UAV Flight Simulation: Credibility of Linear Decoupled vs. Nonlinear Coupled Equations of Motion

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Abstract: The dynamical modeling of an Unmanned Air Vehicle (UAV) forms the heart of its simulation. The equations of motion can take five different forms: 1) nonlinear fully coupled, 2) nonlinear semi-coupled, 3) nonlinear decoupled, 4) linear coupled, and 5) linear decoupled. In the fully coupled equations of motion, two new coupling stability derivatives \((C_{DP}, C_{LP})\) are incorporated. The main purpose of this paper is to compare each version of the equations of motion, and to demonstrate positive and negative features of each form. This paper also compares the five different dynamical models using eight distinct UAV missions. It analyzes them from three different aspects, and gives recommendations for which model is best for a specified mission. MATLAB/Simulink is used to implementation the simulation. The final results are compared by analyzing the resulting trajectories and control deflections.

I. Introduction

The UAV field is one where extensive use is made of modeling and simulation technologies. The numerical simulation of the aircraft’s dynamics is the most important tool in the development and verification of the flight control laws for a UAV. The availability of special-purpose simulation languages, massive computing capabilities at decreased cost, and advances in simulation methodologies have made simulation one of the most widely used and accepted tools in flight operations research and aircraft systems analysis.

The complete aircraft systems and dynamics model incorporates different subsystem models (e.g. aerodynamics, structures, propulsion, and control subsystems) that have interdependent responses to any input. These subsystems also interact with the other subsystems. The dynamical modeling of a UAV is at the heart of its simulation. The response of a UAV system to any input, including commands or disturbances (e.g. wind gusts), can be modeled by a system of ordinary differential equations (i.e. the equations of motion).

Dealing with the nonlinear, fully coupled differential equations of motion is not an easy task. While the acquisition costs for UAVs are often lower than piloted aircraft, the development cost for a UAV is still very high. Control system errors may result in a crash of a UAV. The higher crash rate for UAVs when compared with manned aircraft demonstrates this.

The key component in a low-cost simulation software package is the UAV dynamic model represented as a set of ordinary differential equations. The dynamics of an aircraft can be modeled in different ways. The equations of motion take five different forms: 1) nonlinear fully coupled, 2) nonlinear semi-coupled, 3) nonlinear decoupled, 4) linear coupled, 5) linear decoupled.

To develop a computer simulation to evaluate the performance of a UAV including its control system, we have to invariably use a nonlinear fully coupled model. In order to design a UAV control system, one of the above five models are utilized. Each of these models has advantages and disadvantages. These include precision, accuracy, complexity, and credibility. The use of flight simulation tools to reduce risk and flight testing for a UAV system reduces the overall program schedule.

The equations of motion for an aircraft are nonlinear and fully coupled. In general, because of these nonlinearities, no closed form solution exists and a steady state solution can only be found by using a numerical method. Therefore, many researchers simplify these equations when accomplishing a