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Research Article

Minimizing deflection on the yaw axis on VTOL type air-vehicles with three rotors

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ABSTRACT

This study provides an effective solution to the problem of deflection on yaw axes of air-vehicles capable of three-rotor Vertical Take-Off and Landing (VTOL). Most VTOL aircraft are produced with five rotors in national context. Four of these rotors are used for landing and taking off and are positioned to balance each other. The other rotor is positioned to fly with fixed wings. Therefore, no deviation in the yaw axis is experienced during descent-off. Three rotor VTOL configurations are available as an alternative to five rotor VTOL air-vehicles. This study is available through the three rotor VTOL prototypes that we have developed. The biggest drawback of three rotor VTOLs is the instability due to the position of the rotors during takeoff. This instability has been eliminated and three rotor VTOLs have been more advantageous than other configurations.

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Authorship contribution statement for Contributor Roles Taxonomy

Kürşat Çiçin: *Writing - original draft, Investigation, Visualization, Conceptualization, Methodology, Software, Formal analysis.* **Emrehan Yavşan:** *Visualization, Supervision, Writing – review & editing.*

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1. Introduction

VTOL type aircrafts are hybrid vehicles that can travel vertically, take off and move off, like fixed wings. VTOL type aircraft can be easily used in civilian and military areas due to reliability and lack of track requirements. NASA's UAM (Urban Air Mobility) [1] project and the KAIA (Korea Aerospace Industries Association) civil aviation works [2] are available to accelerate urban transport research in civil aviation. Most of the work on VTOLs with tilt rotor mechanism is theoretical work [3-5]. There are also different types of VTOL studies conducted nationally [6]. Very few of these studies have been conducted on the tilt rotor. VTOL type air vehicles are divided into tilt rotor (movable rotor) and non-tilt rotor (motionless rotor). Tilt rotors save energy and cost. This operation is based on the VTOL type with three rotors and a tilt mechanism. The moment produced by three rotors during vertical descent and departure causes a deviation in the yaw axis due to the position of the rotors. The tilt motors are given more than 90° angles during vertical descent to remove the deflection. The position of the motors during the vehicle's fixed wing flight is accepted by 0°. The rotors are positioned depending on the condition of the deviation during descent-off. The flight controller determines the degree required for this location. The flight tests have shown that the deviation in the yaw axis has been corrected.

1.1 VTOL (Vertical Take-off and Landing)

Drones (UAV) are divided into three fixed wing, rotary wing and hybrid (VTOL). VTOL type drones fly as rotating blades, as a fixed wing during vertical descent and travel. With this feature, it doesn't need a track to land. It can track as a fixed wing or rotary wing on the speed of the target during target tracking. In hazardous situations when flying, the VTOL can switch to rotary wing mode and safely land. The main drawbacks of the VTOL type are the cost and weight of energy consumption and the number of motors.

1.2 VTOL types

VTOL type air vehicles are categorized according to the condition of the rotors. These categories are shown in Figure 1. SUAVI for tailsitter type of non-tilt multicopter rotor category [7] and Mirac K. Aksugur's [8] operation can be shown as an example.

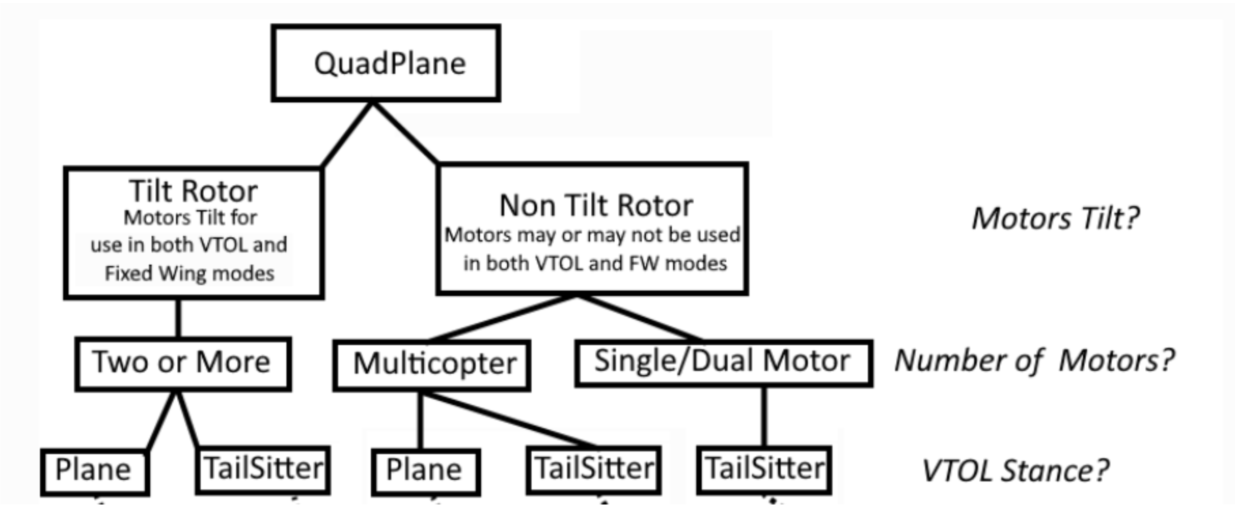

Fig. 1. VTOL types according to rotor conditions [9]

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The rotating part of the electric motors is called the rotor. Figure 2 shows the rotor part of an electric motor.

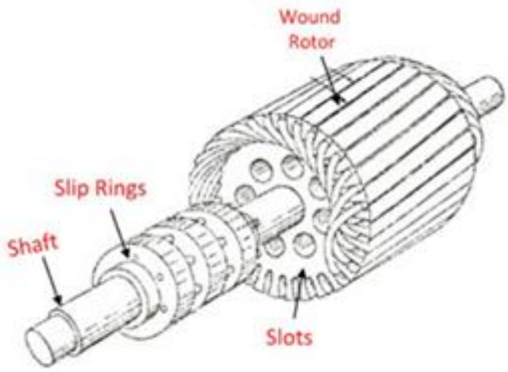

Fig. 2. Engine structure [10]

The rotors can be split into tilt and non-tilt. Non-tilt rotors are also divided by the number of rotors. They are divided into multi-rotor (multicopter) or single/double rotor (single/dual rotor). Most VTOL type vehicles are designed in the multi-rotor category of the non-tilt lever. Using five rotors, one rotor is fixed for the fixed wing flight mode. VTOL named Tuğberk was given as an example in Figure 3. These types of VTOLs are preferred more frequently due to ease of manufacture and compliance with most tasks.

Fig. 3. Tuğberk

2. VTOL with Three-Rotor Tilt Mechanism

The three rotor VTOL vehicle, Tulpar, used in this study, is given in Figure 4. Tulpar has a total weight of 4 kg. The flight time is 30 min and the travel speed is 18 m/s. It can fly both as a rotary wing and a fixed wing. Tulpar is designed with three rotors to minimize weight and power consumption, and the two leading rotors work on both swivel and fixed wing flights. it falls into the plane category with tilt mechanism. The moving rotors are 920 kv and can produce a maximum of 2360g impulse power with 11x5.5-inch propeller at 14.8V.

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Fig. 4. Tulpar

2.1 Configuration types

VTOLs with three rotors have two different frame combinations. These combinations are shown in Figure 5. The same orientation of the cruise propeller increases the yaw axis drift problem that we will refer to in the following section (Title 2.2). Installing fixed wing propellers to absorb each other slightly reduces the deflection on the yaw axis. For this reason, Tulpar has been selected as in configuration Type-2.

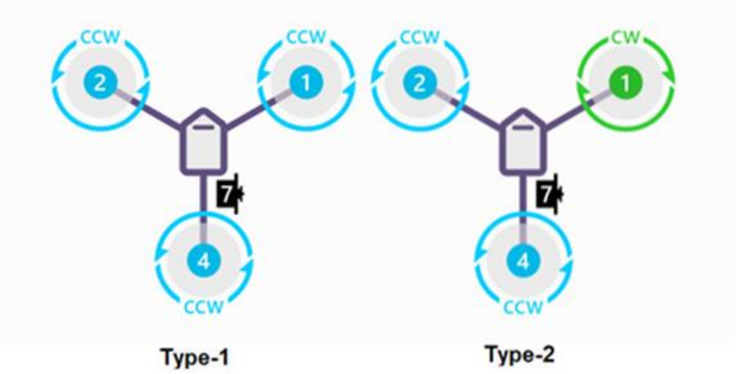

Fig. 5. Propeller direction configurations [11]

2.2 Yaw axis deviation

On flights with Tulpar, it has been observed that the yaw axis deviation occurs during vertical descent approach. The cause of this problem is caused by the momentum produced by the rotors. Fitting the propellers of the two front rotors in the opposite direction absorb the torque of the motors/rotors. Yaw axis deviation occurs because there is no moment in the tail section that dampens the rotor.

2.3 Presentation solution methods for instability

There are two methods for resolving instability on the yaw axis. The first of these methods is to move the tail part. With the moving tail section, instability in the yaw axis will try to dampen by moving the tail pipe. The moving tail section can affect the stability of the vehicle and create a safety issue when flying in a fixed wing mode. Locking of the servo used for travel under load or failing to reach the desired position by noise can cause the vehicle to fall. This method is not preferred due to security issues.

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Another method is to give the moving tilt mechanisms an angle greater than 90° when takeoff. This method can save cost and weight. The angle provided also does not create any safety problems during flight as it will only be valid in drone mode.

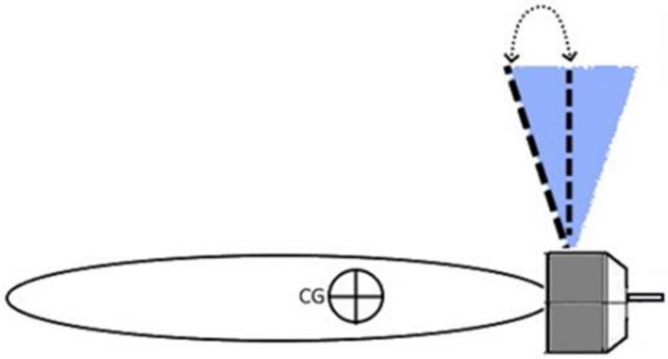

Fig. 6. Positioning the rotor for the vehicle [4]

Figure 6 shows the tilt mechanism on Tulpar. Figure 6 is a symbolic representation. Shows the position of the rotors accepted by 90° and the maximum position of the rotors. CG (Center of Gravity) represents the center of gravity of the vehicle.

2.4 Adjusting the angles of the tilt rotors

The angle of the tilt mechanisms is determined by test flights. After test flights, the logs (flight logs) that the flight computer have been reviewed. The flight logs have analyzed the vehicle's compass data, looking at the amount of deviation of the axes during the vehicle's vertical descent. The maximum tilt angle value of the tilt mechanism is determined according to the amount of deviation. The specified value is defined in the flight controller and the vehicle's rotors are assured that they do not exceed those values during flight. The value given is of the degree. If this value is kept too low, the VTOL will not be able to compensate for the deviation in the yaw axis and will start to rotate around its axis during vertical descent-off. If this value is held too high, the vehicle will react abrupt and overly to deviations in the yaw axis. Following the flight tests, this value for Tulpar was determined by 13° on the graph in Figure 7.

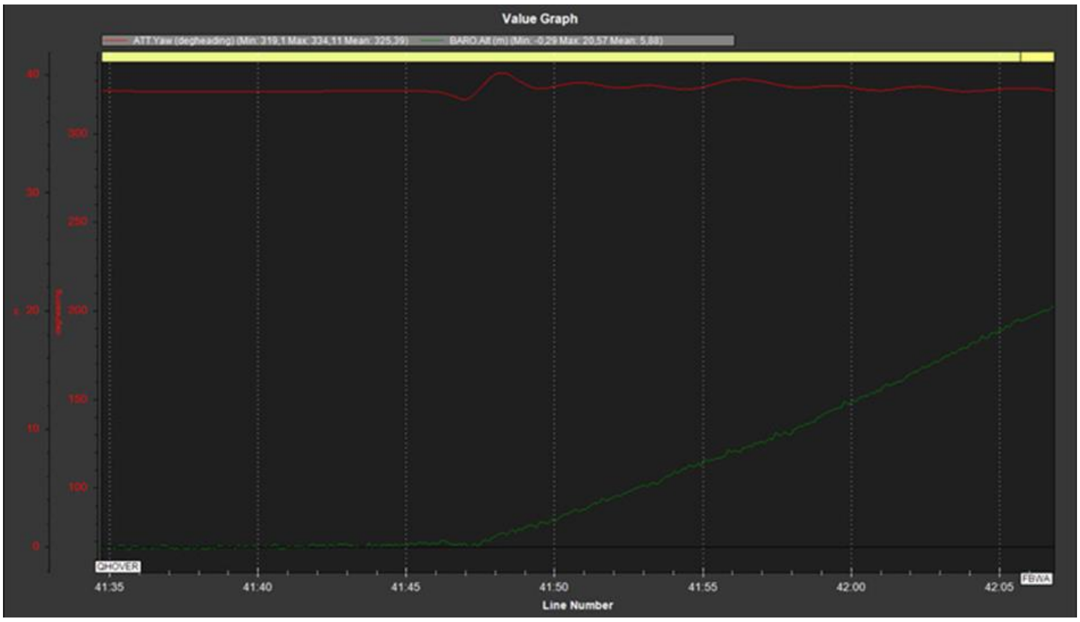

Fig. 7. Altitude and yaw axis graph

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In Figure 7, the red line gives the status of the yaw axis in degrees. The green graph gives the value of the height in meters according to the vehicle's starting position. The X-axis shows the time in seconds, the right column on the Y-axis shows the degree on the yaw axis, and the left column shows the height in meters. The lower left-hand side shows the vehicle is in “QHover” mode, which is the takeoff mode. A small amount of deviation is visible as soon as the vehicle is off the ground. The graph continued decisively. The maximum degree of tilt is 13° when flying. The graph shows that this value is the best value for Tulpar.

5. Result

In this study, the yaw axis deviation of VTOLs with three rotor tilt mechanism has been corrected. The solution is an alternative to five common rotor non-tilt VTOLs. Compared to the five rotor VTOLs, the two leading rotors work as both swivel wings and fixed wings saving a lot of cost and weight. The work conducted will contribute significantly to the choice of three rotor VTOLs with tilt mechanism. Another disadvantage is that energy consumption continues.

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