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# Dynamic Simulation of Tilted Rotor Quadcopter

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***Abstract*: *Application of quadcopter unmanned aerial vehicle (UAV) has already become common today. As the name suggests, quadcopter has four rotors and these rotors can be classified into two types: fixed and tilted rotors. The maneuvering of quadcopter using the fixed rotor is achieved through the thrust differential. On contrary, a tilted rotor can be rotated or tilted and the resultant thrust component will move the quadcopter longitudinally. In this study, the dynamic behavior of HMF SL300 tiltrotor quadcopter is analyzed through simulation. The study is limited to longitudinal behavior of the HMF SL300 tiltrotor quadcopter in z- and x-axis. A Simulink model has been developed based on the longitudinal dynamic model of the quadcopter and acceleration, velocity and displacement of the quadcopter in z- and x-axis when the tilt angle is varied are presented. Based on the findings from the simulation, it can be concluded that the higher the tilt angle, the higher the rate of motion in x-axis but the lower the rate of motion in z-axis.***

***Keywords*: *quadcopter, HMF SL300, tilted rotor, dynamics, Simulink.***

## I. INTRODUCTION

Modern unmanned aerial vehicles (UAVs) are becoming more intelligent than ever and has gradually taken the role of an indispensable human assistant [1]. In general, UAVs can be effectively divided into four categories according to their geometric configuration: fixed wing, rotorcraft, flapping wing and other unconventional UAVs [2]. A quadcopter, which is classified under the rotorcraft category, is a flying vehicle that is consisted of four motors located at the corners of its square body. There are many shapes of the quadcopter airframe that contains two, four, six or even eight arms to hold the motor and form a shape. For instance, the H-shape airframe has two arms at both the front and the back of the body. At the corner of each arm, there is a motor that will spin the propellers.

The motion of the quadcopter in six degrees of freedom is controlled by varying individual rotation-per-minute (rpm) of its four rotors, thereby changing the lift and rotational forces. In view of this, the quadcopter will tilt towards the direction of the slower spinning motor, which allows it to roll and pitch.

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The roll and pitch angles divides the thrust into two directions due to which the linear motion will be achieved [3]. The basic dynamical model of the quadcopter is the important starting point for the conduct of further studies but the more complex aerodynamic properties have to be introduced as well [4]. At the moment, several control methods for quadcopter have also been investigated including the research works presented in [5]–[8]. The control of quadcopter is difficult and interesting issue since its flight dynamics are highly nonlinear, especially if the complex aerodynamic effects are taken into account [9]. Today, the quadcopter drone is probably one of the most sought-after theoretical concepts to be explored and used. The quadcopter's frame is symmetrical, light and thin construction of propulsors. Propulsor motors and propellers are connected directly and all propulsor axes are fixed and parallel [10]. In most of the quadcopter, only the motor speed is controlled and this means that attitude and altitude that the system produced are based solely on the motor propeller speed [11]. The focus of the study reported in this paper is on the investigation of the dynamic longitudinal behavior of tiltrotor quadcopter through a conducted simulation study.

## II. METHODOLOGY

As shown in Fig. 1, the HMF SL300 tiltrotor quadcopter is the model to be investigated in this study, which is available in the market. Furthermore, Table I and also Fig. 2 present the parameters of the quadcopter with the value or dimension that are being used in the dynamic analysis.

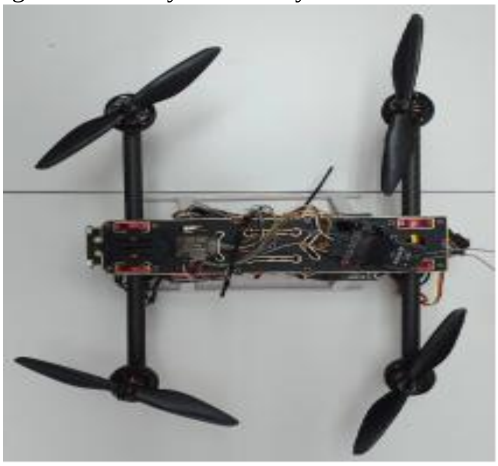


**Fig. 1. HMF SL300 tilted quadcopter**

**Table-I: Parameters of the analyzed quadcopter**

| Parameters | Dimension |
|---|---|
| Mass of quadcopter | 0.660 kg |
| Mass of each motor | 0.022 kg |
| Mass of each arm rod | 0.030 kg |
| Length from motor to motor | 0.300 m |
| Radius of propeller | 0.0765 m |

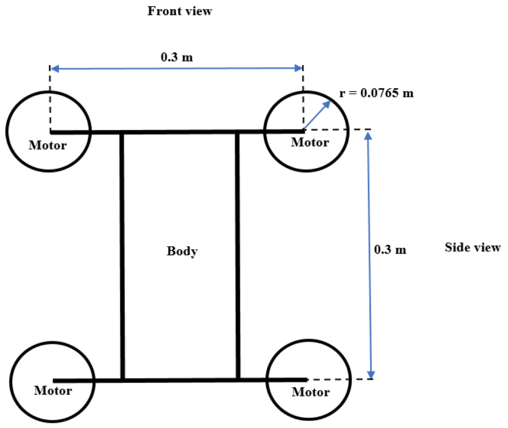



**Fig. 2. Dimensions of the quadcopter in this study**

For the investigation of the dynamic longitudinal behavior of this quadcopter, the considered movement due to tilting of its rotors is in x-direction and z-direction only. There is no angular motion as the moment is too small and hence, it is not considered in the dynamic equations.

Fig. 3 and Fig. 4 illustrate the quadcopter system that will be referenced in constructing the related dynamic equations. The Newton's second law of motion states that acceleration and net external force are directly proportional to each other. On contrary, the relationship between acceleration and mass is inversely proportional. These conditions are highlighted in (1), where *F* is net external force, *a* is acceleration and *m* is mass.

$$\sum \vec{F} = m\vec{a} \tag{1}$$

Taking $\ddot{X}$, $\ddot{Y}$ and $\ddot{Z}$ as acceleration in *x*, *y* and *z* direction, respectively, then (1) can be rewritten as (2).

$$\sum \vec{F} = m\begin{bmatrix}\ddot{X}\\ \ddot{Y}\\ \ddot{Z}\end{bmatrix} \tag{2}$$

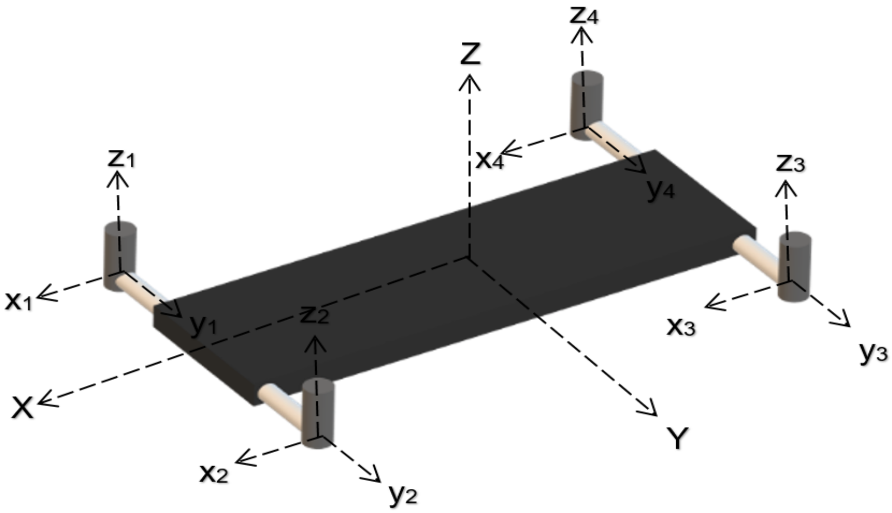



**Fig. 3. Body frame of the tiltrotor quadcopter under study**


**Fig. 4. Tiltrotor quadcopter**

Assuming that $ft_1$, $ft_2$, $ft_3$ and $ft_4$ are the thrust forces from each of the four rotors of the quadcopter, the forces in *x*- and *z*-axis can be determined. Note that the total force in *y*-axis is not considered in this study. With $\theta$ as tilt angle of the rotor, $\rho$ as the air density in kg/m$^3$, $v$ as the velocity of the quadcopter, $m$ as mass of the quadcopter, $g$ as gravitational acceleration, $C_D$ as the drag coefficient and $A$ as the cross sectional area, the calculation of the total force in *x*-coordinate,

$F_x$ and the total force in z-coordinate, $F_z$ can be made through the use of (3) and (4), respectively.

$$F_x = ft_1 sin\theta + ft_2 sin\theta + ft_3 sin\theta + ft_4 sin\theta - 0.5\rho v^2 C_D A \quad (3)$$

$$F_z = ft_1 cos\theta + ft_2 cos\theta + ft_3 cos\theta + ft_4 cos\theta - mg - 0.5\rho v^2 C_D A \quad (4)$$

By substituting these estimated values of forces $F_x$ and $F_z$ in (1), the acceleration of the quadcopter can be determined. The velocity is then evaluated through integration of acceleration equation and subsequently, displacement can be obtained by integrating the velocity equation.

After establishing all the necessary dynamics equations for the tiltrotor quadcopter, corresponding Simulink model can be built. It should be noted that in the simulation, the tilt angle is varied between 0° up to 30°. All required parameters for the simulation are highlighted in Fig. 5 whereas Fig. 6 illustrates a Simulink block diagram that represents dynamics equations for the tiltrotor quadcopter.

## III. RESULTS AND DISCUSSION

The results from the conducted simulation are tabulated in Table II, which show the obtained values for the quadcopter's acceleration, velocity and also displacement in *z*- and *x*-axis after 10 seconds of flight. As anticipated, when the tilt angle is zero, the movement is purely a vertical motion. Furthermore, it can be observed that as the tilt angle gets higher, the rate of motion in the x-axis has also increased. However, for the same condition, the rate of motion in z-axis actually becomes lower.

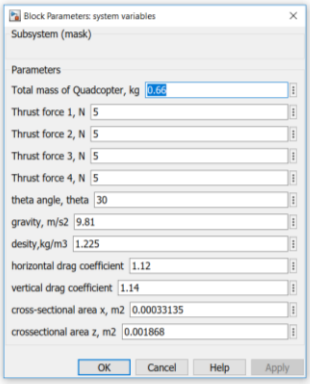



**Fig. 5. Parameters in constant value**

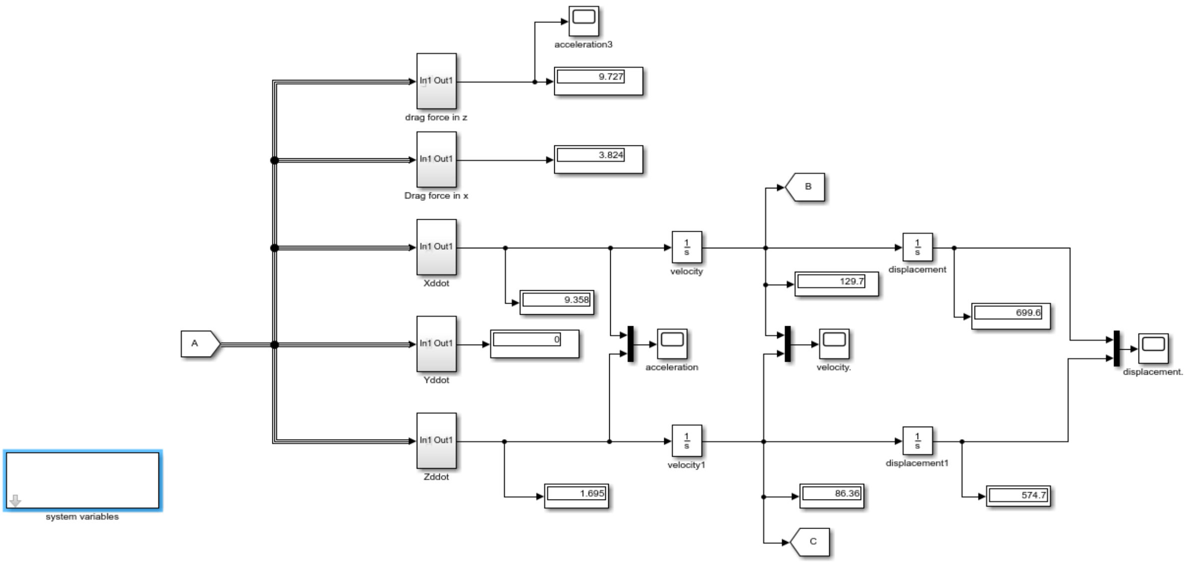


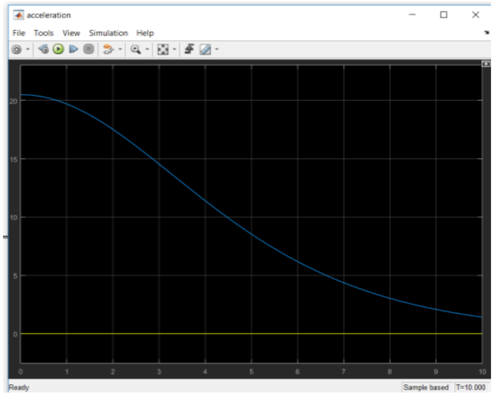

**Fig. 6. Simulink block diagram overview**

**Table-II: Simulation results for acceleration, velocity and displacement**

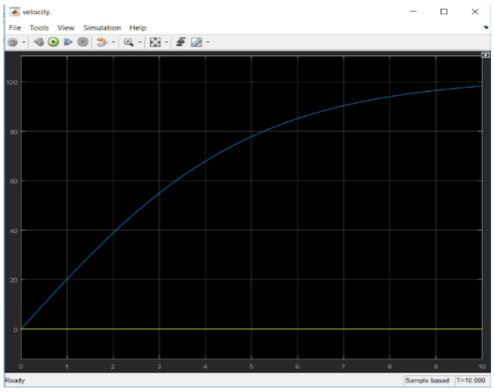
| Tilt angle (degree) | Acceleration in x direction (m/s$^2$) | Acceleration in z direction (m/s$^2$) | Velocity in x direction (m/s) | Velocity in z direction (m/s) | Displacement in x direction (m) | Displacement in z direction (m) |
|---|---|---|---|---|---|---|
| 0 | 0 | 1.413 | 0 | 98.26 | 0 | 676.5 |
| 10 | 4.413 | 1.444 | 49.66 | 96.99 | 255.5 | 665.4 |
| 20 | 7.395 | 1.536 | 92.85 | 93.1 | 490 | 631.9 |
| 30 | 9.358 | 1.695 | 129.7 | 86.36 | 699.6 | 574.7 |

Fig. 7 shows the acceleration, velocity, and displacement of the quadcopter up to 10 seconds of flight when the tilt angle is zero. The blue lines indicate motion in *z*-direction while the yellow lines indicate motion in x-direction. Meanwhile, Fig. 8 depicts the acceleration, velocity and also displacement of the quadcopter up to 10 seconds of flight when the tilt angle is 30 degrees.

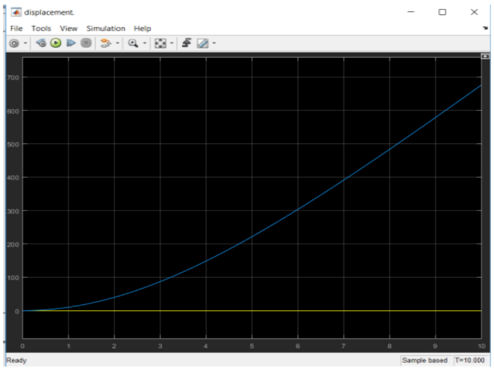
In similar manner, the blue lines indicate motion in *z*-direction and the yellow lines indicate motion in x-direction. By observing and comparing these two figures, it is clear that as the tilt angle gets higher, the rate of motion in the x-axis has also increased but on contrary, the rate of motion in the z-axis becomes lower.




**(a) Acceleration**

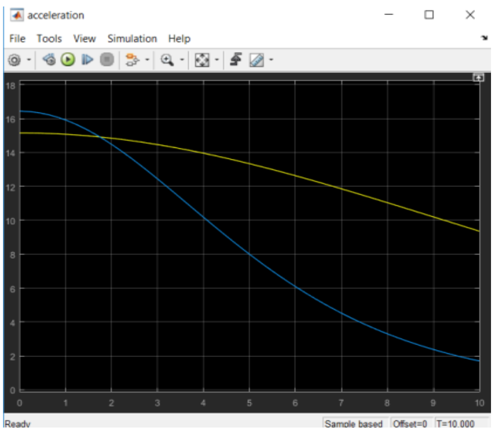



**(b) Velocity**

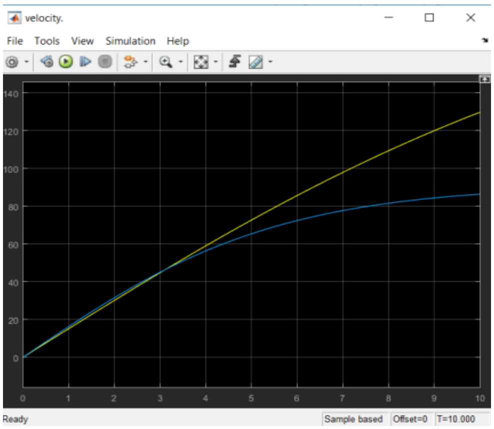



**(c) Displacement**

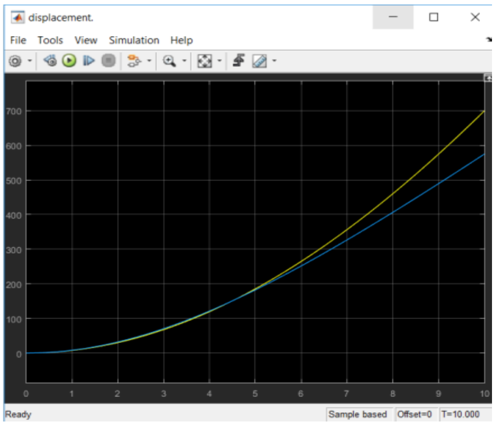
**Fig. 7. Simulation results when tilt angle is zero degree**




**(a) Acceleration**




**(b) Velocity**




**(c) Displacement**

**Fig. 8. Simulation results when tilt angle is 30 degrees**

## IV. CONCLUSION

Dynamic behavior in longitudinal mode of the HMF SL300 tiltrotor quadcopter has been observed through the simulation in Simulink. From the results of the simulation, it can be taken that there is a notable relationship between the tilt angle of the quadcopter and its resultant motion. The tilting of the rotors with no thrust differential will give no-rotational motion of the quadcopter. Moreover, at zero tilt angle, only a purely vertical motion is produced. It has been observed that as the tilt angle is increased, the rate of motion in *x*-axis becomes higher but the rate of motion in *z*-axis becomes lower.

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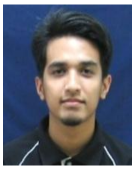

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