Numerical method for solving problems of dynamics of marine complexes and ship auxiliary mechanism

S A Osmukha
Admiral Ushakov Maritime State University, 93 Lenin Ave., Novorossiysk, 353924, Russian Federation
E-mail: rusalsvetik@mail.ru

Abstract. The article describes the study of methods of hydrodynamic coefficients using finite volumes, as well as numerical methods based on the study of data from the air tube experiment. The methods of converting the data of air tube experiments when working out the elements of the fixed assets of the fleet in the bases of orthogonal functions (bursts) were investigated and described. The study is based on the obtained mathematical models of processes using the methods of multi-turn engineering design, methods for constructing computer models in a structure that provides for an open process of developing and approving proposed project elements. An urgent task is to develop methods for reducing costs associated with the design and creation of marine infrastructure facilities and fixed working capital. The relevance of the tasks follows from the expensive cycles of project development, the labor costs of highly qualified specialists.

1. Introduction
The aim of the work is to develop methodological foundations of digital data transformation platforms in structural-parametric synthesis of multi-turn engineering design in the field of complex theory of water transport.

The solution of the scientific and technical problem of digital transformation of the production system, reconstruction and modernization of the fleet's fixed assets is based on theoretical research, including the stages of:
- air tube experiments;
- descriptions by methods of structural-parametric synthesis of a mathematical model;
- creating a basic digital model in a mathematical orthogonal basis;
- investigation of model properties;
- stability and transformation of the model through the technology of compression of maps in the space of bursts.

In the article we show one of the problems based on the Interpolation of hydrodynamic coefficients on the Clifford algebra.

2. Materials and methods
Let us estimate the change in the coefficients of resistance to the flow of the element (experimental site) as a function of the change in the angle of attack, the change in the angle of the longitudinal axis (yaw) and the speed roll of the object under the conditions of the air tube experiment.
The conditions of the air tube experiment are the resistance to the laminar flow of the liquid according to the Reynolds numbers. This is considered as the ratio of the kinetic energy of the liquid involved by the moving body to the energy loss over the characteristic length of the element (due to internal friction of the liquid).

The classical approach to solving the problem, taking into account the kinematics of the fluid, provides for the action of a hydrodynamic force on the site from the fluid, represented as the sum of two components: normal and tangent, calculated respectively as shown in Figure 1:

\[ q_n = q_0\sin^2\alpha; \]  
\[ q_k = q_0\cos^2\alpha; \]  
\[ q_{n0} = c_n q S, \quad q_{k0} = c_k q S, \]  

where \( c_n, c_k \) – dimensionless coefficients of normal and tangential forces; 
\( q = \rho V_0^2/2 \) – high-speed pressure; 
\( \rho \) – liquid density; 
\( V_0 \) – flow rate; 
\( S \) – drag cross-sectional area; 
\( \alpha \) – angle of attack, relative to the projection on the \( x_g \) axis of the associated coordinate system; 
\( \beta \) – yaw angle relative to the projection on the \( z_g \) axis of the associated coordinate system; 
\( \gamma \) – angle of the velocity roll of the longitudinal plane of the nozzle relative to the cross-section, the projection on the \( y_g \) axis of the associated coordinate system.

For a site with Reynolds numbers \( R_e \) from \( 10^3 \) to \( 5 \times 10^5 \), the \( c_h \) coefficient lies in the range from 1.1 to 1.4, the \( s/c_h \) ratio is on the order from 0.01 to 0.05, so it is permissible to ignore the tangent component of the hydrodynamic force when calculating [1].

Figure 1. Model of interaction between the platform and the flow from the screw

Taking into account the made assumptions, the equilibrium equations of the site in the flow will have the form:

\[
\begin{align*}
    T \frac{d\alpha}{ds} &= G\sin\alpha; \\
    T \frac{d\gamma}{ds} &= G\cos\alpha - q_{n0}\sin\alpha|\sin\alpha; \\
    \frac{dx}{ds} &= \cos\alpha; \\
    \frac{dy}{ds} &= \sin\gamma; \\
    \frac{dz}{ds} &= \sin\beta
\end{align*}
\]

where \( S \) is the cross-sectional area of the site, calculated from the cross-section in displacement mode, which sets the position of the point on the displacement line, the \( S_{mid} \) cross-section corresponds to the cross-section by the middle points of the cross-section is calculated as:
\[ T_0 = \left[ (\sum X_i)^2 + (\sum Y_i)^2 \right]^{\frac{1}{2}}; \]
\[ \alpha_i = -\arctg \left( \frac{\sum Y_i}{\sum X_i} \right). \]

where \( \sum X_i \) is the sum of the projections of all forces acting on the platform on the \( x \)-axis, the direction of which coincides with the flow velocity vector; \( Y_i \) is the sum of the projections of all forces acting on the platform on the \( y \)-axis.

To estimate the flow resistance conditions of the site under study, we will use the data of the air tube experiment. Figure 2 shows the values \( C_x(\alpha) = f(\alpha), \beta = 0; C_y(\beta) = f(\beta), \alpha = 0 \).

Analysing the dynamics of the roll angles \( \gamma \), we define \( \varphi(\gamma) \) as a function having a distribution within \(-30\)⋅\( +30 \) degrees (figure 3). It is necessary to obtain the analytical dependence of the distribution as the distribution of the complex argument in the dynamics of each of the samples of the angle \( \gamma \).[2]

Let us consider the integral of the limits of the angle change \([\alpha_-, \alpha_+], [\beta_-, \beta_+], [\gamma_-, \gamma_+]\):
For a set of implementations \( \sum \frac{t_{n-\delta}}{\alpha \beta \gamma} \exp \left( i \varphi_n \left( \frac{t_{n-\delta}}{\alpha \beta \gamma} \right) \right) \) the distribution of the function \( \varphi_n (\delta, \alpha, \beta, \gamma) \) is defined as the phase distribution by shifts and angle maps:

\[
\varphi_n (\delta, \alpha, \beta, \gamma) = \arctan \left\{ \frac{A_1 \sin \left[ \varphi_n (\frac{t_{2-t_1}}{\alpha \beta \gamma}) \right] + A_2 \sin \left[ \varphi_n (\frac{t_{2-t_1}}{\alpha \beta \gamma}) \right]}{A_1 \cos \left[ \varphi_n (\frac{t_{2-t_1}}{\alpha \beta \gamma}) \right] + A_2 \cos \left[ \varphi_n (\frac{t_{2-t_1}}{\alpha \beta \gamma}) \right]} \right\},
\]

(8)

As you can see under these conditions, we have the equality:

\[
\begin{align*}
\sum |\varphi_n| \left( \frac{t_{2-t_1}}{\alpha \beta \gamma} \right) &= \sum |\varphi_n| \left( \frac{t_{2-t_1}}{\alpha \beta + \gamma} \right), \\
\sum |\varphi_n| \left( \frac{t_{2-t_1}}{\alpha \beta - \gamma} \right) &= \sum |\varphi_n| \left( \frac{t_{1-t_2}}{\alpha \beta - \gamma} \right).
\end{align*}
\]

(9)

Again, a uniform grid, the argument values for the angle change limits \([\alpha_-, \alpha_+], [\beta_-, \beta_+], [\gamma_-, \gamma_+]\) is defined on a uniform grid in increments of \(360° / n \pi\).

The system of Morlet bursts [4], the basis for the decomposition of functions \( C_\alpha (\alpha), C_\beta (\beta), C_\gamma (\gamma) \), we can get both the shifts and the angle function mappings \( \alpha_n, \beta_n, \gamma_n = \frac{\omega_0 (t_{1-t_2})}{n \pi} \).

**Theorem 1:**

The decomposition of the function of a complex variable in the basis of wavelets (bursts) is always equal to the spectral power of the invariants.

Indeed, considering the basis \( \sum \frac{t_{n-\delta}}{\alpha \beta \gamma} \exp \left( i \varphi_n \left( \frac{t_{n-\delta}}{\alpha \beta \gamma} \right) \right) \) for orthogonal angles \( \alpha, \beta, \gamma \) coefficient value \( \frac{t_{n-\delta}}{\alpha \beta \gamma} \) uniquely determined by projections on the associated axes \( x, y, z \), each subsequent value of \( t_n \) with a fixed step \( \delta \) is described by a polynomial of the form:

\[
\varphi_n (k) = \sum_{k=1}^{n} (t_n - \delta)^k
\]

(10)

for each of which \( \sum |\varphi_n| \left( \frac{t_{n-\delta}}{\alpha \beta \gamma} \right) = n \pi \), in this case the basis \( \sum \frac{t_{n-\delta}}{\alpha \beta \gamma} \exp \left( i \varphi_n \left( \frac{t_{n-\delta}}{\alpha \beta \gamma} \right) \right) \) is the spectrum of the complete system [5, 6]:

\[
\varphi_n (\delta, \alpha, \beta, \gamma) = \sum \frac{t_{n-\delta}}{\alpha \beta \gamma} \exp \left( i \varphi_n \left( \frac{t_{n-\delta}}{\alpha \beta \gamma} \right) \right).
\]

The example is as follows. We will define a uniform angle-measuring grid, as shown in Figures 2-3, with the angle changing from \(-30°\) to \(+30°\) with increments \( t=\delta \). Coefficient values \( C_\alpha (\alpha), C_\beta (\beta), C_\gamma (\gamma) \) are defined on a uniform grid in increments of \(3°\).

Using the Lagrange polynomial, we obtain the interpolation of the function at the grid nodes as shown in figures 2-3:
\[ C_{x,y,z}(\alpha, \beta, \gamma) = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} \left( C_{ijk} \frac{(t-t_{n+1})}{(t_{n}-t_{n+1})} \right); \]

\[ C_{x,y,z}(\alpha, \beta, \gamma) = i(0.0075t + 0.76) + j(-0.0025t + 0.14) + k(0.00043t^2 + 0.01717t + 0.1). \]

3. Results and discussion

The study of methods for describing hydrodynamic coefficients using finite volumes gives good results in solving systems of differential equations for given surfaces that make up the profile of a marine mobile object. The problem considered as a set of different angular moments, which are difficult to describe by a set of surfaces that flow around a liquid.

Numerical methods based on the study of the data of the air tube experiment have a significant computational complexity, which consists in the choice of a scale grid. A regular grid is considered as large-scale if it is necessary to approximate the flow of "small" structural elements, but then it is necessary to estimate the spectrum of the vortex flow dynamics.

The solution to this problem is seen in the application of sets of basis expansions or a bank of expansions in an orthogonal basis obtained by compression and transformation of the basis.

Strictly speaking, the splash basis is used to decompose the spectrum of vortices separated by the difference in the flow velocities of the surface profiles of a marine mobile uninhabited object.

The reliability of the obtained research results is confirmed by the base of air tube experiments conducted on a wide range of engineering problems, the practice of coordinating the problems of approximation of hydrodynamic coefficients and computational methods in mathematical and graphical packages.

4. Conclusion

The construction of a family of hydrodynamic characteristics depending on the values of the angles of attack, yaw, and roll velocity at the nodes of the angle-measuring grid is provided by the decomposition of Morlet wavelets (bursts) in the basis. The power spectral density according to the Morlet basis is always equal to the power of the invariants. The study of the model in a computational experiment using the decomposition in orthogonal bases gives a good approximation on the grid for the functions of a complex variable.

References

[1] Dantsevich I M, Lyutikova M N, Novikov A Y, Osmukha S A 2020 Analysis of a nonlinear system dynamics in the Morlet wavelet basis IOP Conf. Series: Materials Science and Engineering 873 012035. doi:10.1088/1757-899X/873/1/012035
[2] Heuberger P, Van Den Hof P and Wahlberg B 2005 Modelling and identification with rational orthogonal basis functions
[3] Bertram V 2012 Practical Ship Hydrodynamics (Elsevier Ltd)
[4] Slavič J, Mihalec M, Javh J and Boltežar M 2017 Morlet-wave damping identification: Application to high-speed video Conference Proceedings of the Society for Experimental Mechanics Series vol 10B (Springer New York LLC) pp 27–30
[5] Andersen Bachelor K 2016 Development of a Time-Domain Modeling Platform for Hybrid Marine Propulsion Systems
[6] Zaslonov V V, Golovina A A, Popov A N2020 Creating a Crewless Ship in the Framework of the Technological Paradigm of the Russian Federation Lecture Notes in Networks and Systems 115468-474.DOI: 10.1007/978-3-030-40749-0_56