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Adaptation of Aircraft's Wings Elements in Turbulent Flows by Local Voting Protocol

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Abstract: Miniaturization and increased performance calculators, sensors and actuators are opening up the new possibilities of intelligent control complex mechatronic systems under the transient and turbulent conditions. Earlier adaptive control in a changing environment and with time-varying structure of the state space explored slightly due to the limited possibilities of practical implementation. The paper considers the model of an aircraft with a large number of sensors and actuators, distributed over surfaces of wings. In turbulent wind flows, it is shown that the multi-agent Local Voting Protocol with non-decreasing to zero step size allows equalization effects of disturbing forces acting on the different elements of wings.

Keywords: Adaptation, self-organization, turbulent wind flows, non-equilibrium statistical mechanics, Local Voting Protocol.

1. INTRODUCTION

The modern science and technical achievements have shown that our world is not so determined to describe theoretically and to predict many phenomena recently found out. Crisis of the modern theoretical concepts of the world construction is not overcome till present. It requires a new understanding based on other concepts than those developed in last centuries but, in the absence of others, used outside their validity. For example, everybody adopted the formalism of dynamic systems in finite dimensional spaces which really describe many phenomena at macroscopic level with a good degree of accuracy. Meanwhile, a validity of the mathematical description at small spatiotemporal scales is questionable. The increased miniaturization of calculators, sensors, and actuators highlights the problem of an adequate modeling of processes at micro- and, that even more important, at nano-scale level.

Problems of modern technique, technology, biology and medicine require the development of mathematical models of the processes far from thermodynamic equilibrium when on account of external actions the system reconstructs itself and continues change their properties even after the actions ceased. In paper Granichin and Khantuleva [2004] it is shown that for a variety of practical problems it is expedient to construct models with the changing in course of time structure of the state space. The system reconstruction is followed by self-organization of new internal structure and the interaction between the structural elements, in their turn, changes the macroscopic system properties.

In Bamieh [2014], the networked systems of control and distributed parameter systems are considered as instances of dynamical systems, distributed along the discrete and continuum space, respectively. This unified perspective provides insightful connections, and gives rise to new questions in both areas. Among new directions in the research of the distributed systems the deep inner connections were outlined between the theory of the distributed systems and problems of turbulence and statistical mechanics. For some problems, spatio-temporal dynamical analysis clarifies the old and vexing questions of the theory of shear flow turbulence. For other problems, the structured and distributed control design exhibits dimensionality-dependence and phase transition phenomena similar to those in statistical mechanics.

The diverse vortex-wave turbulent structures arising in high-rate flows of not only fluids and multi-phase media, but also in solids during plastic deformation under dynamic loading, see Meshcheryakov and Khantuleva [2015], Khantuleva and Meshcheryakov [2016]. At the micro level the structure formation is observed in nuclear physics Unzhakova et al. [2017]. Living systems are characterized by multi-scale structure hierarchy, beginning from the protein structures in the cells. About the dynamic structure formation it is possible to speak in sociology, psychology and economy.

In non-equilibrium statistical mechanics it was shown by Zubarev [1971], that a set of variables to construct mathematical model of non-equilibrium process is even never been complete due to the changing of freedom degrees' number. It means that real processes far from equilibrium can not be correctly described by differential dy-

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namic models. Modeling high-rate and high-speed processes, problems connected to the influence of systematic errors, generated by the model itself, and experimental measurement challenges, can not be avoided. New, more flexible, mathematical models are able, as the complicated systems themselves, to adapt to the changing interaction with surroundings, are needed to describe such transitional processes. The adaptation can be achieved only on account of internal control via feedbacks included into the model Khantuleva [2013].

Multi-agent technologies effectively help to solve numerous of problems related to non-stationary complicated distributed systems far from equilibrium by substituting instead of the general system model a set of local models. In the system consisted of many agents their interaction leads to formation of groups with coherent behavior. Such clusters formation results in a reduced dimension of the system state space. To the opposite, violation of coherence in group causes an increase of its dimension. Nowadays in solving practical problems such as cooperative control of multivehicle networks Ren et al. [2007], Amelin et al. [2012] distributed control of robotic networks Bullo et al. [2009], flocking problem Virágh et al. [2014], load balancing problem Amelina [2012], optimal control of sensor networks Kar and Moura [2010], Chilwan et al. [2014] the consensus approach is widely used. Obtaining the corresponding consensus conditions for such systems was considered in many works (see e.g. Ren and Beard [2007], Chebotarev and Agaev [2009], Lewis et al. [2014], Proskurnikov and Cao [2017]).

This paper deals with the problem of compensation of the influence of disturbing turbulence effects by different elements of the airplane wing with a large array of sensors and actuators distributed over the surface. To solve this problem, we study the possibility of using multi-agent Local Voting Protocol (LVP) with constant step-size. This protocol was justified early under significant and external noise Amelina et al. [2013, 2015]. In our previous research Granichin et al. [2017], LVP was used for the equalizing the pressures effected to the different elements of the airplane wing. But the new simulation results show that, in a turbulent flow, it is better to equalize the forces acting on the airplane through “feathers” and to make the influence of flow as in the case of laminar flow.

The paper is organized as follows. In Section II we describe the non-equilibrium statistical mechanics approach, and we applied it for the airplane with “feathers” flying in the turbulence flow. In Section III we discuss the self-organization of “feathers” and the possible way for an practical implementation of the considered approach using developed simulation stand and Local Voting Protocol. Section IV contains the concluding remarks.

2. NON-EQUILIBRIUM STATISTICAL MECHANICS APPROACH FOR THE AIRCRAFT DYNAMICS IN TURBULENT FLOW

For the last several centuries the linear approach, based on the assurance that a reaction of the system is proportional to an external action and therefore additive, prevailed in science. As a result, the system behavior should be deterministic because of the uniqueness of solutions to the linear equations. Processes described by the linear mathematical models should be stable and well reproduced in experiments. However, it was found out that such behavior the systems demonstrate only near thermodynamic equilibrium. With an increase in rates of processes the linear approach fails. Far from equilibrium the system reaction begins to depend on size and geometry of the system, retarding from the action. The collective interaction does not allow for a separation of the influence of a one factor among many others. The collective and retardation effects give rise to oscillations making the system unstable and difficult to study and control. As a result the system behavior become probabilistic and poor reproducible in experiments.

2.1 Modeling of Non-equilibrium Transport Processes in Open Systems

From the point of view of non-equilibrium statistical mechanics any set of averaged variables to describe the system state far from equilibrium should be incomplete. It was proved that equations, describing the processes far from equilibrium in terms of the incomplete set of variables, can not being differential i.e. local both in space and time Richardson [1960], Piccirelli [1968].

Developed by Zubarev [1971], Kuzemsky [2007], a method of non-equilibrium statistical operator allows for a correct description of the processes far from equilibrium and results in new nonlinear and nonlocal mathematical models with memory for macroscopic systems. Dynamic fields of densities of mass ρ, momentum $\mathbf{p}$ ($\mathbf{p}/\rho = \mathbf{v}$) and internal energy E are governed by set of transport equations:

$$\begin{aligned} \frac{\partial \rho}{\partial t} + \rho \nabla \cdot \mathbf{v} = 0, \\ \rho \frac{d\mathbf{v}}{dt} + \nabla \cdot \mathbf{J}^{(v)} = \mathbf{F}, \\ \rho \frac{dE}{dt} + \nabla \cdot \mathbf{J}^{(E)} + \nabla \mathbf{v} \otimes \mathbf{J}^{(v)} = \Psi, \end{aligned} \tag{1}$$

where $\mathbf{J}^{(v)}$, $\mathbf{J}^{(E)}$ are momentum and energy fluxes respectively, and $\mathbf{F}, \Psi$ are external sources of momentum and energy.

Derived by Zubarev's method, the integral both in space and time relationships between the thermodynamic forces determined by the macroscopic fields gradients $\mathbf{G}^{(v,E)}(\mathbf{r},t)$ (action) and fluxes of momentum $\mathbf{J}^{(v,E)}(\mathbf{r},t)$ complete the macroscopic equations (1): $\mathbf{J}^{(v,E)}(\mathbf{r},t) =$

$$= k_0^{(v,E)} \int\limits_{-\infty}^{t} dt' \int\limits_{V} d\mathbf{r}' \mathcal{R}^{(v,E)}(\mathbf{r},\mathbf{r}',t,t',\mathbf{s}) \mathbf{G}^{(v,E)}(\mathbf{r}',t')$$

$$= \int\limits_{-\infty}^{t} dt' \int\limits_{Vol} d\mathbf{r}' \mathcal{R}^{(v,E)}(\mathbf{r},\mathbf{r}',t,t',\mathbf{s}) \mathbf{J}_0^{(v,E)}(\mathbf{r}',t'). \tag{2}$$

The relationships (2) generalize the linear and local thermodynamic relationships $\mathbf{J}_0^{(v,E)}(\mathbf{r}',t') = k_0^{(v,E)} \mathbf{G}^{(v,E)}(\mathbf{r}',t')$ ($k_0^{(v,E)}$ denotes coefficients of the momentum and energy transport — viscosity and thermal conductivity) which is valid near the local equilibrium state to non-equilibrium processes. Substitution of the linear relationships into (1) results in differential hydrodynamic equations in Navier-Stokes approximation. The integral relationships (2) average macroscopic gradients with weight functions (integral kernels) $\mathcal{R}^{(v,E)}(\mathbf{r}, \mathbf{r}', t, t', \mathbf{s})$, that present spatiotemporal correlation functions of thermodynamic fluxes. Being projections of non-equilibrium distribution function in the system phase space into configuration space, the correlation functions are unknown nonlinear functionals of the history of macroscopic fields and external actions on the system. Appearance of the spatiotemporal correlations in (2) indicates to the possibility of their use for the description of the collective effects and the structure formation. Non-equilibrium state is a result of interaction with other systems (with an external environment). As a result boundary conditions form new characteristic spatiotemporal scales $\mathbf{s}$ Khantuleva [2013] which represent a current structure of the state space. Depending on external actions and the process history the transport (1) with integral expressions for the momentum and energy fluxes (2) can become differential in the limiting cases of infinite correlations (wave type transport) and of zero correlations (diffusive type transport) and, as shown in Khantuleva [2013], even change their type.

Attempts to construct simple space-time dependencies with empiric parameters for the correlation functions lead to rough models that can not satisfy to the imposed boundary conditions and provide the needed predictive ability. For a long time this circumstance was an obstacle for the nonlocal models to apply for high-rate processes in real problems.

Based on the nonlocal relationships (2) with memory obtained in non-equilibrium statistical mechanics, a new theory of the non-equilibrium transport processes has been developed by Khantuleva [2013]. The proposed approach introduces an intermediate scale level between the macroscopic and microscopic ones by means of the first moments of the correlation functions which characterize the internal structure scales. The model spatiotemporal dependence corresponding to asymptotic conditions, should depend on the structure parameter (having dimension of length) incorporated into the model. According to the approach, the imposed boundary conditions, caused by external influences, lead to discretization of spectra of the structure parameters (structuring of the system phase space at a mesoscale) as in quantum mechanics. The effects of self-organization in open system far from equilibrium were observed in experiments Meshcheryakov and Khantuleva [2015], Khantuleva and Meshcheryakov [2016]. Interaction between the structure elements gives rise to the internal structure evolution going in accordance with the adaptive control theory via feedbacks between the system reaction and its structure evolution Fradkov [2017], Fradkov and Khantuleva [2016]. The proposed interdisciplinary approach at the junction of mechanics, physics and cybernetics allows for a construction of "flexible" adaptive models for actively interacting systems far from equilibrium. The prediction of the internal structure changing during the high-rate processes opens new opportunities for the development of modern technologies, high-velocity technique, materials with desired properties and internal structure.

2.2 An Aircraft with "Feathers"

According to the results of non-equilibrium statistical mechanics the imposed on the system perturbation fields are smoothing with time and the forces gradually equalize. Technical systems also can be constructed on this principle but the perturbation smoothing can be accelerated by organizing the rapid interaction between the system elements.

Let an airplane with the total mass m is flying at a velocity $\mathbf{V}(t)$ due to the sum of forces acting on it

$$m\frac{d\mathbf{V}(t)}{dt} = \mathbf{F}_e + \mathbf{F}_d + \mathbf{F}_g + \mathbf{F}_l \quad (3)$$

where the forces $\mathbf{F}_e, \mathbf{F}_d, \mathbf{F}_g, \mathbf{F}_l$ are engine thrust, drag, gravity and lift respectively. If the regime of the flight is stationary all the forces are counterbalanced $\mathbf{F}_e + \mathbf{F}_d + \mathbf{F}_g + \mathbf{F}_l = 0$, the plane is moving along the straight line at a constant velocity $\mathbf{V}_0 = col(V_0, 0, 0)$. The gas flow over the plane considers being laminar and known for the given body's form. It means that the distribution of the forces over the body's surface is also known. When the airplane gets into the turbulent wind flow the forces distribution changes, the total balance of forces is broken, the flight becomes non-stationary and jolting

$$\mathbf{V} = \mathbf{V}_0 + \mathbf{V}_1, \; m\frac{d\mathbf{V}_1}{dt} = \mathbf{F}_1(t).$$

Besides deviations from the given trajectory due to the force $\mathbf{F}_1$ applied to point $\mathbf{r}_1(t)$, moment of the force $\mathbf{M}_1(t) = \mathbf{r}_1(t) \times \mathbf{F}_1(t)$ causes irregular rotation of the plane around its center of mass changing angular momentum of the plane $\mathbf{L}_1(t) = \mathbf{r}_1(t) \times m\mathbf{V}_1(t)$ according to the law $\frac{d\mathbf{L}_1(t)}{dt} = \mathbf{M}_1(t)$. To a large extent the irregular rotation of the plane is connected to the effect of jolting.

In order to reduce jolting it would be desirable to compensate the forces acting on the plane from the turbulent flow by additional forces. To achieve this goal the special constructive elements like the bird's feathers on the body's surface are needed. Assume that the upper surface of an airplane wing consists of n finite element ("feathers") $a^1, \ldots, a^n$ (this scheme is valid for the both sides of the wing). Hereandfurther we will use upper indexes to indicate the unique number of feathers. Feathers may change its angle of inclination (rotation) within certain limits.

In the laminar flow all feathers are lying on the surface (see Fig. 1).

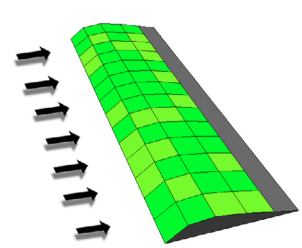

Fig. 1. The aircraft in a laminar wind flow.

In turbulent flow feathers begin to rise and turn. Each feather is a plate on which the force is acting depending on its position relative to the flow direction. Fig. 2 shows the different forces for different units of airplane in case of a turbulent wind flow when all feathers remain the initial (equal) orientations.

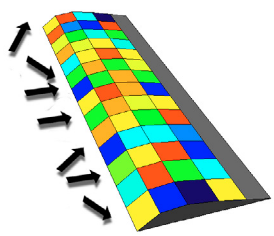

Fig. 2. The aircraft in a turbulence wind flow.

In general case the force acting on i-th element has three components and three degrees of freedom (normal reaction of the plate and two angles) are needed to control the feathers

$$\mathbf{R}^i(t) = \mathbf{n}^i(t) C_r(\alpha^i(t), \beta^i(t)) S \rho (v^i(t))^2/2$$

where $\mathbf{n}^i(t)$ is the normal vector to i-th plate at instant t with area S, $C_r(\alpha^i(t), \beta^i(t))$ is the aerodynamic coefficient of the plate which position at instant t is defined by two angles $\alpha^i(t), \beta^i(t)$, $v^i(t)$ is the velocity magnitude of the flow over the i-th element on the plane's surface at instant t. These forces are induced by the small laminar flow perturbations during the plates' turns and by the turbulent flow around them.

The force $\mathbf{R}^i(t)$ has three projections: one component along x-axis defines air resistance, vertical component determines the lift and the third is lateral yaw component. Summarizing the activities of all the feathers one gets a total force acting on the plane and changing its trajectory. When the forces induced by the turbulent wind flow are leveled the total force correction on account of the feather's work tends to $\bar{\mathbf{F}}_1 = const$ and the flow over the body becomes almost laminar again until the turbulent wind will not change. Because of the small and constant force $\bar{\mathbf{F}}_1$ the trajectory of the plane is slowly changing in one direction and can be corrected by the external control.

It can be easily demonstrated that when all forces acting to different feathers are leveled $\mathbf{R}^i(t) = \bar{\mathbf{R}}$, $\forall i$, the sum moment of the forces $\bar{\mathbf{R}}$ becomes equal to 0

$$\mathbf{M}_1(t) = \sum_{i=1}^{n} \mathbf{r}^i \times \mathbf{R}^i(t) = \mathbf{Z} \times n\bar{\mathbf{R}} = \mathbf{Z} \times \mathbf{F}_1.$$

For homogeneous distribution of feathers on the symmetrical body $\sum_{i=1}^{n} \mathbf{r}^i = \mathbf{Z} = 0$ and $\bar{\mathbf{M}}_1 = 0$. So, the most disturbing factor connected to jolting disappeared during the process of equalization of the forces acting on different feathers.

3. SELF-ORGANIZATION OF AIRCRAFT "FEATHERS"

Different forces act on different elements and make the flight unstable. The elements with sensors measuring their force reactions should turn around to equalize all the forces and to smooth perturbations. It is hardly possible to control all feathers in real time therefore the forces must equalize much more quickly than the turbulent wind change.

We consider "intellectual feather" which are able to arrange a self-regulation in the system. Assume that all feathers can exchange by the information about the forces $\mathbf{R}^i(t)$ and angels $\alpha^i(t), \beta^i(t)$ between neighbors automatically. More precisely, we denote set N^i of feather i neighbors and assume that each feather i gets the information about $\mathbf{R}^j(t)$ and angels $\alpha^j(t), \beta^j(t)$ for $j \in \{i\} \cup N^i$. This process should be much faster and can be repeated at any change of the turbulent flow.

The system of such miniature intellectual agents has the ability to self-organization. As a result of the forces synchronization, groups of agents get approximately equal components of the forces acting on agents and form clusters on the surface of the plane (see Fig. 3). Such structuring is provided by the goal-directed collective behavior of the system.

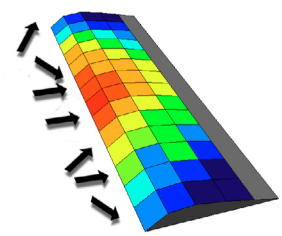

Fig. 3. The aircraft in a turbulence wind flow. Clustering of "feathers".

The collective effects are described by the integral relationship obtained in non-equilibrium statistical mechanics (2). The relationship applied to the momentum transport can be rewritten for the surface forces instead of the stress components as following

$$\langle \mathbf{F}_1(\mathbf{r}, t) \rangle =$$

$$\int_S d\mathbf{r}' \frac{k_0}{q(t)} \exp\left\{ -\frac{(\mathbf{r}' - \mathbf{r} - \mathbf{z}(t))^2}{q(t)^2} \right\} \mathbf{F}_1(\mathbf{r}', t), \qquad (4)$$

where $\langle \mathbf{F}_1(\mathbf{r}, t) \rangle$ is the averaged field of the forces and $\mathbf{F}_1(\mathbf{r}', t)$ is the initial forces distribution induced by the turbulent flow at instant t. The weight function under the integral determines the interaction at point $\mathbf{r}$ approximately covering the circle with radius $q(t)$ and with the center shifted by a vector $\mathbf{z}(t)$ which grows with time. So, the mechanism of the feather's interaction is given by the weight function and the rate of averaging is defined by the transmission speed and by the triggering mechanism to turn feathers. By using the relationship (4) it is possible to show how the clusters are growing due to their interaction.

3.1 Study of Transition Process Duration

Consider the equalization of the forces as an averaging over the feathers inside niobous. The averaged force acting on i-th feather at instant t in (4) can be calculated by the more simple averaging model using interconnection between neighbors

$$\langle \mathbf{R}^i(t) \rangle = \mathbf{R}^i(t) + \frac{1}{|N^i|} \sum_{j \in N^i} (\mathbf{R}^j(t) - \mathbf{R}^i(t)) \qquad (5)$$

The equalization means that $\langle \mathbf{R}^i(t) \rangle \to \bar{\mathbf{F}}_1 = const$ as $t \to \infty$.

In real physical systems the equalization is governed by the Speed-Gradient principle Fradkov [2017], Fradkov and Khantuleva [2016]. According to the principle all systems evolve in the direction of maximal entropy produced by the system during the process and of the minimal rate of the entropy production. The SG-algorithm shows the fastest evolution trajectory leading to the goal. The global goal of the forces equalization is stabilization of the plane's flight by redistribution of the kinetic energy imparted by the turbulent wind flow to the plane from rotational degrees of freedom to translational ones. The entropy production in laminar flow is always more then in the turbulent flow at the same velocity Klimontovich [1987]. Due to dissipation of the kinetic energy the entropy production during the forces equalization increases. According to the Konig theorem the kinetic energy of a solid moving at the velocity $\mathbf{V_1(t)}$ and rotating at the angular velocity around an instantaneous axis ω can be written as follows $E_1 = mV_1^2/2 + J\omega^2/2$ where J is the moment of inertia of the plane. Considering the full kinetic energy E_1 imparted by the turbulent wind flow to the plane fixed the maximal energy of translational degrees of freedom corresponds to the minimal rotational energy. As a result the fight become more stable and its regime change closer to the laminar one. So, we can choose the maximization of the energy of translational degrees of freedom as a goal function. SG algorithm minimizes the rate of the equalization.

By using the formula $m\frac{d\mathbf{V}_1(t)}{dt} = \sum_i \mathbf{R}^i(t)$ that determines the correction of the trajectory, resulted from the turbulent flow, the translational part of energy E_1 can be expressed through the forces during the equalization. $E_1^{tr} = \left(\int_0^t \sum_i \langle \mathbf{R}^i(t')\rangle dt'\right)^2 /2m$.

Let's consider the goal function

$$\Delta E_1^{tr} = \left(\int\limits_0^t \sum_i \langle \Delta\mathbf{R}^i(t')\rangle dt'\right)^2 /2m. \tag{6}$$

where $\langle \Delta\mathbf{R}^i(t)\rangle = \langle \mathbf{R}^i(t)\rangle - \bar{\mathbf{R}}^i$.

The rate of change is

$$\frac{d\Delta E_1^{tr}}{dt} = \left(\int\limits_0^t \sum_i \langle \Delta\mathbf{R}^i(t')\rangle dt'\right) \sum_i \langle \Delta\mathbf{R}^i(t)\rangle/m.$$

For the averaged force $\langle \mathbf{R}^i(t)\rangle$ chosen as a control parameter the finite form of the SG-algorithm gives an equation describing the equalization of the forces acting on each feather

$$\langle \Delta\mathbf{R}^i(t)\rangle = const - \gamma \frac{\partial}{\partial\langle \Delta\mathbf{R}^i(t)\rangle}\frac{dE_1^{tr}}{dt} \tag{7}$$

where γ is gain parameter. By virtue the initial condition Eq. (7) takes form

$$\langle \Delta\mathbf{R}^i(t)\rangle = \langle \Delta\mathbf{R}^i_{t=0}\rangle - \frac{\gamma}{m}\int\limits_0^t \sum_j \langle \Delta\mathbf{R}^j(t')\rangle dt'. \tag{8}$$

One can see that the averaged force acting on a feather is decreasing with time. Differentiating the equation with respect to time one gets a linear differential equation for the averaged force changing $\frac{d}{dt}\langle \Delta\mathbf{R}^i(t)\rangle = -\frac{\gamma}{m}\sum_j \langle \Delta\mathbf{R}^j(t)\rangle$. The solution of this linear differential equations describes exponential decreasing of the force difference

$$\langle \Delta\mathbf{R}^i(t)\rangle = \langle \Delta\mathbf{R}^i_{t=0}\rangle e^{-\frac{\gamma}{m}t} - \frac{\gamma}{m}\int\limits_0^t e^{\frac{\gamma}{m}(t-t')}\sum_{j\neq i}\langle \Delta\mathbf{R}^j(t')\rangle dt'.$$

The characteristic time of the forces equalization is evaluated by the coefficient m/γ where the gain parameter depends on the transmission rate between the feathers.

3.2 Stand for Simulation with Local Voting Protocol

Let assume that "feathers" are able to communicate with neighbors during short time interval h and to change (rotate) their angles in the interval from α^- to α^+. For simplicity, hereandafter we consider only one of force $\mathbf{R}^i$ projections and one angel α^i. For time instants $t_k = hk,\ k = 0, 1, \ldots$ and for each "feathers" a^i, $i = 1, 2, \ldots, n$, we denote its angel α^i_k, its set of neighbors N^i_j, and magnitude of the force $\mathbf{R}^i_0$ in laminar wind flow. For the difference between vertical projection of disturbing force $\mathbf{R}^i(t_k)$ and $\mathbf{R}^i_0$ we have

$$y^i_k = R^i(t_k)\cos(\alpha^i_k) - R^i_0$$

where $R^i(t_k)$ is magnitude of $\mathbf{R}^i(t_k)$ ($R^i(t_k) = |\mathbf{R}^i(t_k)|$, $R^i_0 = |\mathbf{R}^i_0|$). Internal control low takes the discrete form

$$\alpha^i_{k+1} = Pr_{[\alpha^-,\alpha^+]}\left(\alpha^i_k + \gamma\sum_{j\in N^i_k}(y^j_k - y^i_k)\right) \tag{9}$$

where $Pr_{[\alpha^-,\alpha^+]}(\cdot)$ is the projector into interval $[\alpha^-, \alpha^+]$, γ is a step-size, and initial conditions $\alpha^i_0 = 0$. Equation (9) is called *Local Voting Protocol* Amelina et al. [2015].

To test the above algorithm the experimental stand with glider is designed (see Fig. 4). It allows studying the glider under affecting by a variety of wind flows. Swipe glider wings is 1 m, length of the profile is 0.3 m, and the thickness is from 5 to 35 mm. Almost the entire surface of the wing is covered with plates ("feathers") with sensors. Number of plates is 100 pc. The size of one plate 60 mm × 60 mm. Plates are placed evenly over the surface. The angle of inclination of the plates can be varied by actuators to change the force of air on them. For the force measurement is used the pressure-sensitive resistor of round shape. Collecting data and generating the PWM control signal of each plate are performed by debug Arduino Nano boards. Each board Arduino Nano is connected with six neighbors. Collecting data from all cards Arduino Nano and telemetry data transmission to the control station is carried out using the Arduino Mega 2560 R3. One board Arduino Nano designed to work with one actuator and one pressure sensor. It used also for the interaction with the six neighboring boards. The stand is used 100 of such boards. One Arduino board 2560 provides telemetry data collection from 15 plates. All information from the Arduino Mega board is transmitted from the main control computer. All plates are equipped by LEDs to indicate the status of "the consensus achievement". To provide a variety of wind flows six different fans are used. At the current stage of the project a performance of algorithm (9) is investigated for different user-selectable algorithm parameters.

Fig. 4. The fragment of stand for simulation.

4. CONCLUSIONS AND FUTURE WORK

Miniaturization of control plants and high frequency control actions do not allow a verification of the model of the movement with the traditional high degree of accuracy. This fact emphasizes the key problem of adaptive control development in presence of significant uncertainties and external disturbances when we have only finite time interval for the adaptation process. Traditional asymptotic methods cannot be used and we plan to apply for this case our previous result Amelin and Granichin [2016].

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