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## RATE CONTROL AND MODIFY RESPONSES USING AUTOPILOT SIMULATION

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### Abstract

*The development of Electronic Control Units (ECUs) involves both hardware and software required to perform the functions expected from that particular module. Studies in control theory are concerned with understanding how system behaviour can be modified in a digital and controlled way. During the simulation of autopilot, simulation should be done in such a way that aircraft accommodate the conditions which are normal and the conditions which are abnormal means unfavourable conditions. This is brittle for accident investigations, human factor and for safety.*

### 1. Introduction

Commercial flight simulators are commonplace in the Aeronautical industry today. Aircraft manufacturers, airline operators, training organizations, and research institutions utilize commercial simulators for a wide range of purposes, including aircraft design and development, flight crew training, human factors and safety investigation, and pure and applied research in the various fields of aeronautical engineering and other disciplines.

Autopilot systems have been crucial to flight control for decades and have been making flight easier, safer, and more efficient. However, these autopilot systems are complex devices that require precise control and stability. These systems usually include a form of digital control systems to allow for easier implementation. One example, the Beaver Autopilot system, uses an inner, outer loop system to maintain control. The use of a commercial simulator for a similar purpose can often be either too costly or simply infeasible, due to an inability to reconfigure the simulation parameters required to accurately reproduce an aircraft's behavior or response in unusual (or off-design) circumstances and with unusual internal and external inputs. Since such design flight envelope excursions are frequently encountered either immediately prior to, or during, an incident which leads to safety investigation, the capability to accurately reproduce such excursions is extremely important.

### 2. History

The facility is based on a Link three-degree-of-freedom motion based flight simulator. Formerly a Boeing 707 cockpit, the simulator is being upgraded to operate from a distributed Personal Computer (PC) network. All original computer systems have been replaced by PCs. The visual systems and analogue instruments have been replaced by computer generated graphic representations. The PC system operates all simulation components including:

- Flight models
- Out-of-window displays
- Instrument displays
- Control force feedback
- Motion control system, and
- Sound system

These systems operate in conjunction with one another to provide a powerful, generic, reconfigurable simulation system with high-fidelity visual displays and dynamic response, and unparalleled freedom to reproduce vastly differing operational environments for use in safety and accident investigation, human factors and aeronautical research, and operational training [1].

In converting to new computing systems, our fundamental philosophy is to replace all B707 specific display instrumentation and flight characteristics with a generic system. This is based on the use of “glass cockpit” principles using Cathode Ray Tubes (CRT’s) in the instrumentation panel so that engine and flight instrumentation display arrangements can be tailored to specific aircraft in software. Aircraft models can then be chosen from standard base configurations, for example, multi-jet, turboprop, piston-prop, GA, etc, and then tailored to give specific flight characteristics for aircraft to be represented in the simulation[7].

The Link simulator was previously controlled by a predominantly analogue computer system of 1960’s vintage. Following acquisition, it was decided that the Department could not support this aging equipment. It was decided, instead, to retrofit the simulator with more modern computer hardware and software systems based on a network of PC’s, thus taking advantage of up-to-date simulation and graphics technologies. More importantly, this affords a great degree of flexibility, at a far reduced operating cost.

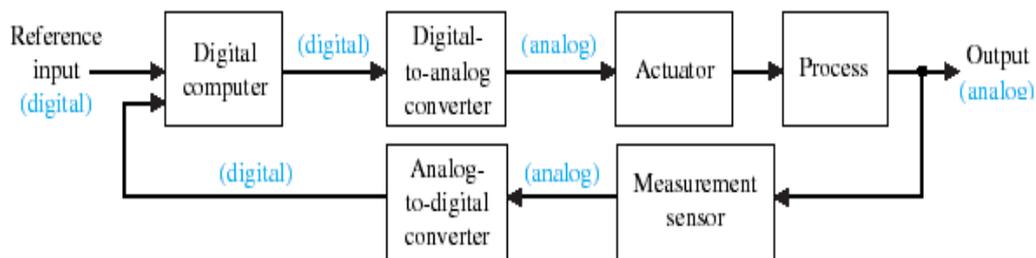


Figure1: Digital Control System Block Diagram

In this system, the digital computer reads in the digital signals from the feedback loop and the input and it sends them to the D/A converter. This converter takes the digital values from the computer and converts the signals into a usable value for the actuator and process. The signals are then sent via the feedback loop through the measurement sensors until it reaches the analog to digital convert. This portion takes the measured value and converts it into a binary digital signal that can be read by the computer [4].

### 3. Mathematical Model of Autopilot Control System

In order to simulate the action of autopilot, we first construct a mathematical model of aircraft system[2].The error signal,  $\epsilon$ , has been defined as the difference between the desired heading, or input,  $\theta_i$ , and the actual heading, or output,  $\theta_o$ , we therefore have the following identity.

$$\epsilon = \theta_i - \theta_o \quad \dots (a)$$

We assume the rudder is turned to an angle proportional to the error signal, so that the force changing the aircraft heading is proportional to the error signal. Instead of moving the aircraft sideways, the force applies a torque which will turn the aircraft. The strength of the torque, or turning force, depends on how far back the ruder is placed. However, just as the automobile movement was resisted by a shock absorber, the turning of the aircraft a resisting, viscous drag, approximately proportional to the angular velocity of the aircraft. The torque acting on the aircraft can therefore be represented by the following equations.

$$\text{Torque} = K \varepsilon - D \dot{\theta}_o \quad \dots(b)$$

Where K and D are constants. The turn on the right hand side is the torque produced by the rudder and the second is the viscous drag.

In case of differential equations, the fundamental law of mechanics is that the acceleration of a body is proportional to the applied force [3]. That was related to linear motion. The same law, however, applies to a turning motion: the coefficient of proportionality is the inertia of the body, denoted by I. Since the angular acceleration of the aircraft is the second derivative of its heading, the equation of the motion is

$$I \ddot{\theta}_o = \text{torque} \quad \dots(c)$$

Substituting from equations (a) and (b), and transposing terms, the resultant equation is

$$I \ddot{\theta}_o + D \dot{\theta}_o + K \theta_o = K \theta_i$$

If we divide both sides of the equation by I, and make the following substitutions:

$$2\xi \omega = D / I,$$

$$\omega^2 = K / I$$

The equation of the motion relating output to input then takes the following form:

$$\ddot{\theta}_o + 2\xi \omega \dot{\theta}_o + \omega^2 \theta_o = \omega^2 \theta_i$$

Suppose the aircraft is initially flying a steady course which, by definition, we take to be the zero heading. If it is asked to change to new heading at time zero, this corresponds to a unit step change of input. Because of the correspondence between the equations of the motion we just noted, the results will be the same, which showed the response of the suspension system to a unit the response will be oscillatory if is less than one.

#### 4. Simulation and Modeling

To simulate how the autopilot can be designed to modify the aircraft response [8], it is more convenient to leave the model in the form of their individual equations:

Equations (a), (b), and (c). Using variables error and torque to represent the error signal and the applied torque, the equations are:

$$\text{ERROR} = q_i - \theta_o$$

$$\text{TORQUE} = K * \text{ERROR} - D * \dot{\theta}_o$$

$I \theta_0 = \text{TORQUE}$

If we also use the variables HEAD, ANGVEL, and ANGACC to represent the aircraft heading, which simply repeats the automobile wheel case, the aircraft is being asked to turn in a circle. The desired heading is then continually increasing at a uniform rate so that

$\text{INPUT} = A * \text{TIME}$

Where A is a constant and TIME is a CSMP[6] variable representing the time,  $t^2$ . The constants K, I, and A have been set to values of 400, 2.00, and 0.0175, respectively. The constant D has been programmed to take different values on five separate runs so that the damping ratio,  $\xi$ , will have the values 0.1, 0.3, 0.7, 1.0, and 2.0.

With t expressed in seconds, the equation of motion gives  $\theta_0$  in radians. The value chosen for A in the simulation makes the input a request for a turn of one degree of second.

PROGRAM:

TITLE AIRCRAFT WITH RATE CONTROL

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PARAM D = (5, 656, 16, 968,39, 592, 56, 56, 113.12)

INPUT = A \* TIME

ERROR = INPUT - HEAD

TORQUE = K \* ERROR - D\*ANGVEL

ANGACC = TORQUE/I

HEAD=INTGRL(0,0,ANGVEL)

ANGVEL=INTGRL(0,0,ANGAAC)

\*

CONST I = 2,0, K = 400.0, A = 0.0175

TIMER DELT = 0.005, FINTIM = 10.5, PRDEL = 0.005

PRINT HEAD

LABEL HEADING VERSUS TIME

END

## 5. Results and Responses of aircraft flying with rate control

The results of the program runs are in non dimensional form by plotting  $\omega\theta_0/A$  against  $\omega t$ . The desired heading is in form of straight line through the origin. However it can be seen that aircraft lags behind the desired heading and never catches up so long as the turn request remains in effect. The size of the lag increases as the damping ration increases. The error signal appears as an electrical signal in the autopilot. It can easily be modified by electrical circuits.

The motion of the the aircraft can also be measured by instruments giving electrical signals that can be added to the autopilot output

## 6. Conclusion

The modifications affect the aircraft response by changing the applied forces. Studies in control theory are concerned with understanding how system behavior can be modified. It is important to eliminate the lag that builds up as the aircraft's turn. One way this can be done is to add to the error signal a component that is proportional to the integral of error signal. This is the one modification with addition of error signal. With this modification control theory shows that for the system to remain stable, we must have

$$K_1 < KD / I$$

The second modification called integral control will eliminate the lag when the aircraft is performing a steady turn.

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