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The Pilot Influence on PIO Conditions. A Longitudinal Approach

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Abstract. This work was inspired by the Swedish Aerodata model ADMIRE [4] and the processed results of the Institute Straero [1]. In terms of obtaining stability and increasing the robustness relative to negative consequences of PIO, the initial model is adjusted. The pilot model is improved by considering the dynamics of neuro-muscular system given by ([2], 2001). The system is considered flying at constant speed and altitude. The coupled system pilot-machine result stable from the simulation.
Key words and phrases. Longitudinal, Pilot Model, Flight Control System, Stability, Simulation.

1. Introduction

The goal in this analysis is to express the factors that contribute to the PIO phenomenon (pilot induced oscillations which are "sustained or uncontrollable oscillations resulting from the efforts of the pilot to control the airplane" [6](1980)). Among these factors there is the human pilot although he is not be blamed because "serious PIO's can nearly always be traced to one or more control system characteristics that are conducive.." R.Hess [7](2003). The oscillation susceptibility analysis on a longitudinal flight model was studied, for example, by Balint et. al. [5](2008).

2. Longitudinal movement

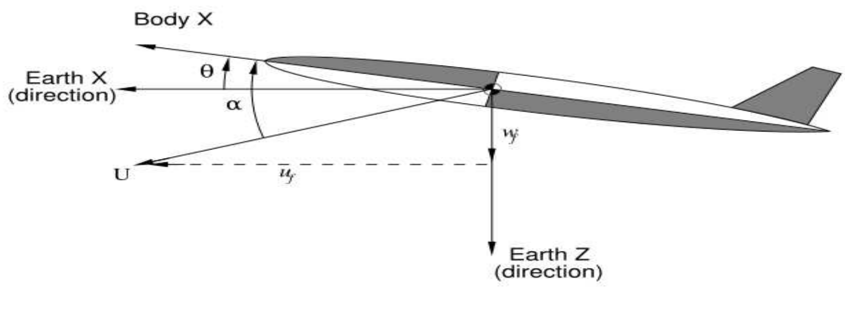

Figure 1. The elements of the longitudinal flight

2.1. The initial system.

- α - the angle of attack
- $(q = \dot{\theta})$ - pitch rate
- θ - Euler pitch rate
- δ_e - the elevator command

$$\begin{cases} \dot{\alpha} = z_\alpha \alpha + z_{\delta_e}\delta_e + \frac{g}{V_0}\cos(\theta) + q \\ \dot{q} = \bar{m}_\alpha \alpha + \bar{m}_q q + \bar{m}_{\delta_e}\delta_e + \frac{g}{V_0}Z(\theta) - \frac{1}{a}\alpha q \\ \dot{\theta} = q \\ \dot{\delta_e} = \omega_a \Psi(\sigma) \end{cases} \tag{1}$$

Remark 2.1. *$Z(\theta)$ is a linear combination of trigonometric functions with the argument θ.*

Remark 2.2. *The constants from the system (1) are specific longitudinal flight constants.*

$$\Psi(\sigma) \quad = \quad \begin{cases} \sigma, \text{ daca } |\sigma| \leq \frac{V_L}{\omega_0} = e_L \\ e_L sgn\sigma, \text{ daca } |\sigma| > e_L \end{cases} \tag{2}$$

Remark 2.3. *Ψ is a saturation for the system (1). This saturation plays an important role, often complicating the effects of PIO.*

Remark 2.4. *δ_c from the equation (3) is a variable which perturbate the dynamical equilibrium of the aircraft and will be considerate almost 0.*

$$\sigma = \delta_c + \delta_e \tag{3}$$

$$\delta_c \approx 0 \tag{4}$$

$$\delta_e = k_\alpha \alpha + k_q q + k_p \theta(t - \tau) \tag{5}$$

2.2. Trim analysis. Trim analysis is obtained by solving the equations of motion for a straight and level flight condition.

We start with:

$$\begin{cases} \dot{\alpha} = 0 \\ q = 0 \\ \dot{\theta} = 0 \\ \dot{\delta_e} = 0 \end{cases} \tag{6}$$

From the system (1) we determine $\bar{\theta}$, $\bar{\alpha}$, $\bar{\delta_e}$ numerically:

$$(\bar{\alpha}, \bar{q}, \bar{\theta}, \bar{\delta_e}) = (0.128573546505, 0, -0.000000000002873, 0.051557992147) \tag{7}$$

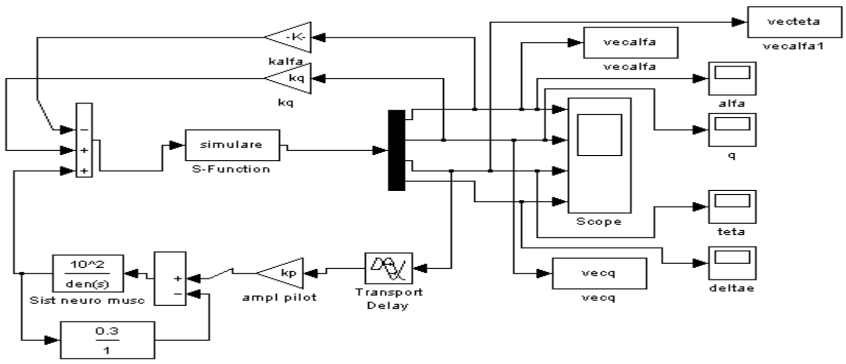

FIGURE 2. The $simulink^{TM}$ schema of the system (1) with variation of the structural pilot model

2.3. The stability of the linear model. The numerical matrix of the system is

-0.798566785714286	1.000000000000000	0.000000000000334	-0.260291571428571
-6.477364743867250	-0.165233242324542	-0.165316666666721	-8.266758414594111
0	1.000000000000000	0	0
-8.020000000000000	25.680000000000000	10.420000000000000	0

and by studying the root locus:

-0.145274312067512 +14.714815476520140i
-0.145274312067512 -14.714815476520140i
-0.336625701951902 + 0.348741462362198i
-0.336625701951902 - 0.348741462362198i

we can determine the fact that the system is stable (because all the imaginary parts are in the left side of the complex plane).

3. The nonlinear model

3.1. Considered pilot model - The structural model variation. In the scheme from Figure (2) is represented a modified pilot ([2], 2001) p. 13, which is a variation of the structural model ([3], 1997) p. 2, in the sense that it contains two components for *simulation*:

- the central nervous system
- neuro-muscular system

The model used was preferred to other models of pilots because express in an explicit manner the processes regarding generation of the output (optimal control model is based usually on a number of parameters that can't be estimated directly from experimental data ([2], p.8).

Although the initial model [2] is used to simulate human operator behavior in the flight with the helicopter, it was adapted to simulate the flight of a fighter plane.

3.2. The Simulink model and results. In Figure (2) we have the simulink schema which express the couple between the pilot and the airplane.

In the Figures (3)-(6) we see that all the functions converge.

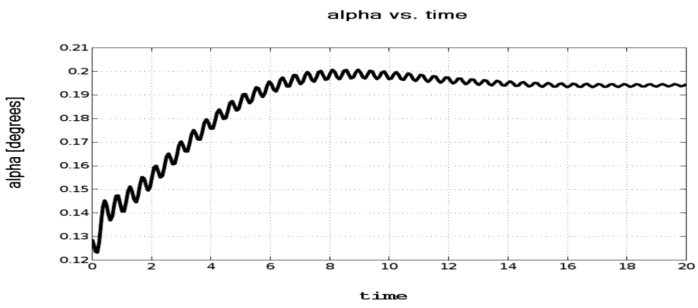

FIGURE 3. The $simulink^{TM}$ schema of the system (1) with variation of the structural pilot model

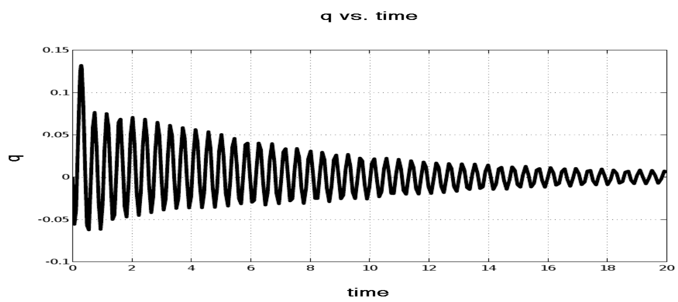

FIGURE 4. The $simulink^{TM}$ schema of the system (1) with variation of the structural pilot model

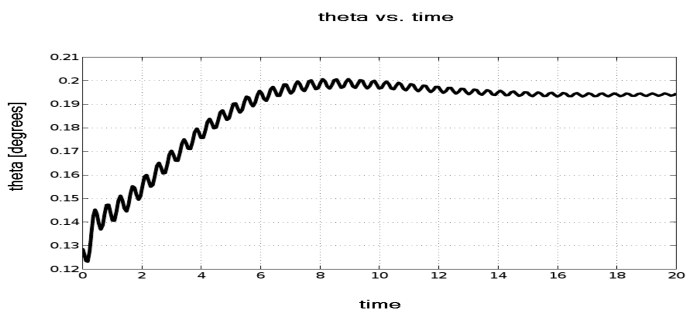

FIGURE 5. The $simulink^{TM}$ schema of the system (1) with variation of the structural pilot model

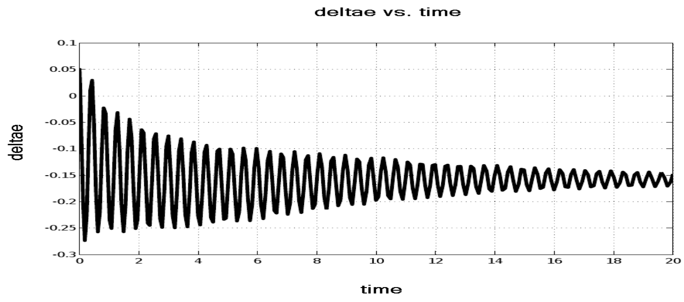

FIGURE 6. The $simulink^{TM}$ schema of the system (1) with variation of the structural pilot model

4. Conclusions and future work

In terms of obtaining stability and the increase of the robustness regarding the possibility of negative actions PIO, the model responds properly.

An interesting result is represented by the fact that the pilot model is improved by considering the dynamics of neuro-muscular system of ([2], 2001) which is a pilot model for the helicopter, nevertheless this is also proof of universality of the chosen pilot model.

As a future work we propose to integrate the results with a virtual simulation environment improving the use of the pilot models.

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