JOURNAL OF THEORETICAL
AND APPLIED MECHANICS
49, 1, pp. 175-186, Warsaw 2011

PILOT SUBJECTIVE DECISIONS IN AIRCRAFT ACTIVE CONTROL SYSTEM

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The aircraft conventional control systems including pilot-operators in loop are called as active endogenous systems, because the pilots react actively to real situations evaluated by them and their solutions origin from their minds, from the nervous system. The pilots must make decisions in situations characterised by lack of information, human robust behaviour and their individual capabilities. So, decisions born from reactions of pilot are an effect of subjective analysis.
This paper investigates the aircraft landing. The subjective factor is the ratio of required and available time to decision on the go around. The decision depends on the available information and psycho-physiological condition of operator pilots and can be determined with the use of theory of statistical hypotheses. This paper introduces a modified Lorenz attractor for the modelling of the endogenous dynamics of the given active system.

Key words: active control system, endogenous system, subjective analysis

1. Introduction

The central deterministic element of the aircraft conventional control systems is the subject that is an operator-pilot. Such systems are called as active endogenous systems (Kasyanov, 2007). The pilots make a decision on control depending on their situation awareness, knowledge, practice and skills. The pilots must make decisions in situations characterised by lack of information, human robust behaviour and their individual capabilities. So, the decisions origin from analysis of pilot-subjects or subjective analysis.

Aircraft control can be characterised with the use of subjective analysis together with the aircraft motion models. The general model of solving the control problems includes passive (information, energy-like aircraft control system in its physical form) and active (physical, intellectual, psychophysiology, etc. behaviour of subjects) resources. The decision making is the right choosing of the required results giving the best (effectively, safety, etc.) solutions.

This paper investigates the aircraft landing. The applied equations of motion describe the motion of aircraft in the vertical plane only. The boundary constraints are defined for velocity, trajectory angle and altitude. The subjective factor is the ratio of required and available time for making a decision on the go-around. The decision depends on the available information and psychophysiological condition of the operator pilots and can be determined with the use of theory of statistical hypotheses. This paper proposes a modified Lorenz attractor for the modelling of the endogenous dynamics of the given active system.

2. Aircraft motion as the situation process

Safety of active systems is determined by risks initiated by subjects who are the central elements of the given systems. For example, the flight safety is the probability of that the flight will be realised without an accident.

The aircraft are moving in three dimensional space depending on the aircraft aerodynamic characteristics, flight dynamics, environmental stochastic disturbances (wind, air turbulence) and applied control. The pilots make a decision on the control after evaluation of the flight situation awareness. Principally, they must define the problem and after that they must choose a solution from their resources. There is a reason why the human controlled active systems are endogenous. Resources are methods, technologies, etc. that can be applied for solving the problems. There are passive (finance, materials, information, energy-like aircraft control system in its physical form) and active (physical, intellectual, psycho-physiological, etc. behaviors, possibilities of subjects) resources. The passive resources are the resources of the system (air transportation system as, ATM, services provided, etc.), while the active resources belong to the pilot itself. The decision making is the right choosing of the required results giving the best (effectively, safety, etc.) solutions.

The subjects (like pilots) develop their available active resource during learning and practice (developing their competences). However, the ability of choosing and using the right resources depend on the information support, time available for decision making, real knowledge, way of thinking and skills of the subjects. Such decisions are results of the subjective analysis (Berger, 1985; Kasyanov, 2007).

There is not enough information about the physical, systematic, intellectual, psychophysiology, etc. characteristics of the subjective analysis about the way of thinking and decision making of subjects-operators like pilots. Only limited information is available about the time effects, possible damping of non-linear oscillations, long term memory, etc. making the decision system chaotic.

In our case, safety of personal planes can be characterized with the use of subjective analysis together with the aircraft motion models.

At first (Fig. 1a), the pilot as a subject Σ must identify and understand the problem (situation) S_i, then from the set of accessible or possible devices, methods and factors, S_p must choose the disposable resources R^{disp}, available for possible solution of the identified problem, and finally must decide and apply the required resources R^{req}. As it has been mentioned, the pilot utilizes the passive and active resources (Kasyanov, 2007). The active resources are defined by pilot's decision which and how will the passive resources be used

$$R_a^{req} = f(R_p^{req}) \tag{2.1}$$

Often, instead of function (2.1) between the resources, the velocity of transferring the passive resources into the active ones is used

$$v_a^{req} = f_v(v_a^{req})v_a^{req} \tag{2.2}$$

where

$$v_a^{req} = \frac{dR_a^{req}}{dt} \qquad\qquad v_p^{req} = \frac{dR_p^{req}}{dt} \tag{2.3}$$

and in simple cases

$$f_v = \frac{\partial R_a^{req}}{\partial R_p^{req}} \tag{2.4}$$

It is clear that the operational processes can be given by a series of situations: pilot identifies the situation S_i makes a decision and applies the control R_a^{req}, which transits the aircraft into the next situation S_j randomly (the situation S_j is one of the sets of possible situations). This is a repeating process (see Fig. 1b), in which the transition from one situation into another depends on (i) the evaluation (identification) of the given situation, (ii) available resources, (iii) appropriate decision of the pilot, (iv) correct application of the active resources, (v) limitation of the resources and (vi) the affecting disturbances.

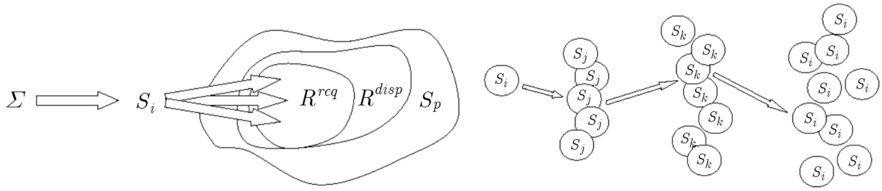

Fig. 1. Aircraft operation as the active endogenous system; (a) pilot decision – action process, (b) siyuation chain process

The situation chain process can be given by the following mathematical representation (Berger, 1985; Kasyanov, 2007)

$$c(t): \quad \Big(x_0, t_0, \omega(t_f \in [t_0, t_0+\tau]); R^{disp}(t_0), R^{req}(t_0), \ldots\Big) \tag{2.5}$$

or in a more general approach

$$c(t): \quad \Big(P: \sigma_0(t_0) \to \sigma_j(t_f \in [t_0, t_0+\tau]) \in S_f \subset S_a, R^{disp}(t_0), R^{req}(t_0), \ldots\Big) \tag{2.6}$$

where x_0 is the vector of parameters at the initial state (actually starting) state at t_0 time; σ is the state of the system at the given time; τ is the available time that is enough for transition of the state vector into a set of ω not later than $[t_0, t_0+\tau]$; P are the problems how to transit the system from the initial state into another one of the possible state $S_f \subset S_a$ not later than τ.

During a flight, one flight situation is followed by another. So the flight as the aircraft operational process in a continuous state space and time can be approximated by a stochastic process of flight situations in a continuously time and discrete state space (Rohacs and Németh, 1997; Rohacs and Simon, 1989). This means that the flight is a typical situation chain process.

3. Aircraft landing

As an example, the aircraft landing process as motion of aircraft in the vertical plane is investigated. There is no side wind, no lateral motion. With the use of the trajectory reference system (when the x axis shows the wind direction, the axis z is perpendicular to x in the local vertical plane, and the centre of system is put into the centre of gravity of the aircraft) motion of the aircraft can be defined by motion of its centre of gravity and rotation around the centre of gravity (Kasyanov, 2004)

$$m\frac{dV}{dt} = T(V,z,t) - W\sin\theta - D(V,z,t) \qquad mV\frac{d\theta}{dt} = L(V,z,t) - W\cos\theta$$
$$I_y\frac{dq}{dt} = M(\alpha,q,V,z,t) \tag{3.1}$$

The thrust T, lift L, drag D and aerodynamic moment M are clearly depending on time because of the applied control. The altitude z also has influence on them through the ground effect. The mass m and, of course, then the weight W of the aircraft are assumed as constant. The aircraft velocity V and pitch rate q describe the aircraft motion, while the flight path angle (or descent angle) θ depicts the aircraft position. The angle of attack α is a difference between the pitch attitude ϑ and the flight path angle

$$\alpha = \vartheta - \theta \tag{3.2}$$

The pitch rate and the changes in altitude can be determined very simply

$$q = \frac{d\vartheta}{dt} \qquad \frac{dH}{dt} = V\sin\theta \tag{3.3}$$

According to flight operational manuals and airworthiness requirements, there are limitations on the velocity, descent angle and decision altitude

$$V \in [V^*_{min}, V^*_{max}] \qquad \theta \in [\theta^*_{min}, \theta^*_{max}] \qquad H \geqslant H^*_{D\,min} \tag{3.4}$$

A simple assumption can be applied: during the approach, pilots should decide whether to land or to make a go-around. For this decision they need time, which is the sum of (i) the time to understand and evaluate the given situation σ_k, (ii) the time for decision making and (iii) the time to react (covering also the reaction time of the aircraft for the applied decision) (Kasyanov, 2007)

$$t^{req} = t^{req}_{ue}(\sigma_k) + t^{req}_{dec}(S_a) + t^{req}_{react}(\sigma_k, S_a) \tag{3.5}$$

Here σ_k defines all possible situations (e.g. σ_1 might be the situation of landing at the first approach without any problems, σ_2 could be related to the situation when the undercarriage system could not be opened, σ_3 might stand for a landing on the fuselage, σ_5 for go-around, or σ_5 for a successful landing after the second approach).

S_a is the chosen solution from the set of possible solutions. It is clear that all solutions have a limiting drawback, such as extra cost or extra fuel.

4. Subjective factor in aircraft landing control

The subjective factor of pilots can be assumed by the ratio of the required and disposable resources (Kasyanov, 2007)

$$\overline{r}_k = \frac{R^{req}(\sigma_k)}{R^{disp}(\sigma_k)} = \frac{t^{req}(\sigma_k)}{t^{disp}(\sigma_k)} \tag{4.1}$$

By making use of this factor, an endogenous index can be defined as

$$\varepsilon_k(\sigma_k) = \frac{\overline{r}_k}{1-\overline{r}_k} = \frac{\tau^{req}(\sigma_k)}{\tau^{disp}(\sigma_k) - \tau^{req}(\sigma_k)} \tag{4.2}$$

Naturally, we can assume that the pilots are able to evaluate the consequences of their decisions, namely they can evaluate the risk of the applied solutions. Such an evaluation can be defined as the subjective probability of situations $P(\sigma_k)$, the canonic distribution of which as a distribution of the canonic assemble of preferences is assumed to hold the following form

$$p(\sigma_k) = \frac{P^{-a}(\sigma_k)\mathrm{e}^{-b\varepsilon_k(\sigma_k)}}{\sum_{q=1}^{2} P^{-a}(\sigma_q)\mathrm{e}^{-b\varepsilon_k(\sigma_q)}} \tag{4.3}$$

where $p(\sigma_k)$ describes the distribution of the best alternatives from a negative point of view.

The time-depending coefficients α and β should be chosen in a way to model the endogenous dynamics, i.e. the subjective psycho-physiological personalities of pilots. The qualities of the pilots depend on different factors including "periodical" unfixity that increases while getting closer to the decision time (altitude) of go-around.

Formula (4.3) has special features when

$$\overline{t}_k = \frac{t^{req}(\sigma_k)}{t^{disp}(\sigma_k)} \to 0$$

the preferences are determined by the subjective probability, $P(\sigma_k)$ only, and in the case $\overline{t}_k \to 1$, the preferences turn to zero. Expression (4.3) comes from solution of the functional

$$\begin{aligned} \varPhi_p = -\sum_{k=1}^{N} p(\sigma_k)\ln p(\sigma_k) - \beta\sum_{k=1}^{N} p(\sigma_k)\varepsilon_k(\sigma_k) + \\ -\alpha\sum_{k=1}^{N} p(\sigma_k)\ln P(\sigma_k) + \gamma\sum_{k=1}^{N} p(\sigma_k) \end{aligned} \tag{4.4}$$

A special feature of this functional is that the structure of the efficiency function includes the logarithm of the subjective probability

$$\eta_p = -\sum_{k=1}^{N}[\alpha \ln P(\sigma_k) + \beta\varepsilon(\sigma_k)]p(\sigma_k) \tag{4.5}$$

The complexity of decision making could be characterised by uncertainties and the hereupon unfixedness of the pilots that are increasing while getting closer to the minimum decision altitude $H^*_{D\,min}$. To make decisions, the pilots must overcome their "entropic barrier" H_p. The rate of unfixity can be defined with a norm of entropy

$$\overline{H}_p = \frac{H_p}{\ln N} \tag{4.6}$$

Figure 2 shows a simplified decision making situation at an approach about the go-around (Kasyanov, 2004, 2007). At (t_0, x_0), $S_a : (\sigma_1, \sigma_2)$ indicates the set of alternative situations with the distribution of preferences $p(\sigma_1)$ and $p(\sigma_2)$ (where σ_1 indicates the landing and σ_2 defines the go-around).

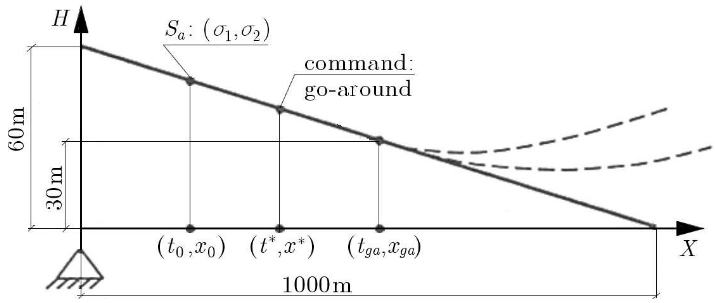

Fig. 2. Final phase of aircraft approach

The preferences are oscillating because of the exogenous fluctuation (while the decision altitude is getting closer) and the endogenous processes (depending on the uncertainties in the situation awareness and unfixedness of the pilots). If the pilots are able to overcome their entropy barrier up to the command for go-around (reaching the decision minimum altitude) (t^*, x^*), then they could make a decision. Due to this decision, the set of situations S_a , can be given by the following

$$\begin{aligned}
&\Big(S_a : (\sigma_2); p(\sigma_2); T < t^*; p(\sigma_1) + p(\sigma_2) = 1\Big) \Rightarrow \\
&\quad \Rightarrow \Big(S_{a1} : (\sigma_2); p(\sigma_2) = 1; p(\sigma_1) = 0\Big) \vee \Big(S_{a2} : (\sigma_1); p(\sigma_1) = 1; p(\sigma_2) = 0\Big) \\
&\quad t \geqslant t^*
\end{aligned} \tag{4.7}$$

If they are not able to overcome their entropy barrier before reaching (t^*, x^*), the flight situation would become more complex, and therefore the possibility to perform a go-around (case σ_2) might be even out of the possible set of situations.

5. Pilot endogenous dynamics

Professor Kasyanov introduced a special chaotic model (Kasyanov, 2007) based on the modified Lorenz attractor (Strogatz and Steven, 1994) for the modelling of the endogenous dynamics of the described process.

$$\frac{dX}{dt} = aY - bZ - hX^2 + f(t) \qquad \frac{dY}{dt} = -Y - XZ + cX - mY^2$$
$$\frac{dZ}{dt} = XY - dZ - nZ^2 \tag{5.1}$$

where a, b, c, d, h, m, n are constants while f takes into account the disturbance. In the case of $h = m = n = 0$ and $f(t) = 0$, the model turns into the classic form of Lorenz attractor.

In this model, the coordinates of attractors can be defined as X – the inner endogenous parameter, $Y = \beta$ and $Z = \alpha$.

Principally, there are not strong arguments (Kasyanov, 2007) explaining the use of Lorenz attractor for the modelling of the human way of decision making (human thinking), but the results of its application are close to real situations that need further investigation (Dartnell [2]).

Professor Kasyanov has investigated various types of the model, and evaluated model parameters (Kasyanov, 2007). For a medium sized aircraft (weight $W = 10^6$ N; wing area $S = 100\,\mathrm{m}^2$; wing aspect ratio $A = 7$; thrust $T = 9.4 \cdot 10^4$ N; and velocity $V = 70\,\mathrm{m/s}$) with commercial pilots, he recommended to use the following values: $a = 8$, $b = 8$, $c = 20$, $d = 43$, $f = 0.8$, $h = 0.065$, $m = 0.065$, $n = 0.065$.

Subjective probabilities might be chosen as $P(\sigma_1) = 0.53$, $P(\sigma_2) = 0.6$ and $\varepsilon_1 = 5.5 + 0.01t$, $\varepsilon_2 = 5.4 + 0.04t$ which take into account the decreasing difference in the required and available time for a decision.

The results of using the described model are shown in Fig. 3.

In this example, the figures demonstrate that pilots are unfixed for a period about 10 s, during which their preferences (A, B) are changing by sudden oscillations, and the entropy H at the beginning is rather high. If the limit

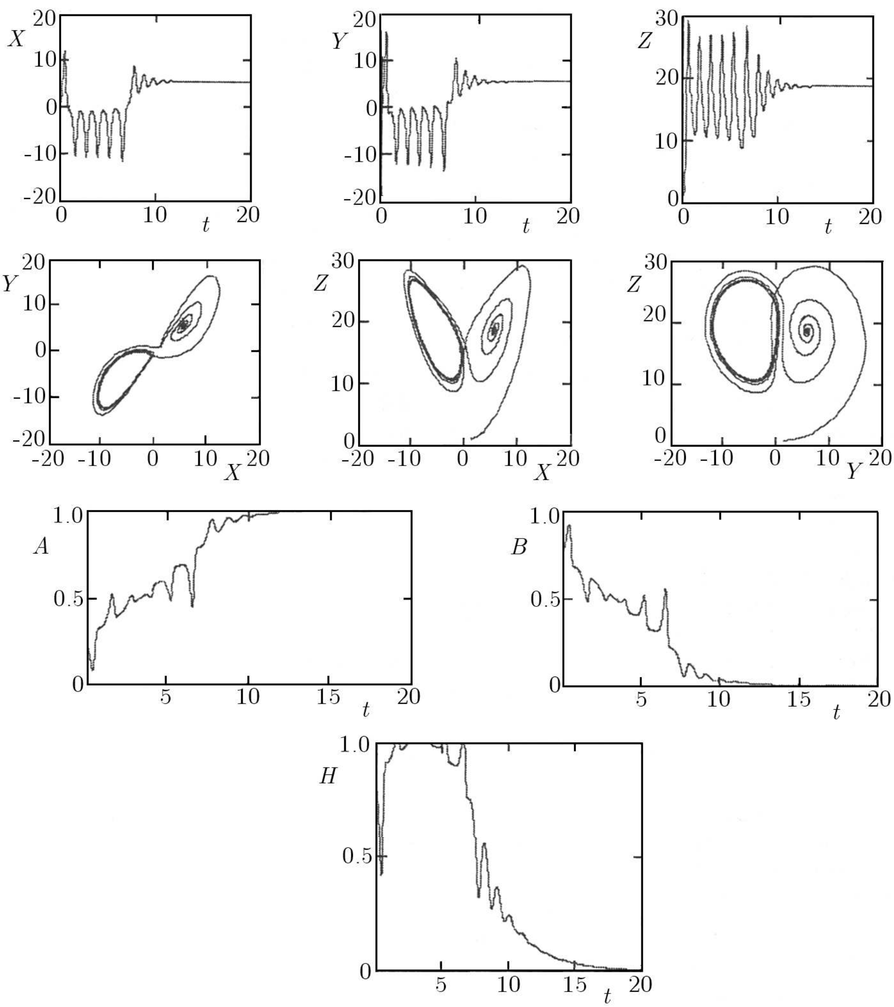

Fig. 3. Results of using the developed model for a medium sized aircraft

for the entropy would be 0.7 (that is still quite high) then decisions could be made in about 10 s. This means that the pilots will not be able to do that with accordance to Fig. 2.

If the parameters are set to $a = 10$, $b = 10$, $c = 35$, $d = 1$, $f = 0$, $h = 0.065$, $m = 0.065$, $n = 0.065$ and $P(\sigma_1) = 0.53$, $P(\sigma_2) = 0.6$, then (see Fig. 4) the entropy would quickly decrease and the decision could be made in about 3 s. According to the ICAO requirements, the time $t = t_{ga} - t^*$ (see Fig. 2) should not be less than 3.16 s. Therefore, if the situation presented in Fig. 2 appears before (t_0, x_0), then the right decision could be made.

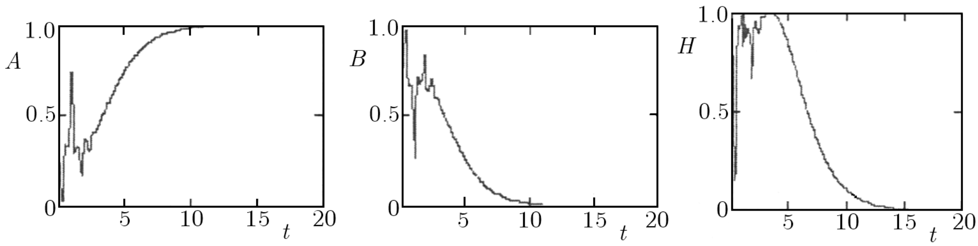

Fig. 4. Results when the parameters are chosen for well-skilled pilots

From the results of the developed model, (after application and analysis of the described method by Hungarian national projects SafeFly: development of the innovative safety technologies for a 4-seats composite aircraft and EU FP7 project PPlane: Personal Plane) we can conclude that in the case of a problem at the final approach, common airliner pilots require about three times more time to decide than the well-skilled crew.

The developed model can also be applied for small aircraft, controlled by less-skilled pilots. From Fig. 2, the descent velocity of a small aircraft is calculated to be about 100 km/h for airliner common pilots, and 75 km/h for those less-skilled.

In this case, the airport can be designed with a landing distance of less than 600 m (runway about 250-300 m) and a protected zone under the approach (to overfly the altitude of 100 m) of about 1500 m. These characteristics enable to place small airports close/closer to the city center.

These are the preliminary results and draft description. We are going to make some other calculations and we will make more accurate conclusions.

6. Conclusions

This paper introduced a subjective analysis methodology into investigation of the real flight situation, flight safety. The subject – the pilot operator generates his decision on the basis of his subjective situation analysis depending on the available information and his psycho-physiological condition. The subjective factor is the time available for the decision of the given task.

The paper concerns the aircraft landing. The subjective decision making of pilots was modelled by the modified Lorenz attractor that needs further investigation and explaination, however the practice shows good applicability of the developed model. The model is well usable for the investigation of differences between skills of well- and less-trained pilots. The model helped to define requirements for the aircraft and airport characteristics for the personal air transportation system.

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Subiektywne decyzje pilota w aktywnym układzie sterowania samolotu

Streszczenie

Konwencjonalne układy sterowania samolotem, włączając w to rolę pilotów, nazywane są aktywnymi układami endogennymi z racji znaczenia bieżącej oceny sytuacji i reakcji pilotów wynikających z ich świadomości i cech układu nerwowego. Piloci muszą podejmować decyzje w warunkach braku pełnej informacji o parametrach lotu, posiadając przy tym swoiste cechy reaktywnych zachowań i własny zestaw wytrenowanych nawyków. W ten sposób analiza właściwości monitorowania samolotu staje się badaniem układu zawierającego zmienne subiektywne. W pracy zbadano problem podejścia do lądowania. Za czynnik subiektywny wzięto stosunek czasu wymaganego do faktycznie posiadanego przed podjęciem decyzji o możliwej rezygnacji z lądowania.

Decyzja ta zależy od ilości zgromadzonych informacji w danej chwili oraz kondycji psycho-fizjologicznej pilotów i została opisana za pomocą hipotez statystycznych. Do zamodelowania dynamiki rozważanego endogennego układu sterowania samolotem użyto zmodyfikowanego atraktora Lorentza.

Manuscript received June 21, 2010; accepted for print July 30, 2010