eVTOL UAM 천이 비행을 위한 Tilt Schedule 최적화

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Optimal Tilt Schedule for eVTOL Tiltrotor Transition Flight

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Key Words : Tiltrotor (틸트로터), eVTOL (전기추진수직이착륙기), Transition Flight (천이 비행), Optimization (최적화), Tilt Schedule (틸트 스케줄)

Introduction

In this study, we propose a method for deriving a Tilt Schedule for stable and efficient transition flight of Tiltrotor eVTOL. Tiltrotor have the characteristic of transitioning between fixed-wing mode and multi-copter mode, and problems may arise with altitude loss or failure to reach the target speed depending on the specific tilt angle of the propulsion system and flight speed(1). To achieve stable transition flight, appropriate tilt angle adjustment according to the flight speed is necessary. Using optimization techniques, we derive the Tilt Schedule within the Tilt Corridor that represents the limited range of minimum and maximum flight speed values for a specific tilt angle based on the trim analysis results(2,3). This enables stable and efficient transition flight of Tiltrotor aircraft.

Main

Vehicle Modeling

The vehicle of this study is a scaled down model of a concept designed aircraft by the Aircraft Design Certification Research Institute at Konkuk University, which has a box wing and V-tail configuration. The vehicle has a total of four motors, two front motors that can change the direction of thrust and two rear motors fixed in the upward direction relative to the aircraft's body. Figure1 and Table1 below show the configuration and specifications of the vehicle, respectively.

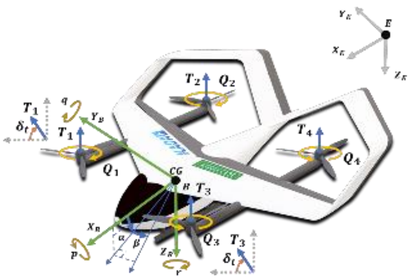

Figure 1 KP-2 Configuration

Table 1 Scale Down Model Specifications

Parameter	Value	Unit
Wing Area(S)	0.8	m^2
Wingspan(b)	1.62	m
Wing Mean Chord Length($\bar{c}$)	0.32	m
Mass(m)	14.28	kg
X Direction Length CG to Motor(l_x)	0.4997	m
Y Direction Length CG to Motor(l_y)	0.45	m
Z Direction Length CG to Motor(l_z)	0.1512	m
Maximum RPM(ω)	10000	rpm

The propulsion system of the vehicle uses Brushless DC (BLDC) motors and fixed-pitch propellers. For the motor thrust database, the Blade Element Moment Theory (BEMT) was used to construct a Table Look-Up (TLU) format database for thrust, torque, and power based on the inflow velocity and motor rotational speed. For the aerodynamic database of the aircraft, a high-fidelity TLU format database was constructed by data fusion a small amount of CFD data and a large amount of AVL data. For transition flight, analyzing the longitudinal direction that significantly affects altitude, attitude, and speed is common. Therefore, the aerodynamic coefficients were constructed for only the longitudinal direction for static stability coefficient being based on the angle of attack and the control stability coefficient being based on the angle of attack and the tail control surface. The following are the coefficient equation and the aerodynamic equation summarized for the longitudinal direction coefficient.

$$\begin{cases} C_D = C_D(\alpha) + C_D(\alpha, \delta_{ruddervator}) \\ C_L = C_L(\alpha) + C_L(\alpha, \delta_{ruddervator}) \\ C_m = C_m(\alpha) + C_m(\alpha, \delta_{ruddervator}) \end{cases} \tag{1}$$

$$\begin{cases} D = \frac{1}{2}\rho V^2 S C_D \\ L = \frac{1}{2}\rho V^2 S C_L \\ M = \frac{1}{2}\rho V^2 S \bar{c} C_m \end{cases} \tag{2}$$

Through the above process, the vehicle model was constructed using the derived models. The vehicle model components include propulsion, aerodynamics, and gravity models, and they were summarized in earth coordinate system in the longitudinal direction as follows:

$$\begin{cases} \Sigma F_{X_E} = -\frac{1}{2}\rho V^2 S C_D + \cos(\theta+\delta_t)(T_1+T_3) - \sin(\theta)(T_2+T_4) \\ \Sigma F_{Z_E} = W - \frac{1}{2}\rho V^2 S C_L - \sin(\theta+\delta_t)(T_1+T_3) - \cos(\theta)(T_2+T_4) \\ \Sigma M_{Y_E} = \frac{1}{2}\rho V^2 S\bar{c} C_m - (l_x \sin\delta_t - l_z\cos\delta_t)(T_1+T_3) - l_x(T_2+T_4) \end{cases} \quad (3)$$

Tilt Schedule

Trim analysis for the longitudinal direction was conducted for Steady-Level Flight, which maintains altitude, attitude, and flight speed. It was analyzed for flight speed, angle of attack, and tilt angle according to the operational range of the vehicle. In the analysis process, Tilt Corridor, which represents the minimum and maximum flight speed limits for a specific tilt angle, was derived. The Tilt Schedule in the Tilt Corridor ensures stability during the transition process. However, flight efficiency during the transition cannot be guaranteed. Therefore, to obtain an efficient Tilt Schedule within the Tilt Corridor, it is necessary to set an objective function that optimizes the desired goal and connects the points that satisfy it to form a Tilt Schedule. Performing trim analysis over the entire analysis area for this process takes a considerable amount of time. Thus, GA (Genetic Algorithm) was applied to reduce the time required by excluding unnecessary analyses. The optimization function in this process is a function that conducts trim analysis for flight speed and angle of attack at a specific tilt angle, and the objective function was set to minimize motor power while considering energy efficiency. Figures 2 and 3 and Table 2 below show the results of obtaining Tilt Schedule within the Tilt Corridor and GA's setting parameters.

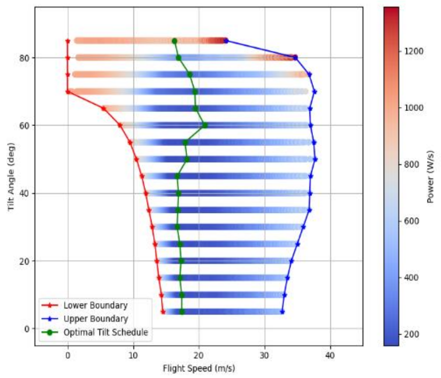

Figure 2 Tilt Schedule with Power

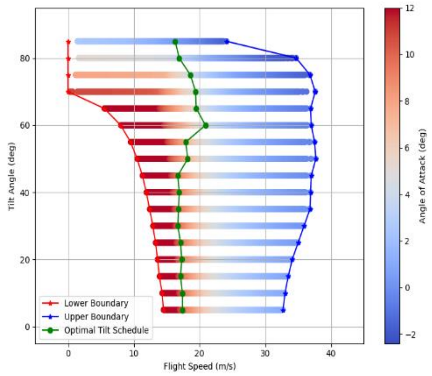

Figure 3 Tilt Schedule with Angle of Attack

Table 2 Genetic Algorithm Parameters

Parameter	Value
Number of Variables	2
Population Size	100
Max Generations	50
Mutation Rate(%)	0.1(10%)

Conclusion

this paper studied the method of obtaining Tilt Schedule based on trim analysis for Steady-Level Flight using optimization techniques for stable and efficient transition flight of Tiltrotor aircraft. In the process, a Tilt Schedule that ensures stable and efficient transition flight was derived. As a result, a more optimized Tilt Schedule was obtained with less time consumption compared to the existing method of deriving Tilt Schedule using only trim analysis.

Future Work

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