Assignment 3, TTK4190

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1 Autopilot design

1.1 Heading autopilot

Analysis of ship characteristics

To be able to model the ship in a good way we ran many simulations with different rudder angle and measured the steady-state yaw rate. We then made a $\delta - r$ plot of the result. Since the ship was turning port while giving a positive rudder command, this plot the rest of the assignment is made with a fixed gain of -1 on δ_c.

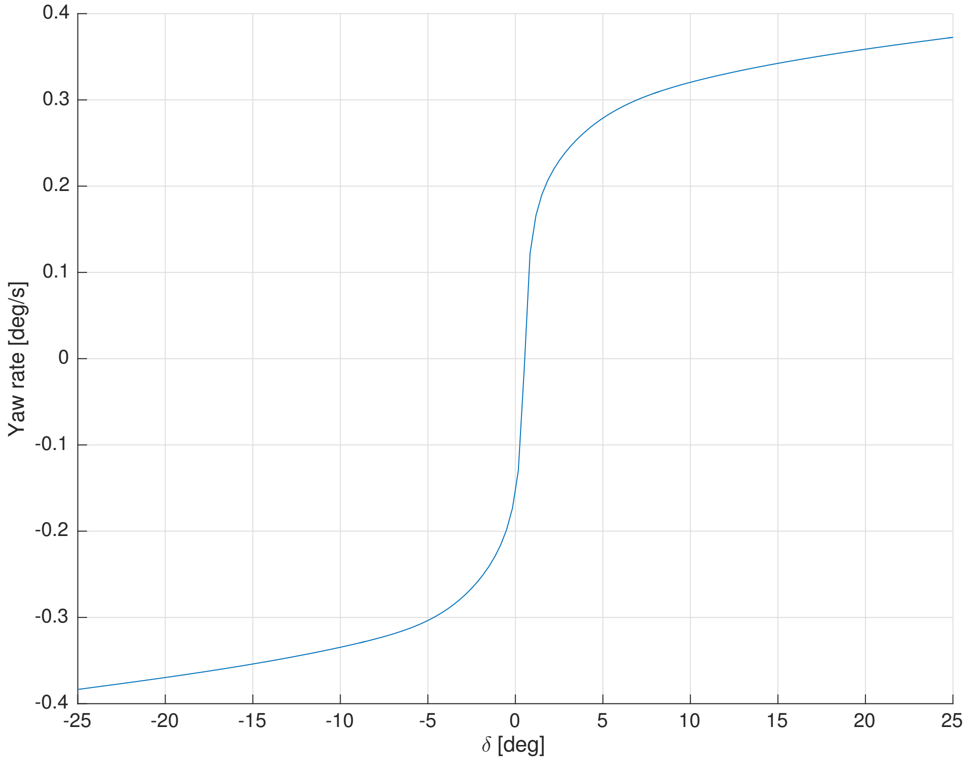

Figure 1: $\delta - r$ plot

From figure 1 we clearly see the non-linear behavior of the ship. This motivates a 1-DOF heading model i.e. first- or second order Monoto model with non-linear extensions. To further investigate the effect of the non-linear characteristics of this ship, we compare the actual response with different models at different rudder angles. It should also be noticed that the ship has a constant drift to starboard with $\delta_c = 0$, as seen by the curve not passing through the origin. We compensate for this through the rest of the modeling part by adding a fixed rudder angle of 0.52° to the rudder input. We only need this correction while estimating the model parameters. In a closed loop, the integral effect will cancel both this drift and drift caused by wind, current and waves.

2. order linear Nomoto

$$\frac{r}{\delta}(s) = \frac{K_\nu(1+T_3 s)}{(1+T_1 s)(1+T_2 s)}$$
$$T_1 T_2 \dddot{\psi} + (T_1 + T_2)\ddot{\psi} + \dot{\psi} = K(\delta + T_3\dot{\delta}) \tag{1}$$

The second order Nomoto model follows the ships overshoot some, but not enough.

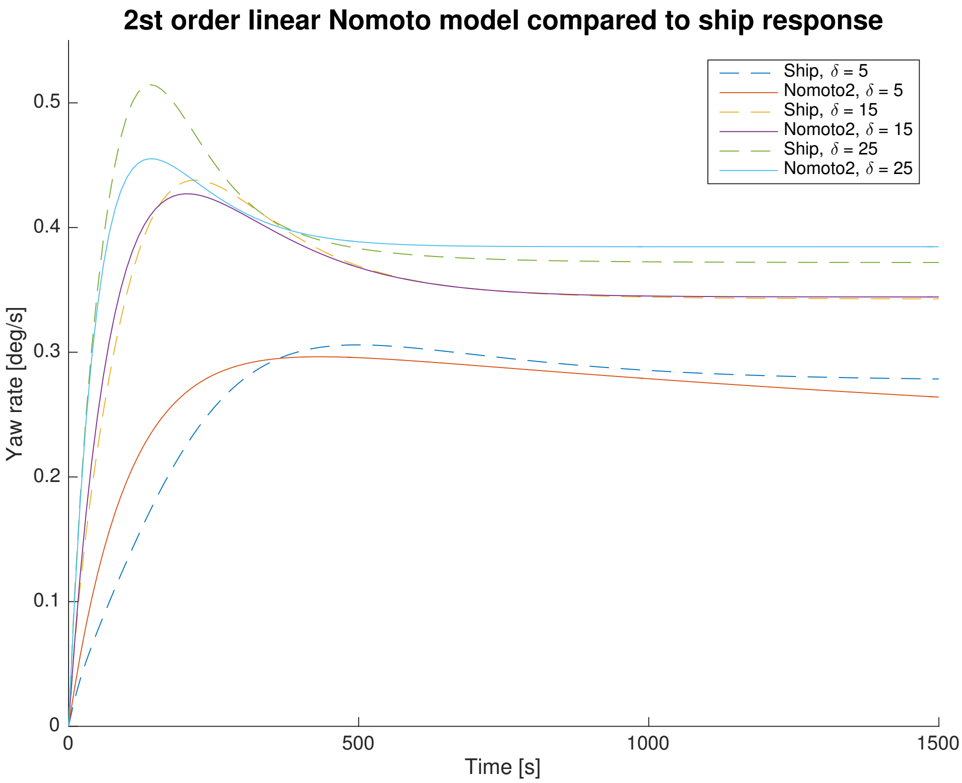

Figure 2: 2.order linear Nomoto model

1. order linear Nomoto

$$\frac{r}{\delta}(s) = \frac{K}{(1+Ts)}$$
$$T\ddot{\psi} + \dot{\psi} = K\delta \tag{2}$$

We also tried the first order version Nomoto, and as expected the model will only be accurate for small rudder angles, and is therefore not very good for modeling the non-linearities.

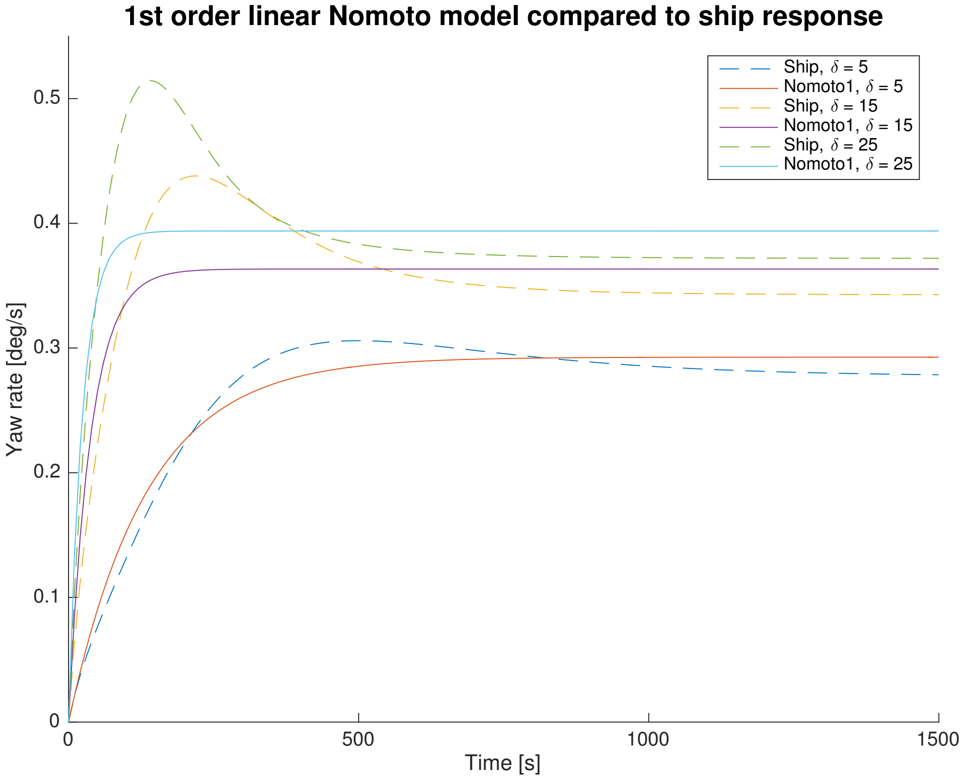

Figure 3: 1.order linear Nomoto model

2. order non-linear Nomoto

$$
\begin{aligned}
T_1T_2\ddot{r} + (T_1 + T_2)\dot{r} + KH_b(r) &= K(\delta + T_3\dot{\delta} \\
H_B(r) &= b_3r^3 + b_2r^2 + b_1r + b_0
\end{aligned}
\tag{3}
$$

Where the steady state of $H_B(r) = \delta$. b_0 have already been taken care of in the fixed rudder offset, and by symmetry in the hull leads to $b_2 = 0$. We then only need the first- and third-order term to describe the maneuvering characteristics. From ref:(Fossen) we know that $b_i = n_i|b_1|$. Since our ship is stable we know that $n_1 = 1$, and thus resulting in following model.

$$
\begin{aligned}
T_1T_2\ddot{r} + (T_1 + T_2)\dot{r} + KH_b(r) &= K(\delta + T_3\dot{\delta} \\
H_B(r) &= b_3r^3b_1r
\end{aligned}
\tag{4}
$$

1. order non-linear Nomoto

Norbins' extension of the linear first order model:

$$
\begin{aligned}
T\dot{r} + H_N(r) &= K\delta \\
H_N(r) &= n_3r^3 + n_2r^2 + n_1r + n_0
\end{aligned}
\tag{5}
$$

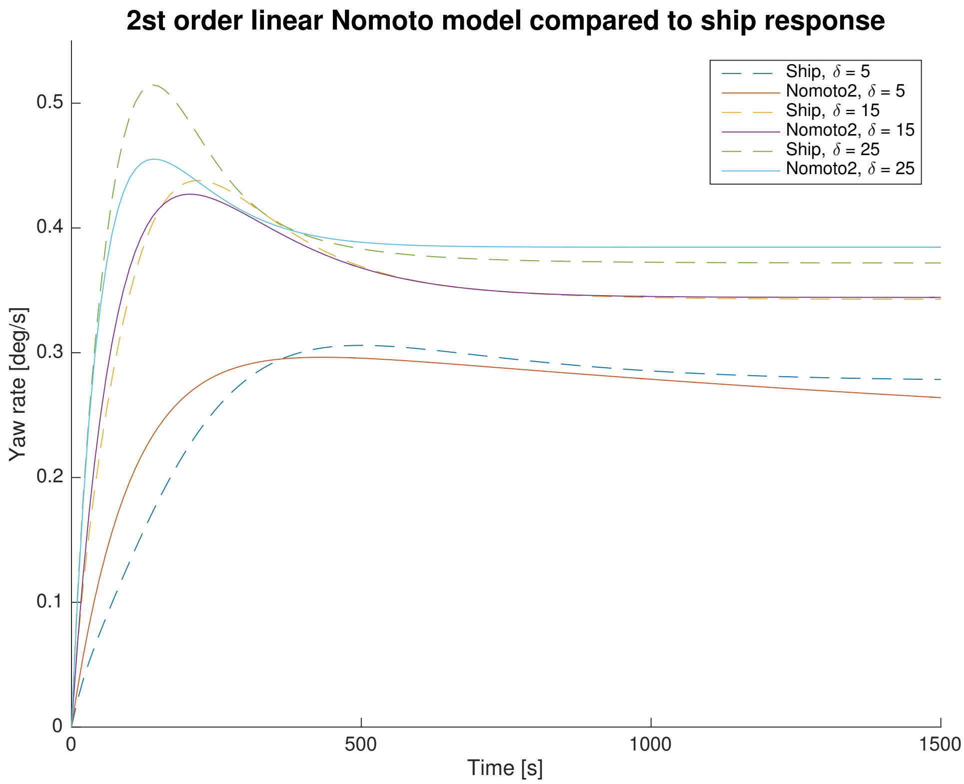

Figure 4: 2.order non-linear Nomoto model

Where the steady state of $H_N(r) = K\delta$. We know that $n_i = \frac{b_i}{|b_1|}$, and since our ship is stable we know that $n_1 = 1$, and thus resulting in following model.

$$T\dot{r} + n_3 r^3 + r = K\delta \tag{6}$$

With the nonlinear first order Nomoto we...

1.2 Speed autopilot

To control the surge speed of MS Fartøystyring we suggest using a linearized model, where the surge speed is decoupled from the rest of the system. We are assuming

$$u >> v$$

which leads to the conclusion that

$$U = u$$

. We then use a first order linear speed model

$$(m + X_{\dot{u}})\dot{u} - X_u u_r - X_{|u|u}|u_r|u_r = \tau \tag{7}$$

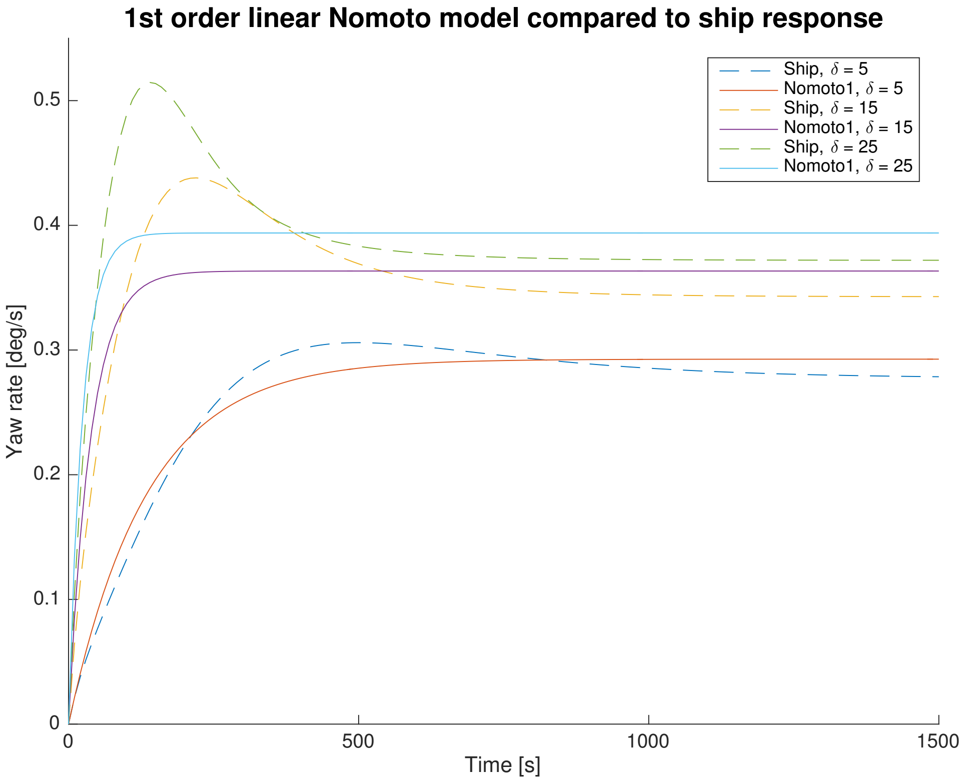

Figure 5: 1.order non-linear Nomoto model

which leads to

$$\dot{u} = \frac{\tau + X_{|u|u}|u_r|u_r + X_u u_r}{m - X_{\dot{u}}} = \frac{X_{|u|u}|u_r|u_r + X_u u_r}{m - X_{\dot{u}}} + \tau_{nl} \tag{8}$$

where

$$\tau_{nl} = \frac{\tau}{m - X_{\dot{u}}} \Rightarrow \tau = \tau_{nl}(m - X_{\dot{u}}) \tag{9}$$

2 Path following and Path tracking

2.1 Path Generation

Her skriver vi om Path generation

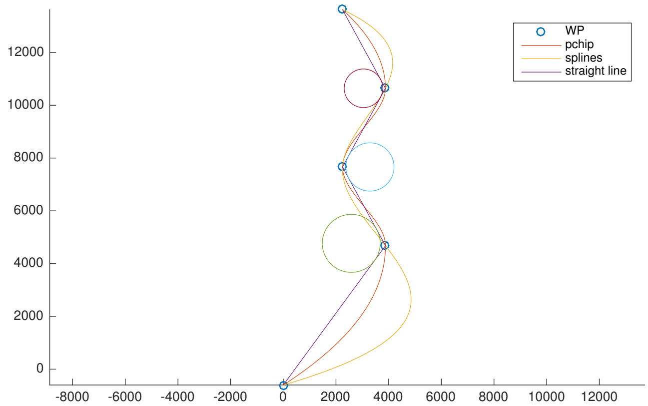

Figure 6: Different trajectories

2.2 Path following

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2.3 Path Tracking

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