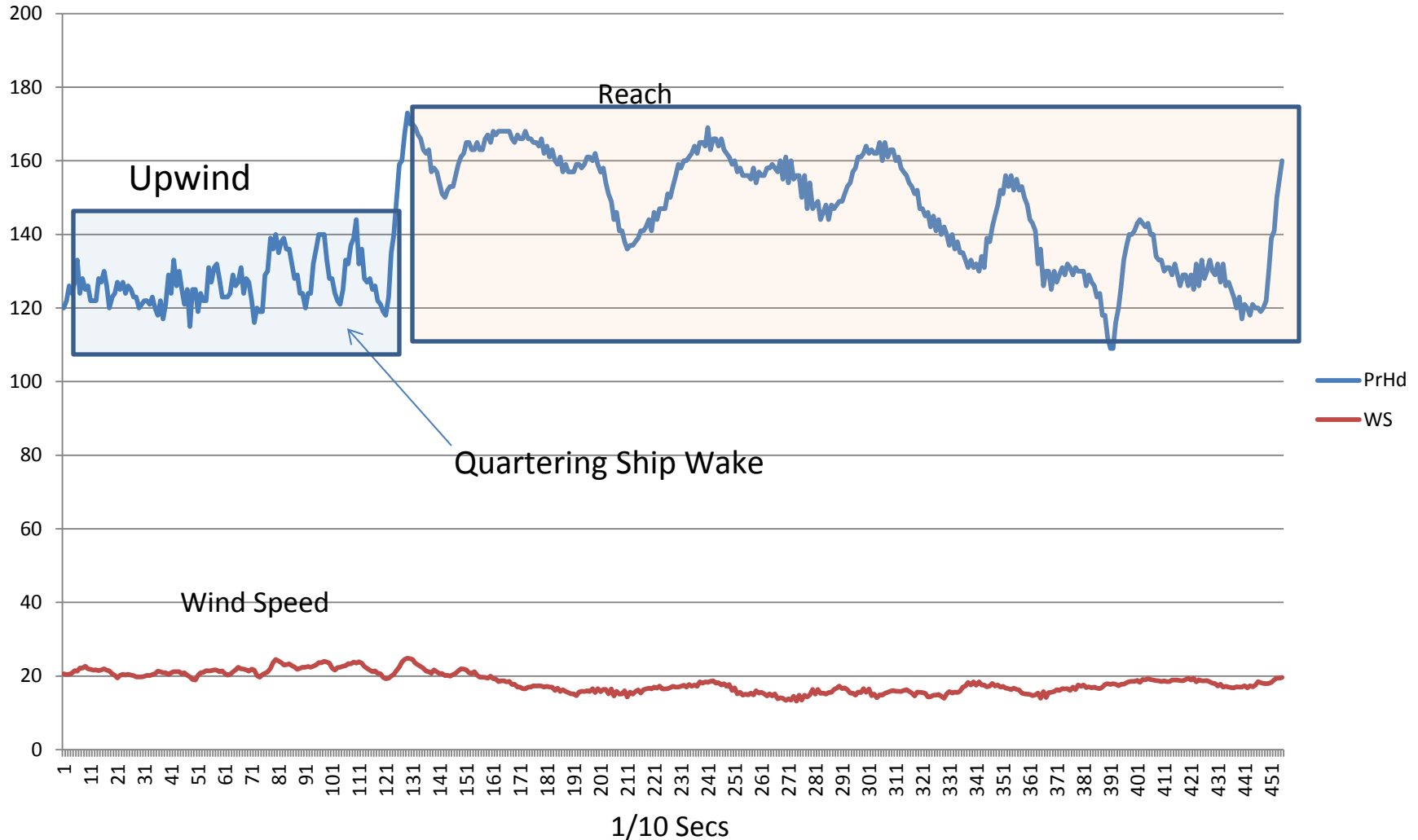
# Compass Type Characteristics

Mechanical	Fluxgate Magnetometer	Solid State 3 Axis Magnetometer
<p>Magnet to detect North. Sea State variations masked via heavy damping. Gimbal mount.</p>	<p>Uses iron oxide/ceramic core to detect magnetic field. Sea State Variations suppressed via gimble mounting with damping.</p>	<p>Uses 6 solid state sensors to measure heading. Low cost with advance of semiconductor MEMS.</p>
<p>Dynamic motion in the range of 1 to 3 secs.</p>	<p>Speed of gimble (1-3 sec) determines dynamic response to pitch and roll. Filtered to suppress dynamic error which slows response. Rate gyro's are added improve dynamics.</p>	<p>Dynamic response is slow due to filtering. 3 axis accelerometer needed for tilt compensation. Rate gyro's are added to improve dynamics.</p>
<p>Aligns with horizontal component of earth's mag. field.</p>	<p>Measures horizontal component of earth's mag. field, returning data in X and Y.</p>	<p>Measures horizontal &amp; vertical component of earth's magnetic field. <b>Sensitive to mechanical vibration.</b></p>

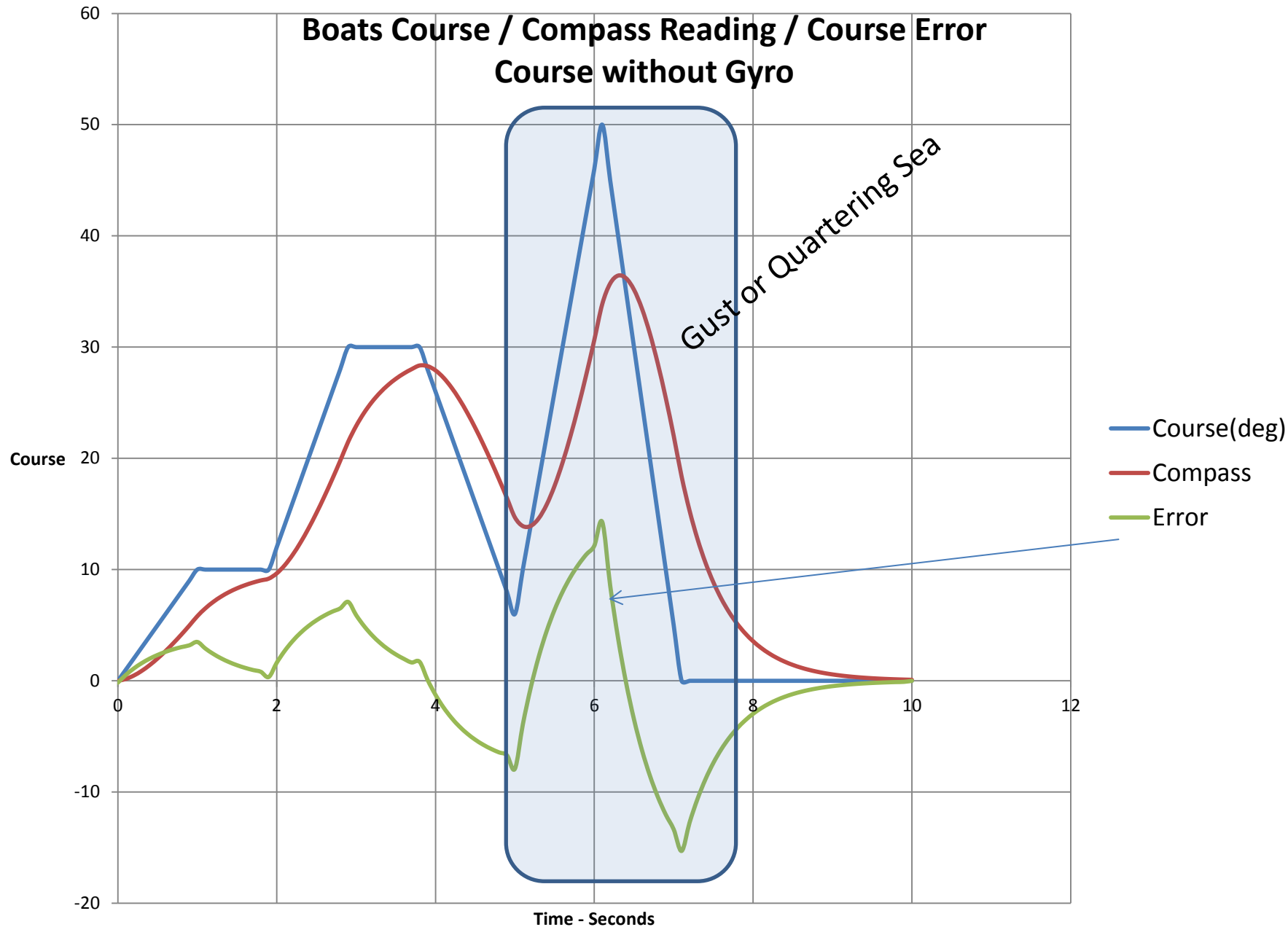
# RM X5 Upwind and Reaching

Resp = 9, Bay chop to 3'

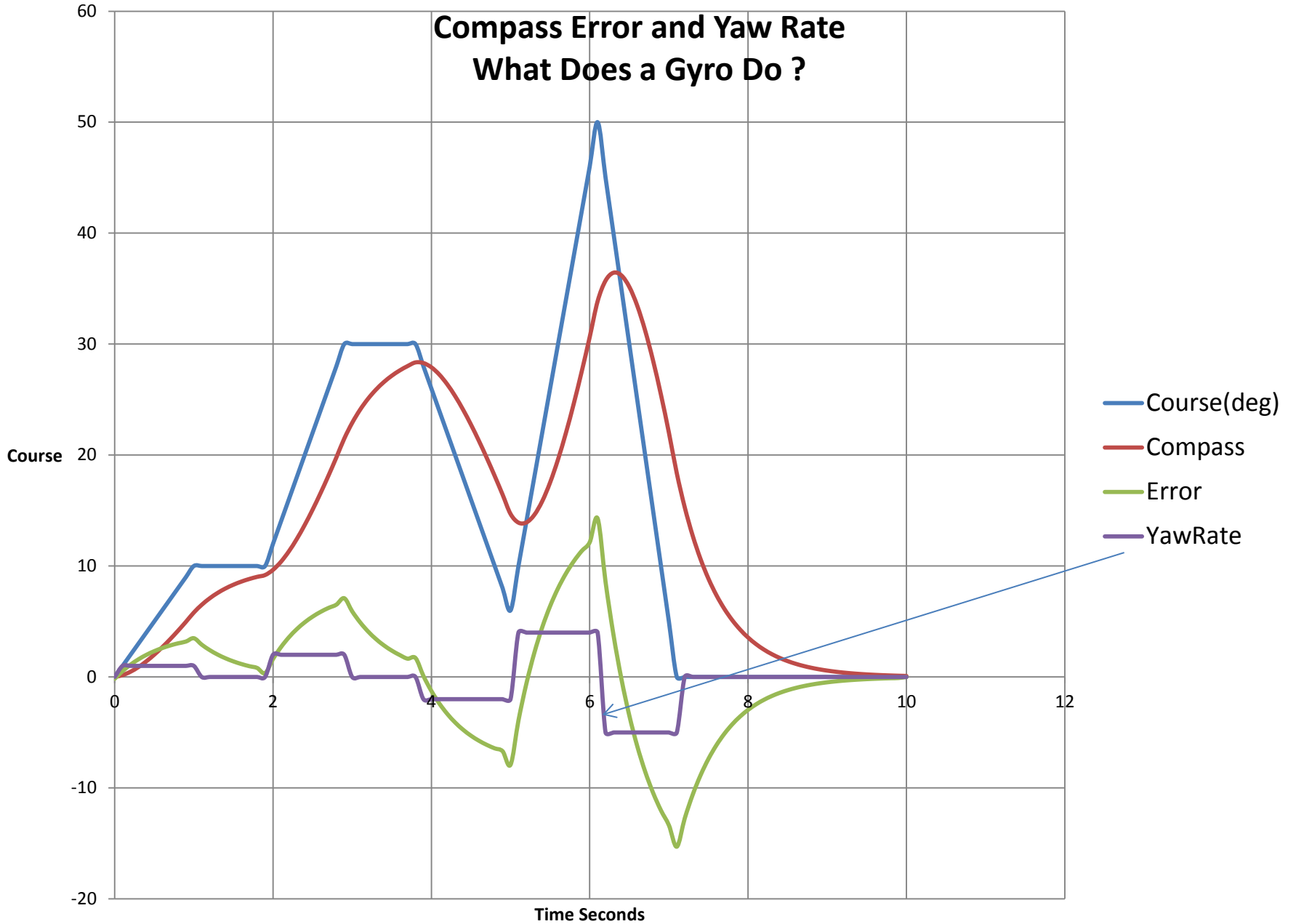
Sail = #2 Jib, Reefed Main



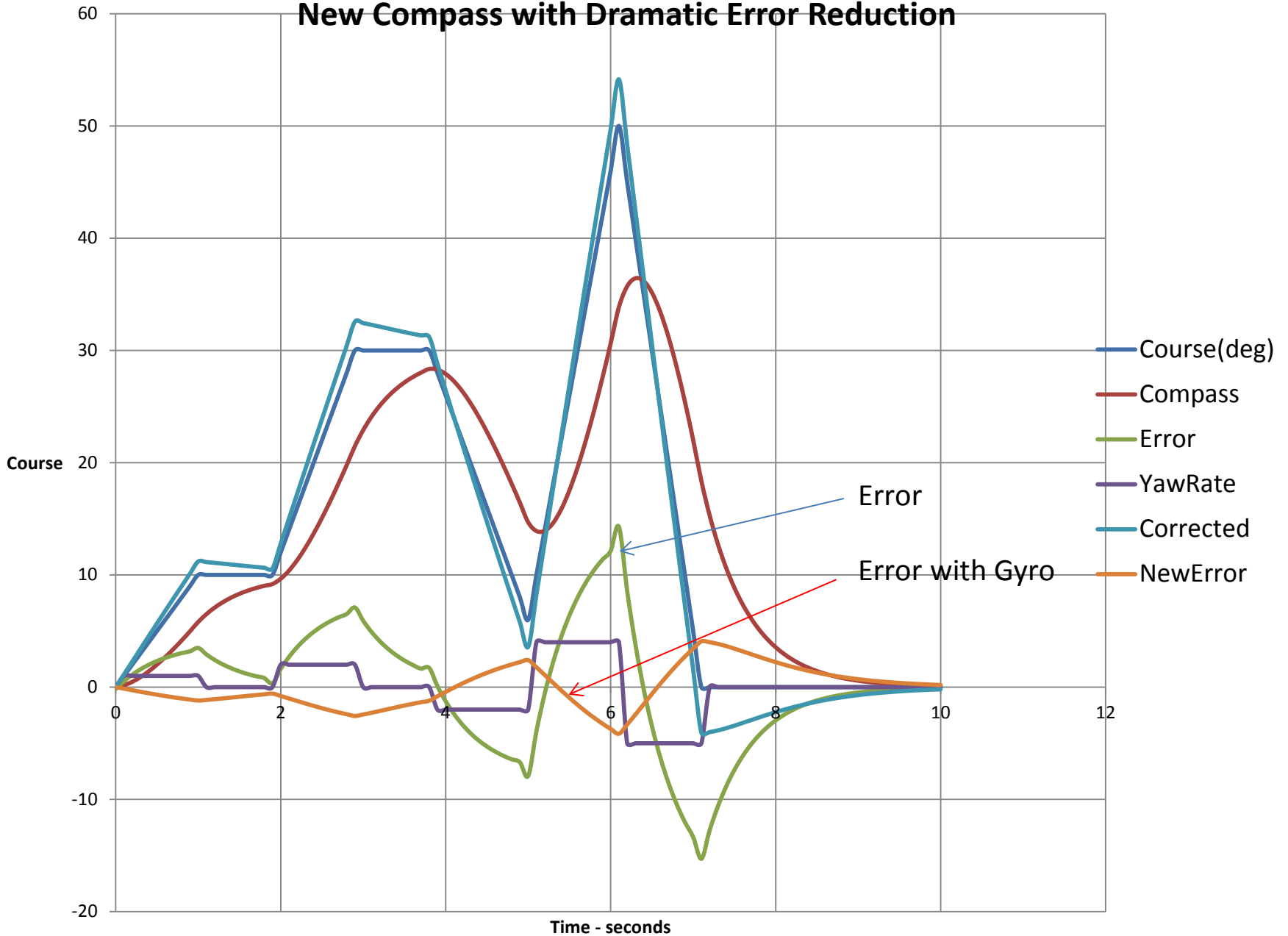
# Boats Course / Compass Reading / Course Error Course without Gyro



# Compass Error and Yaw Rate What Does a Gyro Do ?



# New Compass with Dramatic Error Reduction



# Wind Steering and Surfing

## True Wind Angle is Key

- Your Maverick's gun has nothing on your sport boat when hooking into a 20' roller with 24 kts at your back ?
- But you are tired of clinging to the lee cloth and looking straight down at the port bunk, 10 ft below you ?
- The solution, very accurate and fast wind instruments and an autopilot that can make use of the data.
  - NKE and B &G are the weapons of choice.
  - Pick the top line software upgrade and top line sensor packages.
- The key is the ability to make accurate true wind calculations.
- Placement of the instruments without wind flow interference is a challenge. AND – get the installation right !
- Lesser solutions will follow the wind but:
  - Slower wind shift and acceleration reaction times.
  - Plan on hand steering in the surfing conditions.
  - Still useful for large portions of the course (IMO).



# In Network vs Out of Network Sensors

## Network must accept Sensor data rate

- Why ? Out of network sensors can be more accurate and have a faster response time.
- Why not ? The AP brain may not be able to use data at the sensor rate.
- Airmar is a supplier that has world class accuracy and sample rates.
- Must use NMEA2000 data link for fast response.
- Check with your AP supplier to be assured you are not wasting your effort.



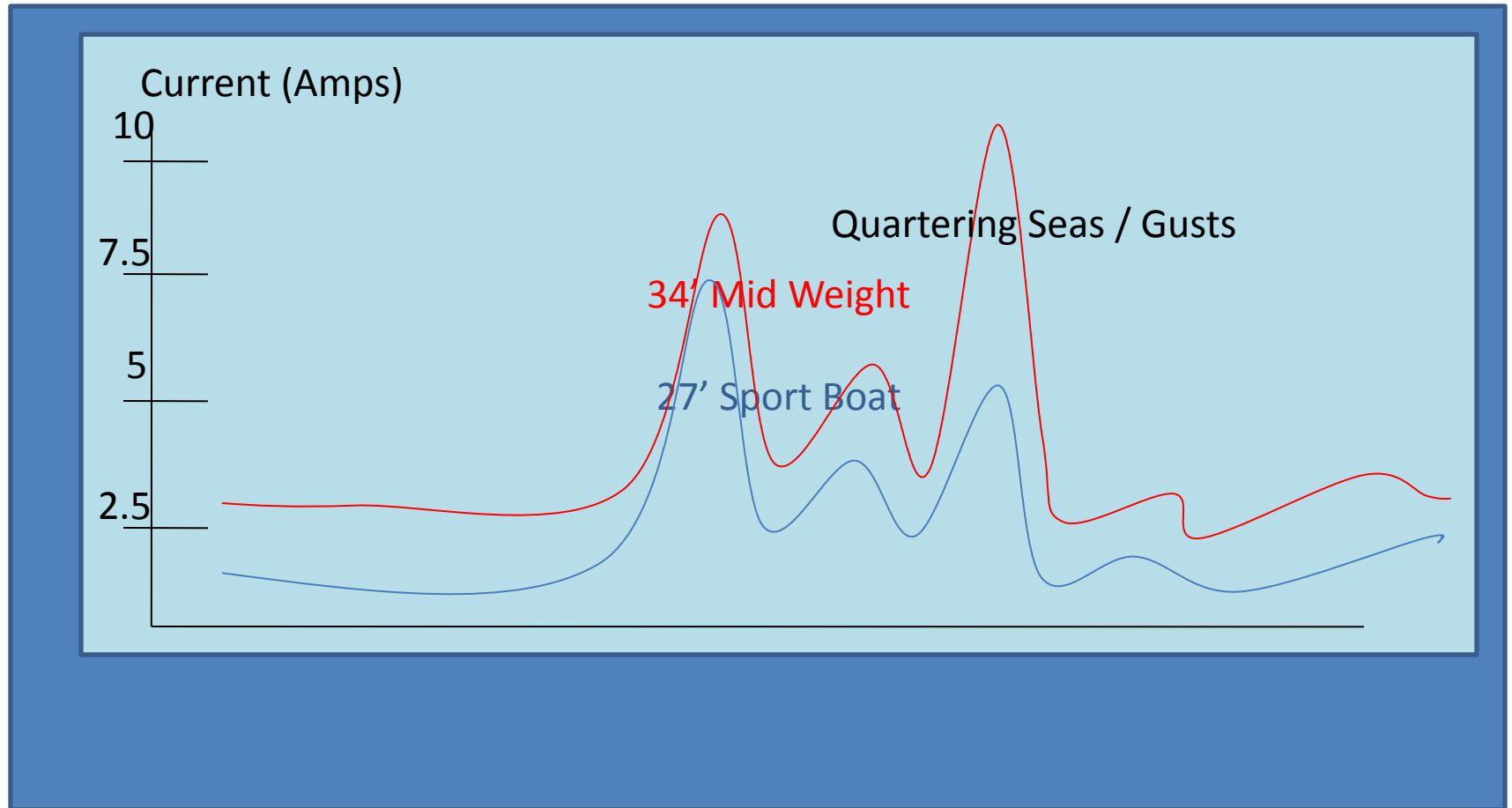
- High sample rates.
- Accuracy of wind angles = 5deg
- Accuracy of wind speeds = 10%.

# AP Power Use

- Helm load and sea state determine the power usage.
- Ignore the vendor's data, you will likely see several times the current stated in rough conditions.
- Worst case on this playing field is the first 300 to 400 miles: big winds, large seas, little sunlight.
- If you are going pure solar you have to size your battery bank to make it to the sunlight.
- Be realistic about the amount of hand steering you will do.

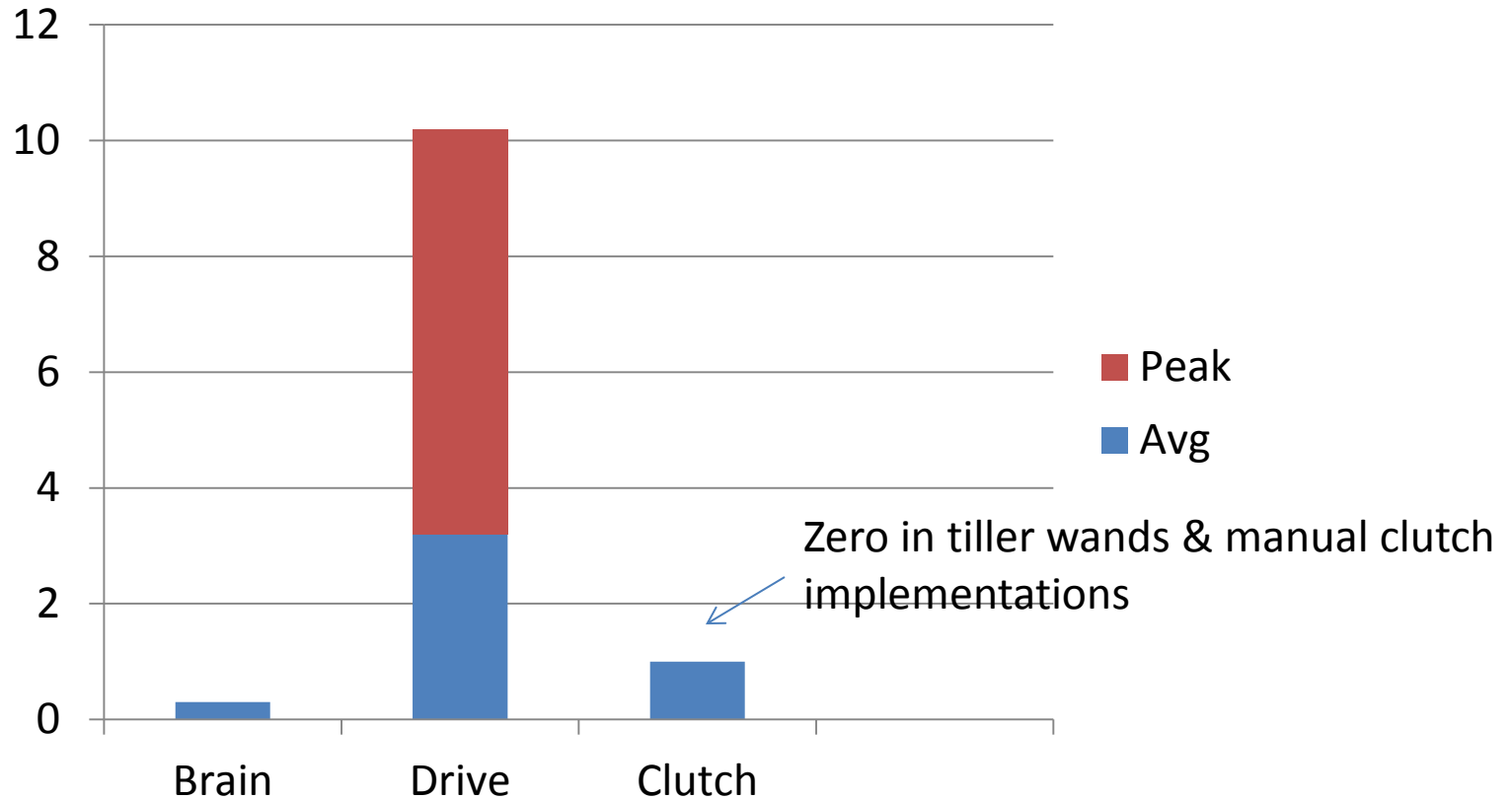
# Type 1 Typical Current Load for Hydraulics and GP Tiller Wands

(there is no such thing as a low power autopilot and your amperage will vary)



# Autopilot Current Breakdown

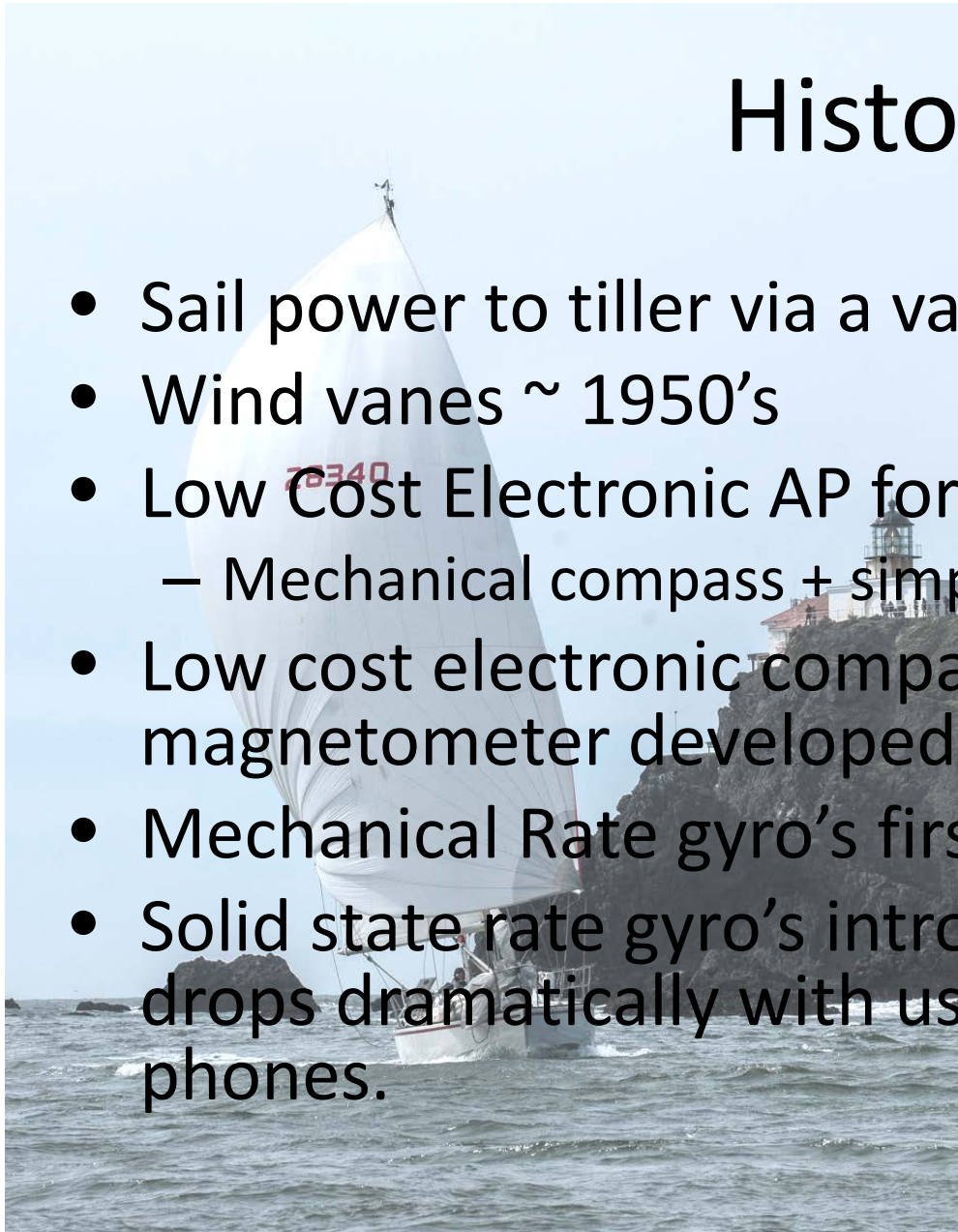
for a below deck system don't ignore clutch power





# History

- Sail power to tiller via a variety of lines/blocks
- Wind vanes ~ 1950's
- Low Cost Electronic AP for yachts ~ 1960's
  - Mechanical compass + simple electronics
- Low cost electronic compass (flux gate magnetometer developed for sub warfare) 1970's
- Mechanical Rate gyro's first used late 1990's
- Solid state rate gyro's introduced ~ 2000. Cost drops dramatically with use of sensors in cell phones.



# Wire Sizes for AP Install

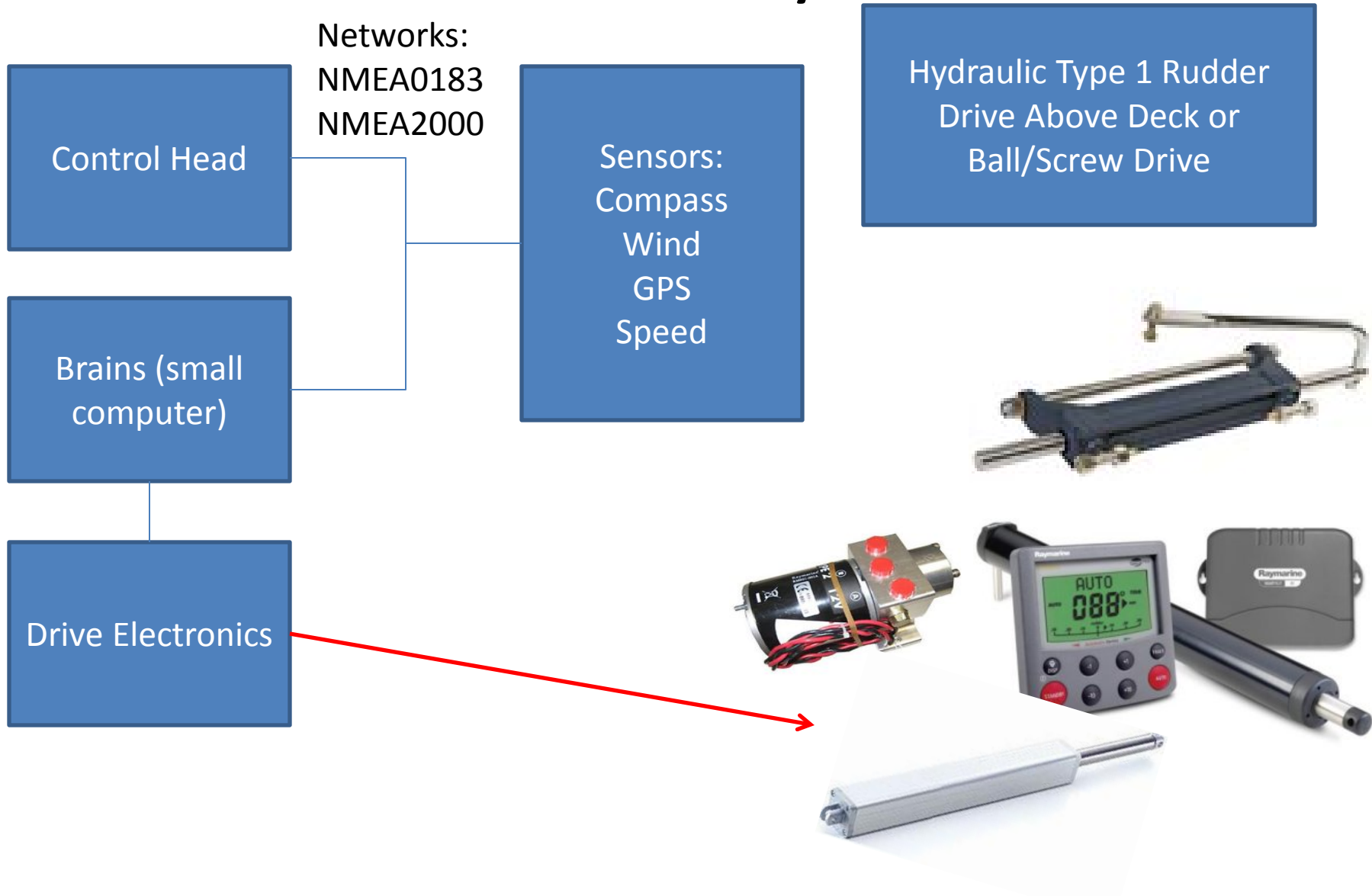
	10 amps 10' run	10 amps 20' run	20 amps 10' run	20 amps 20' run	
0.3 Volt Drop	16	14	14	12	Brains Connection **
1.0 Volt Drop	18	16	16	14	Drive Motor connection.

\*\* Assumes Brain box drives motor (Raymarine).

NKE separates' Brain power lines from motor drive power lines, use wire size table for motor drive.

WH has standalone power box (separate wire to Brain), use wire size table for motor drive .

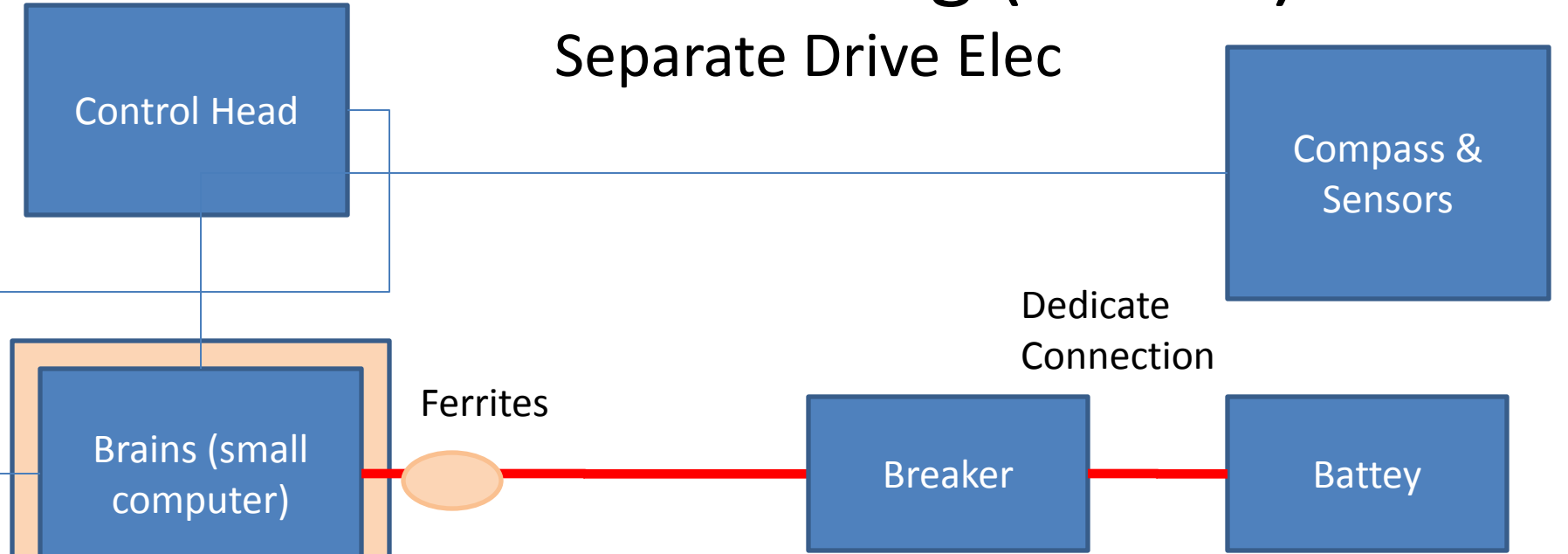
# AP Electronic Systems





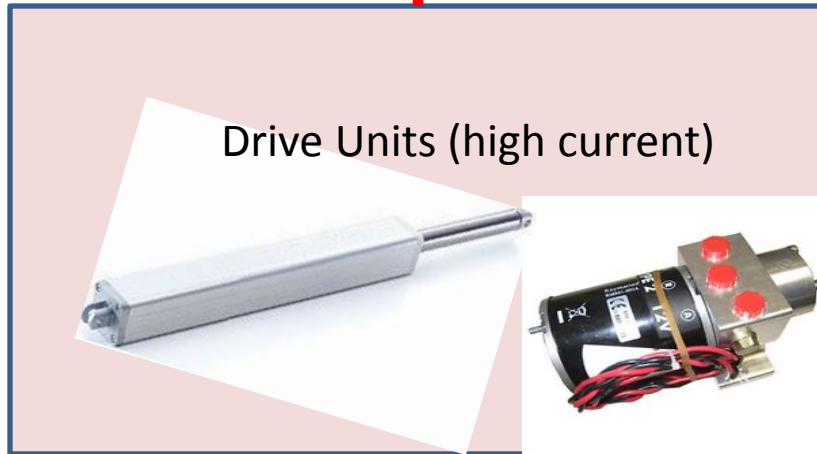
# AP Robust Wiring (RM X5)

Separate Drive Elec

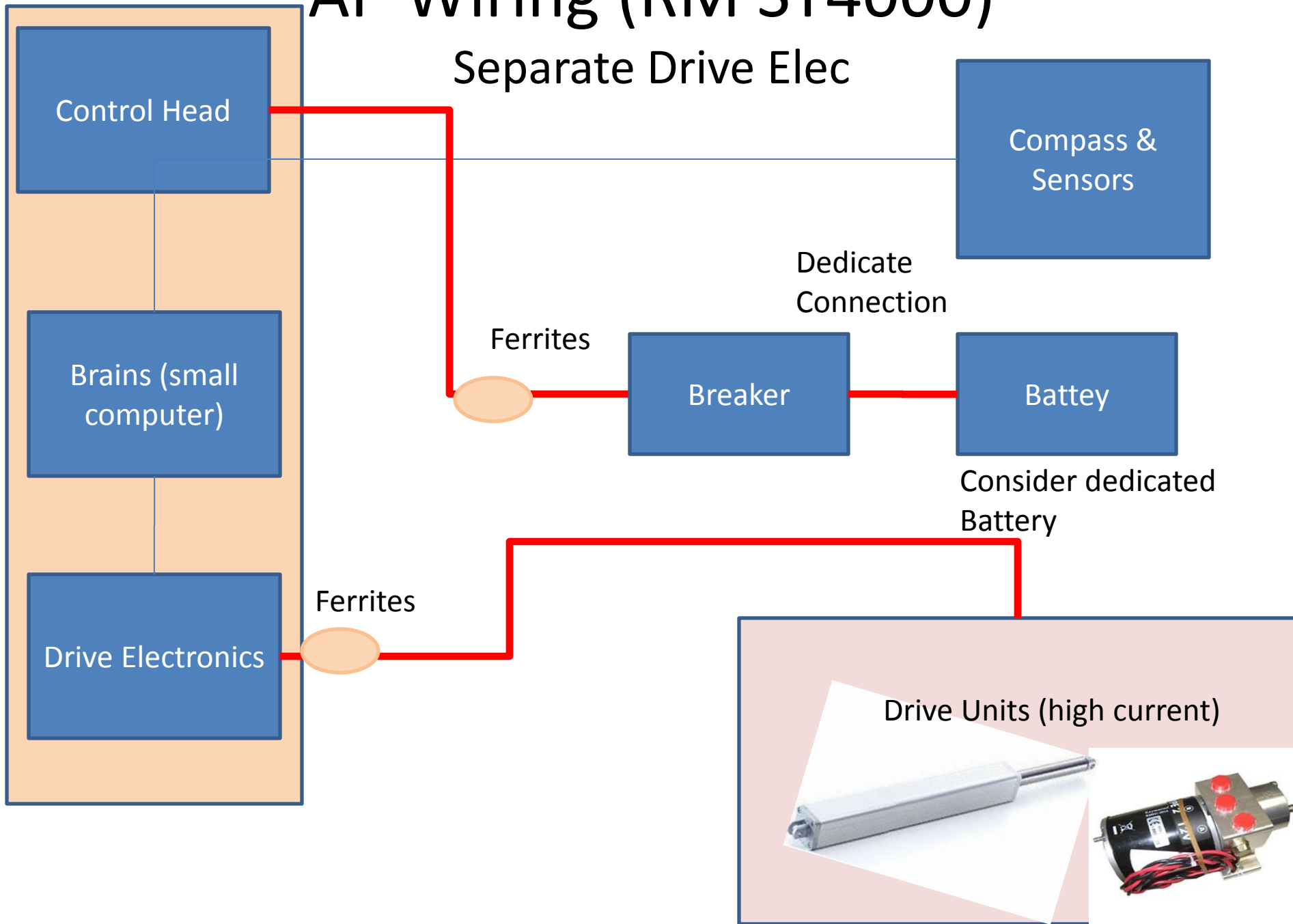


Dedicate Connection

Consider dedicated Battery

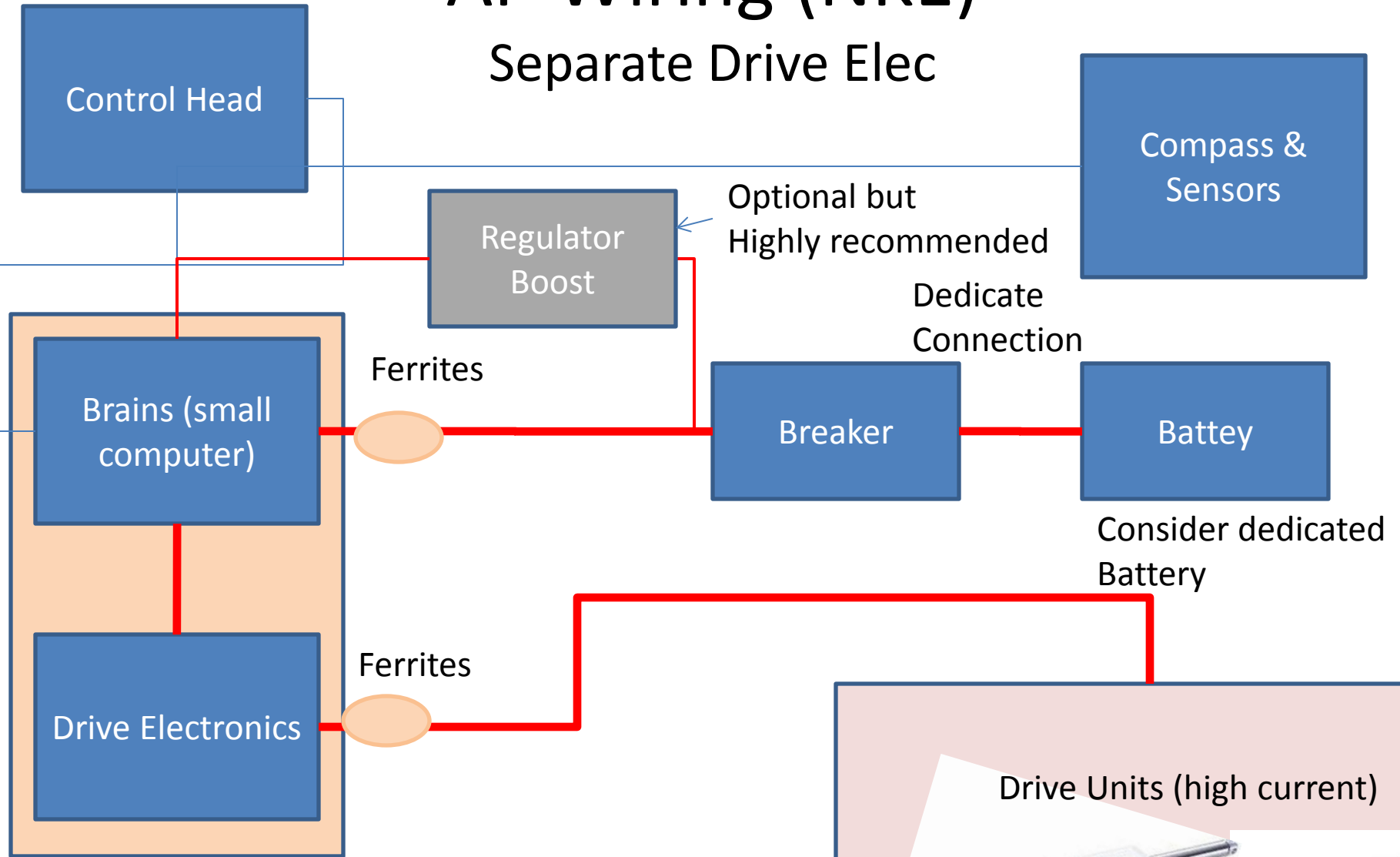


# AP Wiring (RM ST4000)



# AP Wiring (NKE)

## Separate Drive Elec



Drive Units (high current)



# Wiring & Mounting Practices

- Mount sensors in area of low vibration, avoid motor housing.
- Keep away from speakers or other magnetic devices.
  - Keep tool box far away. (missed Catalina in fog once due to wrench)
- Place near boats central axis (not critical but helps a bit).
- Motor wires run parallel and attached (twisted) to each other.
  - Keep away from compass sensor.
  - Keep away from SSB & VHF Coax.
  - Use Jesus beads (ferrite beads) on motor and compass wires.
- All boat power wires keep away from compass sensor.

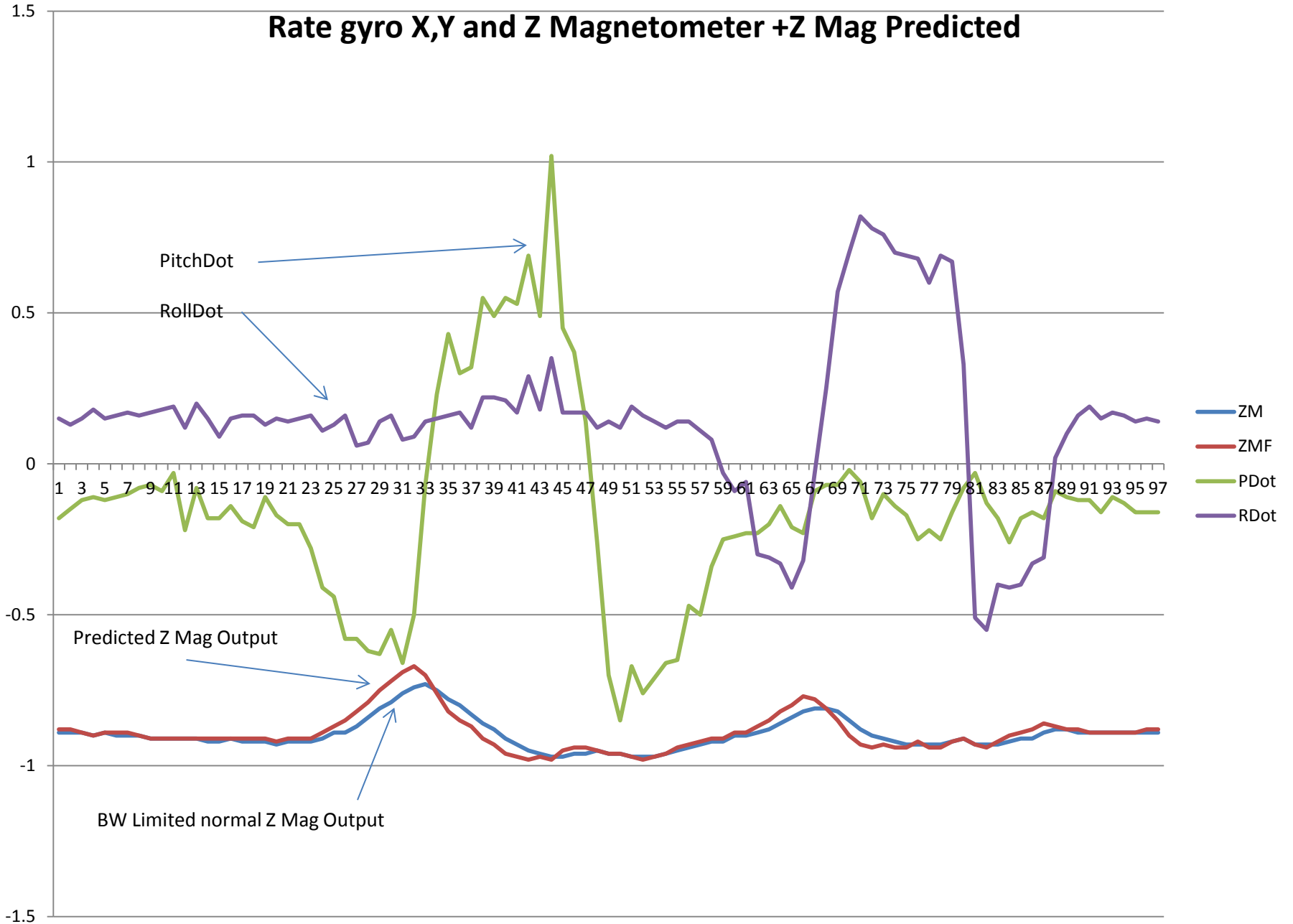
# Examples of Challenged Boats in 2012

- Warriors Wish: Moore 24, solar, B&G below deck hydraulic. Both power and installation issues that led to hand steering – 18 hours / day.
- Taz: Express 27, solar + generator backup, RM-X5. Ran batteries very low in first few days. Recovered with Honda Generator (IMO – great idea)
- Idefix: Olson 30, large solar array: Had sufficient power but just barely. SSB check ins were very brief to save energy. Once in the sun all was good. Adrian's solar array was ~230 watts, sized just right.
- Red Sky: Broke home brew electronics with wet glove on day 9. Went to X5 back up.

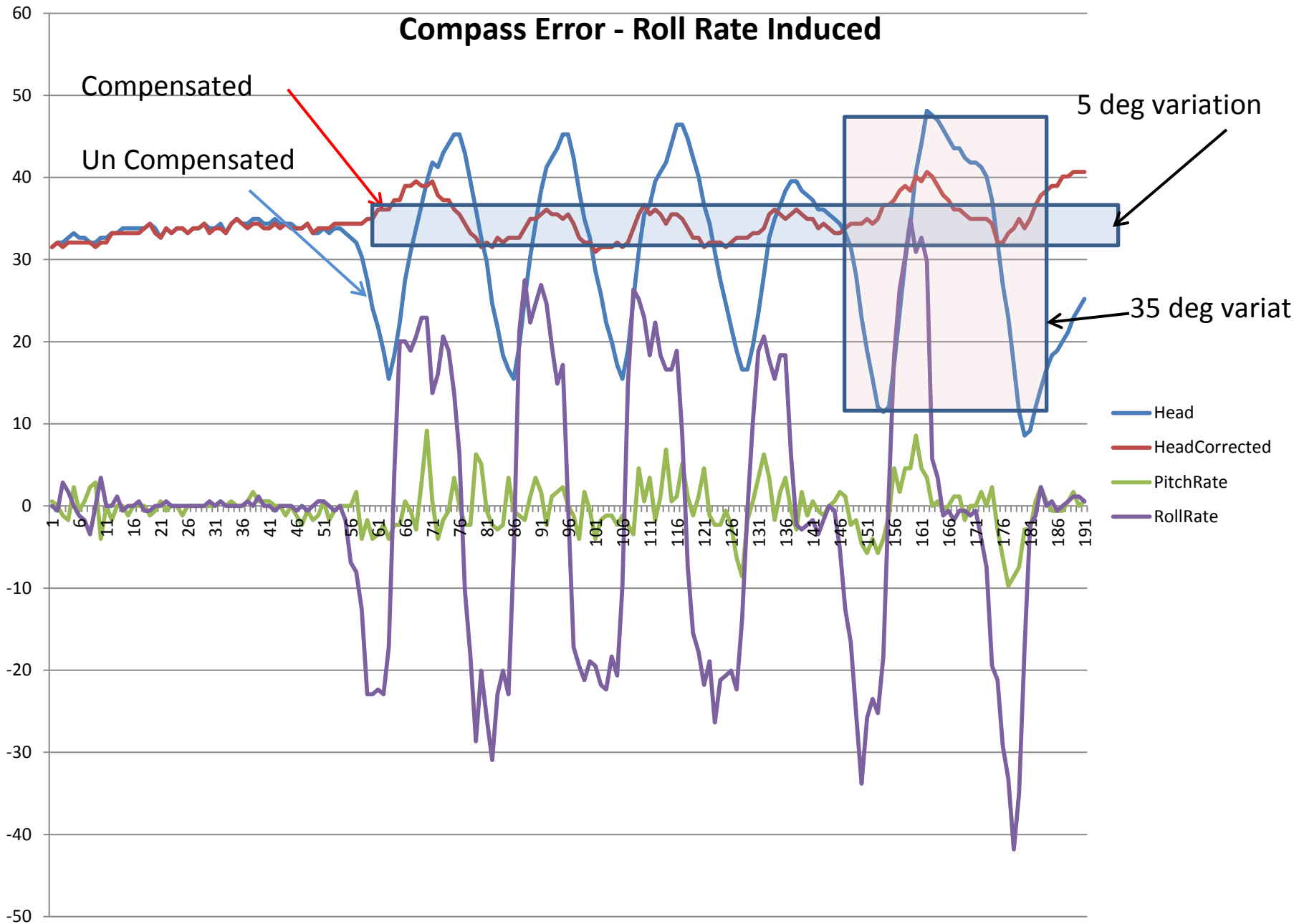
# Compass – 3 Major Types

- Mechanical compass – Chinese invention ? Uses magnet carefully balanced. Use for fung-shey, navigation by birds, bees, sea life, and lastly humans. Slow response.
- Fluxgate - electronic magnetometer with mechanical tilt compensation. Slow response to pitch and roll, simple electronics.
- MEMs Sensors – Magnetometer+Accelerometers+Rate Gyros
  - Cost reduction over fluxgate due to adoption in huge cell phone market and reduced cost of computation.

# Rate gyro X,Y and Z Magnetometer +Z Mag Predicted



# Compass Error - Roll Rate Induced

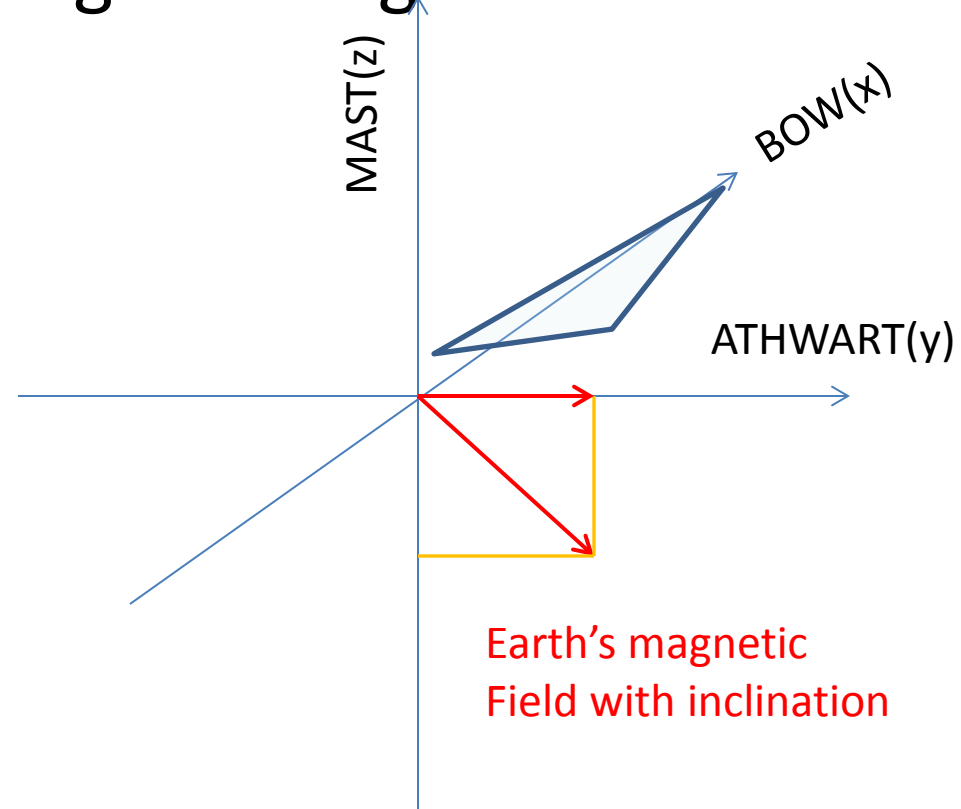




## Effect of Earth's Magnetic Field Tilt on AP Dynamic Accuracy

- Pitch and Roll disturb the compass reading.
- In mechanical mechanisms this is masked with damping (traditionally fluids).

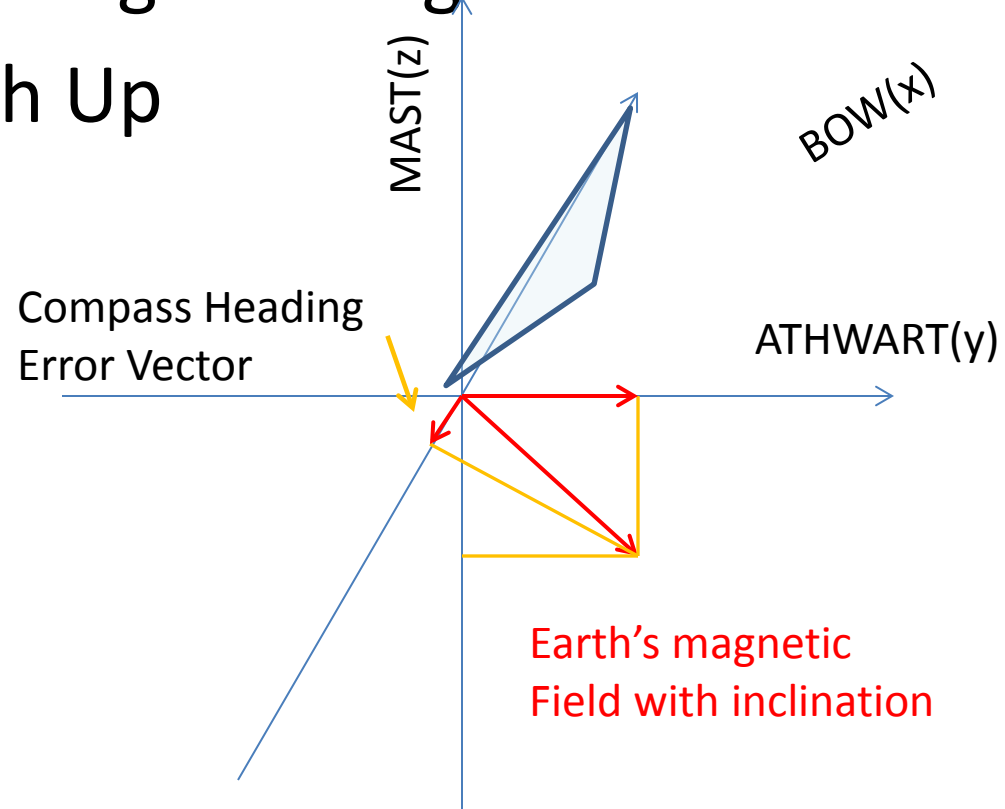
# Heading 270 Deg



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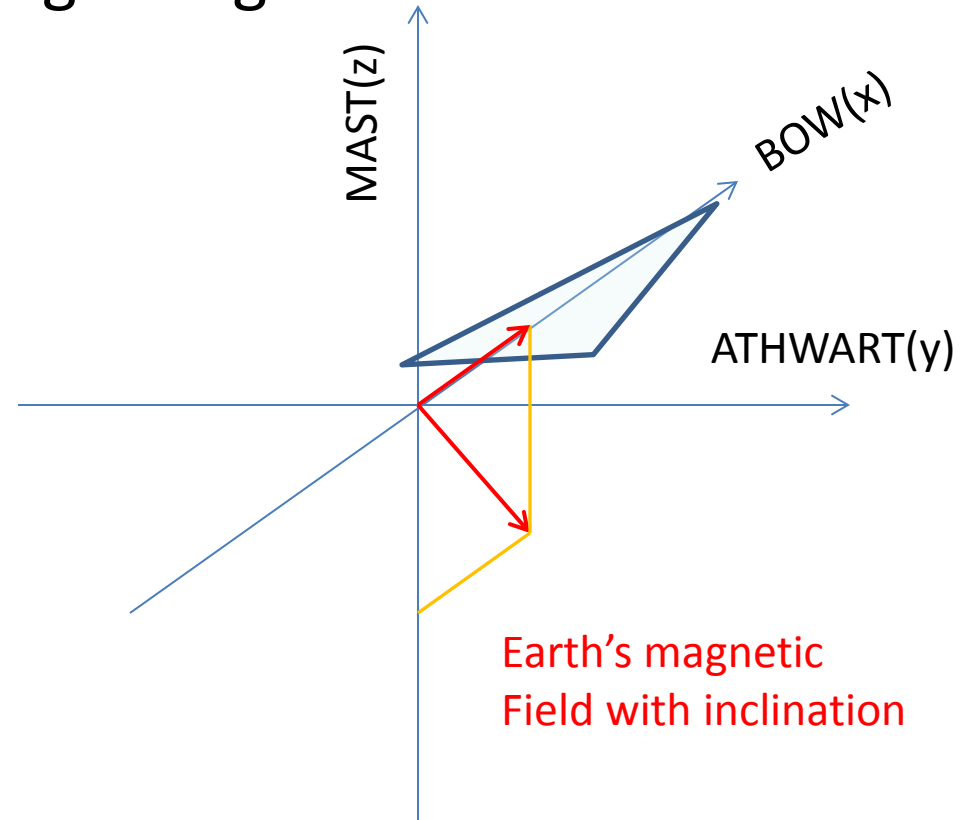
## Heading 270 Deg Pitch Up



## Effect of Earth's Magnetic Field Tilt on AP Dynamic Accuracy

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Heading 0 Deg



Earth's magnetic  
Field with inclination

## Effect of Earth's Magnetic Field Tilt on AP Dynamic Accuracy

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Heading 0 Deg  
Roll to Starboard

Compass Heading  
Error Vector

