0.0.1 Step tests

There were several step tests performed, all at the calm water sea trials in August. One intention is to find the responsiveness of the thrusters. That is, the time constant for the shaft speed, and for the thrust force. Also, the goal is to find the time constants for the vessel speed in surge, sway, and yaw. The shaft speed and thrust time constants are found for surge and sway. The tunnel thruster response is not included in this analysis since the values for the tunnel thruster are of low sampling rate, and it is difficult to determine when steps are applied. In the agility plots of Section (**??**) the tunnel thruster response (including dead time) is plotted, and it can be verified that it is faster than the main propellers. Therefore, the response of the main propellers has the highest time constant, and the response of the tunnel thruster is not of great interest.

For the surge and sway step tests the proposed model of Eq. (**??**) is applied to find the shaft speed time constant and dead time, and also the thrust force time constant and dead time.

For surge, the proposed model of Eq. (**??**) from commanded thrust (or shaft speed) to surge speed is applied for the speed time constants and delay time. The same approach is used for sway speed time constant, by using the model of Eq. (**??**). For the yaw step tests, time constants and delays are found for the yaw rate according to Eq. (**??**). Also, the rudder time constants are found according to the FOPDT approach of Section **??**.

For all the tables below, the time constant is represented by T, and T_n is the time constant for the shaft speed, and T_{thrust} is the time constant for the thrust. Similarly is δ a time delay (or dead time), and δ_n is the delay for shaft speed, and δ_{thrust} is the delay for thrust.

About how tests are read

For all the step tests no setpoints are available. To figure out when steps are applied, the curves for power feedback is applied, since power responds quickly. In the cases where the power curve is unclear the shaft speed feedback curve is used.

Surge step tests

Several step tests in surge were performed for both forward and backward speed. For forward speed the step tests were run for a step in thrust magnitude [%] of $0-5\%$, $5-10\%$, $10-15\%$, $15-25\%$, $25-40\%$, $40-0\%$, $0-80\%$ and $80-0\%$. Figure 1 and 2 show the surge velocity, shaft speed feedback, and power feedback for the forward speed step tests. Table 1 present the time constants and delay time for the shaft speed and thrust feedback, whereas Table 2 show the speed time constant and delay. Some of the step tests results are omitted, due to uncertainty, or for the case of $40-0\%$, and$80-0\%$ they are not included since they did not reach steady state before the tests were finished.

For backward speed the step tests were run for a step in thrust magnitude [%] of $0-5\%$, $5-10\%$, $10-15\%$, $15-20\%$, $20-0\%$, $0-40\%$, and $40-0\%$. Figure 3 and 4 show the surge velocity, shaft speed feedback, and power feedback for the backward speed step tests. Table 3 present the time constants and delay time for the shaft speed and thrust feedback, whereas Table 4 show the speed time constant and delay. As with the forward speed test results, the tests with poor data is not included in the tables.

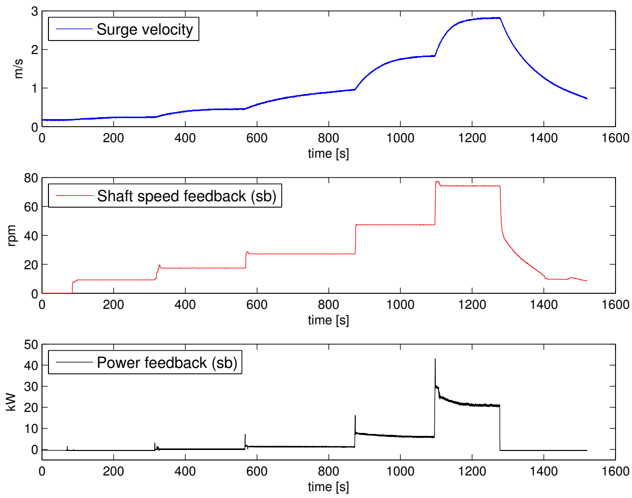

Figure 1: Step test in surge - forward velocity. Surge velocity (top, blue), shaft speed feedback for starboard thruster (red), and power feedback for starboard thruster (black). Power and shaft speed feedback is used to indicate when the input is applied. The steps shown in the figure are test number 0-5,5-10,10-15,15-25, 25-40, and 40-0 (ref. Table (ref. Table 1, and 2).

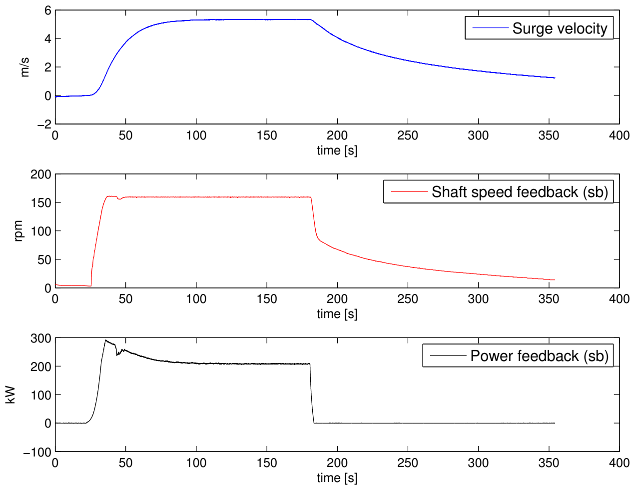

Figure 2: Step test in surge - forward velocity. Surge velocity (top, blue), shaft speed feedback for starboard thruster (red), and power feedback for starboard thruster (black). Power and shaft speed feedback is used to indicate when the input is applied. The step shown in the figure is for 0-80 (ref. Table 1, and 2).

Table 1: Surge step tests, forward speed - thrust and shaft speed time constants

Step mag. [%]	$T_n[s]$	$\delta_n[s]$	$T_{thrust}[s]$	$\delta_{thrust}[s]$
0-80	5.5	2.9	4.7	5.6
25-40	1.1	2.0	2.2	1.5
15-25	1.0	1.9	1.4	1.8
10-15	1.4	11.6	0.3	12.7

Table 2: Surge step tests, forward speed - speed time constants

Step mag. [%]	$T[s]$	$\delta[s]$
0-80	16.4	8.5
25-40	34.2	1.4
15-25	59.2	1.8
10-15	135.0	7.2
5-10	63.3	5.0
0-5	65.5	6.0

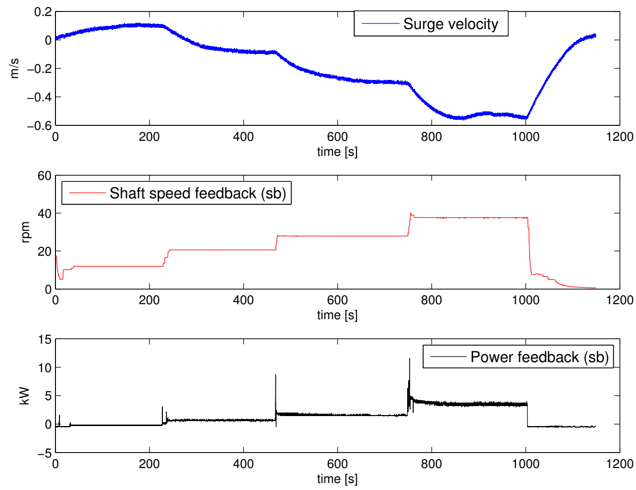

Figure 3: Step test in surge - backward velocity. Surge velocity (top, blue), shaft speed feedback for starboard thruster (red), and power feedback for starboard thruster (black). Power and shaft speed feedback is used to indicate when the input is applied. The steps shown in the figure are test number 0-5,5-10,10-15,15-20, and 20-0 (ref. Table Table 3, and 4).

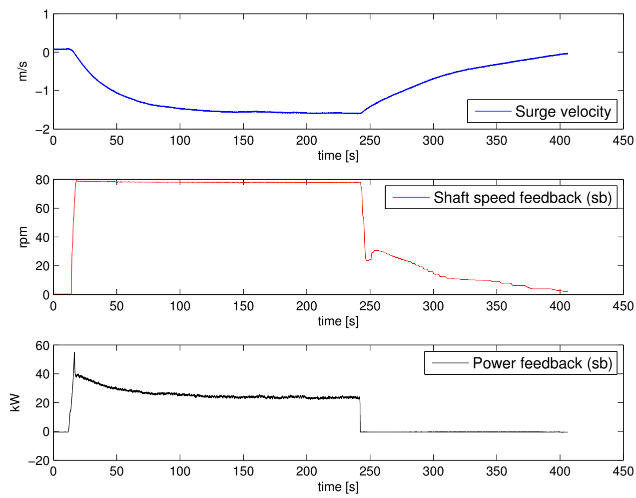

Figure 4: Step test in surge - backward velocity. Surge velocity (top, blue), shaft speed feedback for starboard thruster (red), and power feedback for starboard thruster (black). Power and shaft speed feedback is used to indicate when the input is applied. The step shown in the figure is for 0-40 (ref. Table 3, and 4).

Table 3: Surge step tests, backward speed - thrust and shaft speed time constants

Step mag. [%]	$T_n[s]$	$\delta_n[s]$	$T_{thrust}[s]$	$\delta_{thrust}[s]$
0-40	1.6	2.7	1.6	3.4
15-20	4.4	1.2	4.4	1.3
10-15	2.6	4.3	0.6	6.4
5-10	0.5	5.4	0.8	5.3
20-0	2.7	2.3	1.2	2.4

Table 4: Surge step tests, backward speed - speed time constants

Step mag. [%]	$T[s]$	$\delta[s]$
0-40	30.7	3.1
15-20	36.6	5.5
10-15	76.6	0.6
5-10	64.6	1.4
20-0	51.4	9.0

Sway step tests

For the sway step tests, step tests were performed for starboard and port side. For the starboard tests steps of thrust magnitude of [%] of $0-25\%$, $0-50\%$, $0-75\%$, $0-100\%$ and $100-0\%$ were run. For port side, all the same tests except $0-75\%$ were performed.

As seen from Figure (5) and 7 the surge velocity is considerable for the step tests. This is probably because of the thruster configuration. The vessel has one tunnel thruster, and two propellers in the stern, and the vessel needs a certain surge velocity to have full flexibility to move in sway. If only the tunnel thruster is used it would induce a moment that have to be counteracted by the stern propellers.

Due to the high surge velocity the total speed is used. That is,

$$\sqrt{v^2+u^2}, \tag{1}$$

where u and v are the surge and sway velocity, respectively. The plots for total speed, shown in Figure (5) and 7 indicate a clearer step response shape, but for some of the step tests, it does not seem like steady state is reached. The values found are therefore of lower quality. The values reported for starboard are found in Table 5 for the thrust, and shaft speed time constants, and in Table 6 for the speed time constants. For the port step response the values are found in Table 7 for the thrust time constants, and in Table 8 for the speed time constants.

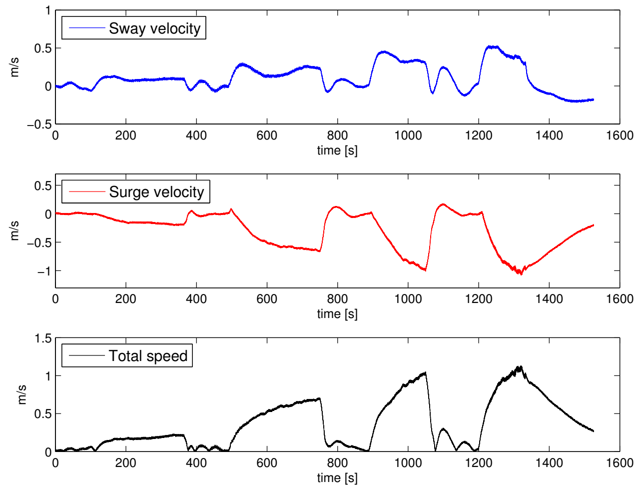

Figure 5: Step test in sway - starboard. Sway velocity (top, blue), surge velocity (red), and total speed (black). The steps shown in the figure are test number 0-25,0-50,0-75,0-100, and 100-0 of (ref. Table 5, and 6).

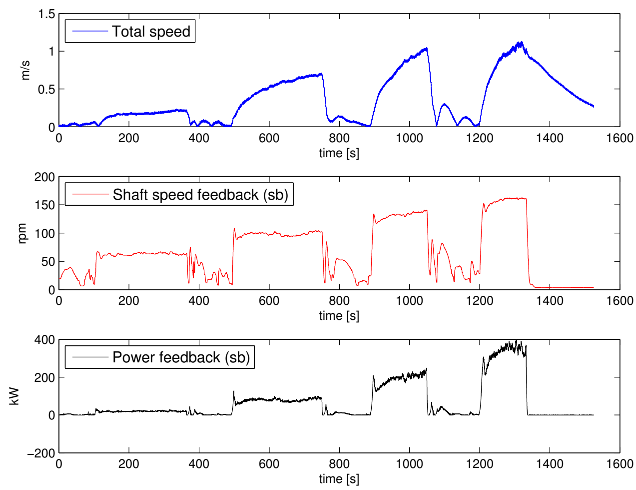

Figure 6: Step test in sway - starboard. Total speed (top, blue), shaft speed feedback for starboard thruster (red), and power feedback for starboard thruster (black). Power and shaft speed feedback is used to indicate when the input is applied. The steps shown in the figure are test number 0-25,0-50,0-75,0-100 (ref. Table 5, and 6).

Table 5: Sway step tests, starboard speed - thrust and shaft speed time constants for sb thruster

Step mag. [%]	$T_n[s]$	$\delta_n[s]$	$T_{thrust}[s]$	$\delta_{thrust}[s]$
0-100	4.7	3.3	4.4	4.9
0-75	3.9	2.7	3.5	4.1
0-50	2.5	3.0	2.5	3.8
0-25	2.1	1.2	1.2	2.7
100-0	4.2	1.6	2.8	1.1

Table 6: Sway step tests, main propellers, starboard - speed time constants

Step mag. [%]	$T[s]$	$\delta[s]$
0-100	10.7	2.7
0-75	12.5	2.6
0-50	15.6	1.1
0-25	14.4	4.0

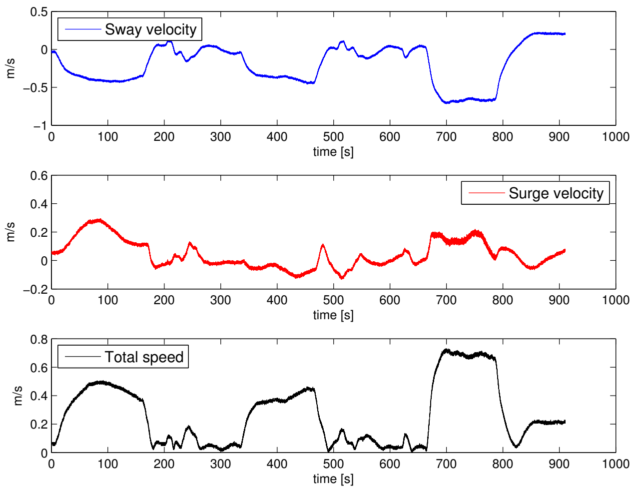

Figure 7: Step test in sway - port. Sway velocity (top, blue), surge velocity (red), and total speed (black). The steps shown in the figure are test number 0-25,0-50,0-100 (ref. Table 7, and 8).

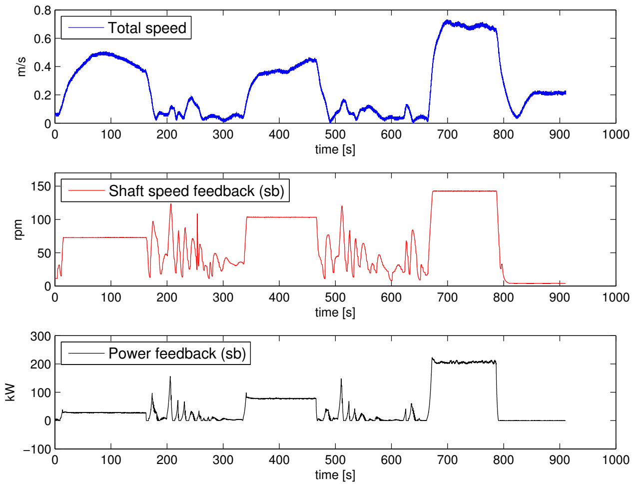

Figure 8: Step test in sway - port. Total speed (top, blue), shaft speed feedback for starboard thruster (red), and power feedback for starboard thruster (black). Power and shaft speed feedback is used to indicate when the input is applied. The steps shown in the figure are test number 0-25,0-50,0-100 (ref. Table 7, and 8).

For the port step responses, the shaft speed curve does not resemble a first order step response for 0-25, and the values for the thrust and shaft speed time constants should not be trusted as much.

Table 7: Sway port step tests - thrust and shaft speed time constants for port thruster

Step mag. [%]	$T_n[s]$	$\delta_n[s]$	$T_{thrust}[s]$	$\delta_{thrust}[s]$
0-100	4.5	2.9	4.0	5.0
0-50	2.4	2.9	2.7	3.2
0-25	1.0	3.4	1.1	3.4
100-0	4.2	1.5	2.7	1.0

Table 8: Sway step tests, main propellers, port - time constant

Step mag. [%]	$T[s]$	$\delta[s]$
0-100	9.0	2.5
0-50	12.8	1.3
0-25	18.8	1.0

Yaw step tests

Four yaw step tests were performed. Two where the vessel turned starboard (at speeds of 3 knots, and 6 knots), and two where the vessel turned port (at speeds of 3 knots, and 6 knots). For all the yaw step tests both the rudder angles are first stepped to 20 degrees, and then the rudders are stepped to their maximum angle (about 47 degrees). Notice for instance from Figure (9) that the step in rudder angle from 20 to 47 degrees gives an initial pulse in yaw rate, but does not significantly change the steady state yaw rate value. The yaw rate time constant found in Table (9) is for the step response from 0 to 20 degrees rudder angle, and for Table (10) for 47 to 0 degrees rudder angle. For the step from 20 to 47 degrees a time constant is not found since the response is so unclear and does not resemble a normal step response. The rudder angle change is used to indicate when a step is applied. All the steady state yaw rates oscillate after the new value is reached, and the steady state value is chosen as the observed mean value of this oscillation.

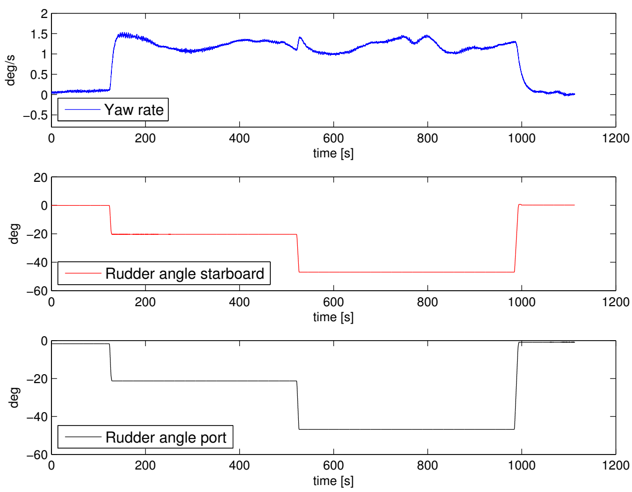

Figure 9: Step test in yaw - starboard at 3kn. Yaw rate (top, blue), rudder angle starboard (red), and rudder angle port (black). The steps shown in the figure are for rudder angle steps of 0-50 (ref. Table), 50-100, and 100-0 (ref. Table 9, 10, and 11).

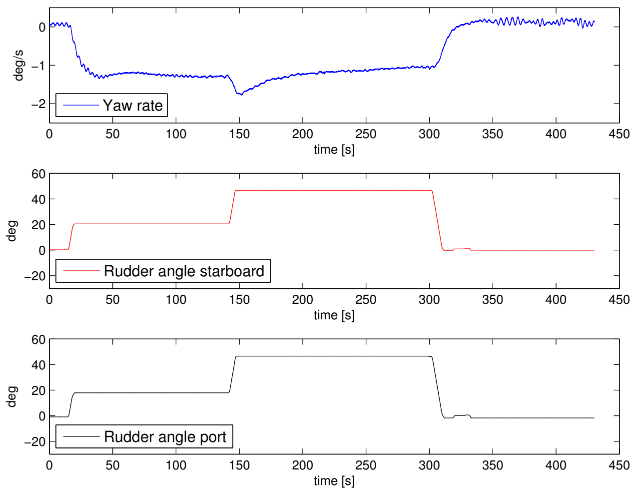

Figure 10: Step test in yaw - port at 3kn. Yaw rate (top, blue), rudder angle starboard (red), and rudder angle port (black). The steps shown in the figure are for rudder angle steps of 0-50 (ref. Table), 50-100, and 100-0 (ref. Table 9, 10, and 12).

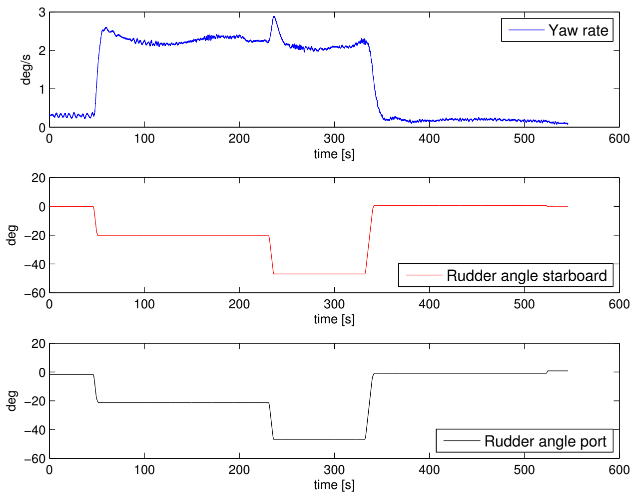

Figure 11: Step test in yaw - startboard at 6kn. Yaw rate (top, blue), rudder angle starboard (red), and rudder angle port (black). The steps shown in the figure are for rudder angle steps of 0-50, 50-100, and 100-0 (ref. Table 9, 10, and 13).

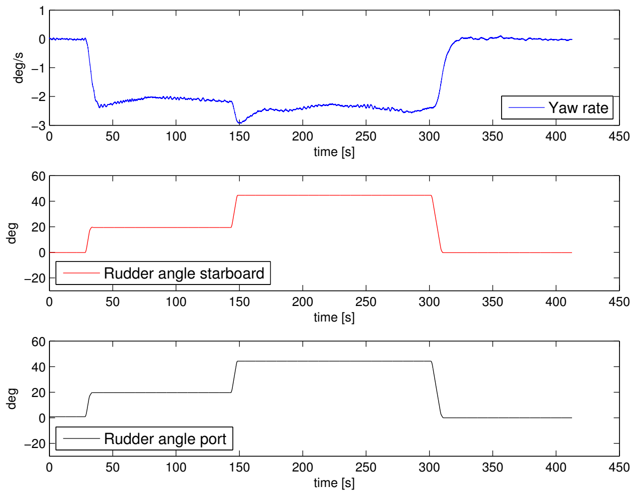

Figure 12: Step test in yaw - port at 6kn. Yaw rate (top, blue), rudder angle starboard (red), and rudder angle port (black). The steps shown in the figure are for rudder angle steps of 0-50, 50-100, and 100-0 (ref. Table 9, 10, and 14).

Yaw rate time constant The yaw rate time constants for $0-50[\%]$ and $100-0[\%]$ are shown in Table 9 and 10, respectively.

Table 9: Yaw step tests - time constant 0-50

Step 0-50 $[\%]$	$T[s]$	$\delta[s]$
Starboard, 3kn	4.7	2.1
Port, 3kn	5.6	2.0
Starboard, 6kn	2.9	2.0
Port, 6kn	3.0	1.9

Table 10: Yaw step tests - time constant 100-0

Step 100-0 $[\%]$	$T[s]$	$\delta[s]$
Starboard, 3kn	10.5	5.2
Port, 3kn	7.4	5.6
Starboard, 6kn	4.7	6.1
Port, 6kn	5.1	5.6

Rudder time constant Based on the plot of rudder angle, and assuming that the steps were applied when the rudder starts to change angle, the time constant is found for the rudder response for the different yaw maneuvers in the tables below.

Table 11: Yaw step tests - rudder time constant, starboard 3 kn

Step mag. [%]	$T_{sb}[s]$	δ_{sb}	$T_{port}[s]$	$\delta_{port}[s]$
0-50	1.8	0.8	1.7	1.3
50-100	2.4	1.0	2.3	1.0
100-0	4.2	1.4	4.2	1.5

Table 12: Yaw step tests - rudder time constant, port 3 kn

Step mag. [%]	$T_{sb}[s]$	δ_{sb}	$T_{port}[s]$	$\delta_{port}[s]$
0-50	1.8	0.9	2.0	0.7
50-100	2.4	1.0	2.4	1.2
100-0	4.2	1.4	4.4	1.5

Table 13: Yaw step tests - rudder time constant, starboard 6 kn

Step mag. [%]	$T_{sb}[s]$	δ_{sb}	$T_{port}[s]$	$\delta_{port}[s]$
0-50	1.8	1.0	1.8	1.0
50-100	2.1	1.2	2.3	1.1
100-0	4.2	1.5	4.1	1.5

Table 14: Yaw step tests - rudder time constant, port 6 kn

Step mag. [%]	$T_{sb}[s]$	δ_{sb}	$T_{port}[s]$	$\delta_{port}[s]$
0-50	1.8	0.9	1.7	1.0
50-100	2.3	1.1	2.3	1.0
100-0	4.1	1.4	4.1	1.4

0.1 Conclusions and further work

The data logging of this chapter is simple, but also not very accurate. The results all give a rough indication of performance of the system. The agility tests give a measure of response time. The DP 4 corner is prone to a small error when it comes to decide when the different parts of the maneuver is performed. For logging of thrust data for the pure DP logs, and the DP 4 corner, the thrust mapping is not accurate. On top of this, for the November sea trials, the rotational direction of the shaft speed is not known, so the thrust data is not very reliable.

A DP 4 corner for the new thruster configuration could give good indications on power consumption, and total (accumulated) thruster force. It is a drawback that so much data for the tunnel thruster is lacking. The pure DP tests of Section **??** should give some indication of how much thrust the tunnel thruster generate, and how much power it consumes.

However, because of this the DP 4 corner would only give a rough performance comparison. Also, the thrust mapping used is somewhat simple, and does not take loss effects into account. This means that the thrust force calculated is more accurate under normal (no significant thrust losses), and zero speed conditions. For the November sea trials the weather was quite calm, so the basis for comparison could be satisfactory, if the DP 4 corner tests for the new thruster system is also conducted under similarly calm conditions.

For further work similar tests should be run with the new thruster configuration, and the new tests should be performed under similar environmental conditions. For the agility plots, the DP 4 corner, and the pure DP maneuvers the values should be reported for the new system to compare. Similarly for the step tests it could be interesting to how the new thurster system responds, and how it makes R/V Gunnerus respond. For the step tests, especially for the sway step tests, longer tests should be run, such that it is certain that steady state is reached.