LATERAL MOVEMENT CONTROL ALGORITHMS FOR GENERAL AVIATION PLANES

B. Dolega, T. Rogalski
Rzeszow University of Technology, Rzeszow, Poland; E-mail: dolbog@prz.edu.pl orakl@prz.edu.pl
Received 01-03-2007, accepted 10-09-2007

Bogusław DOŁĘGA, PhD. Eng.
Education: Rzeszow University of Technology.
Affiliations and functions: Rzeszow University of Technology, assistant; 1994 — PhD degree from the Department of Mechanical Engineering of Rzeszow University of Technology; 1995 to present — Assistant to Professor on Avionics and Control Systems Department at the University.
Research interests: Diagnostic aircraft navigation and control systems, with a focus on the development of the control theory for online fault detection and localization methods.
Experience: Co-organizer of Avionics Conferences.
Publications: Over 40 scientific articles.
Present position: Assistant to Professor on Avionics and Control Systems Department at the University.

Tomasz ROGALSKI, PhD
Date and place of birth: 1972 in Tarnow, Poland.
Education: 1996 - Reshow University of Technology. 2004 - Ph.D. degree.
Affiliations and functions: 1996 – Present - Aviation Department of Reshow University of Technology.
Research interests: Pilot friendly control system for small transportation plane.
Publications: About 30 articles.

Abstract. Light general aviation airplanes become more affordable means of transport for the still raising group of people. This fact brings few consequences, of course. One of them is a set of problems appearing when inexperienced pilots start using such planes. Their habits and reactions to external factors are different to behaviors of professional pilots. So it seems to be purposeful to create the control system adequate to expectations of this group of pilots.
When we analyze the set of actions pilots realize during the standard transportation flight between two airfields, we can notice that the most part of the flight pilots realize mainly two following elements: altitude stabilization and course stabilization. The paper presents selected control algorithms the flight control system uses to modify handling characteristics of the plane. The presented control laws go away from a classical configuration of airplane control devices (stick, control wheel and pedals) to the configuration with the sidestick or centrally mounted ministicks. Such solution creates a situation that the ruder is moved automatically by the control system when necessary or the pilot moves it using the revolving handle of the stick.
Presented in the paper algorithms modify a functionality of control devices in the lateral motion mode of the plane in order to the classical configuration. At classical configuration the stick displacement results in roll rate, which is proportional to it. The proposed solution assumes that the stick displacement results in the proportional heading rate and a bank angle is only a succession of it.
A few tests of described algorithms will be performed using both the specialized laboratory stand and the experimental aircraft equipped with control system SPS-1.

Key words: flight control systems, Fly-By-Wire, general aviation.

Introduction

The aviation industry shows more and more interest in General Aviation Aircraft (GAA) as a mean of transport for ordinary people. The technological progress has caused that small planes became more affordable for a wider group of people. Operational conditions GAA operates in, have been also significantly changed for last years.

Everything what was pointed earlier causes very dynamical growth of General Aviation Traffic (GAT). People who pilot light planes are more often not professional pilots but only use such planes like "sky cars" [3].

The situation presented above has forced aviation industry and scientific aviation centers to take actions going towards increasing the flight safety by increasing pilot's comfort and simplifying the plane control process [6, 7].

The real effect of such situation is a significant number of research projects have been launched in Europe and USA. Some of them like Small Aircraft Transportation System (SATS), Advanced General Aviation Transport Experiments (AGATE) or European Affordable Digital Flight Control System (ADFCS) have budgets reaching many millions dollars.

The paper presents selected results of author's investigations under control systems for GAA. There are few conceptions and suggestions how to modify plane's handling qualities to make flying more comfortable and to reduce pilot's workload during most time-eating flight phases included in this paper.

1. The general assumptions

When the flight of GAA is analyzed it can be noticed that pilots the biggest part of time spend stabilizing course and altitude. More over in pilot's opinions those flight's elements are the most boring and wearisome. So, taking into consideration new tendencies appearing on the general aviation field, it seems to be necessary to prepare the control system which could aid pilots at foregoing flight phases and makes the flight less tiring.

The solution when the fly-by-wire control system is used to control the GAA brings possibilities to modify plane's handling qualities (Fig 1) [1].

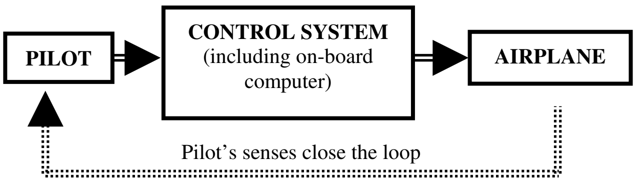

Fig 1. The schematic of the manual computer-aided control system

The computer located in control system's structure can modify signals generated by pilot before they are sent to actuators. Such system makes possible the implementation of control algorithms modifying airplane's handling characteristics. And the plane characterized by those new features will become both more pleasant and pilot-friendly.

2. The classical control

The classical control system mounted at GAA gives the pilot two elements to control the plane in its lateral mode of motion [1, 2, 5]. The stick is used directly to generate the angular rate around the X-axis proportional to its displacement (Fig 2). It is indirectly used to control the bank angle. The second instrument is pedals moving the ruder's surface. The ruder generates the rotation of the plane around the Z-axis (Fig 2).

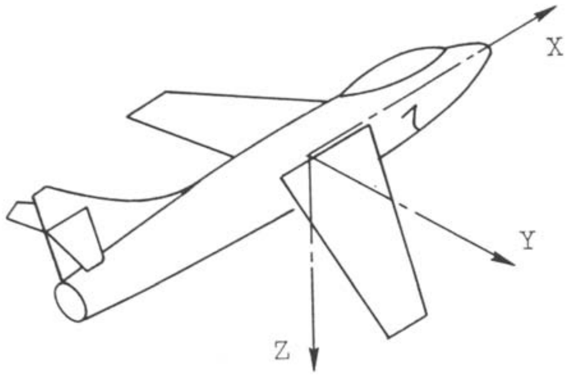

Fig 2. The airplane axis system with its origin located in plane's center of gravity

It must be emphasized that the classical control doesn't mean the mechanical control system. As the classical control author identifies any control system working under that same rules like the mechanical control system operates (plane is controlled by elevator, aileron and ruder, there is proportional dependency between position of control devices and control surfaces). It means that also the fly-by-wire control system can be identified as the classical control if foregoing assumption is met.

The pilot uses ailerons and the ruder to stabilize the demanded heading in two ways. Small course deviations (maximally up to about 3 degrees) pilot reduces using only the ruder. Unfortunately more significant course modifications force the pilot to use the stick and pedals in conjunction. The lateral displacement of the stick generates the roll rate and pedals are used to reduce the slideslip. Even if an assumption that plane's characteristics enable to realize the semi-regular turn using only the stick is met, the process of course stabilization is not quite natural for human.

It must be said that human's actions are the most successful when he works with the time-integral plant (Fig 3), at this point.

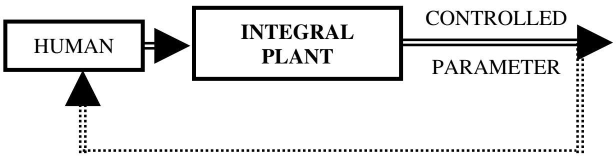

Fig 3. The human working with the time integral plant

In general the system where pilot using the stick or other control device moves ailerons and in this way controls the plane at the heading stabilization process is the second order time integral system with the first order inertial block (Fig 4) [2, 5]. The first order inertial block defines plane's response to aileron input in the roll rate channel [2, 5]. The transfer function for system presented in figure 4 from stick's displacement to the heading has the following form (1).

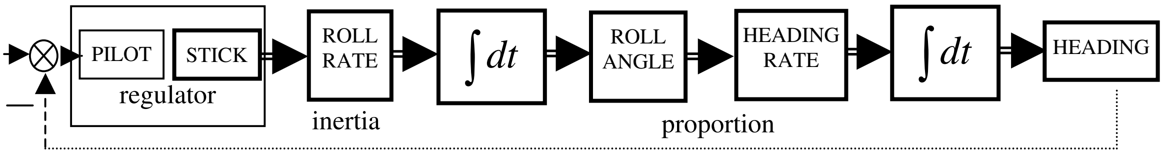

Fig 4. Pilot-aircraft system in heading channel

$$G_{X_s}^{\Psi}(s) = \frac{k}{s^2(Ts+1)} \quad , \tag{1}$$

where s – laplace operator, T, k – parameters.

Figure 5 presents a sample bode diagram for the system defined by the transfer function (1)

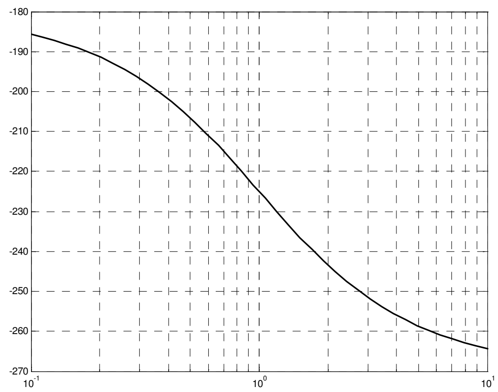

Fig 5. Bode diagram for system pilot-airplane in the heading channel in the case of the classical control

The classical kind of control is characterized by over 180 [deg] phase lag even at small frequencies rising up to 270 [deg] between the input signal (stick displacement) and the output signal (heading) for larger ones. Such type of objects requires from every person operating with it big knowledge about the plant and some kind of skill at controlling it. The pilot has to work as a strongly derivativing regulator to avoid big overshoots. Fortunately for typical right-designed GAA's parameters of the foregoing motion mode of the plane's lateral movement are in fact relatively slow. So this feature enables the pilot to correctly and effectively control the heading. However overshoots and oscillations appear when less experienced pilots fly the plane.

Presented here features of the classical control had become the reason that attempt of improving aircraft flying characteristics in the heading channel has been taken.

3. The heading-oriented control

Previous chapter discusses the case of the classical control system. The pilot using the stick or other control device can directly control the roll rate and the bank angle. However the appearing heading rate was just only the aftermath of the bank angle. Let's try to reverse a situation in this chapter. Let's imagine the situation when the heading rate is just proportional to stick's displacement (just like the roll rate for the classical control). Then the heading control system became the first order integral system. So it should create much better conditions for the pilot to control the heading then the classical control gives.

Let's modify the system presented in figure 4 to the system plotted in figure 6. The additional inner feedback from the heading rate modifies aircraft flying characteristics towards so called the course-oriented control. Foregoing modifications need an additional controller of the heading rate, of course. It calculates necessary deflections of ailerons to generate the roll rate to reach the roll angle correct for the demanded heading rate, in the best way.

Now the pilot moving the stick generates the heading rate, which is proportional to stick's position, in steady state conditions. The simplest form of the new controller is the proportional block. Then the transfer function from stick's position to the heading has the following form (2):

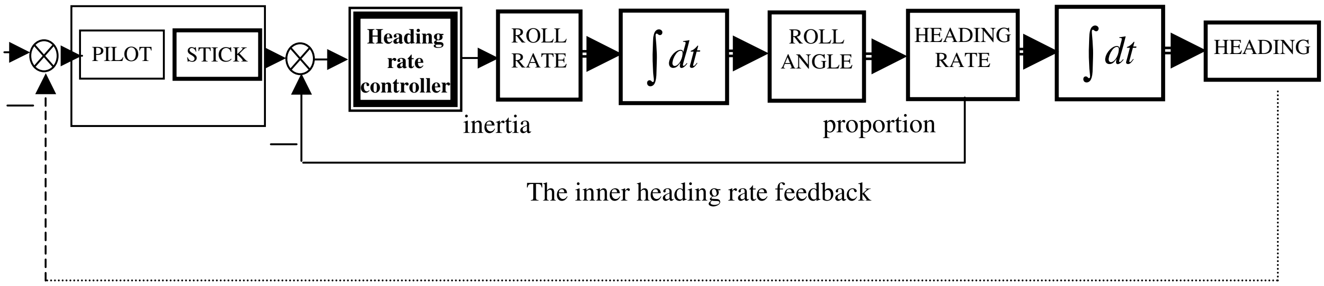

Fig 6. The schematic of the pilot-airplane system in the heading-oriented case of the control

$$G_{X_s}^{\Psi}(s) = \frac{k}{s\left(as^2 + bs + 1\right)}. \tag{2}$$

The proportional-derivational regulator put to the control structure improves the dynamics of the system, much more. And in this case the transfer function has the form (3).

$$G_{X_s}^{\Psi}(s) = \frac{ks + l}{s\left(as^2 + bs + 1\right)} \tag{3}$$

Bode plots for foregoing versions of controls demonstrate that the used heading rate feedback reduced phase lag to little over 90 [deg] for small frequencies up to 180 [deg] for high ones. In the result the pilot can work as a much simpler type of regulator. He is released of necessity of the strong differential action.

Now let's answer the question what are differences the pilot senses between the classical control and control presented in this chapter. Let's compare the heading stabilization process. The pilot doesn't need to work with the significant prediction like in the case of the classical control. It is enough if at the demanded course he retracts the stick to the neutral position. The control system automatically stabilizes the new heading. The pilot doesn't need to do so called "contra deflection" of the stick to put the plane in the horizontal attitude at the new correct heading.

So pilots having less aviation experience can easier and much precisely intercept and stabilize demanded heading because they only inform the system what heading it should keep (removing the control device to its neutral position) and the rest the automatics does.

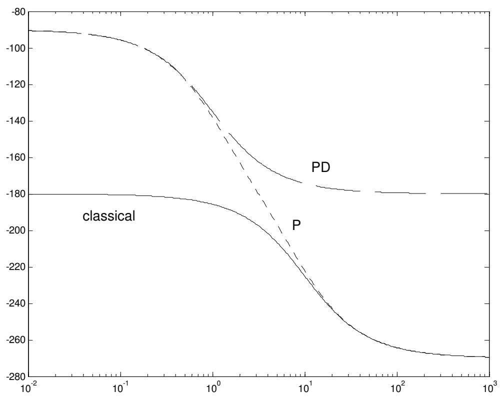

Fig 7. Bode diagrams for systems pilot-airplane in the heading channel for classical plane and for heading oriented control if PD-type or P-type heading rate regulator used

Other flight parameter the pilot can want to control is the bank angle. So in this case significant differences appear. The presented solution doesn't enable to reach each value of the bank angle. Bank angles bigger than one fixed critical value are not reachable. So it is not possible to make full rotation around the X-axis. This critical value follows both the maximum assumed heading rate the pilot can demand and the speed of the flight (4):

$$\overset{\circ}{\Psi} = tg(\varphi)\frac{V}{g}, \tag{4}$$

where:

$\overset{\circ}{\Psi}$ – heading rate [rad/s],
φ – roll angle[rad],
V – speed [m/s],
g – gravity [m/s^2].

Unfortunately this solution implements one unpleasant effect. The main assumption is that heading rate is proportional to stick position so when flight speed varies also maximal value of bank angle is variable. It means that maximal displacement of stick brings always that same value of maximal heading rate but it doesn't produce that same value of the bank angle whet the speed varies.

But GAA are not constructed for acrobatic flights and no one does aviation acrobatics during the typical flight.

However from the second side all bank angles at the range from zero degrees to the mentioned earlier critical value is proportional to stick's position. This is situation quite different than for the classical control. The pilot orienting the plan in the roll channel doesn't need to do double movements with the control device (the first movement generates the roll rate, the second movement retracts the control device to its neutral position and stops the rotation at the demanded bank angle).

The effect of this control is that the roll angle not the roll rate is semi-proportional (in steady state) to the position of the control device.

Another assumption is that autonomously working ruder is controlled to reduce slideslip in the background without pilot's activity.

4. The modified heading-oriented control

The control algorithm from previous chapter assumes that all, even minimal, course deviations are reduced by modifications of the actual bank angle with automatic slideslip angle reduction. Unfortunately this type of the control can sometimes lead to light but very unpleasant undamped oscillations.

The author proposes to use the mixed solution. This assumes that small deviations of course are reduced only by ruder deflections. And course deviation bigger than an absolute value of some critical deviation $\Delta\Psi_c$, are reduced by coordinated turns.

But what does it mean small deviations of the heading and how big is the critical deviation $\Delta\Psi_c$? These values are rather difficult to be calculated by the analytical way. They should be selected dependably on many flight parameters e.g. airspeed, altitude, flight phase, plane's configuration etc. So probably the best way to select them is to make the arbitral selection by an expert on the basis of his knowledge.

The author on the basis of his experiences with control systems for GAA proposes to select the critical heading deviation about 2 degrees.

More over the implementation of that algorithm make possible using the ruder as a yaw damper [1, 2, 5].

5. The leveler mechanism

General aviation aircraft are often used as a mean of transport for medium distances. This fact causes that heading stabilization process is often the most part of the flight. Later in this paper the author proposes a control system, which can aid the pilot to keep the correct heading and can reduce workload of pilots during this process.

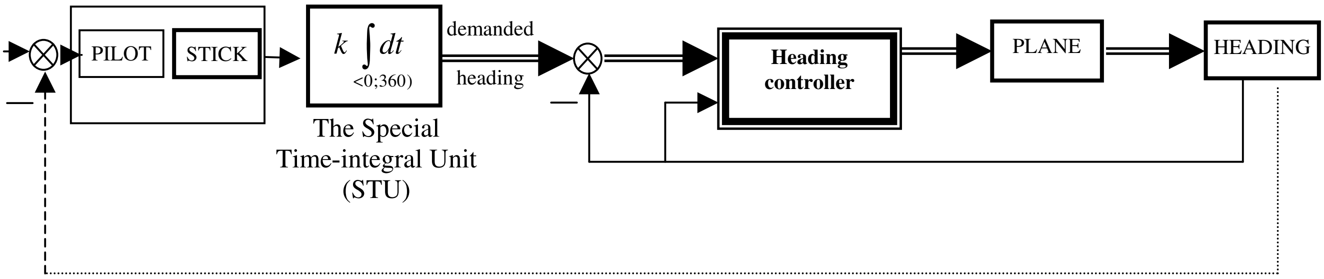

Fig 8. The schematic of the Heading Rate Control Heading Keep (HRCHK) algorithm

Of course it can be said that every autopilot system can stabilize the demanded heading without pilot's interference but presented solution is going to connect features of the classical autopilot and the classical control system.

The main assumptions for presented control are:

- The pilot can control the plane in the lateral motion channel similarly to the classical plan using lateral deflections of the control device to make the turn.
- The control system should sense what heading the pilot intends to stabilize and should to stabilize it in the background.

The additional profit of presented solution is that control system indirectly stabilizes the horizontal attitude of the plane.

The logical schematic of the presented control is put on figure 8. The signal from the control device is understood as a heading rate. It is time integrated giving demanded heading. So in this way the control called Heading Rate Control Heading Keep (HRCHK) is implemented. The special attention should be paid on fact that the demanded heading should vary in the restricted range [0; 360) degrees or using other notation in the range (-180; 180] degrees.

The goal of the automatics is to trace the demanded heading. In fact for the flight's phase when the pilot doesn't make the turn the last set heading is stabilized and the plane attitude is horizontal.

6. Evaluation and tests

Problems presented in this paper are only selected theoretical aspects of aircraft lateral motion controls supporting pilots. They make only the first step to define the main directions of researches on this field.

Control laws presented in this paper will be tested in few ways. The first part of tests is planed to be performed in laboratory conditions with the specialized laboratory stand. This stand is used to test interaction between control laws and pilots. It was presented in position [4], in details. Next series of tests are planed with the flight simulator Alsim MCC 200 located at Aviation Training Center of Rzeszow Technical University. There are also possibilities to test presented algorithms using GAA I-23 near in the future (year 2008) and as control laws the ground operator of UAV controls it remotely from the ground station (Fig 9).

Fig 9. General aviation aircraft I-23 „Manager"

Conclusion

Investigations on the field of control algorithms of lateral motion of general aviation aircraft presented in this paper are the part of wider researches going to construct the small pilot-friendly airplane [5, 6].

Algorithms supporting pilots during the longest and the most boring phases of flight, selected properly can reduce pilot's workload. This leads to increasing the comfort of the human and it increases the flight safety.

The problem of flight safety for GAA has became more and more significant for the last years because of the still arising number of planes and non-professional pilots using them as a sky-cars.

References

1. HODKINSON, J. Aircraft handling qualities. *AIAA Education Series, Blackwell Science Ltd.* 1999.
2. McRUER, D., ASHKENS, I., GRAHAM, D. Aircraft dynamics and automatic control. *Prinston University Press.* 1990.
3. KOCKS, K. Systems that permit everyone to fly. *Avionics Magazine*. March 2001, p. 16–20.
4. ROGALSKI, T., DOŁĘGA, B. The new conception of the laboratory testing of the FBW systems for small aircraft. *Aircraft Engineering and Aerospace Technology*. Emerald Group Publishing Limited, 2004, vol. 76, no. 3, p.293–298.
5. STEVENS, B., LEWIS, F. Aircraft control and Simulation. Willey & Sons, 1995.
6. TOMCZYK, A. A proposal of handling qualities shaping for general aviation aircraft. *Aircraft Engineering and Aerospace Technology*. Emerald Group Publishing Limited, 2002, vol 74, no. 6.
7. TOMCZYK, A. Concept for simplified control of general aviation aircraft. In *SAE/AIAA Paper of Word Aviation Conference*. Anaheim, CA, 1998, no. 985551.