**Scientific Journals**
**Maritime University of Szczecin**

**Zeszyty Naukowe**
**Akademia Morska w Szczecinie**

**2013, 36(108) z. 1 pp. 32–37**
**ISSN 1733-8670**

**2013, 36(108) z. 1 s. 32–37**

# Determination of the inland units models parameters for short-term prediction

**Mateusz Bilewski, Lucjan Gucma, Agnieszka Puszcz**

Maritime University of Szczecin
70-500 Szczecin, ul. Wały Chrobrego 1–2, e-mail: {l.gucma; a.puszcz}@am.szczecin.pl

**Key words:** short term prediction, inland units, manoeuvring, hydrodynamics, navigation simulator

**Abstract**
Short-term prediction is a tool that helps to manoeuvre inland units, allows assessing the effect of the planned manoeuvre and reduces the probability of collision. Model of ships hydrodynamics is required to perform this task. In the paper simple to implement solution based on a Nomoto model is proposed. Method of determining the parameters of the model was presented. Researches were carried out with use of INSim Inland Navigation Simulator.

## Introduction

For the purposes of ships position and state prediction [1] of any vessel it is usually necessary to create the hydrodynamic model. Such models could be adaptive [2] with constantly adjusting parameters. The most commonly used mathematical models are [3, 4, 5]:

- Norrbin model;
- de Witt-Oppe model;
- Nomoto model.

These models vary in complexity and a numbers of included physical phenomena. For the purpose of short-term prediction Nomoto model is adequate [1] because it allows calculating the individual model parameters. There are several methods of determining the parameters of Nomoto model. Two methods which use data from different types of tests are presented and compared. Researches were carried out on the INSim Inland Navigation Simulator (Fig. 1).

## Methods of determining the Nomoto model parameters

Circulation data are used in the first method. Time measurements $t_1$ required for rudder angle inclination from zero to a predetermined rudder

Fig. 1. View of the INSim wheelhouse [2, 6]

position $\delta_r$ were performed. After reaching a constant rate of turn a record of two courses $\psi(t_2)$, $\psi(t_3)$ and time of manoeuvre is made. The model coefficients can be determined from these data as follows follows [7, 8]:

$$K = \frac{\dfrac{\psi(t_3)-\psi(t_2)}{t_3-t_2}}{\delta_r} \tag{1}$$

$$K = \frac{\psi(t_3)t_2-\psi(t_2)t_3}{\psi(t_3)-\psi(t_2)} - \frac{t_1}{2} \tag{2}$$

The second method uses the Z-Manoeuvre Test (Kempf). In this method we obtain an additional parameter correction angle $\delta_c$ [9]. The Z-manoeuvre test (Kempf, 1944) is used to express course changing (yaw checking) and course keeping qualities. Alternating changes of heading are performed. The following data are recorded:

- before heading change: the time $t_i$, heading $\psi_i$ and rate of turn $\dot{\psi}_i$;
- for the maximum heading alternation form of the initial heading: time $t_{mi}$, heading $\psi_{mi}$.

$$\frac{\int_0^{t_{mi}} \delta_r \,\mathrm{d}t}{\psi_{mi}} = \delta_c \frac{-t_{mi}}{\psi_{mi}} + \frac{1}{K} \tag{3}$$

To substitute:

$$y = \frac{\int_0^{t_{mi}} \delta_r \,\mathrm{d}t}{\psi_{mi}} \tag{4}$$

$$a = \delta_c \tag{5}$$

$$x = \frac{-t_{mi}}{\psi_{mi}} \tag{6}$$

$$b = \frac{1}{K} \tag{7}$$

Substituting further test parameters, pairs of values of $x$ and $y$ are obtained. Using the linear regression parameters $a$ and $b$ are determined. Two Nomoto parameters are obtained:

$$\delta_c = a \tag{8}$$

$$K = \frac{1}{b} \tag{9}$$

To obtain the last parameter for the next heading alternation:

$$T = \frac{\psi_{mi} - \psi_i - K\,\delta_c\left(t_{mi}-t_i\right) - K\int_{t_i}^{t_{mi}} \delta_r \,\mathrm{d}t}{\dot{\psi}_i} \tag{10}$$

The final model formula:

$$T\ddot{\psi} + \dot{\psi} = K\left(\delta_c + \delta_r\right) \tag{11}$$

Substitutes zero for $\delta_c$ for the previous method.

## INSim Inland Navigation Simulator description

The INSim simulator allows for visualization of most navigation and manoeuvrability processes in a variety of inland waterway vessels (standard

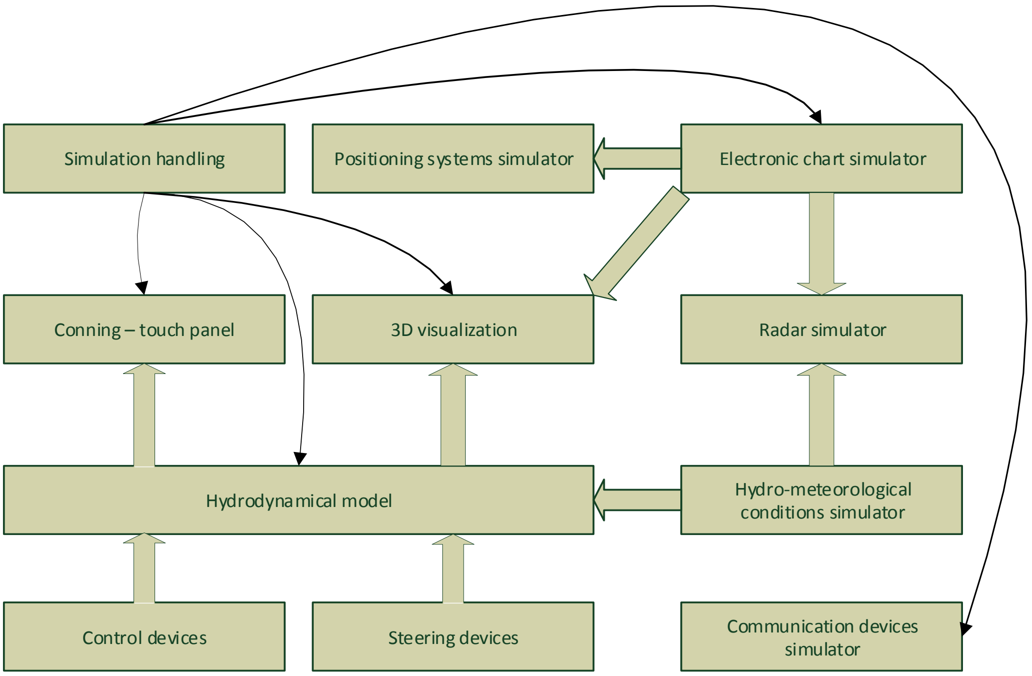

Fig. 2. Simplified block diagram of INSim simulator [11]

units) manoeuvring on various inland navigation waters (river, canal, lock, port and others). A simplified block diagram of a simulator is shown in figure 2. The hydrodynamic model is supplied with data from monitoring and steering devices and with hydro-meteorological conditions model [10]. Electronic charts are used by the simulator positioning systems, radar simulator (which also takes into account the hydro-meteorological conditions) and 3D visualization.

During construction of the conning panel two different visualizations were created:

a) for Astraada touch panel;
b) as a computer virtual panel.

For both connings types an innovative two-way operation mode was created. That allowed for precise operation of the most important controls from a single device. Such functionality is described in [11].

Two interfaces were created for the purpose of communication with both panels:

a) TCP/IP based, Modbus protocol, for communication between touch panel and virtual panel;
b) MDMB protocol for communication between virtual panel and other devices [12].

Virtual conning has the ability to save data (log) such as the telegraph and rudder settings, their current value, geographical coordinates, UTC time, meteorological conditions, rate of turn and the lights and sound signals status.

The mathematical model applied in INSim inland simulator is hydrodynamic model limited to 3DOFs (the horizontal planar motion) taking into account ship movement over the ground (thus the so-called dynamic effect of the water current is introduced) is given by Artyszuk [6] with following parameters ((12a) and (12b)):

$$\begin{cases} (m+m_{11})\dfrac{\mathrm{d}v_x^g}{\mathrm{d}t} = \\ = (m+c_m m_{22})v_y^g\omega_z + (m_{11}-c_m m_{22})v_y^c\omega_z + F_x \\ (m+m_{22})\dfrac{\mathrm{d}v_y^g}{\mathrm{d}t} = \\ = -(m+m_{11})v_x^g\omega_z + (m_{11}-m_{22})v_x^c\omega_z + F_y \end{cases} \tag{12a}$$

$$\begin{cases} (J_z+m_{66})\dfrac{\mathrm{d}\omega_z}{\mathrm{d}t} = \\ = -(m_{22}-m_{11})\left(v_x^g-v_x^c\right)\left(v_y^g-v_y^c\right)+M_z \end{cases} \tag{12b}$$

$$\frac{\mathrm{d}x_0}{\mathrm{d}t} = v_{NS}^g, \quad \frac{\mathrm{d}y_0}{\mathrm{d}t} = v_{EW}^g, \quad \frac{\mathrm{d}\psi}{\mathrm{d}t} = \omega_z \tag{13}$$

$$\begin{bmatrix} v_{NS}^g \\ v_{EW}^g \end{bmatrix} = \begin{bmatrix} \cos\psi & -\sin\psi \\ \sin\psi & \cos\psi \end{bmatrix} \cdot \begin{bmatrix} v_x^g \\ v_y^g \end{bmatrix} \tag{14}$$

where:

$v_x^g$, $v_y^g$, $\omega_z$ – ship surge, sway and yaw velocity over the ground;
$x_0$, $y_0$, $\psi$ – position Cartesian coordinates and heading;
$m$ – ship mass;
$m_{11}$, $m_{22}$, $m_{66}$ – added masses;
$c_m$ – empirical factor;
$F_x$, $F_y$, $M_z$ – external excitations (resultant / total surge, sway force and yaw moment), generally consisting of the following items (denoted by additional subscripts) and being generally the functions of ship speed through the water (“$v_w$”):

$$\begin{cases} F_x = F_x\left(v_x^w, v_y^w, \omega_z\right) \\ F_y = F_y\left(v_x^w, v_y^w, \omega_z\right) \\ M_z = M_z\left(v_x^w, v_y^w, \omega_z\right) \end{cases} \tag{15}$$

$$v_x^w = v_x^g - v_x^c, \quad v_y^w = v_y^g - v_y^c \tag{16}$$

$$\begin{bmatrix} v_x^c \\ v_y^c \end{bmatrix} = \begin{bmatrix} \cos\psi & \sin\psi \\ -\sin\psi & \cos\psi \end{bmatrix} \cdot \begin{bmatrix} \left|\vec{v}^c\right| \cos\gamma_c \\ \left|\vec{v}^c\right| \sin\gamma_c \end{bmatrix} \tag{17}$$

where: $|\vec{v}^c|$ and $\gamma_c$ represent the velocity and geographical direction of the water current (a uniform current by default).

## Researches and results

The chosen parameters of analyzed types of inland vessels are presented in table 1 and figure 3.

Table 1. The parameters of analysed ships

| Ships name | Luis Lynn | Chopin | BM600 |
|---|---|---|---|
| Length overall [m] | 78.81 | 83 | 70.7 |
| Max width [m] | 8 | 9.5 | 9 |
| Engine power | 360 HP | 2×350 kW | 2 × Sulzer-Cegielski, type 4BH22 |

Table 2. Determined Nomoto parameters and average error between the model and measurement

| | Heading | | | COG | | |
|---|---|---|---|---|---|---|
| | *K* | *T* | Mean Error | *K* | *T* | Mean Error |
| Luisa Lynn | 0.069591 | 43.581930 | 2.15 | 0.069112 | 62.194846 | 2.30 |
| BM600 | 0.090737 | 8.867580 | 1.32 | 0.090794 | 10.864230 | 1.27 |
| Chopin | 0.025780 | 2.460860 | 1.55 | 0.025796 | 9.461688 | 0.47 |

Fig. 3. Luisa Lynn (on the left) [13] BM 600 (right) [14]

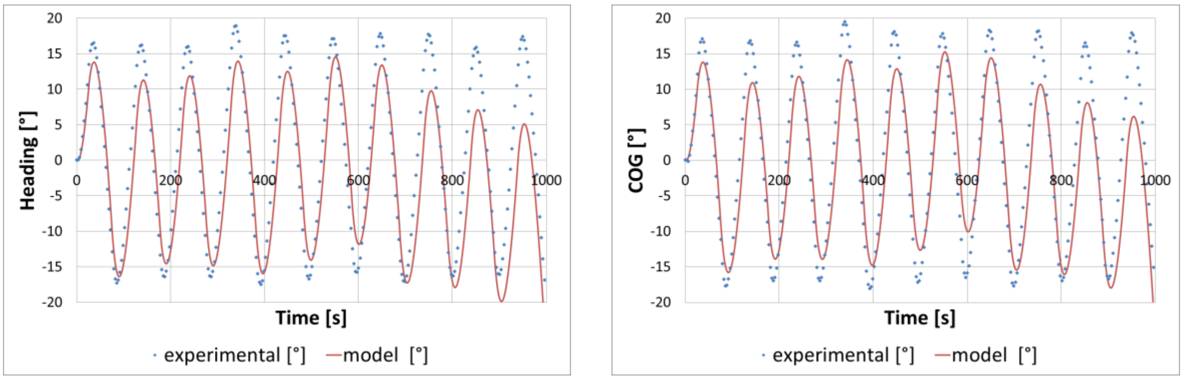

Fig. 4. Heading ($T = 25.69685915$, $K = 0.133517128$, $\delta_c = -0.079667512$) and COG ($T = 29.4517892$, $K = 0.141409932$, $\delta_c = -0.070099909$) for BM600

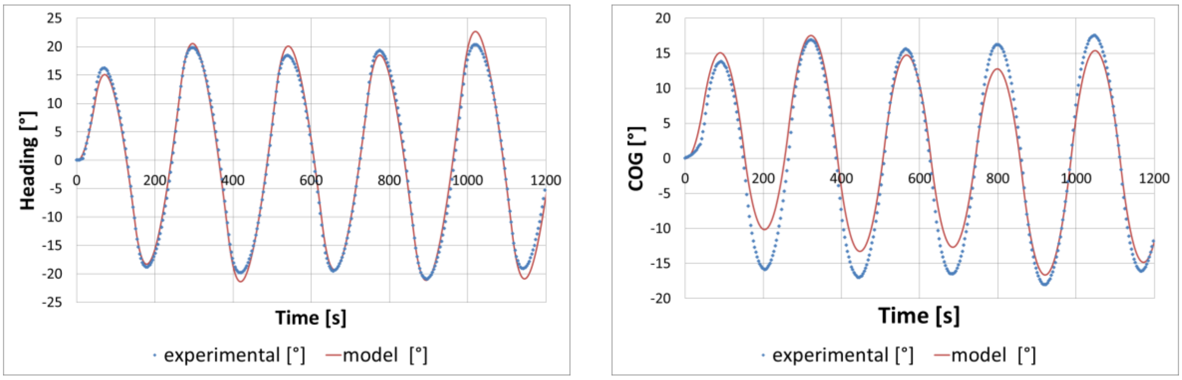

Fig. 5. Heading ($T = 50.66497149$, $K = 0.070000817$, $\delta_c = -0.015940908$) and COG ($T = 568.3399854$, $K = 0.448406806$, $\delta_c = -0.01990968$) for Luissa Lynn

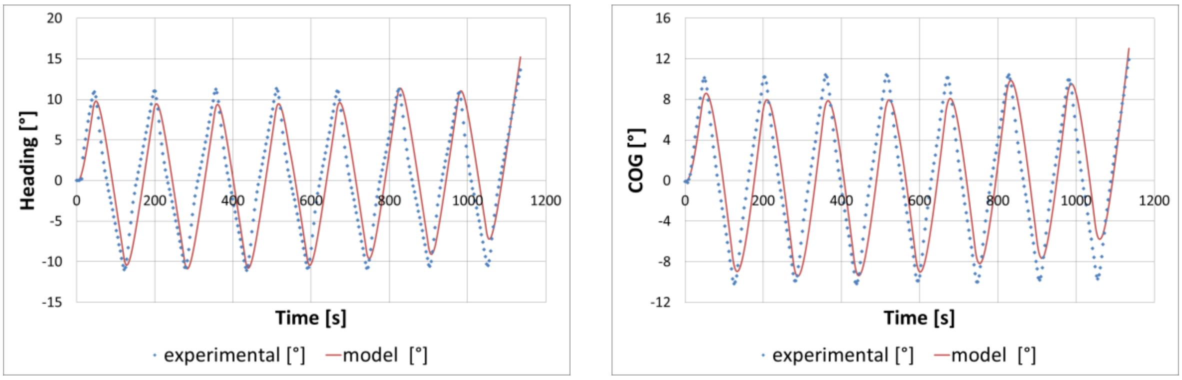

Fig. 6. Heading ($T = 9.895612992$, $K = 0.032766704$, $\delta_c = 0.198203792$) and COG ($T = 17.62053051$, $K = 0.0336303$, $\delta_c = 0.194842589$) for Chopin

On the basis of the circulation manoeuvre Nomoto model parameters were determined as shown in table 2.

Parameters $T$, $K$ and $\delta_c$ for these three vessels were determined on the basis of the Z-Manoeuvre Test (Kempf). Simulated heading and COG for the same input parameters are presented in figures 4, 5 and 6.

Mean error value (the difference between the angle measured on the simulator and the angle at the same time in model during test) is shown in figure 7.

## Conclusions

In this paper the determinations of simplify Nomoto model is presented and validated by INSim inland simulator model which incorporates multi parameters hydrodynamic model.

The achieved results proved that presented methods may be used to determine the simplified models parameters. Depending on the method of parameters determination the results are slightly different (Fig. 8). The method is more accurate with larger ships of less manoeuvrability. The potential of these methods depends on timing accuracy in relation to the speed manoeuvres. It was noted that model parameters which were determined on the basis of one or more tests are sufficient for a long time prediction. It should be remembered, however, that Nomoto model itself has several limitations and can be applied only to the rudder limits of 15–20 degrees.

Due to frequent changes of hydro-meteorological condition on rivers prediction on longer distances is not necessary. Short distances prediction with parameters adjustment for new conditions is sufficient. For the purpose of short-term prediction a simple hydrodynamic model for which parameters can be calculated in a simple and rapid method is needed. The presented method provides to achieve this result with an uncomplicated device

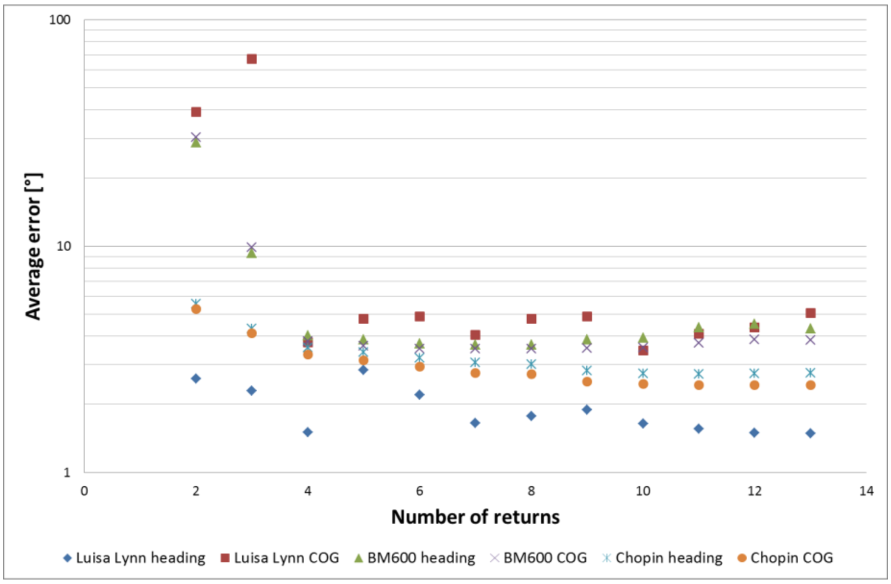

Fig. 7. The mean error value of depending on the amount of selected phrases in the calculation

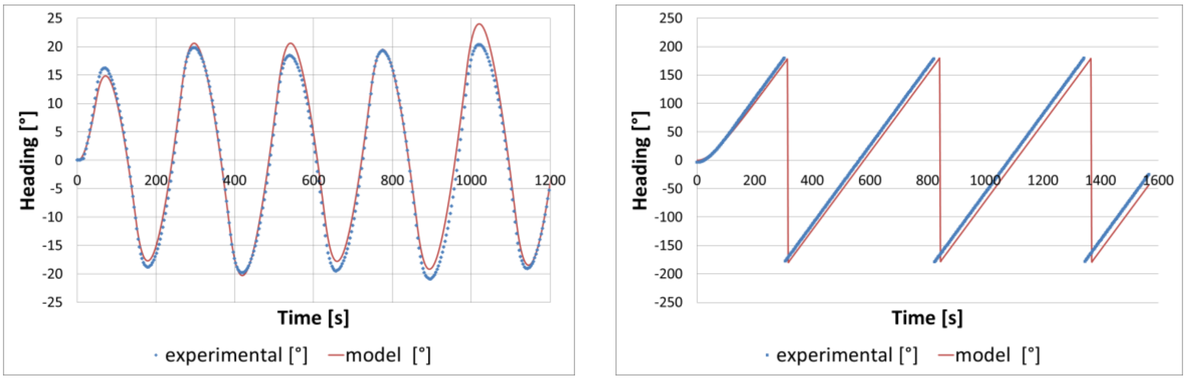

Fig. 8. Heading for Luisa Lynn: Z-Manoeuvre Test (Kempf) for parameters set in circulation (left); for circulation manoeuvre within the parameters of the Z-Manoeuvre Test

such as a microcontroller. Carried out tests were designed to check whether it is possible to have a reliable representation of a simplified model of the ship by Nomoto model. The positive results suggest that it is reasonable to use presented methods for inland vessels.

## References

1. GUCMA L.: Predykcja w systemie map elektronicznych jako czynnik bezpieczeństwa manewru. Rozprawa doktorska obroniona przed Radą Wydziału Nawigacyjnego WSM w Szczecinie, WSM, Szczecin 1999.
2. AMERONGEN VAN J.: Adaptive steering of ships. PhD thesis, Delft University of Technology, 1982.
3. FOSSEN T.I.: Guidance and control of ocean vehicles. Willey and Sons Inc., New York 1994.
4. GUCMA L., KLIMKIEWICZ K.: Analysis of possible application of simplified hydrodynamic models in simulation methods of marine traffic engineering. MTE Conference, 2007.
5. NOMOTO K. et. al.: On the steering qualities of ships. International Shipbuilding Progress Information, Vol. 4, No. 35, 1975.
6. ARTYSZUK J.: Towards a Scaled Manoeuvring Mathematical Model for a Ship of Arbitrary Size. Scientific Bulletin, Maritime University of Szczecin, 2005.
7. JOURNÉE J.M., PINKSTER J.: Introduction in ship hydromechanics. Delft University of Technology, 2002.
8. NOMOTO K.: Analysis of Kempf's Standard Manoeuvre Test and Proposed Steering Quality Indices. First Symposium on Ship Manoeuvrability, DTRC Report 1461, 1960.
9. JOURNÉE J.M.: A Simple Method for Determining the Manoeuvring Indices K and T from Zigzag Trial. Data Report 267, Delft University of Technology, 1970.
10. JUSZKIEWICZ W, MUCZYŃSKI B, GUCMA M., BILEWSKI M.: Functionality of navigation systems interfaces in the integrated interactive simulator for inland ship navigation. Inland Shipping, Szczecin 2013.
11. BILEWSKI M., et. al.: Construction and functionality of integrated interactive simulator for inland ship navigation. Inland Shipping, Szczecin 2013.
12. BILEWSKI M., GUCMA M., DUCZKOWSKI M.: Consolidating navigational information for inland manoeuvre simulator purpose. ExploShip, Świnoujście 2012.
13. http://www.marinetraffic.com
14. http://www.zegluga.wroclawska.pl

### Other

15. GUCMA L.: Modelowanie czynników ryzyka zderzenia jednostek pływających z konstrukcjami portowymi i pełnomorskimi. Wydawnictwo AM, Szczecin 2005.