# Enhancing UAV elevator actuator model using multibody dynamics simulation

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***Abstract:*** *This paper proposes an improved actuator system model for UAV elevators using multibody dynamics simulation. The multibody dynamics simulation employs the Simscape Multibody, module in MATLAB coupled with Simulink to model the servo and hinge moment calculation. The actuator system comprises an electrical servo and mechanical components, including arms, push rods, horns, and the elevator. The electrical servo is modeled using a PID controller and a simplified motor model. The multibody dynamics simulation is employed to capture the dynamics of the mechanical components, coupled with the electrical servo through torque delivery to the mechanical components. The simulation is applied to the elevator of a medium altitude long endurance (MALE) UAV with a Maximum Take Off Weight of 1300 Kg. Generating these quantities provide a benefit in capturing the operational envelope of the servo to be compared to its limitations. Given the features of this simulation, it is proposed to extend the research by integrating this method with flight dynamics simulation.*

***Key Words:*** *Elevator, Actuator, Multibody, Simscape, Simulation, PID*

## 1. INTRODUCTION

Actuators of control surfaces play a critical role in aircraft dynamics by converting control signals into mechanical drive and then triggering the aircraft motion. They are crucial elements of the control systems that influence the motion, stability, and response to external disturbances. In other words, actuators control the aircraft's movements and ensure safety. The performance of the actuator system will affect the flight characteristics of the aircraft, so it is important to ensure that the actuator responds to the control command and does not counteract the desired deflection.
Moreover, actuators have a limited deflection angle, so flight characteristics should not burden the actuators by exceeding their performance to prevent actuator damage.

Accurate consideration of subsystems, such as actuators, is highly important, especially for UAVs whose flight dynamics primarily rely on computer control with minimal human intervention. A precise estimation of subsystem behavior is essential for determining the appropriate commands to achieve the desired flight dynamics response. In developing automatic control systems for UAVs, flight computer simulations typically incorporate the modeling of subsystems, including actuators. Some researchers conduct flight simulations considering the actuator behavior in various ways. Some experiments have been conducted, [1] conducted an experiment to model actuators based on the natural frequency and damping ratio of servo mechanism, while [2], [3], [4] estimated the actuator model by system identification approach with experimental work. In their study on Electro-Mechanical Fin Actuation System, Shelan et.al. [5] incorporated Processor In the Loop technique to assess the performance of the FPGA based controller. A first-order system model of actuator dynamics was used by [6] for radio control actuated control servo and determined the maximum and minimum value of deflection, and [7] examined the time delay between the command signals and the actual response for servo dynamic model through servo delay tester experiment. On the other side, [8] neglected the dynamic behavior of actuators and relied on parameters provided by manufacturers of flight control systems that are believed to be suitable for generic servo-actuated radio control aircraft.

The actuator characteristics modeling described in the previous references did not consider the effects of aerodynamic load acting on the control surfaces during flight. Matlab/Simulink provides a simulation tool to simulate motion systems for multibody dynamics problems through the Simscape module [9]. This module offers more proper simulation enhancement for the actuation system's dynamic and coupled with flight dynamics. One advantage of employing this method is that the aerodynamic load represented by the hinge moment can be estimated to determine the effect during flight.

This paper proposes Simscape Multibody dynamics, a Matlab module, to simulate the dynamics of control surfaces. The problem to be investigated is how the controller responds to the variations of hinge moment during the flight. During the flight, the hinge moment will vary as a function of airspeed, air density, and deflection of the control surface. Usually, the actuator was set in the ground before flight and neglected the hinge moment's effect. The hinge moment fluctuates according to flight speed, deflection angle, and angle of attack, as given by Equation (1). Therefore, the behavior of the actuator systems during flight needs to be better understood when the hinge moment is ignored. Despite testing experimentally using a testbed, with hinge moment included, conducting high-fidelity computer simulation methods will be beneficial in practice.

The modern UAV actuator system for control surfaces typically consists of electric servo, driving rods, and control surfaces. The control surface can be an aileron, a rudder, a flap, an elevator, or a ruddervator. The ruddervator control surface is simultaneously acting as a rudder and elevator. The subsystems of the actuator are connected. If the electric servo provides torque, an angular motion of the control surface is triggered through driving rods. The driving rod configuration depends on the actuation design. This research employs the rod configuration consisting of a servo arm, push rod, and control surface horn, as shown in Figure 1. These are mechanical parts whose properties and mechanical behavior can be simulated using Simscape Multibody. In the actuator system, the electric servo should provide adequate torque to withstand the moment load of aerodynamic hinge moment and inertia.

The electric servo datasheets from manufacturers usually come with torque specifications divided into modes of operation according to their limitations. For instance, the servo from the manufacturer of Volz has three modes, i.e., continuous, short-time, and overload [10]. Continuous mode means that the servo provides a range of torque without limitation, whereas in short-time mode, the torque can be delivered in a certain time (seconds) and then needs seconds to be cooled down. In overload mode, the served torqued is considered to be overloaded and does not apply more than a second and then needs more seconds for cooling down. For [10], the torque of continuous mode is up to 20 N.m., short-time is between 20 N.m to 28 N.m, and overload mode is higher than 28 N.m up to 30 N.m as the peak torque. Since the servo always has operating limits set by the manufacturer, the dynamic of the servo needs to be predicted properly to avoid failure during flight. Therefore, using Simscape Multibody to simulate the actuator system explains further understanding of actuator motion dynamics.

## 2. PROBLEM FORMULATION AND METHOD

The simulation focuses on the UAV's elevator actuator system, driven by an electric servo with an internal PID controller, as discussed in [11]. Electric servos often employ PID controllers, possibly enhanced with other methods like fuzzy logic [12] [13], linear quadratic regulator (LQR) [14], or the Ziegler Nichols method for fractional orders [15]. This UAV belongs to the medium altitude long endurance (MALE) class, with a weight of around 1300 Kg, guiding the selection of actuator properties and loads based on typical MALE class characteristics. The actuator system comprises servo and mechanical components, depicted in Figure 1. The servo's architecture includes a gear system, electric motor, controller, and potentiometer, with torque delivered through a shaft. The mechanical elements consist of the arm servo, pushrod, horn, and the elevator itself. The arm servo and horn connect to the servo and elevator shafts, respectively and work together to convert torque into elevator deflection, all regulated by the servo's internal controller.

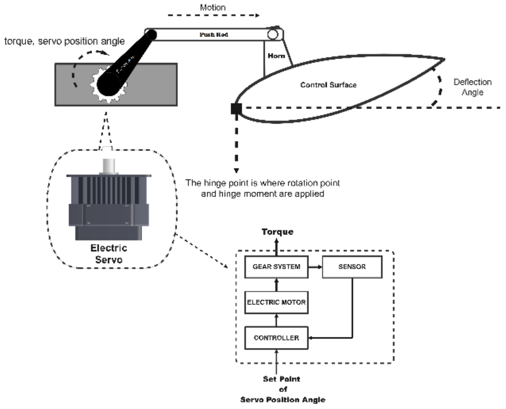


Fig. 1 - The actuator system of elevator

Based on Figure 1, the simulation of the actuator system comprises two main components: servo modeling and mechanical motion modeling. Servo modeling was conducted using Simulink as a transfer function, while mechanical motion modeling utilized a multi-body dynamics model with Simscape. These two components interact with each other.

The manufacturer typically delivers servos as a 'black box' without details on the servo's properties. Therefore, simplification are made when modelling servos. As previously stated, servos consist mainly of an electric motor and a controller. We have simplified the equation from [16], [17], and [18] to estimate the dynamic parameters of a servo motor,, represented by the following equation.

$$T = K_a I_a + K_d \dot{\theta} \tag{1}$$

where $T$, $K_a$, $I_a$, $K_d$, $\dot{\theta}$ are torque, coefficient of amarture, amarture current, coefficient of damping and angular speed of motor, respectively. The equation is a simplified version of the electric motor's equation model. In Equation (1), the servo torque is governed by $K_a I_a$ and

$K_d\dot{\theta}$, which reflect the internal servo's motor and damping torque, respectively. The coefficients of $K_a$ and $K_d$ are determined either experimentally or by the manufacturer datasheet. Fig. 2 depicts the actuator system model using Equation (1) and PID.

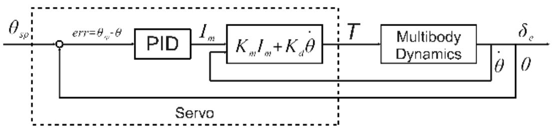


Fig. 2 - Block diagram of actuator system model

Figure 2 illustrates the system's input, the servo's set point for position angle ($\theta_{sp}$). The internal PID controller of the servo adjusts the motor current based on the difference between this set point and the actual servo position angle ($\theta$), which is measured by a sensor angle inside the servo. Multibody dynamics, using Simscape, simulate the mechanical aspect of the system, generating deflection angle ($\theta$) and servo angular speed ($\dot{\theta}$). The rotor's angular speed $\dot{\theta}$ contributes to the damping torque, affecting the total servo torque and providing feedback to the torque calculation block.

The mechanical part's multibody dynamic model is represented by geometric definition and joints, as shown in Figure 3. The revolute joint signifies the connection between two components capable of rotating for each other. A weld joint connecting the horn and the elevator represents a connection where the two components are bound together with no relative movement. The revolute joint connected to the servo receives torque, thus linking the servo and mechanical part. Within the elevator hinges, the joints are subject to an aerodynamic hinge moment, and this hinge moment is calculated using the following equation:

$$H.M = \frac{1}{2}\rho V^2 C_{hm} S_e\, c_e \tag{2}$$

where $H.M$ is the hinge moment, $\rho$ is the mass density, $V$ is the airspeed, $C_{hm}$ is the coefficient of the Hinge Moment, $S_e$ and $c_e$ is the reference area and the chord of elevator, respectively. In this case, $S_e$ and $c_e$ are 0.2937 m2 and 0.33 m. $C_{hm}$ is influenced by the angle of attack and the elevator deflection. In this simulation, the angle of attack is set to be zero and the deflection varies following the command.

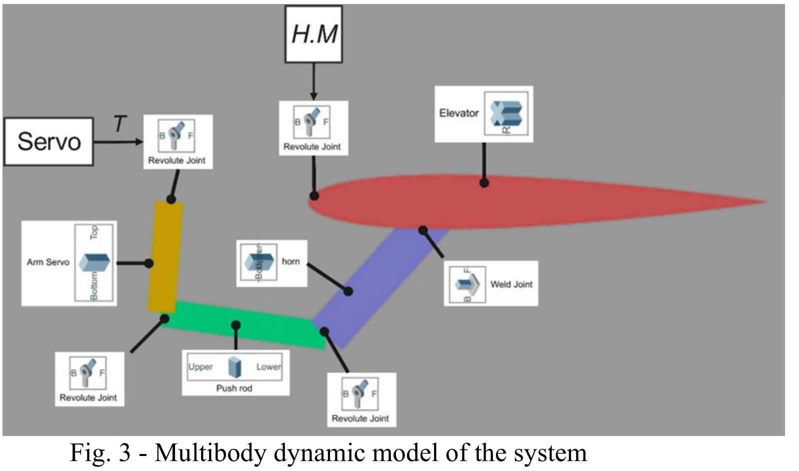


Fig. 3 - Multibody dynamic model of the system

The coefficient of the hinge moment can be calculated using various methods. Some of them mentioned here are the Roskam method [19] [20], the vortex lattice method [21], the panel method [22], the computational fluid dynamic (CFD) [23], or Datcom [24]. We use Datcom to carry out this research.

When considering $C_{hm}$ as a function of the deflection angle for zero angles of attack, it results in a linear relation: $C_{hm}$ = 0.0062 x $\delta_e$, where δe represents the elevator deflection in degrees. The mass density for the simulation is 1.12 kg/m3.

Since the properties have been defined, the hinge moment depends on airspeed (V) and deflection angle ( $\delta_e$ ). The airspeed will vary during the simulation to see the effect on the system dynamics. The deflection angle will also vary following the command and system response.

The geometrical properties of the mechanical parts are defined in Table 1 following the model of the system given by Fig. 3.

Table 1 - Geometrical Properties of the Mechanical Parts

| part | form | size | density |
|---|---|---|---|
| elevator | rectangular shape with an airfoil profile | chord : 0.33 m<br>span : 0.89 | 450 kg/m$^2$ |
| horn | rectangular rod | 0.01 m x 0.03 m x 0.1 m | 2700 kg/m$^2$ |
| push rod | rectangular rod | 0.12 m x 0.02 m x 0.01 m | 2700 kg/m$^2$ |
| arm servo | rectangular rod | 0.08 m x 0.02 m x 0.01 m | 2700 kg/m$^2$ |

Using the mechanical properties of the system parts above, the Simscape will automatically determine the system's mass and inertia.

## 3. SIMULATION AND RESULTS

Initially, a standard PID controller for aerodynamic hinge moment loads on the ground is established by simulating the model at zero airspeed (0 m/s). The MATLAB PID Tuner is employed/ used to determine the optimal gains: P = -2.131, I = -9.8, and Z = -0.1.

Subsequently, this established PID controller is utilized to simulate the motor model across a range of airspeeds. It's worth noting that changes in airspeed will affect the hinge moment as per Equation (2).

The simulation involved commanding the desired elevator deflection angle and varying the airspeed. The command was defined using a series of step signals, including both positive and negative deflections, as depicted by the dashed lines in the initial graphs of Figure 4.

The simulation exhibited parameters such as the elevator's angular motion, the aerodynamic hinge moment, the torque of the servo's arm mechanism, and the servo's current as shown by the first, second, third and fourth graphs in Figure 4, respectively. The motion is visually represented through geometric diagrams, as shown in Fig. 5.

The second graph in/ Fig. 4 illustrates how the transient response of the elevator deflection angle changes with airspeed.

Specifically, as airspeed increases, we observe longer settling times and greater deviations during the transition.

These variations could potentially have an effect on flight dynamics. To better understand this impact, it is important to integrate this actuator system model with a flight dynamics simulation.

Additionally, the results yield valuable data on torque, hinge moment load, and current, which can help us anticipate how these characteristics fall within the operational capabilities and limitations of the servo system.

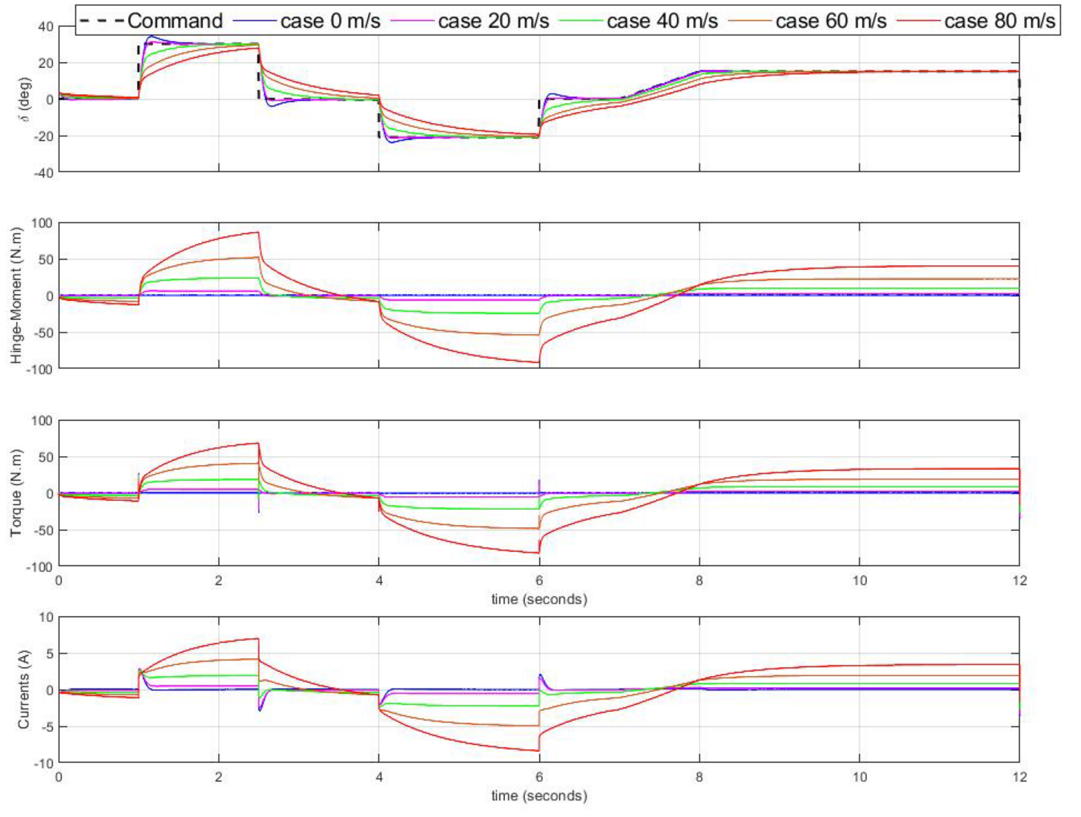


Fig. 4 - Results of the simulation

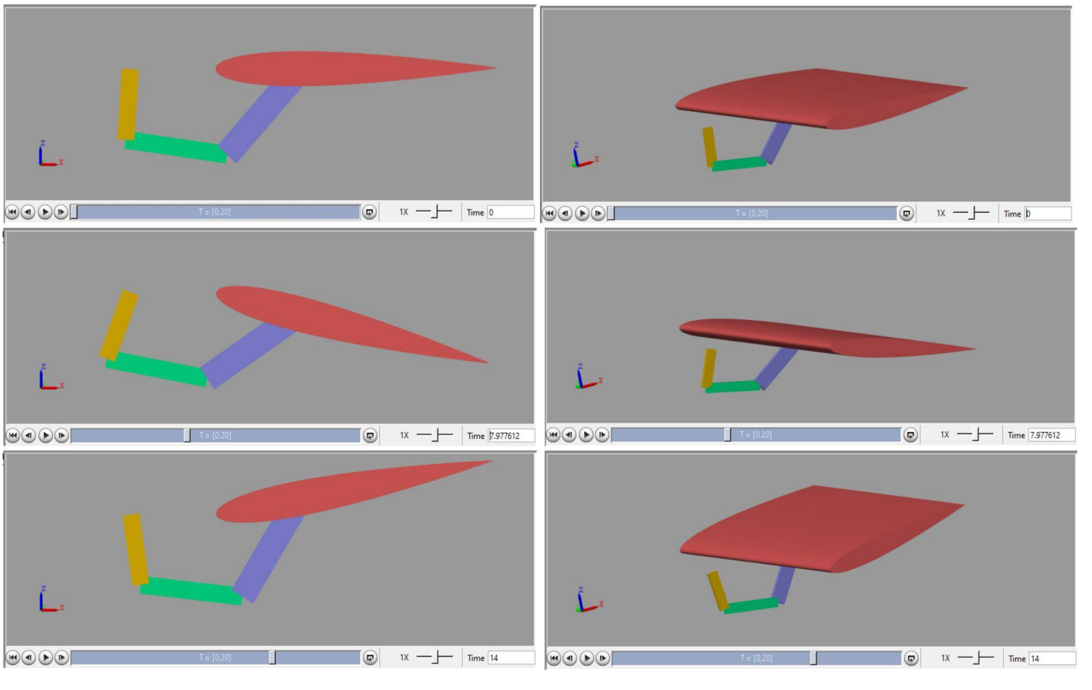

Fig. 5 - Illustration of actuator system while moving in response of the command

## 4. CONCLUSIONS

A multibody dynamics simulation using a simplified electric servo model for the UAV's elevator actuator system is demonstrated. This simulation improves on the prior actuator model for the UAV control surface, including the elevator, for flight dynamics simulation, which largely ignored the dynamics of the actuator under various aerodynamic loads. To extend this work, future research could explore the integration of this simulation with flight dynamics simulations. To extend this work, explore the integration of this simulation with flight dynamics simulations.

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