ANNUAL OF NAVIGATION 8/2004

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EVALUATION OF UNIFORM CURRENT DYNAMIC EFFECT IN PRACTICAL SHIP MANOEUVRING

ABSTRACT: The dynamic model of the uniform current, as introduced in the previous paper of this volume, is assessed against a bit simpler approach called semi-dynamic one. In the latter, a ship is assumed to move in still water and the over ground movement is just computed after each iteration of the differential equations integration. The level of inaccuracy caused by the semi-dynamic method depends upon the manoeuvre type. Also, some aspects of ship berthing in the ahead uniform current are raised, and compared with different degrees of simplification as employed in the shiphandling practise while dealing with the current (referred to in general as the kinematic model).

INTRODUCTION

In the Author's previous paper of this volume [Artyszuk, 2004], a uniform current full dynamic influence upon a ship's inertial linear and angular motion has been inspected. Such an instance of manoeuvring motions is the most severe but pure case that reflects all major symptoms of the uniform current, since there are no other external excitations, which could strangle or enhance the current impact. It is believed that the role of the uniform current action would reduce if the current velocity is relatively lower as compared with the ship's initial velocity and the current specific forces and moment are dominated by hull, propeller or rudder hydrodynamic excitations.

The present study objectives are:

- To examine the mentioned uniform current dynamic effect (formally called 'dynamic'), in terms of induced modifications to all three manoeuvring velocities, on traditional turning circle tests performed at different initial speeds (propulsion throttles) and helm orders. a comparison to the cumulative translation of water-relative track and differential equations written for motions through the still water, hereafter referred to as the 'semi-dynamic' approach, is going to be made. The purpose is to assess the quality of corrected sea trials (the semi-dynamic model is generally used here) both in the aspect of the manoeuvring mathematical model optimisation or identification, and onboard application by mariners.

- To investigate changes in the classical berthing manoeuvre appearance under a bow uniform current, which are implied by the implementation of the current dynamic effect. This is equivalent to the semi-dynamic method because of a ship's heading kept constant by means of a rudder. Details will be explained later. However, since the yaw effect and even the drifting inertia from the uniform oblique current are often ignored in 'practical' manoeuvring (see [Artyszuk, 2004]), so the current is assumed to operate through the velocity triangle (the so-called kinematic model) - exactly constant berthing velocity is thus adopted, which is not true.
- To analyse a turning manoeuvre at the spot as probably demonstrating one of the largest differences between the mentioned semi-dynamic and dynamic model of the uniform current impact.

The whole research will be carried out by means of the computer simulation and well validated manoeuvring mathematical model of a small chemical tanker (6000 tonnes in deadweight, 97.4 metres in length) in the loaded condition. This ship has been presented in the many previous Author's works e.g. [Artyszuk, 2003a, 2004].

SEMI-DYNAMIC APPROACH TO THE CURRENT EFFECT

In the shiphandling practise, the uniform current is mainly considered as an additive velocity vector that shall be combined with the ship's through the water linear velocity vector to obtain the over-ground movement. Hence, and due to the hydrodynamic nature of all external excitations, the first approach to incorporate the current effect in ship manoeuvring mathematical model seems to be solving differential equations of a ship's motions like there is no current. After that, the current allowance is to be applied.

This conduct is not correct- a ship (as a rigid body) normally moves over ground according to the Newtonian laws and all the aspects of the surrounding water (including added masses) shall be treated as external excitations dependent on the water relative velocities. The moving water (even of the uniform type), being just the sea current, may not be regarded as the inertial system, which does not 'disturb' a ship's manoeuvring dynamics as described by differential equations of motions.

The point is that, if a ship starts turning, there exist some centrifugal terms, which shall be directly associated with the over-ground motion instead of the water-relative motion. The following exhibits the normal over-ground manoeuvring motions equations (see [Artyszuk, 2004] for symbols definition, '*c*' superscript denotes the current, 'g' and 'w' stand for the ground- and water-relative motion correspondingly):

$$\begin{cases} \dfrac{dv_x^{g,w}}{dt}\left(m+m_{11}\right) & = & m v_y^w \omega_z + \underline{m v_y^c \omega_z} + c_m m_{22} v_y^w \omega_z + F_x\left(v_x^w, v_y^w, \omega_z\right) \\ \dfrac{dv_y^{g,w}}{dt}\left(m+m_{22}\right) & = & -\left(m v_x^w \omega_z + \underline{m v_x^c \omega_z} + m_{11} v_x^w \omega_z\right) + F_y\left(v_x^w, v_y^w, \omega_z\right) \\ \dfrac{d\omega_z}{dt}\left(J_z+m_{66}\right) & = & -\left(m_{22}-m_{11}\right) v_x^w v_x^w + M_z\left(v_x^w, v_y^w, \omega_z\right) \end{cases} \quad (1)$$

A rejection of the underlined terms in (1) leads to the aforementioned equations of motions through the water (the semi-dynamic model). Hence the yaw equation is the same in both dynamic and semi-dynamic model of the current effect. Nevertheless, though due to the coupled manoeuvring motions, differences in the yaw velocity shall be also obviously expected. The over-ground track in the semi-dynamic model is then completed either by means of the integration of already corrected linear surge and sway velocities (after adding the current vector components) as transformed next to the earth coordinates, or directly as based on the water-relative track:

$$\begin{bmatrix} x^g \\ y^g \end{bmatrix} = \begin{bmatrix} x^w \\ y^w \end{bmatrix} + t \cdot \begin{bmatrix} \left|\vec{v}^c\right| \cos\gamma_c \\ \left|\vec{v}^c\right| \sin\gamma_c \end{bmatrix} \quad (2)$$

where: x, y - ship's position cartesian coordinates, in [m] from arbitrary origin (x axis points up, while y axis to right),

t - elapsed time,

$\left|\vec{v}^c\right|$, γ_c - current velocity and direction (on the Earth, 0° means north current).

SIMULATION OF TURNING CIRCLE TESTS IN CURRENT

It is widely known that even half knot current can substantially change motions of a ship over ground during standard sea trials. In general, the current influence depends among others upon the ratio of its velocity to a ship's linear velocity, and upon the total time of manoeuvre (with regard to a ship's track only).

Fig. 1 presents the classical FAH 35° (maximum speed and throttle, maximum helm) turning test for the tanker in concern, as initially on the north heading, under the north and east uniform current of half knot (0.25m/s) conditions. Other directions of the current have been also tested, but similar absolute deviations to the shown ones between both models of the current impact are observed. The difference in trajectories corresponding to the dynamic and semi-dynamic approach is rather small (only the case of north current is displayed). a negligible variation exists in both surge (through the water) and yaw velocity - that is why they are not included for viewing. The largest contrast appears in the water-relative drift angle β (or in the sway velocity), which exhibits some oscillations against the always steady value in the semi-dynamic current effect (as there would be no current)- see the right part of Fig. 1.

Seeking for other situations, where the dynamic model of the current effect proofs to be more significant, additional turning tests at the dead slow ahead speed and throttle (25% of FAH settings) have been run, anyhow the maximum helm is maintained. Fig. 2 illustrates in turn the south and west current impact of the same magnitude (half a knot). Though the discrepancy between the dynamic and semi-dynamic model of the current is now more pronounced, they are still far from what could be expected at a glance. The visible alterations already occur in the water-relative surge and yaw velocities, but in relation to the nominal (average) values it is very hard to present them in the readable way.

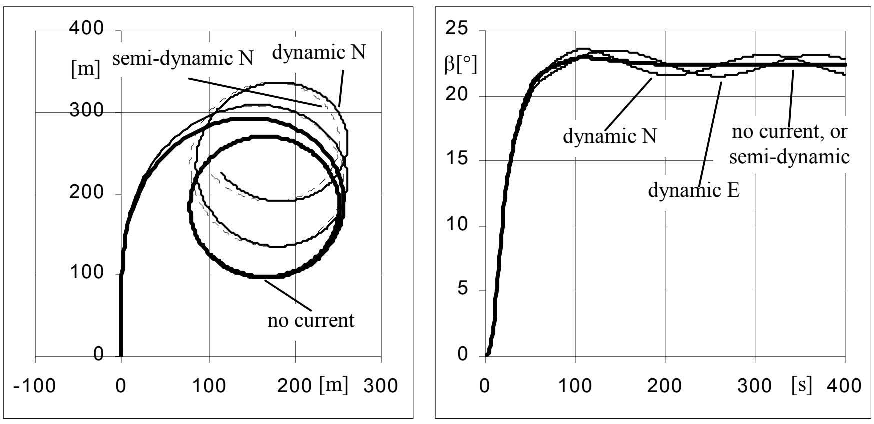

Fig. 1. Turning FAH 35°, current N and E - 0.25[m/s]

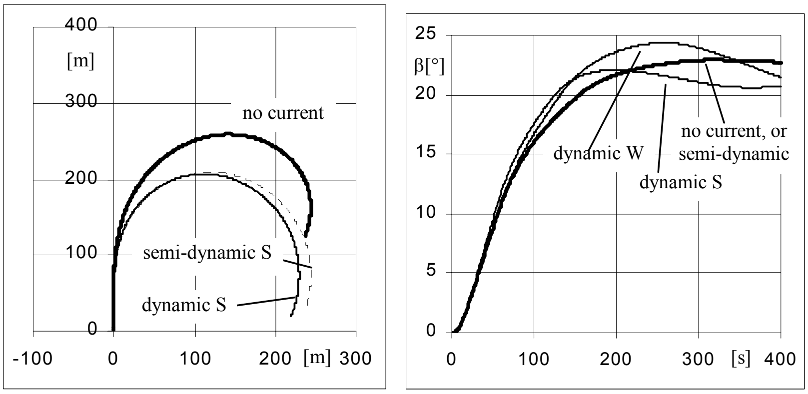

Fig. 2. Turning DSAH 35°, current S and w - 0.25[m/s]

The biggest divergence in motion caused by both uniform current models, in respect of the turning ability, arises just at the very low speed as accompanied by a small helm angle. Fig. 3 demonstrates the turning circle test at the DSAH regime and 10° rudder, in the east current of one knot (0.5m/s) already. The latter doubled current velocity has been selected just for a better perception of water-relative motion state records provided in Fig. 3.

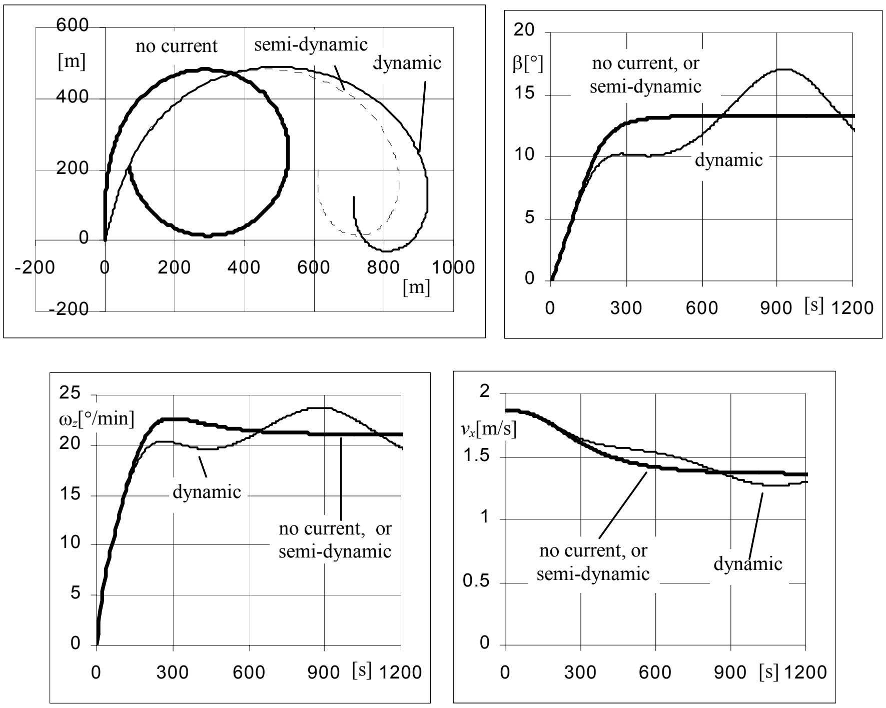

Fig. 3. Turning DSAH 10°, current E - 0.5[m/s]

BERTHING IN AHEAD CURRENT

A port side-to berthing under a uniform stream from a ship's bow is considered hereafter. The quite efficient berthing procedure of developing a perpendicular movement towards a berth on a steady oblique heading is adopted versus other less safe approaches (though much faster). The chosen symbols and initial arrangement are clarified in Fig. 4. The uniform current is parallel to a berth. The ship is slightly inclined towards a berth and initially fixed over ground i.e. both the surge (longitudinal) and sway (lateral) velocity over ground are equal to zero.

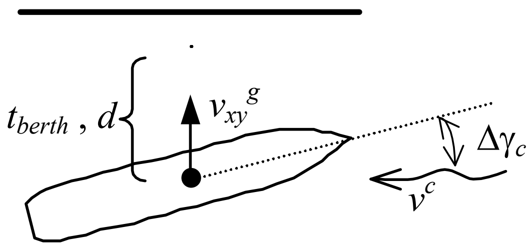

Fig. 4. Berthing in bow current - symbol definition

If the uniform current yaw effect were absent (as in the pure kinematic model of the current action), the ship would start to drift towards the berth at the same heading in a line perpendicular to the berth. Of course, there is a need to apply some occasional short propulsion kicks to overcome the water resistance in the longitudinal direction and maintain the perfect perpendicular motion.

The fundamentals of drifting in the uniform current have been formulated in [Artyszuk, 2004]. This perpendicular drift is accelerated due to decreasing the initial lateral velocity through the water, according to Fig. 4 directed to starboard as equal to the current vector projection into the ship's body axes, but taken with opposite sign. The steady asymptotic value of drift, as coming from the mentioned current velocity projection, is reached after a long time.

Fig. 5 consists of two charts indicating the parameters of berthing in the ahead current for the chemical tanker under investigations - the refined mathematical manoeuvring model as per [Artyszuk, 2004] is employed. The results are presented in relative units to account for any current velocity (it is recommended to construct similar charts for other ships). The independent variable (abscissa) is here the instant travelled distance *d* expressed in the ship's breadth units [B].

The left diagram in Fig. 5 describes the non-dimensional ratio of the instant perpendicular (over ground) drift velocity to the current velocity v_{xy}^{g} / v^{c} . On the other hand, the right graph shows the product of elapsed time t_{berth} and the current velocity v^{c} (being actually a virtual distance made at the current velocity). Both diagrams comprise a family of curves pertaining to the ordinary range of ship's inclination angles $\Delta\gamma_c$ up to 20°. For example, in case of the incidence angle 10° and the current velocity 1m/s, the perpendicular drift velocity will be 0.1m/s after about 150s and at the distance 0.5*B* (8.3m) from the starting position.

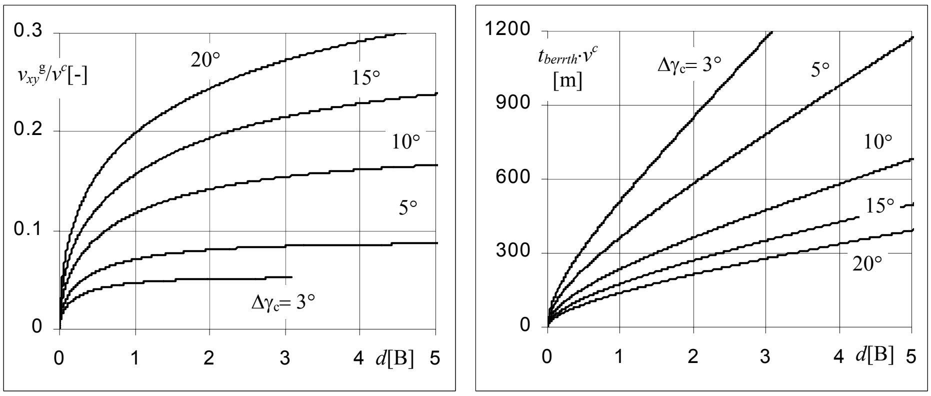

Fig. 5. Nondimensional berthing parameters in bow current - dynamic approach

Fig. 6 displays the time history of motions during a real-time and interactive simulation of the berthing in bow current based on the dynamic (or equivalent semi-dynamic) effect of the uniform current. The 5° deviation of the ship's heading and one knot current are taken into account. Both ship's sway (almost equal to the total perpendicular projection) and yaw velocity are recorded. The run of the sway velocity v_y reveals a few jumps (discrete increments), which are caused by the application of propulsion kicks and starboard helm to counteract the uniform current induced yaw moment. Additionally, the analytical ('anal.') value of pure drift motion as based on Fig. 5 has been inserted into Fig. 6.

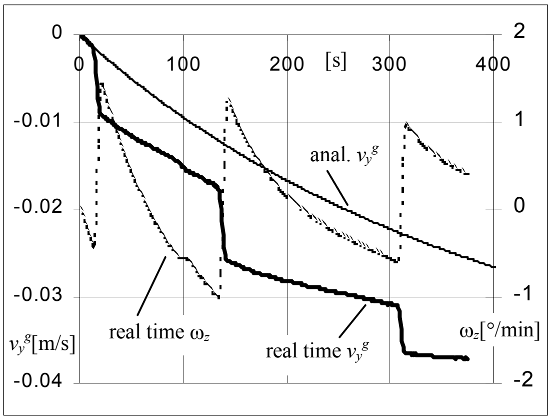

Fig. 6. Real-time berthing simulation in bow current 0.5m/s, 5° inclination

The trend in Fig. 6 between successive helm executions is maintained, though the overall berthing velocity significantly increases in a stepwise manner. The latter behaviour can not be realised if someone 'kinematically' looks at the current effect as mentioned before.

TURNING AT THE SPOT

Another manoeuvre, which exhibits huge differences between the dynamic and semi-dynamic approaches to modelling the uniform current effect, seems to be turning at the spot like in various turning basins. Fig. 7 to 9 display such 360° turning in the astern (following) and ahead (counter) current of one knot accordingly. a dedicated autopilot, designed to carry out such a manoeuvre, has been implemented with a strategy to use SAH (slow ahead) and SAS (slow astern) propulsion orders together with the continued maximum starboard rudder 35° (the rudder does not work anyhow for astern throttles). The propulsion throttles have been switched over when the corresponding longitudinal velocity over ground reaches 0.12 knot for ahead motion and 0.08 knot for astern motion (here a bit lower value appears as the yaw motion increases the astern velocity) to keep the null average velocity.

The observed deviation in tracks between the dynamic and semi-dynamic models of the sea current can be attributed to unequal sway velocities (drift angles) over ground, which contribute to the very important (in this type of manoeuvre) pivot point over ground. Fig. 8 comprises the time history of the sway velocity, while Fig. 9, just for example, presents how the pivot point is affected.

The higher is the sway velocity (the feature of the semi-dynamic model), the further from amidships lies the pivot point (either forward or aft, as affected by the sway velocity sign). During the performed turning at the spot, the yaw velocity is independent of the current effect model.

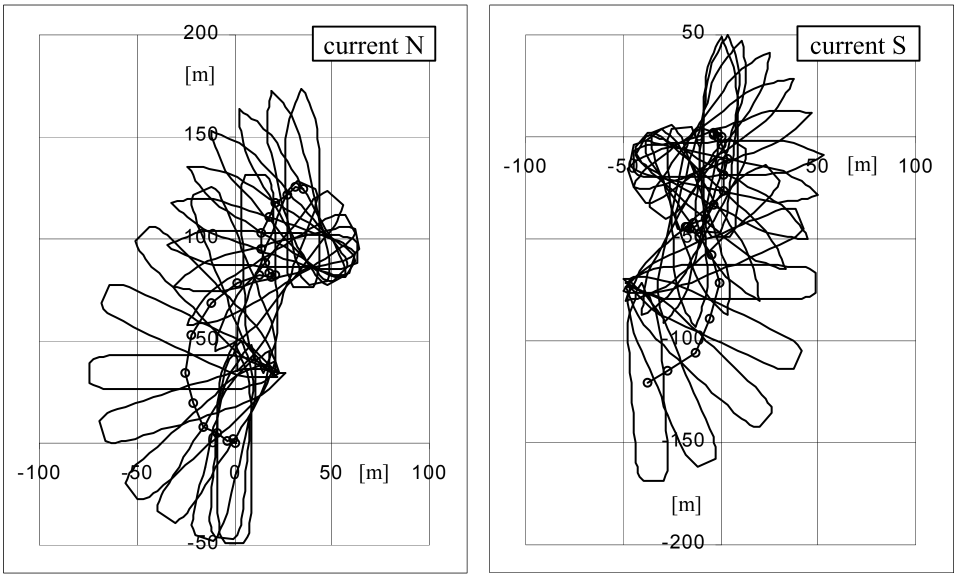

Fig. 7. Turning at spot in current N/S 0.5m/s - ship's contours (dynamic approach only)

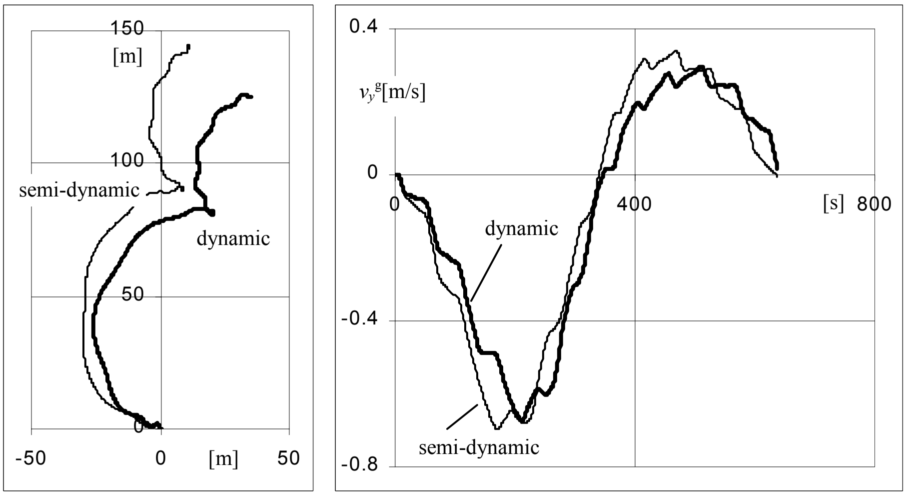

Fig. 8. Turning at spot in current N 0.5m/s - tracks and sway velocity over ground

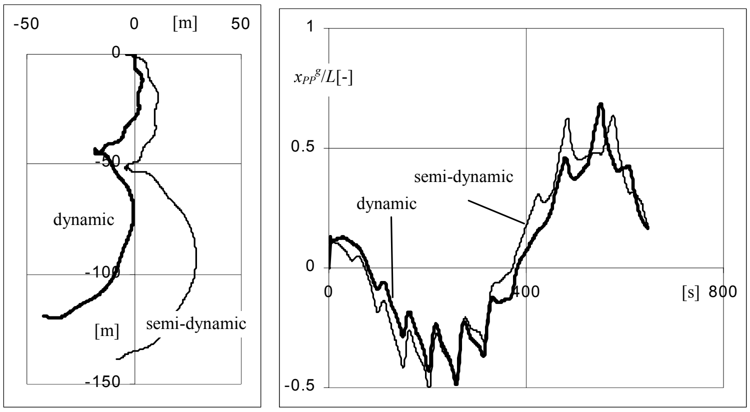

Fig. 9. Turning at spot in current S 0.5m/s - tracks and pivot point over ground

FINAL REMARKS

In view of the achieved results, concerning among others a mutual relationship of the dynamic and semi-dynamic model for the uniform current, it is confirmed that the kinematic correction (see e.g. [Artyszuk, 2003]) of full scale manoeuvring trials for the current allowance is quite accepted in rather wide range of propulsion and steering settings. This is of advantage because the manoeuvring mathematical model (incorporating the appropriate hydrodynamic items) may be sufficiently known just after the corrected trials are acquired in the mathematical model identification/optimisation process.

The zig-zag tests (even DSAH 20°/20°) have been also simulated in the background of this paper. However, they are not worthwhile to be presented in detail due to comparatively low sensitivity on the current effect model.

The present study has also proved, that in many practical situations the full current dynamic effect is really essential.

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Received September 2004
Reviewed October 2004