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Analysis of the delays and failures impact in the remote control system dedicated for the optionally piloted airplane

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***Abstract*- In recent years, there has been a rapid development of unmanned aerial vehicles, and one of the classes of these aircraft are Optionally Piloted Vehicles (OPV). This means that manually piloting aircraft by the pilot is adapted to the remote control by an operator in a flight management ground-based center, and to exercise autonomous, automatically controlled flight. For remotely controlled OPV particularly important are delays in the transmission of control signals and the aircraft controllability degradation in case of partial damage of the on-board control system. Influence to the quality of the plane control is taking into consideration. Handling qualities of OPV are important from operator point of view. These proprieties influence to operational performance and flight safety. Specified areas limits of control system degradation are calculated, and a method of partial compensation of the impact of disability is presented. The model-following method was used for control augmentation system parameters calculations. That main idea of this method is that OPV reaction on the operator steering signals should be similar - almost the same - as reaction of the "ideal" remote controlled aircraft. Article is illustrated with an example of a calculation relate to a medium-sized, optionally piloted aircraft MP-02A.**

***Keywords*- Flight control, Optionally piloted airplane.**

I. Introduction

An optionally piloted vehicle (OPV) can be used with or without a human pilot on board the aircraft. So, the OPV is a hybrid between a classical handling steering aircraft and remotely piloted airplane or unmanned air vehicle. This solution is very useful for flight experiments, UAV operators training and research works. For example, The National Test Pilot School certified an modified Cessna 150 airplane as an Optionally Piloted Aircraft for use as a training device to develop methodology of flight testing unmanned systems. The same tasks are planned for OPV MP-02A designed by Department of Avionics and Control Systems research team. In article the impact of control signal delays and partly damage of the control system is analyzed.

Influence of the control delay time and fault of actuators to flight quality of the aircraft is analyzed in many works (for example [1]). Especially, this influence is important in the case of remote steering of UAV or OPV [2, 3]. In this work the performance degradation of an actuator is represented by lower value of actuator natural frequency, compare with nominal properties. On the base of earlier projects [4, 5] the control augmentation system (CAS) was applied for remote steering UAV [6]. This paper presents next version of this system, dedicated to the optionally piloted airplane.

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II. Remote control system for optionally piloted aircraft

The acceptable handling qualities of the remotely controlled OPV are shape by the control law synthesis for desired properties from pilot-operator point of view. 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. The modified model-following method [7] was used for shaping indirect flight control system properties for general aviation aircraft [4] and it was applied for synthesis of the Control Augmentation System for remotely piloted OPV. The basic idea of the project is to improve the handling qualities of remotely controlled OPV in spite of a non-critical damage of an on-board flight control system. In this paper the reduced characteristics of the remote control system are represented by control signal transportation delay time and failures of actuators represented by smaller value of natural frequency of actuator, modeled as a oscillatory module. The structure of the control augmentation system is showed in Figure 1.

The error between desired (modeled) and real output signals $\mathbf{\Delta Y}(t)$ represents differences on dynamic reaction of modeled and real aircraft. In general, the steady-state performance of aircraft should be established in another way. From pilot-operator point of view the real UAV reaction should be very similar to “ideal” model response to stick deflection. Operator can observe direct attitude and position of OPV (typical case for landing) or the view from on-board camera is shown on the screen. Pilot uses the stick for OPV control during flight, and control augmentation system calculates the control signal $\mathbf{U}(t)$ in this way, that reaction of the OPV should be acceptable and similar to well known “ideal” remote piloted aircraft. Control signal $\mathbf{U}(t)$ is sent via data link to actuator, which deflects aerodynamic surfaces (vector $\mathbf{dh}$).

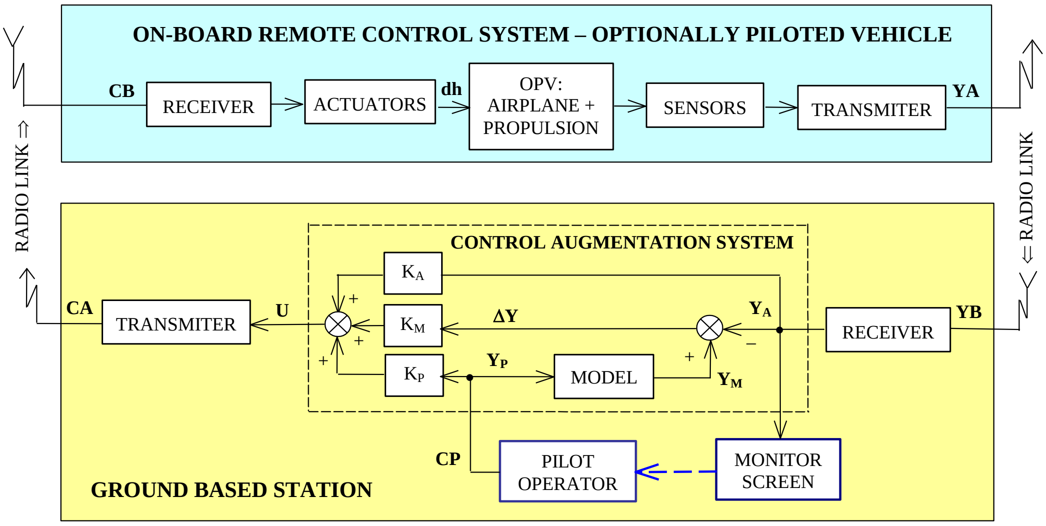

Figure 1. Structure of the model following remote control augmentation system

CAS controller matrices $\mathbf{K_i}$ are calculated using the simulation method of model following control system synthesis [4, 5]. The method based on the computer simulation and employed the direct methods of the searching for the minimum of the performance index. 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 synthesis. The minimum of cost index $\mathbf{J}(\mathbf{K})$ as a function of matrix $\mathbf{K}$ is calculated:

$$\mathbf{J(K)} = \int_0^{T_f} (\Delta Y^T \mathbf{Q} \Delta Y + \mathbf{U}^T \mathbf{R}\, \mathbf{U})dt \qquad (1)$$

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

$$\mathbf{J_W}(\mathbf{K}) = \mathbf{J}(\mathbf{K}) + d\sum_{j=1}^{p} g^{r_j} \qquad r_j = \mathrm{real}(\lambda_j) \qquad (2)$$

where: $\mathbf{Q}$, $\mathbf{R}$, d, g –weighting matrixes and coefficients, λ_j - eigenvalue of the linear approximation of the closed-loop control system, p – number of eigenvalues with real(λ_i)≥0.

III. Numerical Example: OPV MP-02A

The main task of the research team was design the remote flight control system for transforming the medium-size ultralight conventional airplane to Optionally Piloted Aircraft. Figure 2 shows the airplane MP-02A and the main data and performance of the aircraft. Model of MP-02A aircraft was used [8], and the mathematical model of MP-02A with good performance of control system (delay time τ=0, nominal natural frequency of actuator ω_{NOM}) was applied as "ideal model" of remotely piloted OPV. Modified model-following method was used for control augmentation system parameters calculation.

Take-off weight	472.5 kg	1041.7 lb
Max. Airspeed VNE	260 km/h	140 knot
Max. cruise speed	230 km/h	124 knot
Economic cruise speed	165 km/h	89 knot
Minimum speed	64 km/h	34 knot
Fuel consumption	8-16 l/h	2.1-4.2 gal/h
Fuel capacity	114 l	30 gal
Take off distance	120 m	393 ft
Landing run	80 m	262 ft
Rate of climb (One person)	6.5 m/s	1279 ft/min.
Loads	+4/-2 g	

Figure 2. Main data and performance of the MP-02A Optionally Piloted Aircraft

From operator point of view handling qualities of the remote piloted MP-02 airplane equipped with CAS should be similar to "ideal" model of aircraft. Figure 3 presents reactions of the non-augmented and well-augmented MP-02A OPV on the trapezoidal desired pitch angle change, for partly degradation of the control system properties (delay time τ=0.1 s, nominal natural frequency of actuator $\omega=0.5*\omega_{NOM}$). Reaction of the non-augmented airplane is not acceptable from pilot-operator point of view (left column, solid line). It evidently that reaction of the well-augmented real MP-02A OPV is similar to reaction of the "ideal OPV" (right column). The differences are not very important from operator point of view because the pilot-operator 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 remotely piloted OPV are very similar to desired handling qualities.

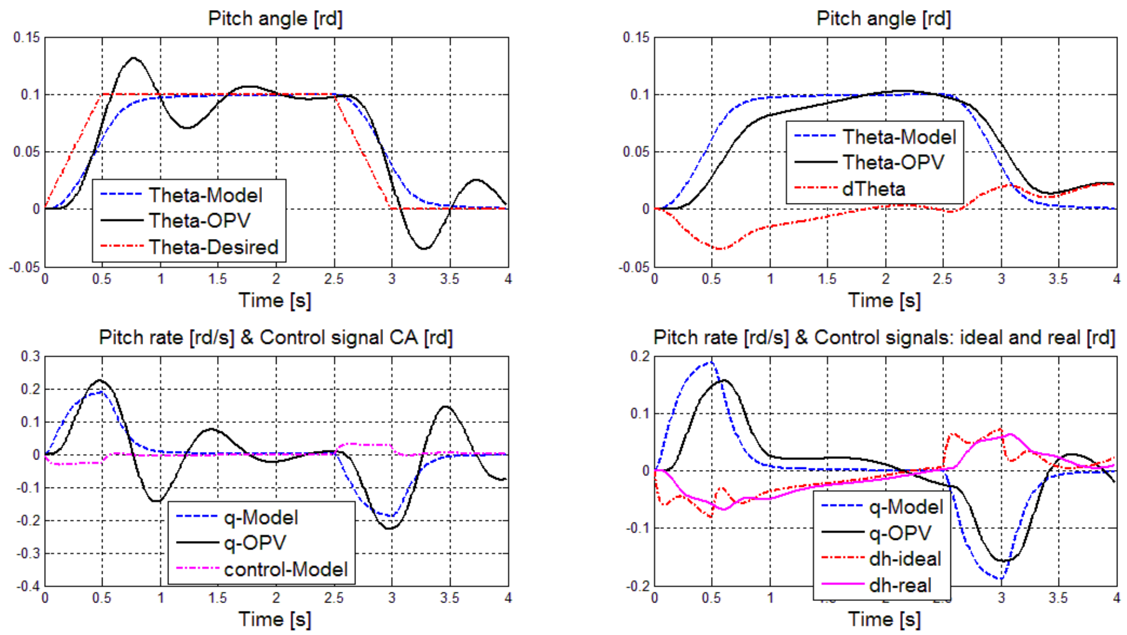

Figure 3. Remote controlled the non-augmented (left column) and well-augmented OPV (right column) for trapezoidal desired pitch angle and control signal transportation delay τ=0.1 s, actuator natural frequency ω=10 rd/s ($\omega=0.5*\ \omega_{NOM}$), where: Theta-Model, q-Model – pitch angle and pitch rate of the "ideal" modeled OPV, Theta-OPV, q-OPV - pitch angle and pitch rate of the MP-02A OPV, Theta-Desired – desired shape of the pitch angle, control-Model – pilot-operator steering signal, dTheta – difference between "ideal" model pitch angle and real OPV pitch angle, dh-ideal, dh-real – elevator deflection angle generated by CAS (signal U) and real OPV elevator deflection angle (dh)

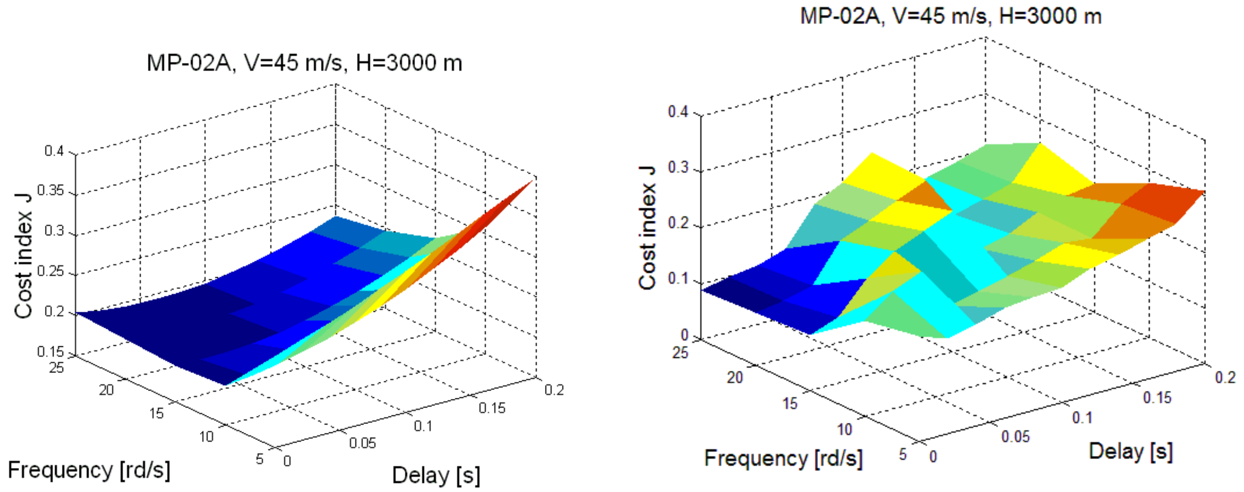

Figure 4. Cost index value as a function of control signal transmission delay and natural frequency of actuator: without CAS (left) and with CAS (right)

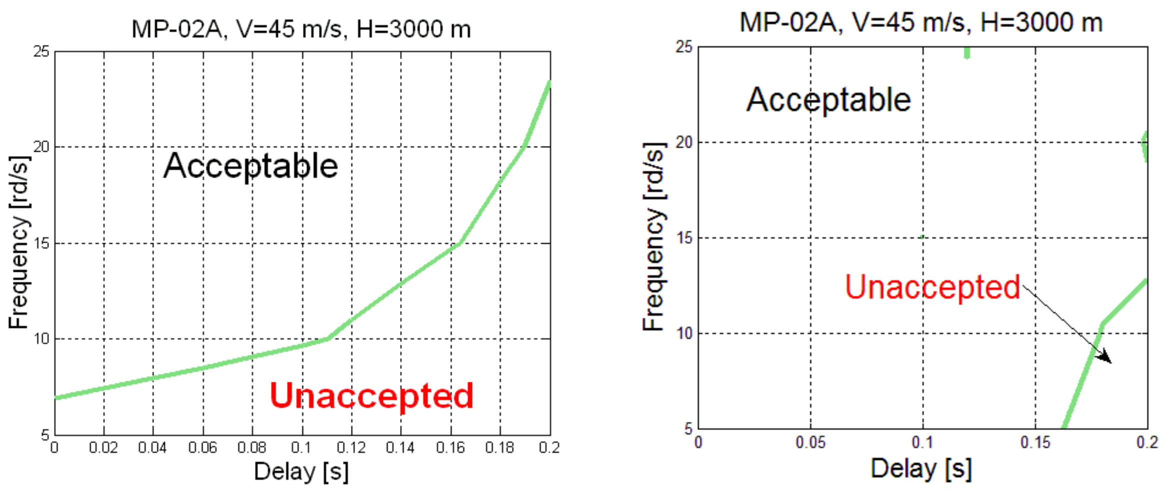

Figure 5. Acceptable area of control signal transmission delay and degradation of the actuator: without CAS (left) and with CAS (right)

Cost index value represents the difference between real aircraft reaction and "ideal" model output signals, and it can be used as a measure of OPV handling qualities. Figure 4 shows surface cost index value as a function of delay time and natural frequency of actuator for OPV without and with CAS using. From operator-expert point of view the handling qualities described by cost index value less then J=0.24 is acceptable. In this way we can found acceptable and unacceptable areas of delay time and natural frequency of actuator. Figure 5 shows results for OPV equipped with CAS and without them. We can see that bigger ranges of parameters τ and ω are acceptable from pilot-operator point of view in the second case. This means that the system proposed in this work favorably modifies the characteristics of the OPV. Safe piloting remotely controlled airplane MP-02A is possible in the case of partial damage to the on-board flight control system.

IV. Final Remarks

Results of the modeling and calculation show that reaction of the OPV equipped with CAS with partly damaged control system for operator's control signal is similar to reaction of the OPV without failure. It is possible to say that handling properties concern attitude orientation of the real OPV is acceptable from operator point of view. The modeling and simulation technique is the good way for synthesis and evaluate of the OPV handling qualities, including analysis of delays and failures of on-board control system. In this work the linear mathematical model of OPV is used. 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. An important advantage of the proposed solution is to place the algorithms improving the handling qualities of the OPV in a ground station computer. This allows the use of more sophisticated methods of control, because the ground station computer has much more computing power than the on-board one. Presented method will be developed in the future and finally will be tested as the element of the remote flight control system of the optionally piloted aircraft MP-02A.

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