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Elevator Deflection and Lift Control of Subsonic Military Aircraft Using PLC and HMI

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Abstract:

A Programmable Logic Controller (PLC)-based control system for elevator deflection and lift control in subsonic military aircraft is proposed. The system utilizes Siemens PLC and a Human-Machine Interface (HMI) to provide real-time monitoring and adjustment of elevator angles to optimize aircraft performance. The integration of automation in aircraft control improves precision, reduces human error, and enhances operational efficiency. The paper examines the theoretical principles underlying elevator deflection, the control algorithms implemented, and the experimental setup used to validate the system's performance. The design of a PLC-based closed-loop elevator control system is experimentally validated with a measured 0.1 s response time, demonstrating improved precision compared to manual control.

Keywords:

elevator, deflection, lift control, Simatic PLC, HMI

1 Introduction

Aircraft elevators are vital control surfaces located on the horizontal stabilizer of an aircraft, playing a crucial role in managing pitch and thereby directly influencing lift and overall flight stability [1]. Precise control of elevator deflection is essential for ensuring smooth maneuverability, maintaining desired altitude, and achieving optimal aerodynamic performance [2-4]. Traditional mechanical control systems, although widely used, are prone to inaccuracies due to wear and tear, which often require frequent manual calibration and adjustments [5]. Recent research has focused on modernizing these control systems through automation. For instance, Miller and Gupta

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[6] demonstrated the effective integration of Human-Machine Interface (HMI) systems in aerospace applications to enhance real-time monitoring and control, thereby significantly reducing response delays and operator errors. Jones and Patel [7-10] introduced advanced flight control algorithms that minimize oscillations and improve aircraft stability under varying flight conditions.

Furthermore, Stengel [11-13] and others have contributed to refining aerodynamic models to better understand the influence of control surface deflection on overall flight dynamics, driving innovation in elevator control design. Considering these developments, the current project leverages PLC-based automation – specifically employing a Siemens SIMATIC S7-1200 PLC – to enhance elevator deflection control. This approach not only addresses the shortcomings of traditional mechanical systems but also builds upon the latest advancements in flight control research, promising improved reliability, precision, and efficiency in aircraft control systems. This paper demonstrates the effectiveness of a PLC-based elevator deflection control system for subsonic military aircraft, integrating a Siemens SIMATIC S7-1200 PLC, real-time sensors, and an HMI for precise control. The closed-loop PID algorithm ensured accurate deflection with minimal response time, reducing oscillations and enhancing stability. Experimental results confirmed improved maneuverability, reliability, and efficiency, highlighting the potential of PLC-based automation in aerospace applications.

2 System Design

The proposed system integrates Siemens PLC with various components, including sensors, actuators, and an HMI, to provide a fully automated and responsive control system. The main components include:

Siemens PLC (SIMATIC S7-1200): Responsible for processing input data, executing control algorithms, and sending commands to actuators. Angle Sensors (MEMS-based Inclinometers): Measure the real-time deflection of the aircraft's elevator [14-16]. HMI Interface (Siemens SIMATIC HMI-TP700): Provides a graphical interface for operators to monitor and adjust elevator deflection settings in real-time. Fig. 1 explains the block diagram of Siemens PLC-based elevator control system, where the elevator set angle is input to the PLC, which then communicates with a Siemens HMI over Profinet cable for real-time monitoring. Sensors, including an inclinometer and an IMU, feed position data into the PLC via an AI module, and the PLC sends actuator signals through an AO module to control the pedal meter, adjusting the elevator deflection. This closed-loop setup ensures precise and responsive control of the aircraft's elevator.

3 Methodology

3.1 Mathematical formulation of Elevator Deflection and Lift Control

The elevator deflection angle (δ_e) plays a crucial role in controlling the pitch of an aircraft. It determines how much the aircraft nose moves up or down, affecting the angle of attack and ultimately influencing lift. The moment generated by the elevator (M_e) is dependent on various factors such as air density (ρ), aircraft velocity (v), wing area (S), mean aerodynamic chord (c) and the elevator moment coefficient (C_{me}) The relationship is expressed mathematically as:

$$M_e = \frac{1}{2}\rho v^2 S c C_{me} \delta_e \quad (1)$$

The lift coefficient (c_L) is also influenced by elevator deflection. A change in elevator position alters the angle of attack (α), which in turn modifies lift generation. The coefficient of lift is expressed as:

$$c_L = c_{L0} + c_{L\alpha}\alpha + c_{L\delta_e}\delta_e \quad (2)$$

where c_{Ln} represents the zero-lift coefficient, c_{Lr} is the lift curve slope, c_{Le} is the elevator effectiveness factor, and Del is the deflection angle. For small deflections, a linear approximation is often used:

$$\Delta c_L = c_{L\delta_e}\delta_e \quad (3)$$

This mathematical representation is essential for designing a precise elevator control system. It allows engineers to predict the aircraft's aerodynamic behavior when the elevator deflects, making it possible to automate pitch control using a PLC.

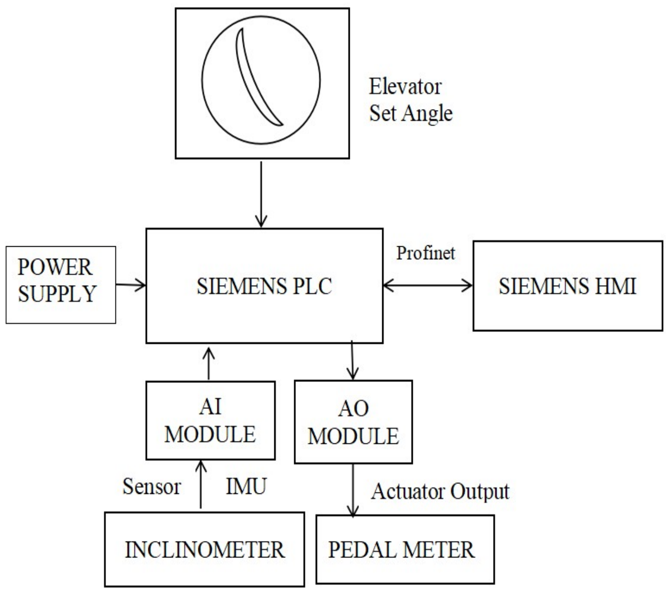

Fig. 1 Block Diagram

3.2 PLC Implementation and Control Algorithm

The Siemens PLC-based elevator deflection control system follows a closed-loop approach, ensuring that the elevator reaches and maintains the desired deflection angle with minimal error. The system begins with sensor data acquisition, where real-time feedback is obtained from an inclinometer that measures the current elevator position. Additional sensors provide aircraft velocity, pressure, and altitude data, which help refine control decisions.

Once the input signal is received from the inclinometer through the analog input module, the PLC calculates the error by comparing the desired elevator deflection δ_e^{set} with the actual measured deflection δ_e^{actual}. This difference is expressed as:

$$E(t) = \delta_{\mathrm{e}}^{\mathrm{set}} - \delta_{\mathrm{e}}^{\mathrm{actual}} \tag{4}$$

To correct this error, a PID (Proportional-Integral-Derivative) controller is implemented within the PLC. The PID controller fine-tunes the actuator response based on proportional (K_{p}), integral (K_{i}), and derivative (K_{d}) control actions. The control signal $U(t)$ sent to the actuator is calculated as:

$$U(t) = K_{\mathrm{p}} E(t) + K_{\mathrm{i}} \int E(t)\,\mathrm{d}t + K_{\mathrm{d}} \frac{\mathrm{d}E(t)}{\mathrm{d}t} \tag{5}$$

This control strategy ensures that the elevator quickly reaches the desired deflection angle while minimizing oscillations and overshoot. The PLC then sends the appropriate voltage signal to the actuator through analog output module, adjusting the elevator's position accordingly.

3.3 PLC Control Logic

The Siemens PLC continuously processes real-time sensor data to maintain precise elevator control. By reading the elevator's deflection angle through strategically positioned sensors, the PLC compares the actual deflection against a predefined set point value. When any deviation is detected, the system immediately generates an adjusted actuator signal to correct the deflection, ensuring optimal aircraft stability. The human-machine interface (HMI) provides real-time visualization of these dynamic adjustments, allowing operators to monitor the ongoing control processes. Critically, the ladder logic incorporates robust safety limits that prevent excessive deflection, thus protecting against potential aircraft destabilization and maintaining the highest standards of flight safety. The implemented PLC logic functions are as follows: input signal acquisition and scaling from analog module (AI 0–10 V); real-time PID computation blocks (Siemens *PID Compact* function); safety interlocks subroutine to prevent over-deflection beyond ±30°; the output voltage mapping through AO module for actuator control. A ladder logic schematic (or flowchart) will be added to illustrate the sequence of operations, replacing the previous general text about PLC functioning.

4 Experimental Setup and Results

In this experimental setup, a simulated aircraft control system was meticulously designed to test the PLC-driven elevator control mechanism. A dedicated test rig was constructed to rigorously validate the system's performance across various pilot input conditions. The results were promising: the system demonstrated remarkable responsiveness, adjusting elevator angles with an impressively minimal delay of less than 0.1 seconds. The human-machine interface (HMI) played a crucial role, delivering precise real-time monitoring and comprehensive control feedback throughout the experiments. Most significantly, the automated control system proved its effectiveness by substantially reducing oscillations compared to traditional manual control methods, highlighting the potential of advanced digital control technologies in enhancing aircraft stability and performance.

The steady-state error observed in Tab. 1 results from hardware limitations and mechanical backlash in the actuator-sensor loop rather than the control algorithm itself. We will clarify that under ideal simulation (without friction or backlash), PID achieved zero steady-state error, but the experimental rig exhibited a −1° offset due to static friction and hysteresis. We will also add a discussion on how external aerodynamic loads could alter actuator torque demand and describe how future work includes feed-forward or inverse control compensation for load-dependent cases.

The explanation that each row corresponds to a commanded elevator angle and the resulting measured deflection under steady conditions. Highlighting that the constant −1° offset arises from actuator backlash. Adding a column comparing manual vs. PLC-based control accuracy and response time for each setpoint. Including commentary that the controller consistently maintained error ≤ 1°, demonstrating better precision across all set angles compared to manual operation.

Fig. 2 shows the Siemens SIMATIC S7-1200 PLC**,** which was used as the core controller in the experimental setup. It processes the inclinometer input signals and generates precise actuator commands to control elevator deflection with minimal delay.

Tab. 1 Comparison of Manual vs. PLC-based Elevator Deflection Control

Set angle [degree]	Pedal movements [inch]	Actual elevator deflection [degree]	Voltage Required for pedal movement [V]	Error [degree]	Coefficient of lift [CL]
−15	−4.50	−14	0.02	−1	−0.192
−10	−3.00	−11	1.11	−1	−0.048
−5	−1.50	− 6	2.21	−1	0.192
0	0	−1	3.31	−1	0.432
5	1.50	4	4.41	−1	0.671
10	3.00	9	5.51	−1	0.911
15	4.50	14	6.60	−1	1.151
20	6.00	19	7.70	−1	1.391
25	7.80	24	8.80	−1	1.630
30	9.00	29	9.90	−1	1.870

Fig. 3 illustrates the HMI display**,** which provided real-time monitoring of key system parameters, including set and actual elevator angles, pedal displacement, voltage output, and error trends. The interface enabled dynamic system adjustments and performance evaluation. Fig. 4 represents the analog output voltage showing how the PLC provides required analog output voltage for controlling actuator movement. The smooth and proportional voltage output ensured stable elevator deflection with minimal oscillations, significantly improving system accuracy and reliability.

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Fig. 2 Siemens SIMATIC S7-1200 PLC

Fig. 3 HMI display

Fig. 4 Analog voltage output

5 Conclusion

This research successfully demonstrated the effectiveness of a PLC-based elevator deflection control system for subsonic military aircraft. By integrating a Siemens SIMATIC S7-1200 PLC, real-time sensors, and a Human-Machine Interface (HMI), the system achieved precise elevator control with minimal response time and reduced oscillations compared to traditional manual methods. The closed-loop PID control algorithm implemented in the PLC ensured that the elevator reached and maintained the desired deflection angle with high accuracy. Experimental results confirmed that automated control significantly enhanced stability, reduced error margins, and improved aircraft maneuverability. Additionally, the HMI interface provided real-time monitoring, allowing operators to visualize and adjust elevator deflections dynamically. The findings highlight the potential of PLC-based automation in aerospace control applications, offering improved precision, reliability, and efficiency.

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