DESIGN AND DEVELOPMENT OF TRANSITION AUTOPILOT FOR VTOL UAV

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ABSTRACT
UAV becomes versatile in nature in terms of application and its compact operation. UAV has its own limits by its design nature. Fixed wing vehicles have high endurance and range where as multi-copter have hovering and various terrain operation. This briefs attempts to blend the combination of both fixed-wing and multi-copter and develops autonomous for transition. The conceptual design made with 1kg payload, 1km range, and 16 minute endurance with VTOL capability. The airframe is selected based on the requirements. The propulsion system designed such a way to adopt hover as well as cruise mode operation. The centre of gravity is fixed such a way to maintain during cruise, hover as well as transition. The autopilot is developed for smooth transition of hover to cruise and cruise to hover.
KEYWORDS: Fixed wing VTOL UAV, Tilt rotor, Transition autopilot, Hybrid tri-copter

INTRODUCTION
In the aviation industry various models of Vertical Take-Off or Landing (VTOL) aircrafts have been produced and flown successfully. In the Radio Control (RC) aircraft world, not many of these projects have been successful. Most can achieve taking off vertically or a hybrid which limits the functionality of the aircraft.

This project studies all the attempts at producing an autonomous VTOL aircraft and current models with limited success and merges the ideas into a fully functioning autonomous Tilt Rotor Aerial vehicle. At a flick of a switch it can perform like a multi rotor or like a fixed wing aircraft.

The traditional Fixed Wing UAV 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 (Quad-copter, Tri-copter 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 Three 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 Tri-copter and a Fixed Wing RC Aircraft and will have the advantages of both Fixed Wing and Rotary Wing Aircrafts.

LITERATURE SURVEY
In this section, we will review some of the more successful or promising types. These designs covered concepts ranging from:
1) Propeller –driven tail sitters
2) Tilting rotors
3) Tilting wings,
4) Deflected slipstream,
5) Lift fans and
6) Jet lift types.

2.1 JET VTOL AIRCRAFT

2.1.1 HARRIER AV-8B

The only platform that was able to match the VTOL capabilities of a helicopter by using jet lift and thrust vectoring was the Harrier (also known as the AV-8B in the United States) Like the helicopter, the Harrier is able to perform vertical takeoff, hover move forward backwards, sideways. In addition it is able to transition to forward flight from a hover. Although it is capable of vertical takeoff, it is more economical in terms of fuel, to perform Short conventional runway take off, by setting the engines at an angle to provide both thrust and lift. The Harrier is categorized as a V/STOL aircraft as it can perform both. The Harrier was the most successful and most practical jet-lift VTOL fixed wing aircraft.

(Figure 2.1: Harrier Front View)

2.1.2 F-35B JOINT STRIKE FIGHTER

The latest in Jet lift VTOL aircraft is the Lockheed Martin Joint Strike Fighter F-35 Lightning. Only the F-35B variant for the United States Marine Corps has this capability. The F-35B has the same V/STOL and thrust vectoring capabilities of the harrier, but much higher top speed.

The Joint Strike Fighter program is the focal point of the US Department of Defense for Creating advanced and affordable next-generation strike aircraft for all four branches of the U.S. armed forces and their allies (JSF, 2005). It attempts to do this by creating three variants; each suited to a particular niche in the armed forces with up to 80% parts commonality between models (Jarrett et al., 2004). The variant of particular interest to this project is the F-35B Short Take-Off and Vertical Landing (STOVL).

(Figure 2.2: F-35B JSF STOVL Aircraft)

2.2 PROPELLER & OTHER SHORT VTOL AIRCRAFT

As with the Jet lift types, many prototypes using propeller driven engines and other methods have been produced. Focusing on some of the more successful or more promising examples, we have two approaches:
(a) Tilting the whole aircraft.
(b) Tilting the rotors/propellers or the engines and rotor/propellers.

2.2.1 TILTING THE WHOLE AIRCRAFT

2.2.1.1 CONVAIR XFY-1 Pogo

A handful of successful prototypes using this idea were built and flown successfully. An example is the Convair XFY-1 Pogo, Figure 2.3. However, practical limitations such as visibility while landing proved too difficult for actual production.

(Figure 2.3: Convair XFY-1 Pogo)

2.2.2 TILTING THE ROTORS/PROPELLERS OR THE ENGINES AND ROTOR/PROPELLER

2.2.2.1 BELL BOEING V-22 OSPREYS

According to Boeing (2005) the V-22 Osprey is the first aircraft designed from the ground up to accommodate the needs of all four branches of the U.S. armed forces. Winning the Naval Air System Command contract in April 1983 the project that was to be known as the Osprey was a collaboration between Bell, known for their experience with tilt wing rotorcraft known for their experience with heavy lifting helicopters (Rogers, 1989). The V-22 is designed for both Vertical Take-Off and Landing (VTOL) and Short Take-Off and Landing (STOL), with the former used for larger payloads. Capable of 510 km/h (Boeing, 2005) in conventional flight the V-22 combines the advantages of helicopters and fixed wing aircraft. A V-22 Osprey in its hover configuration is shown in Figure 2.4.

(Figure 2.4: V-22 Osprey(Boeing))

2.2.2.2 AGUSTA WESTLAND AW609

The **Agusta Westland AW609,** formerly the **Bell / Agusta BA609** is manufactured by united state / Italy on 6th march 2003. It is a twin-engined tilt rotor VTOL aircraft similar to the Bell Boeing V-22 Osprey. It is capable of landing vertically like a helicopter while having a range and speed in excess of conventional rotor craft. It is aimed at the civil aviation market in particular VIP customers and offshore oil and gas operators. The AW609 is powered by a pair of pratt and whitney Canada PT6C-67A turbo shaft engines, which each drive a three bladed prop rotor. Both the engine and prop rotor pairs are mounted on a load-bearing rotatable pylon at the wings ends allowing the prop rotors at various angles. In helicopter mode the prop rotor can be positioned between a 75 and 95 degree angle from the horizontal. In aero plane mode the prop rotors are rotated forward and locked in positioned at a zero degree angle. The flight control software reportedly handles much of the complexity of the transitioning between helicopter and aero plane modes .The aero plane mode where the majority of the lift produced by the wing

(Figure 2.5: Agusta Westland AW609)

2.3 EXISTING TILT-ROTOR VTOL RC AIRCRAFT

2.3.1 AMERICAN DYNAMICS AD-150

The AD-150 is a high speed VTOL tilt rotor UAV that is being developed by American dynamics flight system as a future competitor for the **United States Marine Corps.** A full scale model of the AD-150 was displayed for the first time at the unmanned system North America exhibition in Washington 7th august 2007.The AD-150 utilizes to wing tip mounted high torque aerial lift (HTAL) and propulsion systems to provide the thrust needed to sustain and transition between hover and forward flight. The two HTAL systems are driven by a single **Pratt and Witney Canada PW200** turbo shaft engine. It is having two propulsion systems.

(**Figure 2.6: American Dynamics AD-150)**

are able to tilt from vertical to horizontal mode in order to achieve high speed forward flight. The propulsion systems in AD-150 are also able to pivot longitudinally.

General characteristics:

Length: 4.42 m **Wingspan:** 5.34 m
Height: 1.49 m **Gross weight**: 1020 kg

2.3.2 FALCON-V VTOL UAV

Top engineering group Co. Ltd. Which is duly registered, Thai National Company has successfully planned and developed this fixed wing VTOL aircraft. They started this development starting from small to large, staring at a wingspan of 1 meter followed by 2 meters and 3 meters respectively the end product has a wingspan of 3 meters and can be extended to 4.5 meters. It made up of materials like carbon fiber and aluminum, which provide good performance. Falcon-V is a gasoline engine powered airframe and electric motor model. Both are designed with reliability, durability, fuel efficiency and low noise signature in mind.

General characteristics:

Length: 1.95 m **Wingspan:** 3 m
Gross weight: 18 kg **Wing area:** 1.12 m^2

(Figure 2.7: Falcon-V VTOL UAV)

2.3.3 PIGEON-V VTOL UAV

Pigeon-V VTOL is a professional FPV plane and UAV EPO aircraft, light weight with wing span 1.8 m, combine new technology of TOP Engineering Group allows for precision VTOL for précised take off and landing area. For VTOL it requires 5*5 m area this will enable un-experienced pilot to operate the UAV. It is a fully automated UAV.

General characteristics

Wing span: 1.8 m **Length:** .65 m
Body width: 0.16 m **Take-off weight:** 5 kg

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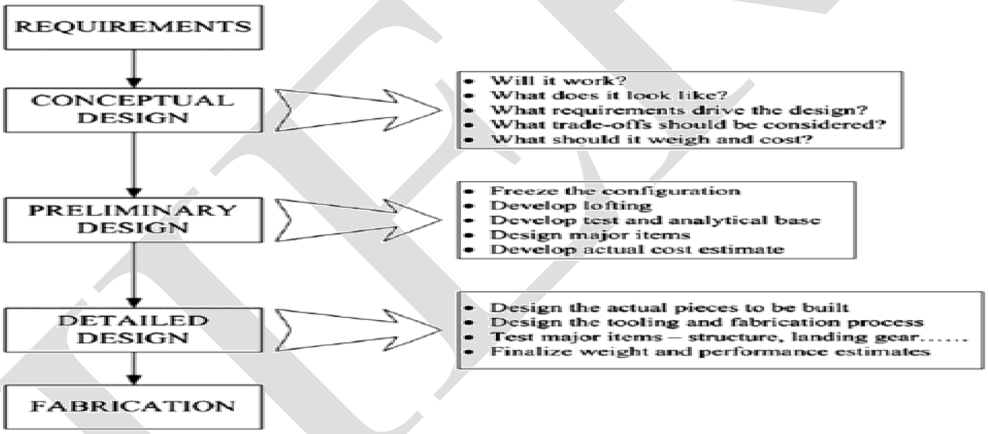
(Figure 2.8: Pigeon-V VTOL UAV)

2.4 DATA OF EXISTING RC's

(Table 2.1: Weight, Wing loading, Aspect Ratio of different RC plane)

RC Plane Name	Weight(W) In kg	Wing Loading(W/S) In kg/m^2	Aspect Ratio(AR)
Artesia GP110	4	6.713	5.44
Gold wing ARF	8.1	8.15	5.33
USAF BOBCAT JET	2.5	5.814	3.93
Gold wing SU-26	4.3	7.049	4.9
Extra 330	4.08	6.1399	5.095
Pigeon-V	5	12.67	8.181
Falcon-V	18	16.07	7.03

3. DESIGN METHODOLOGY



(Figure 3.1: Design methodology flowchart)

3.1 SPECIFYING THE REQUIREMENTS

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 Tri-copter.
3. capable of carrying a payload of 1 Kg.
4. capable of CTOL, STOL, VTOL.
5. Ability to fly at high speed to reach the target area as quickly as possible.
6. Execute the Transition mission autonomously or manually.
7. All-up Weight (AUW) less than 5 kg.
8. Wing span & Length less than 2 meters for ease of Transportation
9. Tri-rotor system (three power plants) for stability and weight reduction

3.2 DESIGN SELECTION

Table 1 below shows the performance matrix for each of the configuration. The scores were based on our research from books and hobby forums. 5 will denote the best and 1 will denote the worst.

(Table 3.1: Configuration Performance Matrix)

Requirements	Ducted Fan/ Thrust Vectoring	Tilt Rotor	Tilt Wing	Multi Rotor
Vertical Take-off Capability	4`	4	4	5
Conventional Take off/Landing Capability	4	5	5	1
Hovering Capabilities	4	5	5	5
Transition from Vertical to Conventional & Vice Versa	2	5	4	1
Degree of Freedom	2	4	5	1
Complexity	1	4	3	5
Light weight	2	5	5	3
Total Score	19	32	31	21

As shown in the Design Selection Matrix above, Tilt Wing & Tilt Rotor have the best scores while Ducted Fan configuration receive lowest, mainly due to the complexity of the system and its high power consumption, thrust to weight ratio. However this project has integration with fixed wing which requires the use of a Tri-rotor system. The reason for selecting 3 rotors rather than 2 rotors in the TILT Rotor Mechanism is to have higher stability and higher maneuverability which is absent if only 2 rotors are selected & The reason for selecting 3 rotors rather than 4 rotors is to reduce weight. We will incorporate the multi rotor configuration. So according to our requirement and based on above table we choose tilt rotor concept.

AIRCRAFT DESIGN PARAMETERS

For designing an aircraft there are certain parameters that should be followed to ensure that the aircraft will be able to perform its tasks efficiently. Based on our research through books and RC forums, the general rule of thumb for aircraft parameters are as follows:

1. Determine weight of model
2. Determine wing loading of model
3. Determine Wingspan
4. Determine wing Chord/Aspect Ratio
5. Fuselage length will be approximately 70% of the wingspan
6. Nose length = 20% of the Wingspan
7. Wing Trailing Edge to stabilizer = 40% of Fuselage length
8. Horizontal tail surface area = 30% of Wing area
9. Vertical tail = 35% of stabilizer area

With these general guidelines, we can proceed with sizing up the model. The dimensions can be adjusted accordingly after the model have been built up and tested.

4.1 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.

(Table 4.1: Weight estimation for building UAV)

Description	Quantity	Mass (g)	Total Mass (g)
Body frame	1	1000	1000
Motors	3	180	540
Tilting Servos	4	60	240
Control Servos	3	20	60
ESCs	3	40	120
Receiver and Flight Controller	1	25	25
Propeller	3	5	15
Other Accessories and Battery	-	-	700
Payload	1	1000	1000
Total			3700

Let, take the total weight of UAV with Payload is 4kg.

4.2 WING SIZING

Total take-off weight (W) = 4 kg

Once the weight estimation for the UAV is completed the next step is the section of wing loading.

Wing Loading = W/S

By Literature Survey Let,

$W/S = 9\ kg/m^2$

For the proposed Aircraft

Area of Wing (S_W) = 9/4 = 0.4444 m^2

Next we need to find the wing span 'b_w' in meters which can be calculated by aspect ratio.

Aspect Ratio (AR) = b_w^2/S_w

By Literature Survey Let, Aspect Ratio (AR) = 7

So, Wing Span (b_w) = $(7 * 0.444)^{0.5}$=1.762 ≅ 1.8 m**;** Therefore we fix b_w = 1.8m

Actual AR = $b_w^2/S_w = 1.8^2/0.4444 = 7.297$

By considering rectangular cross-section of the wing,

$S_w = C_w*b_w$

Chord of wing (C_w) = 0.4444/1.8 = 0.2468 m

Aileron Sizing:

As we know that, Aileron area (S_a) = 35% of S_w

$S_a = 0.35*0.4444 = 0.15554\ m^2$

As Aspect ratio (AR) = 7.297

Span of aileron (b_a) = $(AR*S_a)^{0.5}$ = 1.065 m

By considering rectangular cross-section,

$S_a = C_a*b_a$

Chord of aileron (C_a) = 0.15554/1.065 = 0.146 m

4.3 TAIL ESTIMATION

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

Horizontal Tail:

As Area of Horizontal Tail (S_h) = 30% of S_w

$S_h = 0.3*0.4444 = 0.1333\ m^2$

For horizontal tail aspect ratio is normally 2 to 3.

$b_h = (AR_t*S_h)^{0.5}$

Span of horizontal tail (b_h) = $(2*0.1333)^{0.5}$ = 0.5163 m

Actual AR = $b_h^2/S_h = 0.5163^2/0.1333 = 1.999 \cong 2$

$C_h = S_h / b_h$ = 0.1333/0.5163 = 0.2581 m

Vertical Tail

As Area of Vertical Tail (S_v) = 20% of S_h

$S_v = 0.20*0.1333 = 0.02666\ m^2$

$b_v = (AR_t*S_v)^{0.5} = (2*0.02666)^{0.5}$ = 0.23091 m

4.4 FUSELAGE ESTIMATION

Total length of aircraft = 70% of Wing span (b_w) = 0.70*1.8 = 1.26 m

As per our design requirement,

Fuselage length would be 1.26/2 or 0.63m.

As we know the relationship,

Span of wing (b_w) / Height of Fuselage (h) = 12

So, h = 1.8/12 = 0.15 m

As we know that,

Nose length = 20% of the Wingspan = .20 * 1.8 = .36 m

Wing Trailing Edge to leading edge of horizontal tail = 40% of Fuselage length

= 0.40 * 1.26 = 0.504 m

(Table 4.2: calculated data for geometrical figuring)

Name	Span(b) / Length in m	Chord(C) in m	Area(S) in m^2	Aspect Ratio(AR)
Wing	1.8	0.2468	0.4444	7.297
Aileron	1.065	0.146	0.15554	7.297
Horizontal tail	0.5163	0.2581	0.1333	1.999
Vertical tail	0.23085	-	0.02666	1.999
Fuselage	0.63	-	-	-

STRUCTURAL FRAME DESIGN

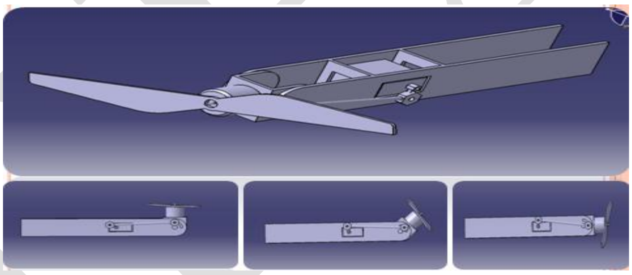
A general aircraft frame must be as light as possible while still being sufficiently strong to carry all components and not fail. Furthermore for a VTOL platform the frame must provide sufficient actuation, as just discussed, to enable a sustained, stable hover. The frame must also be sufficiently configurable to accommodate any design changes. The aircraft shape was designed using the Computer Aided Design (CAD) package CATIA-V5 as per our calculated dimensions according to our requirements.

5.1 MATERIAL

Aluminum was chosen as the base frame material due to its low cost and easy fabrication properties, despite Carbon Fiber Tubing having significant strength to weight advantage and HD-foam is used for main structure.

5.2 TILT ROTOR CONCEPTS

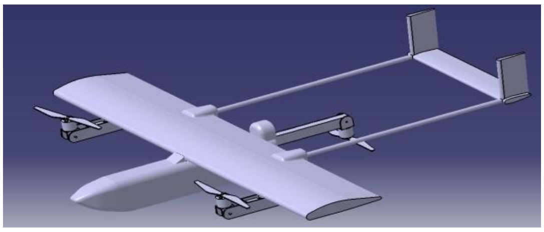
As previously discussed the thrust generating unit that is motor and propeller of our proposed model design must be able to rotate over 90 degree to meet the control requirements. Several concepts to allow this were considered, before the current solution was chosen. Combining several of the advantages of the concept solution, the final solution is shown in Figure 5.1.



(Figure 5.1: final tilting mechanism)

5.3 FRAME DESIGN SELECTION

This frame has several strong features, fuselage including wing arms, a rigid boom mounts for tail and versatile motor mounts. The final frame design is estimated and designed in CATIA-V5 which is shown in figure 5.2.



(Figure 5.2: Final frame design in catia-v5)

6.1 MOTOR

Brushless motors were chosen over conventional brushed motors to drive the propellers based on their high RPM and torque capabilities in conjunction with the minimal associated wear, resulting in constant motor characteristics over the life of operation. We have selected the **Avionic PRO C3536 KV1100** which is illustrated in Figure 6.1

(**Figure 6.1: Avionic PRO C3536)**

6.2 ELECTRONIC SPEED CONTROLLER (ESC)

Electronic Speed Controller or ESC is an electronic circuit that controls the speed and direction of an electric motor. We have to select an ESC that has gives a same current rating as the motor. It is tolerable to select a slightly higher esc but not lower. Based on the performance of the avionic 3536 motors, we have selected the wolf pack 40 AMP esc as shown in Figure 6.2.

(Figure 6.2: Wolf pack 40AMP)

6.3 PROPELLER

The propeller choice for this project was primarily dependant on the static thrust required to achieve stable hover. The actual selection was an iterative process, as the required maximum thrust was dependant on the final weight of the model.

The final choice of propeller consisted of a 12” × 5” APC nylon two-blade fixed-pitch propeller, which is available as a pusher/tractor pair. The size constraints were confirmed by basic propeller theory, which estimated the propeller diameter to be approximately 11”. This is a lower estimate because it does not consider in-ground effects, which will occur during initial stages of hover. When such effects are factored into the calculations, a resultant propeller diameter of approximately 13” is found.

6.4 BATTERY

There were Nickel-Cadmium (NiCd), Nickel-Metal Hydride (NiMH) and Lithium Polymer (LiPo). The battery is chosen based on a simple calculation of the specifications;

Battery Capacity =1500mAh = 1.5Ah

Constant Discharge Rate =90C

Maximum Discharge Current = 1.5Ah x 90C= 135A

The battery is able to provide 135A if needed which is more and near to that what all the three avionic 3536 motors will be drawing.

(**Figure 6.3:1500mah infinity Battery)**

6.5 SERVOS

When choosing servos, the important specifications are the torque and the servo speed. For our application we will need the speed to be as slow as possible and the torque must be enough to move the weight of the motor and the thrust it provides. After researching for a suitable servo, the most economical and high performing is the TS X57 Ultra Torque Digital Metal Gear Servo.

For control surfaces any normal 16G Micro servos would be sufficient and for tilting mechanism 13kg metal gear servos are chosen.

(**Figure 6.4: TS X57 Ultra Metal gear servo)**

6.6 FLIGHT CONTROLLER

A flight controller is the brain of the aircraft. It is basically a circuit board and has built-in sensors that detect orientation changes. It also receives user commands, and controls the motors in order to keep the multi-copter in the air. Flight controller is also a hub for many other peripherals, such as GPS, LED, SONAR sensors etc. The popular flight controller should be listed first. APM 2.8, CC3D, NAZE 32, KK2.0, Multiwii lite V1.0, DJI Naza-M lite, multiwii SE V2.0, 3DR Pixhawk etc . so we compare for these flight control boards and select **cc3d-board** is the best controller for our model. In this model program is installed by using open pilot software**.**

(Figure6.5: CC3D-board)

6.5RADIO-CONTROLLER

The transmitter communicates with receiver for the controlling of aircraft. So For wireless flying we need to choose appropriate transmitter and receiver. According to our requirement by keep in mind the above prospects we are choosing **AVIONIC 10 channel telemetry FHSS transmitter** (RCB OS 10).

Figure6.5: Transmitter and Receiver

6.6 CIRCUITASSEMBLY

6.6.1 Power Distribution Circuit

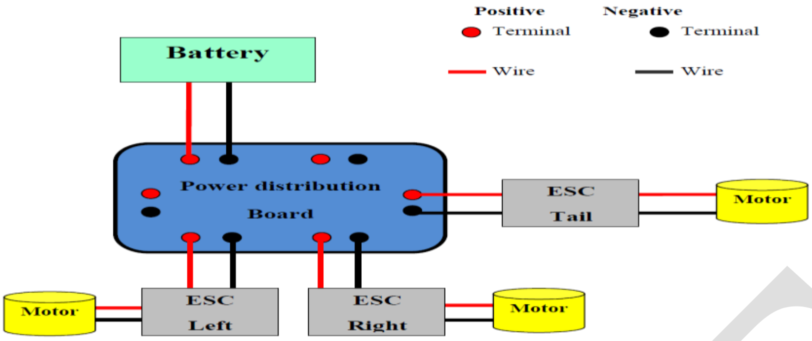


Figure 6.6: Schematic diagram of power distribution

6.6.2 CONTROL SYSTEM ARCHITECTURE

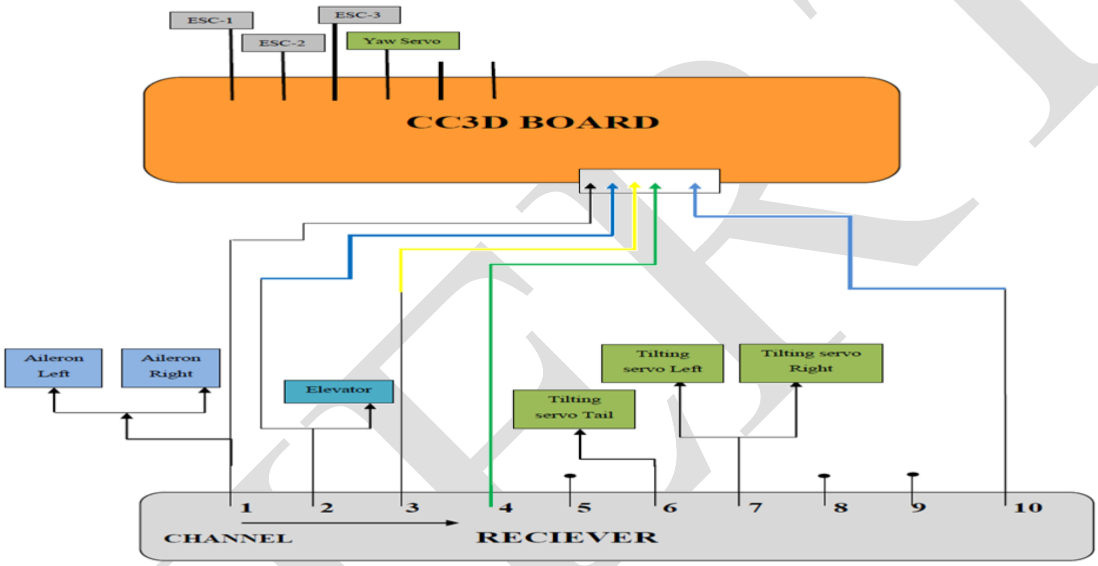


Figure 6.7: Control architecture

6.7 AUTOPILOT SYSTEM

For the transition autopilot system we are using arduino board (arduino UNO) and set up program for the arduino board by using arduino software. Transition autopilot benefits to pilot to reduce work load s well as increases the safety.

(Figure 6.6: Arduino uno board)

7. FABRICATION PROCESS OF VTOL UAV

In this Chapter, we will describe the fabrication process of our model. We will describe mainly with photos taken during the process with short description.

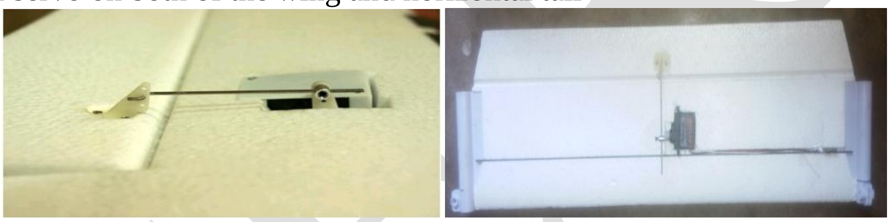
1. The different parts of fuselage made up of HD-foam by injection molding process according to the dimensions as specified in Chapter 5, Detailed Design are assemble and glue using foam glue. The hatch of the fuselage is fixed in such a way that it can be removable.

(Figure 7.1: Assemble of fuselage)

2. Cut slots for Thin Carbon strip for both the wing and the strip place in wings using foam glue to prevent flexing and insert the longer carbon tubes to their half way point in both the wing to provide strength and prevent from bending.

(Figure 7.2: place of carbon strip and insert the carbon tube in the wing)

3. Mount the control servo on both of the wing and horizontal tail

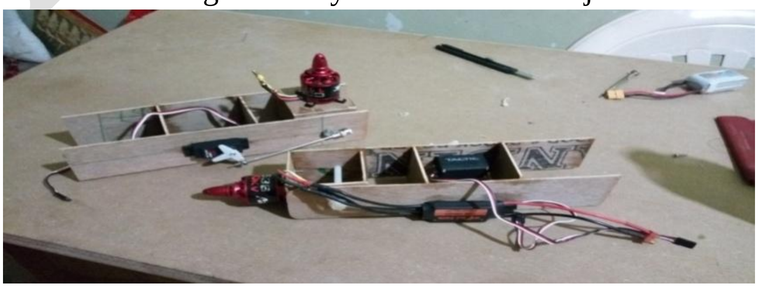


(Figure 7.3: Fixing of Control Servos on wings and Horizontal Stabilizer)

4. Take 3mm Indian plywood and cut the ply wood as per desired dimensions first make the main frame and then the motor mount. Cut 45 degree groove for tilting mechanism and hole for fixing the motor mount and frame by using drilling machine and file for smoothness. Fix the servo in the main frame by using glue and screw the motor on the motor mount.

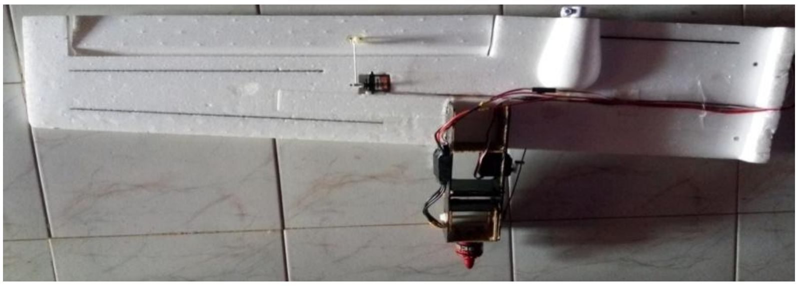
(Figure 7.4: Construction of tilting frame and motor mount)

5. Fix the motor mount and the main frame by a nylon bolt and check that the motor mount is free to move inside the frame or not according to the smoothness of movement tight the bolt with screw. Connect the servo with the motor mount screw which is passes through the groove by the help of a push pull rod and check that the motor mount is moving smoothly or not and then adjust the rod according to the requirement.



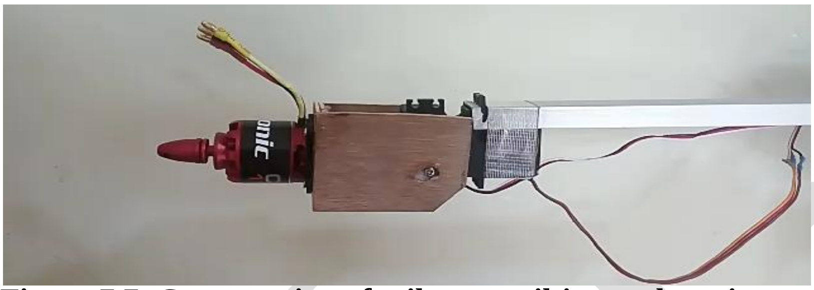
(Figure 7.5: complete tilting mechanism)

6. Cut grew bellow the wing and fix the tilting frame on both the wing at desired position by using glue stick and glue gun as bellow.



(Figure 7.6: Fixing of Tilting mechanism)

7. For tilting of tail motor we are using two servos one is for tilting of motor and other is for yawing moment .Here we are using aluminum frame to mount the complete mechanism .in this mechanism one servo coupled with another servo and the motor mount is mounted over it. Both the servo together perform tilting as well as yawing moment .according to the CG position as well as tri-copter specification we need to mount the tilting motor of tail.



(Figure 7.7: Construction of tail motor tilting and yawing mechanism)

8.Cut plywood according to the desired dimension for fix the landing gear .For fixing the front landing gear with the plywood we are using a special type of fixture (balsawood powder + flexkwik) and the back landing gear is screw with the plywood then both the landing gear are mount as per the calculation.

(Figure 7.8: Construction and installation of landing gear)

9. By using extensions, y-connectors, 16AW wire connect the ESCs, motors, Servo with the CC3D board, receiver and battery. The connection procedure for the circuit is shown in chapter 6 (section 6.5). Then set the program in CC3D board as per our requirement.

(Figure 7.9: Electronic circuit installation)

10. After completing programming of CC3D board assemble the complete UAV.

(Figure 7.10: Different views of fabricated VTOL tri rotor RC UAV)

TESTING

8.1 TILTING SERVO TESTING

1. Connect the wing tilting servo with the servo tester and check the tilting of the motor mount and sliding is smooth or not. Again check whether it is tilting to exact 90 degree to 0 degree and vice-versa.

. **(Figure 8.2: Tilting testing)**

2. Connect the tail tilting and yawing servo with the receiver and check the tilting and yawing moments and trim according to the requirement.

(Figure 8.1: Yawing testing)

8.2 BENCH CHECK

1. Ensure that props are not installed.
2. Power the radio and connect the battery to the aircraft.
3. Watch applicable controller LED indications and verify that the CC3D board initialize correctly.
4. Check that the transition switch tilting the motor or not.
5. In hover mode adjust the transition servo moves forward while in cruise mode transition servo moves backward.
6. Verify correct movement. Correct response to right stick inputs are as follow:

Push left: Left aileron up, Right aileron down
Push right: Right aileron up, Left aileron down
Push forward: Elevator down
Pull back: Elevator up

Correct response to left stick inputs are as follow

Pull back: Thrust reduces
Push forward: Thrust increases
Push right: Move yawing servo right
Push left: Move yawing servo right

7. Check the throttle response of all the three motors as expected and deviate on command with correct spin direction (important).

8.3 FLIGHT TESTING

After about 10 flight days,15 take off attempts several changes are done due to failures such as changing of landing gear, increase propeller size, use constraints for over tilting of motor mount, changing the push pull linkage finally the aircraft is lift up. But still it was having some stability problem due to that it's not hover properly.

(Figure 8.3: Unstable flight behavior)

After spending many hours computing moments of inertias, thrust force, and thrust vectors, and bounding the errors associated with the calculations, something major was missing in the physics in our pitch axis. The only thing we concluded not included in the calculation for the pitch control where the aerodynamic forces associated due to the tail part. As a "last chance" test we **reduce** the distance between wing trailing edge to the horizontal tail leading edge (**boom length**). This resulted in a **very stable hover**, which got even batter with some tuning.

(Figure 8.4: Stable flight behavior during final stage of flight testing)

RESULT

Stable hover was achieved during the course of the project; transition autopilot is also achieved by using arduino board there were still a number of significant achievements throughout the project.

CONCLUSION

The project's overall objective was to develop and build an aerial vehicle which is able to perform both VTOL & CTOL and also having autonomous transition system with1kg payload, 1km range, 16minute endurance. All the testing carried out where with the first objective of achieving vertical takeoff and maintains stable hovering capabilities.

All in all, despite the number of structural failure and repeated re-builds of the mechanisms, we would consider this project to be a success.

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