



## **DYNAMIC POSITIONING CONFERENCE**

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**Control**

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### **What is the DP Current?**

**Nils Albert Jenssen**

***Kongsberg Maritime AS***

***Kongsberg, Norway***

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## Introduction

Over the years there has been much confusion about and misunderstanding of the current estimate presented on the DP screen. The paper elaborates on what it really represents, why it is needed, and is also discussing some implementation aspects.

The paper further discusses the behaviour of the DP current in different environmental conditions and the effect of vessel modelling errors (inaccurate thruster models represented by set-point / feedback errors and wind sensor reading errors).

## Mathematical Vessel Model

### Theoretical Basis

The theoretical background of the DP current is based on the mathematical model of a vessel. There are many ways to model ship motions; based on hydrodynamic derivatives which is a standard way of modelling ship manoeuvring, simple Nomoto black box models for steering, modelling based on hydrodynamic first principles, etc. This paper will concentrate on current modelling and its relation to the other hydrodynamic effects in the context of Kalman filtering. An overview of hydrodynamic modelling may be found in Fossen (1994)<sup>1</sup>.

When using first principles sea current becomes an important factor. In summary the vessel model can be expressed as follows:

First we define the 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
- $\psi$  vessel heading

The kinematics:

$$\begin{aligned}\dot{x}^E &= u \cos \psi - v \sin \psi \\ \dot{y}^E &= v \cos \psi + u \sin \psi \quad \text{transforming vessel related velocities to earth fixed position} \\ \dot{\psi} &= r\end{aligned}$$

The dynamics:

$$\begin{aligned}\dot{u} &= (M_y vr - F_{cx}(u_r, v_r) + F_{tx} + F_{wx} + F_x) / M_x \\ \dot{v}_r &= (-M_x ur - F_{cy}(u_r, v_r) + F_{ty} + F_{wy} + F_y) / M_y \quad \text{transforming forces to velocities} \\ \dot{r} &= (-M_c(u_r, v_r) + M_t + M_w + M) / M_\psi\end{aligned}$$

where

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<sup>1</sup> Fossen: Guidance and Control of Ocean Vehicles, John Wiley & Sons, 1994

$$\begin{aligned} u_r &= u - u_c \\ v_r &= v - v_c \end{aligned}$$

is the vessel velocity through water

and

$$\begin{aligned} u_c &= u_c^E \cos \psi + v_c^E \sin \psi \\ v_c &= v_c^E \cos \psi - u_c^E \sin \psi \end{aligned}$$

is the vessel relative current

and

$M_x, M_y$  and  $M_\psi$  are vessel mass and moment of inertia (included added mass)

$F_{cx}, F_{cy}$  and  $M_c$  is the current load (unknown)

$F_{tx}, F_{ty}$  and  $M_t$  is the resulting thruster forces (may be measured)

$F_{wx}, F_{wy}$  and  $M_w$  is the wind load (may be measured)

$F_x, F_y$  and  $M$  represents all other forces; such as wave drift and other phenomena not accounted for above (unknown)

Hence we have two unknown forces; ( $F_{cx}, F_{cy}, M_c$ ) and ( $F_x, F_y, M$ ). The wave drift force may be significant. Unfortunately it is not feasible to establish a mathematical model of this force, 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. This means that in the context of Kalman filtering current and waves must be aggregated to a common unknown force. We call this the “DP current” and is estimated through the Kalman filtering process.

## Typical Vessel Characteristics

Both current and wind loads may be written as (example for current shown)

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

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

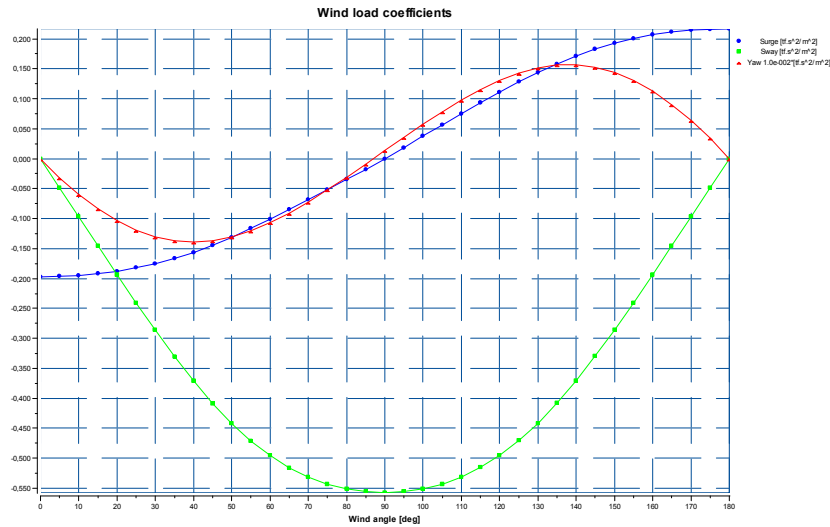
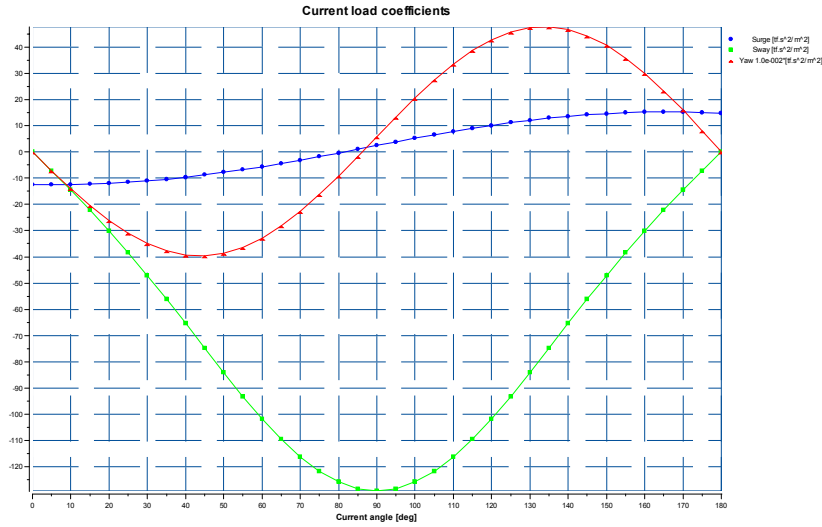
$$M_c(u_r, v_r) = C_\psi(\alpha)(u_r^2 + v_r^2)$$

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

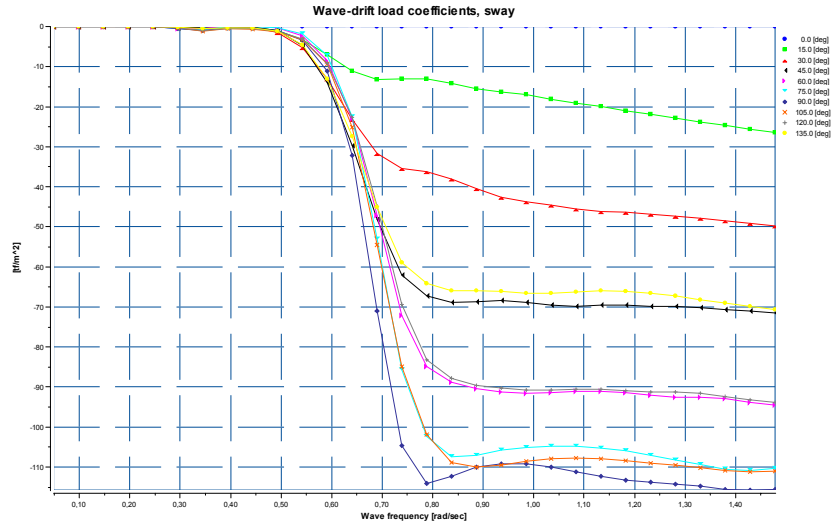
where

$C_x, C_y$  and  $C_\psi$  are the force characteristics, i.e. force and moment as a function of angle of attack

A typical wind and current example of for a drilling vessel is shown below.

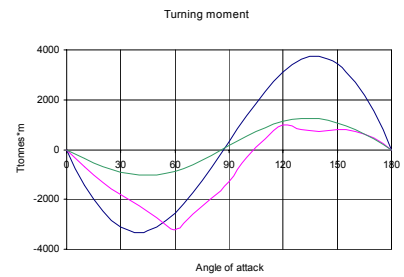
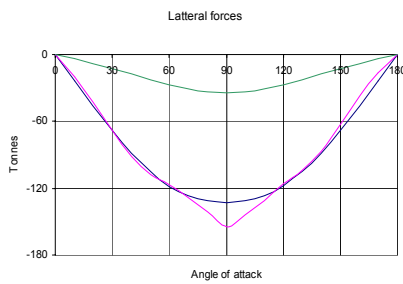


The wave drift forces are much more complicated and can not be represented as simple characteristics. An example of wave drift coefficients are shown below. These tell wave drift force as a function of wave height and frequency. Such kind of modelling is impossible in a Kalman filter context.



To get an idea of how all the wave drift force change with angle of attack we must look at a particular condition. In the example below the following weather condition is analysed:

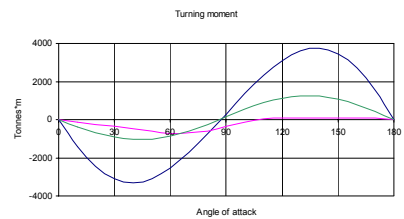
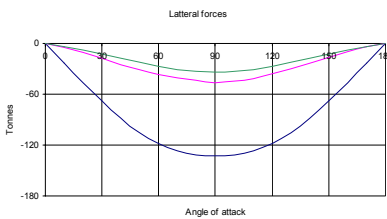
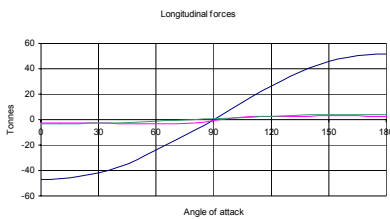
wind 30 knots, current 1 knot, waves 5 m Hs



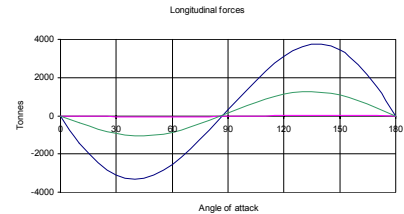
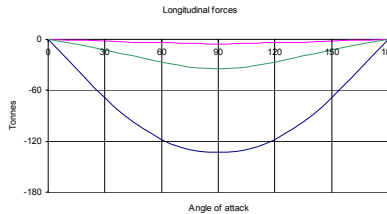
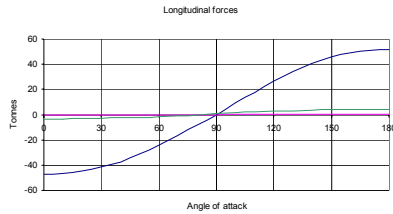
Legend:

— Wind — Wave — Current

Similar for: wind 30 knots, current 1 knot, waves 2 m Hs



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



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

The question arises; how to model these two slowly varying unknown forces?

Is the best way to best approach just to consider them as totally unknown without any relation to physics? I.e. just an unknown force with three independent components ( $F_x$ ,  $F_y$ ,  $M$ ).

Should there be any relationship between these components similar to the figures above? If current and wave directions were more or less coinciding the answer would be simple since we see that the shapes of the current and wave curves are almost identical, but so is not the case.

Another question is; how reliable are these load characteristics? Would the use of such relations introduce principal incorrect couplings between the different degrees of freedom? The rationale of introducing such couplings in the model is that the model itself could then be used to decouple real effects to obtain a better control. In control systems, however, it is always dangerous to introduce improper decoupling between control variables since this may result in bad robustness and even instability.

In the end there is no correct answer, we have to make a decision based on pro and cons. 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). The certain fact is that we are not really dealing with current loads, but with residual forces not covered by our mathematical model. In the following we will proceed using the structure of a current profile describing these unknown forces.

There are some great advantages if load characteristics where 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 question is whether the drawbacks are greater. This question is related to how representative the load characteristics are.

## Modelling Errors

All model errors will be mapped into the DP current, i.e. wind sensor errors, thruster set-point/feedback errors as well as the errors in the wind characteristics and wave forces.

### Thruster set-point – feedback error

Traditionally pitch control inaccuracies (set-point – feedback discrepancies) especially for main propellers has been a well known source to modelling errors. Since both set-points and feedbacks are used in the DP control, a mismatch will be reflected in the DP current as shown in the example below:

Here an artificial ahead DP current of about 2.5 knots is estimated as a result of a bias error of 25% (of full pitch) in the pitch feedback for a main propeller, marked (10) in the figure below (left). This represents a significant “additional load”. We observe that the thruster arrow is much larger than that of the other main propeller. In reality they are almost providing the same thrust.

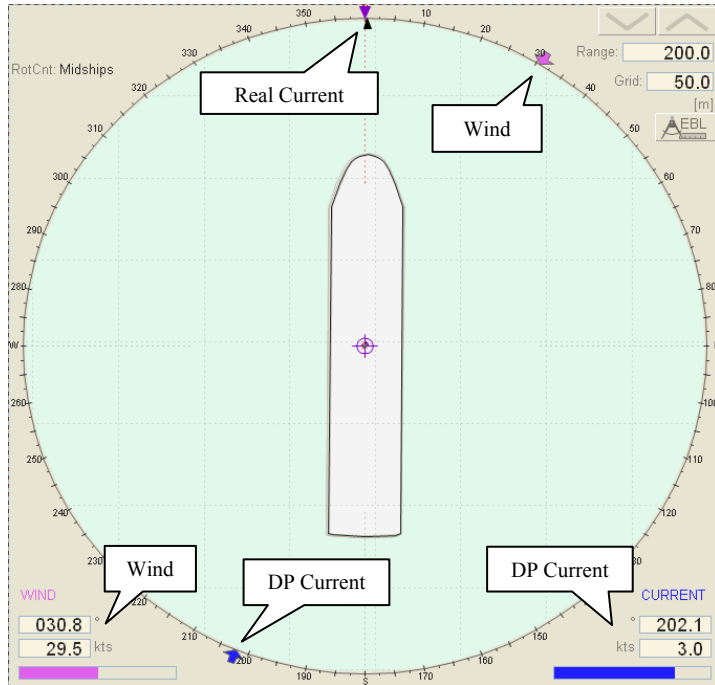


The large artificial current is a result of the quadratic nature of drag. If there would have been a real current of 1 knot, the resulting DP current would have been just below 3 knots.

### Wind Sensor Error

In this simulated scenario the wind sensor is manipulated. The real wind is coming from 30 degrees with speed 20 knots. The sensor is wrongly scaled providing a speed exceeding the correct one with 50%, i.e. average value 30 knot. Additionally there is a current coming from North of 1 knot.

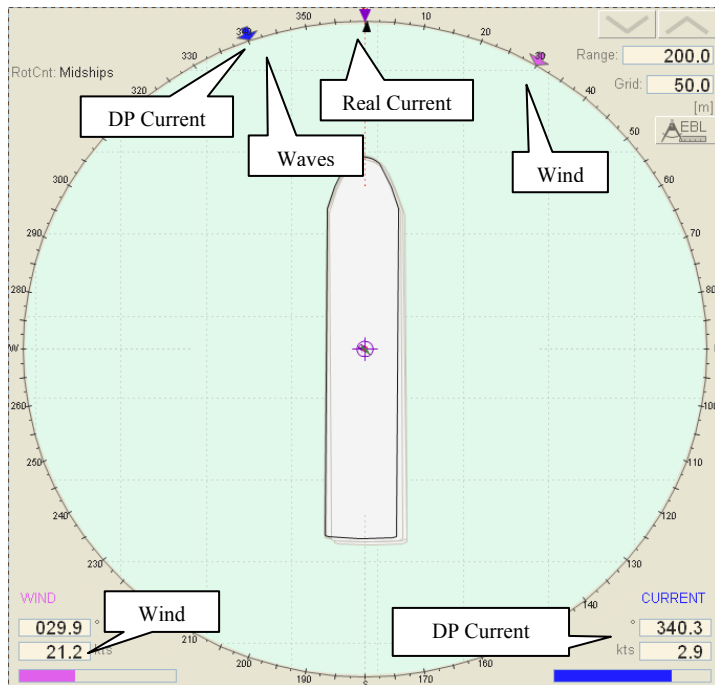
As can be seen from the figure to the right the DP current is heavily corrupted showing 3 knots from a direction almost opposite to the wind.



### Wave Drift Forces

In this case we consider wave drift forces only. No failures are included. The wind and current condition is as above, but with waves of 5 m Hs from 15 degrees to port bow (345 degrees).

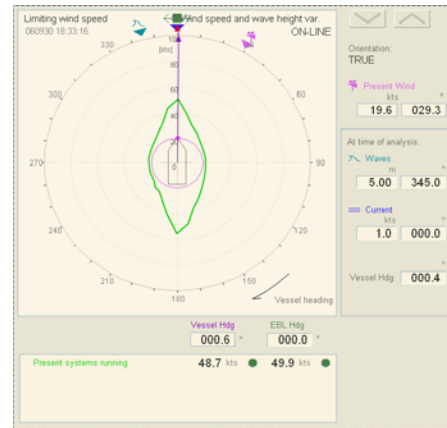
Since waves are interpreted as current we observe that the current speed is overestimated (about 3 knots vs. the correct 1 knot) with direction 340 vs. 0 degrees. Since the real current is coming from 0 degrees, one might presume that the direction of the DP current should be somewhere between the real current and wave directions. However, the wave drift force characteristics is somewhat steeper than the current characteristics, hence the direction of the DP is somewhat more to the port side.



On-line capability plots for this condition are shown in the figures below.



Wave data set to zero



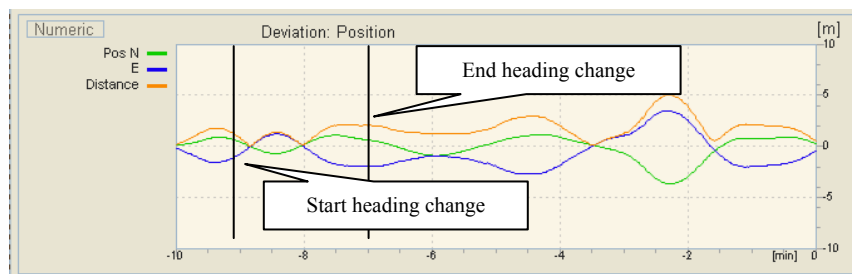
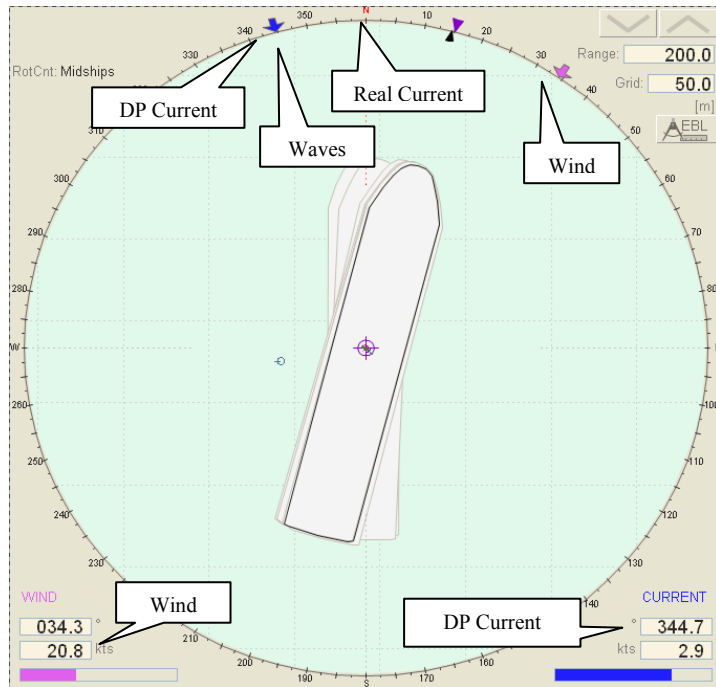
Correct wave data entered

(the capability tool has built-in advisory for specifying wave height based on wind speed)

The next example shows the effect of turning the vessel 15 degrees towards the wind. From the capability plot (above right) we can see that the condition will be close to the station keeping limit due to heavier exposure to waves even though the wind load will decrease.

The most interesting to note is that the magnitude of the DP current does not change significantly during the turn; neither does the direction (about 5 degrees). This is the benefit from the fact that the shape of wave drift and current force characteristics are similar in nature and that the two directions are rather coinciding.

We also see that position excursions as a result of the heading change are not recognisable. The position variations in the graph are the result of the slowly varying wave drift forces.



## How to Estimate DP Current

The DP current is model as slowly varying parameters:

$$\dot{u}_c^E = 0$$

$$\dot{v}_c^E = 0 \text{ where } m_c \text{ is corrections to the turning moment.}$$

$$\dot{m}_c = 0$$

The resulting DP current force and moment then become:

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

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

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

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

The normal mathematical model as described earlier is augmented with the current state variables and put into an Extended Kalman filter framework for estimation of all state variables.

Since there are unknown phenomena (not modelled) the DP current is needed to make the estimates from the Extended Kalman filter biased free (with correct statistical expectancy value).

## Implications for Control

An important question is: Does “incorrect” DP current influence the station keeping performance, or is the DPO just exposed to some artificial figures?

From a theoretical point of view the 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

The first method is similar to just forgetting any structural properties of the external forces. See earlier discussion on unknown force with three independent components ( $F_x, F_y, M$ ).

The other methods incorporate the necessary integrator to secure zero average station keeping deviation. Without making a feedback from the DP current the vessel would experience a stationary offset from the wanted position.

The second method takes into account the structural knowledge, providing the following feedback

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

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

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

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

Note that here we are not using the relative speed, but the current directly. By doing so, the model will have different dynamic properties when moving with or against the current. On the other hand robustness (dynamic stability) is favoured.

If the DP current were the real current, the third method would have been far the best with respect to station keeping accuracy. In that case we would feed back

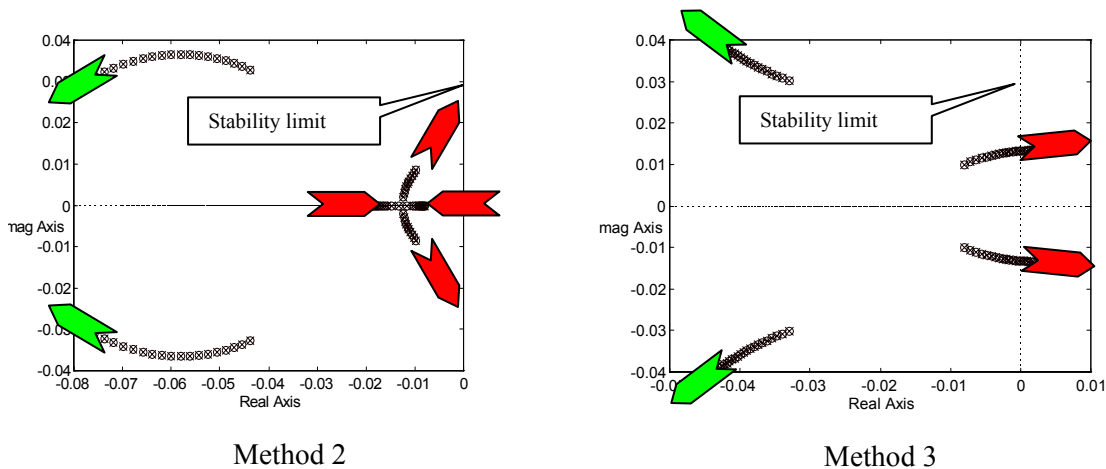
$$F_{cx}(u_r, v_r) = C_x(\alpha)(u_r^2 + v_r^2)$$

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

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

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

Looking at typical root locus plots (for one degree of freedom) for the last two methods we would see that method 3 may get unstable if the model errors were too large.



The symbols (estimator error) and (control) indicates increasing modelling errors

## 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.