THE USE OF MODEL FOLLOWING CONTROL FOR QUALITY IMPROVEMENT IN CONTROLLING THE AIRCRAFT LATERAL MOTION DURING APPROACH

Grzegorz Kopecki, Andrzej Tomczyk,

Rzeszow University of Technology, W. Pola 2, 35-959, Rzeszow, Poland

Abstract: *One of the modern control methods is the usage of model following control. This method was applied to control the aircraft lateral motion during approach with the use of ILS-LOC. The results were compared with the classical solution (PID controller) and the solution with PID and supervisory fuzzy controllers. Mathematical description of the problem was made too.*

Key words: *Aircraft Control Systems, Model Following Control, Approach.*

1. INTRODUCTION

The approach is a very complicated phase of flight. During this operation the pilot is under stress caused by the amount of information as well as psycho-physical factors. This fact has been proved by many disasters. Disasters are much more frequent during the approach and landing then during other phases of flight. Therefore, automatic control of approach is expected to assure flight safety [1].

One of the most popular systems which enables automatic landing is Instrument Landing System (ILS) [2]. This paper presents the control of lateral motion during approach. It is realized through the control of ε_s angle, which is the angle between the approach axis and a line connecting the localizer (LOC) and aircraft's center of gravity (Fig. 1). General control scheme is presented in Fig. 2.

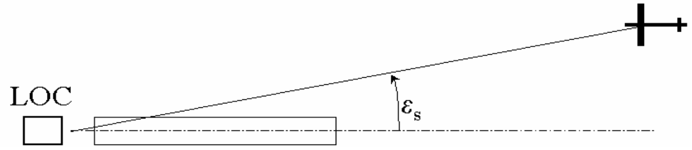

Fig. 1. The ε_s angle definition

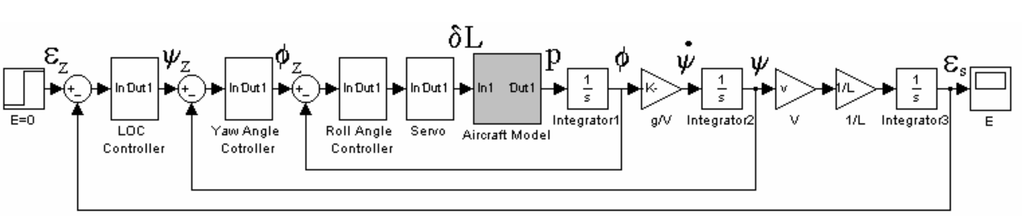

Fig. 2. General ILS-LOC Approach Control Scheme, ε_z – expected ε_s; ψ_z-expected heading; ψ-heading; δL – aileron displacement; $\dot{\psi} = \frac{d\psi}{dt}$;

For synthesis of the approach control system, the methodology of the control quality assessment was adopted. The following factors were taken into consideration:

- ✓ assessment of the overshoot. It is essential to strive at minimum overshoot.
- ✓ assessment of oscillations. They can be accepted only in certain cases. Dimensionless damping ratio should be less then 0.7.
- ✓ elimination or minimization of the trajectory flex point, which can appear as a result of a change in the control laws.

All factors are based on expert knowledge. This knowledge is the result of pilots' practice and simulation experiments [3].

2. CHOSEN POSSIBILITIES OF AIRCRAFT LATERAL MOTION CONTROLING DURING APPROACH

Autopilots with constant coefficients.

The simplest autopilots for the control of lateral motion during approach are those with constant P (proportional), PD (Proportional-Differential) or PID (Proportional-Integrational-Differential) controller coefficients. These controllers are designed for only one distance between the aircraft and the localizer. With a longer distance, the regulation is slower. If the distance is shorter, oscillations can appear. Therefore, the pilot has to switch the autopilot off.

Autopilots with coefficients depending on the distance between the aircraft and the localizer.

To improve the quality of control, P, PD, or PID controllers with coefficients dependent on the distance between the aircraft and localizer can be used. Consequently, the quality of control remains the same at every distance between the aircraft and the localizer.

PD and PID controllers with supervisory fuzzy controllers

In the case of P or PD controllers the approach control is possible without the overshoot. However, with wind disturbances the control error cannot be eliminated and therefore, PID controllers are used. On the other hand, the integration in PID controllers results in the overshoot.

In order to minimize this overshoot, controllers with a control law change depending on the distance between the aircraft and the axis of approach can be used. If the distance between the aircraft and the axis of approach is long, the PD controller is used. If the aircraft is close to the axis of approach, then PD is replaced by PID. The control law is changed by supervisory fuzzy controllers [3]. However, in this case the trajectory flex point can appear.

Model following control (MFC)

One of the major problems in flight control is the wind. Although this disturbance cannot be measured, indirect information on wind can be obtained through the comparison of the aircraft trajectory without wind with a real trajectory. The trajectory can be calculated by a model consisting of an aircraft model connected with a control system. The difference between the model and the real aircraft trajectory is the information used for the wind compensation.

In the model following control the plant follows the trajectory generated by the model [4].
Wind is compensated by a course change. If a signal proportional to the integrated difference between the plant and model trajectories to the course regulator input is added, the course will change. The idea is illustrated in Fig. 3.

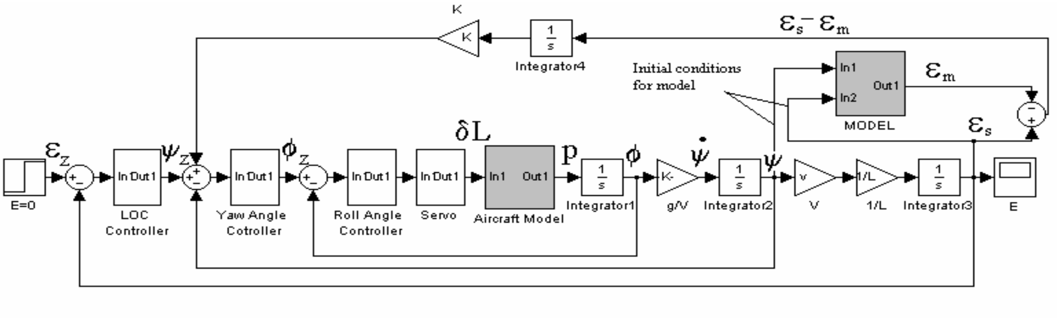

Fig. 3. The usage of model following control

3. METHODS USED FOR SYNTHESIS OF MFC SYSTEM

The first step in MFC system design is creating a classical system as shown in Fig. 2. The LOC controller is created as PD with coefficients depending on the distance between the aircraft and the localizer. This part of system synthesis does not cause problems, e.g. the root locus method can be used [5]. The system presented in Fig. 2 can also be used as a model (see fig. 3). However, a question arises how to find the coefficient K shown in fig. 3, as well as other necessary feedback coefficients from the remaining states of the system. Two possible solutions are described below.

Linear Quadratic Regulator

For calculations, it can be assumed, that the model-trajectory generator (the block shown in fig. 3 as a *MODEL*) is described by two inertial elements. For the aircraft description the approximation of an aperiodic bank motion was used. As a LOC controller a proportional regulator was used.

For calculations, the system scheme has to be transformed. All feedbacks must be added in one point (system input). However, in this case *1/P* element appears. The input shown in Fig. 3 as $\varepsilon_Z=0$ equals zero, thus it can be disregarded. The whole system, except for some feedbacks, has to be described in a state-space. The new state-space area is shown in Fig. 4. Feedbacks from all states of the system are calculated by the LQR method. Feedbacks calculated by the linear quadratic regulator (LQR) are shown in the form of dashed lines in Fig. 4, or disregarded not to complicate the drawing.

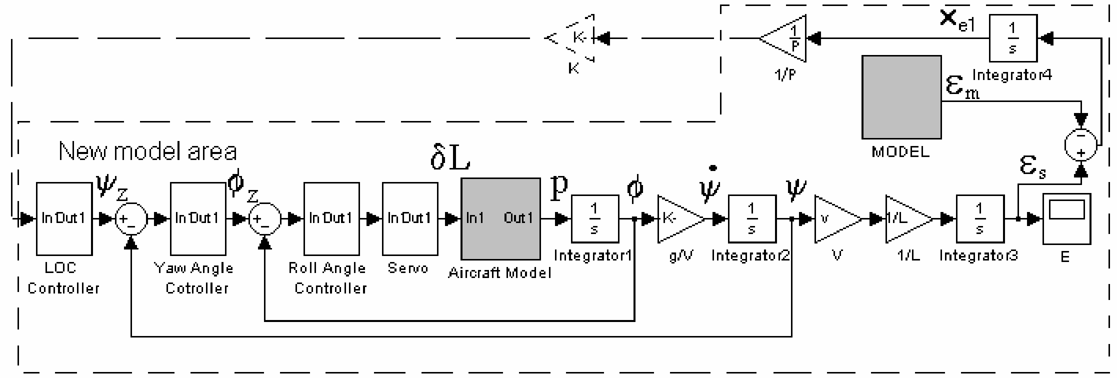

Fig. 4.Scheme changes and new state-space area.

The new model is described in the following state-space:

$$\dot{\boldsymbol{x}} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{B}\boldsymbol{u} \qquad (1)$$

$$\boldsymbol{y} = \boldsymbol{C}\boldsymbol{x} \qquad (2)$$

$$\boldsymbol{x} = [\varepsilon_{loc} \quad \psi \quad \phi \quad p/L'_{\delta L} \quad x_5 \quad \varepsilon_{mod} \quad \underline{x}_2 \quad \int(\varepsilon_s - \varepsilon_m)dt \quad \varepsilon_s\text{-}\varepsilon_m]^T \qquad (3)$$

$$\boldsymbol{C}=\boldsymbol{I}. \qquad (4)$$

where $\boldsymbol{x} = \boldsymbol{y}$ is a vector of all states in the area shown in Fig. 4 as the *New model area*, $\boldsymbol{u}$ is the LOC controller input vector, x_5 is the servo state and $\underline{x}_2$ is the model state.

It is assumed that the measured output vector $\boldsymbol{y(t)}$ is available for feedback purposes. The control law formula is:

$$\boldsymbol{u} = -\boldsymbol{K}\boldsymbol{y} \qquad (5)$$

where $\boldsymbol{K}$ is a vector of constant feedback coefficients to be determined by the design procedure. Since the regulator problem involves only stabilizing the aircraft and inducing good closed-loop time responses, u(t) was taken as a pure feedback with no auxiliary input [4].

To calculate vector K, quadratic performance index was created:

$$J = \frac{1}{2}\int_0^\infty (\boldsymbol{x}^T \boldsymbol{Q}\boldsymbol{x} + \boldsymbol{u}^T \boldsymbol{R}\boldsymbol{u})dt \qquad (6)$$

where $\boldsymbol{Q}$ is a symmetric positive semi-definite and $\boldsymbol{R}$ is a positive definite weighting matrix. These matrices were chosen in this way, to minimize the state described in Fig. 4 as x_{e1}.

Vector $\boldsymbol{K}$ was calculated with *Matlab*.

The results of system simulations are shown in Fig 5.

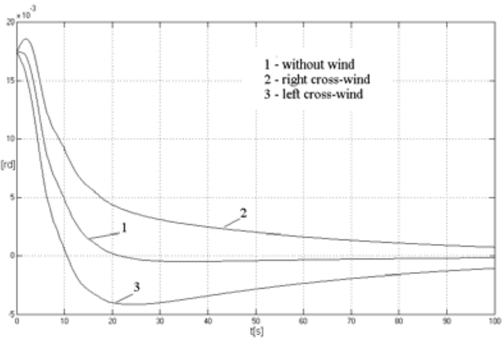

Fig. 5. Simulation Results

The results are not as good as expected, and due to numerous sensors or state observers, it is also difficult to design the system in practice. Therefore, another solution for the control system synthesis was applied.

Modified Classical Solution

This solution is based on the classical theory of control. The model is treated as an input source. The system can be presented in transfer function and after transformation it can be drawn as in Fig. 6.

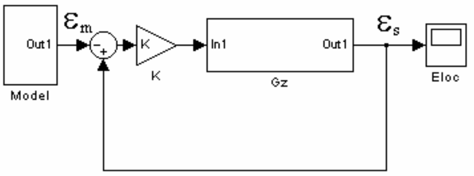

Fig. 6. Transformed system; K – coefficient shown in Fig. 3.

Now the problem is much easier and classical methods, e.g. the root locus method can be used. The results, compared with other solutions (PID, PD with constant regulator coefficients and PID with supervisory fuzzy controllers[3]), are shown in Fig. 7.

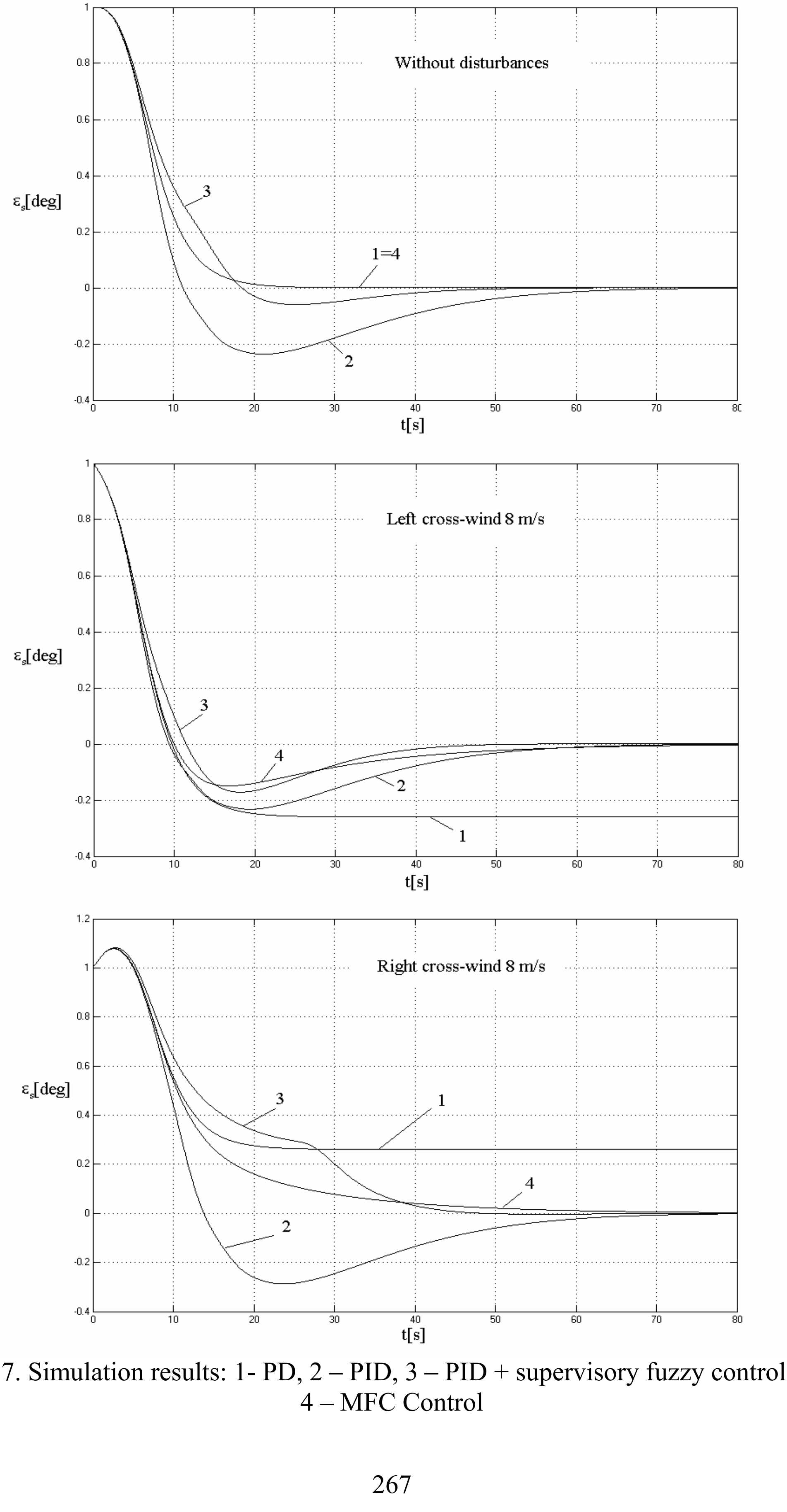

Fig. 7. Simulation results: 1- PD, 2 – PID, 3 – PID + supervisory fuzzy controllers,
4 – MFC Control

As a *MODEL*, the system from Fig. 3 with PD LOC controller was used. The aircraft model in the *MODEL* block was identical with the *Aircraft model*. It did not complicate the calculations because the *MODEL* was treated as an input. The aircraft model was linear. Simulations were made with the limitation imposed on ϕ_z, ψ_z and the angular velocity of the servo engine (in *Matlab-Simulink saturation* block was used).

4. SUMMARY

The system synthesis and first simulations have been presented. The first idea of system synthesis (LQR) was not satisfactory enough from the practical point of view. Moreover, because of many additional sensors (feedbacks from all states), the system could be expensive. The second solution (Modified classical solution) turns out to be more satisfying. Only one additional feedback occurred, and in practice the usage of additional sensors is unnecessary, because ε_S is measured also in classical solution. These results of simulations are highly promising.

The presented problems and solutions result from the initial research which will be continued. Simulations with differences between aircraft model used in *MODEL* block and in *AIRCRAFT MODEL* will be carried out. Moreover, nonlinear aircraft model will be applied. Further results will be shown in next works.

5. REFERENCES

[1] S. Bociek, J.Gruszecki *Układy sterowania automatycznego samolotem,* Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów 1999

[2] Z. Polak, A. Rypulak *Awionika, przyrządy i systemy pokładowe, WSOSP,* Dęblin 2002

[3] A. Tomczyk, G. Kopecki *Wykorzystanie systemów eksperckich do syntezy układów sterowania samolotem podczas podejścia do lądowania*, ML-X 2002 (in print)

[4] B. L. Stevens, F. L. Levis *Aircraft Control and Simulation*, John Willey & Sons, Inc. New York / Chichester / Brisbane / Toronto / Singapore 1992

[5] K. Wajs *Linie pierwiastkowe w automatyce. Problemy i zastosowania.* Wydawnictwa Naukowo-Techniczne, Warszawa 1973