BLOT OUT AND 3D MODELLING OF STRAIGHT CLOSE BY ABSENT AND DOCKING (VTOL) TILT QUAD ROTORRC AIRCRAFT

[1]B. V. SANDILYA, [2]SACHIN K. K, [3]SAMPATH K. P, [4]SANTOSH S. Y

[1,2,3,4]Mechanical Engineering Department JSS Academy of Technical Education, India
Email: [1]bvijaysandilya@gmail.com, [2]sachin962k@gmail.com, [3]sam2_kumr@ymail.com, [4]santoshyam92@gmail.com

Abstract: The traditional Fixed Wing RC aircraft requires a long runway. It is incapable of a vertical take-off and landing (VTOL) scenario. Also its maneuvering capability around objects is limited. This makes it inaccessible for certain applications. On the other hand the Rotary Wing Aircraft (Quadcopter or Helicopter) will have the VTOL ability but the disadvantage is its slow operational speed. Also the consumption of energy is greater than a Fixed Wing RC aircraft.The proposed tilt Quad Rotor Aircraft would be capable of the VTOL feature like a Rotary Wing Aircraft. It would also have features resembling a Fixed Wing Aircraft. Hence, the proposed solution would be a hybrid of a Quadcopter and a Fixed Wing RC Aircraft and will have the advantages of both Fixed Wing and Rotary Wing Aircrafts.

Keywords: Quad Rotor, VTOL, Design, RC Aircraft, Tilt Rotor.

I. INTRODUCTION

Traditionally in Fixed Wing Aircrafts, lot of research has been done to incorporate vertical take-off and landing (VTOL) feature and to increase the manoeuvrability of the fixed wing aircraft. The alternative was the Rotary Wing Aircraft which is more maneuverable and has the VTOL Feature. The Rotary Wing Aircrafts include the helicopter, tri-copter, quad-copter etc. The problem associated with Rotary Wing Aircrafts is that their efficiency and speed are on the lower side. Other problems like the retreating blade stall are also present. These disadvantages have to be removed or nullified.

Hence the solution to the above mentioned problems is a hybrid Aircraft. It will have the advantages of both the Fixed Wing and the Rotary Wing Aircrafts and to a large extent should be successful in removing their disadvantages. The V-22 Osprey was the first famous aircraft which incorporated the advantages of both fixed wing and rotary wing aircrafts. The concept used was the TILT ROTOR mechanism. Since then a lot of work was put into similar Hybrid Mechanisms.

The proposed Vertical Take off and Landing (VTOL) Quad Tilt Rotor RC Aircraft consists of 4 motors, and is a combination of a Fixed Wing Aircraft and a Quadcopter. It has higher efficiency and can attain higher speeds than a Quadcopter or Helicopter. As the name suggests, it houses the TILT ROTOR Mechanism.

In this paper, a detailed Design process and 3D Modelling of a VTOL Tilt Quad Rotor RC Aircraft has been shown. A prototype of the VTOL Tilt Quad Rotor RC Aircraft has been successfully fabricated to prove the concept.

II. DESIGN METHODOLOGY

2.1. Literature Survey

For the designing of a Tilt Quad Rotor Aircraft, a thorough literature survey of past fixed wing, rotary and Hybrid Aircrafts will provide valuable information to start with the design process. 31 different aircrafts with 2 kinds of parameters were considered for the survey. The first kind was the Aircraft parameters consisting of and the second were the Performance parameters. The relation between these 2 kinds of parameters was found out which will help in improving the overall efficiency of the aircraft and will also make the design process easy.

The parameters considered were:

1. Speed(m/s)
2. Range(km)
3. Endurance(hr)
4. Gross Weight(Kg)
5. Service Ceiling(m)
6. Wingspan(m)
7. Length(m)
8. Payload(Kg)

Certain graphs were then plotted taking 2 parameters at a time. Valuable information was then extracted depending on the graphs obtained.

2.2. Specifying Requirements:

The requirements of the proposed VTOL Tilt Quad Rotor RC Aircraft should be specified keeping in mind 2 aspects. The first aspect is to specify the requirements in such a way that they are practically feasible. This knowledge would be obtained from the literature survey conducted. The second aspect is the requirements should clearly explain the concept proposed.
The basic requirements are:

1. The main feature to be incorporated is the VTOL Feature.
2. The RC Aircraft should be highly maneuverable like a Quad-copter and
3. The RC Aircraft should be capable of carrying a payload of 1.5 Kg.
4. The maximum velocity should be approximately 25m/s.
5. The Aircraft should have high lift characteristics and
6. The Aircraft should possess improved safety and stability characteristics.
7. The wingspan should be approximately 1.5 m.

The reason for selecting 4 rotors rather than 2 rotors in the TILT Rotor Mechanism is to have higher stability and higher manoeuvrability which is absent if only 2 rotors are selected.

2.3. Total Aircraft Weight Estimation:

The approximate weight of the aircraft was estimated. This is a very vital step and it is the basis on which the entire design calculation is done. It is always better to design the Aircraft for a little higher weight than the estimated weight.

1. Payload Weight W_P = 1.5 Kg
2. Weight of Propeller = 0.05 kg
3. Weight of Motor = 4*0.2 Kg = 0.8 kg = 1 kg
4. Weight of controls = 0.3 kg
5. Weight of battery = 0.5 kg
6. Weight of structure = 1.5 kg

Therefore total take-off weight W_{to}= 4.85 Kg ≅5 kg

2.4. Wing Design:

Initially the wing loading has to be calculated.

$$W_l = W_{to} \div S \quad \text{(Eqn 1)}$$

Where S is the surface area of the wing in m^2.We find that because of 4 rotors and the tilting mechanism that is to be housed in the wing, the wing loading will be high. It will be between 20 to 30 kg/m^2. We select the wing loading as 25 Kg/m^2 for the proposed Aircraft.Therefore from equation 1, S is found to be 0.2 m^2.

Next the wing span 'b' in calculated in meters.

Aspect Ratio $AR = b^2/S$

Generally the Aspect ratio is dependent on the type of Aircrafts. Fighter jets have Aspect Ratios from 1-4. Normal Aircrafts have Aspect Ratios from 5-10. Gliders have high Aspect Ratios. They can be as high as 25. For the wing required to house the tilt rotor mechanism, the aspect ratio should be on the higher side for better gliding ability. This is to give utmost importance to safety in case of motor failure.addition. Hence we initially select AR = 10.

$$\therefore 10 = b^2/S$$

Therefore b = 1.414 m

We want b to be close to 1.5 m.

Therefore we fix b = 1.48m (± 0.02m)

Hence the actual Aspect ratio will be

$$AR = 1.48^2/0.2$$
$$AR = 10.952$$

To find root chord C_r :

Considering rectangular cross section:

$$S = C_r \times b$$
$$0.2 = C_r \times 1.48$$
$$\therefore C_r = 0.135 \text{ m}$$

To check Reynold's number R_e:

$$R_e = \frac{\rho V C_r}{\mu}$$

For air at STP:

$$\rho = 1.225 \text{ Kg/m}^3$$
$$V = 20 \text{ to } 25 \text{ m/s}$$
$$C_r = 0.135 \text{ m}$$
$$\mu = 1.7875 \times 10^{-5} \text{ Ns/m}$$

On substituting all the values, we get

For V = 20 m/s $\quad R_e = 1.84 \times 10^5$

For V = 25m/s $\quad R_e = 2.3 \times 10^5$

Hence even at maximum speed, $R_e \leq 2.3 \times 10^5$. Therefore the flow will be laminar. This shows that the calculations carried out so far are satisfactory.

To find Coefficient of Lift,

$$C_l = \text{lift}/(\frac{1}{2}\rho V^2 S)$$
$$\text{Lift} = \text{Weight} \times 9.81$$
$$\text{Lift} = 5 \times 9.81 = 49.05 \text{ N}$$
$$\therefore C_l = 49.05/((\frac{1}{2} \times 1.225 \times 25 \times 25)$$
$$\therefore C_l = 0.64$$

For Aerofoil Selection of Wing the following considerations should be taken into account:

- It should have high strength to house the tilting mechanism and 4 rotors. Hence it should be thick.
- High lift at lowest possible angle of attacks ≅ 0 degree.
- This is possible only for asymmetric aerofoil.

In the standard aerofoils given by NACA, GOE series suits the requirement very well. Hence we choose GOE 523 which has l/d ratio of 75 at 1.75 degrees angle of attack (AOA).

2.5. Winglet Design:

Winglets are extra protrusions given at the end of the wing surfaces. The reasons for including winglets are:

- Rolling Stability
- Reduces vortex
- Less drag
- More efficiency

Without increasing the surface area, we can increase wing span. This will give higher gliding ability to the Aircraft.

Nominal range ofvalues for Tip chord to root chord ratio λ is 0.4 to 0.5

Choose $\lambda = 0.45$

$$\lambda = C_t / C_r$$

$C_t = 0.07$m

Where C_t is the tip chord of the winglet.

Nominal range of values for Dihedral angle is 2 to 5 degrees. Choose 3 degrees as dihedral angle.

2.6. Tail Design:

Tail in general provides added stability to the Aircraft. It is present to counter balance the moment produced by the wing.

As stability and safety are one of our requirements, A H tail was chosen instead of the conventional V tail. The H tail provides added stability and also better controlling of the Aircraft.

The H tail consists of 1 Horizontal Tail and 2 Vertical Tails. The Tail parts are generally very small in size as compared to the wing sections as they increase the overall weight. The tail parts also have an aerofoil shape. Symmetric aerofoils are generally preferred for tail sections.

Horizontal Tail:

The first step in tail design is to select the length of the moment arm, which is the distance between the leading edge of the wing to the leading edge of the horizontal tail. We choose it as 0.4m..

$$\therefore l = 0.4m$$

Semi wingspan, $b^1 = 0.74$

$C_r = 0.135$m

Nominal range of values for Standard horizontal volume tail coefficient $\bar{v}_H$ is 0.1 to 0.3

Taking $\bar{v}_H = 0.2$

$$\bar{v}_H = \frac{l \times S_{ht}}{b_{ht} \times c}$$

$$\therefore S_{ht} = 0.04995 \sim 0.05m^2$$

Where S_{ht} is the Surface area of the Horizontal tail.

By taking Standard Aspect Ratio for tail sections as AR = 2

$$\text{AR} = \frac{{b_{ht}}^2}{S_{ht}}$$

$$= \frac{{b_{ht}}^2}{0.05}$$

$$\therefore b_{ht} = 0.3m$$

We know that $S_{ht} = b_{ht} \times c_r$

$0.05 = 0.3 \times c_r$

$$\therefore c_r = 0.166m$$

Therefore, for Horizontal tail

$$s = 0.05m^2$$

$$b_{ht} = 0.3m$$

$$c_r = 0.166m$$

$$l = 0.4m$$

Vertical Tail:

There are 2 vertical tails.

Nominal range of values for Standard vertical volume tail coefficient $\bar{v}_r$is 0.05 to 0.1

Taking $\bar{v}_r = 0.08$

$$\bar{v}_r = \frac{l \times S_{rt}}{b \times c}$$

$$0.08 = \frac{0.4 \times S_{rt}}{0.74 \times 0.135}$$

$$\therefore S_{rt} = 0.01998m^2 \sim 0.02m^2$$

Where S_{rt} is the Surface area of the Vertical Tails.

Since there are two tails,

$S_{rt} = 0.01m^2$each

Take AR=2,

We know that, $\text{AR} = \frac{{b_{vt}}^2}{S}$

$$2 = \frac{b^2}{0.01}$$

$$\therefore b_{vt} = 0.14\text{m}$$

For vertical tail,

S = 0.01m

$b_{vt} = 0.14$m

$C_r = 0.07m$

l = 0.4m.

2.7. Fuselage Design:

The fuselage is basically designed to carry the payload and to carry the entire wing. It does not have any separate calculations. The only constraint is that it should be aerodynamic in shape for smooth flow of air over the fuselage area. It also houses the battery and other servo mechanisms required for the Tilt Rotor Mechanism

III. TILT ROTOR MECHANISM

The purpose of the mechanism is to enable 2 modes of flying. There would be 2 modes while flying. The first one would be the Hovering mode. This mode is responsible for the VTOL feature. In this mode all 4 rotors would be in the horizontal position (the rotor axes will be perpendicular to the body of the Aircraft).

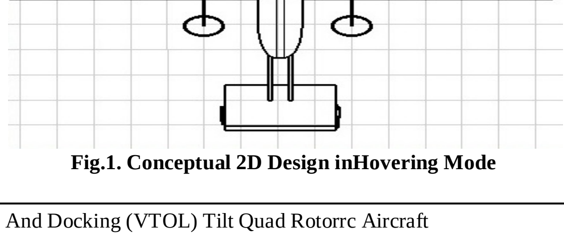

Fig.1. Conceptual 2D Design inHovering Mode

The second mode would be the Cruise Flight mode in which the aircraft would behave like a conventional Fixed wing Aircraft. In this mode the rotors would be in the vertical position. When in transition from one mode to the other the rotors would "Tilt" 90 degrees which facilitate the hybrid use of the proposed RC Aircraft. Hence the name "VTOL Tilt Rotor RC Aircraft".

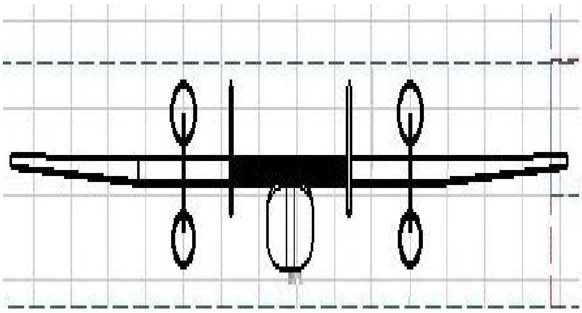

Fig.2. Conceptual 2D Design in Cruise Flight Mode

3.1. Mechanism Construction

The mechanism is housed on the wing itself. There are 2 carbon rods namely the rotor rods. Each rotor rod holds 2 rotors; one at each end. Each rotor rod is 32 mm long. Both the rotor rods are supported by the spar of the wing. They would be placed in 2 grooves made in the wing; One on either side of the fuselage.

These 2 rotor rods are again connected to a concentric 2 rod mechanism that run parallel to the wing spar and located next to it. The 2 rod mechanism is one solid carbon rod inside another hollow carbon rod. The hollow carbon rod is fixed to the wing whereas the solid carbon rod is free to rotate. This solid carbon rod is attached to the rotor rods as well as to a servo mechanism housed in the fuselage. The servo used here is of 12K capacity and is responsible for actuating the tilting mechanism. This servo rotates 90 degrees. This rotation is imparted to the solid carbon rod via a steel connecting rod through a nylon arm. The solid carbon rod in turn tilts the 2 rotor rods as and when required with respect to the 2 modes of flying.

IV. 3D MODELLING METHODODLOGY

Basic steps in 3D Modelling (done in Catia V5 Software):

1. 2D part Design
2. Projecting it in 3D
3. Assembly
4. Drafting

4.1. Wing Modelling

Standard NACA coordinates are available for the aerofoil GOE 523. Using them in sketcher workbench in 2D part Design, the 3D model of wing is obtained by using PAD Tool (which allows extrusion).

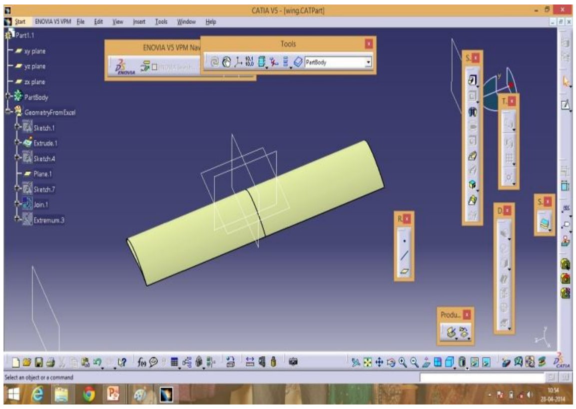

Fig.3. 3D modeling of the wing section

4.2. Winglet Modelling:

It is designed using multisection tool for which 2 sections and a guide curveare required. One section is obtained from the wing designand the other section is obtained by scaling down the same wing section in such a way that the trailing edge of the first and second sections are on the same line. The root to tip chord ratio is obtained from the design calculation which governs the scaling down factor. The guide curve is drawn in a way that it joins the leading edge of both the sections.

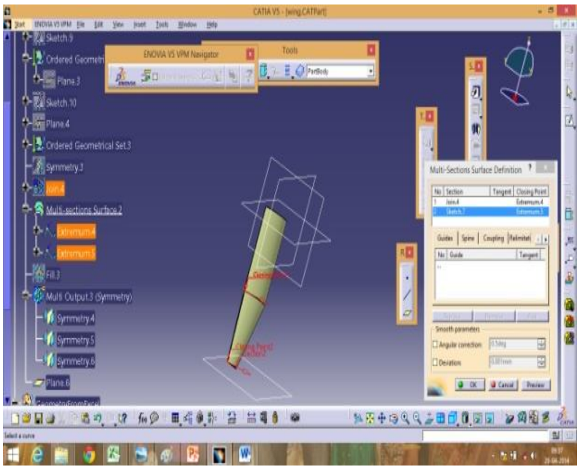

Fig.4. 3D Modelling of the Winglet Section

1.3. Horizontal and Vertical Tail Modelling:

Standard NACA coordinates are available for the aerofoil NACA 0012 for both Horizontal Tail and for Vertical Tail. Using them in sketcher workbench in 2D part Design, the 3D model of wing is obtained by using PAD Tool(which allows extrusion).

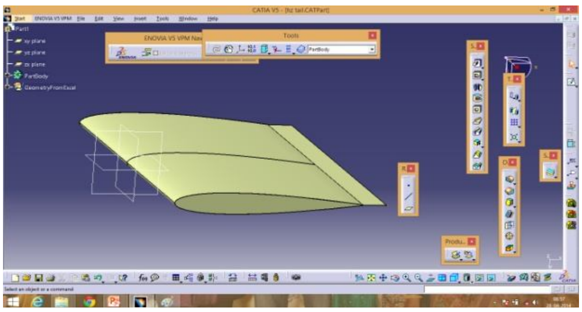

Fig.5. 3D Modelling of the Horizontal Tail Section

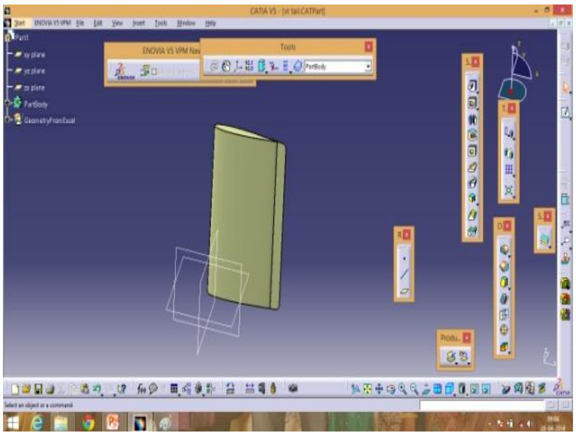

Fig.6. 3D Modelling of the Vertical Tail Section

1.4. Fuselage Modelling:

The fuselage is given a aerodynamic shape. It also contains 2 rods connecting it to the tail section.

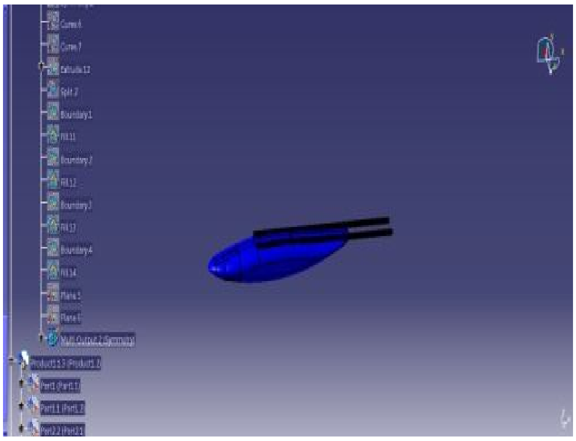

Fig.7. 3D modeling of the Fuselage

1.5. Mechanism Modelling:

The mechanism is modeled so as to rotate 90 degrees.

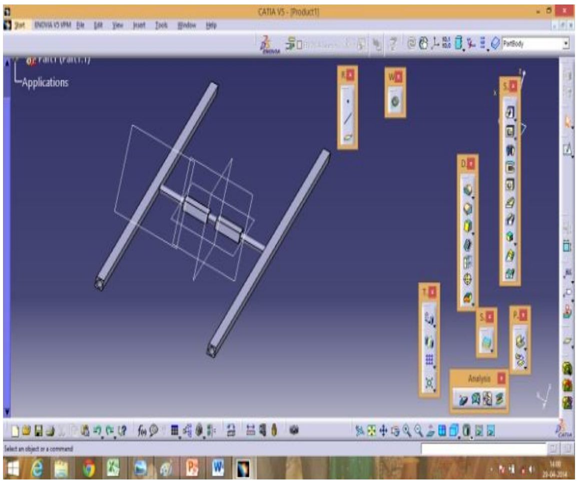

Fig.8. 3D Modelling of the Mechanism

1.6. Assembly:

All the various part designs are assembled in the assembly work bench to obtain the final 3D model of the RC Aircraft**.**

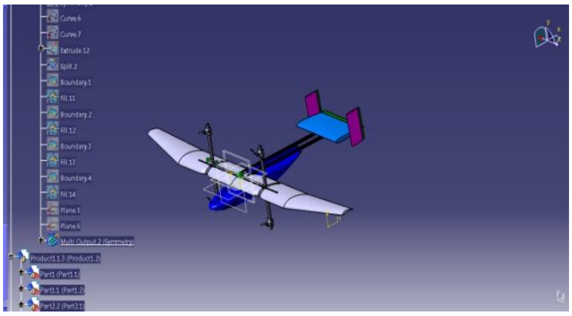

Fig.9. 3D Assembly

1.7. Drafting:

Drafting of the various sections can be carried out. This would be the basis on which fabrication would be carried out.

V. ADVANTAGES & LIMITATIONS

The various advantages of the VTOL Tilt Quad Rotor RC Aircraft are:

1. Vertical Take-Off and Landing(VTOL)
2. High maneuverability
3. Energy Efficient
4. High Operational Speed
5. Greater Speed Control

There are certain limitations to the VTOL Tilt Quad Rotor RC Aircraft. The main limitation is that it is still not extensively tested for it to be completely incorporated in passenger and military aircrafts. The other limitation is that in the forward flight mode or the Cruise Flight mode the Aircraft uses 4 rotors where actually 1 rotor is sufficient. Though it gives higher power, lift and thrust; there is a trade off with efficiency if only the forward flight is considered. The other limitation is if we compare the Aircraft separately with Fixed Wing Aircraft or Rotary Wing Aircraft, the cost is on the higher side.

VI. FUTURE WORK

The proposed VTOL Tilt Rotor RC Aircraft can be made into a full fledged Major UAV. An autopilot system can be installed to make the Aircraft fully autonomous. A GPS Tracker can also be included in the Auto Pilot system. In the above proposed prototype the tilting mechanism is being actuated by a servo mechanism. A gear system can be used instead which will give smoother and accurate rotation.

While tilting, the rotors directly tilt 90 degrees. An intermediate tilt between 0 to 90 de can be achieved. This will have added applications. It will also increase the efficiency.

CONCLUSION

After completing our research work on Tilt Rotor Mechanism and Quad Tilt Rotor RC Aircraft for this paper we can come to the conclusion that the Quad tilt rotor concept has tremendous potential. If improved into an autonomous full fledged UAV, this concept has wide military and civilian applications.

To further prove our concept, we have successfully fabricated our own RC Aircraft prototype.

Fig.10. Fabricated VTOL Tilt Quad rotor RC Aircraft

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