Optimal Modeling of Ship Moving

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***Abstract*-We consider some aspects allowing to optimize the designing of ships with the desired propulsion properties and to estimate the tactical and technicoeconomic characteristics. First question concerns a forecasting of characteristics of flow near hull, including one in boundary layer and viscous wakes, and, above all, a data on water resistance in real conditions. Simulation is carried out in the towing tank with help of the developed methods allowing to reproduce a full-scale experiment with position of description of some hydrodynamic parameters. Also the classification of supercritical regimes of dynamic systems is given and the mechanism of occurrence of self-organization, low-mode chaos and multimode turbulence is predicted. It can be used, in particular, for modeling of ocean processes, in oceanography, etc. We noted the mechanism allowing to approach to the problem of ship moving with substantial decreasing of power inputs in terms of thin coherent formations moving along body.**

I. INTRODUCTION

We consider some aspects allowing to optimize the designing of ships with the desired propulsion properties and to estimate the tactical and technicoeconomic characteristics.

II. APPROACH TO EXPERIMENTS IN THE TOWING TANK

First question concerns a forecasting of characteristics of flow near hull, including one in boundary layer and viscous wakes, and, above all, a data on water resistance in real conditions. Traditionally, the study of such questions in towing tank is to the methods of partial modeling because of scale effects. It's determined by absence of complete dynamic similarity as since in view of claim to equate Froude number and Reynolds number (in real and model conditions), only first one is secured. In this work, we give the results of experimental and theoretical prove of the method of modeling of flow in turbulent boundary layer that is corresponding to full-scale Reynolds number Re_0 in the towing tank by means of using of hydrodynamically active drag reduction polymer solutions.

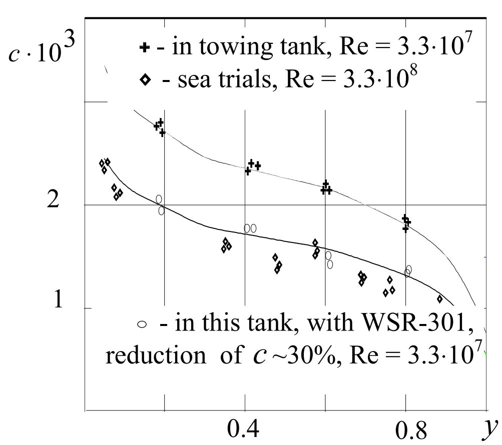

Fig. 1. Change of c along body of revolution: curves respond to calculations

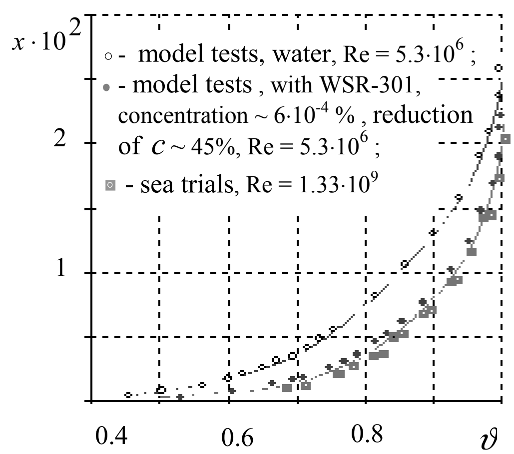

Fig. 2. Velocity ϑ distribution in boundary layer of "Krym" tanker

Such approach is based on the fact that for Re_0 , the coefficient of friction resistance c_0 is less substantially than for model tests in towing tank and application of polymer additives allows to decrease the coefficient c on ship model to values corresponding to Re_0. Mathematical basis of such modeling is considered, e.g., in [1]. Analysis achieved good agreement of real and model tests with suggested method (e.g., Fig. 1, 2, where ϑ, x, y are dimensionless values; x is the ratio of the coordinate, that is orthogonal to ship surface, to e current longitudinal coordinate). Here the special flow channel facility designed to study a diffusion of polymer additives and the towing tanks of Krylov Shipbuilding Research Institute are used.

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III. GENERAL NONLINEAR PARABOLIC EQUATION

A decrease of hydro resistance can be obtained, in particular, by organizing of certain flow pattern. Further, the problems, in particular, concerning an operating by boundary layer are considered. The development of instability leads to the appearance of self-ordered monochromatic, low-mode chaotic and multimode turbulent regimes [2]. A large class of unstable thermophysical, physico-chemical, chemically reacting, electrochemical, physical, biological and hydrodynamic nonlinear processes are described by the systems of nonlinear partial differential equations

$$\frac{\partial \phi}{\partial t}+\mathbf{N}(\phi)+\sum_{i=1}^{2}\mathbf{Q}_i(\phi)\frac{\partial \phi}{\partial x_i}+\sum_{i,j=1}^{2}\mathbf{M}_{ij}(\phi)\frac{\partial^2 \phi}{\partial x_i \partial x_j}=0, \quad (1)$$

where $\phi=\left\|\phi_1 ... \phi_n\right\|^{\mathrm{T}}$ is the real vector determined in the region $D=\{t\geq 0, \ -\infty < x_i < \infty\}$; $\mathbf{N}=\left\|N_1 ... N_n\right\|^{\mathrm{T}}$; $\mathbf{Q}$ and $\mathbf{M}$ are $n\times n$ matrices, $M_{12}=M_{21}$.

The first two terms in (1) are contained in the known equations of kinetics and biophysics and in the equations of kinetics reactions of Belousov–Zhabotinskii type with the appropriate concretization of form of the coefficients. The first, second and fourth terms describe the same reactions with diffusion and also the heat conduction with nonlinear sources (sinks) of energy. In the complete form, the equations in form (1) characterize various hydrodynamic phenomena and can be converted to a system of quasilinear differential equations with source terms [3]. Thus, the system can describe combined processes, for example, the convective heat- and mass-exchange as since restrictions are absent on nature of substance for the vector $\mathbf{N}$.

Let the system of equations (1) allow the stationary solution $\phi=\phi_0$, which loses stability for certain values of the parameters in open system as result of external action or stochastically. In the supercritical region, perturbations belonging to continuous spectral region of wave numbers are excited and grow. The perturbed solution of system (1) is given in the form

$$\phi=\phi_0+\tilde{\phi}. \quad (2)$$

The problem of nonlinear development of perturbations from the continuous spectral region of wave numbers is solved using wave packets

$$\tilde{\phi}=\int_{k_{10}-\Delta k_1}^{k_{10}+\Delta k_1}\int_{k_{20}-\Delta k_2}^{k_{20}+\Delta k_2} F(k_1,k_2)\exp i(k_1x_1+k_2x_2-\omega t)dk_1dk_2 + $$
$$+\,\text{com.con}, \quad (3)$$

where k_{10}, k_{20} and $\Delta k_1, \Delta k_2$ are the centres and widths of the wave packet along the axes x_1, x_2, respectively; $\omega=\omega_r+i\omega_i$; com.con is the complex conjugate quantities.

Under the following assumption:

$$\frac{\Delta k_1}{k_{10}}=0(\varepsilon);\ \frac{\Delta k_2}{k_{20}}=0(\varepsilon);\ \frac{\tilde{\phi}}{\phi_0}=0(\varepsilon);$$
$$(\partial\omega_i/\partial k)/\omega_{i=0}=0(\varepsilon);\ \varepsilon \ll 1, \quad (4)$$

the spectrally narrow wave packet is represented in the form of quasimonochromatic wave

$$\tilde{\phi}=\int_{k_{10}-\Delta k_1}^{k_{10}+\Delta k_1}\int_{k_{20}-\Delta k_2}^{k_{20}+\Delta k_2} F(k_1,k_2)\exp i(k_1x_1+k_2x_2-\omega t)dk_1dk_2 + $$

$$\text{com.con}=A\exp i(k_{10}x_1+k_{20}x_2-\omega(k_{10},k_{20})t)+\text{com.con}= \quad (5)$$
$$=a(\varepsilon t,\varepsilon^2 t,\varepsilon x_1,\varepsilon x_2)\exp i\theta(\varepsilon t)\exp i(k_{10}x_1+k_2x_2)+\text{com.con},$$

where $A=A(x_{11},x_{21},x_{12},x_{22},t_1,t_2)+0(\varepsilon^3)$;

$$A=\int_{-\Delta k_1}^{\Delta k_1}\int_{-\Delta k_2}^{\Delta k_2} F\left(k_{10}+\delta k_1, k_2+\delta k_2\right)\exp i\left(\delta k_1 x_1+\delta k_2 x_2-\right.$$
$$-\left(\frac{\partial\omega}{\partial k_1}\right)\delta k_1 t-\left(\frac{\partial\omega}{\partial k_2}\right)\delta k_2 t-\frac{1}{2}\left(\frac{\partial^2\omega}{\partial k_1^2}\right)(\delta k_1)^2 t- \quad (6)$$
$$\left.-\frac{1}{2}\left(\frac{\partial^2\omega}{\partial k_2^2}\right)(\delta k_2)^2 t-\left(\frac{\partial^2\omega}{\partial k_1\partial k_2}\right)\delta k_1\delta k_2 t\right)\partial\delta k_1\partial\delta k_2+0(\varepsilon^3);$$

the amplitude a and phase θ are functions of slow variables (εt and εx):

$$t_0=t;\ t_1=\varepsilon t;\ t_2=\varepsilon^2 t;\ x_1=x_{10};\ x_2=x_{20};\ x_{11}=\varepsilon x_1;\ x_{21}=\varepsilon x_2;$$
$$x_{12}=\varepsilon^2 x_1;\ x_{22}=\varepsilon^2 x_2. \quad (7)$$

We introduce the expansion

$$\phi=\phi_0+\sum_{j=1}^{\infty}\sum_{l=-\infty}^{\infty}\varepsilon^j A_l^{(j)}\exp il(k_1x_{10}+k_2x_{20}-\omega_r t_0)+\text{com.con} \quad (8)$$

and the following operators taking into account that the processes occur on many scales:

$$\frac{\partial}{\partial x_1}=\frac{\partial}{\partial x_{10}}+\varepsilon\frac{\partial}{\partial\eta_1}+\varepsilon^2\frac{\partial}{\partial x_{12}};\ \frac{\partial}{\partial x_2}=\frac{\partial}{\partial x_{20}}+\varepsilon\frac{\partial}{\partial\eta_2}+\varepsilon^2\frac{\partial}{\partial x_{22}};$$
$$\frac{\partial}{\partial t}=\frac{\partial}{\partial t_0}-\varepsilon\frac{\partial\omega_r}{\partial k_1}\frac{\partial}{\partial\eta_1}-\varepsilon\frac{\partial\omega_r}{\partial k_2}\frac{\partial}{\partial\eta_2}+\varepsilon^2\frac{\partial}{\partial t_2}; \quad (9)$$

$$\eta_1=\varepsilon\left(x_1-\frac{\partial\omega_r}{\partial k_1}t\right);\ \eta_2=\varepsilon\left(x_2-\frac{\partial\omega_r}{\partial k_2}t\right), \quad (10)$$

$\mathbf{A}_{-l}^{(j)}$ is the vector that is complex conjugate to $\mathbf{A}_l^{(j)} = \left\| A_{l1}^{(j)} .. A_{ln}^{(j)} \right\|^{\mathrm{T}}$.

Here the reduction of the system of equations (1) to the equation for the amplitude of nonlinear perturbation is carried out in a complex manner, i.e. using the wave packets (3), the methods of many scales (9) and modification of the Mandelshtam method according to which m harmonic waves with different wave numbers and frequencies are rearranged to the quasimonochromatic waves with nonlinear amplitude and phase depending on the slow variables. The expression (10) takes into account the group velocity of envelope wave, that is typical for actual nonlinear dispersion mediums.

In the ε -th approximation, the nonlinear system of partial differential equations that is obtained after substitution of expansion (8) into system (1) with allowance for (9) and (10) becomes inconsistent. For its solvability, it is required that right-hand side of the obtained system would be orthogonal to any solution of homogeneous conjugate system. Independently from the methods in the third approximation, the equation for the amplitude of envelope wave has the same form

$$\frac{\partial A_0}{\partial t_2}+\frac{\partial \omega_r}{\partial k_1}\frac{\partial A_0}{\partial x_{12}}+\frac{\partial \omega_r}{\partial k_2}\frac{\partial A_0}{\partial x_{22}}+\frac{i}{\varepsilon}\frac{\partial \omega_i}{\partial k_1}\frac{\partial A_0}{\partial \eta_1}+\frac{i}{\varepsilon}\frac{\partial \omega_i}{\partial k_2}\frac{\partial A_0}{\partial \eta_2}-$$
$$-\frac{i}{2}\left(\frac{\partial^2 \omega_r}{\partial k_1^2}+i\frac{\partial^2 \omega_i}{\partial k_1^2}\right)\frac{\partial^2 A_0}{\partial \eta_1^2}-\frac{i}{2}\left(\frac{\partial^2 \omega_r}{\partial k_2^2}+i\frac{\partial^2 \omega_i}{\partial k_2^2}\right)\frac{\partial^2 A_0}{\partial \eta_2^2}-$$
$$-i\left(\frac{\partial^2 \omega_r}{\partial k_1 \partial k_2}+i\frac{\partial^2 \omega_i}{\partial k_1 \partial k_2}\right)\frac{\partial^2 A_0}{\partial \eta_1 \partial \eta_2}+(\beta_1+i\beta_2)\left|A_0\right|^2 A_0=0, \quad (11)$$

where β_1, β_2 are the Landau constants characterizing the nonlinear damping of perturbations and dispersion, respectively, and can be found from previous approximation.

Substituting into (11) the wave amplitude in the form

$$A_0 = A_+ \exp i\left[\delta k_s x_s + \left(\frac{\partial \omega_r}{\partial k_s}\delta k_s + \frac{1}{2}\frac{\partial^2 \omega_r}{\partial k_s \partial k_t}\delta k_s \delta k_t\right)t\right],$$

where the double subscripts in $\delta k_s x_s$ indicate the summation, and going from the variables of scale t_2, x_{12}, x_{22} to the variables $\eta_{12} = x_{12} - \frac{\partial \omega_r}{\partial k_1}t_2$, $\eta_{22} = x_{22} - \frac{\partial \omega_r}{\partial k_2}t_2$, for the amplitude A_+ of the wave packet, whose centre is removed on $\delta k_1, \delta k_2$ from the neutral stability curve, the general two-dimensional nonlinear parabolic equation is obtained in the form

$$\frac{\partial A_+}{\partial t_2}+\frac{i}{\varepsilon}\left(\frac{\partial \omega_i}{\partial k_1}\frac{\partial A_+}{\partial \eta_1}+\frac{\partial \omega_i}{\partial k_2}\frac{\partial A_+}{\partial \eta_2}\right)-\frac{1}{2}\left(\frac{\partial^2 \omega_r}{\partial k_1^2}+i\frac{\partial^2 \omega_i}{\partial k_i^2}\right)\frac{\partial^2 A_+}{\partial \eta_1^2}-$$
$$-\frac{i}{2}\left(\frac{\partial^2 \omega_r}{\partial k_2^2}+i\frac{\partial^2 \omega_i}{\partial k_2^2}\right)\frac{\partial^2 A_+}{\partial \eta_2^2}- \quad (12)$$
$$-i\left(\frac{\partial \omega_r}{\partial k_1 \partial k_2}+i\frac{\partial^2 \omega_{i2}}{\partial k_1 \partial k_2}\right)\frac{\partial^2 A_+}{\partial \eta_1 \partial \eta_2}=\frac{\omega_i}{\varepsilon^2}A_+-(\beta_1+i\beta_2)\left|A_+\right|^2 A_+.$$

We write (12) in dimensionless variables η_{12}, η_{22},

$$\eta_{10} = \eta_1\sqrt{\frac{2\omega_i}{\varepsilon^2\left|\frac{\partial^2 \omega_i}{\partial k_1^2}\right|}};\ \eta_{20} = \eta_2\sqrt{\frac{2\omega_i}{\varepsilon^2\left|\frac{\partial^2 \omega_i}{\partial k_2^2}\right|}};$$
$$\tau = \frac{t_2 \omega_i}{\varepsilon^2};\quad A = A_+\sqrt{\frac{\varepsilon^2 \beta_i}{\omega_i}}. \quad (13)$$

Then

$$\frac{\partial A}{\partial \tau}+i\left(\alpha_{31}\frac{\partial A}{\partial \eta_{10}}+\alpha_{32}\frac{\partial A}{\partial \eta_{20}}\right)+\left(\operatorname{sgn}\frac{\partial^2 \omega_i}{\partial k_1^2}-i\alpha_{11}\right)\frac{\partial^2 A}{\partial \eta_{10}^2}+$$
$$+\left(\operatorname{sgn}\frac{\partial^2 \omega_i}{\partial k_2^2}-i\alpha_{12}\right)\frac{\partial^2 A}{\partial \eta_{20}^2}+\left(\alpha_r-i\alpha_i\right)\frac{\partial^2 A}{\partial \eta_{10}\partial \eta_{20}}=$$
$$=A-\left(1+i\alpha_2\right)\left|A\right|^2 A, \quad (14)$$

where

$$\alpha_{1j}=\frac{\partial^2 \omega_r / \partial k_j^2}{\partial^2 \omega_i / \partial k_j^2};\ \alpha_2=\frac{\beta_2}{\beta_1}; \quad (15)$$

$$\alpha_{3j}=\frac{\partial \omega_i}{\partial k_j}\sqrt{\frac{2}{\omega_i\left|\frac{\partial^2 \omega_i}{\partial k_j^2}\right|}};\ \alpha_r=\frac{2\frac{\partial^2 \omega_r}{\partial k_1 \partial k_2}}{\sqrt{\left|\frac{\partial^2 \omega_i}{\partial k_1^2}\right|\left|\frac{\partial^2 \omega_i}{\partial k_2^2}\right|}};\ \alpha_i=\frac{2\frac{\partial^2 \omega_i}{\partial k_1 \partial k_2}}{\sqrt{\left|\frac{\partial^2 \omega_i}{\partial k_1^2}\right|\left|\frac{\partial^2 \omega_i}{\partial k_2^2}\right|}}.$$

IV. Results and discussion

The dimensionless complexes (15) have simple physical meaning: α_{1j} characterizes the ratio of dispersion of the group velocity in the j-th direction to dispersion of the increment; α_{3j} characterizes the deviation of the centre of wave packet characterizes from the harmonic of maximum increment; α_2 characterizes the nonlinear dependence of phase (frequency) on the amplitude, i.e. nonlinear dispersion.

Equation (14) describes the evolution of the envelope wave appearing as a result of the nonlinear interaction of perturbations given in the form of wave packet. From (14) the known equations are obtained as particular cases and, e.g., for conservative systems of the plasma physics, nonlinear optics and hydrodynamics of ideal fluid with $\omega_i = \beta_i = 0$, the equation is reduced to the nonlinear parabolic equation of Schrodinger [4]. The quantitative characteristic of attractor is the Lyapunov exponents determined similarly [5]; to characterize the behavior of dynamic systems and dynamic chaos, the Kolmogorov–Sinai entropy and Poincare mapping are used also [6, 7]. The measure of development of turbulence was the positiveness of the metric invariant of dynamic systems that leads to scattering of phase trajectories exponentially.

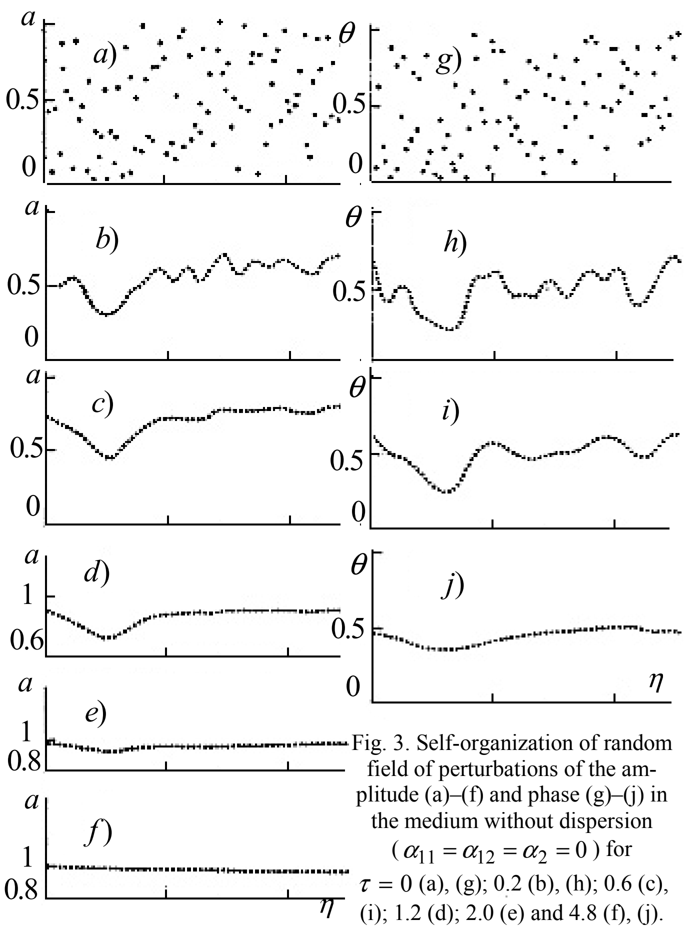

Fig. 3. Self-organization of random field of perturbations of the amplitude (a)–(f) and phase (g)–(j) in the medium without dispersion ($\alpha_{11} = \alpha_{12} = \alpha_2 = 0$) for $\tau = 0$ (a), (g); 0.2 (b), (h); 0.6 (c), (i); 1.2 (d); 2.0 (e) and 4.8 (f), (j).

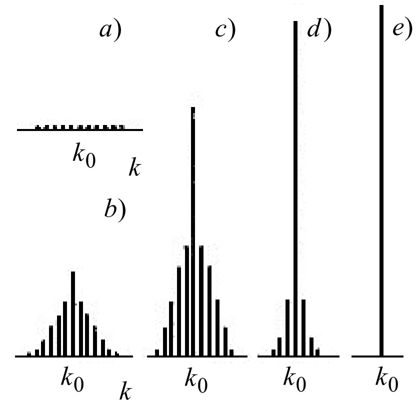

Fig. 4. Contraction of the wave packet under occurrence of self-organization in the medium without dispersion ($\alpha_{11} = \alpha_{12} = \alpha_2 = 0$) for $\tau = 0$ (a), 1.5 (b), 4 (c), 8 (d) and 14 (e)

In the terms of such complex investigation of GNPE (14), the qualitative changes in the trajectories of these systems are studied under the change of its parameters (15). On different stages of evolution of the nonlinear interaction of perturbations, the following bifurcation sequences leading to strange attractor appears: ones that cause alternation, doubling of period on Feigenbaum, production and destruction of a three-dimensional torus and the sequence that results in homoclinic contour.

By numerical solution of (14), it is established that all governing parameters $\alpha_{1j}, \alpha_{3j}, \alpha_2$ influence on behavior of perturbation, but the parameter α_2 play dominating part in reconstruction of perturbations that determine the appearance of self-organization or chaos (turbulence). The following mechanism of occurrence of self-organization and chaos and of transition between them, which can be used for their controlling, is revealed.

1) The linear dependence of the phase or frequency on the amplitude of perturbation is the necessary condition for self-organization. Degenerate cases of this linear dependence are also possible: the slope or the free term, or both simultaneously are equal to zero (Figs. 3, 4).

2) The basic condition for occurrence of chaos is the nonlinear dependence of the phase for distributed systems or the frequency for nondistributed systems on the perturbation amplitude (Figs. 5, 6). Increasing of dispersion favors the occurrence of self-organization (Fig. 7).

3) Self-organization, coherent structures and order occur owing to the nonlinear interaction of perturbations in chaotic, disordered systems, and conversely.

4) The transition from one type of nonlinear interaction to another and also the appearance of structure or phenomenon are

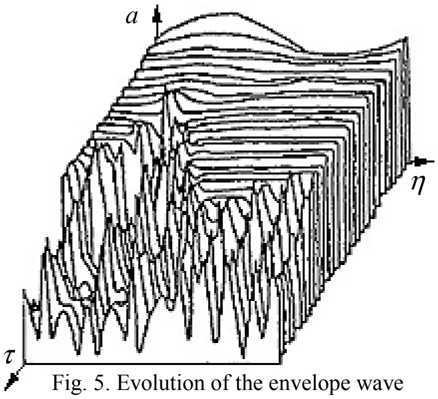

Fig. 5. Evolution of the envelope wave under occurrence of turbulence

accompanied by change in the energy distribution on spectrum: by contraction (self-organization) (Fig. 4) or expansion (chaos) (Fig. 6); intermediate state is possible.

The typical examples of the occurrence of self-organization and turbulence. Development of random field of amplitude and phase perturbations in the medium without

The typical examples of the occurrence of self-organization and turbulence. Development of random field of amplitude and phase perturbations in the medium without dispersion ($\alpha_{11} = \alpha_{12} = \alpha_2 = 0$) that leads to self-organization is presented on Fig. 3 (owing to self-organization, the values of a and θ are constant at all points of the space). This field is chosen at the initial instant ($\tau = 0$)with the help of random numbers and the condition 1 is used under development. The characteristics of the wave packet, represented by (3), evolved to monochromatic envelope wave obtained as result of the nonlinear interaction of perturbations (condition 3). In this case, the continuous spectrum of the wave numbers of packet is narrowed. The wave packet evolves to monochromatic wave (condition 4, Fig. 4).

In the case of the nonlinear dependence of the phase (frequency) on the amplitude, the graph of dependence of the perturbation amplitude a takes the form of sharp wedges (Fig. 5). With multimode instability the perturbations from belonging to continuous spectral region of wave numbers are excited and grow, the wave packet expands (Fig. 6). The amplitudes of perturbations that are symmetric relative to its centre are not equal to each other. The perturbation energy is rather uniformly distributed over the spectrum of the excited wave packet. The trajectories of the initially close systems diverge exponentially. The multimode turbulence develops in the system.

From Figs. 5 and 6, it follows that monoharmonic wave is initially imposed during the process (natural fluctuation interaction) or upon the process (forced interaction). Next, by means of some interactions, the condition 2 is satisfied, i.e. the phase or the frequency is nonlinearly dependent on the amplitude. In this case, the spectrum of the wave numbers expanded and the transition to turbulence occurred that is confirmed by the known criteria for dynamic systems. Thus, condition 4 is required for all transitions characterizing the qualitative changes in trajectory of dynamic systems, i.e. the transition of system to self-organization is accompanied by the narrowing of the spectrum, by the expansion of the spectrum under the transition to turbulence and by energy transfer over the spectrum in both cases (Figs. 4, 6).

To prevent the occurrence of multimode turbulence, it is possible by increasing the linear dispersion or decreasing the nonlinear dependence of the frequency on the amplitude. The increase of dispersion favors the formation of coherence-type structures. In flows of incompressible fluid, the increase of dispersion of Tollmien–Schlichting waves can be obtained by changing the composition of moving medium and by introducing high-molecular compounds into the fluid. The behavior of the nonlinear interaction of waves can also be changed by decreasing the period length L or increasing considerably the amplitude of the initial monochromatic perturbation. It is determined that in linearly non-dispersion medium with strong dependence of phase on amplitude, the action of white noise on the multimode turbulent regime can lead to the establishment of ordered monochromatic regime or limiting cycle. The self-organization of chaotic regimes under the action of white noise (Fig. 7) is explained by the fact that there are stable nodes corresponding to monochromatic regimes together with limiting cycles and chaotic attractors in non-dispersion systems. White noise favors the system getting into the domain of attraction of stable node.

Mechanism of occurrence of turbulence. The envelope wave is topological mapping of the nonlinear interaction of perturbations, and for the multimode turbulence, one is broken into wedge-shaped wave packets with rather large spatial and frequency spectrum. The inhomogeneity in group velocity appears in the medium. The group velocity of short waves entering into the

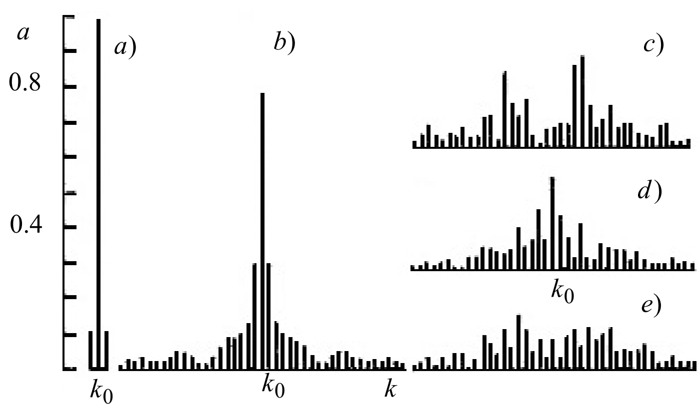

Fig. 6. Expansion of the wave packet under development of multimode instability in the medium with $\alpha_2 \neq 0$ for $\tau = 0$ (a), 5 (b), 10 (c), 15 (d) and 20 (e)

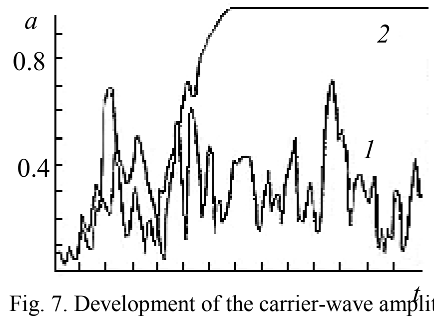

Fig. 7. Development of the carrier-wave amplitude for $\alpha_1 = \alpha_3 = 0, \alpha_2 = 3$ ($L = 50$) in the absence of noise (1) and in the presence of white noise (2)

wave packet is higher than one of the carrier wave, as a result of which the short waves overtake the carrier wave and are concentrated on the leading edge of the wave packet. The group velocity of long waves is lower than one of the carrier wave, and therefore, the long waves are at the tail end of the wave packet. At that waves of various nature are formed on different sides from the carrier wave.

Owing to the nonlinear interaction, each type of waves forms attractors, including strange ones. Natural perturbations are the wave packets containing tens of modes, and in the case of combined wave numbers under excitation of two modes, tens and hundreds of effectively interactive modes appear (for the nonlinear dependence of phase). The number of modes increases in geometric progression, and therefore, the filling of the spectrum of wave numbers occurs very rapidly. Then turbulence is result of the interaction of rather large number of strange attractors that agrees, in particular, to the results of experimental investigations of turbulence in round tube [8]. The suggested mechanism doesn't contradict the existing models according to which large-scale perturbations (long waves at the tail end of the wave packet) are unstable and ones produce the perturbations with small scale (short waves on the leading edge of the wave packet). Since the concentration of waves at the wave-packet boundaries is something material and it is also agreed to the conclusions that in the case of the occurrence of turbulence the quasiparticles forming the gas of turbulence play the considerable part [9].

The results can be used, in particular, for modeling of ocean processes, in oceanography, etc. So, it was determined that necessary condition of self-organization is linear dependence of phase in distributed systems or of frequency in undistributed ones on perturbation amplitude that is also observed for swimming of fishes and cetaceans. This can be explained including the following: in view of oscillations of bow of fish, on body surface, there is wave flow with certain ratio of phase velocity and amplitude. Thin coherent formations move along the body and then the ordered swirling structure is created. This mechanism allows to approach to the problem of ship moving with substantial decreasing of power inputs.

Even if there is simple exact solution of the developed mathematical models, it is possible to obtain incorrect values of the estimated characteristics conditioned by strong influence of errors in experiment data. Therefore the mathematical description requires a revision on the basis of the sensitivity theory particularly for multivariable cases. Algorithms of the parametric identification methods [10] include a study of observability and identifiability in terms of Jacobi matrix, creating and optimization of quality function, calculation of covariance matrix of estimated parameters from dispersion of experiment data, verification of adequacy of model and choice of optimal experiment conditions. Further results can be used for optimal planning of experiments allowing to minimize a costs of full-scale tests, for predicting and modeling of different working situations.

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