CONTROL AUGMENTATION SYSTEM FOR REMOTE STEERING UAV

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Abstract

A typical way to guidance of the Unmanned Aerial Vehicle is autonomous flight control system activation. However, in some cases it is necessary to use remote manual control, such as during takeoff and landing of UAV. In many cases the dynamic properties of remote controlling UAV are not suitable for obtaining the desired properties of the handling qualities from operator's point of view. In this case, the control augmentation system (CAS) should be applied. This paper proposes a synthesis of the remote CAS properties method according to the model of desired dynamic characteristics. The structure of the system is shown and examples of the system properties calculation is presented.

1 Introduction

Remote manual control of unmanned aerial vehicle is used more often during take-of and landing phases. There are very difficult phases of flight. Depends on UAV take-off mass and speed (total energy) the potential crash can be very danger for airplane and environment. So, handling qualities of UAV is important from user point of view [2, 3, 6, 10].

Dynamic characteristics of the airplane can be modified by using the Control Augmentation System (CAS). This module can be employed at on-board control system of UAV or it can be used as part of ground station (or two variants can be apply). The second solution makes possible to control of UAV in the cases of critical failures of on-board control system. Receiver, simple amplifiers and actuators are necessary for UAV steering in this specific case.

Properties of the remote controlled UAV should ensure high quality of attitude stabilization and a transitory process of regulation. This choice follows from designer's experience, and it can be named as an "ideal model with good performance" [12]. In practice, the dynamic properties of the well-known aircraft which has good handling qualities characteristic from operator point of view can be used as the "ideal" model of UAV.

The acceptable dynamic properties and handling qualities of the remote controlled UAV are shape by the control law synthesis for desired properties of the modeled "ideal" UAV obtaining. This task will be performed by application of the remote indirect flight control system (similar to fly-by-wire method), used to obtain the possibility of control system property modification. As a result, handling qualities of the real UAV will be shaped.

This paper presents main properties of the project, which has been worked out by Department of Avionics and Control Systems staff and students. The research team has some experience in this area. The first control system for UAV was designed in 1995 and a few next different projects were done [5, 17, 18]. Besides, the remote control task of UAV is similar to indirect flight control systems (Fly-by-Wire) designed by a Department team [14, 15, 16].

2 Calculation method of CAS properties

Algorithm to correct the properties of the control system is placed in the ground remote flight control station - Figure 1. The task of synthesis consists in calculate the values of the coefficients matrix $\mathbf{K_A}$, $\mathbf{K_M}$ and $\mathbf{K_P}$, to minimize the difference (**ΔY**) of reaction between the UAV (state $\mathbf{Y_U}$) and model output signals ($\mathbf{Y_M}$). In this way, the handling quality of UAV should be similar to "ideal plane" from the operator point of view.

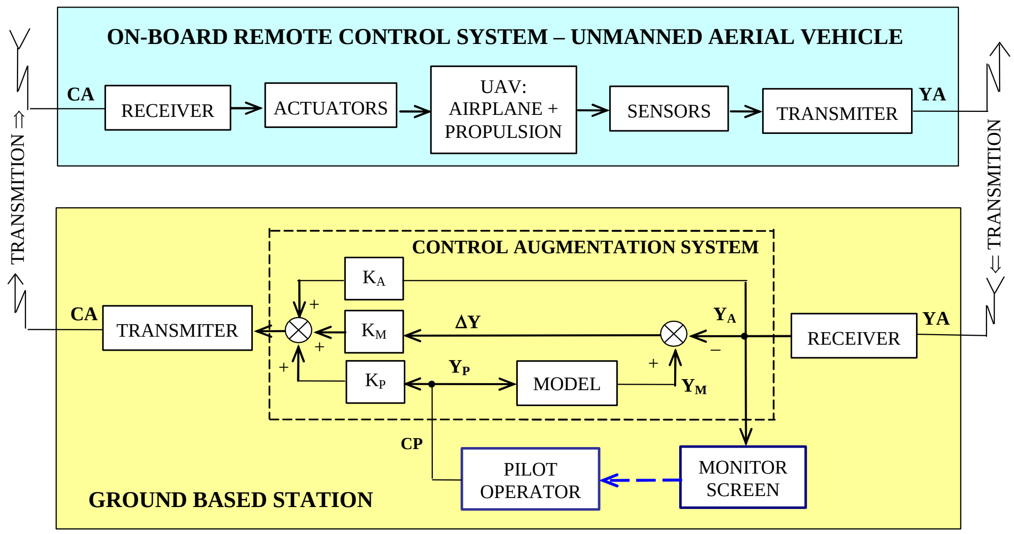

Fig. 1. Diagram of the model-following control augmentation system of UAV

Model-following design technique is a well-known method for a control system synthesis, and it is very often used in design practice [1, 7, 8]. In this paper the original modified version of the direct model-following method, based on computer simulation is applied, which was described in the previous publications [13].

The properties of the optimal controller were calculated applying the indirect (implicit) model following method. In particular, the modified version based on the computer simulations was used. Model following method allows shaping properties of the flight control systems that satisfactorily approximate those of the desired model of controlled aircraft. In this way, the expected handling qualities from operator point of view can be reached. Choosing the different models of desired aircraft we can test the new control laws, which are proposed for implementation in the UAV control systems.

Establishing desired properties of operator-controlled, but automatically augmented UAV, requires selecting proper control system structure. On the basis of to-date experiments, a direct model-following control structure, presented in figure 1, has been chosen.

CAS algorithm matrices $\mathbf{K}=[\mathbf{K_A}, \mathbf{K_M}, \mathbf{K_P}]^T$ are calculated using the simulation method of model following control system synthesis and computer simulation. It means that the non-linear model of UAV and actuators can be used on the design calculations. The solution of the classical linear problem for the problem's simplified version may be used as a first approximation of the desired solution. Finally, the non-linear programming method with the inequality constraint functions will be used for the sub-optimal control laws choosing.

It is necessary to check if simplifying of control laws leads to significant deterioration in the attitude stabilization quality and a transition process. For this purpose, the computer simulation is particularly convenient, as a part of the synthesis method.

3 Remote Control Augmentation System Synthesis Method

The properties of the control augmentation system were calculated applying the indirect (implicit) model following method [8], and in particular the modified version described in the previous paper was used [13, 16]. Model following method allows shaping properties of the flight control systems that satisfactorily approximate those of the desired model of controlled aircraft. Selection of the model is the important stage of this method. Chosen model can contain desired dynamic properties of the plane (for example the "ideal model with good performance" [12]) or it can describe the performance of the known real aircraft.

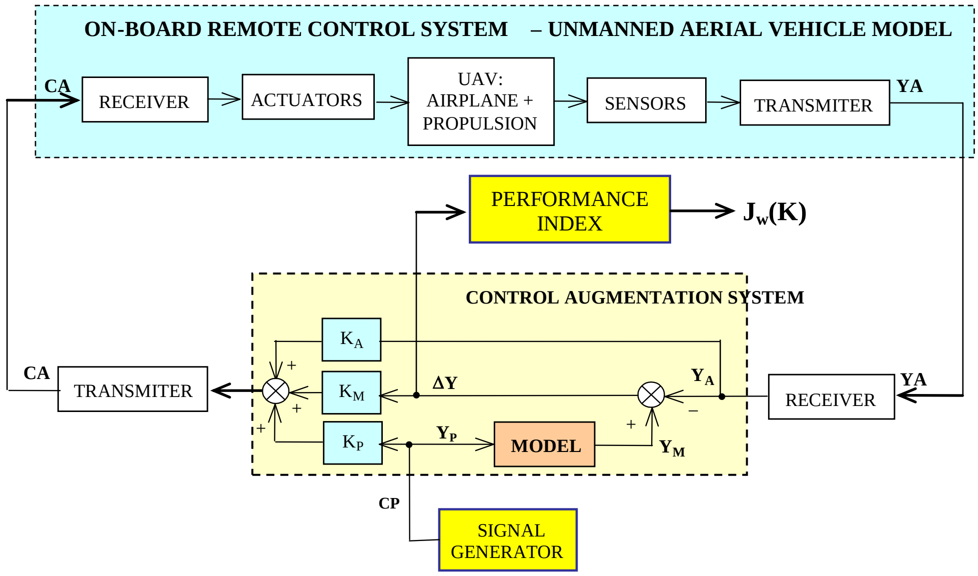

Fig. 2. Scheme of the model-following control augmentation system parameters calculation

The difference between the real aircraft and the desired model performance is defined as (see Fig. 2)

$$\mathbf{E}(t) = \dot{\mathbf{Y}}_{\mathbf{M}} - \dot{\mathbf{Y}}_{\mathbf{A}} \tag{1}$$

This kind of error between desired (modeled) and real output signals represents differences on dynamic reaction of modeled and real aircraft. In general, the steady-state performance of aircraft should be established in another way. The control function **U**(t) will be chosen to minimize the value of a quality control index

$$\mathbf{J} = \int_{0}^{\infty} \left(\mathbf{E}^{\mathbf{T}} \mathbf{Q}\, \mathbf{E} + \mathbf{U}^{\mathbf{T}} \mathbf{R}\, \mathbf{U} \right) \mathbf{dt} \tag{2}$$

For suboptimal simplified model following controller with feedback from observability output signals (UAV and model output signals) and operator input signal, the control law is described by the following equation (see Fig. 2):

$$\begin{aligned} &\mathbf{U} = \mathbf{K_P Y_P} + \mathbf{K_M Y_M} + \mathbf{K_A Y_A} \quad \textit{or} \\ &\mathbf{U} = \mathbf{KY}; \quad \mathbf{K} = [\mathbf{K_P}, \mathbf{K_M}, \mathbf{K_A}], \ \ \mathbf{Y} = [\mathbf{Y_P}, \mathbf{Y_M}, \mathbf{Y_A}]^{\mathbf{T}} \end{aligned} \tag{3}$$

CAS controller matrices $\mathbf{K_i}$ are calculated using the simulation method of model following control system synthesis [13]. The method based on the computer simulation and employed the direct methods of the searching for the minimum of the performance index. The practical application becomes even more evident if we consider that in such a case a simplified linear model of the object's dynamics may be replaced with the full non-linear model. It is also possible to take into consideration many real-life restrictions, e.g. those concerning control signals. The solution of the classical linear problem for the problem's simplified version may be used as a first approximation of the desired solution. Finally, the non-linear programming method with the inequality constraint functions will be used for the sub-optimal control laws choosing [4]:

$$\mathbf{J(K)} = \int_0^{T_f} (\mathbf{E}^T \mathbf{Q} \mathbf{E} + \mathbf{U}^T \mathbf{R} \mathbf{U}) dt \qquad (4)$$

where: $\mathbf{K} \in [\mathbf{K}^{min}, \mathbf{K}^{max}]$ – suboptimal value of the control matrix, lower and upper limitations of the gain matrix, respectively, T_f - finite period of integration, it is approximate equal period of the phugoid mode or the largest of the time constant of the aircraft motion.

In practice, because of the stability requirements, the modified version of performance index $\mathbf{J_W}$ is used

$$\mathbf{J_W}(\mathbf{K}) = \mathbf{J}(\mathbf{K}) + d\sum_{j=1}^{p} g^{r_j} \qquad r_j = \mathrm{real}(\lambda_j) \qquad (5)$$

where: λ_j - eigenvalue of the linear approximation of the closed-loop control system, p – number of eigenvalues with $\mathrm{real}(\lambda_i) \geq 0$, d, g – parameters (weighting coefficients).

The shame of the control matrix **K** calculation is shown in Figure 2. The typical control signals are generating and matrix $\mathbf{K}=[\mathbf{K_A}, \mathbf{K_M}, \mathbf{K_P}]^T$ is chosen for the minimum of the performance index $\mathbf{J_W(K)}$.

It is necessary to check if simplifying control laws leads to significant deterioration in the attitude stabilization quality and a transition process. For this purpose, the computer simulation is particularly convenient, as a part of the synthesis method.

4 Numerical Example

The first examples of the results of CAS algorithm applying are presented in Figure 3 and 4. In this case, the PZL M20 "Mewa" – 6 seats, twin-engine propeller aircraft will be used as a model of "ideal" aircraft from UAV operator point of view. Plots show the time-history of the pitch rate and pitch angle after displacement of the ground operator's control stick, and roll angle and sideslip angle in lateral motion, respectively.

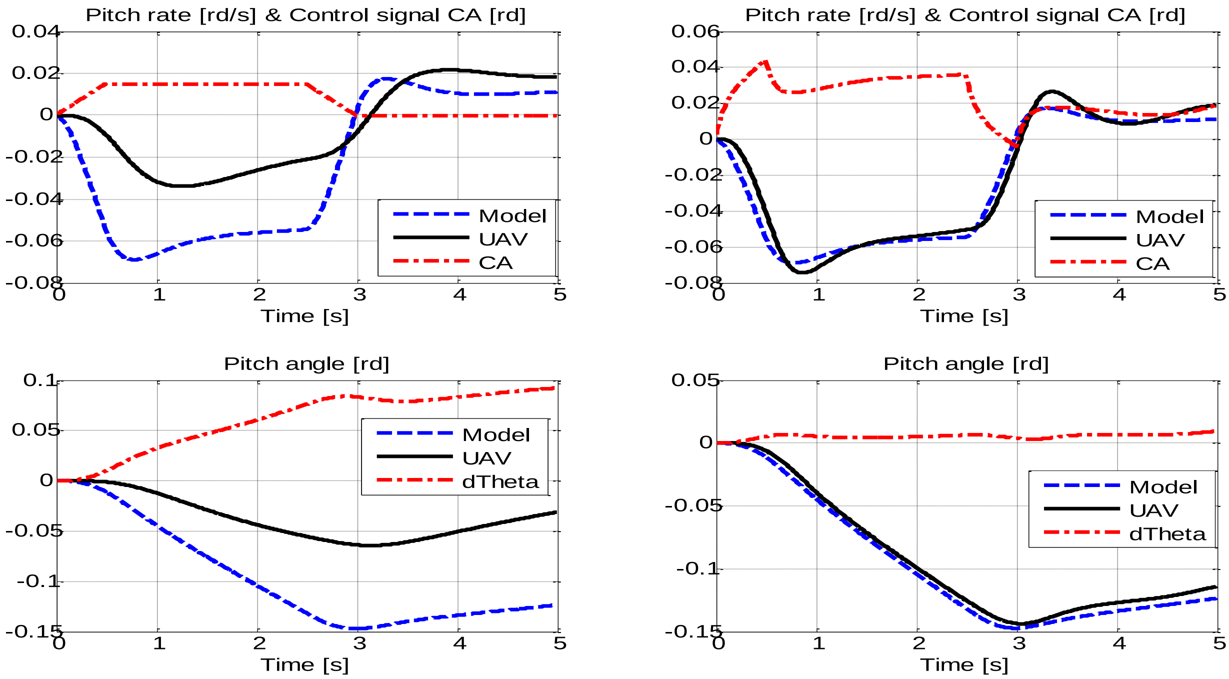

Figure 3. The time-history for modeling of UAV handling performance in landing configuration for trapezoidal stick deflection; control augmentation system switched off (left) and switched on (right)

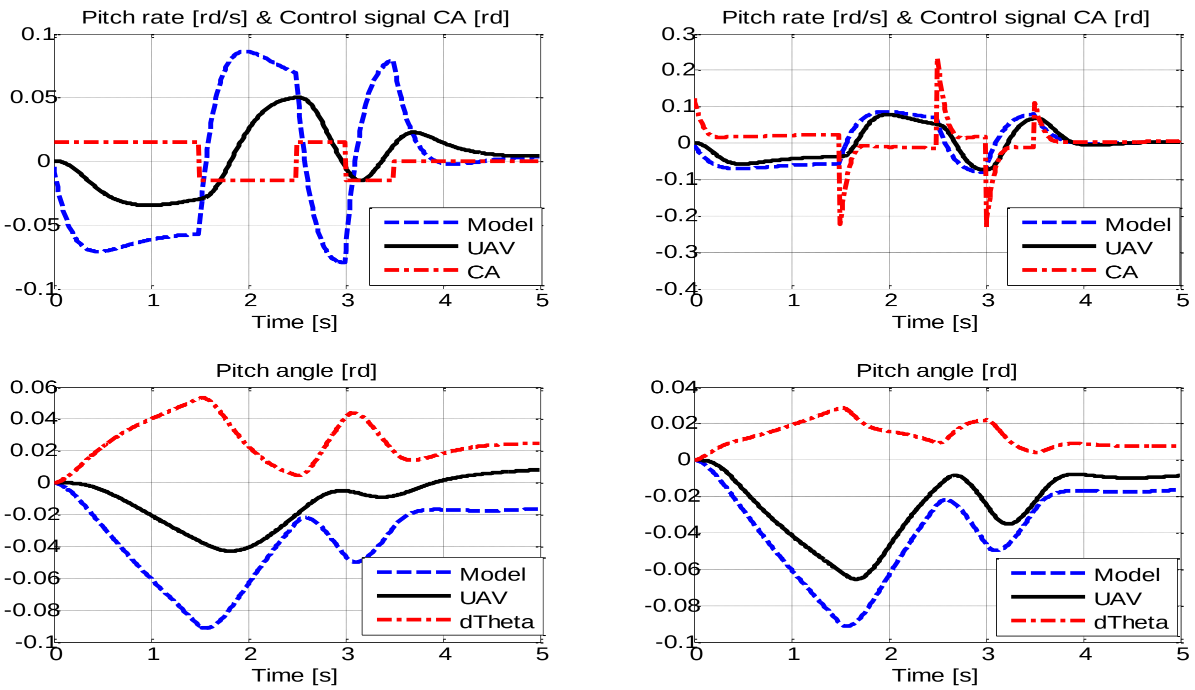

Figure 4. The time-history of the state variables with the augmentation control system switched off (on the left) and switched on (on the right), where: CA – control signal of UAV elevator actuator, dTheta – pitch angle difference between modeled aircraft and UAV

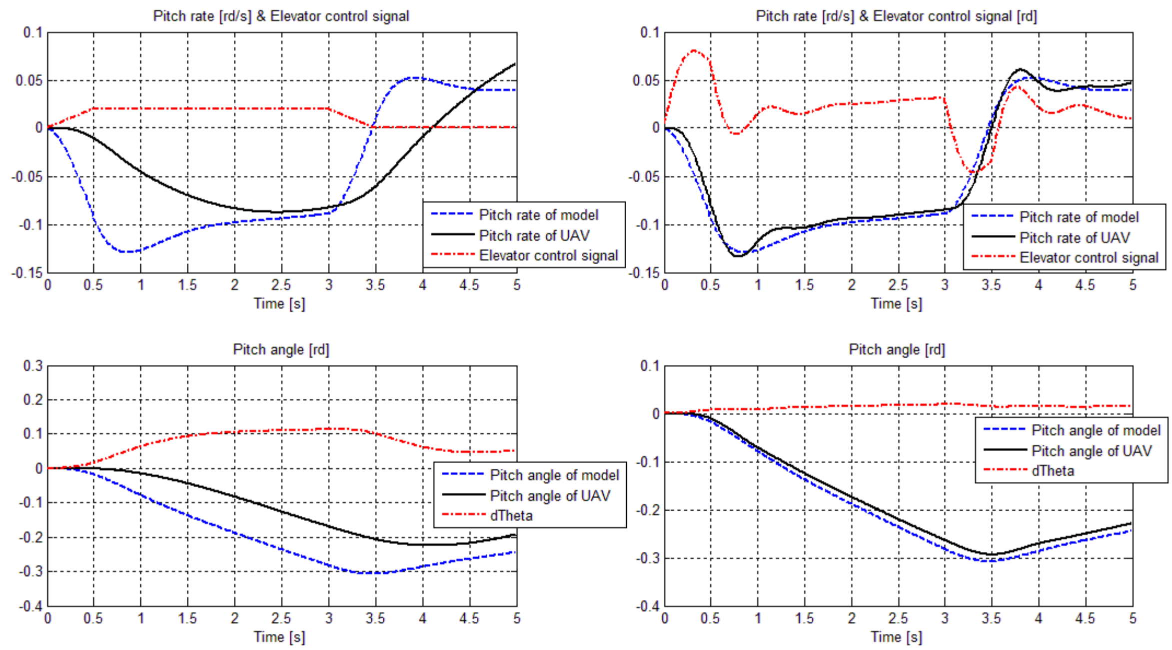

Fig. 5. Reaction of the augmented UAV on trapezoidal control signal – pitch channel

Calculation were performed with Matlab-Simulink package. The operator's control signal has a trapezoidal shape in Figure 3 and a typical shape used in flight testing named "3211" for next pictures (Fig. 3 & 4, signal CA on upper left pictures). Plots show reaction of UAV and modeled "ideal aircraft" for landing configuration on the same operator's control signal. If control system is switched on, the same operator's action causes different control signal generation, which activates actuator of elevator (line CA, pictures on the right). The delay causes by actuator inertia is visible. Pitch rates and pitch angles of the model and real UAV are very similar. In this way, from pilot point of view the augmented UAV reaction on control stick displacement is similar to "ideal" aircraft reaction on the same pilot action. It is possible to say that handling properties concern attitude orientation of the UAV is similar to modeled "ideal" aircraft.

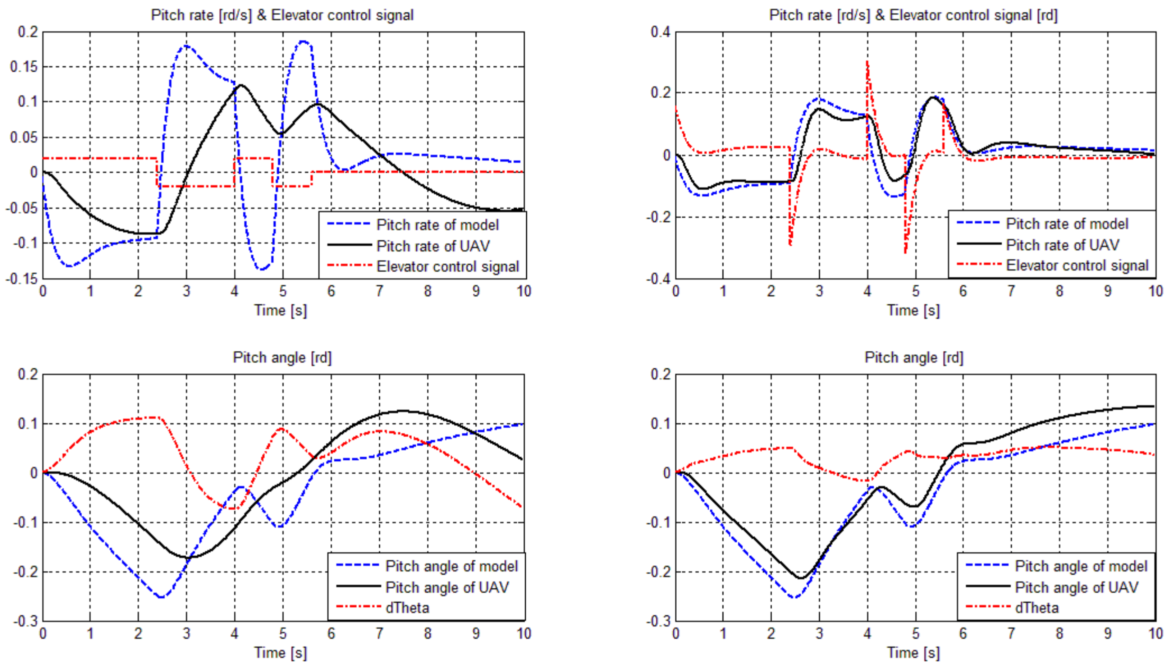

Fig. 6. Reaction of the augmented UAV on "3211" control signal – pitch channel

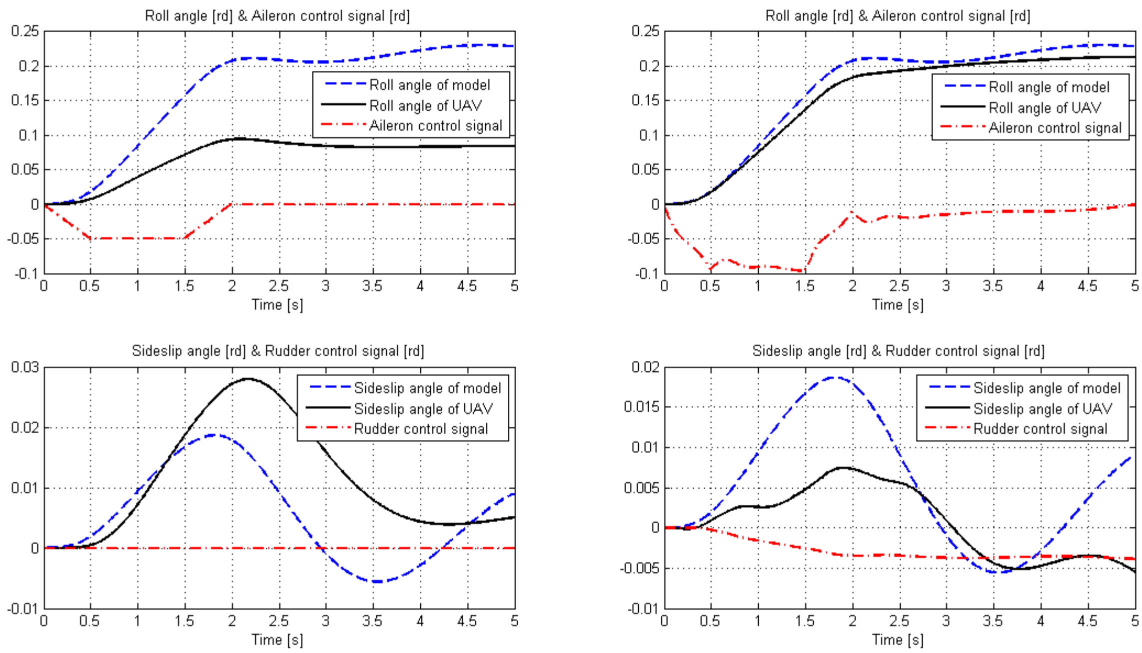

Fig. 7. Reaction of the augmented UAV on trapezoidal control signal – roll channel

The dynamic properties of the typical UAV are similar to handling qualities of classical aeroplanes. From the remote-piloted operator point of view the properties of the UAV defined as "rate control, attitude hold" are more useful [9, 16]. It means that control stick displacement causes change of UAV orientation (pitch rate or roll rate is generated) and new pitch and/or roll angles are stabilized after moving of the control stick to neutral position. This kind of "ideal UAV" is used in the analyzed examples.

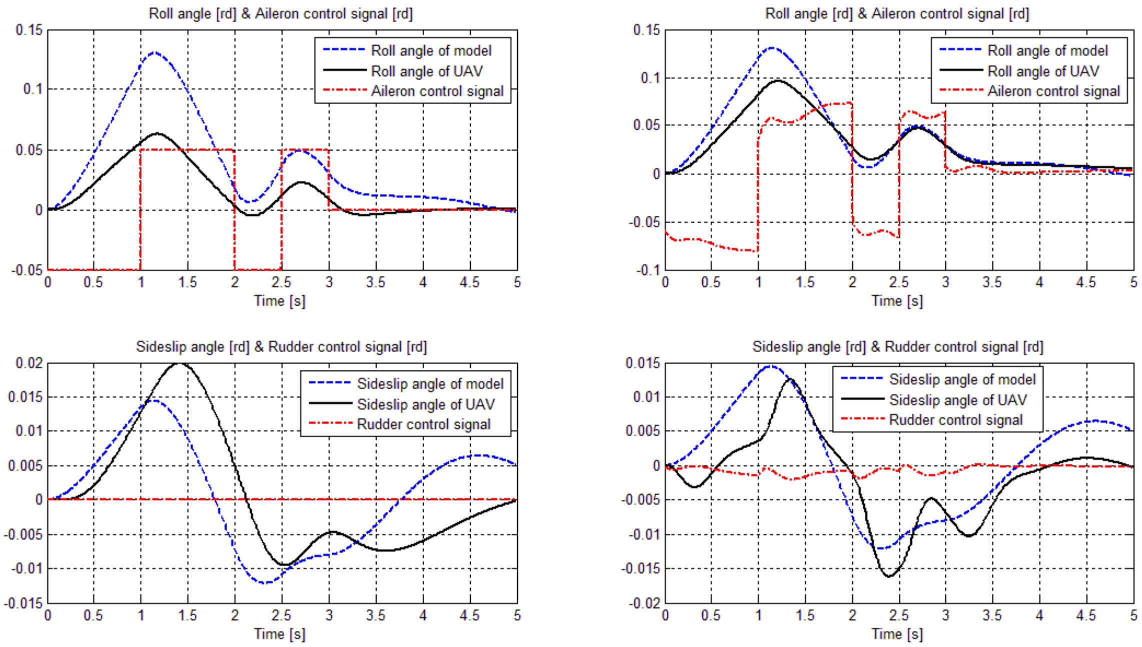

Fig. 8. Reaction of the augmented UAV on "2211" control signal – roll channel

At present a new version of control system for medium size UAV (aerial observer) is designed at Rzeszów University of Technology. Figures 5-8 show the results of the control augmentation system design calculation for MP-02A UAV project (piston engine, take-off mass m=470 kg, IAS=70-220 km/h). The control augmentation system properties (described by matrix **K**) are calculated for approach to landing configuration (flaps in 48^0 position) with airspeed IAS=24.9 m/s and vertical speed VS= 2.4 m/s. It evidently that reaction of the UAV for control stick deflection is similar to reaction of the "ideal UAV". The differences are not very important from operator point of view because he is still active in the control loop and he can compensate the control errors (deviation from desired attitude). Another words, the dynamic properties of the controlled UAV are very similar to desired handling qualities.

5 Summary

The presented method of the control augmentation system properties calculations and numerical examples concern the remote steering of the unmanned aerial vehicles. Results of the calculation show that reaction in longitudinal and lateral motion of the UAV for operator's control stick displacement should be similar to reaction of the modeled "ideal UAV". It is possible to say that handling properties concern attitude orientation of the real UAV is similar to desired ones. It means that it is possible to modify dynamic characteristics of the UAV in this way. From on-ground operator point of view the unmanned aerial vehicle dynamic properties can be acceptable. The safety flight, especially during take-off and landing phases, is possibility of success. The second reason for control augmentation system applying is standardization of the handling qualities of different unmanned aerial vehicles.

. The proposed method will be applied in the control system which is designing now at Rzeszów University of Technology and testing in flight of it is planned as well. The next step for approving remote control of UAV is intended. The active control stick is under development [11] which enables using force feedback for simplification remote manual control of UAV.

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