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THE SYSTEM OF FULL-SCALE MODELLING OF MOVABLE OBJECT WITH AN OPERATOR IN THE CONTROL LOOP

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Abstract: *The principles of organization of a full-scale modelling of a moving object with an operator in its control loop are considered in the article. The task of reproducing the required dynamic characteristics, which the simulated moving object possesses, is solved by correcting the control signals for a moving object with similar dynamic properties. The developed method, for example, can be used to simulate the dynamic characteristics of the aircraft by another aircraft provided with a unit of adjustment of control.*

Keywords: *modelling of a moving object, reproduction of required dynamic characteristics, full-scale modelling.*

Introduction

The development of science and technology leads to the need to manage increasingly complex systems, and therefore the role of reliable forecasting of their movement increases. The necessary condition of such forecast is reception of the mathematical model which parameters reflect real physical, constructive technological and other factors influencing dynamics of system. However, it is often impossible to build a sufficiently accurate model because of the lack of adequate model elements and the interconnection of the system with the external environment [1]. To overcome this difficulty are created modelling complexes, containing in its composition real elements of the system, models of which are complex or unknown. Complexes of this kind are test benches for the refinement and testing of technical systems, as well as various simulators for training personnel, managing complex objects [2-4] — simulators for training of operators of power stations, ground transport drivers, crews of ships, pilots of aircrafts, etc.

The next step in the direction of approximation of the model to the original is the use of natural simulators or natural modelling complexes, allowing to simulate the movement of the studied objects in the natural conditions of their operation. The use of natural simulators with the operator in the control circuit gives an opportunity to develop the elements and technical systems with which the operator interacts, effectively organize professional selection, training and training Maintenance personnel in the real conditions of functioning of the investigated ergatic system.

1. Statement of a problem

In recent years as abroad, and in our country, considerable attention is paid to the creation of natural simulators of aircraft.

With the use of mobile simulators of aircrafts are solved such research tasks.

1. Choice of parameters defining characteristics of longitudinal and lateral stability and control, including at asymmetric thrust of engines, at excitation of adverse lateral and longitudinal oscillations, at flight on critical modes.

2. Selection settings control systems (power of steering drives, inertia and characteristics of loading mechanisms of control bodies, etc.).

3. Score of behavior of the aircraft when changes of mass.

4. Comparison of the results of the bench and flight control of aircraft, and other tasks.

In addition to research tasks, simulators of flying vehicles allow to solve the following tasks of training and training of flight crews:

1. Training of pilots to test new or developed aircraft.

2. Training and training of crews of expensive or difficult in operation aircraft.

3. Training of piloting on dangerous, critical modes and other tasks.

Advantages of learning and training of flight crews on simulators in comparison with training on a natural aircraft:

economy — due to use of simple in operation, enough light and cheap aircraft, and also at the expense of use aircraft for direct purpose;

improved — flight safety by building simulators based on aircraft with good own stability, reliability of systems, power installations and navigation-flight equipment.

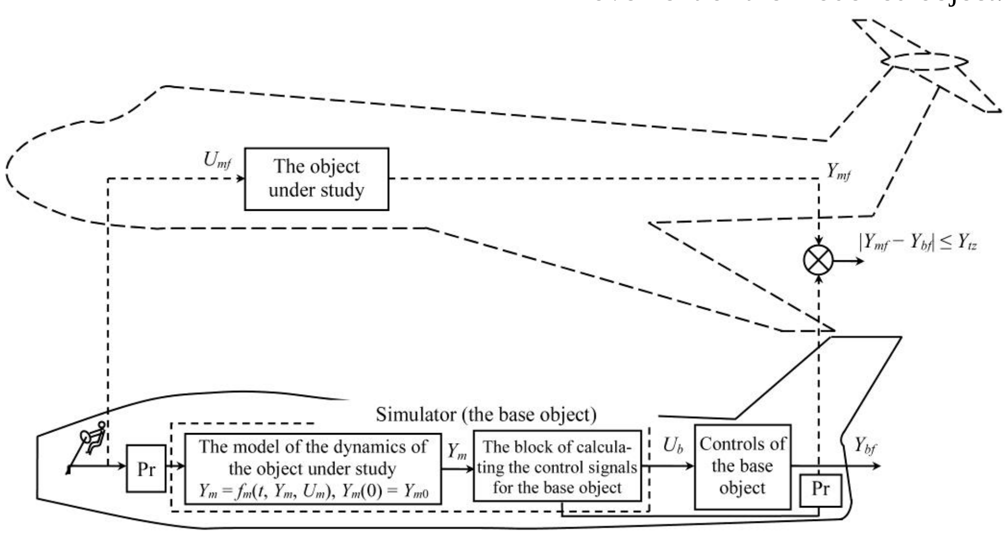
The solution of tasks similar to those listed is achieved by the use of natural simulators of movable objects and other classes (for example, ground and water transport, etc.).

The above illustrates the relevance of the work on the creation of simulators of the controlled movable objects.

2. The concept of the problem decision

The principle of reproduction of the dynamics of an object, which is investigated on its full-scale simulator is shown in Figure 1. The movable natural simulator is a full-scale modelling complex, which consisting of three main elements:

- of a reference model that provides input to the system of the studied motion of the modelled object;
- of a natural model, or a basic object that provides the actual conditions for the functioning of the modelling system;
- of a control system that generates such control signals for the underlying object, in which the motion of the base object reproduces the movement of the modelled object.



$Y_m = \overline{Y}_m + Y_{m0}$, $Y_b = \overline{Y}_b + Y_{b0}$. Calculating U_b from equations $f_m(t, \overline{Y}_m + Y_{m0}, U_m) = f_b(t, \overline{Y}_b + Y_{b0}, U_b)$ provides a dynamic similarity of the simulator and the object under study: $\dot{Y}_m = \dot{Y}_b$, $Y_m = Y_b + Y_{b0} - Y_{m0}$.

Figure 1. ***Reproduction of dynamics on the movable simulator of the object under study***

3. Realization of the concept

The complexity of the modes reproduced on the simulator depends on the completeness of the description of the reference model of the dynamics of the motion being studied. Therefore, the development of a movable simulator with advanced research capabilities leads to the problem of determining the control of a base object in a nonlinear formulation, when the models of motion of the modelling object and the base object are systems of nonlinear differential equations. In this formulation, the problem of ensuring the similarity (with respect to the derivatives of their coordinates) of two moving objects is posed as follows.

Let the simulated object movement be described by the system

$$\frac{dZ}{dt} = A(t, Z, V), \quad Z(0) = Z_0, \tag{1}$$

and the base object is described by the system

$$\frac{dY}{dt} = B(t, Y, U), \quad Y(0) = Y_0. \tag{2}$$

In (1) and (2) Z, Y — vectors of phase coordinates of simulated and base objects; V, U — vectors of control of the simulated and base object; A, B — operators (right parts) of simulated and basic movable objects.

The task of modeling the dynamics of the movable object, described by the system (1), on a natural simulator, the movement of which is described by the system (2), with the requirement of equality of derivatives

$$\frac{dZ}{dt} = \frac{dY}{dt} \tag{3}$$

simulated and basic objects in the mathematical plan is reduced to finding the vector U of controls of the base object from the system of algebraic equations

$$\begin{aligned} &A(t, Z, V) = B(t, Y, U), \\ &Z(0) = Z_0, \quad Y(0) = Y_0. \end{aligned} \tag{4}$$

Taking $\bar{Z} = Z - Z_0$, $\bar{Y} = Y - Y_0$ ratios (3), (4) can be written in equivalent form

$$A(t, \bar{Z} + Z_0, V) = B(t, \bar{Z} + Y_0, U), \tag{5}$$

from which there is a fundamental possibility of defining the control in such a way that the similarity of a natural simulator and the researched software on derivatives of their coordinates will be provided. The error in the coordinate values will be equal to the difference of the corresponding balancing values.

So, the task of modeling the dynamics of movable objects with using the natural simulator is formulated so: we need to find vector functions $U(t) \in R_u$ (R_u — allowed controls area), to perform inequalities

$$\begin{cases} \Phi_0(Z_0(V_0) - Y_0(U_0)) \le \delta_0, \\ \Phi(A(t, \bar{Z} + Z_0, V) - B(t, \bar{Z} + Y_0, U)) \le \delta, \\ U(0) = U_0, \ t \in [t_s, t_f]. \end{cases} \tag{6}$$

Here Φ_0, Φ — functional of norm type, δ_0, δ — specified tolerances for coordinate equality Z, Y and their derivatives respectively.

As a result of the analysis, which was conducted, recommended control system embodiment of the full-scale simulation in which the main part of the function of control $U(t)$ is computed using a closed cycle with using part of a state variables of the base object, and with using an open cycle — for the rest of the coordinates. This results in a combined system in the main control channel of the base object control. In the auxiliary channel using disagreement signals $e = Y - Z$ amendments to the basic management are formed. The scheme of the recommended variant of the system of calculating of the control of a natural simulator is given in Fig. 2. (To simplify the drawing, on it instead of the case PID of the law of regulation, shows proportional law of regulation in both channels of calculating of the control $U(t)$).

The reference model of the investigated object in the computational device is indicated by block A. The base object model is part of a block $B_{r_{осн}}$ of main channel and in the block $B_{r_{всп}}$, when using a combined cycle in the auxiliary channel. The transition from the combined to the closed loop in the auxiliary channel is conditionally indicated in the figure by the switch C. The symbol ^ in the figure indicates the physical variables: $\hat{Y}(t)$ — output coordinates of the base object, $\hat{P}_c$ — parameters of the environment, $\hat{V}(t)$ — the simulated control, that occur from the simulators of controls units.

The need to control the base object in real time presents for the control unit the stringent requirements for speed, the weakening of which are achieved by permissible simplification of models of the dynamics of the objects under study in compliance with the accuracy requirements. The maximum simplicity of the dynamics model, which determines the motion reproduced in the simulator with the required accuracy, is a necessary condition for the minimum time required to calculate the control of the base object.

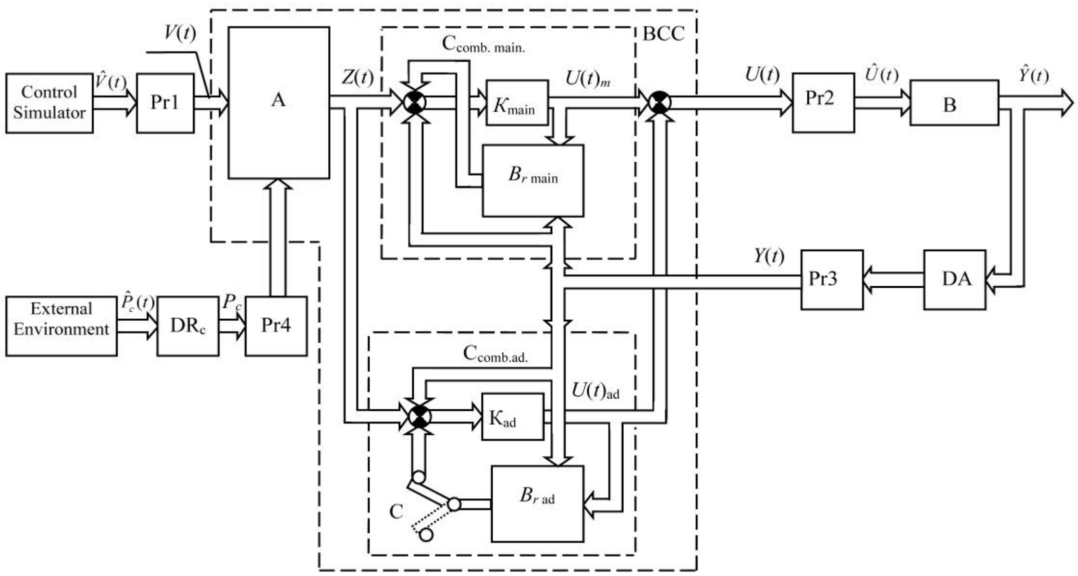


Figure 2. ***Scheme of the system for calculating the control of the full-scale simulator***

To realize this condition, in this paper, the goal was to develop a technique for simplifying (reducing) the mathematical model of dynamics with estimating the accuracy requirements to the parameters of the elements of the simulator to ensure a specified accuracy of dynamic similarity.

We confine ourselves to models of dynamics, given in the form of a system of differential equations, in which parameters and fragments reflect the influence on dynamics of physical, constructive, technological, etc. factors, so that with simplification of the model it becomes less accurate. Simplification of such model can go only at the expense of insignificance (on criterion of accuracy) of some fragments and parameters of model. Thus, the assigned task is the task of accuracy reduction of the given mathematical model.

Conclusion

Thus, the proposed principles of the organization of a full-scale simulation system allow one to simulate the required dynamic characteristics of another movable object using a single real movable object. The obtained results can be used to construct simulators for new movable objects on the basis of available ones.

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