Stability of a Tilt Rotor Unmanned Aerial Vehicle

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Abstract **:** This research work focus on the stability part of a tilt rotor unmanned aerial vehicle. The work starts from the definition of tilt rotor mechanism and proceeding to the design of the same. Thrusters have been used to fly this aircraft both in helicopter mode as well as in airplane mode. Tilting the thrusters with servos will tilt the thrust vector associated with the thrusters. Keeping that principle in mind this research work has been carried out. So the positioning of thrusters explained in this paper adds a weight age to this research work. Rectangular wing is used to generate lift during the airplane mode made the design simple as well as effective.

The major step taken for the stability of the aircraft in helicopter mode, airplane mode as well as in the transition period is the design of the tail. The tail is designed in such a way that it can counteract any disturbances occurring in horizontal plain or vertical plane. The design of the tail makes this research paper work unique. Servos are used to tilt the whole tail which consists of horizontal stabilizer as well as vertical stabilizers. To define the stability this research work considered the contribution of the wing, fuselage and tail which together will define the longitudinal stability of the aircraft. The results after the stability calculations are more satisfying. From the results this research work concluding that the designed tilt rotor unmanned aerial vehicle will be stable in its flight.

Keywords—unmanned aerial vehicle, tilt rotor, stability.

I.INTRODUCTION

Tilt rotors are the type of hybrid next generation aircrafts where the aircraft lifts off from the ground like a helicopter and fly like an aero plane.

The main advantage of this type of configuration is that while it is operational in helicopter mode, vertical thrust helps the aircraft to put in the sky with less ground space requirements for takeoff and in aero plane mode, the horizontal thrust cruise the aircraft in desired direction where the wing produced to keep the aircraft in the desired altitude.

Unmanned aerial vehicles are becoming popular not only in the aviation sector but also in other sectors as well. Unmanned aerial vehicles are generally controlled by remotes through radio waves or programmed to fly automatically. If the UAVs are remotely operated than stability of the vehicle has to be maintained manually with great human efforts. If the UAVs are controlled and operated automatically, the stability of the vehicle is taken care by pre programmed micro controller.

The main purpose of the research work is to design a tilt rotor UAV so that it is stability during helicopter and aero plane mode.(Ferit Çakici, 2009). (K. Senthil Kumar et al, 2014)

II.DESIGN

2.1. Thrusters:

The tilt rotor UAV which is designed must contain two BLDC motors with propellers which will take care of the thrust during both phase of the operation. We can call the combination of the BLDC motors with propeller as thruster so the thrusters are generally used to produce the vertical thrust in helicopter mode and horizontal thrust in aero plane mode. These thrusters also help the UAV to maintain the altitude during transition phase. In the transition phase thrust vector is neither perpendicular nor parallel to the earth surface. So when the thrust vector is resolved in two components, these two components gives the vertical and horizontal trust which helps the UAV to maintain altitude as well as horizontal speed. Though there will be little loss of lift during this transition piloting and pre programming losses can be minimized but it can’t be nullified because gravity will affects the response time. These thrusters are regulated through BLDC electronic speed controller which regulates the voltage supplies by the battery and hence the speed of the motor. If the speed of the motor is changed i.e. RPM is changed, then the velocity contributing the thrust from the thrusters will change, this in turn affects the position of the UAV in the air. The BLDC electronic speed controller has three terminals namely position, height, and pulse signal. The pulse signal terminal being situated at the middle sends PWM signals to the BLDC motor which is responsible to change the voltage supplied to the motor for a particular time. The other two terminals positive and negative used to change the polarity of the motor. A polarity of the terminals plays a major role in the tilt rotor UAV as the direction of rotation need to be altered accordingly. This is done to counter the moment produced by the thrusters.

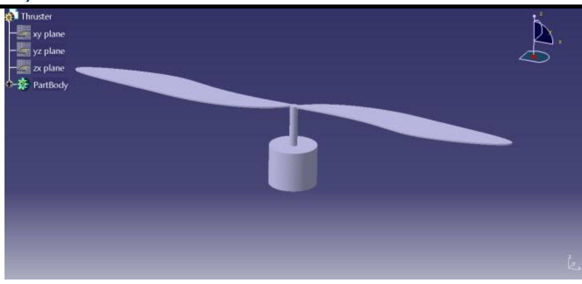

Fig. 2.1: Thruster designed in CATIA

2.2. Position of the thrusters:

In case of the tilt rotor UAV, position of these thrusters plays major role as it is going to decide the stability of the vehicle. In conventional aero plane the thrusters are generally placed below the wing near the centre of gravity, away from the fuselage line (in case of twin thrusters) to balance the vehicle as well as to move it forward by providing thrust. In conventional helicopter the thruster are placed at the top of fuselage near the centre of gravity. This helps to pull the vehicle up by pushing it through centre of gravity.

In case of tilt rotor design the thruster is not going to remain fixed but it is going to be tilted so that the thrust direction also get tilted as it is aligned in the direction of the axis of motor and propeller. So here the position of the thrusters means the position of the axis about which the thrusters are needed to be pivoted. The axis about which the wings are needed to be pivoted is kept near to the centre of mass. In this research work the first point is kept above the centre of mass at the end of the tip of the wings through this position it is easy for us to pull the weight, which is acting through the centre of mass in desired direction by tilting the thruster in that direction by aligning the thrust rotor in that direction.

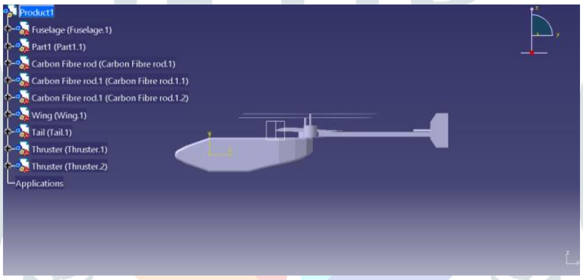

Fig. 2.2: Positioning of Thrusters

2.3. Fuselage:

The fuselage is made up of chloroplast material which will be carrying the electronic equipments like batteries, receiver, ESC's and other connectors. The electronic are placed at the aft end of the fuselage so that the thrusters can act from the aft end of the fuselage as centre of gravity is located there. The fuselage front part is given aerodynamics shape which help to cruise in aero plane mode. The fuselage will having the flat bottom and with no landing gear as the aircraft will take off and land vertically like helicopter .

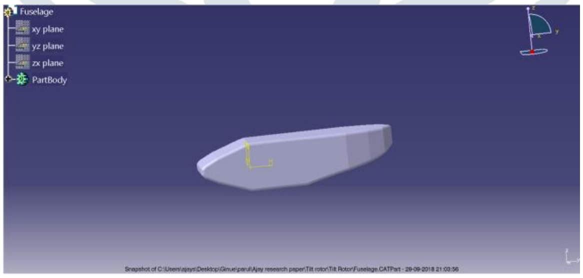

Fig. 2.3: Fuselage

2.4. Wings:

The wings will be rectangular wing with bell A821201 (23%) airfoil which is most suitable for tilt rotor aircrafts. The aircraft has flat bottom and stream lined top which helps the wing to float even when the trust direction is tilted at different angles. The wing will strengthen through main wing span which is made up of carbon fiber having square section. The pivots of the thrusters will be mounted at the end of the main wing spare through servo motors. This servo motors being situated at the end of the wingtips will tilt the thrusters in desire direction. The material used in the wing is acrylic foam. The skin of the wing is coated with taper to reduce the skin friction drag.

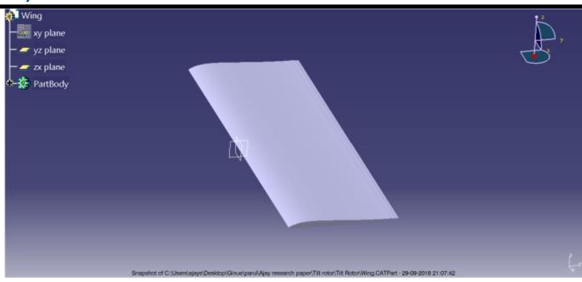

Fig. 2.4: Wing made in CATIA

2.5. T- Section:

The main wing spare and the bottom is made up of same material with same cross sections are connected with glass fiber reinforced plastic at the middle to form a T- section. The carbon fiber spar is attached to the glass fiber reinforced plastic plates through steel both and with the middle part of the 'T-section' is being situated at the aft of the fuselage through which connections goes to servo motors. The T- section is going to play major role in tilt rotor UAV as the moments about tail and wing is going to act along the axis of T-section only and the centre of gravity is going to be placed on the middle of the T-section only.

2.6. Tail:

This tilt rotor UAV will be having a horizontal stabilizer with no elevators on it and at the vertical stabilizers being situated at the ends of the horizontal stabilizers. The vertical stabilizers also will not be rudders. The tail part will be placed on the end of the tail boom of the T-section.

The uniqueness of the tail is that the whole tail can tilted up and down like an elevator. The horizontal stabilizer and vertical stabilizer itself will tilt up and down. The mechanism is done by servo motors mounted at the end of tail boom. The tail is made to tilt up and down because to provide stability at desired angle as thrust is also oscillating in different angle.

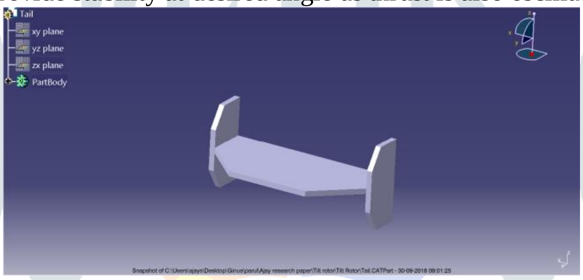

Fig. 2.5: Tail

III.METHODOLOGY

3.1. Stability:

If the forces and moments after the disturbances bring the aircraft back to the decided initial position we can call that the aircraft is stable. Depending upon the three axis system we can classify the stability as longitudinal stability, lateral stability and directional stability.

In this tilt rotor UAV, we can notice there is no aileron as well as rudder. Even the elevator is absent, but the whole tail can tilt up and down. These up and down motion of the tail will create the change and pitching motion above the lateral axis. So it contributes to longitudinal stability. This paper mainly focuses on the longitudinal stability of the aircraft.

The definition of longitudinal stability says that the plot between the coefficient of pitching moment about center of gravity with angle of attack should be linear as well as the slop must be negative. So after considering the stability of all the contributions of parts of aircrafts, if we achieve $\frac{dC_m}{d\alpha}$ as negative, the aircraft is said to have longitudinal stability. Also the value of Cm0 should be positive.

3.2. Wing contribution:

If we consider the wing contribution alone in the aircraft, then we need to place the center of gravity before the aerodynamic center, but since we need to consider tail contribution as well as the fuselage contribution, we may get the solution other way. To obtain wing contribution, we keep the thrusters in airplane mode. (Dr.Robert C Nelson, 1989)

$$C_{m_{0_w}} = C_{m_{ac_w}} + C_{L_{0_w}} \left(\frac{x_{cg}}{\bar{c}} - \frac{x_{ac}}{\bar{c}} \right) \qquad (3.1)$$

$$C_{m_{\alpha_w}} = C_{L_{\alpha_w}} + C_{L_{0_w}} \left(\frac{x_{cg}}{\bar{c}} - \frac{x_{ac}}{\bar{c}} \right) \qquad (3.2)$$

Where

$C_{m_{0_w}}$ is the coefficient of pitching moment at zero angle of attack of wing

$C_{m_{ac_w}}$ is the coefficient of pitching moment about aerodynamic center of plain

$C_{L_{0_w}}$ is the coefficient of lift at zero angle of attack of wing

x_{cg} is the distance between the center of gravity to wing's leading edge

x_{ac} is the distance between aerodynamic centers to leading edge

$\bar{c}$ is the chord length of the wing
$C_{m_{\alpha_w}}$ is the slop of the curve plot between coefficients of pitching moment with angle of attack of wing
$C_{L_{\alpha_w}}$ is the slop of the curve plot between coefficients of lift with angle of attack of the wing

3.3. Tail contribution:

In this tilt rotor UAV, tail contribution is very important as it will affect the C_{m_α} value much more than other contributions. For obtaining the tail contribution, we keep the thrusters in airplane mode; also the tail is not moved. Than in this case, the tail will be affected by the downwash created by the wing .(Dr.Robert C Nelson, 1989)

$$C_{m_{0_t}}=\eta V_H C_{L_{\alpha_t}}(\varepsilon_0 + i_w - i_t) \quad (3.3)$$

$$C_{m_{\alpha_t}}=\eta V_H C_{L_{\alpha_t}}\left(1-\frac{d\varepsilon}{d\alpha}\right) \quad (3.4)$$

Where
$C_{m_{0_t}}$ is the coefficient of pitching moment at the zero angle of attack of tail
η is the ration of the dynamic pressures of tail to wing, also called the tail efficiency
V_H is called the horizontal tail volume ratio
$C_{L_{\alpha_t}}$ is the slope of the curve plot between coefficient of lift with angle of attack of tail
ε_0 is the downwash angle at zero angle of attack
i_w is the angle made by the wing chord to the fuselage reference line
i_t is the angle made by the tail chord to the fuselage reference line
$C_{m_{\alpha_t}}$ is the slope of the curve plot between coefficients of pitching moment with angle of attack of tail
$\frac{d\varepsilon}{d\alpha}$ is the rate of change of downwash angle with angel of attack

3.4. Fuselage contribution:

The main purpose of the fuselage is to provide space for the electronic devices and to hold the wing and tail parts firmly. (Dr.Robert C Nelson, 1989) The perfect shape where the internal volume is maximum with least drag is a body which has larger length than the width or height. From Multhopp's method forC_{m_0} and C_{m_α} contribution of fuselage, we get

$$C_{m_{0_f}}=\frac{k_2-k_1}{36.55\bar{c}}\int_0^{l_f} w_f^{\,2}(\alpha_{0_w}+i_f)dx \quad (3.5)$$

$$C_{m_{0_f}}=\frac{x_2-x_1}{36.55\bar{c}}\int_0^{x=l_f} w_f^{\,2}(\alpha_{0_w}+i_f)\Delta x \quad (3.6)$$

Where
k_2-k_1 is the correction factor for the body fineness ratio
S is the wing reference area
$\bar{c}$ is the wing mean aerodynamic chord
w_f is the average width of the fuselage sections
α_{0_w} is the wing zero lift angle relative to the fuselage reference line.
i_f is the angle of incidence of the fuselage camber line relative to the fuselage reference line at the center of each fuselage increments.
Note-The incidence angle is defined as negative for nosed droop and aft upsweep
Δx is the length of the fuselage increments.

$$C_{m_{\alpha_f}}=\frac{1}{36.55\bar{c}}\int_0^{l_f} w_f^{\,2}\frac{d\varepsilon}{d\alpha}x\,dx \quad (3.7)$$

$$C_{m_{\alpha_f}}=\frac{1}{36.55\bar{c}}\sum_{x=0}^{x=l_f} w_f^{\,2}\frac{d\varepsilon}{d\alpha}x\Delta x \quad (3.7)$$

3.5. Total contribution:

$$C_{m_0}=C_{m_{0_w}}+C_{m_{0_f}}+C_{m_{0_t}} \quad (3.8)$$

$$C_{m_\alpha}=C_{m_{\alpha_w}}+C_{m_{\alpha_f}}+C_{m_{\alpha_t}} \quad (3.9)$$

If C_{m_0} is positive also C_{m_α} is negative the aircraft is said to be having longitudinal stability. (Dr.Robert C Nelson, 1989)

IV. CALCULATIONS

4.1.Weight estimation:

Table 1: Weight estimation of UAV

2 × BLDC motor = 320gm	Elevator = 100gm
2 × ESC = 80gm	Fuselage = 200gm
2 × Propellers = 40gm	3 × Servo motor = 60gm
1 Battery = 250gm	Receiver = 20gm
Carbon fiber tail boom = 300gm	Extras = 130gm
Total weight = 1.5 kg	

4.2.Airfoil Data:

The airfoil used in this UAV is Bell A821201(23%) FX-66-H-60, because most of the thrust vector is going to be away from the chord line. This airfoil has flat bottom surface and streamlined upper surface which helps UAV to float stably irrespective of thrust direction.

4.3.Propeller Data:

Propeller: Radius 12.7 cm

$$\text{Area} = \pi r^2 = 0.0507\ m^2 \qquad (4.1)$$

4.4.Different Contribution:

4.4.1.Wing contribution:

$$C_{m_{0w}} = C_{m_{acw}} + C_{L_{0w}}\left(\frac{X_{cg}}{\bar{c}} - \frac{X_{ac}}{\bar{c}}\right) = 0.00575 \qquad (4.2)$$

$$C_{m_{\alpha w}} = C_{L_{\alpha w}}\left(\frac{X_{cg}}{\bar{c}} - \frac{X_{ac}}{\bar{c}}\right) = 0.000133 \qquad (4.3)$$

4.4.2.Tail configuration:

$$AR_w = \frac{b^2}{s} = 4 \qquad (4.4)$$

$$\epsilon = 2\frac{C_{L_W}}{\pi AR_W} = 0.1592\ C_{L_W} \qquad (4.5)$$

Table 2: Downwash angle and C_L for corresponding AOA

α	C_L	ϵ
-5	-0.4	-0.0637
-3	-0.32	-0.0509
-1	-0.15	-0.0238
0	0.05	0.00796

$$\eta = \frac{1}{\cos\epsilon} = 1 \qquad (4.6)$$

$$V_H = \frac{L_t \times S_t}{s \times \bar{c}} = 0.5 \qquad (4.7)$$

$$\frac{d\epsilon}{d\alpha} = 0.006366 \qquad (4.8)$$

$$C_{m_{0_t}} = \eta V_H C_{L_{\alpha_t}}(\varepsilon_0 + i_w - i_t) = 0.0001592 \qquad (4.9)$$

$$C_{m_{\alpha_t}} = \eta V_H C_{L_{\alpha_t}}\left(1 - \frac{d\varepsilon}{d\alpha}\right) = -0.0019872 \qquad (4.10)$$

4.4.3.Fuselage Contribution:

$$C_{m_{0_f}} = \frac{k_2 - k_1}{36.5\ s\bar{c}}\int_0^{l_f} {w_f}^2(\alpha_{0_w} + i_f)dx = 0 \qquad (4.11)$$

$$C_{m_{\alpha_f}} = \frac{1}{36.5\ S\bar{C}}\int_0^{L_t} {w_f}^2 \frac{d\varepsilon_u}{d\alpha}\,dx = 0.000177 \qquad (4.12)$$

V.Results and Discussion

As we defined earlier the aircraft is said to have longitudinal stability, if the value of C_{m_0} is positive as well as the value C_{m_α} is negative. We can see that wing alone contribution has positive cmalfa. Also the fuselage contribution has positive C_{m_α}. But the tail contribution has larger negative C_{m_α} which pushes the overall C_{m_α} of the aircraft to negative. From that we can say that for an aircraft to be stable tail is very important. We even got the overall C_{m_0} of the aircraft to be positive. The values of C_{m_0} and C_{m_α} are found out to be

$$\boxed{C_{m_0} = 0.005909}$$

$$\boxed{C_{m_\alpha} = -0.0016772}$$

Since the overall C_{m_0} value of the aircraft is positive as well as the overall C_{m_α} value of the aircraft is negative we can conclude that the designed tilt rotor unmanned aerial vehicle will have a stable configuration during its flight.

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