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Numerical Investigation for the Longitudinal Stability of the Quad Tilt Propeller UAV

Y. Lee*, J. Choi* and C. Kim*
Corresponding author: cwkim@kari.re.kr

* Aerodynamics Group, Korea Aerospace Research Institute, Daejeon, Republic of Korea

1 Introduction

Multicopter driven by several propellers has been widely used since it has excellent flight stability. However, multicopter has difficulties in long range flight and high speed flight due to the limitation of battery capacity and low flight speed. To overcome these problems, quad-tilt propeller (QTP) unmanned aerial vehicle (UAV) is being developed. QTP equipped with four propellers, uses the propellers for vertical take-off, landing and hovering, and tilts forward for high speed cruise. The propeller is driven by electric motor powered from battery or hybrid propulsion system composed of generator and internal combustion engine. Increasing the fuel amount of the hybrid engine leads to the long endurance of the UAV.
The configuration of the QTP is shown in Fig. 1 and the center of the mass coincides with the center of the thrust lines of the propellers at hovering mode. However, coinciding the center of mass with the center of the thrust lines causes additional difficulty in occupying the longitudinal stability at cruise mode. At the presentation, attempts to occupy the longitudinal stability of the QTP will be introduced and the effect of the wake from the front propellers on the stability also will be analyzed. Finally, strategies to occupy the stability will be discussed.

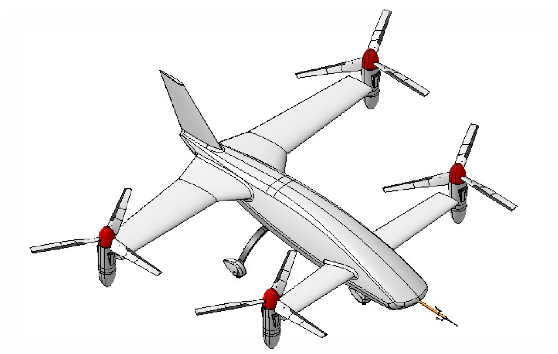

Figure 1: Configuration of QTP at vertical mode

2 Numerical results of unpowered model

The numerical analysis was attempted, first of all, for the unpowered model at cruise mode. Total number of surface grid amounts to 256,400 and the volume grid is 24,630,000. Fluent v.12.1 was utilized for the simulation. Fig.2 shows the pressure coefficient contour of the UAV, low speed contour around the vehicle and aerodynamic characteristics. The angle of attack is 10 degree which is slightly above the stall angle which is assumed to be 8 degree. The separated flow from the front wing deteriorates the aerodynamic characteristics of the rear wing. The longitudinal stability of the vehicle can be determined from the pitching moment distribution. The recommendable pitching moment distribution is that pitching moment is close to zero at the cruise angle of attach and decreases linearly versus angle of attack or lift. Fig.2, right shows lift, drag and pitching moment coefficient distribution. Pitching moments of angle of attack between 0 and 6 are negative and slope versus angle of attack is very shallow. Therefore, control surface should be actuated to occupy the trim condition and longitudinal stability.

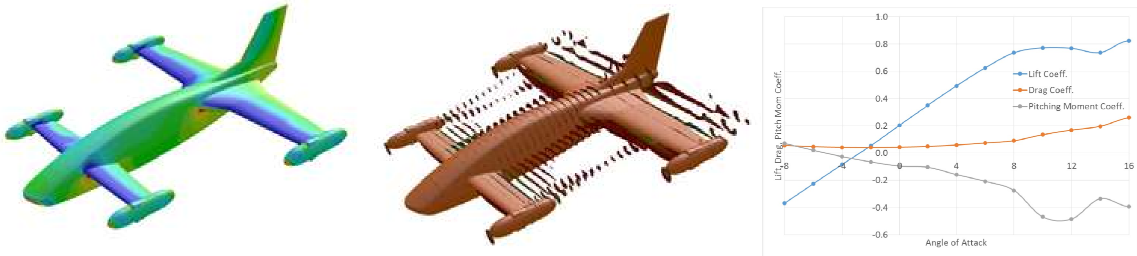

Figure 2: Numerical results of unpowered model, left: surface pressure contour, center: low speed contour around vehicle, angle of attack=8^o, right: aerodynamic characteristics

To observe any variation of the pitching moment distribution, front and rear wings were moved vertically as shown in Figure 3. Front wing was lowered and rear wing was moved high in Type-01 and front and rear wing were moved high in Type-02. Rear wing was lowered in Type-3. Surface and volume grids were prepared at same quality and simulation procedures were consistent.

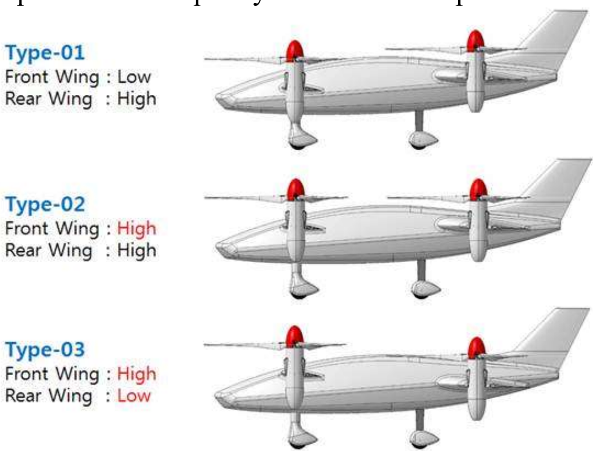

Figure 3: Vertical position variation of front and rear wing. Type-1: low front wing & high rear wing, Type-2 : high front wing & high rear wing, Type-3 : high front wing & low rear wing

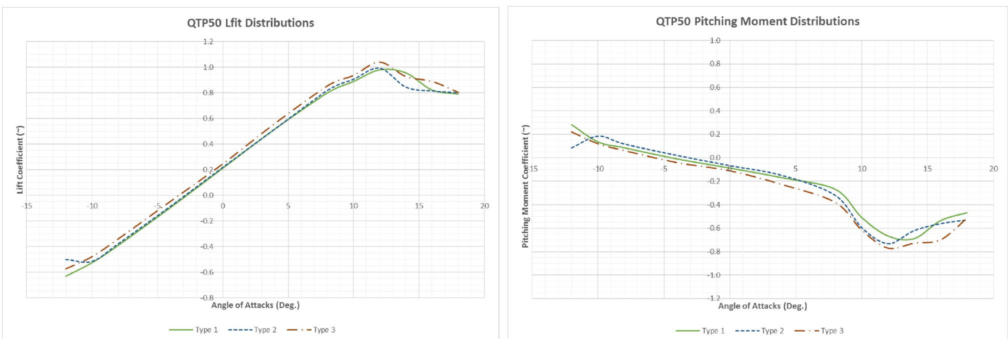

Figure 4: Lift and pitching moment distribution versus angle of attack for vertically varied front and rear wing positions

Figure 4 presents lift and pitching moment coefficient distributions of type-1, 2 & 3. Although pitching moment coefficients are different from each others, the deviations are minor. Furthermore slopes of the distribution are almost identical and present same longitudinal stability characteristics.

To investigate pitching moment characteristics of QTP UAV, the rear wing was modified slightly. The incidence angle was increased from 0 degree to 1 degree but the wing area was decreased from

0.629 m^2 to 0.579 m^2. This change decreased the lift of the rear wing and the contribution of the rear wing to the negative pitching moment. Therefore, the pitching moment is constant at angle of attack

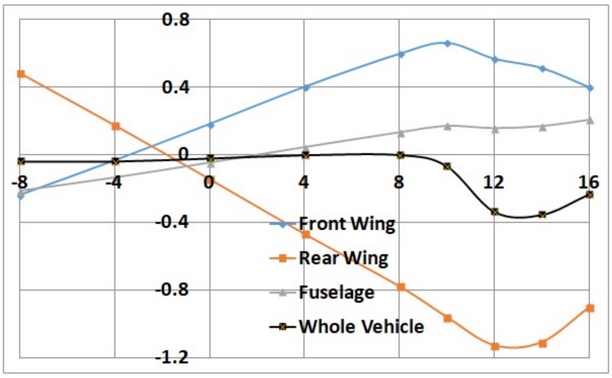

Figure 5: Pitching moment distribution for the decreased area and increased incidence angle of rear wing

between -8° and 8°, and the value is close to zero(Figure 5). Analysis of the decreased rear wing area leads to deteriorate the longitudinal stability and return to the original configuration.

To analyse the effect of the control surface (front and rear flaps) on the longitudinal stability, numerical simulation with deflected control surface was continued. Control surface deflection increases the lift of the UAV and helps to obtain the high lift, but does not change the lift slope versus angle of attack and pitching moment slope. Pitching moment distribution is shown in Figure 6 and pitching moments are almost parallel with some deviations. At a certain angle of attack, pitching moment can be changed and UAV can be controlled by flap deflection but the UAV does not contain its own stability characteristics.

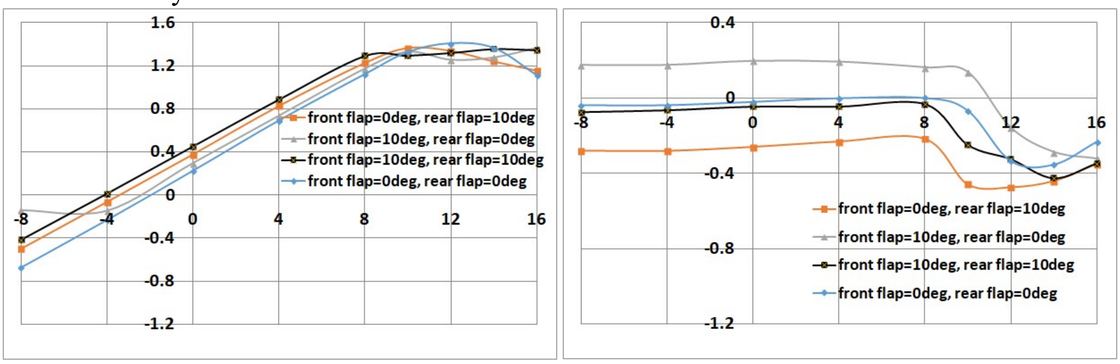

Figure 6: Lift(left) and pitching moment(right) coefficient distribution with deflected flaps

3 Numerical results of powered model

Fig. 7 & 8 show the numerical results of the powered model. The propeller was rotated with sliding mesh technique. Numerous iteration was performed to obtain the statically converged solution. The wake from the front propeller and wing, affects on the aerodynamics of the rear wing and propeller. Therefore the rear wing upper surface presents very distinct pressure contour. The outboard of the wing around nacelle reserves very low pressure (very blue color) compared to the inboard area. The inboard area is affected by the wake from the front wing and the incoming flow angle to the rear wing is reduced. Thus the flow with reduced angle of attack makes relatively high pressure and low lift.

Figure 8 compares the power effect on the aerodynamic characteristics of QTP at cruise mode. They compare the lift and pitching moment of unpowered model, powered model including and excluding (dotted line) propeller aerodynamics. Lift comparison is shown in Figure 8, left. The propeller rotation does not change the value and slope of the lift generated on the UAV but increases the stall angle and max lift. Including the aerodynamic force of the propeller does change the value and slope of the lift. The pitching moment coefficient excluding propeller aerodynamics shows very similar slope with the unpowered model but the pitching moment was reduced. Including the propeller made the pitching moment flat and UAV neutrally stable.

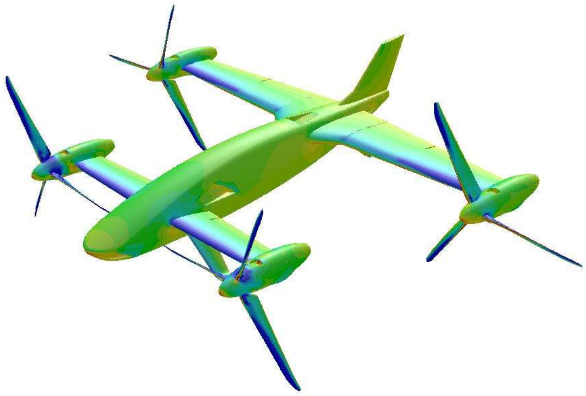

Figure 7 : Pressure contour of powered model, blue : low pressure

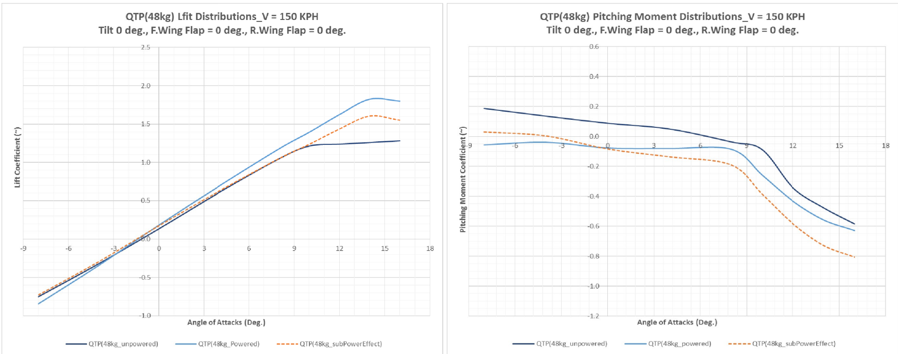

Figure 8 : Numerical results of powered model, left: lift coefficient, right: pitching moment coefficient

4 Conclusions

QTP was simulated to occupy the longitudinal stability at cruise mode but it was turned out to be very difficult to design the vehicle longitudinally stable with center of gravity coincident center of thrust line. Increasing the rear wing area may be a choice but large wing increases the weight of the rear part of vehicle. Another choice is move the center of gravity forward to maintain longer arm length of the rear wing and increases the amount of nose down moment.

References

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[2] Y. Chang, J. Hur, N. Lee, S. Lee and Y. Park, Comparative Study on the Prediction of Aerodynamic Characteristics of Aircraft with Turbulence Models, 2017 Asia-Pacific International Symposium on Aerospace Technology