

One Approach to the Aircraft Brake Control System Numeric Identification Method

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ABSTRACT

Aircraft anti-skid brake control system is considered one of the most complex aircraft systems whose performance depends not only on subsystem parameters but rather on many other external conditions and physical parameters which are difficult to control and predict. Over the years aircraft brake control system performance and fault diagnostics have been simulated and analyzed from various aspects. Based on the task to enhance aircraft brake control system diagnostic methods, this article presents one approach to mathematical modeling and a numeric identification method of the hydro-mechanical brake control components.

For any complex system behavioral or performance analysis approach, system modeling and simulation are the most common tools. Most often, the complete system model is unknown, and only simple segments of the unknown system or a small number of subsystem components may be known in a form of transfer function with static and dynamic characteristics. For that reason, mathematical modeling and system identification methods have evolved and become a part of greater control systems theory.

In this article, using a time domain input and output parameters from flight test aircraft, hydro-mechanical elements of the brake control system have been modeled as linear, time-invariant dynamic subsystem with unknown constant parameters. For the model parameters identification, a numeric algorithm has been developed and implemented based on Lüders-Narendra's adaptive observer. Finally, simulated and real system dynamic responses were compared and evaluated. With regards to dynamic performance, the results of the simulation demonstrate the model is stable and accurate in comparison with real system test data.

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INTRODUCTION

A simplified aircraft anti-skid brake control system is shown in Figure 1. It includes electrical, hydraulic and mechanical components combined together, to perform a controlled and efficient aircraft braking during landing and ground maneuvering. For that purpose, aircraft hydraulic power is used to actuate the brake pistons against a pressure plate. As a result of the brake piston actuation, a force is applied on the pressure plate. As the wheel is rotating, a friction between the brake rotor and stator plates is generated, and an opposite torque is created. With aircraft dynamics, the resulting torque acting on the wheel will cause a wheel speed slip and a friction force between the wheel tire and runway surface. A combination of friction force caused by brake application and aerodynamic drag will cause the aircraft to decelerate. The aircraft may have multiple main gear wheels with each wheel having its own brake, with an independent brake control channel.

Aircraft braking is initiated when pilot activates the brake pedals. Using position transducers, the brake pedal position is converted into an electrical brake control signal, which serves as an input command

to the Brake Control Unit. The Brake Control Unit is an electronic box with a brake control algorithm which provides brake control command in proportion to the force applied to the brake pedals. The brake control command is a current signal which is applied to the brake control valve. In Figure 2, a static characteristic of the Brake Control Valve is shown as a linear function between the input control current and output brake pressure.

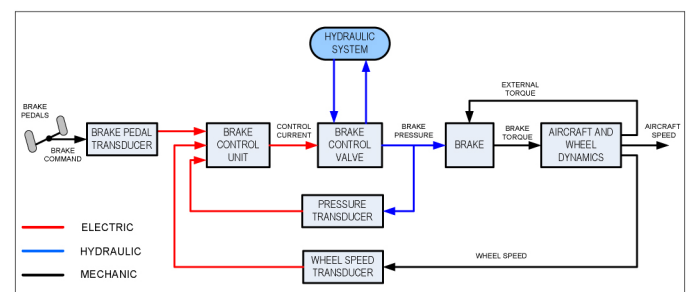


Figure 1. Aircraft anti-skid brake control system block diagram.

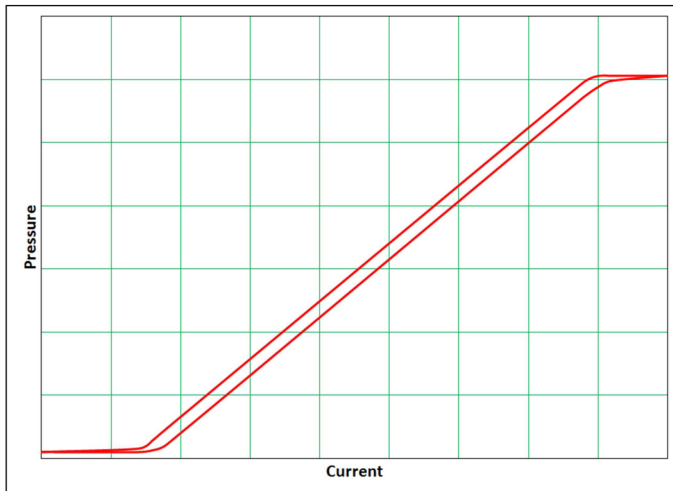


Figure 2. Static characteristic of the Brake Control Valve, where an output pressure is a function of the input control current.

On an aircraft with multiple main gear wheels, each wheel has its own brake assembly. Each brake assembly is a hydro-mechanical device with multiple brake hydraulic actuators located on the brake housing. The brake hydraulic actuators are hydraulically connected in the parallel circuit configuration so that hydraulic brake pressure is applied at the same time to all brake actuators. When brake pressure is applied, with the existence of the external torque applied to the wheel, the pressure from multiple brake actuators acts perpendicular to the brake plates to create a friction force between the brake rotor and brake stator plates. As a result an opposing torque is developed, causing the wheel to decrease its own angular velocity, and thus increases a friction between the tire and contact surface. Brake hydraulic pressure is brought from aircraft hydraulic system through a shutoff valve and Brake Control Valve. A simplified hydraulic connection between the Brake Control Valve and single brake assembly is shown in Figure 3. Each brake hydraulic line may include a shuttle valve, hydraulic fuse, metal tubing, and flexible hydraulic hoses. These elements with different material stiffness, hydraulic flow restrictions, tubing length and geometry have their own contribution to the brake pressure dynamic characteristics, which is difficult to calculate. For those reasons, experimental data has been collected to create a mathematical model to be used for further analysis and system diagnostic simulation.

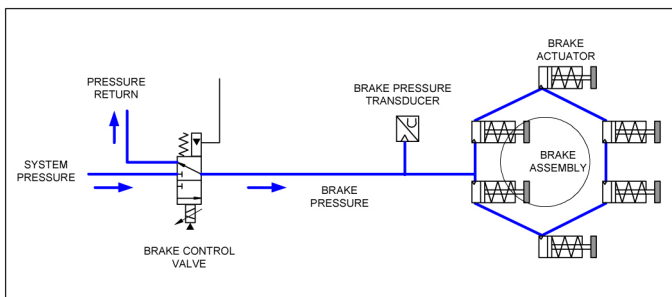


Figure 3. Simplified aircraft hydraulic connection between the Brake Control Valve and designated single brake assembly, with brake pressure transducer used for the brake control feedback.

BRAKE CONTROL SYSTEM AS AN OBJECT OF IDENTIFICATION

To determine the brake pressure dynamic characteristics and transfer function of the brake assembly, aircraft flight test data has been collected during one braking performance interval, with hundred samples per second. The control current from the Brake Control Unit was monitored through the ARINC 429 bus parameters while brake pressure data was collected through the brake pressure transducer. The Brake Control Valve current and brake pressure signals, which were recorded during the aircraft braking performance, are presented in Figure 4 and Figure 5, respectively.

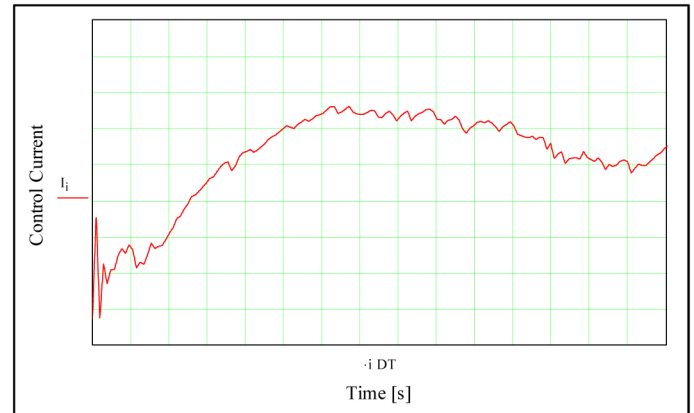


Figure 4. Command current for the Right Inboard Brake Control Valve during one aircraft braking performance interval.

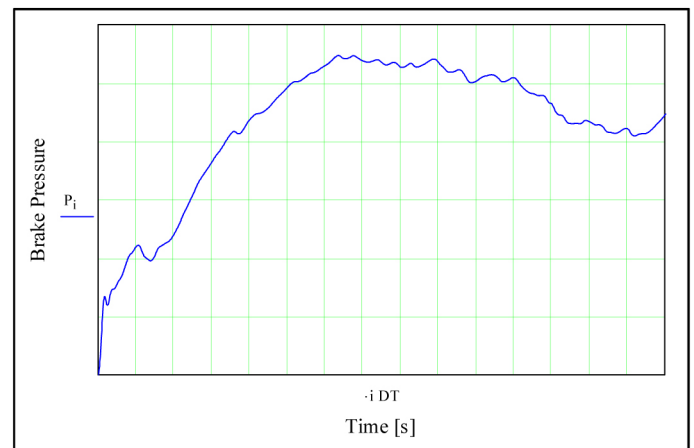


Figure 5. Right Inboard Brake Pressure during one aircraft braking performance interval.

LÜDERS-NARENDRA'S ADAPTIVE OBSERVER AS THE DYNAMIC SYSTEM IDENTIFICATION METHOD

By definition, system identification is the process of developing or improving the mathematical representation of the unknown physical system using experimental data [6]. Typically, the system identification process consists of the following four steps: Experiment design, analytical model approximation, model parameters estimation and model validation [7]. If an analytical linear time invariant model structure is known, and if it is presented in parametric form, then the

problem of system identification becomes a problem of model parameters identification. One of the methods used for model parameters identification is adaptive observer. This method is based on an algorithm which use an output error signal $e(t)$ to modify model parameters in a way to reduce an output error to zero. Figure 6 illustrates a system parameters identification method, based on an error between the estimated and real system output signals as a response to the common input signal.

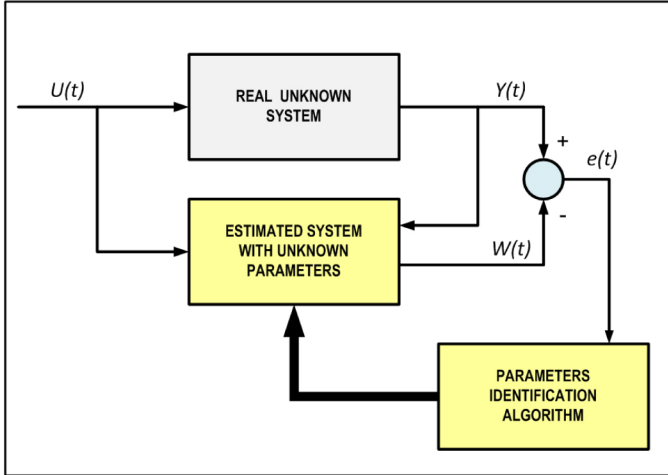


Figure 6. System identification method based on an output error between the real unknown system and estimated system.

Lüders-Narendra's adaptive observer identification method starts with assumption that unknown deterministic linear single input- single output (SISO) system has adopted a transfer function $G(S)$ in a form of:

$$G(S) = \frac{\beta_1 S^{n-1} + \beta_2 S^{n-2} + \dots + \beta_n}{S^n + \alpha_1 S^{n-1} + \dots + \alpha_n} \quad (1)$$

with unknown constant coefficients α_i and β_i ($i = 1, 2, \dots, n$). Allowing polynomial transformation of the numerator and nominator, with introduction of the positive and real coefficients λ_j ($j = 2, 3, \dots, n$), $\lambda_j > 0$, the adopted transfer function $G(S)$ can be changed in the following form:

$$G(S) = \frac{b_1 + \frac{b_2}{S+\lambda_2} + \dots + \frac{b_n}{S+\lambda_n}}{S - a_1 - \frac{a_2}{S+\lambda_2} - \dots - \frac{a_n}{S+\lambda_n}} \quad (2)$$

where α_j and b_j ($j = 1, 2, \dots, n$) are unknown real time constant parameters.

To determine unknown parameters of the adopted transfer function $G(S)$ from the equation (2), we can use an estimated model with variable parameters

$$a_j = a_j(t) \quad (3)$$

($j = 1, 2, \dots, n$)

and

$$b_j = b_j(t) \quad (4)$$

($j = 1, 2, \dots, n$).

If a such estimated model has an output signal $W(t)$, as response on the same input signal $U(t)$ applied on real system, than the difference between output signal $Y(t)$ from the real system and $W(t)$ from estimated model can be expressed as:

$$e(t) = Y(t) - W(t) \quad (5)$$

where $e(t)$ is an estimated system output error. The process which creates an estimated system output error is presented in Figure 7.

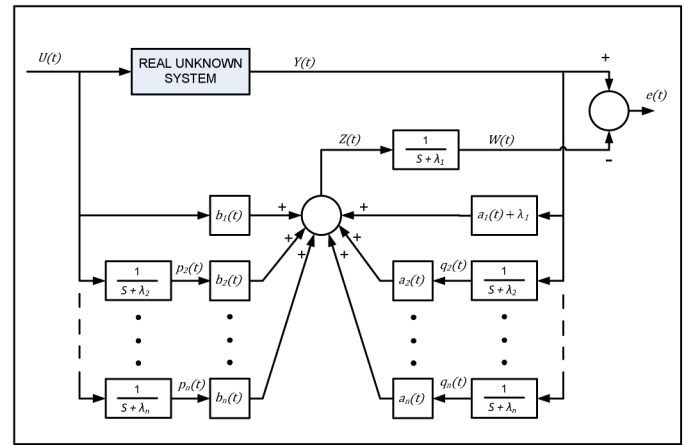


Figure 7. Process which creates an estimated system output error $e(t)$.

Further, Lüders-Narendra's adaptive observer has a set of time domain correlations where time derivations of the variable coefficients a_j and b_j ($j = 1, 2, \dots, n$) are continuous functions of the estimated system output error $e(t)$. Based on Lüders-Narandra adaptive observer, the mathematical expression of the adaptive observer and relationship between input/output signals and variable coefficients of the estimated system can be defined as:

$$\frac{da_1}{dt} = \gamma_1 e(t) Y(t), \gamma_1 > 0 \quad (6)$$

$$\frac{db_1}{dt} = \delta_1 e(t) U(t), \delta_1 > 0 \quad (7)$$

$$\frac{da_j}{dt} = \gamma_j e(t) q_j(t), \gamma_j > 0 \quad (8)$$

($j = 2, 3, \dots, n$),

$$\frac{db_j}{dt} = \delta_j e(t) p_j(t), \delta_j > 0 \quad (9)$$

($j = 2, 3, \dots, n$),