Control

What is the DP Current?

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WORLD CLASS – through people, technology and dedication

Mathematical Vessel Model

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State variables:

u, v, r	vessel velocity surge, sway and rate of turn
u_c^E, v_c^E	current velocity north and east, assumed constant or slowly varying
x^E, y^E	vessel position north and east
ψ	vessel heading

Mathematical Vessel Model

$$\dot{u} = (M_y vr - F_{cx}(u_r, v_r) + F_{tx} + F_{wx} + F_x)/M_x$$

$$\dot{v}_r = (-M_x ur - F_{cy}(u_r, v_r) + F_{ty} + F_{wy} + F_y)/M_y$$

$$\dot{r} = (-M_c(u_r, v_r) + M_t + M_w + M)/M_\Psi$$

where

$$u_r = u - u_c \quad \text{and} \quad v_r = v - v_c$$

$$u_c = u_c^E \cos\psi + v_c^E \sin\psi$$

$$v_c = v_c^E \cos\psi - u_c^E \sin\psi$$

Relative velocity

$M_x\, M_y\, M_\psi$	vessel mass (included added mass)
$F_{cx}\, F_{cy}\, M_c$	current load (unknown)
$F_{tx}\, F_{ty}\, M_t$	resulting thruster forces (may be measured)
$F_{wx}\, F_{wy}\, M_w$	wind load (may be measured)
$F_x\, F_y\, M$	represents all other forces (unknown)

Mathematical Vessel Model

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- Two unknown variables (parameters)

  (F_{cx}, F_{cy}, M_c) - current

  (F_x, F_y, M) – others

- Not feasible to establish a mathematical model of (F_x, F_y, M)
  - neither based on simple inputs such as e.g. wave height measurements from wave radar or buoy
  - nor describing the dynamics mathematically in such a way that it can be distinguished from effects of current
  - but, (F_{cx}, F_{cy}, M_c) may be
- This means that in the context of Kalman filtering current and waves must be aggregated to a common unknown force - the "DP current"

Vessel Characteristics

Wind & Current

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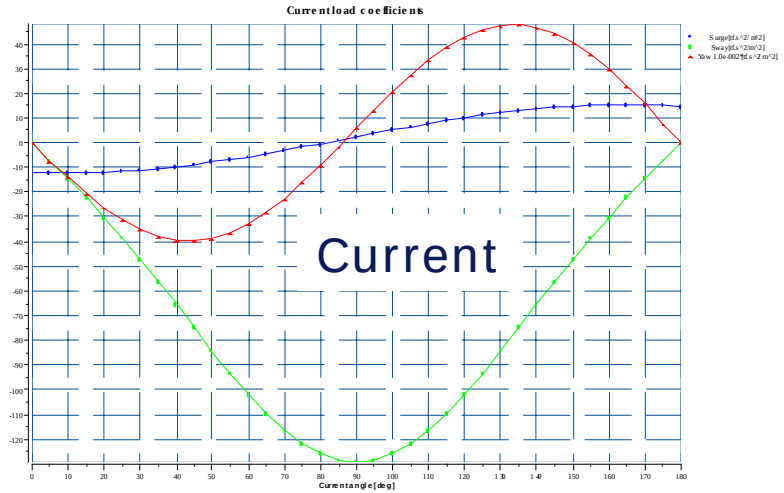
$$F_{cx}(u_r, v_r) = C_x(\alpha)(u_r^2 + v_r^2)$$

$$F_{cy}(u_r, v_r) = C_y(\alpha)(u_r^2 + v_r^2)$$

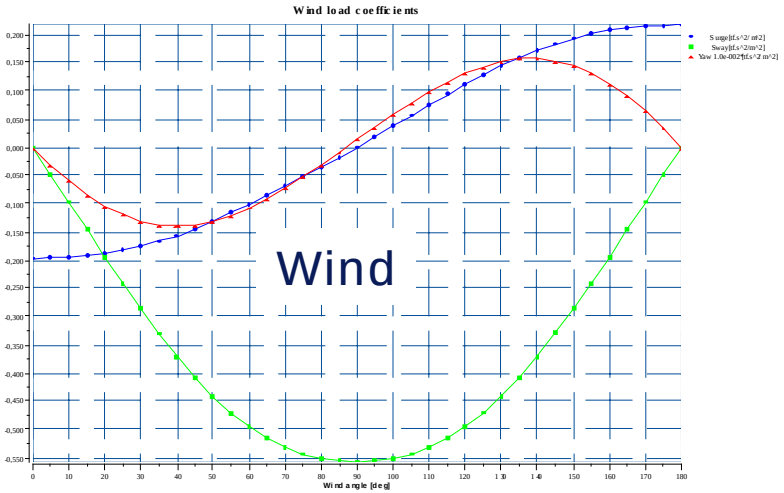
$$M_c(u_r, v_r) = C_\psi(\alpha)(u_r^2 + v_r^2)$$

$$\alpha = \tan^{-1}\left(\frac{v_r}{u_r}\right)$$

C_x , C_y and C_ψ are the force characteristics, i.e. force and moment as a function of angle of attack



Bow Angle of attack Stern



Vessel Characteristics

Wave drift

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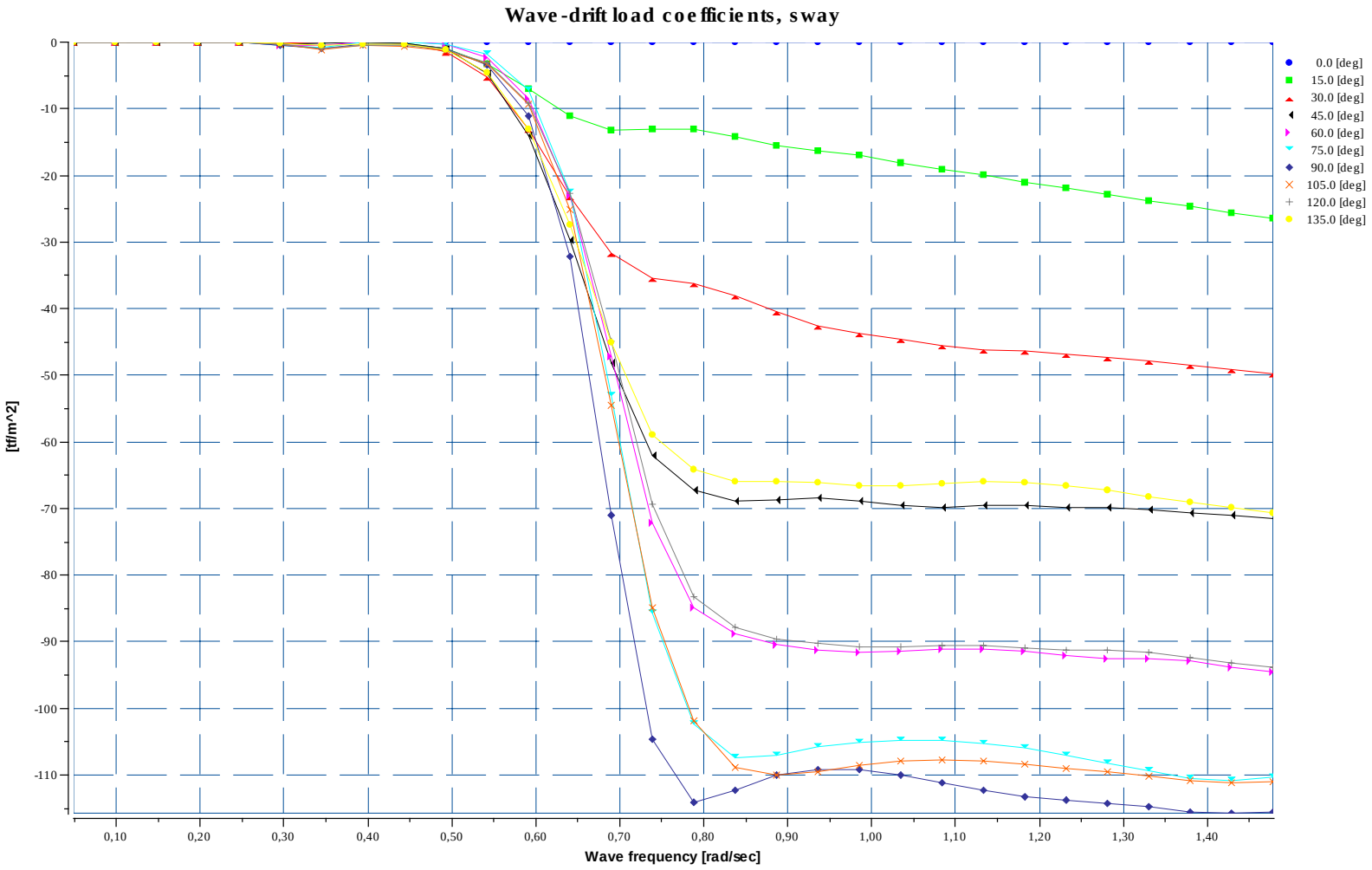

Load Conditions

wind 30 knots, current 1 knot, waves 5 m Hs

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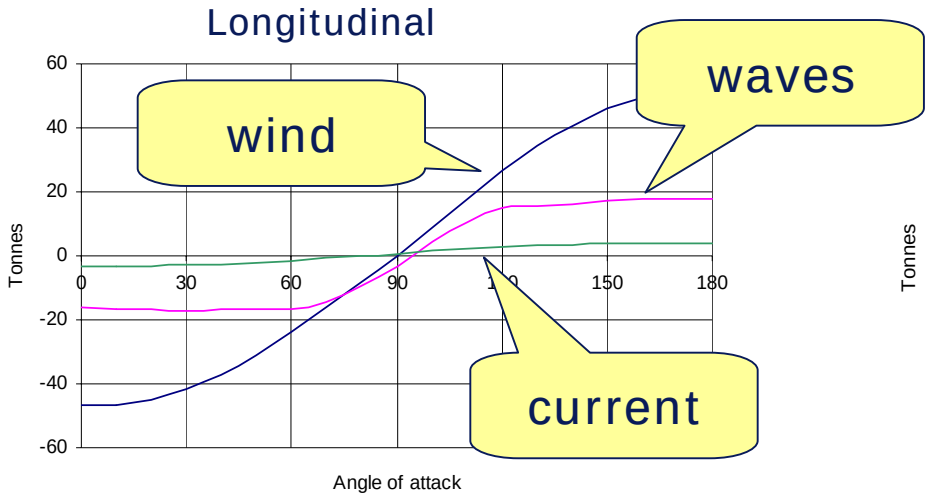
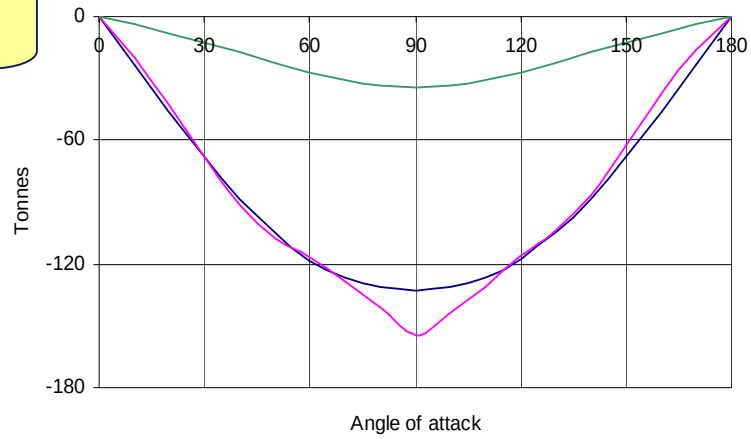
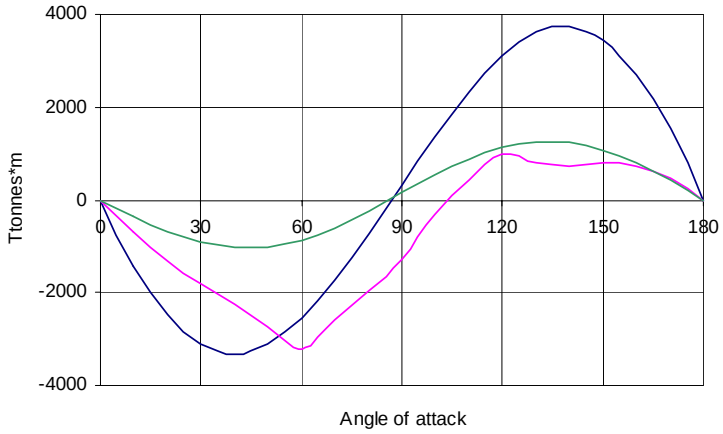
Longitudinal



Lateral



Moment



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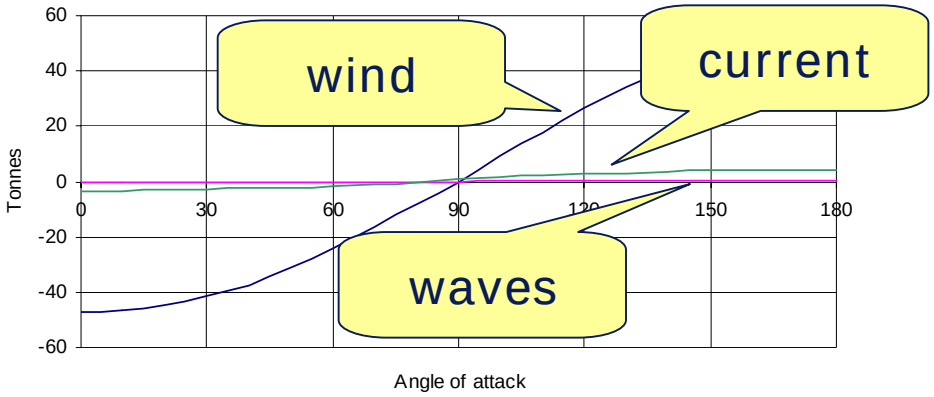
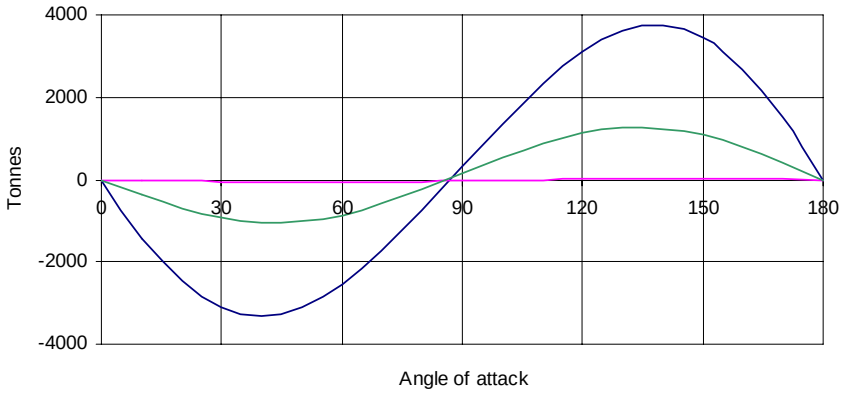
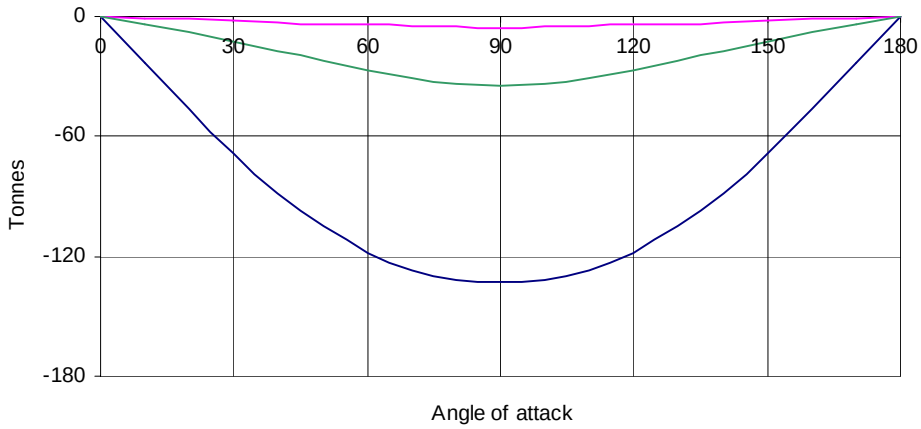


Lateral

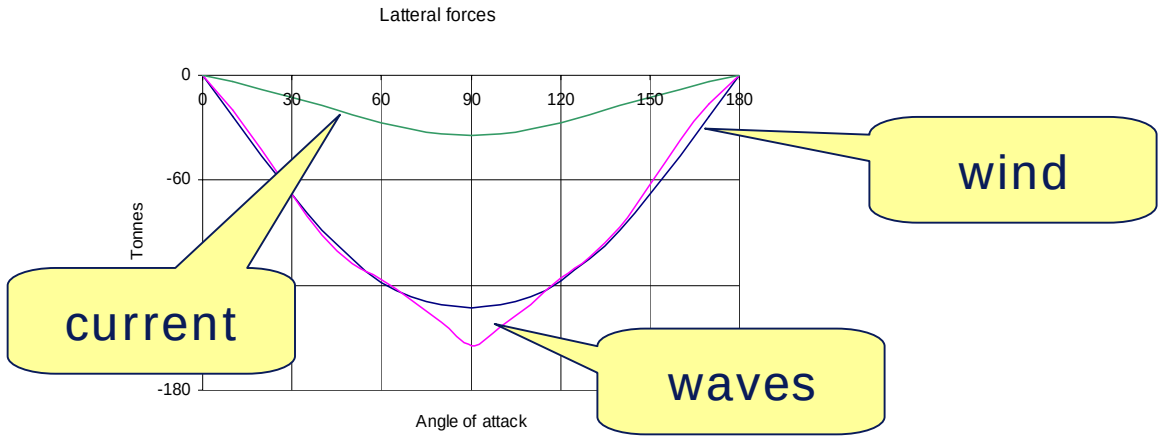


Moment



Some Observations

- The shape of current and wave characteristics is similar especially with respect to the longitudinal and lateral forces
- At high beam seas wind loads and wave loads are quite similar in strength
- At ahead sea the wave loads are modest



Discussion

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- Is the best approach just to consider forces as totally unknown without any relation to physics? I.e. just an unknown force with three independent components (F_x , F_y , M)
- Should the current load be measured?
- Should there be any relationship between these components similar to the figures shown?
- How reliable are the load characteristics? Would the use of such relations introduce principal incorrect couplings between the different degrees of freedom?
- There may be two approaches; assuming three totally unknown external force components, or assuming the external forces to be modelled as current load characteristics (or any other for that matter)

Advantages if load characteristics were known

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- Rotating the vessel would not affect the station keeping since we could calculate the external load at any angle of attack and compensate for it
- Moving towards or with the current would not have any impact since we could use nonlinear decoupling to virtually make the vessel move in vacuum.

- The fact is that we are not really dealing with current loads, but with residual forces not covered by inputs to our mathematical model

Modelling Errors

Thruster set-point – feedback error

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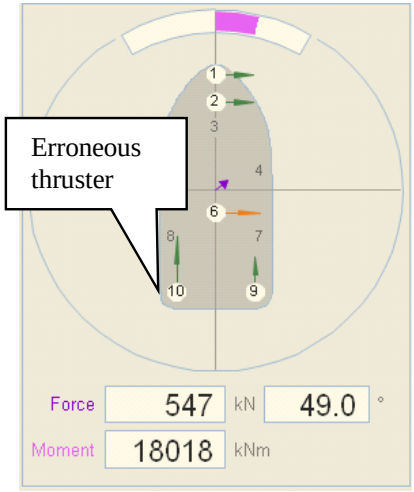
- Bias error of 25% (of full pitch) in the pitch feedback for a main propeller
- Result
  - Artificial ahead DP current of about 2.5 knots



  - The large artificial current result of the quadratic nature of drag. If there would have been a real current of 1 knot, the resulting DP current would have been below 3 knots

Modelling Errors

Wind Sensor Error

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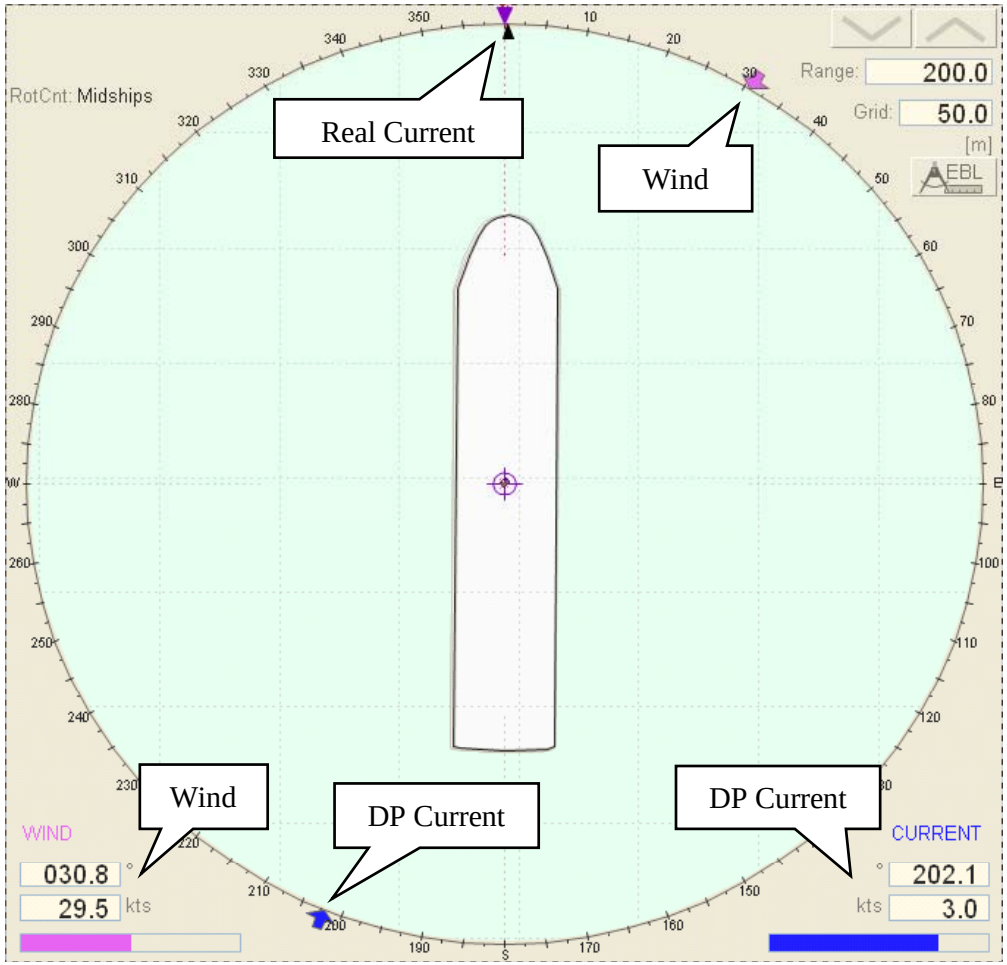
Scenario:

- Current 1 knot from 0 deg
- Wind 20 knots from 30 deg
- Scaling error 50%

Observations:

- DP current is heavily corrupted
- 3 knots from a direction almost opposite to the wind



Modelling Errors

Wave Drift Forces

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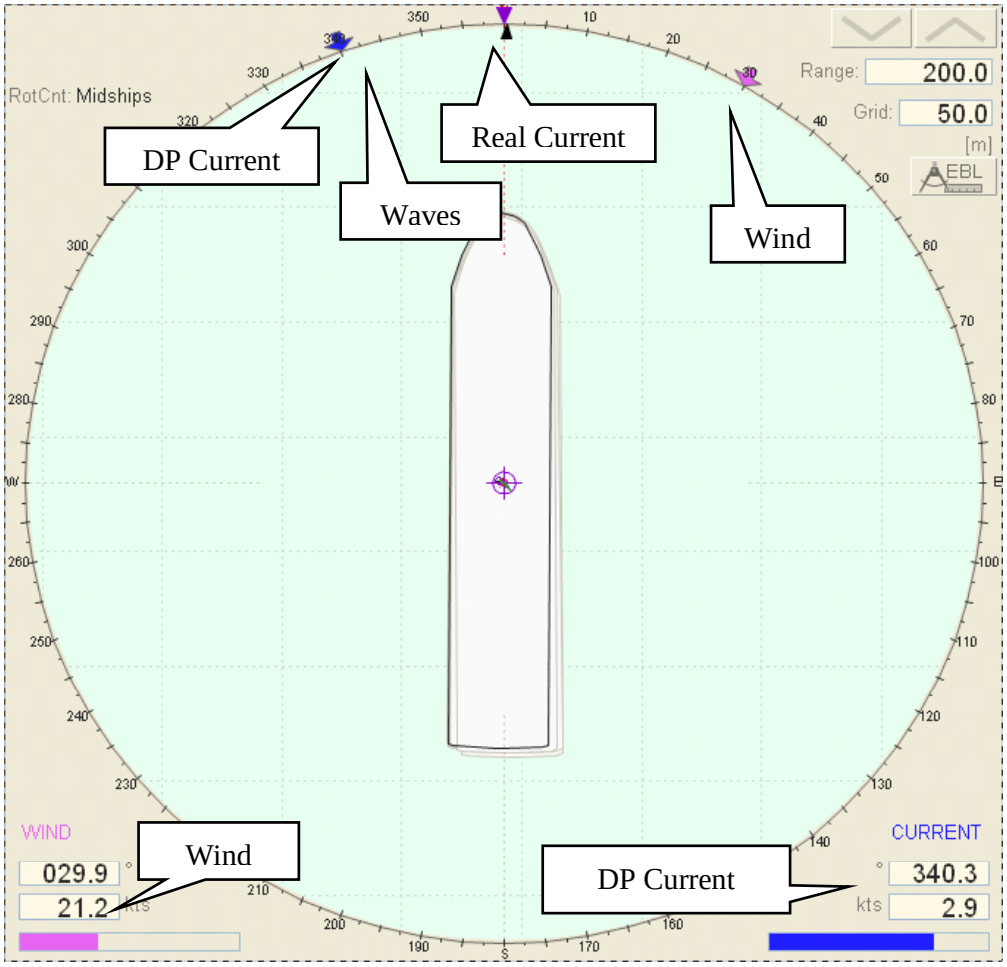
Scenario:

- Current 1 knot from 0 deg
- Wind 20 knots from 30 deg
- Waves 5 m from 345 deg

Observations:

- Current speed is overestimated (about 3 knots with direction 340 deg)



Station Keeping Capability

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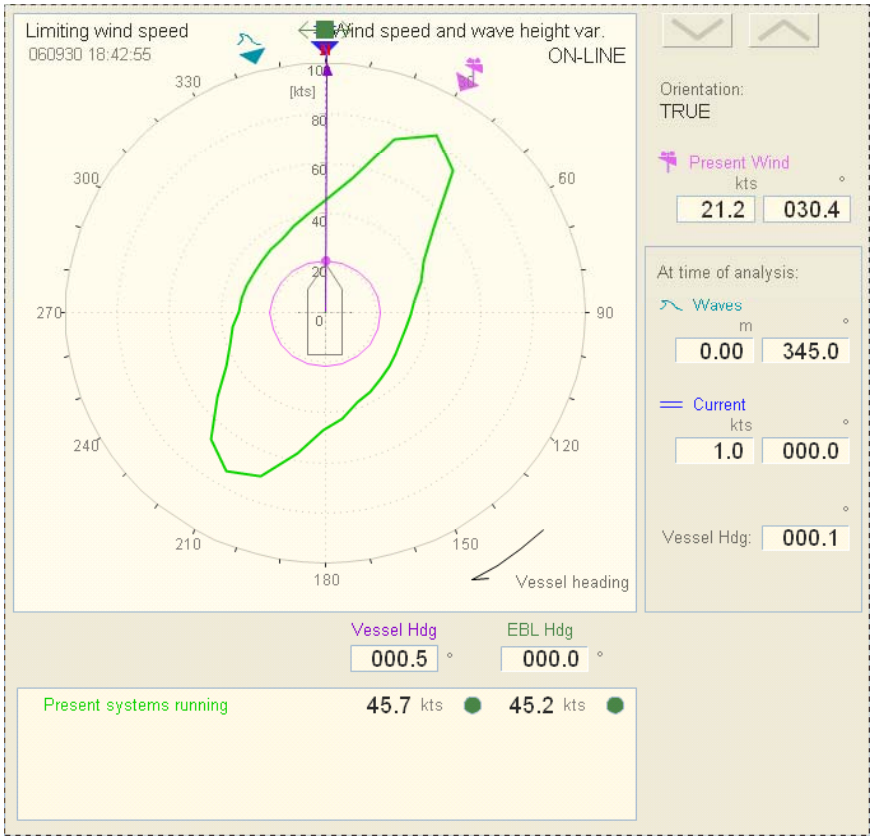
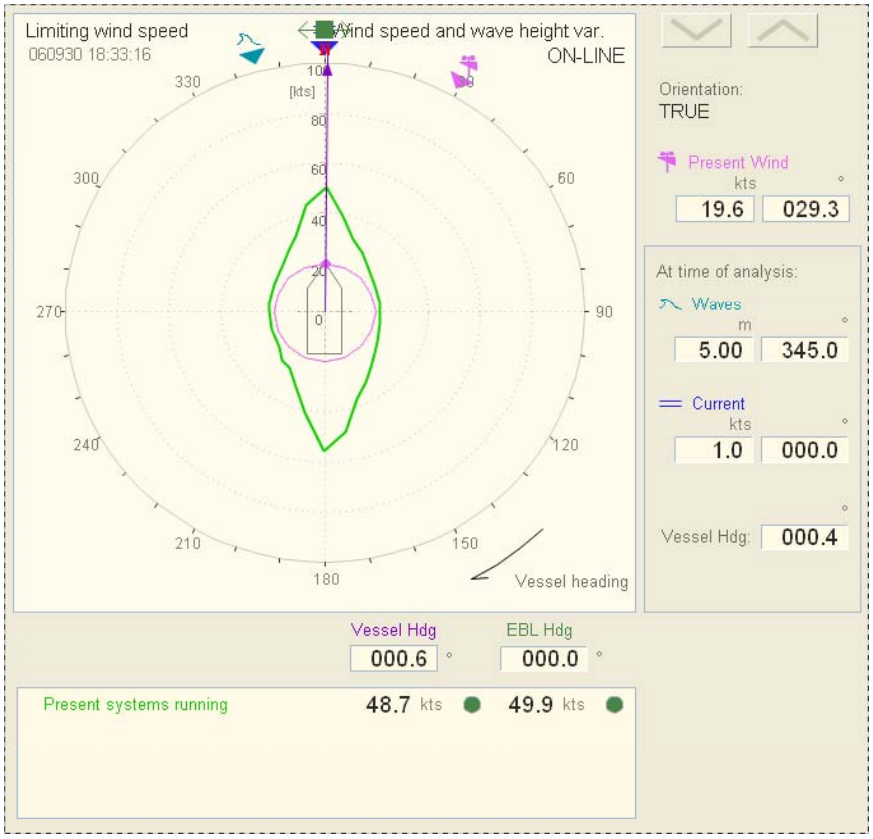


Waves set to zero



Correct wave setting

Heading Change

Wave drift

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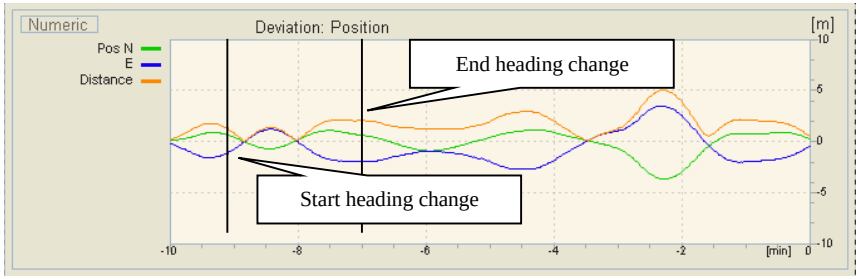
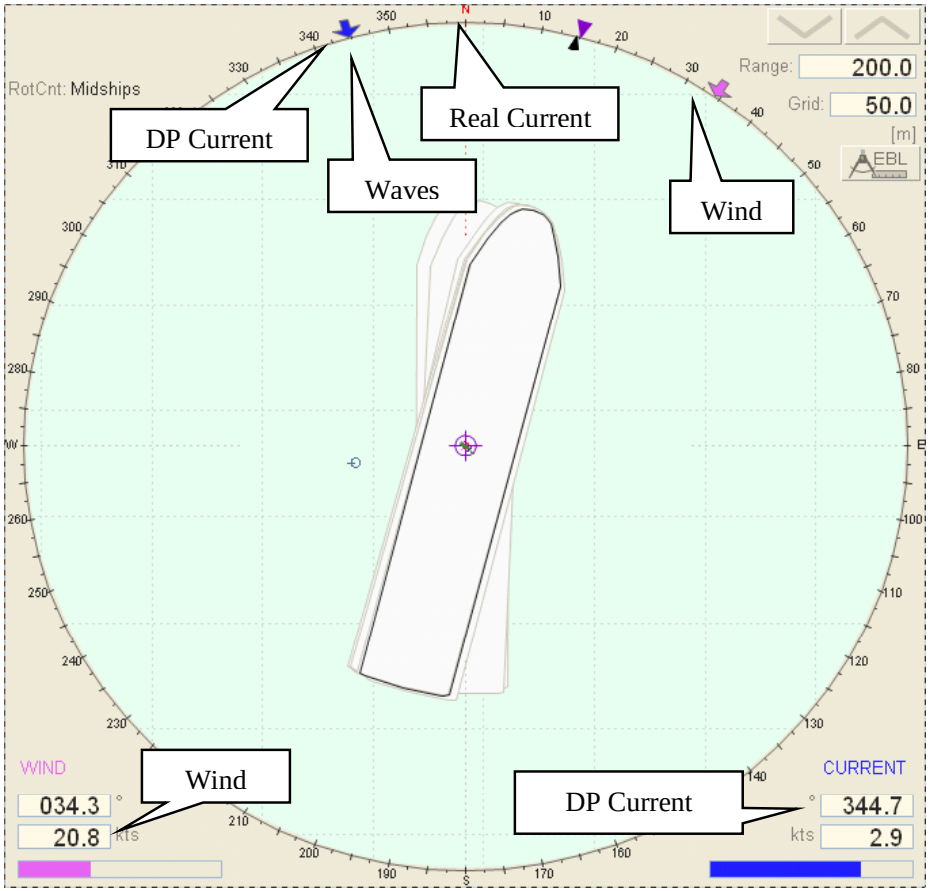
Scenario:

- Heading change +15 deg towards wind

Observations:

- DP current does not change significantly
- No significant position excursion





DP Current and Control

DP current may be utilised in several ways:

Method 1: Not directly used for control at all. Instead an external integrator shall secure zero mean positioning offset

Method 2: Used for feedback of non-modelled external forces

Method 3: Used for nonlinear decoupling making the vessel virtually behave as if moving in vacuum

Method 2

$$F_{cx} = C_x(\alpha)(u_c^{E2} + v_c^{E2})$$

$$F_{cy} = C_y(\alpha)(u_c^{E2} + v_c^{E2})$$

$$M_c = C_\psi(\alpha)(u_c^{E2} + v_c^{E2}) + m_c$$

$$\alpha = \tan^{-1}(\frac{v_c}{u_c})$$

Method 3

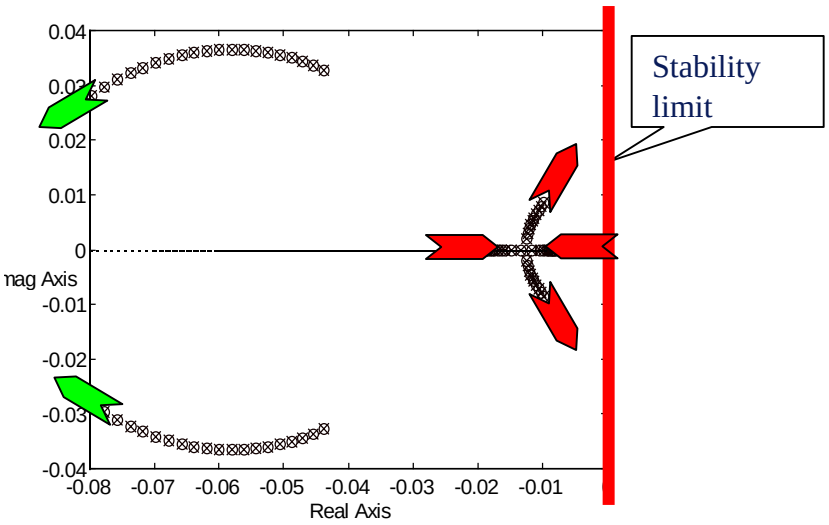
$$F_{cx}(u_r, v_r) = C_x(\alpha)(u_r^2 + v_r^2)$$

$$F_{cy}(u_r, v_r) = C_y(\alpha)(u_r^2 + v_r^2)$$

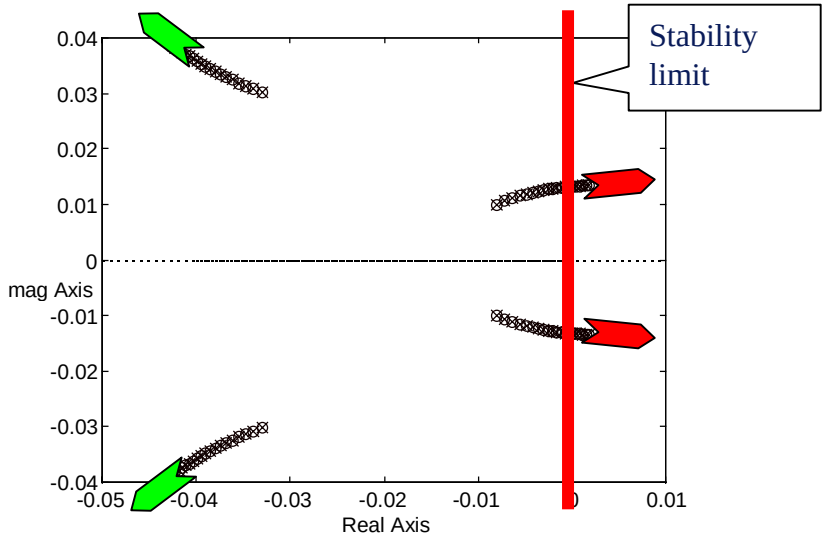
$$M_c(u_r, v_r) = C_\psi(\alpha)(u_r^2 + v_r^2) + m_c$$

$$\alpha = \tan^{-1}(\frac{v_r}{u_r})$$

Robustness to modelling error



Method 2



Method 3

Growing modelling error, Kalman filter

Growing modelling error, control

Conclusion

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- The DP current is to be considered an expression of **all non-modelled phenomena** in the mathematical DP model
- We have seen that **sensor errors** (anemometers as well as thruster set-point – feedback problems) and **unknown environmental loads** such as wave drift will cause the DP current to grow
- This may be a nuisance to the DPO but **does not destroy system stability**