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EL Pankratov
Nizhny Novgorod State University, 23 Gagarin Avenue, Nizhny Novgorod, 603950, Russia

Corresponding Author:
EL Pankratov
Nizhny Novgorod State University, 23 Gagarin Avenue, Nizhny Novgorod, 603950, Russia

On control of movement of a ship with account of changing of load

EL Pankratov

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Abstract
In this paper we introduce a model of movement of a ship with account of changing of cargo. The model is a generalization of the previously considered models and the analytical approach, which were used to analyze the introduced model, is also more general and gives a possible one to take into account a larger quantity of factors affecting the movement of the ship. The analysis of the influence of various factors on the movement of the ship is carried out.

Keywords: Model of movement of ship; analytical approach for analysis of movement

Introduction
An analysis of the dynamics of the movement of ships is necessary for prognosis the occurrence of difficult situations and to optimize cargo transportation. One of the classical stages of choosing a ship's route is the calculation of its possible trajectory depending on various parameters [1-5]. It is also attracted an interest to increase the stability and buoyancy of the ship. In this paper we introduce a model, which is more general in comparison with the models recently published in literature. An analytical approach for analyzing the model is also introduced.

Method of analysis
Movement of ship could be described by solving of the following equations [1-6]

$$\begin{cases} (L_{xx}+L_x)\frac{d\omega_x}{dt} = M_{kr} - \rho g V x_1 + \sum_{n=1}^{N} P_n x_{2n} + M_{x1} + M_{x2} \\ (L_{yy}+L_y)\frac{d\omega_y}{dt} = M_{diff} - \rho g V y_1 + \sum_{n=1}^{N} P_n y_{2n} + M_{y1} + M_{y2} \\ (m+m_z)\frac{dv_z}{dt} = \rho g V - F_g - \sum_{n=1}^{N} P_n + F_{z1} + F_{z2} \end{cases} \quad (1)$$

where $d\,z\,/d\,t = v_z$; $d\,\psi\,/d\,t = \omega_y$; $d\,\theta\,/d\,t = \omega_x$; m is the mass of ship; z is the vertical coordinate of ship; ψ is the trim angle of ship; θ is the roll angle of ship; m_z is the added mass of water; L_x and L_y are the added moment of water; ω_x and ω_y are the roll and differential angular velocities; v_z is the projection of the ship's speed on the axis Oz; ρ is the density of water; g is the acceleration of gravity; V is the volumetric displacement of the ship at the given embarkation; F_g is the ship's gravity (weight displacement); $\sum_{n=1}^{N} P_n$ is the total weight of the cargo received on the ship at a given time; F_{z1} is the force of resistance of water to movements of the body; M_{x1} and M_{y1} are the moments of resistance of water to movements of the body; F_{z2} is the disturbing vertical force; M_{x2} and M_{y2} are the moments in roll and trim from the action of waves; L_{xx} and L_{yy} are the central moments of inertia of the ship's mass relative to the longitudinal and transverse axes; $x_1 = x_{1c}-x_{1g}$, $y_1 = y_{1c}-y_{1g}$, x_{1c} and y_{1c} are the abscissa and ordinate of ship center, x_{1g} and y_{1g} are the abscissa and ordinate of center of gravity; M_{kr} is the heeling moment of external forces acting at a given time; M_{diff} is the trimming moment of external forces. Integration of the left and right sides of equations of the system (1) on time leads to the following result.

$$\begin{cases} (L_{xx}+L_x)\omega_x = M_{kr}t - \rho g V x_1 t + \sum_{n=1}^{N} P_n x_{2n} t + M_{x1} t + M_{x2} t \\ (L_{yy}+L_y)\omega_y = M_{diff}t - \rho g V y_1 t + \sum_{n=1}^{N} P_n y_{2n} t + M_{y1} t + M_{y2} t \\ (m+m_z) v_z = \rho g V t - F_g t - \sum_{n=1}^{N} P_n t + F_{z1} t + F_{z2} t \end{cases} \quad (2)$$

The initial values of coordinates and speeds of movement, as well as the angles of rotation and the corresponding speeds were considered be zero. Re-integration of the equations of system (1) over time gives a possibility to obtain equations of motion of the considered ship in the final form

$$\begin{cases} 2(L_{xx}+L_x)\theta = M_{kr}t^2 - \rho gVx_1t^2 + \sum_{n=1}^{N} P_n x_{2n}t^2 + M_{x1}t^2 + M_{x2}t^2 \\ 2(L_{yy}+L_y)\psi = M_{diff}t^2 - \rho gVy_1t^2 + \sum_{n=1}^{N} P_n y_{2n}t^2 + M_{y1}t^2 + M_{y2}t^2 \\ 2(m+m_z)z = \rho gVt^2 - F_g t^2 - \sum_{n=1}^{N} P_n t^2 + F_{z1}t^2 + F_{z2}t^2 \end{cases} \tag{3}$$

Discussion

In this section we analyze the equations of motion (3) for different values of considered parameters. Figs. 1 and 2 show dependences of the coordinate z, angles θ and ψ on various parameters. Figs. 3 and 4 show similar dependences of the velocities v_x, as well as the frequencies ω_x and ω_y.

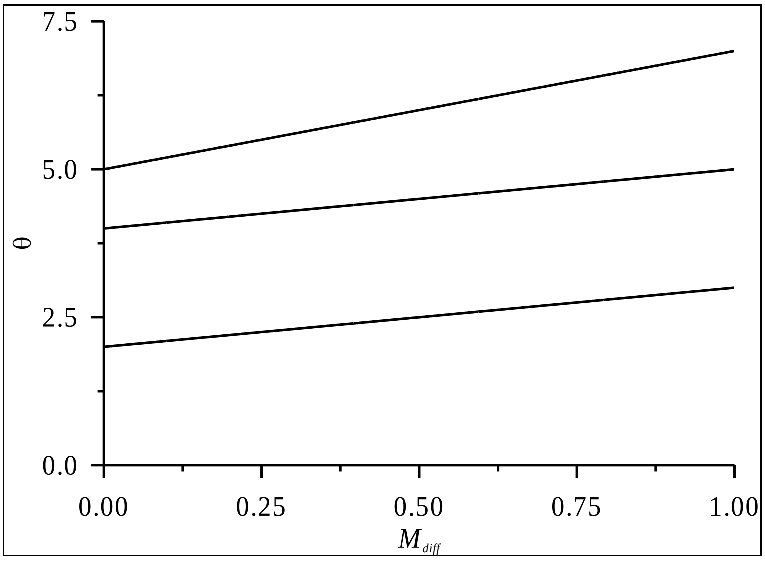

Fig 1: Typical dependences of the ship's roll angle θ on the heeling moment of external forces M_{kr}. Similar will be the dependences of this angle on the moments M_{x1} and M_{x2}, the weights of the cargo P. The dependences of the z coordinate on the density of water ρ, the acceleration of gravity g, the volumetric displacement of the vessel V, the forces F_{z1} and F_{z2}

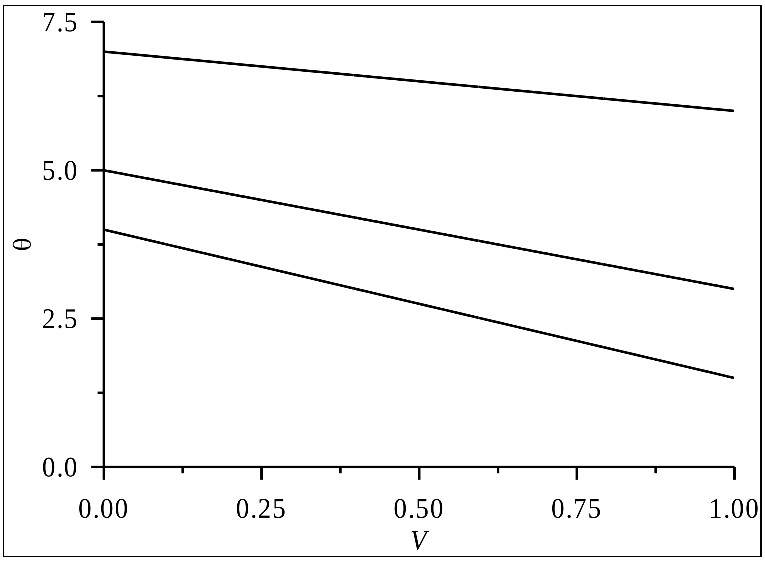

Fig 2: Typical dependences of the ship's roll angle θ on the volumetric displacement of the ship V. The dependences of this angle on the density of water ρ and the acceleration of gravity g will be similar. The dependences of the z coordinate on the gravity F_g of the weights of the cargo received on the ship P

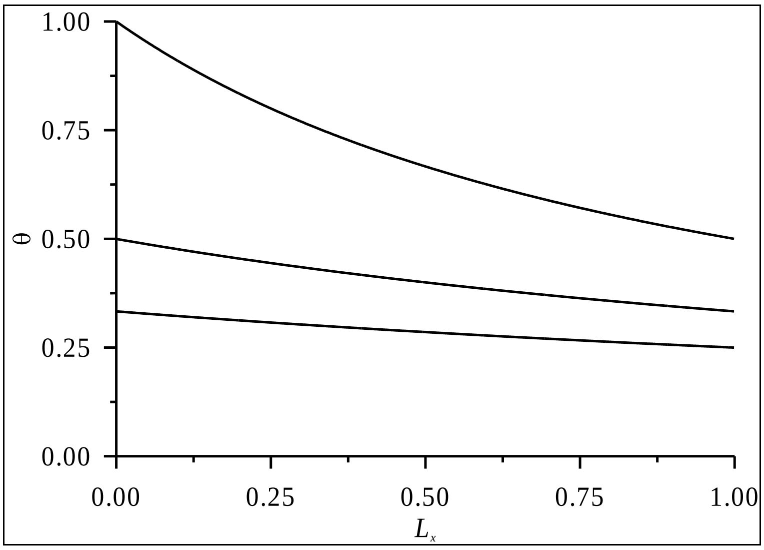

Fig 3: Typical dependences of the ship's roll angle θ on the central moment of inertia of the ship's mass L_{xx}. The dependence of this angle on the added moments of water L_x will be similar. The dependences of the trim angle of the ship ψ of the same moments will be similar. Also, the dependences of the *z* coordinate on the masses *m* and m_z will be similar

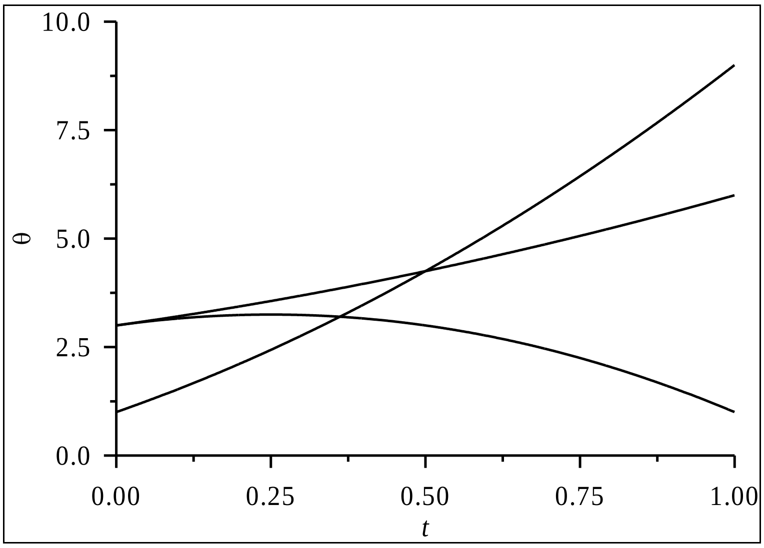

Fig 4: Typical dependences of the ship's roll angle θ on time *t*. The time dependences of the ship trim angle ψ and the *z* coordinate are similar

Conclusion

In this paper we propose a quantitative approach for analyzing the movement of the ship, taking into account the change in load. The analysis of the influence of various factors on the movement of the ship is carried out.

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