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Unmanned Aerial Vehicle Flight Control over a Circular Path by Means of Manual Takeoff and Automatic Landing

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ABSTRACT : *The present paper advices a platform used for research of standard unmanned aircraft flight scenarios. Autopilot control method was used to model an unmanned aircraft flight in the line of sight. Ideas of manual takeoff and automatic landing were tested. Authors present to researchers the aircraft control test results. In the essence of the presented approach is the creation of highly simplified control from the pilot point of view. Such a method allows the operator to control the airplane through abrupt inputs to the control panel without leading to a crash.*

KEYWORDS: *Flight control, Unmanned aerial vehicle (UAV) autopilot, Unmanned aerial vehicle (UAV) safety.*

I. INTRODUCTION

In the last few years unmanned aerial technology has been analyzed from various aspects including the issues of technical reliability. About 40% of all lost unmanned aircraft vehicles (according to *Internet data* by and large 48 airplanes for three months) in the NATO coalition war in Yugoslavia are a result of malfunction. The rest of the losses are caused by air defense. Performing a flight analysis and disclosing the crash causes is labored on the account of absence of information such as the one found in piloted aviation. It is sound to think that loss of control is one of the possible reasons for aircraft crashes. Hence, it becomes useful to create a platform that models specific flight scenarios and possesses the ability to exactly follow the consequences of various control system states. The current material attempts to create such a platform and study the most traditional flight – piloted takeoff, flight following a route around the airfield in automatic mode and landing, carried out by a preprogrammed autopilot. The goal is to verify the aircraft control idea, where the pilot-operator has no access to the control surfaces, but realizes the control "through model and autopilot". In the basis of this idea is the creation of highly simplified control from the pilot point of view, through which even abrupt inputs to the control panel would not lead to a crash, because the actions of the pilot-operator are "supervised" and realized by the autopilot. Using an autopilot in programmed flights creates benefits in the quality of transitional processes.

The model was developed in a connected reference frame GOST (Russian: ГОСТ, set of technical standards maintained by the Euro-Asian Council for Standardization) with axis Ox_1 oriented forward parallel to the airplane line of flight, axis Oz_1 along the right semi-wing, and axis Oy_1 – lying in the plain of symmetry and has direction coincident with the direction of the vertical stabilizer (Mikeladze & Titev, 1990). The trajectory is modeled in normal earth reference frame $Ox_g y_g z_g$ according to GOST 20058-80, where axis Oy_g points along the local vertical line, plane $Ox_g y_g$ is always the local vertical plane, and $Ox_g z_g$ is the local horizontal plane (Mindova, 1985). The controlled object is a small unmanned airplane having mass of 50 kg. Turns and roll control are realized through ailerons. Rudder is working only as an automatic damping mechanism (Byushgens & Studnev, 1979). The general form of the aileron control law is:

$$\delta_e = K_e^{\gamma}(\gamma - \gamma_{set}) + K_{1e}\int(\gamma - \gamma_{set})\,dt + K_e^{\omega_x}\omega_x \quad , \quad \text{where}$$

$$\gamma_{set} = K_v^{\psi}(\psi - \psi_{programmed}) + \gamma_{programmed} + \gamma_{setbypilot} - K_Z(Z - Z_{programmed})\ ;$$

The γ_{set} equation is written in reference frame GOST 20058-80.

$$\gamma_{setbypilot} = K_{pilot}(\gamma - \gamma_{pilotprogram})\frac{\kappa}{Tp + 1}.$$

In the above equations angle ψ is the yaw angle. In the GOST reference frame it changes with a sign opposite to the sign of the navigational course (when rotating the airplane nose to the left, yaw angle increases, while the navigational course angle decreases). Left turn is managed with left banking inclination. If modeled in ISO the change of yaw angle and course angle will have the same signs (ψ may be treated as course angle). It follows that one should negate K_v^{ψ} using minus sign, in order to achieve left inclination during left banking turn.

The set value of the roll angle is formed by:

- Flight program according to yaw angle (course) or roll angle. The program is preprogrammed in a computer model of flight program in the base control station (Mikhalev at al., 1971).
- Pilot commands in manual mode are modified using an inertial module model and are fed as the desired by the pilot roll angle during manual control when the autopilot roll routines are switched off (there is no program input in the autopilot but only pilot input).
- If the pilot, using visual contact, notices a shift in the attitude and position from the runway direction, the side shift elimination program $\Delta Z = Z - Z_{set}$ is activated. This activation is achieved by the pilot before landing using a button in the ground control station. In the specific case $Z_{set} = 0$, because the landing is performed in the direction of the takeoff.

Control rudder deflection is accomplished using the following law (movement damping automaton in yaw axis):

$$\delta_y = K_y^{\omega_y}\omega_y$$

The pitch control commands (elevator control) are formed using the following law:

$$\delta_{p\ autopilot} = K_v^H(H - H_{setbyautopilotprogram}) + K_p^{\vartheta}(\vartheta - \vartheta_{setbyautopilot}) + K_p^{\omega_z}\omega_z$$

$$\vartheta_{setbyautopilot} = K_{pilot}(\vartheta - \vartheta_{pilotprogram})\frac{k_1}{Tp + 1}$$

In manual mode control, the autopilot receives the desired pitch angle from the pilot as input and, through an inertial module, forms elevator deflection angle. In the mode of automatic control, the elevator is deflected by signal from the flight program following autopilot altitude that defines the laws of climb after manual takeoff and incidence during automatic landing. Various models were verified for pilot signal modification. Most acceptable results were obtained by the inertial system. Gains of the control laws are chosen in the process of modeling in 'Simulink' seeking the principles of good transitional processes (Gultyaev, 1999). The autopilot program alterations and switching from automatic to manual control is carried out in strong points of the trajectory. Using 'Simulink', the adjustment of the manual and automatic control loops is achieved in a simple way in Earth computer model. The aircraft location in space is calculated by integrating the differential equations in normal earth reference frame.

The general form of the model, developed in a few levels of detail is shown on figure 1. The flight modeling results are presented on figures 2-6. In model adjustment it is expected a remote control signal delay of $\Delta t = 0.7$ s, which is large interval for direct manual piloting. If a control loop with direct movement of the pilot controls, functions with such delay, oscillation instability of the process will be reached. That is why control through a model was introduced: the pilot sets the desired pitch and roll angles in the autopilot. Autopilot adopts them as set values and through the inner control loop achieves them exactly with high quality and stability.

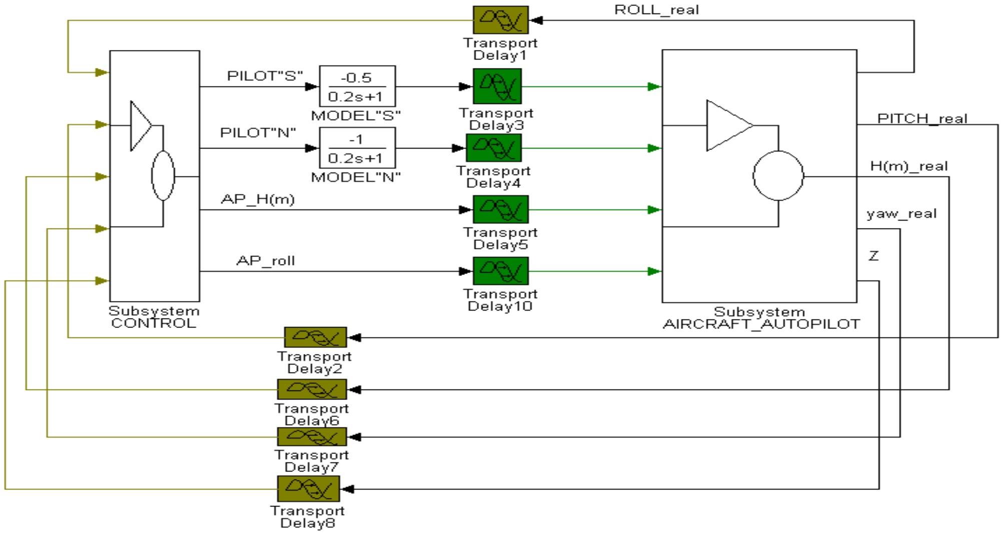
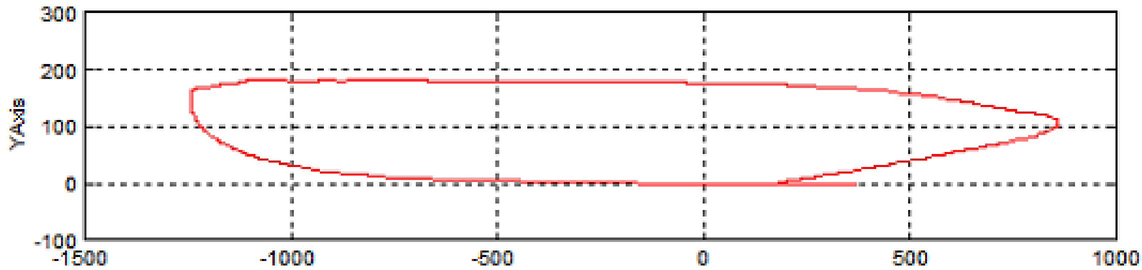


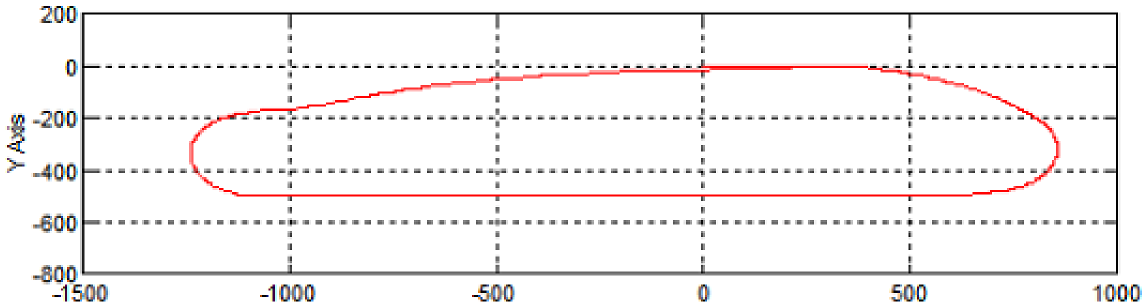
Fig.1. General form of the 'Simulink' model – the negative signs in the numerator of the inertial systems MODEL 'S' and MODEL 'N' are modifying the operator command and set the roll and pitch angle signs, aimed by the autopilot.

The adjustment of the delays in blocks 'Transport Delay' is $\Delta t = 0.7$ s.

Block 'Subsystem CONTROL' is imitating the work of ground control station equipped with the needed installations for receiving and transmitting of signals, as well as instrument based flight control (Mikhalev at al., 1974).



a) Vertical plane trajectory projection (flight altitude change in meters);



b) Horizontal plane trajectory projection (change in meters);

Fig.2. Flight trajectory in the region of the airfield, managed with manual piloting up to 30 s and automatically after that with two programmed right turns of 180^0 (course change) and location correction before landing.

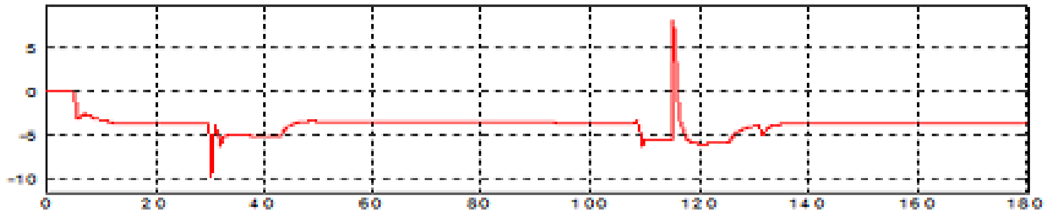


Fig.3. Elevator deflection in degrees.

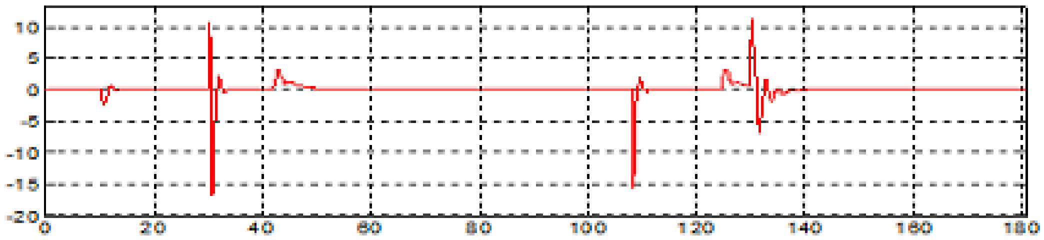


Fig.4. Aileron deflection in degrees.

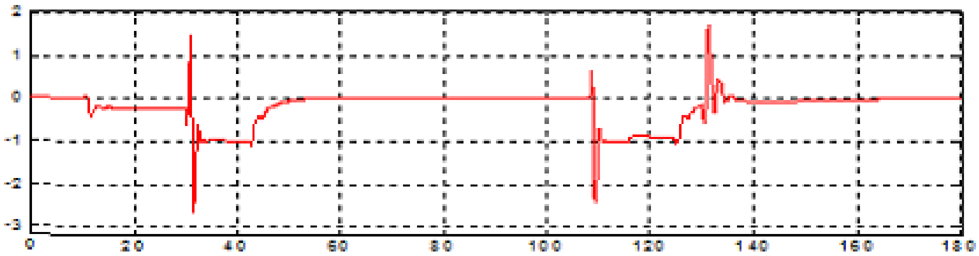
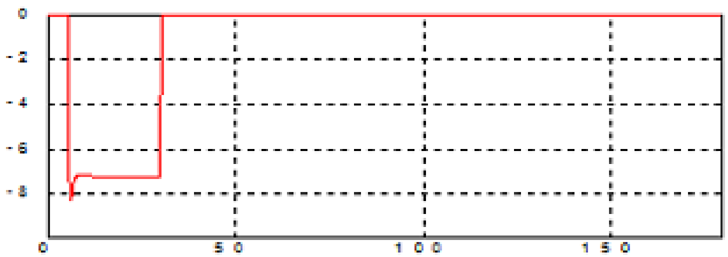
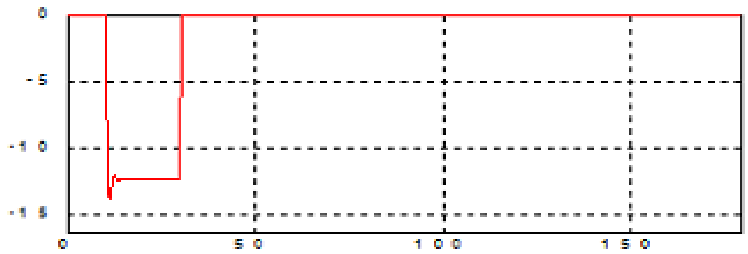


Fig.5. Rudder deflection in degrees.



a) Autopilot pitch increase manipulator movement during takeoff;



b) Autopilot manipulator movement during right turn;

Fig.6. Autopilot-operator actions during takeoff input through the control lever (manipulator) in degrees up to t=30 s – their sign is equal to the signs of the elevator and aileron deflection when climbing with right turn, but commands of pilot-operator in the model are modified by sign by the inertial system and in the autopilot enters as set pitch angle (positive) and roll angle (again positive – for right turn).

II. CONCLUSIONS:

- The modeling shows that the chosen control model fulfills the flight program and can be used as basis for development of real control system.
- The movements with the control station manipulator are very simple and by sign resemble the commands to control surfaces in manual flight mode. For example, when controlling using joystick the operator firstly pulls the lever "against themselves" to about -7^0 in t=5s and holds it for about 30 s, thus unsticks the airplane from the runway. After t=10 s he/she holds it in about 13^0 deflection diagonally to the right to t=30 s – without new regulatory movements. The aircraft enters right banking turn and climb in a spiral, after that the autopilot engages for programmed turn and "flight over a circle". If autopilot was not engaged, the aircraft continues climbing in a spiral following the pilot's command until releasing the control.
- Special attention is drawn at the yaw autopilot synthesis, because during banking for certain duration of time the aircraft starts to lose altitude, until it is restored by the autopilot. This situation is critical on low altitudes as is the situation during landing and entering correction for yaw angle. The modeling process shows that it is more favorable to choose lower values of the gains for the *Z* coordinate correction and to apply them for a longer period of time. In this case there will be no abrupt loss of lift leading to a stall during banking turn close to ground and the automatic landing is performed softly with low velocities in the range of 0.1…0.2 m/s.

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