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PULL-UP FROM A DIVE

INTRODUCTION

In case of some type of aircraft, like military and acrobatic exists the pull-up from a dive manoeuvre. Pull-up from a dive is a curved line motion in vertical plane, in which an aircraft flying with negative pitch angle is constrained suddenly to fly horizontal or with positive pitch angle under the effect of the elevator. In some cases at pull-up from a dive, the loading factor can be higher than the loading factor associated to fiziology or to aircraft structure. At the same time, an aircraft flying with given velocity can not make pull-up from a dive under a minimal altitude.

In this paper it is presented the analysis of the minimal altitude (in function of the entrance velocity in pull-up from a dive manoeuvre), which assures security according with the restriction factors.

The analysis was made especially for an UAV, called IAR-T, which was designed and built by the Romanian National Institute for Aerospace Research "Elie Carafoli" (INCAS).

Fig. 1. IAR-T

IAR-T has the following main characteristics:

Length: 1,82 m	Highness: 0,6175 m
Wing area: 0,91 m^2	Wing span: 2,6 m
Mass: 15 kg	Power of engine: 4,1 HP
Range of speed: 14-44 m/s	
Loading factors: n_x=5-6, n_y=2-3, $-1<n_z<2$	

THE EQUATIONS OF MOTION

The simulations are based on the nonlinear equations of longitudinal motion of the aircraft, which are the following:

$$\begin{cases} \dot{V} = \dfrac{1}{m}\left[(F_x + T)\cos\alpha + F_z \sin\alpha\right] \\ \dot{\alpha} = q - \dfrac{1}{mV}\left[(F_x + T)\sin\alpha - F_z \cos\alpha\right] \\ \dot{q} = \dfrac{1}{J_y}\left(m_y + T \cdot z_T\right) \\ \dot{\Theta} = q \\ \dot{x}_n = V\cos(\alpha - \Theta) \\ \dot{z}_n = V\sin(\alpha - \Theta) \end{cases} \tag{1}$$

The forces and the pitching moment are expressed by:

$$\begin{gathered} F_x = k\left(C_L \sin\alpha - C_D \cos\alpha\right) - G\sin\Theta \\ F_z = -k\left(C_D \sin\alpha + C_L \cos\alpha\right) + G\cos\Theta \\ m_y = kcC_m \end{gathered} \tag{2}$$

where $k = \frac{1}{2}\rho V^2 S$, $\rho = \rho(z_n)$ and “c” means the wing chord.

The aerodynamics coefficients are given by:

$$\begin{gathered} C_L(\alpha, q, \delta_e) = C_{L_0} + C_L^{\alpha}\alpha + C_L^{q} q + C_L^{\delta_e}\delta_e \\ C_D(\alpha, \delta_e) = C_{D_0} + C_D^{\alpha}\alpha + C_D^{\delta_e}\delta_e \\ C_m(\alpha, q, \delta_e) = C_{m_0} + C_m^{\alpha}\alpha + C_m^{q} q + C_m^{\delta_e}\delta_e \end{gathered} \tag{3}$$

Introducing these expressions of forces and of pitching moment in system (1) and separating the fifth equation from it, the final system of simulation will be:

$$\begin{cases} \dot{V} = \left[-kC_D + T\cos\alpha - G\sin(\Theta - \alpha)\right]/m \\ \dot{\alpha} = \left[mVq - kC_L - T\sin\alpha + G\cos(\Theta - \alpha)\right]/mV \\ \dot{q} = \left(kcC_m + T \cdot z_T\right)/J_y \\ \dot{\Theta} = q \\ \dot{z}_n = V\sin(\alpha - \Theta) \end{cases} \tag{4}$$

PULL-UP FROM A DIVE MANOEUVRE

It will be consider, that before the pull-up from a dive manoeuvre the aircraft is in free fall with $\Theta = -\pi / 2$. In this paper it is not analyzed how can arrive the aircraft in this position. The stabilized value of state and control variables in free fall, can be calculate using the first four equations of system (4) in which, the left side will be zero, expect the first equation in which the left side will be equal with the gravitational acceleration (g).

$$\begin{cases} T\cos\alpha + G\cos\alpha - kC_D - mg = 0 \\ T\sin\alpha + G\sin\alpha + kC_L = 0 \\ T \cdot z_T + kcC_m = 0 \end{cases} \tag{5}$$

Solving this system, results the stabilized value for T, α, δ_e at the beginning of the pull-up manoeuvre. In this manouevre the elevator will have a linear variation in function of the time ($\dot{\delta}_e =$ constant) and the block structure is presented on fig. 2. The manoeuvre will be finished and will be continue with horizontal flying when the pitch angle becomes positive.

$$\xrightarrow{\delta_e} \boxed{\dot{x} = f(x, \delta_e)} \xrightarrow{x}$$

Fig. 2. The block structure of control system in pull-up manouevre

FLYING AFTER THE PULL-UP

If the purpose is to fly horizontal after the pull-up manouevre, this equation will be used for the motion of elevator:

$$\delta_e = -k_z\left(z_{npr} - z_n\right) - k_\Theta\left(\Theta_{pr} - \Theta\right) \tag{6}$$

The programmed pitch angle $\Theta_{pr} = 0$ and the programmed altitude z_{npr} will be approximately the altitude where the aircraft arrived after the pull-up. In this case the simplified block structure of system control is presented on fig. 3. and the coefficients k_z, k_Θ will be determined using the linearized longitudinal model and the method of the standard coefficients [1].

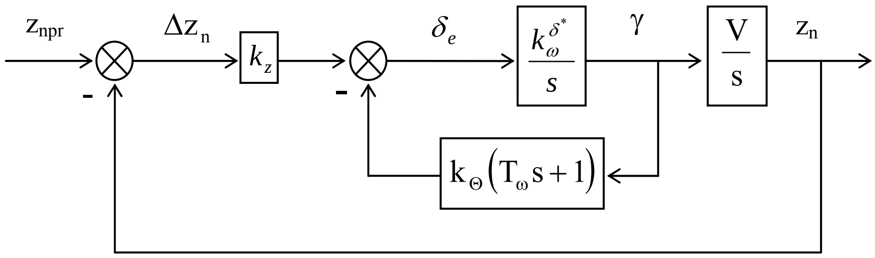

Fig. 3. Simplified block structure of longitudinal motion with the control of linear and angular deviation

The transfer function of the control system is given by:

$$H(s)=\frac{\dfrac{k_z k_\omega^{\delta^*} V}{1+T_\omega k_\Theta k_\omega^{\delta^*}}}{s^2+\dfrac{k_\Theta k_\omega^{\delta^*}}{1+T_\omega k_\Theta k_\omega^{\delta^*}}s+\dfrac{k_z k_\omega^{\delta^*} V}{1+T_\omega k_\Theta k_\omega^{\delta^*}}} \tag{7}$$

and the corresponding standard transfer function is:

$$H_0(s)=\frac{\Omega_0^2}{s^2+1{,}5\Omega_0 s+\Omega_0^2} \tag{8}$$

The coefficients k_z and k_Θ could be calculated on the base of the identification between this two transfer function:

$$k_z=\frac{\Omega_0^2}{Vk_\omega^{\delta^*}\left(1-1{,}5T_\omega\Omega_0\right)} \qquad k_\Theta=\frac{1{,}5\Omega_0}{k_\omega^{\delta^*}\left(1-1{,}5T_\omega\Omega_0\right)} \tag{9}$$

where

$$k_\omega^{\delta^*}=\frac{k_\omega^\delta}{1+k_\omega^\delta k_\delta^q} \tag{10}$$

$$k_\delta^q=\frac{1{,}5T}{k_\omega^\delta T_\omega}\left[\left(\frac{1{,}5}{2}\frac{T}{T_\omega}-\frac{2\xi}{1{,}5}\right)+\sqrt{1+\frac{1{,}5^2}{4}\frac{T^2}{T_\omega^2}-2\xi\frac{T}{T_\omega}}\right] \tag{11}$$

Other notations used in the above mentioned expressions:

— own frequency of the standard system (Ω_0);

— the inverse of the own frequency of system (T);

— advance time in pitching command (T_ω);
— command factor of pitching (k_ω^δ);
— relative pitching damping factor (ξ);

RESULTS AND CONCLUSIONS

With simulations were determined at three entrance velocity (20, 40, 60 m/s), the minimal entrance altitude which still permits to the control system the execution of the pull-up manouevre above 100 m altitude.
The results are presented on fig. 4. – fig. 8. From its is visible, that the state and control variables have a good damping factor and they are in concordance with the expected results. With more simulations it is possible to construct a range for minimal entrance altitude in function of entrance velocity, in which the pull-up manouevre is executable in security.
On fig. 7 it is observable, that the velocity of motion of the elevator depends at least on the entrance velocity and the next step of this work can be the determination of this dependence. This means to close the control system in fig. 2.

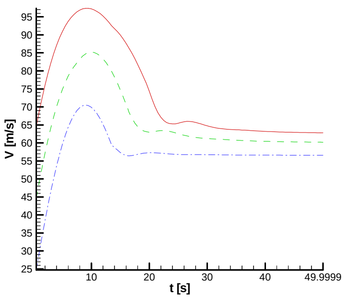

Fig. 4. Velocity

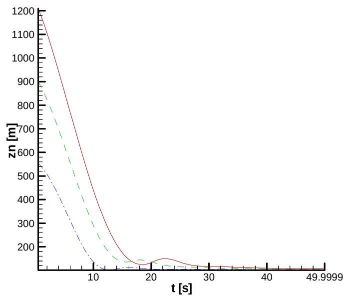

Fig. 5. Altitude

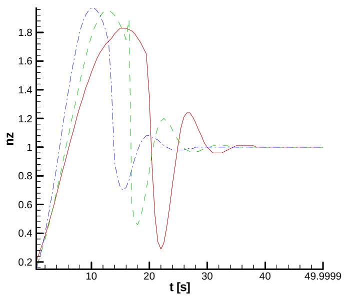

Fig. 6. Loading factor

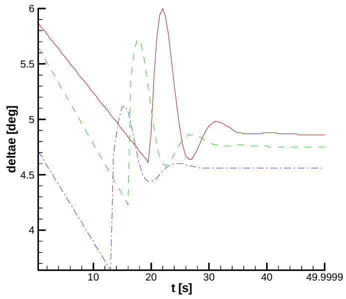

Fig. 7. Motion of the elevator

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