

VTOL with Thrust Vector Control

Design and Implementation of a Small-Scale Demonstrator

Graduate



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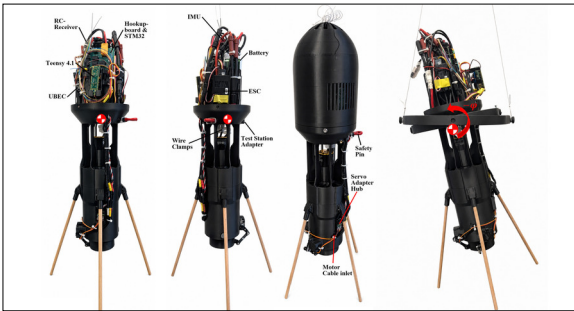
Objective: The objective of this thesis was to design, build, and test a small-scale vertical take-off and landing demonstrator with thrust vector control (TVC). The goal was to create an experimental platform with a fixed propulsion system and a separate thrust vector control mechanism, similar to aerospace thrust-vectoring concepts, that can perform take-off, hover and landing. The finished demonstrator, the electronics tower, and the suspended test setup are shown in Figure 1.

Approach: The propulsion system uses two coaxial electric ducted fan (EDF) units with counter-rotating rotors to generate thrust. The propellers were partly self-designed, manufactured by FDM printing, and tested as paired front and rear rotor configurations to identify a setup with high static thrust. The TVC mechanism uses two servos to actuate the deflector funnel to redirect the outlet flow, as shown in Figure 2. This creates moments around the center of mass of the demonstrator to stabilize the system mid-flight. The entire structure is 3D-printed and is built around the fixed coaxial EDF setup and the separate TVC mechanism. State-space models were developed for attitude and position modeling and LQR control. These models were implemented in MATLAB and Simulink and used to design discrete LQR controllers. Figure 3 shows the complete control concept. The orange frame marks the attitude control loop implemented on the real demonstrator, while the green frame shows the full concept developed in simulation. The actuators were modeled using empirical and standard values.

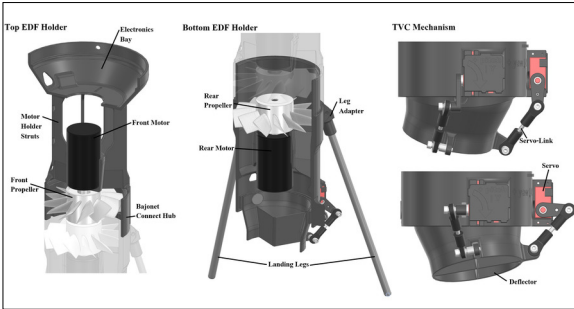
Result: The demonstrator has a final mass of 3.35 kg. The TVC mechanism achieves a max deflection range of ± 15 degrees, with an estimated deflection time, from 0 to 15 deg, of 40.21 milliseconds. The coaxial EDF setup reached a maximum measured thrust of 3.45 kg. This is only slightly above the required hover thrust of 3.35 kg and is therefore not sufficient for free-flight testing, where a safety factor of at least 1.75 is needed, due to deflection and acceleration. The limited thrust is mainly caused by losses in the inlet and outlet flow path, the electronics tower close to the intake, the printed propellers. Additionally, the test setup for thrust testing is not optimal and may not provide accurate data. The implemented LQR attitude controller could stabilize roll and pitch after manual deflections on the suspended test station, shown in Figure 1. The measured response had overshoot between 47-58 %, settling times between 2.6-3.5 seconds, and remaining steady-state angle error of less than one degree. The results show that the demonstrator, the thrust vector control mechanism, and the embedded attitude controller are functional. However, the main restriction is the limited thrust of the EDF setup.

Future work should focus on increasing the available thrust by improving the inlet and outlet flow path. The test station should also be adapted to better constrain translational motion and provide more reliable measurement data. This would improve the identification of the real system parameters, support a more accurate state-space model and improve controller performance.

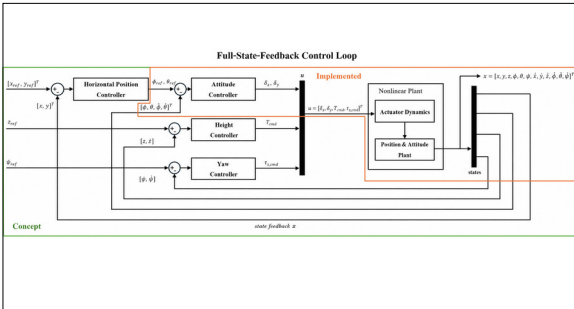
(1) Finished demonstrator with major components (CoM marked in red) and the test station (to the right). Own presentation



(2) Coaxial EDF setup consisting of the Top & Bottom EDF Holder and the Thrust Vector Control mechanism. Own presentation



(3) Implemented state feedback control-loop (orange) and concept (green) for the entire system. Own presentation



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Subject Area

Mechatronics and Automation Technology