Optimal control in the transition phase of an eVTOL UAV in a hybrid configuration

Katarzyna Pobikrowska[1)], Tomasz Goetzendorf-Grabowski[1)]
[1)] Warsaw University of Technology (WUT), Institute of Aeronautics and Applied Mechanics, Nowowiejska 24, 00-665 Warsaw, Poland

Abstract:

Recent years have seen a notable increase in the popularity of contemporary eVTOL aircraft, both in academic and commercial contexts. However, the high energy consumption of vertical propulsion systems represents a significant challenge. Insufficient energy density of batteries on the market hinders the endurance of vertical flying aircraft, therefore a need for energy-optimal solutions arises. It is postulated that optimizing the trajectory of the transition phase is a viable option in mitigating the above shortcomings. The transition of a VTOL aircraft consist of accelerating from hovering to forward flight, at which point the full lift force is provided by the wings, instead of the vertical propulsion.

Figure 1. Example Quad Plane VTOL UAV – Spectre Solutions Chimera [1]

The following paper presents the results of a study in which the trajectory of an electric VTOL UAV has been optimized using methods of direct numerical optimal control. As a test case, a Quad Plane VTOL aircraft was selected as being one of the most popular configurations on the market. An example of the aircraft is shown in Figure 1. One of the most pronounced benefits of the configuration is that it is easy to retrofit a fixed-wing aircraft by enhancing it with vertical flight propulsion system to maintain the high endurance in forward flight. The Optimal Control Problem (OCP) has been posed on the basis of a numerical model of the Quad Plane VTOL UAV motion, as well as a set of constraints on the state and control variables. The mentioned model includes the aerodynamic models of aircraft body, and the propulsion system. The OCP has been solved with a nonlinear programming solver IPOPT to yield a feasible, energy-optimal trajectory during which the aircraft performs a fast and aggressive pitch down maneuver to complete the transition phase. The pitch angle during the energy-optimal transition trajectory is shown in figure 2.

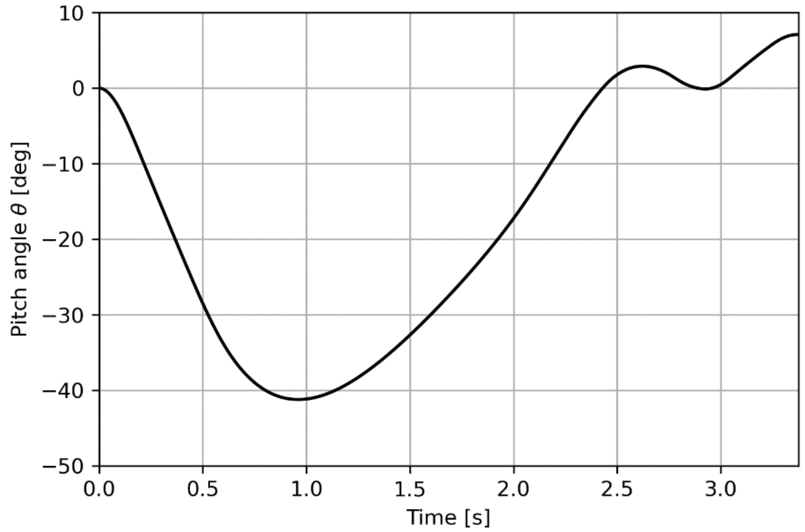

Figure 2. Optimal energy-saving trajectory – pitch angle profile in the transition phase

The resulting trajectory profile shows a reduction in energy consumption of up to 70% in comparison to a zero pitch reference case. Findings show that the best results are achieved not only in a proper propulsion control but also in reducing the time spent in the high power, transition regime. The saved energy can lead to higher endurance of the drone, a smaller battery and a more efficient usage of onboard resources. Furthermore, the approach may help to reduce the time spent in the high-energy transition phase, which is an important consideration for the feasibility and usability of eVTOL drones in today's world and in the future.

References:

[1] Spectre Solutions | Drones for special tasks, https://spectre.solutions/