



Control

What is the DP Current?

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Kongsberg Maritime AS – Kongsberg, Norway

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What is the DP Current?

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WORLD CLASS – through people, technology and dedication



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Mathematical Vessel Model

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

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

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

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

where

$$\left. \begin{array}{l} u_r = u - u_c \\ v_r = v - v_c \end{array} \right\} \text{and} \left. \begin{array}{l} u_c = u_c^E \cos \psi + v_c^E \sin \psi \\ v_c = v_c^E \cos \psi - u_c^E \sin \psi \end{array} \right\} \text{Relative velocity}$$

$M_x M_y M_\Psi$

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

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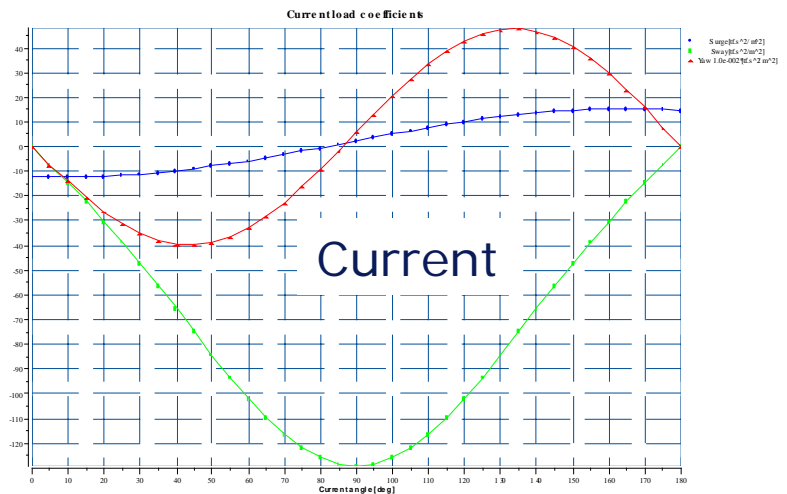
$$F_{cx}(u_r, v_r) = C_x(\alpha)(u_r^2 + v_r^2)$$

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

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

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

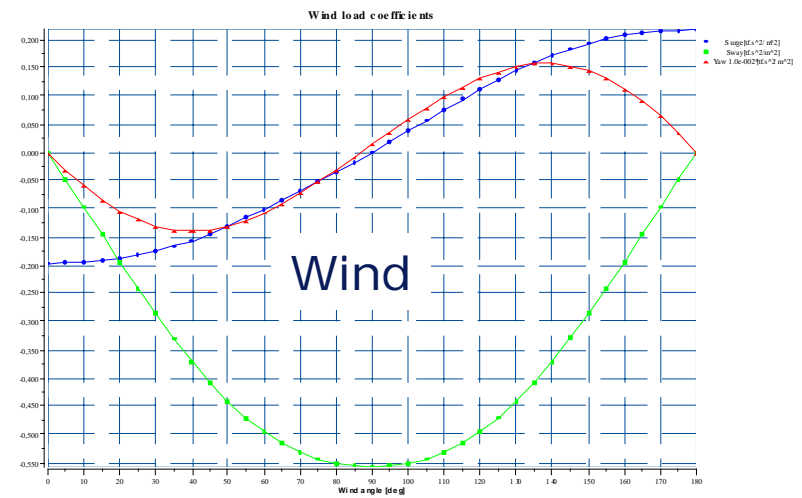
C_x , C_y and C_ψ are the force characteristics, i.e. force and moment as a function of angle of attack



Bow

Angle of attack

Stern

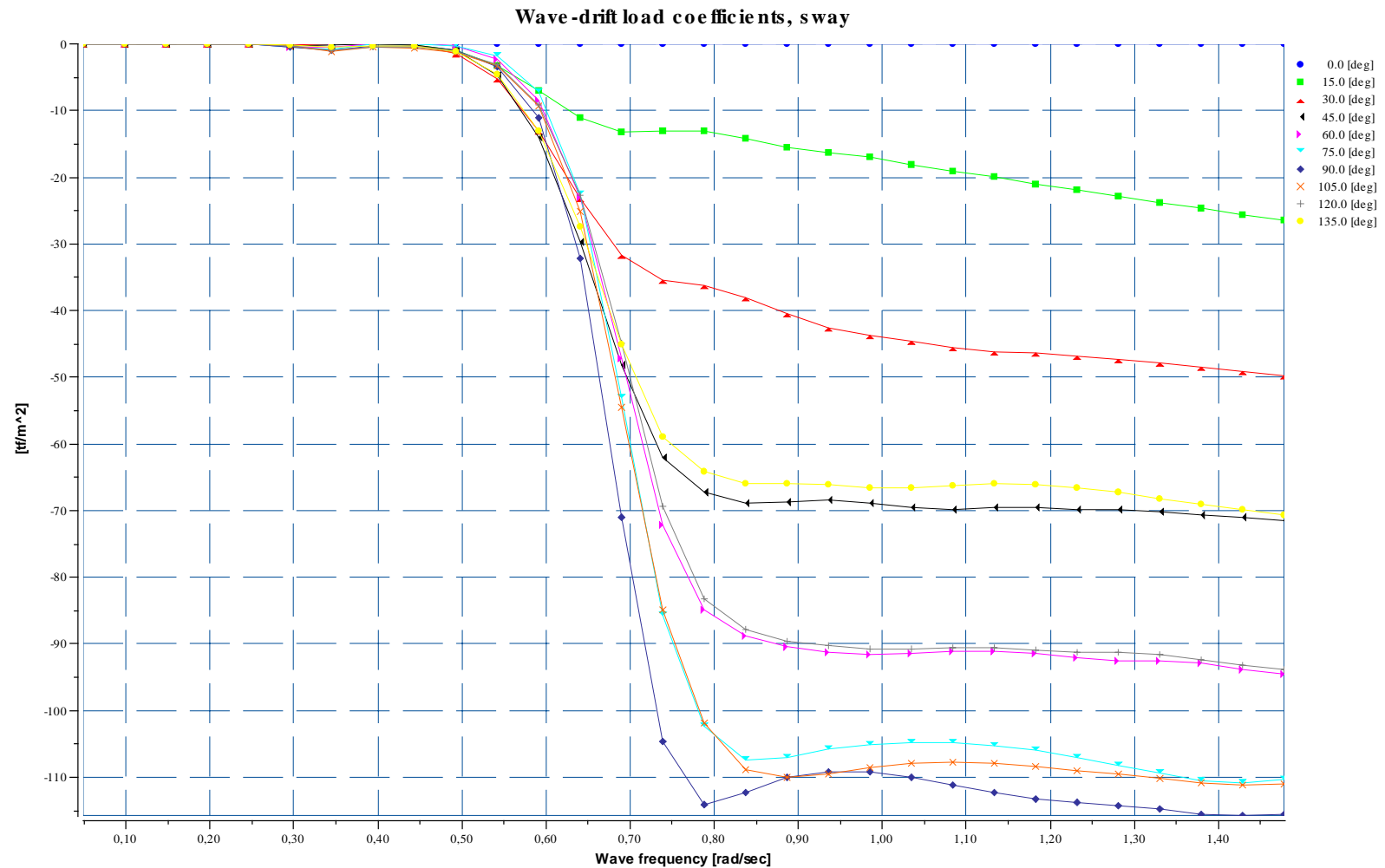


Vessel Characteristics

Wave drift



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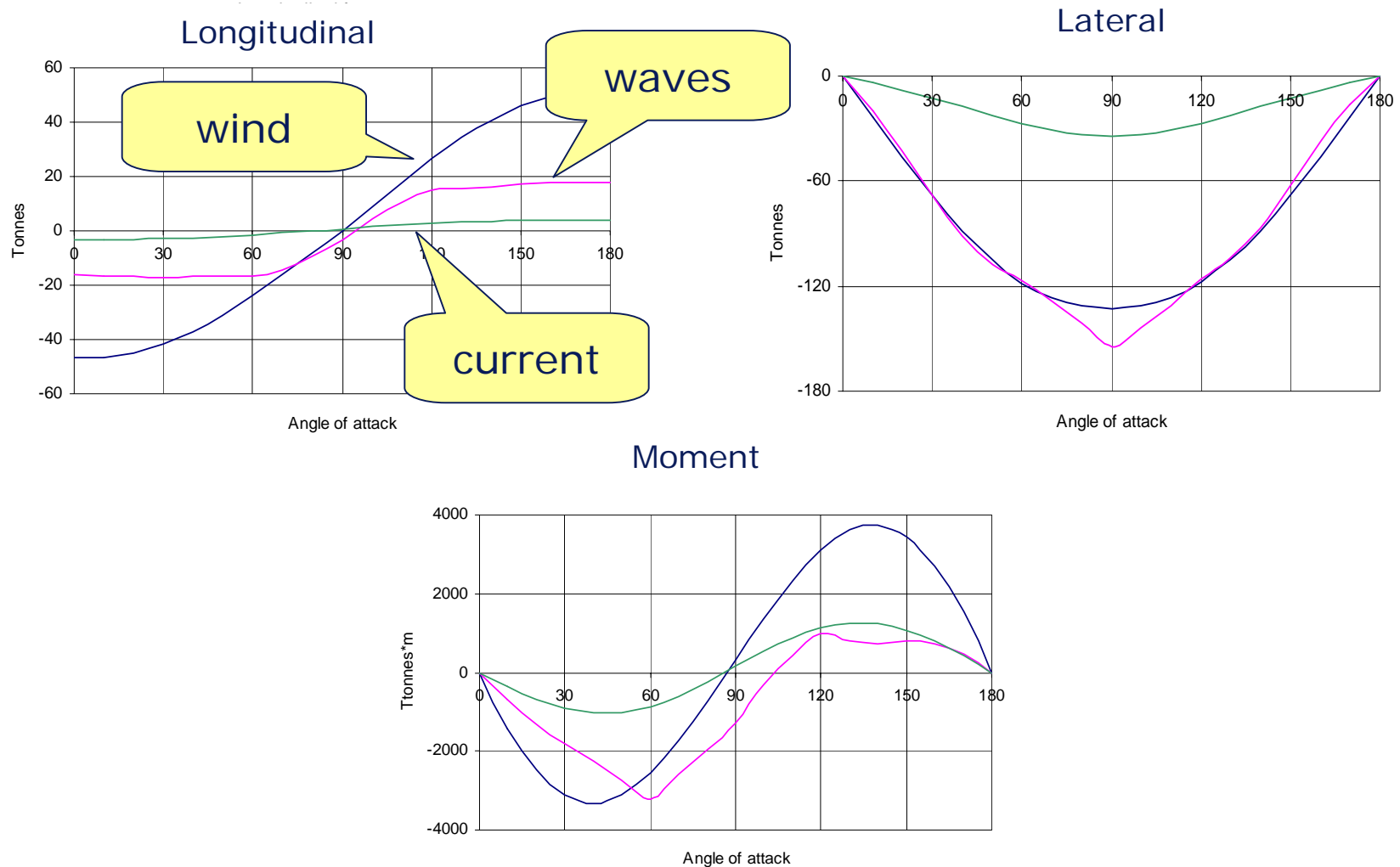


Load Conditions

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



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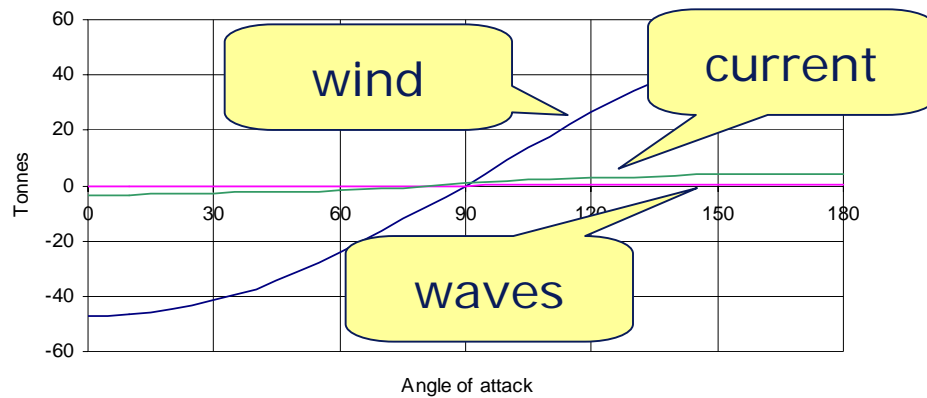
Load Conditions

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

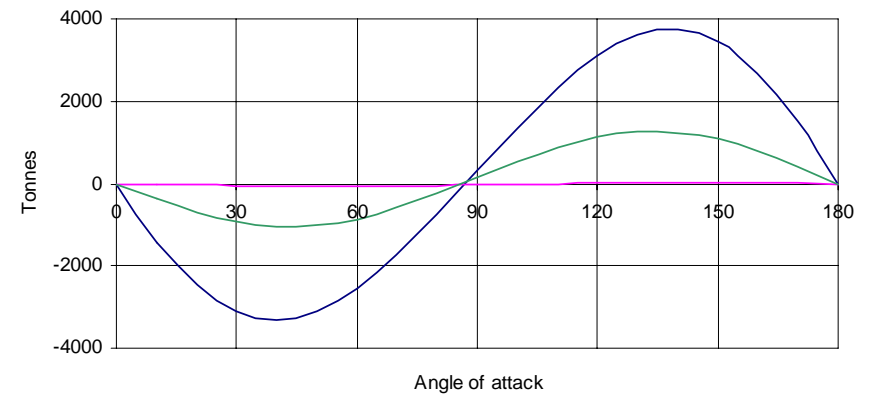


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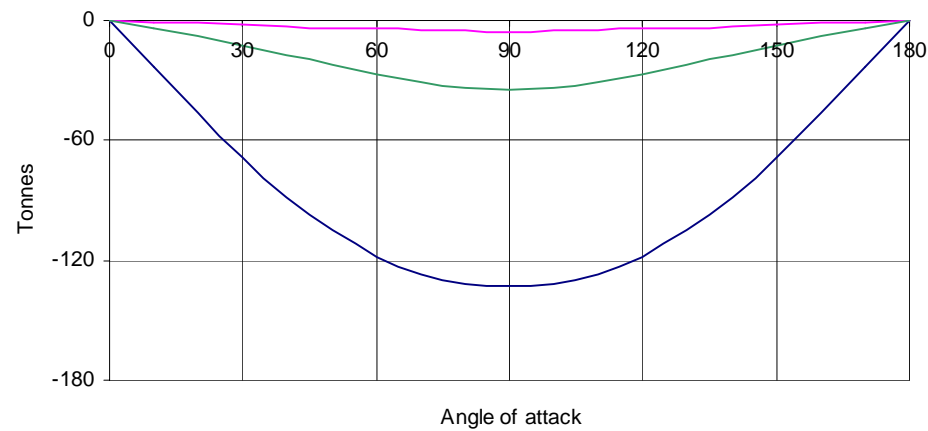
Longitudinal



Lateral



Moment

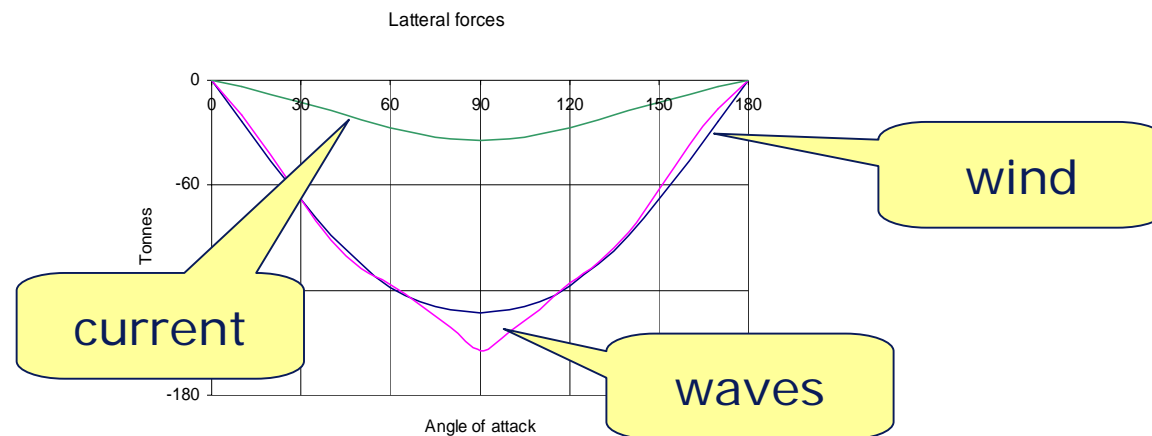




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Some Observations

- 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

- 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)



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Advantages if load characteristics were known

- 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

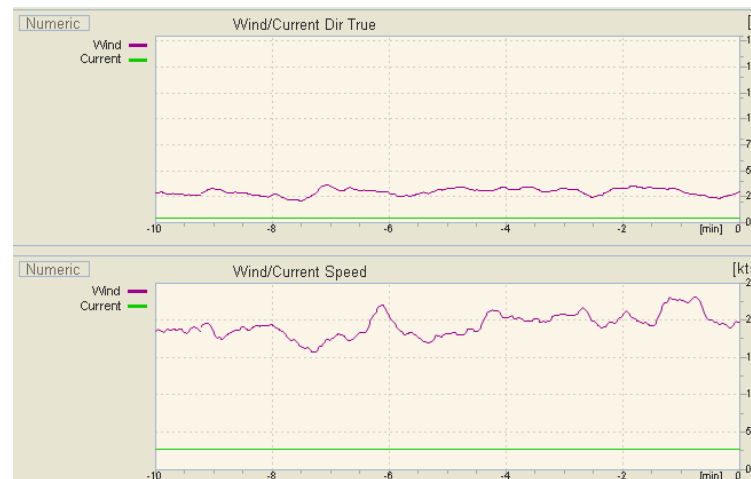
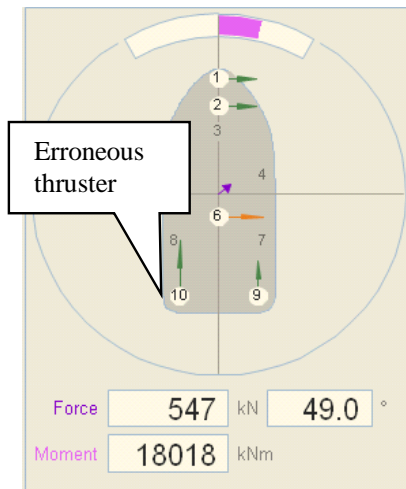
Modelling Errors

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



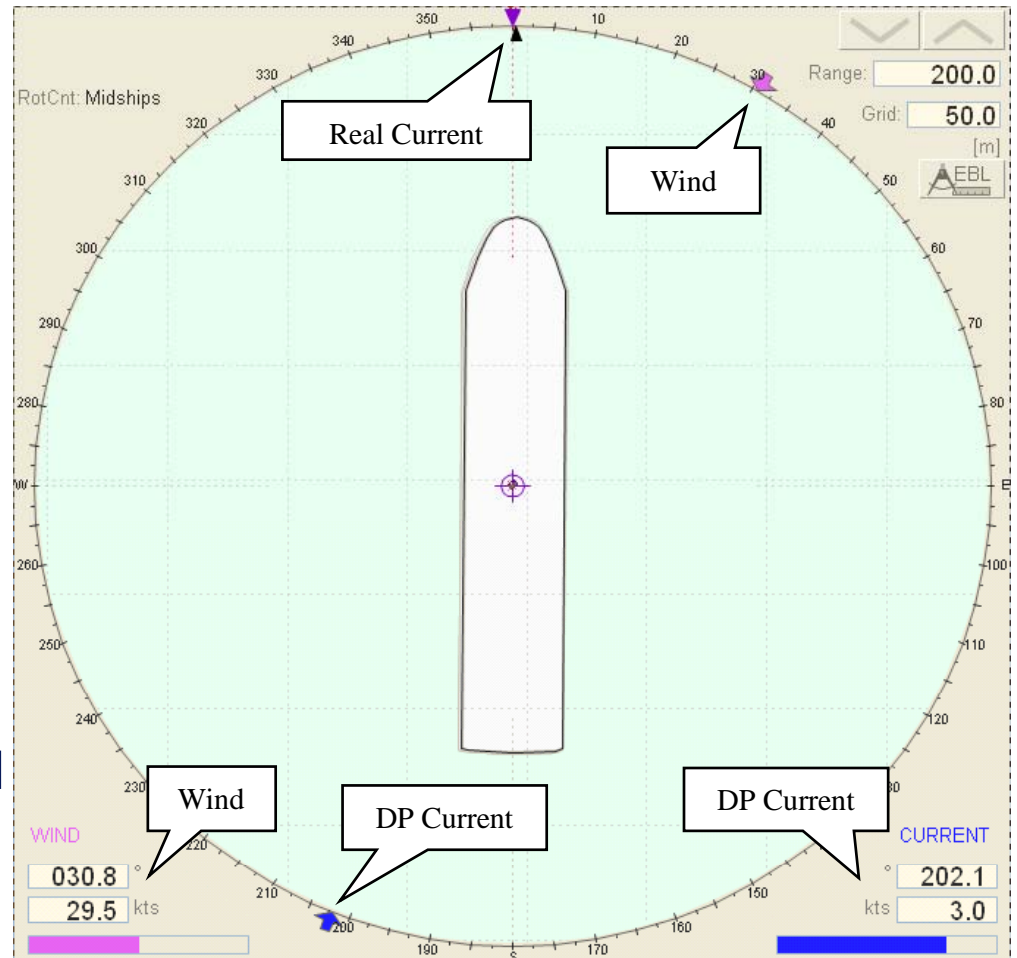
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Scenario:

- 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



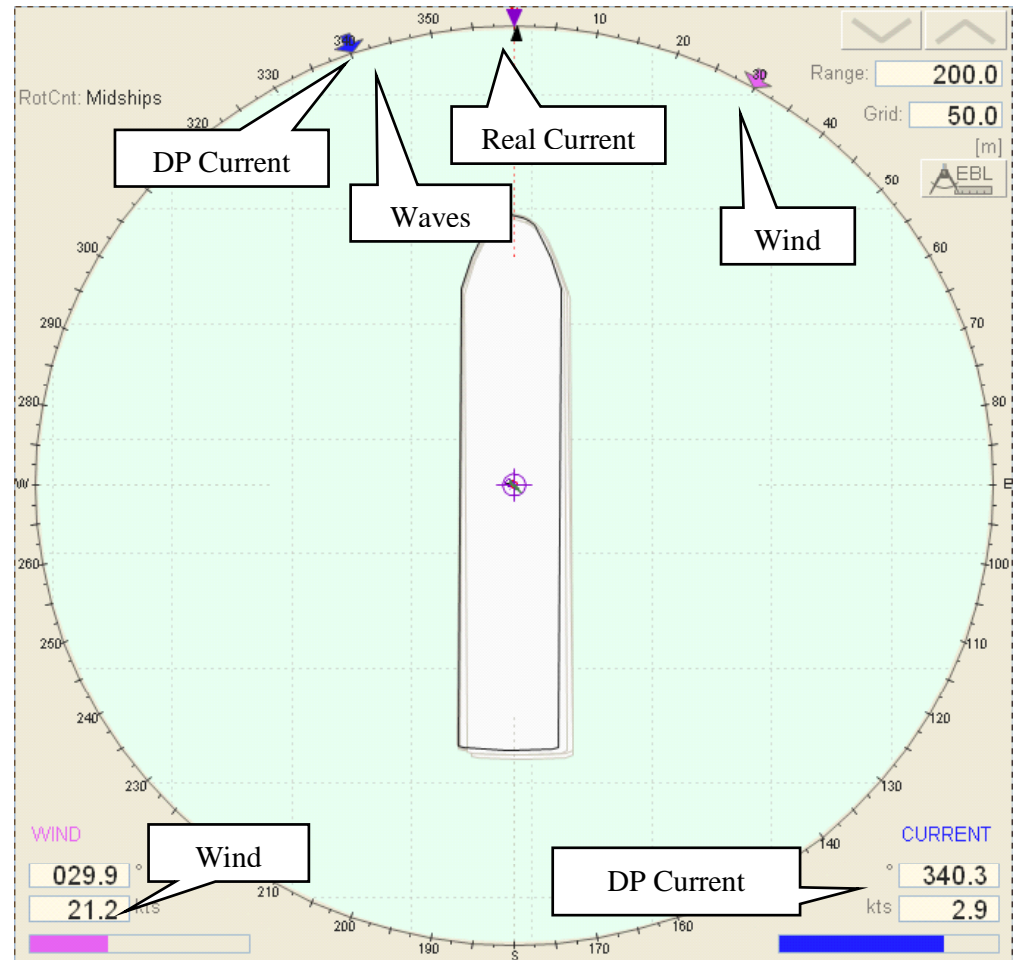
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Scenario:

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

Observations:

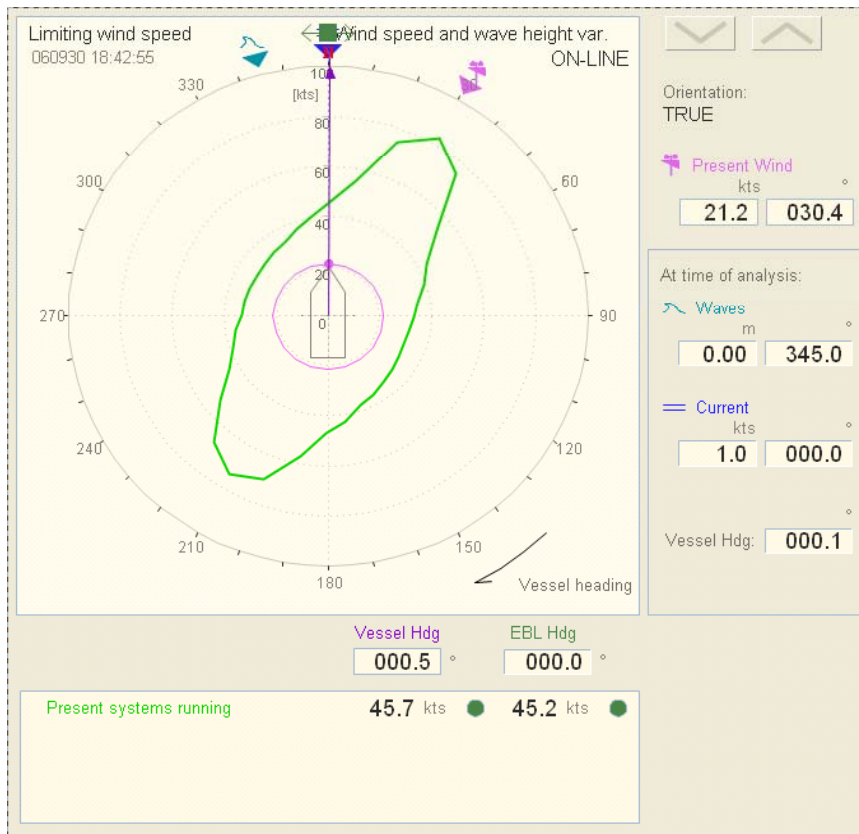
- Current speed is overestimated (about 3 knots with direction 340 deg)



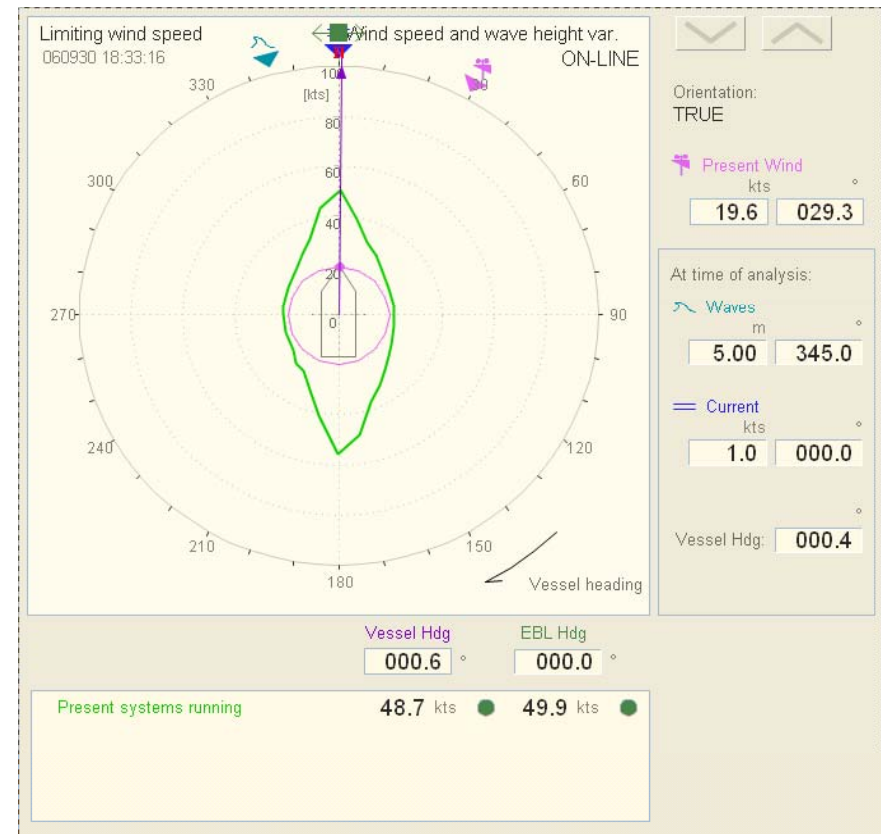


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Station Keeping Capability



Waves set to zero



Correct wave setting

Heading Change

Wave drift



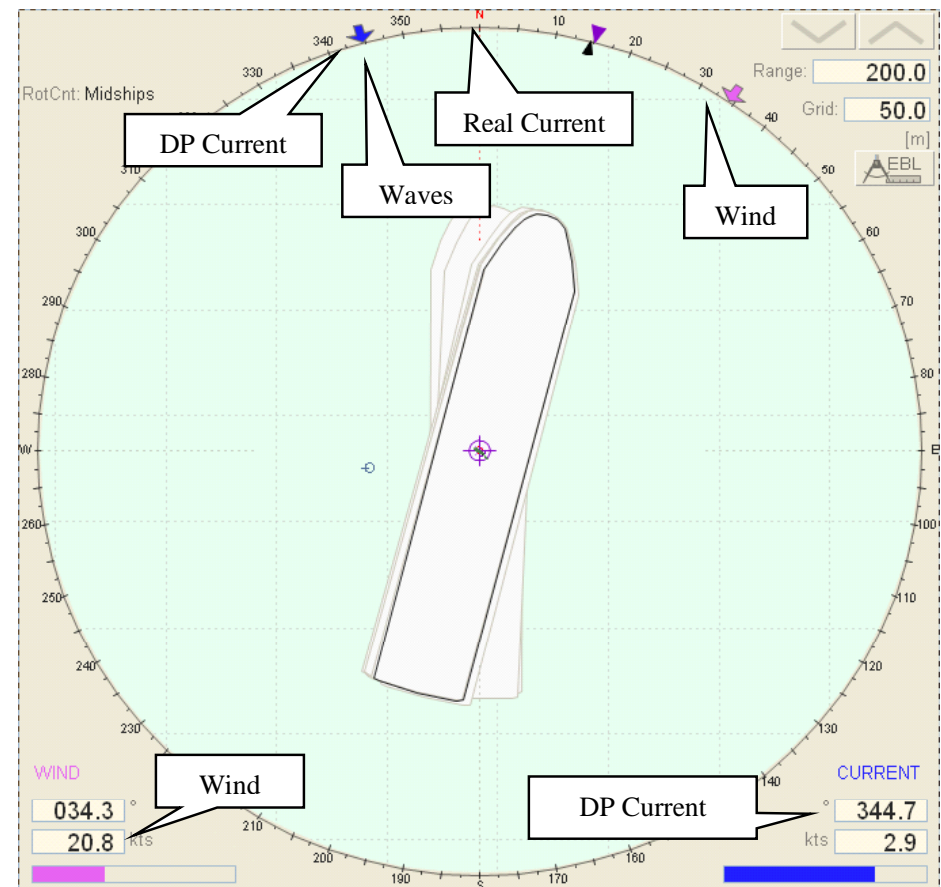
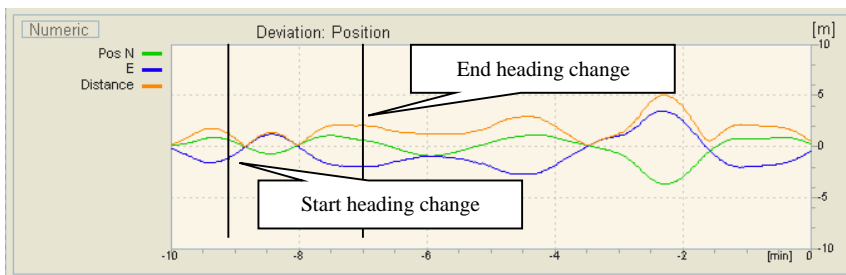
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Scenario:

- 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

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

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

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

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

Method 3

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

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

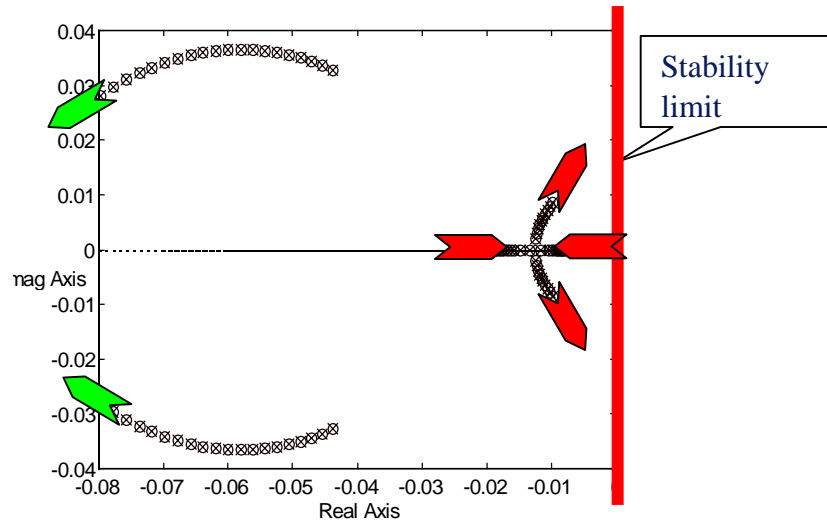
$$M_c(u_r, v_r) = C_\psi(\alpha)(u_r^2 + v_r^2) + m_c$$

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

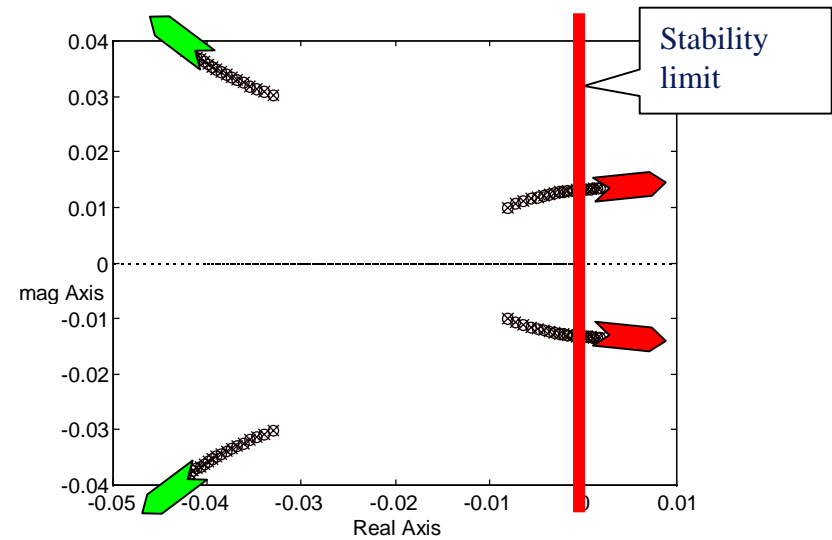


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Robustness to modelling error



Method 2



Method 3

-  Growing modelling error, Kalman filter
-  Growing modelling error, control



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Conclusion

- 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**