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# Manoeuvring behaviour of push convoys

Sub report 9
Additional verification of Class Va Vessel

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# Manoeuvring behaviour of push convoys

## Sub report 9 –
## Additional verification of Class Va Vessel

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# Abstract

This report describes the verification of the fast simulations for the Peche Melba (CEMT-) Class Va vessel. The discussion is based on results of steady and unsteady turning circle manoeuvres, performed with fast simulations. Available experimental data of captive tests are used to compare the results of fast time simulations. The analysis was focused on unsteady manoeuvres and in the transition from negative to positive velocities.

It was shown in previous reports that unsteady turning circle fast simulations show suddenly a drop in yaw rate near the change of sign of advance velocity from negative to positive[3]. Verification shows that the progression in tactical diameter on the steady turning circle manoeuvre was affected for the coefficient tuning performed to correct strange behaviour on the evolution of unsteady turning circles.

It is demonstrated that the yaw rate dropping is generated by a drastic drop on the propeller horizontal moment (Np). The propeller moment drop rises due to a rapidly crossing of the beta angle from the fourth to the fist quadrant on the NP coefficient table. In some cases, the values on the first quadrant near the limit of fourth quadrant are relatively high. This produces undesirable jumps and discontinuities on the transition from negative to positive speed. It is verified by using the experimental captive tests that in all cases the thrust predicted by the model was underestimated in the fourth quadrant. It was detected, as well, that in some cases the transversal rudder force during simulation was almost zero. This because the factor (1 + aH) that multiplies the transversal component was almost zero.

A proposal to correct these issues is presented and a preliminary fast time simulation set of standard manoeuvres is performed.

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# 1 Overview

It was shown in previous reports that unsteady turning circle fast time simulations show a sudden drop in yaw rate near the change of speed from negative to positive [3]. These drop becomes greater as the rudder angle and the initial negative speed increase. Another strange behavior that was detected is a final negative velocity for higher rudder angles.

*"In several conditions the rate of turn during these unsteady turning manoeuvres wasn't smooth. A drop of the rate of turn could be noticed. Starting with a negative speed, in some conditions it was not possible to reach a positive speed with the larger rudder angles. This was solved by reducing coefficient $F_X$. By reducing $N_P$, the drop issue of the rate of turn was improved. Additional to the reduction of $N_P$, a few outliers were removed in the tables YPBetaTabel and YPGammaTabel. "* [3]

The tuned coefficients to achieve a smoother yaw rate evolution and avoid a negative final speed corrected the behavior for the unsteady turning circle but affected the behavior for the steady turning circle maneuver (See Figure 1 and Figure 2). This study analyzes the possible sources for these strange responses verifying the evolution in time of the main variables involved and their behavior on the transition from backwards to forward. A revision of the involved coefficients is performed to verify possible discontinuities.

Figure 1 – Turning circle with tuned values

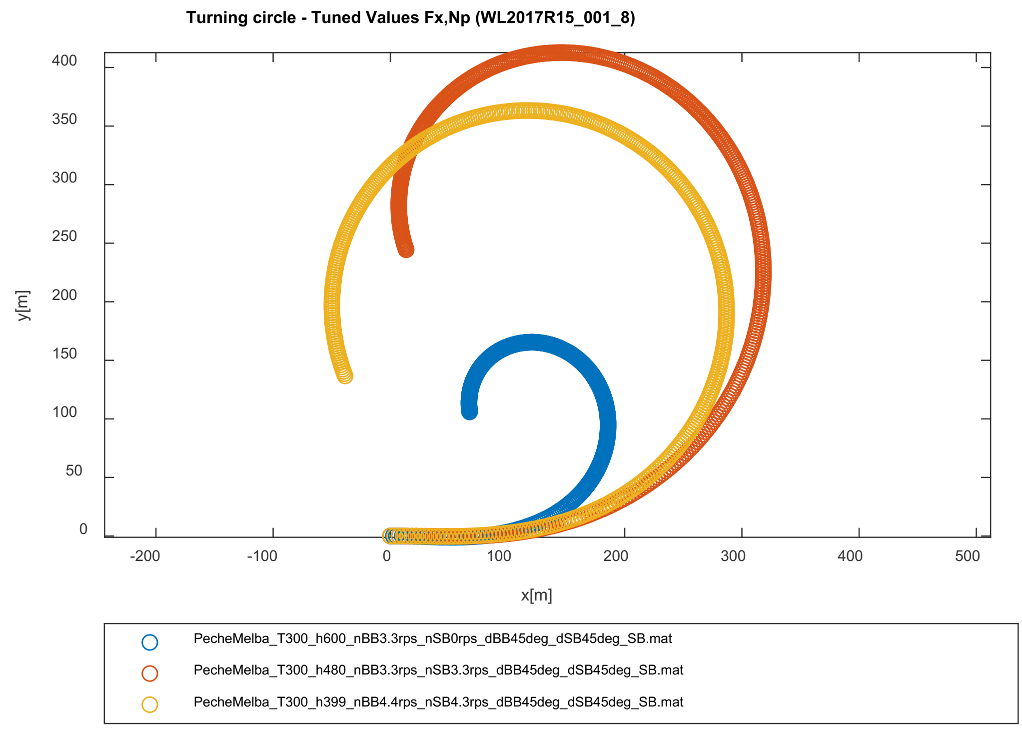
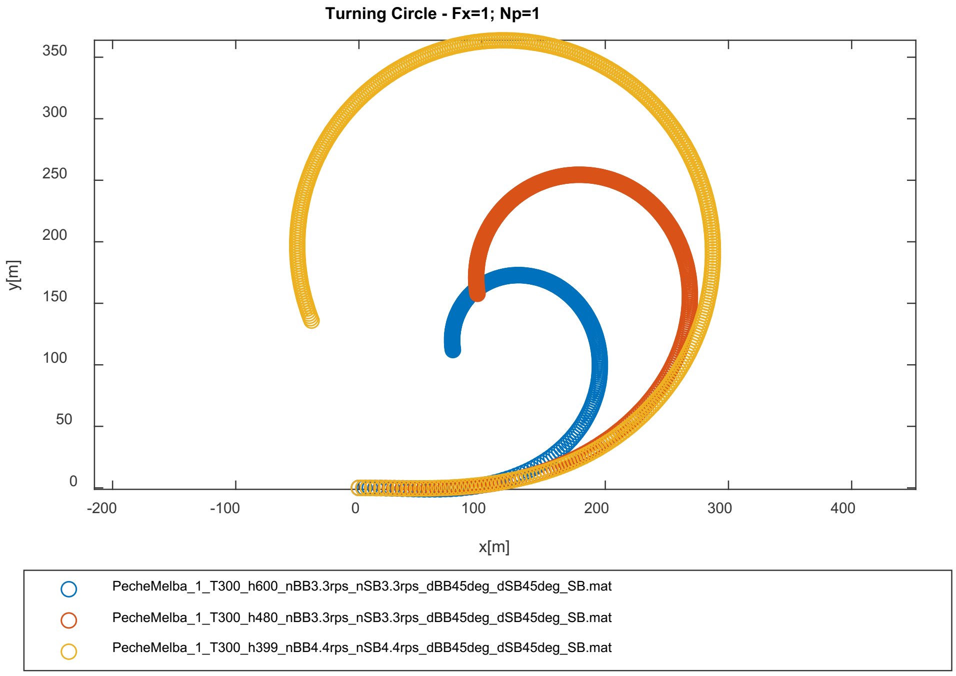
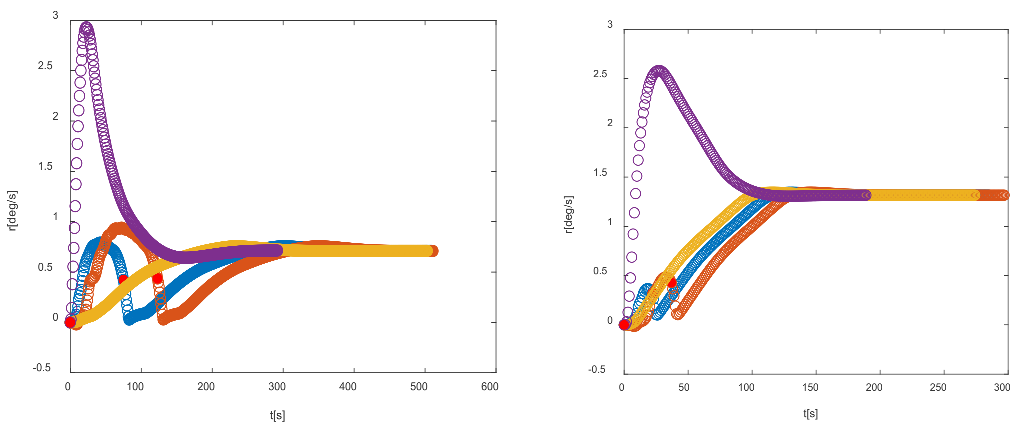


Figure 2 – Turning circle with Fx=1; Np=1 without tuned values.




In an unsteady turning circle maneuver, a significant transient behavior could be expected. As shown in Figure 3, the drop of the yaw rate starts around the time when the speed changes from negative to positive (red point).

Figure 3 – Yaw rate evolution with different initial speeds
Self-propulsion speed (purple), zero speed (yellow); -1knot (blue) and -2knots (orange)




In theory, combinations of forward speed and propeller action astern (and vice versa) (quadrants II and IV) generate oscillatory contributions in the lateral force and yaw moment. It is observed that these actions are not constant with time. These fluctuations contain an important slowly varying component with an amplitude whose order of magnitude is that of the propeller thrust.

# 2 Ship model's particulars

The ship model's particulars are presented in Table 1.

Table 1 – Main characteristics of Peche Melba

| Parameter | Peche Melba |
|---|---|
| Loa [m] | 110 |
| Lpp [m] | 108.6 |
| BWL [m] | 11.4 |
| T / $T_{fore}$[1] [m] | 3 |
| $T_{aft}$[2] [m] | 3 |
| Volume [m³] | 2871.95 |
| CB [-] | 0.773 |
| RM [kg] | 2943750 |
| XG [m] | 6.8 |
| RIXX [kg.m²] | 2943750 |
| RIYY [kg.m²] | 0.205E+10 |
| RIZZ [kg.m²] | 0.217E+10 |
| S [m²] | 1712 |
| GML [m] | 374.2 |
| GMT [m] | 3.07 |
| Nb propellers | 2 |
| Position bow thruster [m] | 53 |
| Power bow thruster [kW] | 350 |
| Position stern thruster [m] | / |
| Power stern thruster [kW] | / |
| $A_{WX}$ [m²] | 52 |
| $A_{WY}$ [m²] | 419 |

The vessel was modelled with one draft (3 m) and three under keel clearances (100%, 60%, 33%). Following telegraph positions were defined:

- Full: 330 rpm;
- Half: 264 rpm;
- Slow: 198 rpm;

[1] Fore: barge most in front
[2] Aft: barge closest to the pusher

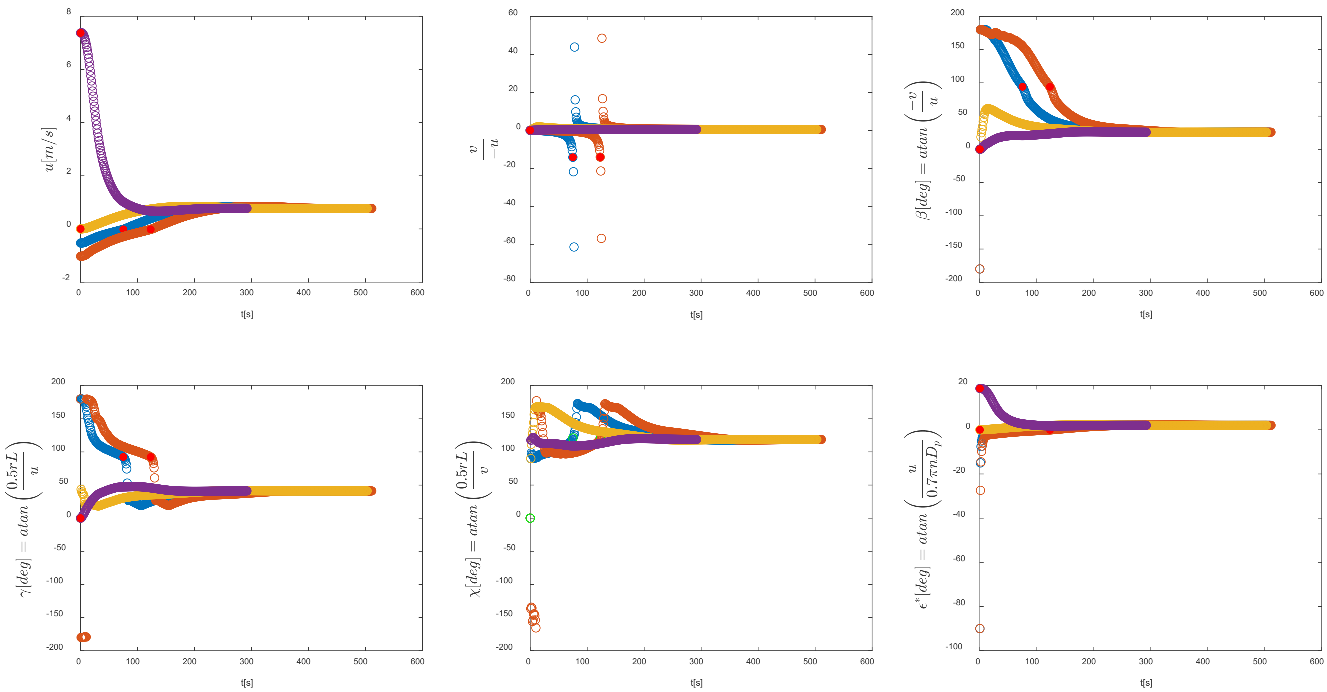
# 3 Fast time simulation analysis

## 3.1 Evolution of the hydrodynamic angles in an unsteady turning circle

In general, the mathematical expression for the calculation of angles are related to inverse tangents of relatives velocities ratios (i.e. u/v). During the unsteady turning circle maneuver, the maneuver starts with an initial negative speed. Due to the propeller action ahead, the speed increases crossing zero and reaches a final positive speed. Therefore, the velocities are quite small and tend to zero. It is expected that these values in the denominator generate large final values nearby zero speed. Figure 4 shows the jumps to very larges values near the zero speed (red point) on the (v\u) graph. For the calculation of the drift angle this jump does not cause any inconvenient because the function *atan* does not change much with very large values. Mind that a modified atan function is used in the mathematical model:

- atan(y/x) = atan1(y/x) for x > 0;
- atan(y/x) = atan1(y/x)+π for x < 0 and y > 0;
- atan(y/x) = atan1(y/x)-π for x < 0 and y < 0;
- atan(y/x) = π/2 for x = 0 and y > 0;
- atan(y/x) = -π/2 for x = 0 and y < 0.

Figure 4 – Evolution of hydrodynamic angles
Self-propulsion speed (purple), zero speed (yellow); -1knot (blue) and -2knots (orange)

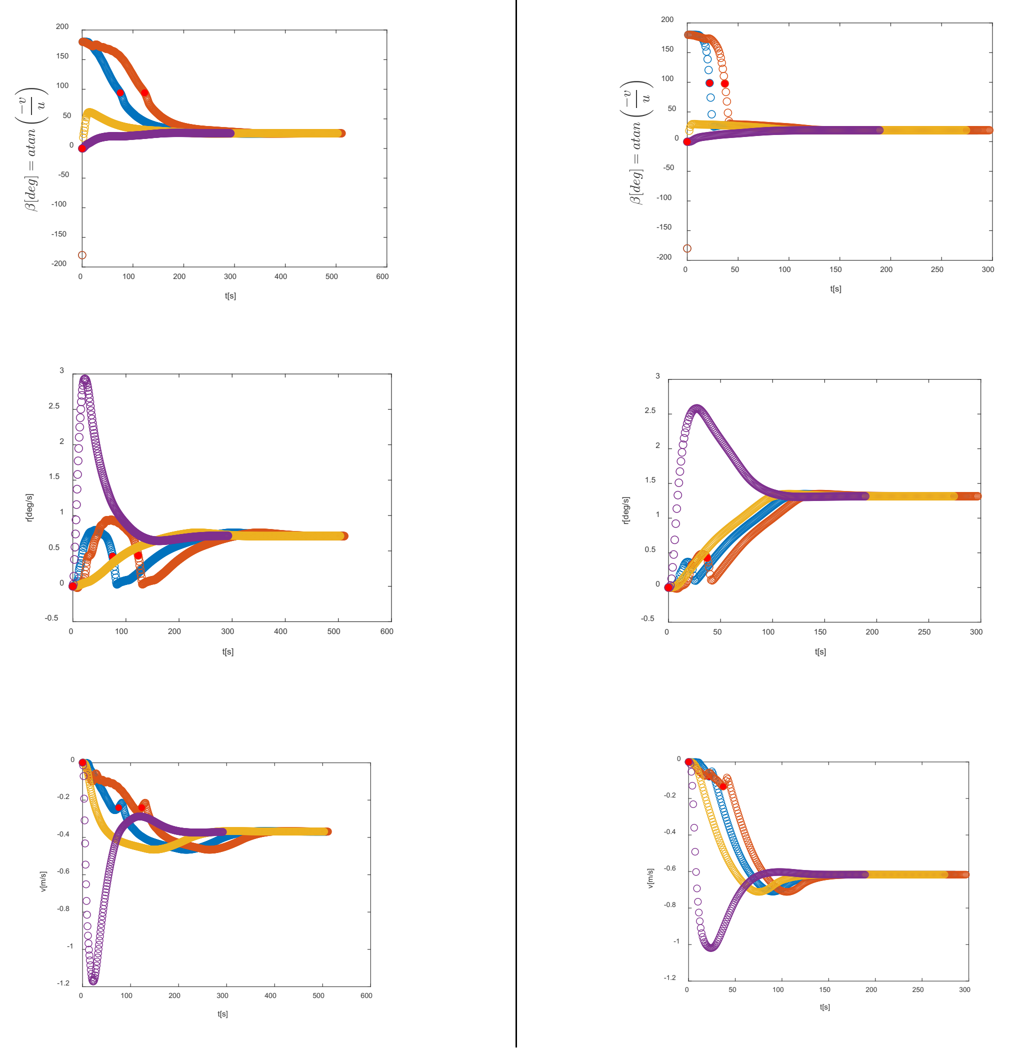


### 3.1.1 Drift angle

The transition from negative to positive ship speed makes the drift angle change from +/-180 deg (negative speed) to the final drift angle value. The velocity of this transition depends on the rudder angle and the rate of propeller. Figure 5 below shows the drift angle evolution for rudders angles of 60 and 35 degrees. The red point indicates the change from negative to positive ship speed.

Figure 5 – Drift angle, yaw rate and transversal velocity evolution for a rudder angle of 60deg (left) and 35deg(right)
Self-propulsion speed (purple), zero speed (yellow); -1knot (blue) and -2knots (orange)

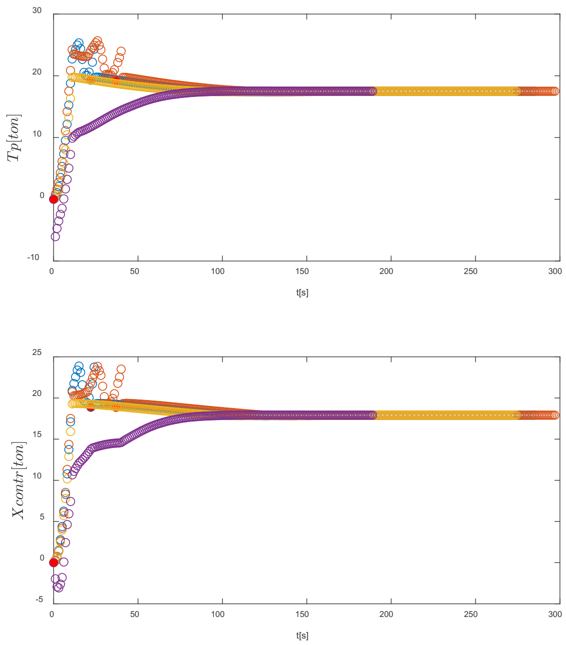
| Rudder angle 60deg | Rudder angle 35deg |
| --- | --- |



## 3.2 Propeller Forces

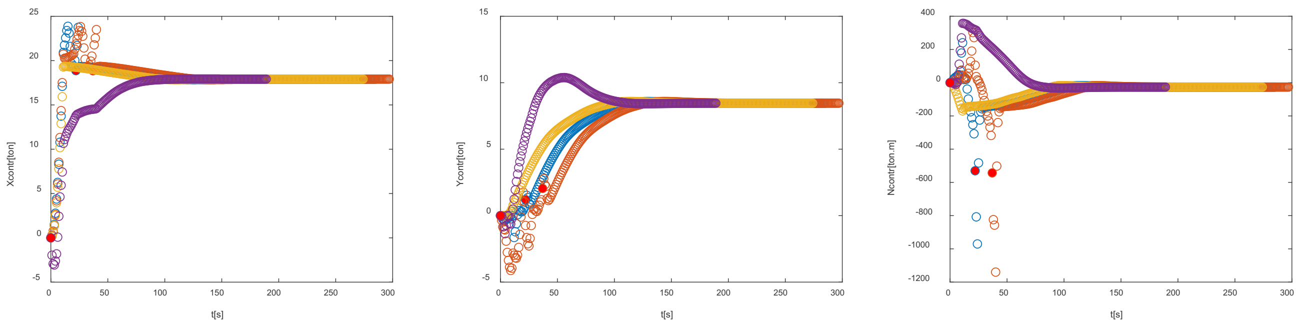
In relation to the propeller action, the longitudinal force of the propeller in unsteady turning circles is larger (with negative speed of advance) than the cases with zero or positive speed. A strange behavior is observed when the speed of the ship is still negative (Figure 6). An irregular oscillatory behavior occurs on the thrust for negative speeds of advance. The graph of the thrust coefficient in function of the loading propeller angle is irregular with negatives speeds, but quite continuous in the region where the simulation is performed (-5 to 5 deg of epsilon star). The bumps of the graph can't produce this irregular response. This needs further investigation.

Figure 6 – Thrust and longitudinal force on the turning circle
Self-propulsion speed (purple), zero speed (yellow); -1knot (blue) and -2knots (orange)




The modelling of the propeller horizontal moment has harmonics terms but it presents a sudden and very important negative peak that occurs on the transition from negative to positive speed (Figure 7). This could produce a drastic impact on the yaw rate. The reason for this behavior is investigated in detail.

Figure 7 – Propeller Forces and Moment
Self-propulsion speed (purple), zero speed (yellow); -1knot (blue) and -2knots (orange)



A verification of the evolution of the coefficients related with the moment due the propeller is performed.

$$N_P = \left|\frac{n}{n_{MAX}}\right| [N_{\dot{v}}^{n}\dot{v} + N_{\dot{r}}^{n}\dot{r}] + \left[[N_{PT}(\beta,\varepsilon^*) + N_{PT}(\gamma,\varepsilon^*)] + K_2 N_{PTA}(\varepsilon^*)\cos\big(\omega(\varepsilon^*)t + \varphi_N(\varepsilon^*)\big)\right] LT_P(\varepsilon^*)$$

Figure 8 shows the evolution of this coefficient NPT(beta, epsilon) as a function of the drift angle. The loading propeller angle (epsilon star) remains with values near to zero: negatives on the beginning and positives after the ahead motion begins. The tables related to NPT are partially shown in the region of interest to explain the interpolation on the boundary between quadrants IV and I (see Table 2).

Figure 8 also shows the problem of interface. It is quite obvious that the drop in rate of turn is because the drift angle crosses 110 deg and a large negative term enters to the range to be interpolated. Then, when the drift angle crosses the 90 deg occurs a jump to another group of greater negative values on the 1st Q. Depending on the value of these coefficients on the border the drops on the propeller moment can be more or less significant . The same occurs with NPT(gamma, epsilon_star) as is presented Figure 9 and Table 3. Furthermore it is surprising that exactly the same values are defined for NPTgamma and NPTbeta for respectively gamma and beta smaller than 90°.

This interface problem with high negative values could be one of the reasons to explain the sudden drop of NP around the change of speed direction.

Figure 8 – NPTbeta evolution and NPTbeta Tabel analysis (Rudder angle -60deg; V0=-2knots)

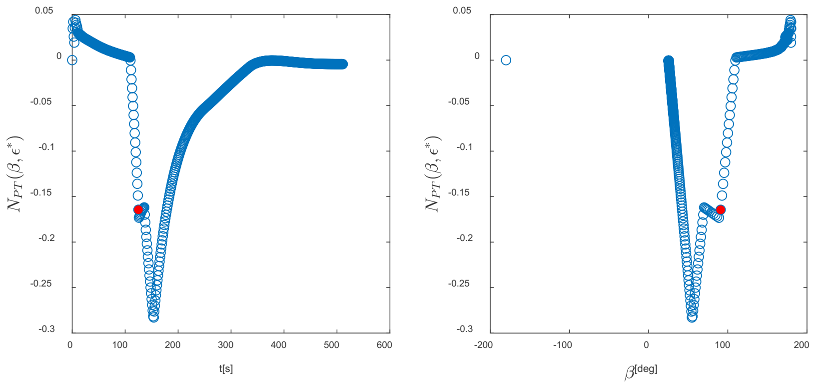



Table 2 – Extract of NPTbeta-table in wlmodel (eps* vs beta)

| | 25 | 40 | 55 | 70 | 90 | 110 | 125 | 140 |
|---|---|---|---|---|---|---|---|---|
| **-3** | 0 | 0 | 0 | 0 | 0.036272 | 0.036272 | 0.036272 | 0.036272 |
| **0** | 0.001965 | -0.14172 | -0.2854 | -0.1618 | -0.1739 | 0 | 0 | 0 |
| **90** | 0.001965 | -0.14172 | -0.2854 | -0.1618 | -0.1739 | 0 | 0 | 0 |

Figure 9 – NPTgamma evolution and NPTgamma Tabel analysis (Rudder angle -60deg; Initial speed=-2knots)

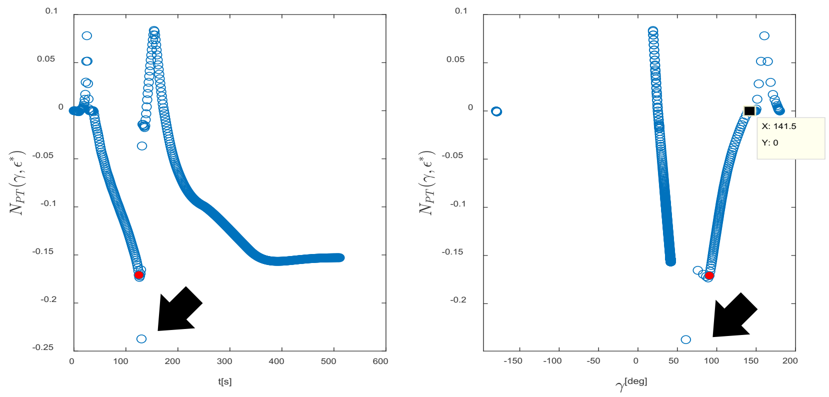



Table 3 – Extract of NPTgamma-table in wlmodel (eps* vs gamma)

| | 25 | 40 | 55 | 70 | 90 | 140 | 150 | 160 | 170 | 180 |
|---|---|---|---|---|---|---|---|---|---|---|
| **-3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0001 | -0.00906 | 0 |
| **0** | 0.001965 | -0.14172 | -0.2854 | -0.1618 | -0.1739 | 0 | 0 | 0.2292 | 0.080665 | 0 |
| **90** | 0.001965 | -0.14172 | -0.2854 | -0.1618 | -0.1739 | 0 | 0 | 0.2292 | 0.080665 | 0 |

Figure 10 shows the behavior of the sum of these two components. The drop is quite significant around the zero speed point and it will affect the propeller moment impacting on the yaw rate.

Figure 10 – Evolution of the sum of two NPT terms. UKC 100%
Self-propulsion speed (purple), zero speed (yellow); -1knot (blue) and -2knots (orange)

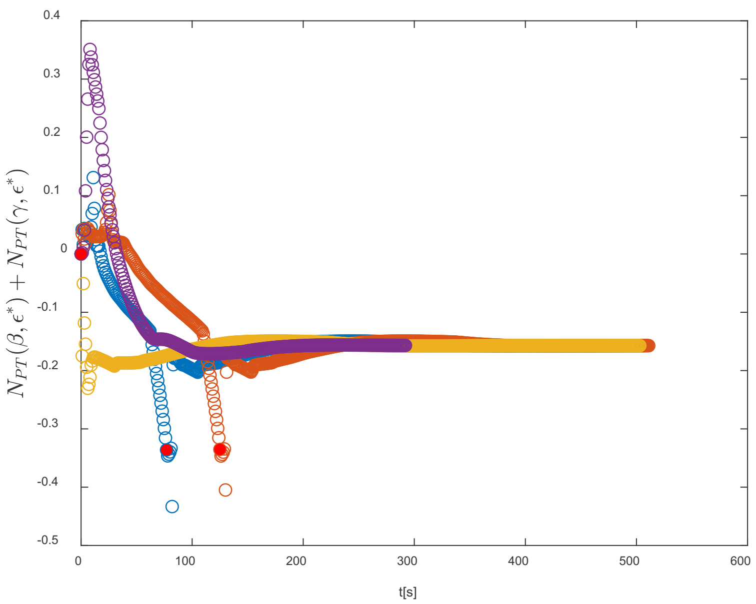
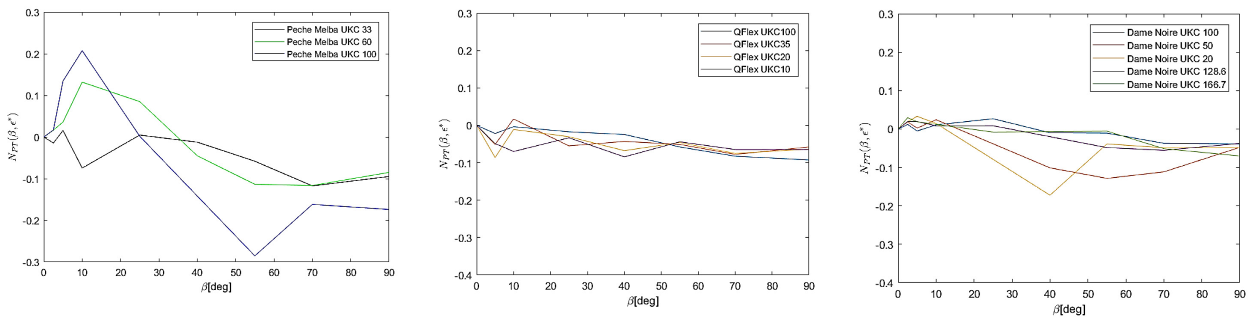



Figure 11 shows the values of the coefficients for the other conditions of the Peche Melba vessel. Figure 11, as well, shows the same coefficients for other models used as reference. It is possible to verify that near the border of the quadrant (90 deg) the values in other models do not reach -0.1. On the present case the values are higher, overall for UKC100. The drift angle changes rapidly and the interpolation could jump from different groups on the table. This generates discontinuities on the evolution of the calculation of coefficients in time.

Figure 11 – NPT values for the 1st Q of Peche Melba(left), QFlex(center) and Dame Noire (right)




The analysis of the evolution of NPT is performed for the other under keel clearances (60% and 33%). It was verified that the drop of the propeller moment happened in all cases but most pronounced in J1001A02 UKC100 . The results for the other cases are showed in Figures 12 to 15.

Figure 12 – Evolution of yaw rate, speed , force and moments. Peche Melba (-60deg) UKC 60%
Self-propulsion speed (purple), zero speed (yellow); -1knot (blue) and -2knots (orange)

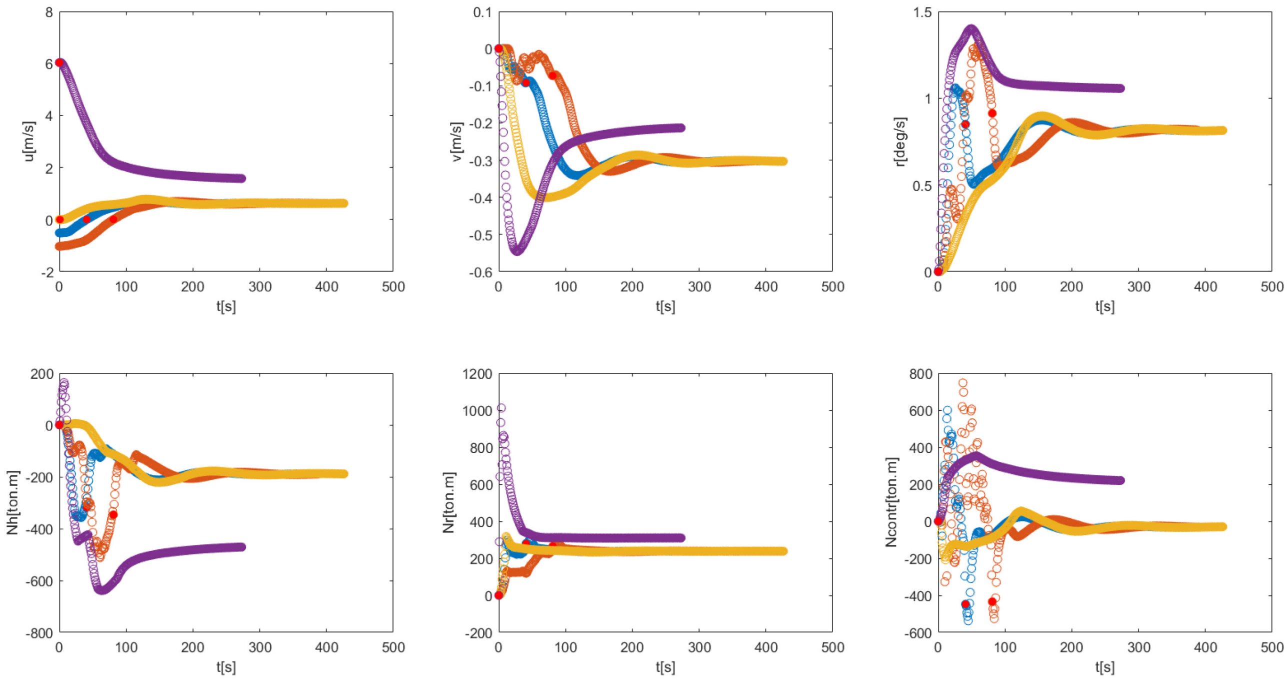


Figure 13 – Evolution of the sum of two NPT terms. UKC 60%
Self-propulsion speed (purple), zero speed (yellow); -1knot (blue) and -2knots (orange)

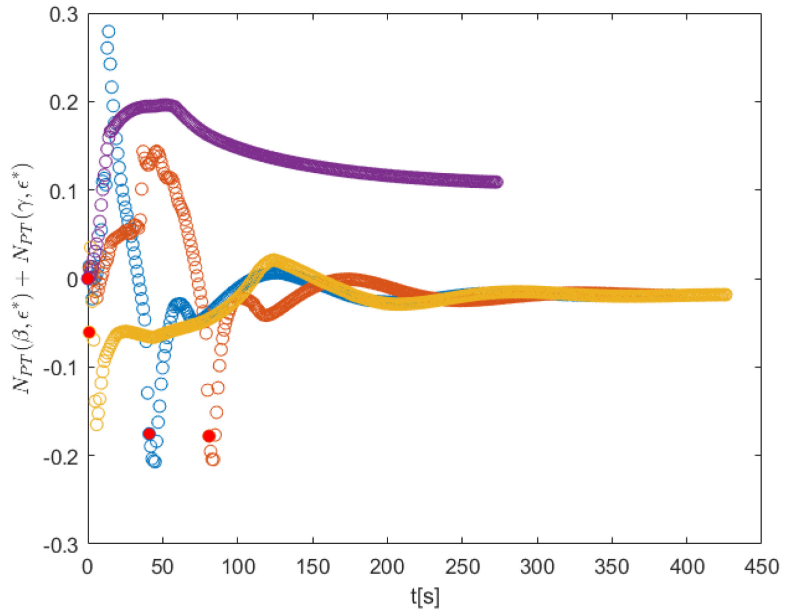



Figure 14 – Evolution of yaw rate, speed , force and moments. Peche Melba (-60deg) UKC 33%
Self-propulsion speed (purple), zero speed (yellow); -1knot (blue) and -2knots (orange)

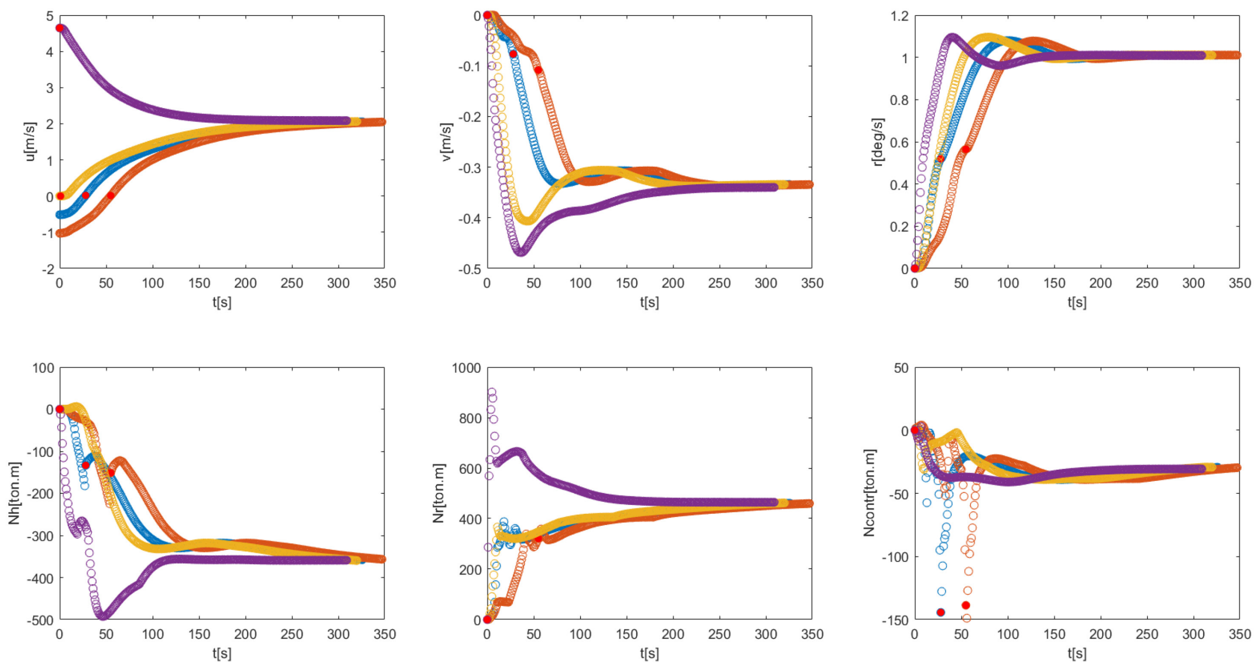
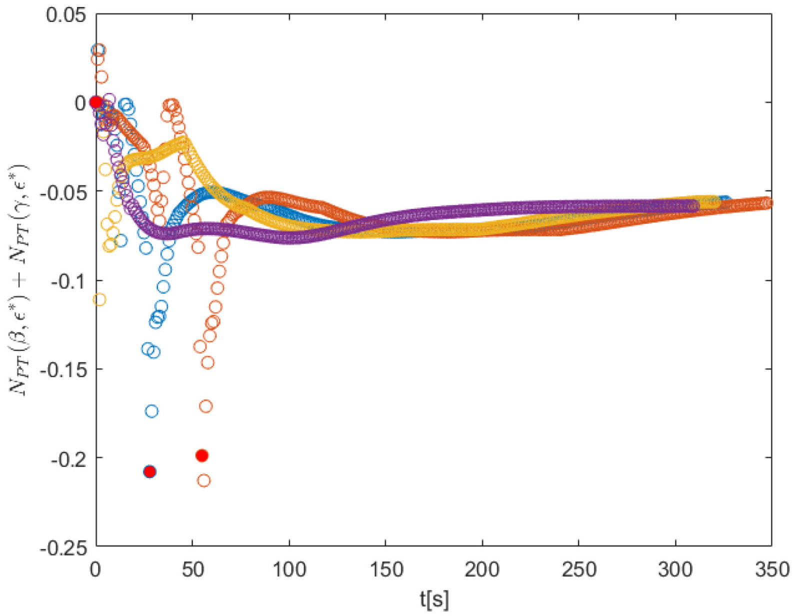


Figure 15 – Evolution of the sum of two NPT terms. (-60deg) UKC 33%
Self-propulsion speed (purple), zero speed (yellow); -1knot (blue) and -2knots (orange)



# 4 Analysis of captive tests simulations (4thQ)

In order to investigate the negative longitudinal forces that occur during the unsteady turning circle maneuvering, the results of the captive model tests with different rudder angles and constant rate propeller were compared with the results of the fast-time simulation with the same conditions using the replay mode. In some cases, the propeller thrust and/or the transversal rudder force are underestimated. Variations on values of XP and aH were performed on the simulations and results are shown in each case.

## 4.1 J1001A02 – 100UKC

Figure 16 shows the results of comparison between the experiment and simulation. A modification of the parameter aH on the fourth quadrant was performed in order to get a better fitting between the transversal rudder force and the available experimental data (see Figure 17). The thrust on all the comparisons of steady experimental tests was underestimated. This needs further investigation. A factor of 1.2 is applied to the longitudinal thrust force. The transversal global force[3] is underestimated on the fourth quadrant.

Figure 17 shows that simulated global longitudinal force is underestimated for all the tested rudder angles.

The transversal forces of the rudder on the cases with constant negative speed are underestimated with values near to zero. The calculation of the transversal component is related with the term:

$$Y_R = \left(1 + a_H(\varepsilon^*, \beta)\right) F_Y$$

The aH is modeled by a 2D Table. Values of the interest zone are plotted on Table 2. For negative velocity the value of eps* is negative as well. On the analyzed cases the drift angle is 25deg. The table shows in orange the aH values for negative eps*. In consequence, the value of FY is multiplied for a value very small, almost zero.

Table 4 – original aH Table (eps* vs beta)

| | -180 | -90 | -70 | -55 | -40 | -25 | -10 | -5 | -2.5 | 0 | 2.5 | 5 | 10 | 25 | 40 | 55 | 70 | 90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -85 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 |
| -2 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 | -0.99 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0.681 | 0.362 | 0.042 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.042 | 0.362 | 0.681 | 0 | 0 |
| 2 | 0 | 0 | 0 | 1.357 | 0.721 | 0.085 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.085 | 0.721 | 1.357 | 0 | 0 |
| 3 | 0 | 0 | 0 | 2.028 | 1.078 | 0.128 | 0 | 0 | 0.025 | 0 | 0.025 | 0 | 0 | 0.128 | 1.078 | 2.028 | 0 | 0 |
| 4 | 0 | 0 | 0 | 2.693 | 1.432 | 0.171 | 0 | 0 | 0.077 | 0 | 0.077 | 0 | 0 | 0.171 | 1.432 | 2.693 | 0 | 0 |

The regression on fourth quadrant is performed by using:

$$Y_{RP} = (1 + a_H) \sum F_{Yi} + Y_{PT}(\gamma) \sum T_{Pi} + \frac{n}{n_{MAX}} \left[ Y_{\dot{v}}^{n} \dot{v} m + Y_{\dot{r}}^{n} \dot{r} m L \right]$$

[3] In this document, we will use the term “Longitudinal or transversal global force” as the component of the resultant force applied to the ship either calculated in the simulation or measured in the experiment.

Figure 16 – J1001A02 - Simulation vs Experiment. V=-3.5knots,960 rpm, psi=25deg (Before modification)

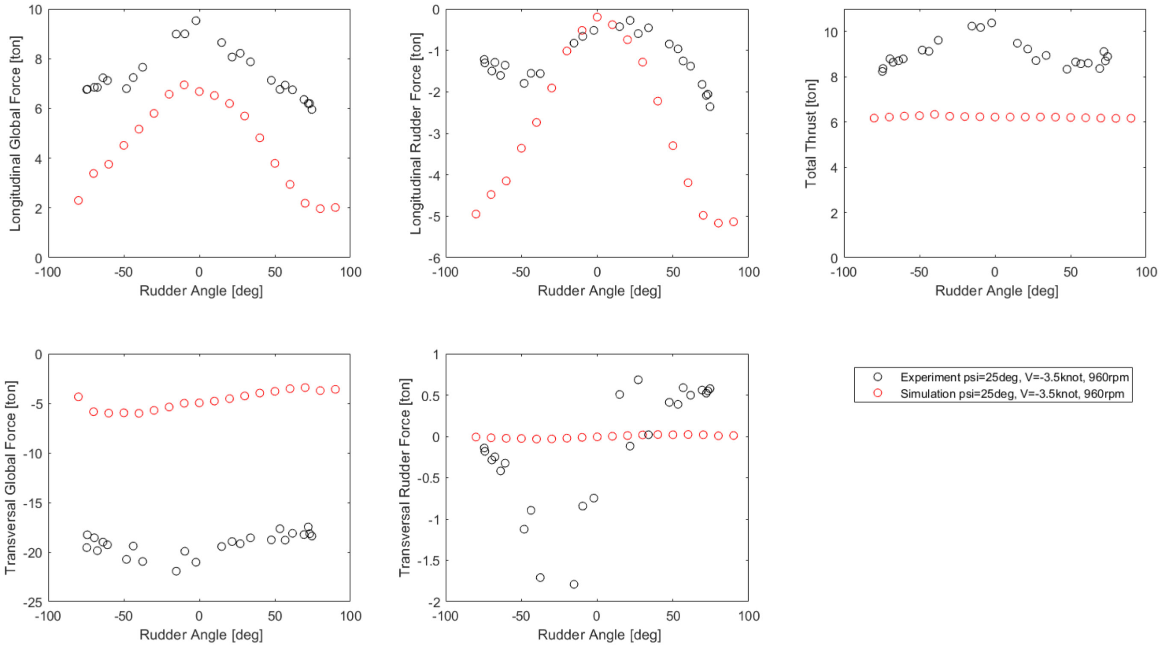
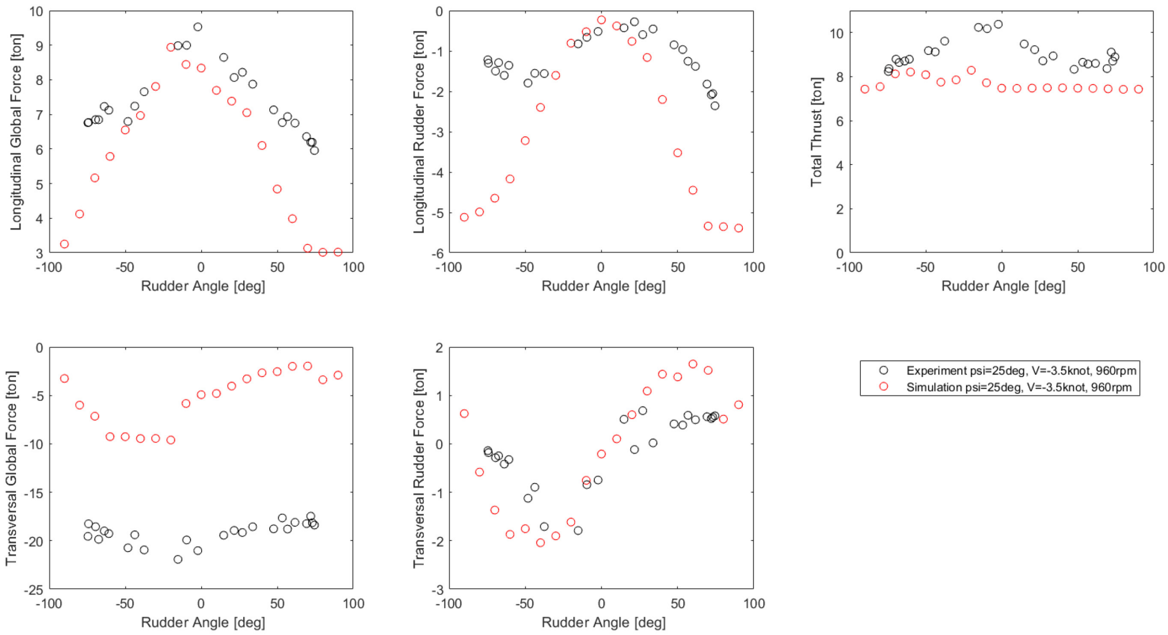



Figure 17 – J1001A02 - Simulation vs Experiment. V=-3.5knots,960 rpm, psi=25deg (After modification)



## 4.2 J1001A03 – 60UKC

Thrust and global longitudinal force are underestimated. The factor XP was increased to 1.1 in order to fit the propeller thrust with the experiment. The final global longitudinal force shows a better fitting after the modification (Figure 18 and Figure 19).

Figure 18 – J1001A03 – 60UKC - Simulation vs Experiment (Before modification)

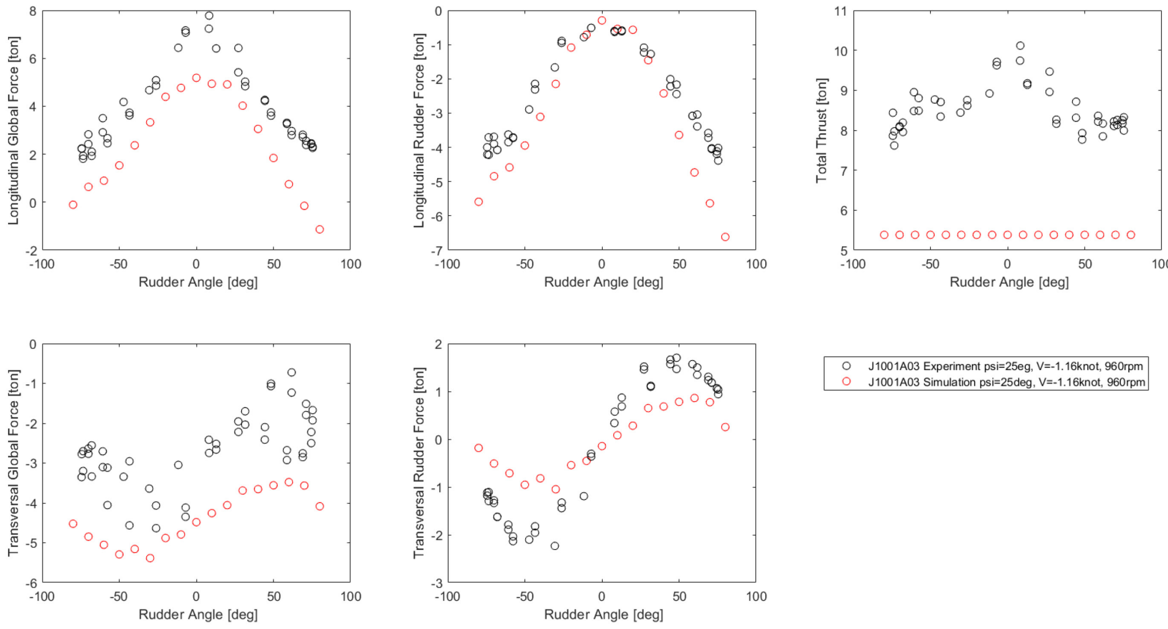
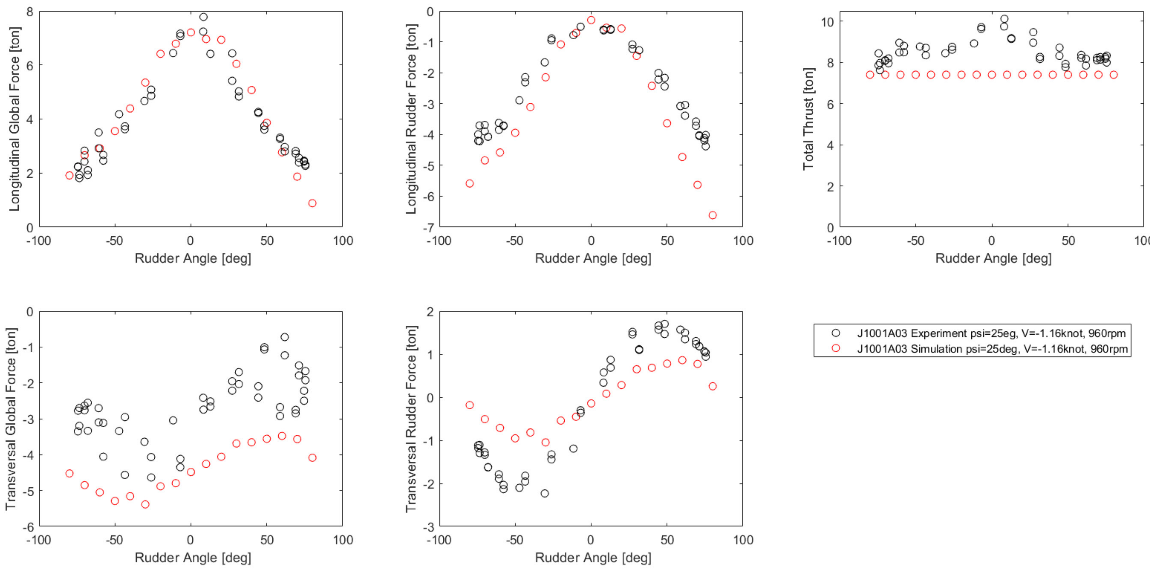



Figure 19 – J1001A03 – 60UKC - Simulation vs Experiment (Before modification)



## 4.3 J1001A04 – 33UKC

In the 4th quadrant the transversal rudder forces are underestimated. This does not occur in the first quadrant. The value of aH was changed to -0.3155 in the fourth quadrant to fit the rudder transversal forces with the experiment. The thrust is underestimated in both the 1st and 4th quadrant. The global longitudinal force tends to be underestimated at large rudder angles. The factor XP was increased to **1.3** in order to fit the propeller thrust with the experiment and to avoid negative longitudinal forces(Figure 20 and Figure 21).

Figure 20 – J1001A04 – 33UKC - Simulation vs Experiment – 4th Quadrant (Before modification)

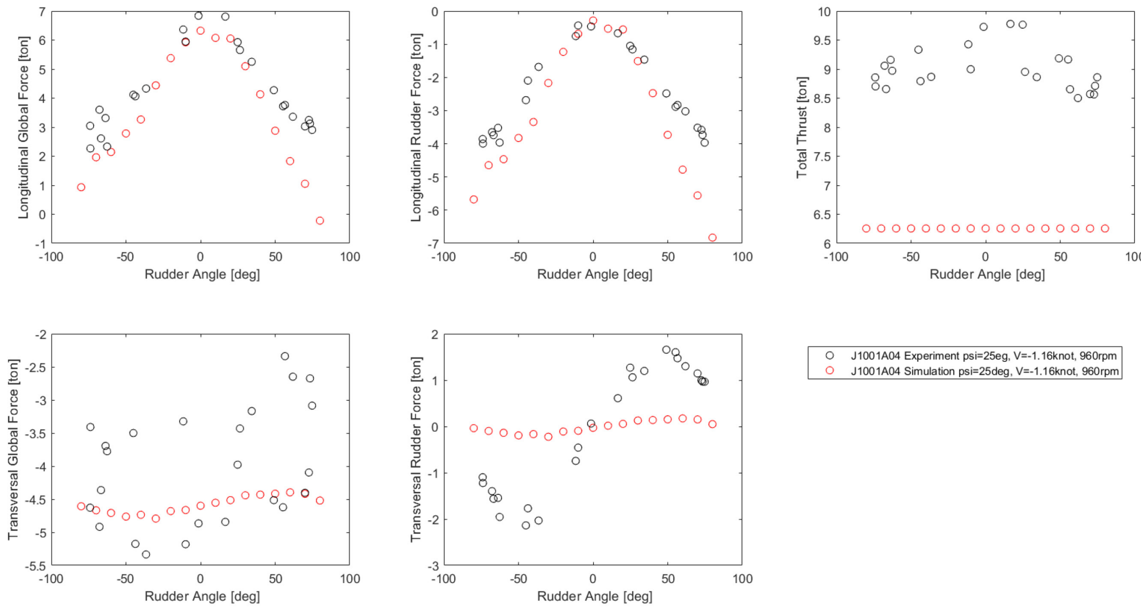
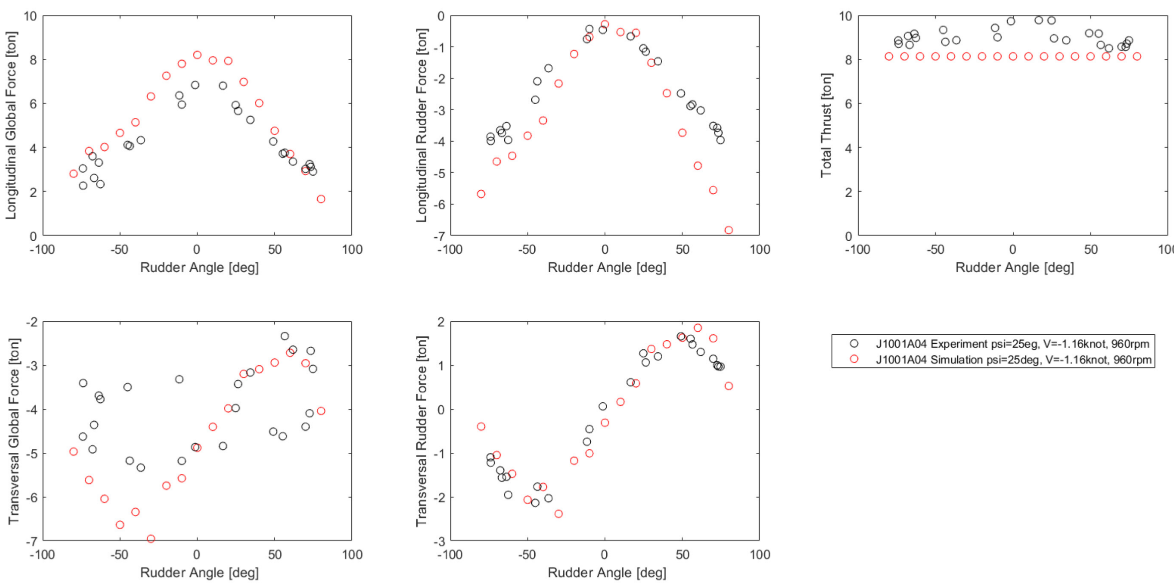



Figure 21 – J1001A04 – 33UKC - Simulation vs Experiment – 4th Quadrant (After modification)



# 5 Proposal for modification

## 5.1 Modification of NPT beta Table

The changed values are on the boundary between the 1st and 4th quadrant. Values were taken of the QFLEX model for the same under keel clearance. For details, see Section 3.2.

### 5.1.1 J1001A02 – Original NPT beta Table

Table 5 – J1001A02. Original NPT beta Table

| | -180 | -170 | -155 | -140 | -125 | -110 | -90 | -70 | -55 | -40 | -25 | -10 | -5 | -2.5 | 0 | 2.5 | 5 | 10 | 25 | 40 | 55 | 70 | 90 | 110 | 125 | 140 | 155 | 170 | 180 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **-180** | 0 | -0.05628 | -0.1324 | -0.0331 | -0.01655 | -0.00946 | -0.00473 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.004729 | 0.009457 | 0.01655 | 0.0331 | 0.1324 | 0.05628 | 0 |
| **-90** | 0 | -0.05628 | -0.1324 | -0.0331 | -0.01655 | -0.00946 | -0.00473 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.004729 | 0.009457 | 0.01655 | 0.0331 | 0.1324 | 0.05628 | 0 |
| **-89** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **-12** | 0.04353 | 0.04353 | 0.04353 | 0.04353 | 0.04353 | 0.04353 | 0.04353 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04353 | 0.04353 | 0.04353 | 0.04353 | 0.04353 | 0.04353 | 0.04353 |
| **-8** | 0.01186 | 0.01186 | 0.01186 | 0.01186 | 0.01186 | 0.01186 | 0.01186 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01186 | 0.01186 | 0.01186 | 0.01186 | 0.01186 | 0.01186 | 0.01186 |
| **-5** | 0.04472 | 0.04472 | 0.04472 | 0.04472 | 0.04472 | 0.04472 | 0.04472 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04472 | 0.04472 | 0.04472 | 0.04472 | 0.04472 | 0.04472 | 0.04472 |
| **-3** | 0.036272 | 0.036272 | 0.036272 | 0.036272 | 0.036272 | 0.036272 | 0.036272 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.036272 | 0.036272 | 0.036272 | 0.036272 | 0.036272 | 0.036272 | 0.036272 |
| **0** | 0 | 0 | 0 | 0 | 0 | 0 | 0.1739 | 0.1618 | 0.2854 | 0.141718 | -0.00197 | -0.2075 | -0.1345 | -0.01698 | 0 | 0.01698 | 0.1345 | 0.2075 | 0.001965 | -0.14172 | -0.2854 | -0.1618 | -0.1739 | 0 | 0 | 0 | 0 | 0 | 0 |
| **90** | 0 | 0 | 0 | 0 | 0 | 0 | 0.1739 | 0.1618 | 0.2854 | 0.141718 | -0.00197 | -0.2075 | -0.1345 | -0.01698 | 0 | 0.01698 | 0.1345 | 0.2075 | 0.001965 | -0.14172 | -0.2854 | -0.1618 | -0.1739 | 0 | 0 | 0 | 0 | 0 | 0 |
| **91** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **171** | 0 | 0 | 0 | 0 | 0 | 0 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | 0 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | 0 | 0 | 0 | 0 | 0 | 0 |
| **175** | 0 | 0 | 0 | 0 | 0 | 0 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0 | 0 | 0 | 0 | 0 | 0 |
| **177** | 0 | 0 | 0 | 0 | 0 | 0 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | 0 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | 0 | 0 | 0 | 0 | 0 | 0 |
| **180** | -0.00553 | 0 | 0 | -0.0331 | -0.01655 | -0.00946 | -0.00473 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | 0 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | -0.00473 | -0.00946 | -0.01655 | -0.0331 | 0 | 0 | -0.00553 |

### 5.1.2 J1001A02 – Modified NPT beta Table

Table 6 – J1001A02 Modified NPT beta Table

| | -180 | -170 | -155 | -140 | -125 | -110 | -90 | -70 | -55 | -40 | -25 | -10 | -5 | -2.5 | 0 | 2.5 | 5 | 10 | 25 | 40 | 55 | 70 | 90 | 110 | 125 | 140 | 155 | 170 | 180 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **-180** | 0 | -0.05628 | -0.1324 | -0.0331 | -0.01655 | -0.00946 | -0.00473 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.004729 | 0.009457 | 0.01655 | 0.0331 | 0.1324 | 0.05628 | 0 |
| **-90** | 0 | -0.05628 | -0.1324 | -0.0331 | -0.01655 | -0.00946 | -0.00473 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.004729 | 0.009457 | 0.01655 | 0.0331 | 0.1324 | 0.05628 | 0 |
| **-89** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **-12** | 0.04353 | 0.04353 | 0.04353 | 0.04353 | 0.04353 | 0.04353 | 0.04353 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04353 | 0.04353 | 0.04353 | 0.04353 | 0.04353 | 0.04353 | 0.04353 |
| **-8** | 0.01186 | 0.01186 | 0.01186 | 0.01186 | 0.01186 | 0.01186 | 0.01186 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01186 | 0.01186 | 0.01186 | 0.01186 | 0.01186 | 0.01186 | 0.01186 |
| **-5** | 0.04472 | 0.04472 | 0.04472 | 0.04472 | 0.04472 | 0.04472 | 0.04472 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04472 | 0.04472 | 0.04472 | 0.04472 | 0.04472 | 0.04472 | 0.04472 |
| **-3** | 0.036272 | 0.036272 | 0.036272 | 0.036272 | 0.036272 | 0.036272 | 0.036272 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.036272 | 0.036272 | 0.036272 | 0.036272 | 0.036272 | 0.036272 | 0.036272 |
| **0** | 0 | 0 | 0 | 0 | 0 | 0 | 0.09262 | 0.082455 | 0.057775 | 0.024465 | -0.00197 | -0.2075 | -0.1345 | -0.01698 | 0 | 0.01698 | 0.1345 | 0.2075 | 0.001965 | -0.02447 | -0.05778 | -0.08246 | -0.09262 | 0 | 0 | 0 | 0 | 0 | 0 |
| **90** | 0 | 0 | 0 | 0 | 0 | 0 | 0.09262 | 0.082455 | 0.057775 | 0.024465 | -0.00197 | -0.2075 | -0.1345 | -0.01698 | 0 | 0.01698 | 0.1345 | 0.2075 | 0.001965 | -0.02447 | -0.05778 | -0.08246 | -0.09262 | 0 | 0 | 0 | 0 | 0 | 0 |
| **91** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **171** | 0 | 0 | 0 | 0 | 0 | 0 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | 0 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | -0.0029 | 0 | 0 | 0 | 0 | 0 | 0 |
| **175** | 0 | 0 | 0 | 0 | 0 | 0 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0.01734 | 0 | 0 | 0 | 0 | 0 | 0 |
| **177** | 0 | 0 | 0 | 0 | 0 | 0 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | 0 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | -0.00084 | 0 | 0 | 0 | 0 | 0 | 0 |
| **180** | -0.00553 | 0 | 0 | -0.0331 | -0.01655 | -0.00946 | -0.00473 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | 0 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | -0.00181 | -0.00473 | -0.00946 | -0.01655 | -0.0331 | 0 | 0 | -0.00553 |

## 5.2 Modification of NPT gamma Table

The changed values are in the 4th quadrant. The values (J1001A02) were too large in relation with the other under keel clearances (J1001A03, J1001A04). Extrapolated values were inserted. The modification of the values in the 1st quadrant is in accordance with the NPT beta changes.

### 5.2.1 J1001A02 – Original NPT gamma Table

Table 7 – J1001A02 – Original NPT gamma Table

| | -180 | -170 | -160 | -150 | -140 | -90 | -70 | -55 | -40 | -25 | -10 | -5 | -2.5 | 0 | 2.5 | 5 | 10 | 25 | 40 | 55 | 70 | 90 | 140 | 150 | 160 | 170 | 180 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **-180** | 0 | 0.1867 | 0.5301 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.53 | -0.187 | 0 |
| **-90** | 0 | 0.1867 | 0.5301 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.53 | -0.187 | 0 |
| **-89** | 0 | -0.009 | 0.0001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0001 | -0.009 | 0 |
| **-12** | 0 | -0.009 | 0.0001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0001 | -0.009 | 0 |
| **-8** | 0 | -0.009 | 0.0001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0001 | -0.009 | 0 |
| **-5** | 0 | -0.009 | 0.0001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0001 | -0.009 | 0 |
| **-3** | 0 | -0.009 | 0.0001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0001 | -0.009 | 0 |
| **0** | 0 | -0.081 | -0.229 | 0 | 0 | 0.1739 | 0.1618 | 0.2854 | 0.1417 | -0.002 | -0.208 | -0.135 | -0.017 | 0 | 0.017 | 0.1345 | 0.2075 | 0.002 | -0.142 | -0.285 | -0.162 | -0.174 | 0 | 0 | 0.2292 | 0.0807 | 0 |
| **90** | 0 | -0.081 | -0.229 | 0 | 0 | 0.1739 | 0.1618 | 0.2854 | 0.1417 | -0.002 | -0.208 | -0.135 | -0.017 | 0 | 0.017 | 0.1345 | 0.2075 | 0.002 | -0.142 | -0.285 | -0.162 | -0.174 | 0 | 0 | 0.2292 | 0.0807 | 0 |
| **91** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **171** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **175** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **177** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **180** | 0 | -0.017 | -0.026 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.026 | -0.017 | 0 |

### 5.2.2 J1001A02 – Modified NPT gamma Table

Table 8 – J1001A02 – Modified NPT gamma Table

| | -180 | -170 | -160 | -150 | -140 | -90 | -70 | -55 | -40 | -25 | -10 | -5 | -2.5 | 0 | 2.5 | 5 | 10 | 25 | 40 | 55 | 70 | 90 | 140 | 150 | 160 | 170 | 180 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **-180** | 0 | -0.056 | -0.08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0801 | 0.056 | 0 |
| **-90** | 0 | -0.056 | -0.08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0801 | 0.056 | 0 |
| **-89** | 0 | -0.009 | 0.0001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0001 | -0.009 | 0 |
| **-12** | 0 | -0.009 | 0.0001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0001 | -0.009 | 0 |
| **-8** | 0 | -0.009 | 0.0001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0001 | -0.009 | 0 |
| **-5** | 0 | -0.009 | 0.0001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0001 | -0.009 | 0 |
| **-3** | 0 | -0.009 | 0.0001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0001 | -0.009 | 0 |
| **0** | 0 | 0 | 0 | 0 | 0 | 0.0926 | 0.0825 | 0.0578 | 0.0245 | -0.002 | -0.208 | -0.135 | -0.017 | 0 | 0.017 | 0.1345 | 0.2075 | 0.002 | -0.024 | -0.058 | -0.082 | -0.093 | 0 | 0 | 0 | 0 | 0 |
| **90** | 0 | 0 | 0 | 0 | 0 | 0.0926 | 0.0825 | 0.0578 | 0.0245 | -0.002 | -0.208 | -0.135 | -0.017 | 0 | 0.017 | 0.1345 | 0.2075 | 0.002 | -0.024 | -0.058 | -0.082 | -0.093 | 0 | 0 | 0 | 0 | 0 |
| **91** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **171** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **175** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **177** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **180** | 0 | -0.017 | -0.026 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.026 | -0.017 | 0 |

## 5.3 Modification of aH Table

The changed values are in the 4th quadrant. The result is a better fitting with experimental captive tests. For details, see Section 4.1. Modifications were performed in J1001A02 e J1001A04.

### 5.3.1 J1001A02 – Original aH Table

Table 9 – J1001A02 – Original aH Table

| | -180 | -90 | -70 | -55 | -40 | -25 | -10 | -5 | -2.5 | 0 | 2.5 | 5 | 10 | 25 | 40 | 55 | 70 | 90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -180 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 |
| -95 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 |
| -85 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 |
| -2 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 | -0.9891 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0.681022 | 0.3616 | 0.042178 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.042178 | 0.3616 | 0.681022 | 0 | 0 |
| 2 | 0 | 0 | 0 | 1.356888 | 0.7208 | 0.084712 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.084712 | 0.7208 | 1.356888 | 0 | 0 |
| 3 | 0 | 0 | 0 | 2.027598 | 1.0776 | 0.127601 | 0 | 0 | 0.02508 | 0 | 0.02508 | 0 | 0 | 0.127601 | 1.0776 | 2.027598 | 0 | 0 |
| 4 | 0 | 0 | 0 | 2.693152 | 1.431999 | 0.170846 | 0 | 0 | 0.07728 | 0 | 0.07728 | 0 | 0 | 0.170846 | 1.431999 | 2.693152 | 0 | 0 |
| 5 | 0 | 0 | 0 | 3 | 1.607224 | 0.214448 | 0 | 0 | 0.1514 | 0 | 0.1514 | 0 | 0 | 0.214448 | 1.607224 | 3 | 0 | 0 |
| 6 | 0 | 0 | 0 | 3 | 1.629202 | 0.258404 | 0 | 0 | 0.24744 | 0 | 0.24744 | 0 | 0 | 0.258404 | 1.629202 | 3 | 0 | 0 |
| 7 | 0 | 0 | 0 | 3 | 1.651359 | 0.302717 | 0 | 0 | 0.3654 | 0 | 0.3654 | 0 | 0 | 0.302717 | 1.651359 | 3 | 0 | 0 |
| 8 | 0 | 0 | 0 | 3 | 1.673693 | 0.347386 | 0.049488 | 0.009936 | 0.50528 | 0.163567 | 0.50528 | 0.009936 | 0.049488 | 0.347386 | 1.673693 | 3 | 0 | 0 |
| 9 | 0 | 0 | 0 | 3 | 1.696205 | 0.39241 | 0.118017 | 0.064134 | 0.66708 | 0.206522 | 0.66708 | 0.064134 | 0.118017 | 0.39241 | 1.696205 | 3 | 0 | 0 |
| 10 | 0 | 0 | 0 | 3 | 1.718895 | 0.43779 | 0.2004 | 0.1301 | 0.8508 | 0.254479 | 0.8508 | 0.1301 | 0.2004 | 0.43779 | 1.718895 | 3 | 0 | 0 |
| 15 | 0 | 0 | 0 | 3 | 1.835014 | 0.670028 | 0.820125 | 0.63645 | 2.0982 | 0.569294 | 2.0982 | 0.63645 | 0.820125 | 0.670028 | 1.835014 | 3 | 0 | 0 |
| 20 | 0 | 0 | 0 | 3 | 1.95558 | 0.91116 | 1.7862 | 1.437 | 3 | 1.009158 | 3 | 1.437 | 1.7862 | 0.91116 | 1.95558 | 3 | 0 | 0 |
| 30 | 0 | 0 | 0 | 3 | 2.210055 | 1.42011 | 3 | 3 | 3 | 2.264037 | 3 | 3 | 3 | 1.42011 | 2.210055 | 3 | 0 | 0 |
| 40 | 0 | 0 | 0.18312 | 3 | 2.48232 | 1.96464 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1.96464 | 2.48232 | 3 | 0.18312 | 0 |
| 50 | 0 | 0 | 0.466 | 3 | 2.772375 | 2.54475 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2.54475 | 2.772375 | 3 | 0.466 | 0 |
| 60 | 0 | 0 | 0.84372 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 0.84372 | 0 |
| 70 | 0 | 0 | 1.31628 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1.31628 | 0 |
| 80 | 0 | 0 | 1.88368 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1.88368 | 0 |
| 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 178 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 180 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 |

### 5.3.2 J1001A02 – Modified aH Table

Table 10 – J1001A02 – Modified aH Table

| | -180 | -90 | -70 | -55 | -40 | -25 | -10 | -5 | -2.5 | 0 | 2.5 | 5 | 10 | 25 | 40 | 55 | 70 | 90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -180 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 |
| -95 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 |
| -85 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 |
| -2 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 | -0.218 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0.681022 | 0.3616 | 0.042178 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.042178 | 0.3616 | 0.681022 | 0 | 0 |
| 2 | 0 | 0 | 0 | 1.356888 | 0.7208 | 0.084712 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.084712 | 0.7208 | 1.356888 | 0 | 0 |
| 3 | 0 | 0 | 0 | 2.027598 | 1.0776 | 0.127601 | 0 | 0 | 0.02508 | 0 | 0.02508 | 0 | 0 | 0.127601 | 1.0776 | 2.027598 | 0 | 0 |
| 4 | 0 | 0 | 0 | 2.693152 | 1.431999 | 0.170846 | 0 | 0 | 0.07728 | 0 | 0.07728 | 0 | 0 | 0.170846 | 1.431999 | 2.693152 | 0 | 0 |
| 5 | 0 | 0 | 0 | 3 | 1.607224 | 0.214448 | 0 | 0 | 0.1514 | 0 | 0.1514 | 0 | 0 | 0.214448 | 1.607224 | 3 | 0 | 0 |
| 6 | 0 | 0 | 0 | 3 | 1.629202 | 0.258404 | 0 | 0 | 0.24744 | 0 | 0.24744 | 0 | 0 | 0.258404 | 1.629202 | 3 | 0 | 0 |
| 7 | 0 | 0 | 0 | 3 | 1.651359 | 0.302717 | 0 | 0 | 0.3654 | 0 | 0.3654 | 0 | 0 | 0.302717 | 1.651359 | 3 | 0 | 0 |
| 8 | 0 | 0 | 0 | 3 | 1.673693 | 0.347386 | 0.049488 | 0.009936 | 0.50528 | 0.163567 | 0.50528 | 0.009936 | 0.049488 | 0.347386 | 1.673693 | 3 | 0 | 0 |
| 9 | 0 | 0 | 0 | 3 | 1.696205 | 0.39241 | 0.118017 | 0.064134 | 0.66708 | 0.206522 | 0.66708 | 0.064134 | 0.118017 | 0.39241 | 1.696205 | 3 | 0 | 0 |
| 10 | 0 | 0 | 0 | 3 | 1.718895 | 0.43779 | 0.2004 | 0.1301 | 0.8508 | 0.254479 | 0.8508 | 0.1301 | 0.2004 | 0.43779 | 1.718895 | 3 | 0 | 0 |
| 15 | 0 | 0 | 0 | 3 | 1.835014 | 0.670028 | 0.820125 | 0.63645 | 2.0982 | 0.569294 | 2.0982 | 0.63645 | 0.820125 | 0.670028 | 1.835014 | 3 | 0 | 0 |
| 20 | 0 | 0 | 0 | 3 | 1.95558 | 0.91116 | 1.7862 | 1.437 | 3 | 1.009158 | 3 | 1.437 | 1.7862 | 0.91116 | 1.95558 | 3 | 0 | 0 |
| 30 | 0 | 0 | 0 | 3 | 2.210055 | 1.42011 | 3 | 3 | 3 | 2.264037 | 3 | 3 | 3 | 1.42011 | 2.210055 | 3 | 0 | 0 |
| 40 | 0 | 0 | 0.18312 | 3 | 2.48232 | 1.96464 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1.96464 | 2.48232 | 3 | 0.18312 | 0 |
| 50 | 0 | 0 | 0.466 | 3 | 2.772375 | 2.54475 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2.54475 | 2.772375 | 3 | 0.466 | 0 |
| 60 | 0 | 0 | 0.84372 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 0.84372 | 0 |
| 70 | 0 | 0 | 1.31628 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1.31628 | 0 |
| 80 | 0 | 0 | 1.88368 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1.88368 | 0 |
| 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 178 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 180 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 | -0.5185 |

### 5.3.3 J1001A04 – Original aH Table

Table 11 – J1001A04 – Original aH Table

| | -180 | -90 | -70 | -55 | -40 | -25 | -10 | -5 | -2.5 | 0 | 2.5 | 5 | 10 | 25 | 40 | 55 | 70 | 90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **-180** | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 |
| **-95** | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 |
| **-85** | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 |
| **-2** | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 | -0.9358 |
| **0** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **1** | 0 | 0 | 0.3715 | 0.1987 | 0.0982 | 0.1035 | 0 | 0.033 | 0 | 0 | 0 | 0.033 | 0 | 0.1035 | 0.0982 | 0.1987 | 0.3715 | 0 |
| **2** | 0 | 0 | 0.7342 | 0.3924 | 0.193 | 0.2024 | 0 | 0.0715 | 0 | 0 | 0 | 0.0715 | 0 | 0.2024 | 0.193 | 0.3924 | 0.7342 | 0 |
| **3** | 0 | 0 | 1.0883 | 0.5812 | 0.2843 | 0.2964 | 0 | 0.1157 | 0 | 0 | 0 | 0.1157 | 0 | 0.2964 | 0.2843 | 0.5812 | 1.0883 | 0 |
| **4** | 0 | 0 | 1.4338 | 0.7651 | 0.3721 | 0.3858 | 0 | 0.1656 | 0 | 0 | 0 | 0.1656 | 0 | 0.3858 | 0.3721 | 0.7651 | 1.4338 | 0 |
| **5** | 0 | 0 | 1.7705 | 0.9441 | 0.4565 | 0.4705 | 0 | 0.221 | 0 | 0 | 0 | 0.221 | 0 | 0.4705 | 0.4565 | 0.9441 | 1.7705 | 0 |
| **6** | 0 | 0 | 2.0986 | 1.1181 | 0.5375 | 0.5504 | 0 | 0.2821 | 0 | 0 | 0 | 0.2821 | 0 | 0.5504 | 0.5375 | 1.1181 | 2.0986 | 0 |
| **7** | 0 | 0 | 2.418 | 1.2872 | 0.615 | 0.6256 | 0 | 0.3488 | 0 | 0.157 | 0 | 0.3488 | 0 | 0.6256 | 0.615 | 1.2872 | 2.418 | 0 |
| **8** | 0 | 0 | 2.7287 | 1.4514 | 0.6891 | 0.696 | 0 | 0.4212 | 0 | 0.1774 | 0 | 0.4212 | 0 | 0.696 | 0.6891 | 1.4514 | 2.7287 | 0 |
| **9** | 0 | 0 | 3 | 1.5952 | 0.7559 | 0.7618 | 0 | 0.4991 | 0 | 0.1973 | 0 | 0.4991 | 0 | 0.7618 | 0.7559 | 1.5952 | 3 | 0 |
| **10** | 0 | 0 | 3 | 1.6029 | 0.7864 | 0.8228 | 0 | 0.5827 | 0 | 0.2167 | 0 | 0.5827 | 0 | 0.8228 | 0.7864 | 1.6029 | 3 | 0 |
| **15** | 0 | 0 | 3 | 1.6321 | 0.9035 | 1.0571 | 0 | 1.085 | 0 | 0.3059 | 0 | 1.085 | 0 | 1.0571 | 0.9035 | 1.6321 | 3 | 0 |
| **20** | 0 | 0 | 3 | 1.6467 | 0.9616 | 1.1732 | 0 | 1.728 | 0 | 0.3824 | 0 | 1.728 | 0 | 1.1732 | 0.9616 | 1.6467 | 3 | 0 |
| **30** | 0 | 0 | 3 | 1.6314 | 0.9006 | 1.0512 | 0.0959 | 3 | 0 | 0.4971 | 0 | 3 | 0.0959 | 1.0512 | 0.9006 | 1.6314 | 3 | 0 |
| **40** | 0 | 0 | 3 | 1.5571 | 0.6034 | 0.4568 | 0.3678 | 3 | 0 | 0.5608 | 0 | 3 | 0.3678 | 0.4568 | 0.6034 | 1.5571 | 3 | 0 |
| **50** | 0 | 0 | 3 | 1.5 | 0.375 | 0 | 0.7595 | 3 | 0 | 0.5735 | 0 | 3 | 0.7595 | 0 | 0.375 | 1.5 | 3 | 0 |
| **60** | 0 | 0 | 3 | 1.5 | 0.375 | 0 | 1.2712 | 3 | 0 | 0.5352 | 0 | 3 | 1.2712 | 0 | 0.375 | 1.5 | 3 | 0 |
| **70** | 0 | 0 | 3 | 1.5 | 0.375 | 0 | 1.9027 | 3 | 0 | 0.4459 | 0 | 3 | 1.9027 | 0 | 0.375 | 1.5 | 3 | 0 |
| **80** | 0 | 0 | 2.2944 | 1.1472 | 0.2868 | 0 | 2.6542 | 3 | 0 | 0.3056 | 0 | 3 | 2.6542 | 0 | 0.2868 | 1.1472 | 2.2944 | 0 |
| **90** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **178** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **180** | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 |

### 5.3.4 J1001A04 – Modified Original aH Table

Table 12 – J1001A04 – Modified Original aH Table

| | -180 | -90 | -70 | -55 | -40 | -25 | -10 | -5 | -2.5 | 0 | 2.5 | 5 | 10 | 25 | 40 | 55 | 70 | 90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **-180** | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 |
| **-95** | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 |
| **-85** | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 |
| **-2** | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 | -0.3155 |
| **0** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **1** | 0 | 0 | 0.3715 | 0.1987 | 0.0982 | 0.1035 | 0 | 0.033 | 0 | 0 | 0 | 0.033 | 0 | 0.1035 | 0.0982 | 0.1987 | 0.3715 | 0 |
| **2** | 0 | 0 | 0.7342 | 0.3924 | 0.193 | 0.2024 | 0 | 0.0715 | 0 | 0 | 0 | 0.0715 | 0 | 0.2024 | 0.193 | 0.3924 | 0.7342 | 0 |
| **3** | 0 | 0 | 1.0883 | 0.5812 | 0.2843 | 0.2964 | 0 | 0.1157 | 0 | 0 | 0 | 0.1157 | 0 | 0.2964 | 0.2843 | 0.5812 | 1.0883 | 0 |
| **4** | 0 | 0 | 1.4338 | 0.7651 | 0.3721 | 0.3858 | 0 | 0.1656 | 0 | 0 | 0 | 0.1656 | 0 | 0.3858 | 0.3721 | 0.7651 | 1.4338 | 0 |
| **5** | 0 | 0 | 1.7705 | 0.9441 | 0.4565 | 0.4705 | 0 | 0.221 | 0 | 0 | 0 | 0.221 | 0 | 0.4705 | 0.4565 | 0.9441 | 1.7705 | 0 |
| **6** | 0 | 0 | 2.0986 | 1.1181 | 0.5375 | 0.5504 | 0 | 0.2821 | 0 | 0 | 0 | 0.2821 | 0 | 0.5504 | 0.5375 | 1.1181 | 2.0986 | 0 |
| **7** | 0 | 0 | 2.418 | 1.2872 | 0.615 | 0.6256 | 0 | 0.3488 | 0 | 0.157 | 0 | 0.3488 | 0 | 0.6256 | 0.615 | 1.2872 | 2.418 | 0 |
| **8** | 0 | 0 | 2.7287 | 1.4514 | 0.6891 | 0.696 | 0 | 0.4212 | 0 | 0.1774 | 0 | 0.4212 | 0 | 0.696 | 0.6891 | 1.4514 | 2.7287 | 0 |
| **9** | 0 | 0 | 3 | 1.5952 | 0.7559 | 0.7618 | 0 | 0.4991 | 0 | 0.1973 | 0 | 0.4991 | 0 | 0.7618 | 0.7559 | 1.5952 | 3 | 0 |
| **10** | 0 | 0 | 3 | 1.6029 | 0.7864 | 0.8228 | 0 | 0.5827 | 0 | 0.2167 | 0 | 0.5827 | 0 | 0.8228 | 0.7864 | 1.6029 | 3 | 0 |
| **15** | 0 | 0 | 3 | 1.6321 | 0.9035 | 1.0571 | 0 | 1.085 | 0 | 0.3059 | 0 | 1.085 | 0 | 1.0571 | 0.9035 | 1.6321 | 3 | 0 |
| **20** | 0 | 0 | 3 | 1.6467 | 0.9616 | 1.1732 | 0 | 1.728 | 0 | 0.3824 | 0 | 1.728 | 0 | 1.1732 | 0.9616 | 1.6467 | 3 | 0 |
| **30** | 0 | 0 | 3 | 1.6314 | 0.9006 | 1.0512 | 0.0959 | 3 | 0 | 0.4971 | 0 | 3 | 0.0959 | 1.0512 | 0.9006 | 1.6314 | 3 | 0 |
| **40** | 0 | 0 | 3 | 1.5571 | 0.6034 | 0.4568 | 0.3678 | 3 | 0 | 0.5608 | 0 | 3 | 0.3678 | 0.4568 | 0.6034 | 1.5571 | 3 | 0 |
| **50** | 0 | 0 | 3 | 1.5 | 0.375 | 0 | 0.7595 | 3 | 0 | 0.5735 | 0 | 3 | 0.7595 | 0 | 0.375 | 1.5 | 3 | 0 |
| **60** | 0 | 0 | 3 | 1.5 | 0.375 | 0 | 1.2712 | 3 | 0 | 0.5352 | 0 | 3 | 1.2712 | 0 | 0.375 | 1.5 | 3 | 0 |
| **70** | 0 | 0 | 3 | 1.5 | 0.375 | 0 | 1.9027 | 3 | 0 | 0.4459 | 0 | 3 | 1.9027 | 0 | 0.375 | 1.5 | 3 | 0 |
| **80** | 0 | 0 | 2.2944 | 1.1472 | 0.2868 | 0 | 2.6542 | 3 | 0 | 0.3056 | 0 | 3 | 2.6542 | 0 | 0.2868 | 1.1472 | 2.2944 | 0 |
| **90** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **178** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **180** | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 | -0.7487 |

## 5.4 Tuning factors

In order to use less tuning factors, NP and Fx were put back to 1 compared to the previous model (WL2016R15_001_5). The only tuned factors were XP to get a best fitting with experimental captive tests. For more details, see section 4.

### 5.4.1 Previous tuning factors

Table 13 – Tuning factors – previous model WL2017R15_001_8

| Series - %ukc | XP | Ngamma | NR | Ychi | Nchi | NP | Fx |
|---|---|---|---|---|---|---|---|
| **J1001A02 – 100** | 1.00 | 0.90 | 1.00 | 1.00 | 1.00 | **0.3** | **0.75** |
| **J1001A03 – 60** | 0.80 | 1.00 | 0.80 | 1.00 | 1.00 | **0.3** | **0.5** |
| **J1001A04 – 33** | 1.00 | 1.50 | 1.00 | 0.50 | 0.75 | **0.3** | **0.8** |

### 5.4.2 Modified tuning factors

Table 14 – Tuning factors – modified model

| Series - %ukc | XP | Ngamma | NR | Ychi | Nchi | NP | Fx |
|---|---|---|---|---|---|---|---|
| **J1001A02 – 100** | **1.20** | 0.90 | 1.00 | 1.00 | 1.00 | **1.00** | **1.00** |
| **J1001A03 – 60** | **1.10** | 1.00 | 0.80 | 1.00 | 1.00 | **1.00** | **1.00** |
| **J1001A04 – 33** | **1.30** | 1.50 | 1.00 | 0.50 | 0.75 | **1.00** | **1.00** |

## 5.5 Main results comparison

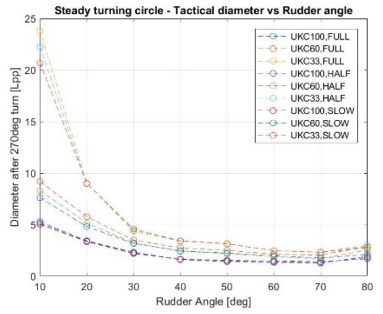
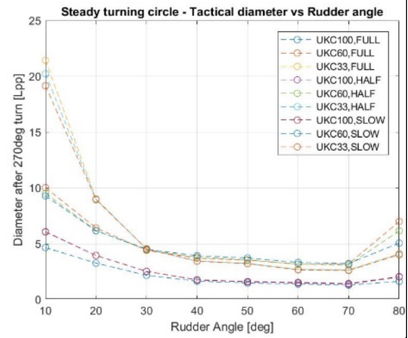
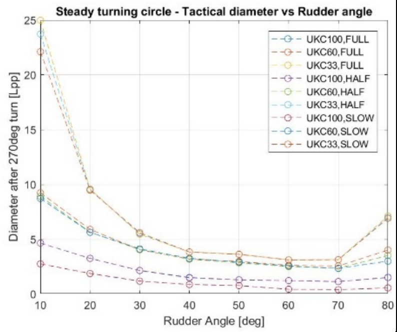
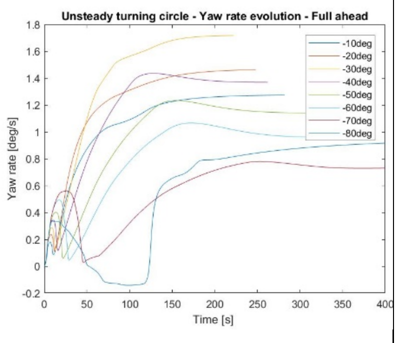
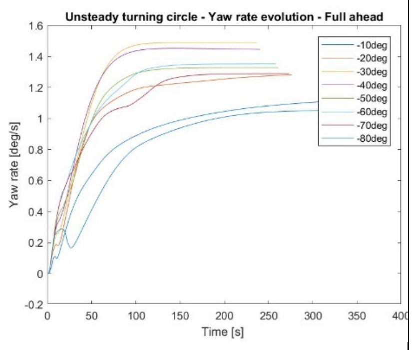
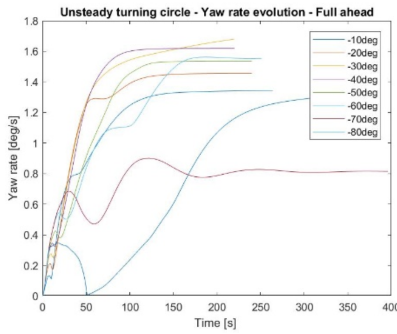
Figure 22 shows the comparison between the behavior of the original model (NP, FX no tuned), the modified model (NP,FX tuned) and the new proposed modification. Comparisons are focused on tactical diameter in the steady turning circle and the yaw rate evolution of the unsteady turning circle manoeuvre.

In the original model (first column), the expected behavior of the tactical diameter increasing as the water depth decreases is verified. The yaw rate evolution presents a drastic drop.

In the tuned model (second column), the results of tactical diameter are not in the expected progression as the water depth changes. It can be noted, that for rudder angles higher than 30 degrees, the tactical diameters for 33UKC are minor that the obtained for 60UKC. Furthermore,  the yaw rate evolution was corrected.

In the new modified model (third column), the expected behavior of progressive evolution of tactical diameters is correct. The yaw rate evolution is better than the no tuned model in the majority of rudder angles. Only for a rudder angle of 80 degrees, in the condition of 100UKC a drop remains.

Figure 22 – Main results comparison
(First row) Tactical diameter of the steady tuning circle maneuver;
(Second row) Yaw rate evolution of the unsteady turning circle maneuver (*Uo*=-1knot) ) and 100UKC

<table>
<tr><td>Initial Model<br>NP, FX (no tuned)</td><td>Model (WL2017R15_001_8)<br>NP, FX (tuned)</td><td>New modification</td></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
</table>

# 6 Conclusions

Verification shows that the expected progression in tactical diameter on the steady turning circle manoeuvre was affected by the coefficient tuning performed to correct strange behaviour on the evolution of unsteady turning circles.

The strange behaviour is related to a sudden drop in yaw rate and a reverse speed, both in the evolution of unsteady turning circle manoeuvres[3].

In relation with the first problem, it is showed that the yaw rate dropping is generated by a significant drop of the propeller horizontal moment (NP). Unsteady turning circle manoeuvre with negative initial speed, typically involves rapid drift angle transitions that begin in +/-180 deg, crossing 90deg and finally reaching the steady drift angle of the manoeuvre. The propeller moment drop is because a rapid crossing of the drift angle from the fourth to the first quadrant in the NPT coefficient table. In some cases, the values of the first quadrant near the limit of the fourth quadrant are relatively high. This produces undesirable jumps and discontinuities in the transition from negative to positive speed. In this case, it was noted that values larger than 0.10 produce a significant drop in the propeller moment impacting the yaw rate evolution. The coefficients of the first quadrant on the limit with the fourth one were modified.

The second problem was verified using the experimental captive tests which showed that in all cases the thrust predicted by the model was underestimated. The same seems to occurs in the first quadrant of the studied cases. This needs further investigation. The tuning coefficient XP was used to get a better agreement with the experimental data. It was detected, as well, in some cases that the transversal rudder forces during simulation were almost zero because the factor (1 + aH) that multiplies the transversal component was almost zero. The parameter aH was modified in the $4^{th}$ quadrant to get a better agreement with available experimental data. The calculation of the coefficient aH needs further investigation in this quadrant. The harmonic nature of the forces in even quadrants and the consequent modelling to capture its global effect need to be verified.

A correction of the coefficients of the NPT table (gamma table) is proposed in order to improve the behaviour of unsteady turning circles. The changed values are in the 4th quadrant. The values (J1001A02) were too large in relation with the other conditions (J1001A03, J1001A04). Extrapolated values were inserted. Other modifications of values in the 1st quadrant are according with the NPT beta changes.

It was verified that the simulated longitudinal rudder forces have an acceptable agreement with the captive experimental tests.

A set of preliminary fast time simulations were performed to verify the effects of modifications. Results were included in this report.

Next steps:

- An improved model for the prediction of the (twin) propeller induced moment is in progress. The modelling issues presented in this report will be useful to verify the performance of the improved model.
- Discussion of manoeuvring criteria will be performed after the implementation of the improved model of the propeller induced moments.

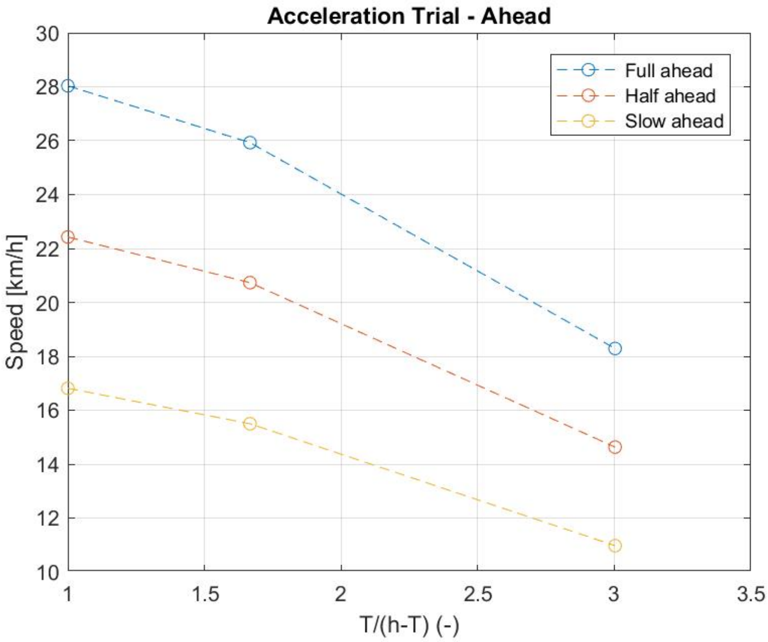
# 7 References

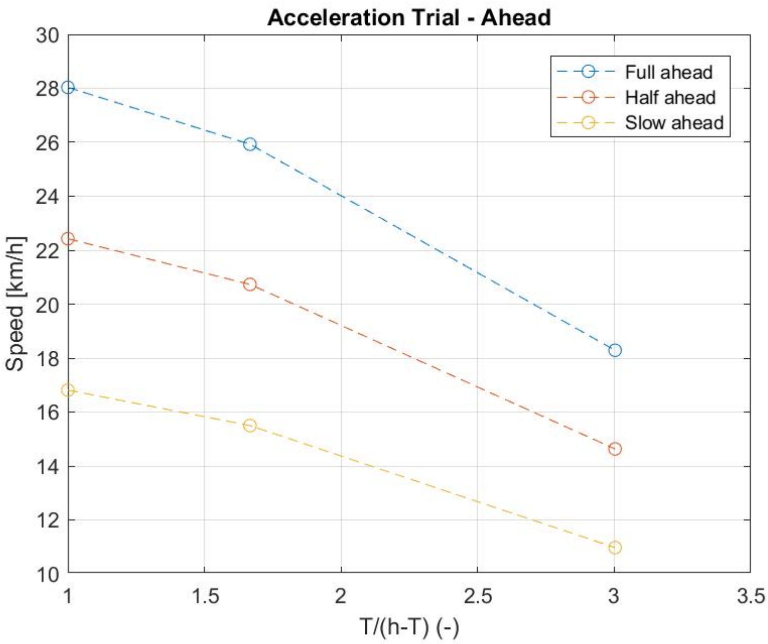
[1] **Delefortrie, G.; Eloot, K.; Peeters, P.; Mostaert, F. (2016).** Manoeuvring behaviour of push convoys: Sub report 5 – Class Va: mathematical modelling and fast time simulations. Version 4.0. WL Rapporten, 15_001. Flanders Hydraulics Research, Antwerp, Belgium.

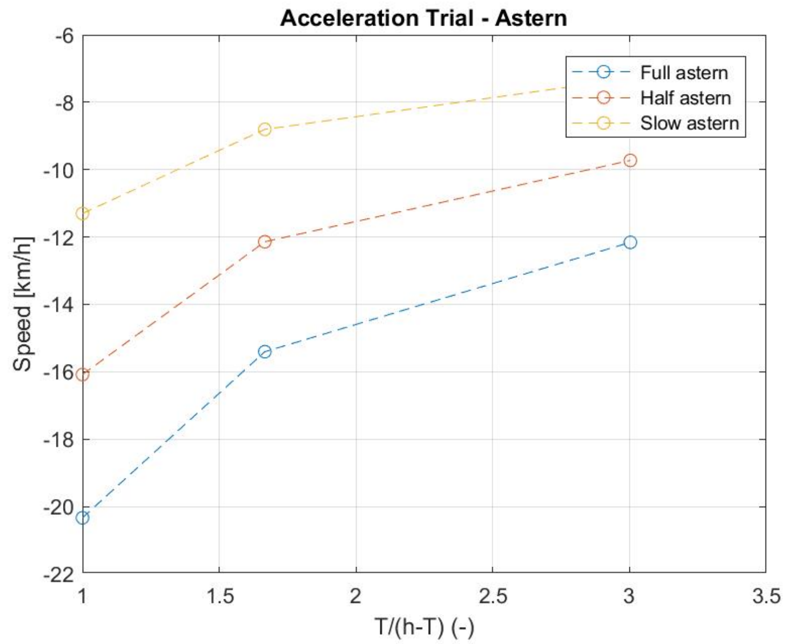
[2] **Delefortrie, G.; Eloot, K.; Peeters, P.; Mostaert, F. (2016).** Manoeuvring behaviour of push convoys: Sub report 4 – Class Vb: mathematical modelling and fast time simulations. Version 4.0. WL Rapporten, 15_001. Flanders Hydraulics Research, Antwerp, Belgium.

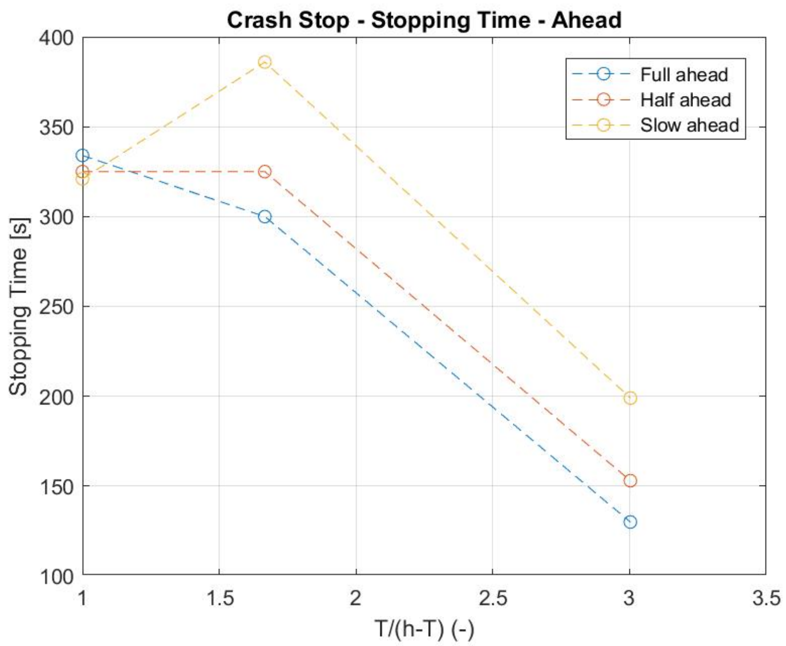
[3] **Vos, S.; Delefotrie, G.; Mostaert, F. (2018).** Manoeuvring behaviour of push convoys: Sub report 8 – Additional Fast Time Validation of Class Va and Vb Vessels. Version 2.0. FHR Reports, 15_001_08. Flanders Hydraulics Research: Antwerp.

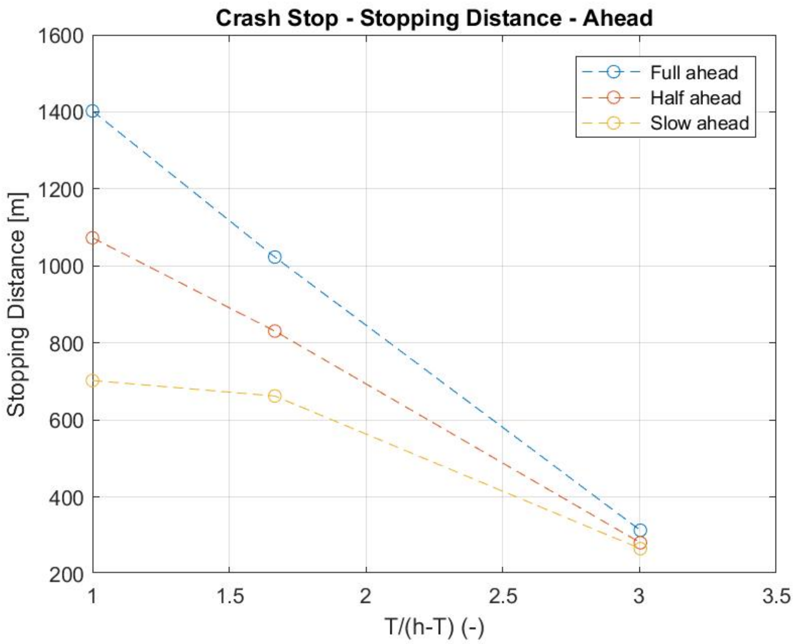
# APPENDIX: Fast Time Simulations – Modified Model

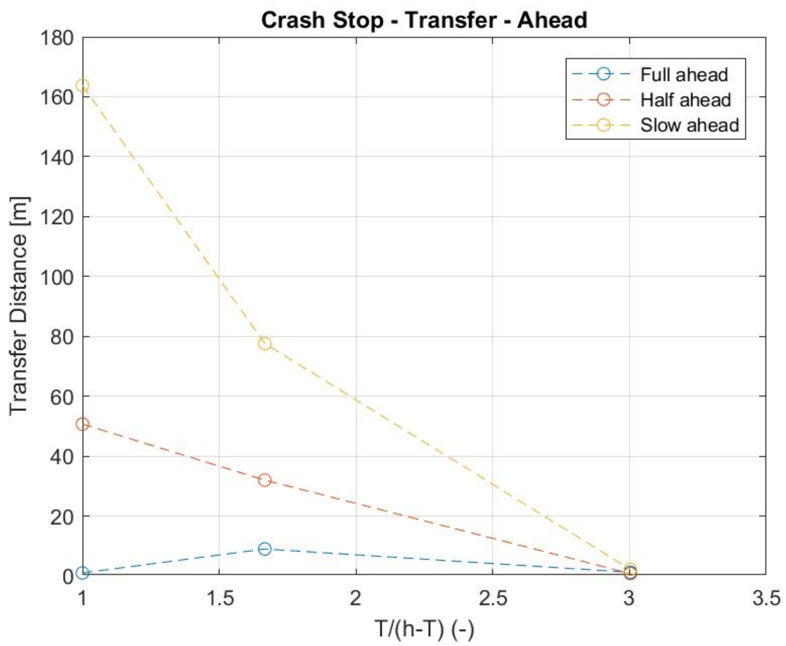


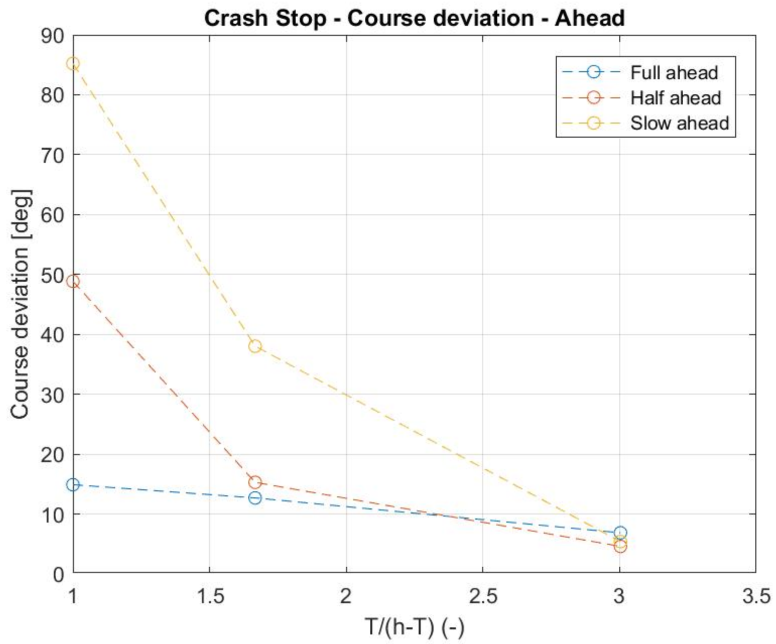



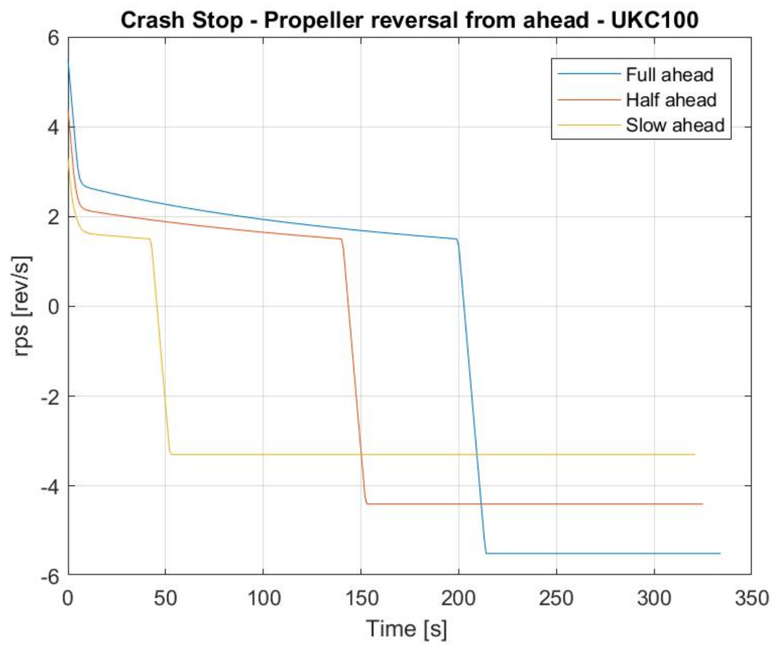

Acceleration Trial - Astern
Full astern
Half astern
Slow astern
Speed [km/h]
T/(h-T) (-)
-6
-8
-10
-12
-14
-16
-18
-20
-22
1
1.5
2
2.5
3
3.5

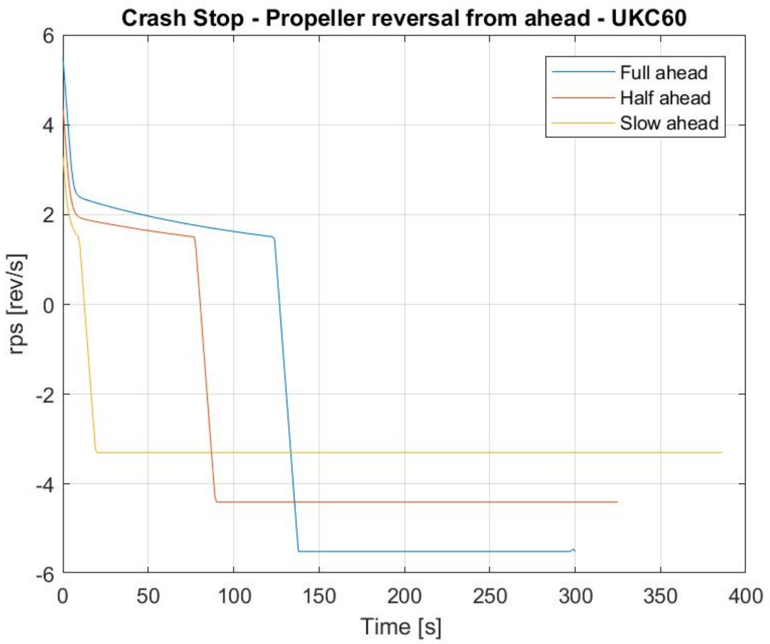

Crash Stop - Stopping Time - Ahead
Full ahead
Half ahead
Slow ahead
Stopping Time [s]
T/(h-T) (-)
400
350
300
250
200
150
100
1
1.5
2
2.5
3
3.5

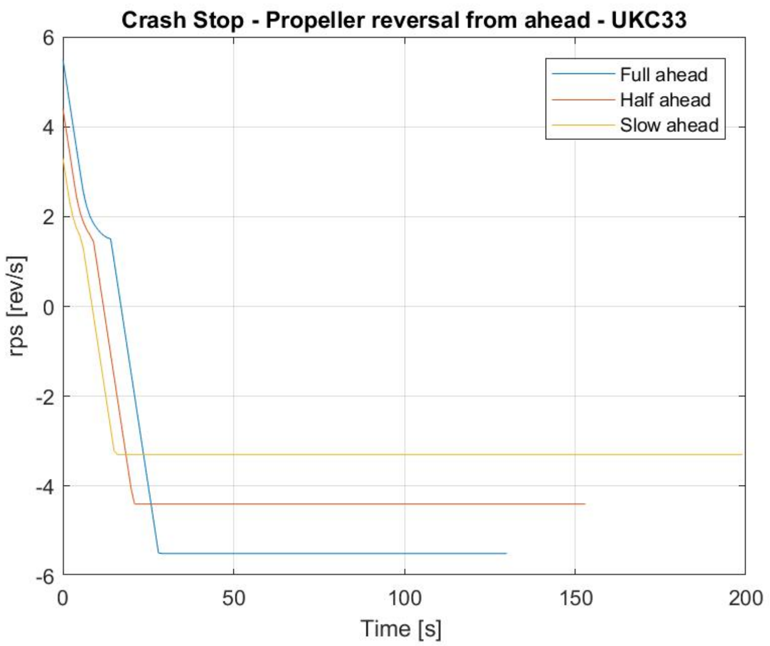

Crash Stop - Stopping Distance - Ahead
Full ahead
Half ahead
Slow ahead
Stopping Distance [m]
T/(h-T) (-)

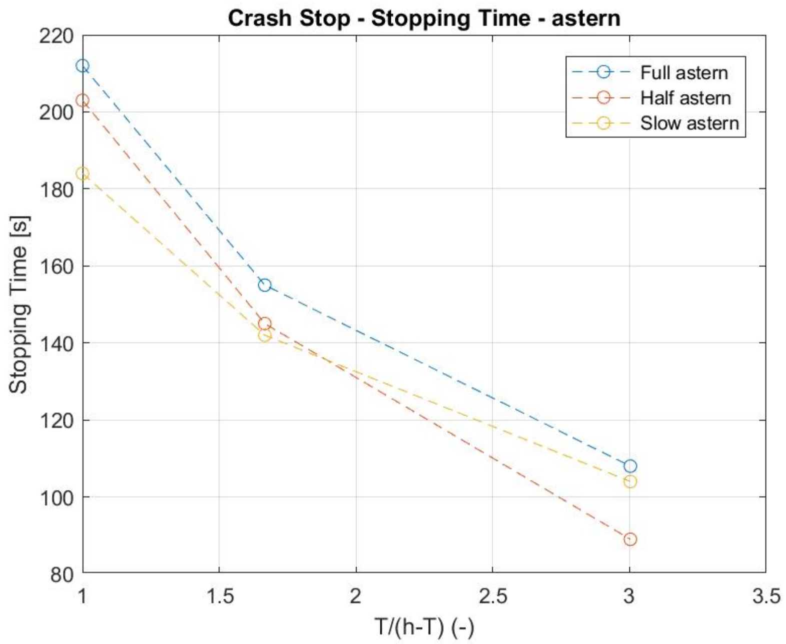

Crash Stop - Transfer - Ahead
Full ahead
Half ahead
Slow ahead
Transfer Distance [m]
T/(h-T) (-)

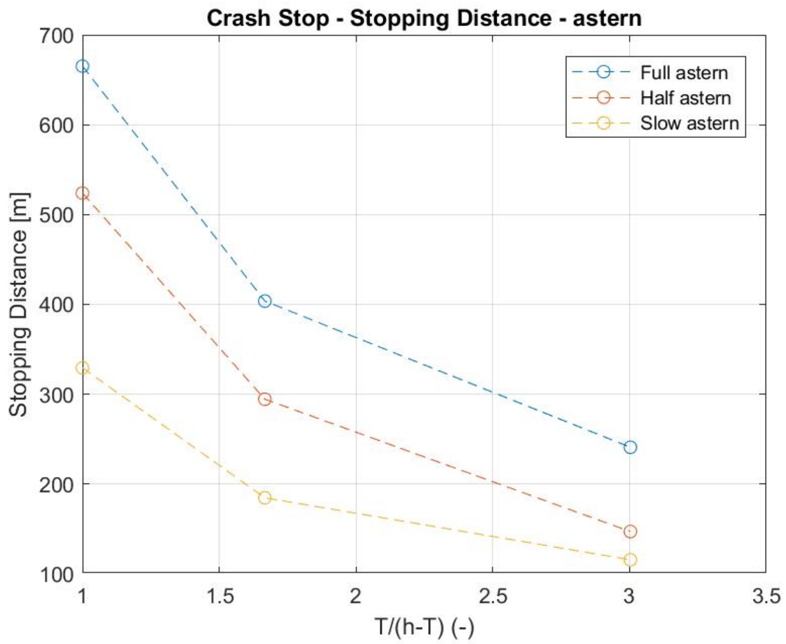

Crash Stop - Course deviation - Ahead
Full ahead
Half ahead
Slow ahead
Course deviation [deg]
T/(h-T) (-)
0
10
20
30
40
50
60
70
80
90
1
1.5
2
2.5
3
3.5

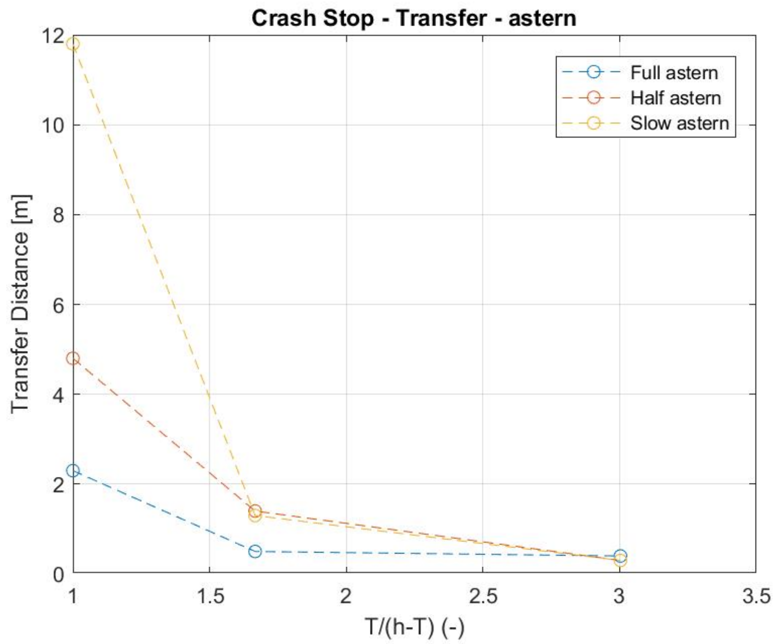

Crash Stop - Propeller reversal from ahead - UKC100
Full ahead
Half ahead
Slow ahead
rps [rev/s]
Time [s]
6
4
2
0
-2
-4
-6
0
50
100
150
200
250
300
350

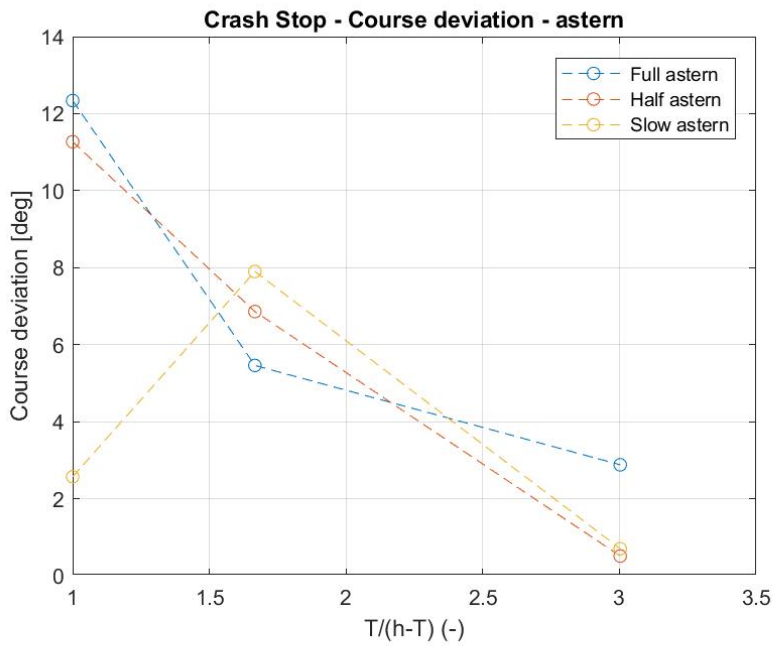

Crash Stop - Propeller reversal from ahead - UKC60
Full ahead
Half ahead
Slow ahead
rps [rev/s]
Time [s]
6
4
2
0
-2
-4
-6
0
50
100
150
200
250
300
350
400

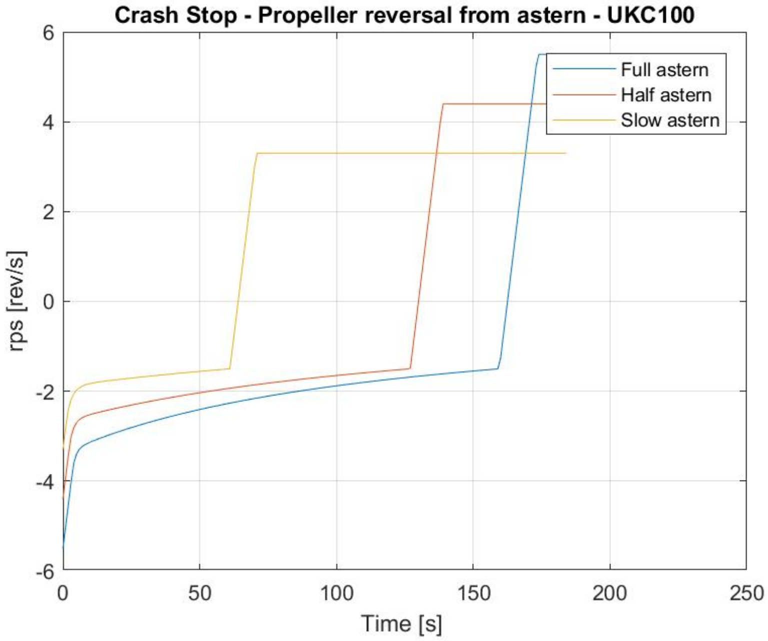

Crash Stop - Propeller reversal from ahead - UKC33
Full ahead
Half ahead
Slow ahead
rps [rev/s]
Time [s]
6
4
2
0
-2
-4
-6
0
50
100
150
200

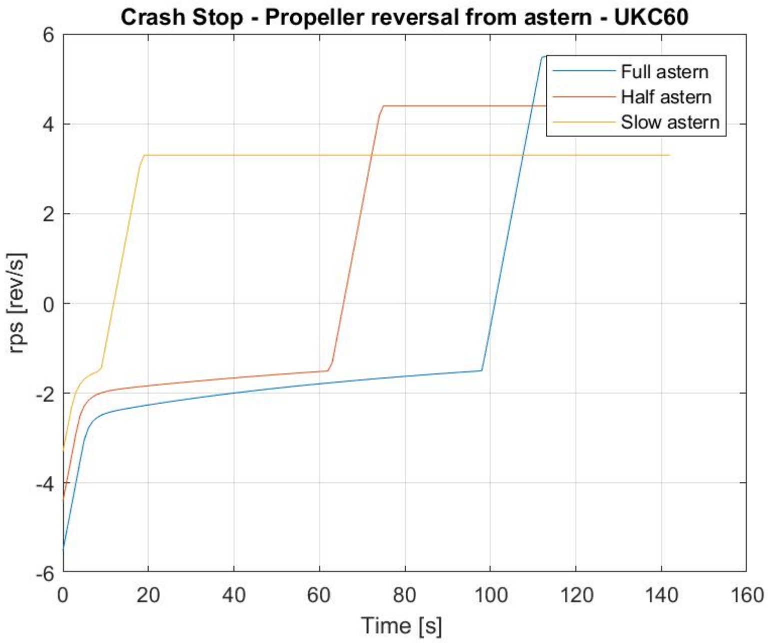

Crash Stop - Stopping Time - astern
Full astern
Half astern
Slow astern
Stopping Time [s]
T/(h-T) (-)
220
200
180
160
140
120
100
80
1
1.5
2
2.5
3
3.5

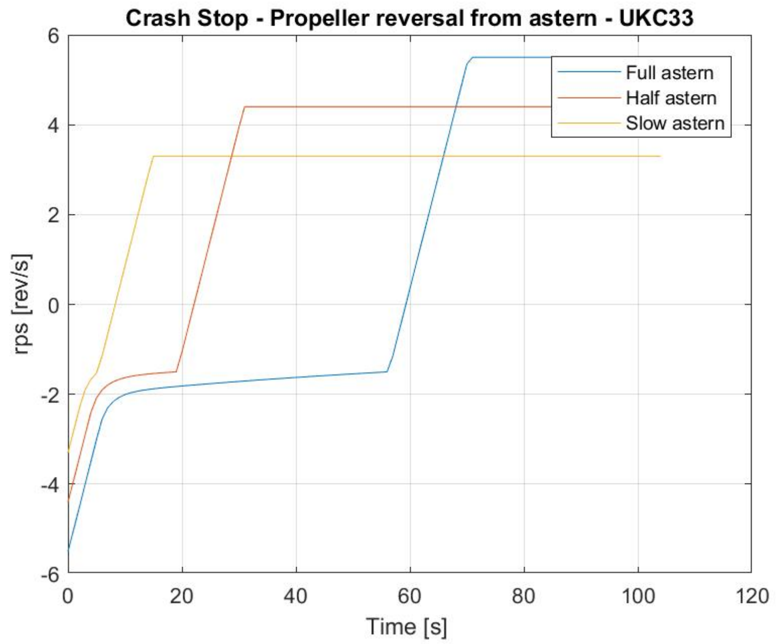

Crash Stop - Stopping Distance - astern
Full astern
Half astern
Slow astern
Stopping Distance [m]
T/(h-T) (-)
700
600
500
400
300
200
100
1
1.5
2
2.5
3
3.5

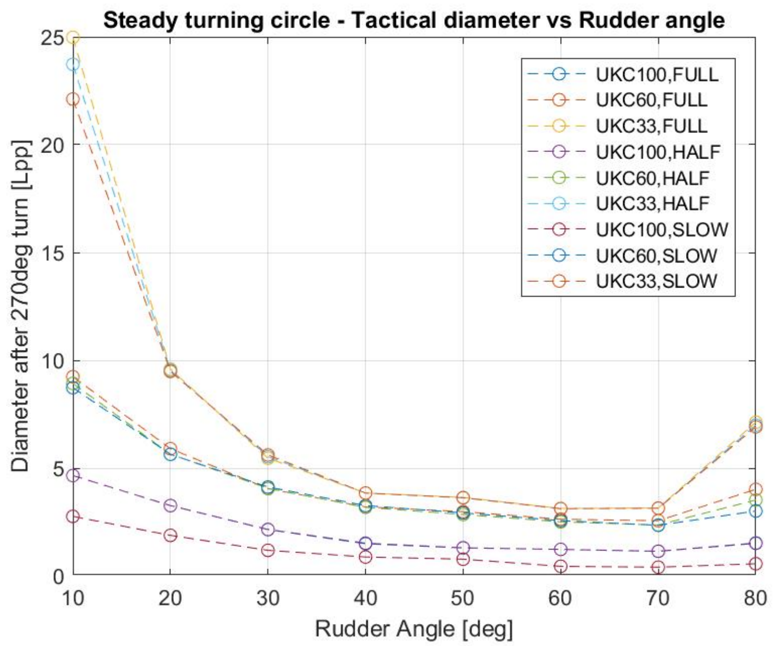

Crash Stop - Transfer - astern
Full astern
Half astern
Slow astern
Transfer Distance [m]
T/(h-T) (-)

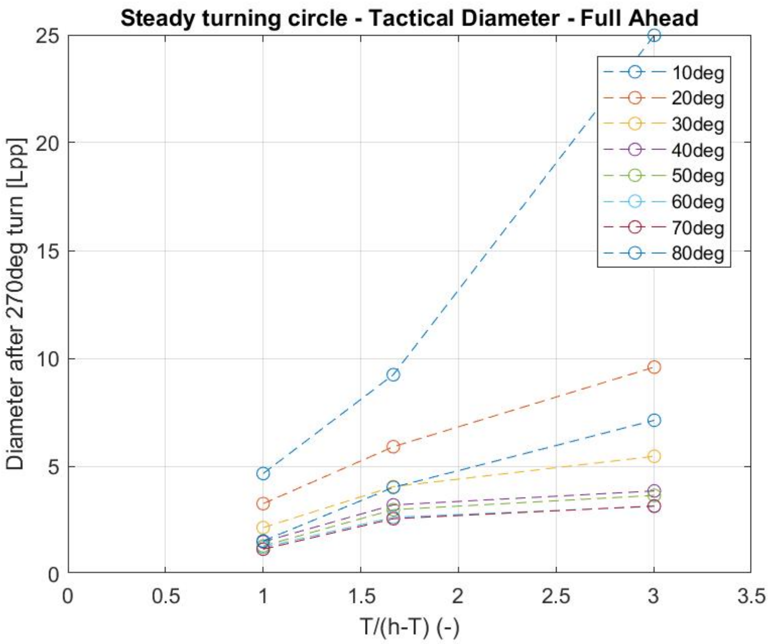

Crash Stop - Course deviation - astern
Full astern
Half astern
Slow astern
Course deviation [deg]
T/(h-T) (-)

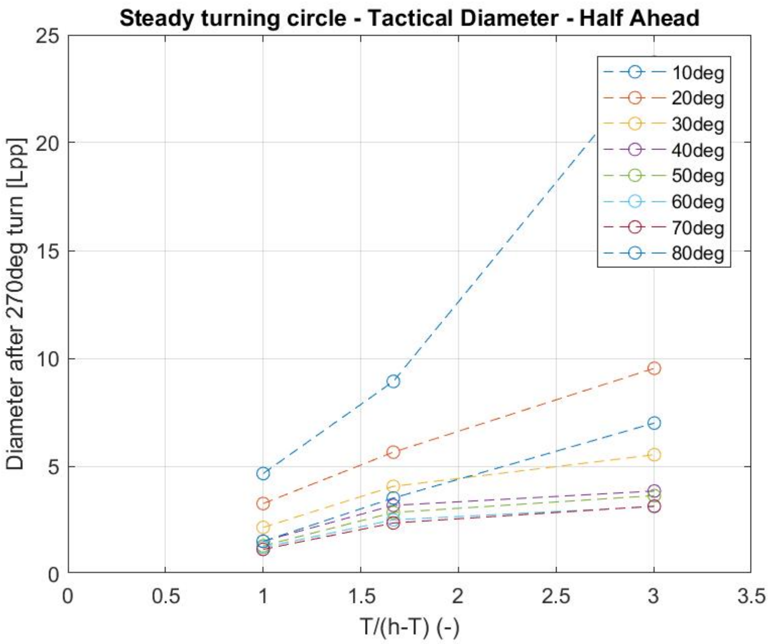

Crash Stop - Propeller reversal from astern - UKC100
rps [rev/s]
Time [s]
Full astern
Half astern
Slow astern
6
4
2
0
-2
-4
-6
0
50
100
150
200
250

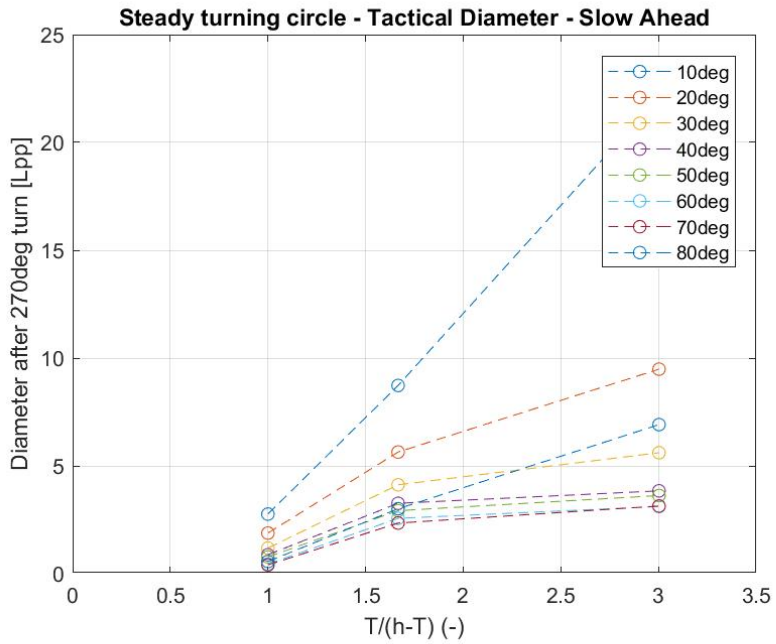

Crash Stop - Propeller reversal from astern - UKC60
rps [rev/s]
Time [s]
Full astern
Half astern
Slow astern
6
4
2
0
-2
-4
-6
0
20
40
60
80
100
120
140
160

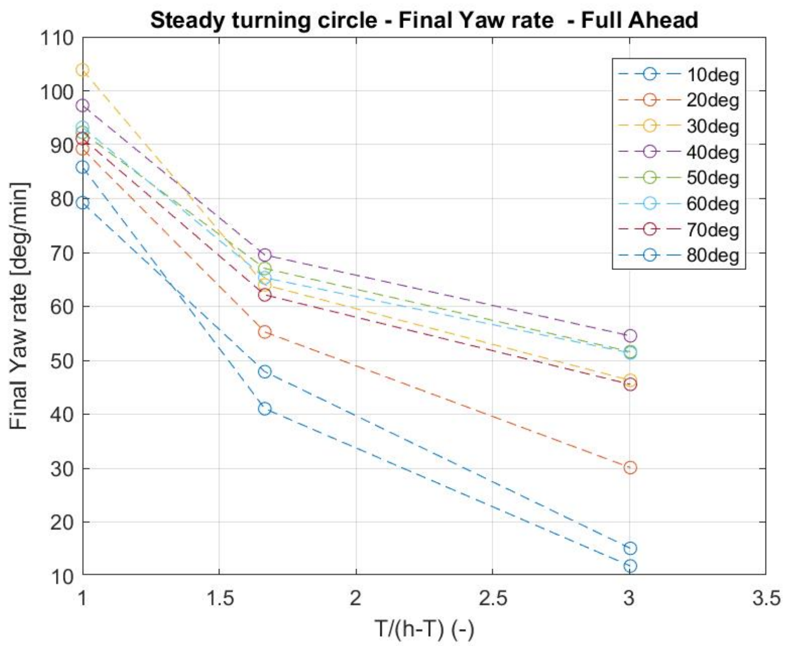

Crash Stop - Propeller reversal from astern - UKC33
Full astern
Half astern
Slow astern
rps [rev/s]
Time [s]
6
4
2
0
-2
-4
-6
0
20
40
60
80
100
120

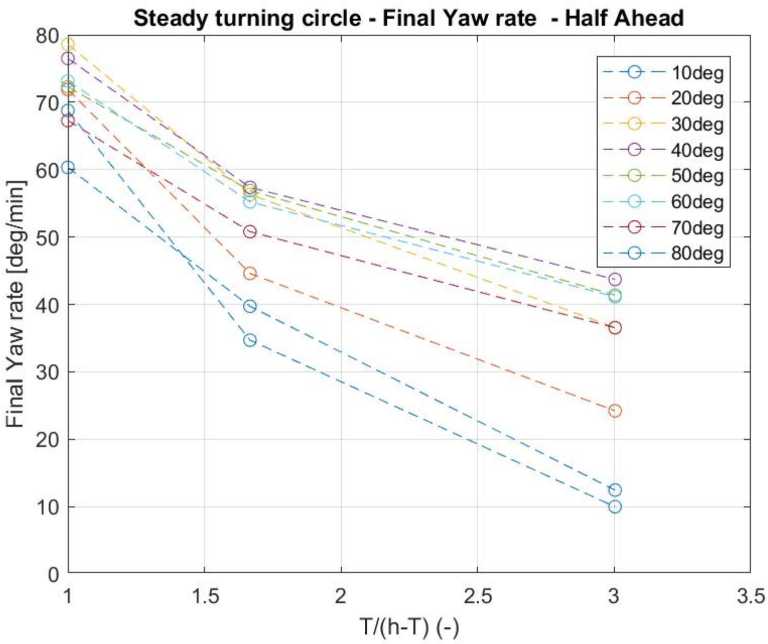

Steady turning circle - Tactical diameter vs Rudder angle
UKC100,FULL
UKC60,FULL
UKC33,FULL
UKC100,HALF
UKC60,HALF
UKC33,HALF
UKC100,SLOW
UKC60,SLOW
UKC33,SLOW
Diameter after 270deg turn [Lpp]
Rudder Angle [deg]
25
20
15
10
5
0
10
20
30
40
50
60
70
80

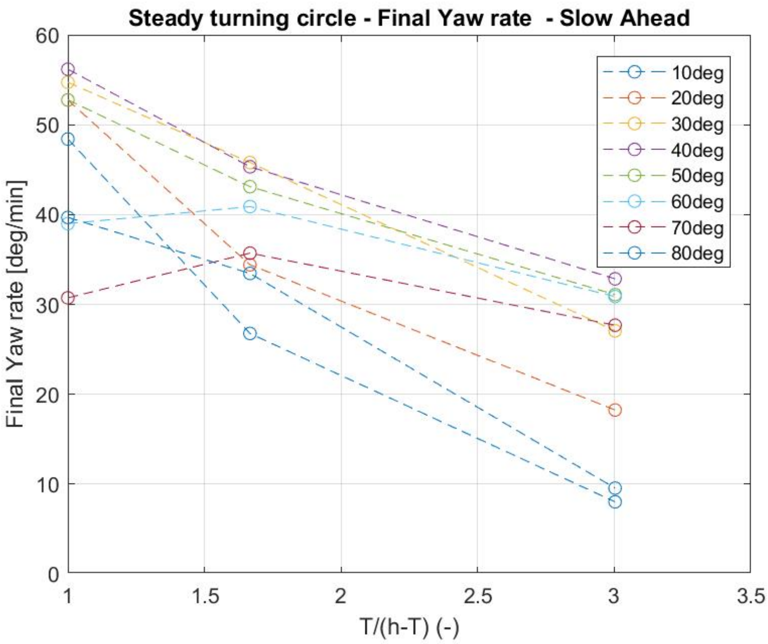

Steady turning circle - Tactical Diameter - Full Ahead
Diameter after 270deg turn [Lpp]
T/(h-T) (-)
10deg
20deg
30deg
40deg
50deg
60deg
70deg
80deg
0
5
10
15
20
25
0
0.5
1
1.5
2
2.5
3
3.5

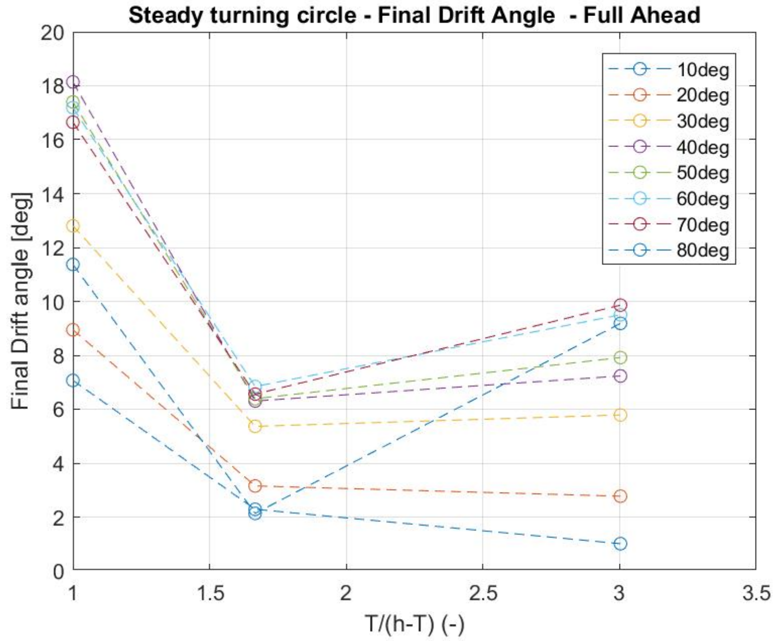

Steady turning circle - Tactical Diameter - Half Ahead
Diameter after 270deg turn [Lpp]
T/(h-T) (-)
10deg
20deg
30deg
40deg
50deg
60deg
70deg
80deg
0
5
10
15
20
25
0
0.5
1
1.5
2
2.5
3
3.5

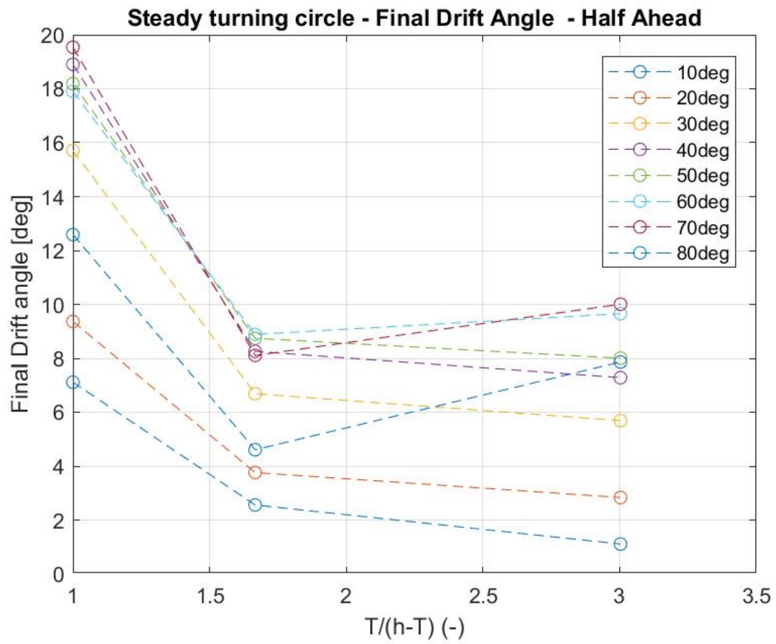

Steady turning circle - Tactical Diameter - Slow Ahead
Diameter after 270deg turn [Lpp]
T/(h-T) (-)
10deg
20deg
30deg
40deg
50deg
60deg
70deg
80deg
0
5
10
15
20
25
0.5
1
1.5
2
2.5
3
3.5

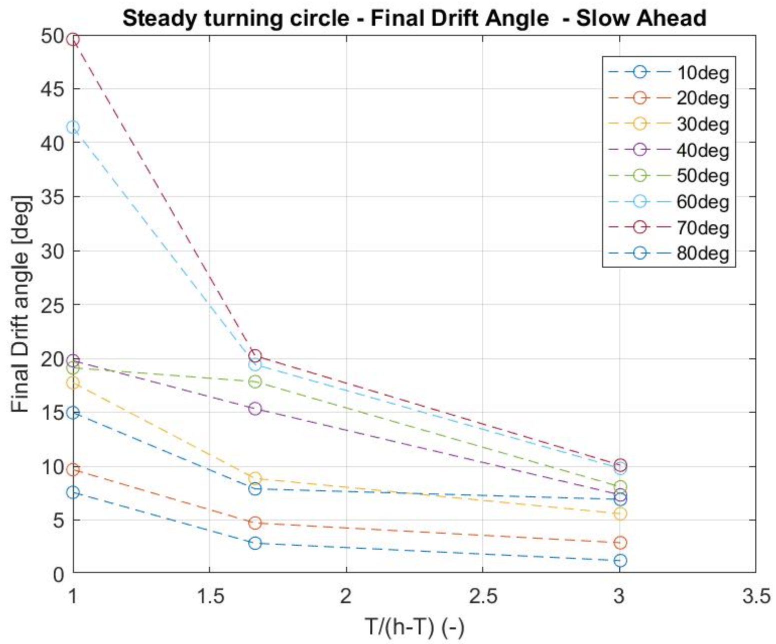

Steady turning circle - Final Yaw rate - Full Ahead
Final Yaw rate [deg/min]
T/(h-T) (-)
10deg
20deg
30deg
40deg
50deg
60deg
70deg
80deg
10
20
30
40
50
60
70
80
90
100
110
1
1.5
2
2.5
3
3.5

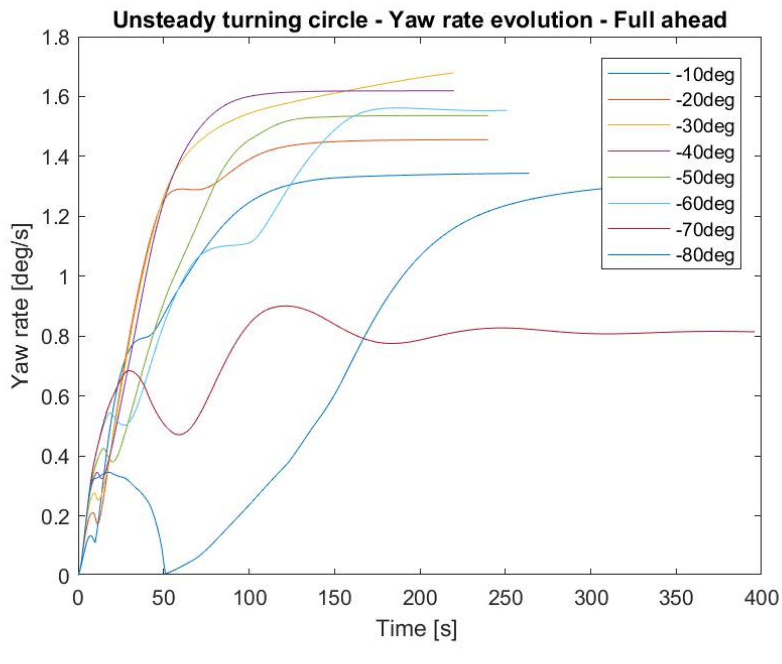

Steady turning circle - Final Yaw rate - Half Ahead
Final Yaw rate [deg/min]
T/(h-T) (-)
10deg
20deg
30deg
40deg
50deg
60deg
70deg
80deg
0
10
20
30
40
50
60
70
80
1
1.5
2
2.5
3
3.5

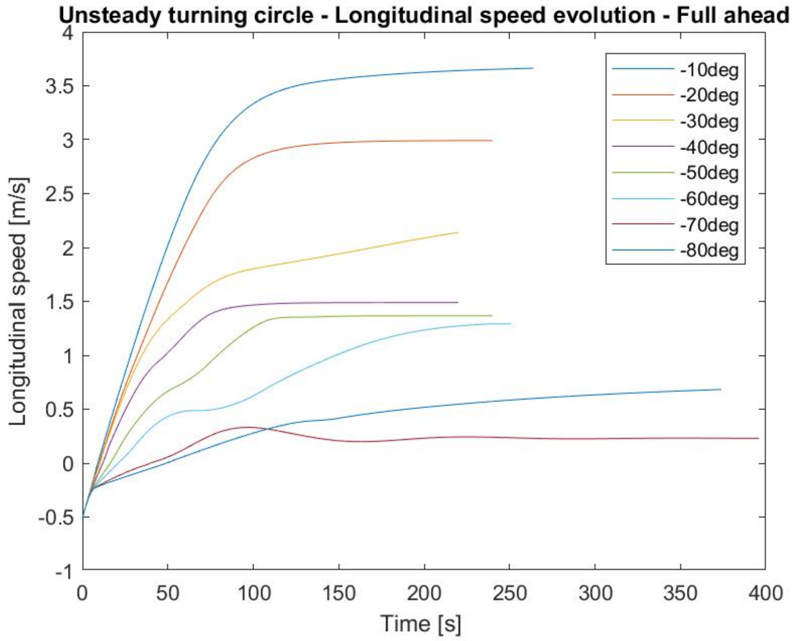

Steady turning circle - Final Yaw rate - Slow Ahead
Final Yaw rate [deg/min]
T/(h-T) (-)
10deg
20deg
30deg
40deg
50deg
60deg
70deg
80deg
0
10
20
30
40
50
60
1
1.5
2
2.5
3
3.5

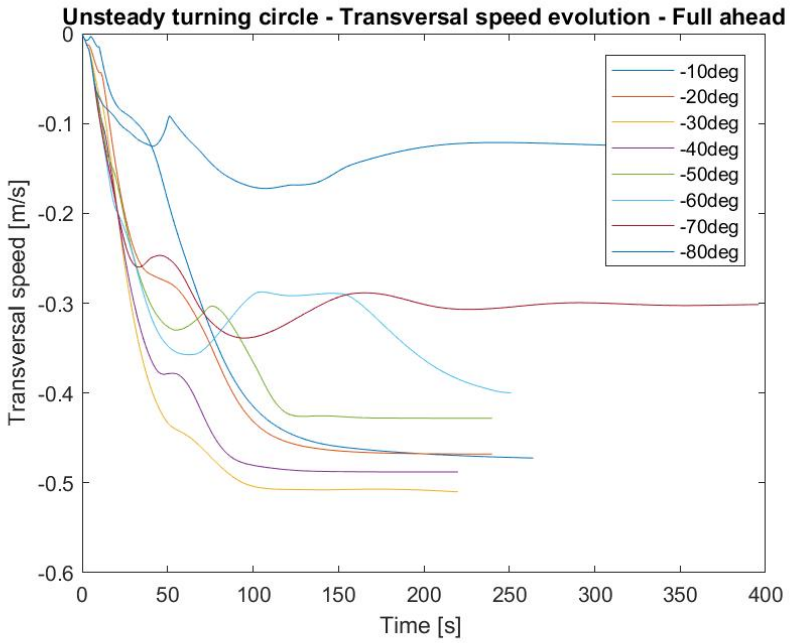

Steady turning circle - Final Drift Angle - Full Ahead
Final Drift angle [deg]
T/(h-T) (-)
10deg
20deg
30deg
40deg
50deg
60deg
70deg
80deg
0
2
4
6
8
10
12
14
16
18
20
1
1.5
2
2.5
3
3.5

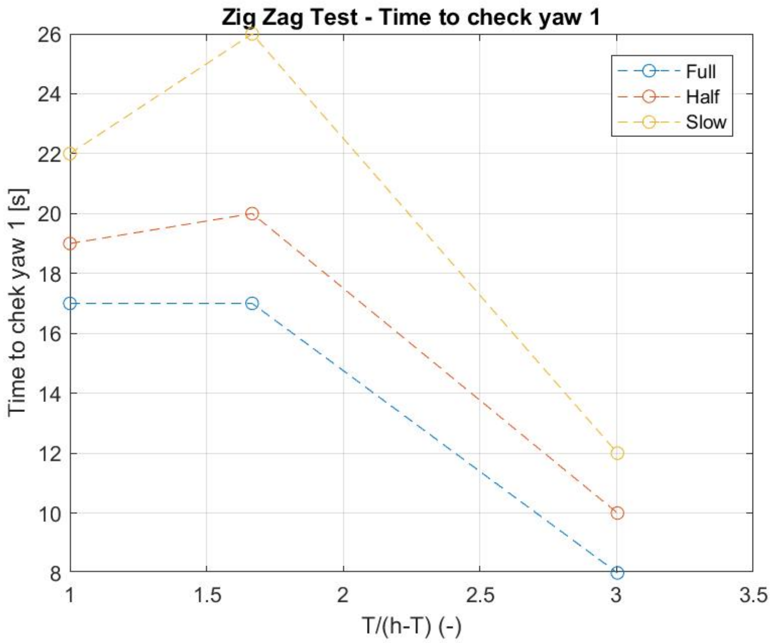

Steady turning circle - Final Drift Angle - Half Ahead
Final Drift angle [deg]
T/(h-T) (-)
10deg
20deg
30deg
40deg
50deg
60deg
70deg
80deg
0
2
4
6
8
10
12
14
16
18
20
1
1.5
2
2.5
3
3.5

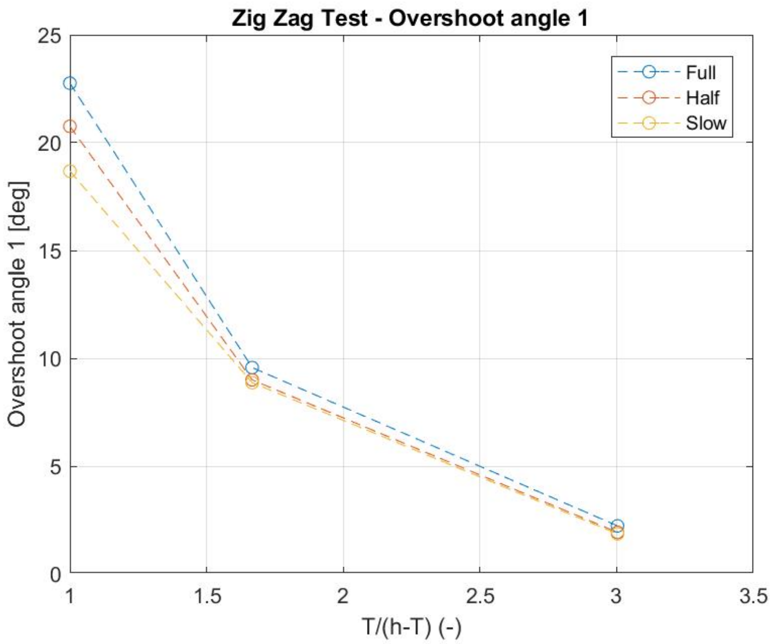

Steady turning circle - Final Drift Angle - Slow Ahead
Final Drift angle [deg]
T/(h-T) (-)
10deg
20deg
30deg
40deg
50deg
60deg
70deg
80deg
0
5
10
15
20
25
30
35
40
45
50
1
1.5
2
2.5
3
3.5

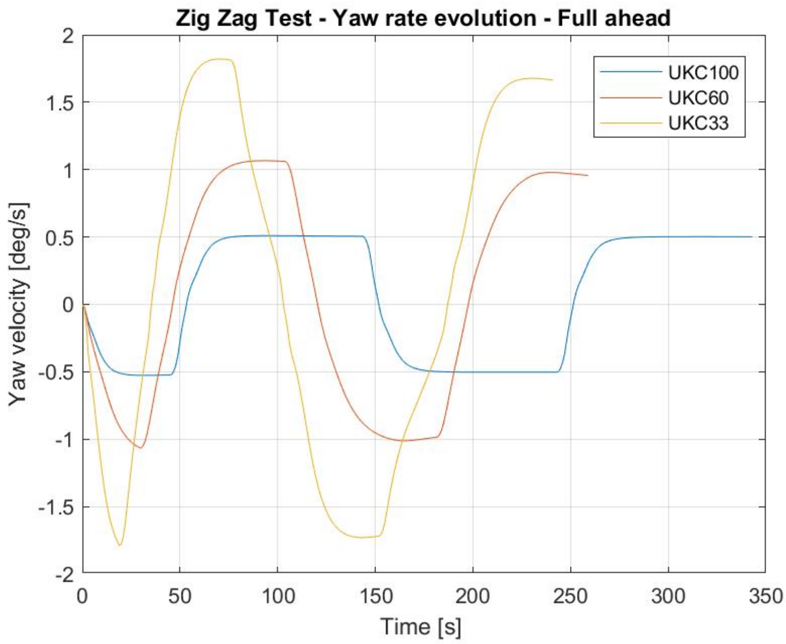

Unsteady turning circle - Yaw rate evolution - Full ahead
Yaw rate [deg/s]
Time [s]
-10deg
-20deg
-30deg
-40deg
-50deg
-60deg
-70deg
-80deg
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
50
100
150
200
250
300
350
400

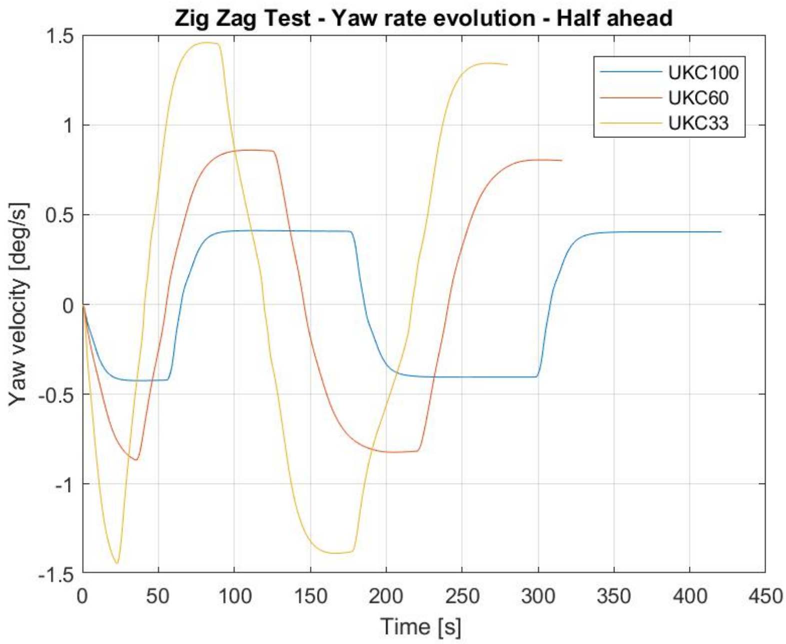

Unsteady turning circle - Longitudinal speed evolution - Full ahead
Longitudinal speed [m/s]
Time [s]
-10deg
-20deg
-30deg
-40deg
-50deg
-60deg
-70deg
-80deg
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
50
100
150
200
250
300
350
400

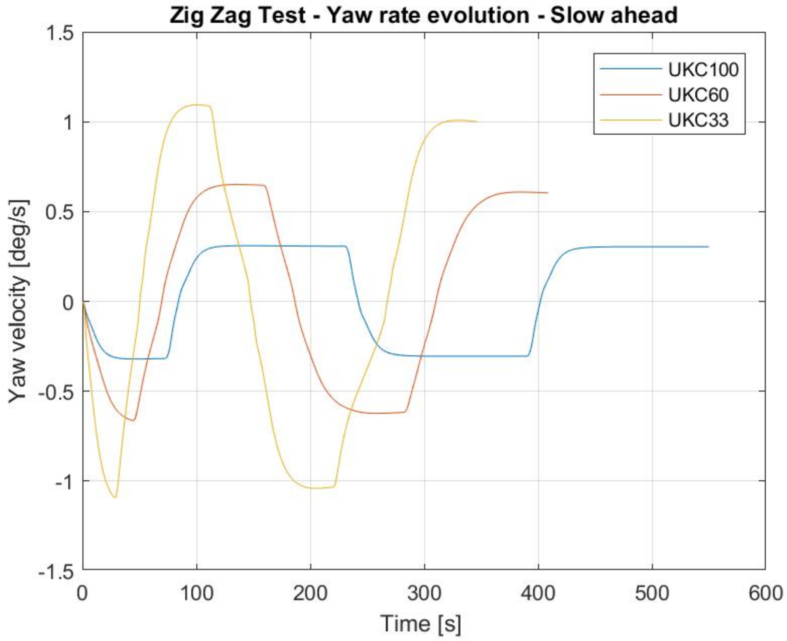

Unsteady turning circle - Transversal speed evolution - Full ahead
Transversal speed [m/s]
Time [s]
-10deg
-20deg
-30deg
-40deg
-50deg
-60deg
-70deg
-80deg
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0
50
100
150
200
250
300
350
400


Zig Zag Test - Time to check yaw 1
Full
Half
Slow
Time to chek yaw 1 [s]
T/(h-T) (-)
26
24
22
20
18
16
14
12
10
8
1
1.5
2
2.5
3
3.5


Zig Zag Test - Overshoot angle 1
Full
Half
Slow
Overshoot angle 1 [deg]
T/(h-T) (-)
25
20
15
10
5
0
1
1.5
2
2.5
3
3.5


Zig Zag Test - Yaw rate evolution - Full ahead
Yaw velocity [deg/s]
Time [s]
UKC100
UKC60
UKC33
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
50
100
150
200
250
300
350


Zig Zag Test - Yaw rate evolution - Half ahead
Yaw velocity [deg/s]
Time [s]
UKC100
UKC60
UKC33
1.5
1
0.5
0
-0.5
-1
-1.5
0
50
100
150
200
250
300
350
400
450


Zig Zag Test - Yaw rate evolution - Slow ahead
UKC100
UKC60
UKC33
Yaw velocity [deg/s]
Time [s]
1.5
1
0.5
0
-0.5
-1
-1.5
0
100
200
300
400
500
600

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