Design and Development of Tristar Unmanned Aerial Vehicle

(with Tilt Rotor Mechanism)

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***Abstract*— The purpose of the work is to design a surveillance system that can cover an area of 50000 m^2 with a mass of 1.5 kg, range of 2km and endurance of 8 minutes with a tilt rotor mechanism using control board. This work will focus on the overall design and realization plan, which allows the UAV for surveillance application. Overall, the entire UAV system pursues a low cost, high reliability approach for surveillance using CCD camera**.

***Keywords*— Survellance, endurance, design,VTOL**

1. INTRODUCTION

An aircraft which has the ability to take off and land without a runway, completely vertically. VTOL aircraft have been important in the aerospace industry for many years, and first began when helicopters were invented. Helicopters are by far the most common type of VTOL UAV, with other types being invented only recently.

VTOL aircraft are useful for a number of reasons, including:

1. No Runway Space Needed - By definition, VTOL aircraft do not need a runway to take off or land.
2. Increased Portability – Because VTOL aircraft do not need a runway to land or take off, they can be used and flown in locations that conventional aircraft don’t have access to.
3. More Useful For Aerial Photography and Videographer – This advantage applies mostly to small UAVs designed for reconnaissance, such as our Draganflyer X6. The ability to stop the aircraft and hover over one location is invaluable when it comes to taking still and precise images.

The various application of UAV are listed below

Civilian uses:

- Aerial photography
- Agriculture
- Coastguard
- Conservation
- Customs and excise
- Electricity companies
- Fire services & forestry
- Fisheries
- Gas and oil supply companies
- Information services

***Military roles*:**

- Radar system jamming and destruction
- Electronic intelligence
- Surveillance of enemy activity
- Monitoring of nuclear, biological or chemical contamination.
- Shadowing enemy fleets
- Decoying missiles by emission of artificial signatures

Advantages

- Surveillance
- Reconnaissance
- Target and decoy
- Logistics
- Research and development
- Civil and commercial UAVs
- Intelligence
- Multipurpose UAV
- Launch and recovery system

2. CONCEPTUAL DESIGN

Conceptual design is the first basic step in aircraft design. It involves the layout of all possible configuration required for specific functions which has been outlined. It may be surveillance, reconnaissance, weather forecasting, target and decoy and research development UAV etc. The initial phase of design for any aircraft involves:-

- Configuration selection and
- Sizing of major components such as wings, tails, fuselage, power plants.

2.1 WING CONFIGURATION

Among all the configurations tapered low wing is selected for work due to the following reasons:

1. It offers good stability & performance at low speed.
2. Ease of construction.
3. It does not interfere with the payload.

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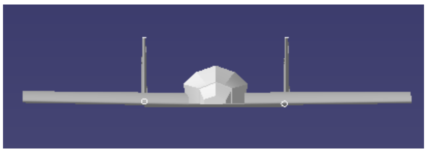


Fig 2.1: Shows the placement of top wing in UAV

2.2 EMPENNAGE CONFIGURATION

Twin boom configuration as in fig 2 has been chosen for the proposed work due to the following reasons:

1. To construct VTOL aircraft with the propeller mounted directly to the aft of the fuselage.
2. To increase an aircraft structure's rigidity & strength
3. It helps in decreasing the overall weight.

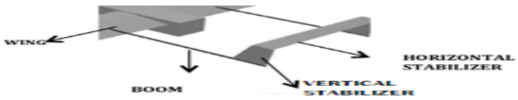


Fig.2.2: T-Tail configuration for work

2.3 FUSELAGE SHAPE

A fuselage with semi-monocoque structure having rectangular shape with semi-circular nose has been chosen. The main advantage lies in the fact that it does not depends on a few members for strength and rigidity. This means that a semi monocoque fuselage, because of its stressed skin construction, may withstand considerable damage and still be strong enough to hold together.

Fig 3and 4 shows the monocoque structure and the fuselage shape for work respectively

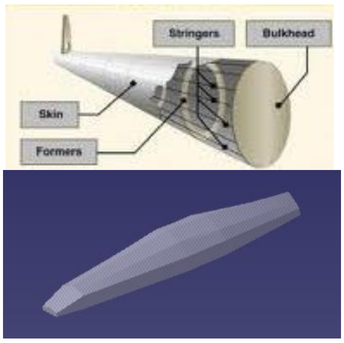


Fig 2.3 & 2.4: The semi-monocoque structure and fuselageshape of Tristar UAV

2.4 LANDING GEAR CONFIGURATION

Tricycle landing gears i.e., one nose wheel and two main landing gears will be installed below the fuselage. Reasons for choosing tri cycle landing gear are given below.

1. It allows more forceful application of the brakes without the danger of nosing the aircraft over.
2. It permits better visibility for the pilot during ground operations
3. It prevents the tendency for the aircraft to ground loop.

2.5 FOUR VIEWS OF TRISTAR UAV

Based on the choice of the wing, empennage, fuselage, propeller and landing gear the final configuration and layout of work were arrived at. The four views of work are shown in the fig.2.5.

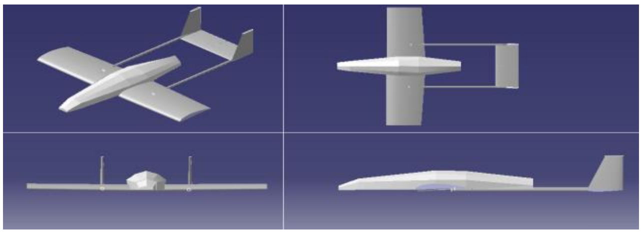


Fig 2.5: Four views of TRISTAR UAV

3. PRELIMINARY DESIGN

Preliminary design is a fine tuning of the conceptual design made through the analysis. This involves wing sizing, airfoil selection, empennage sizing, fuselage sizing and arriving at all the dimensions. A more detailed analysis of the aerodynamic loads and component weights. Structural design is further refined at this stage. The location of spars, stringers and longerons are analyzed. This also includes engine inlet interaction with the fuselage and wing and even wing interaction on control surfaces.

3.1 WING SIZING

Wing sizing is a crucial phase in the design process as wing plays a major role in aircraft's flight. A step by step procedure has been followed for wing sizing.

1. As it is known that wing span has been taken as b= 1.1m
2. Estimated weight w=1.2kg
3. The wing plan form is straight wing without any incidence and dihedral angle. Hence sweep angle $\lambda=0$
4. Now varying the chord length, corresponding aspect ratio is calculated from equation

$$AR= b/c = b^2/s$$

Where, b is wing span

c is chord length

s is surface area of the wing

We get our **c = 0.2m** and **AR = 5.789**

<u>Design Parameters of Tristar UAV</u>

WING SPAN	1.1m
WEIGHT	1.2kg
DENSITY	1.1 kg /m^3
CRUISE SPEED	16 m/s
ASPECT RATIO	5.789
CHORD LENGTH	0.2m & .18m
REYNOLDS NO.	207058.8235
CL	0.56
CLMAX	1.29at13 deg
V STALL	8.314637237m/s

3.2 AIRFOIL SELECTION

The performance of the airplane is associated with the airfoil selection. The lift force which is produced by the wing and tail surfaces is directly related to the design of the airfoil. As a result, the airfoil selection requires intensive computational efforts along with extensive research. For this matter, it was decided to use two software packages XFOIL and PROFILI. These two software packages provide wide-ranging collection of airfoils along with useful sets of data such as coefficients of lift, drag and pitching moment.

Various airfoils have been analyzed using Profili software .

After analyzing NACA 6413 airfoil is selected because NACA 6413 has lift coefficient of 0.57 at 0 deg, negative slope of c_m vs. α graph which is makes it stable. Moreover NACA 6413 has flat lower surface which will be easy to construct. Also NACA 6413 has been used in many airplanes before.

Fig 3.1 shows the geometry of NACA 6413 airfoil plotted through coordinate points

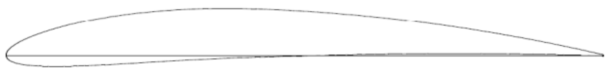
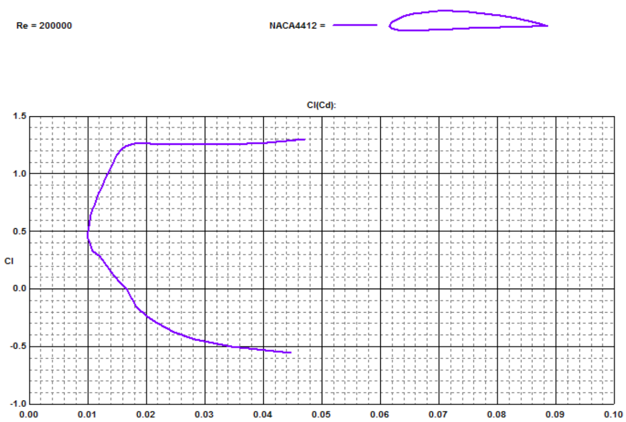


Fig 3.1: NACA 6413 airfoil

After analysis of NACA 6413 in **Profili software**, following graph was obtained. The graph shows the drag polar of NACA 6413 airfoil at Reynolds no. of 200000

After analysis of NACA 6413 in Profili software, following graph was obtained. The graph shows the drag polar of NACA 4412 airfoil at Reynolds no. of 200000



3.3 EMPENNAGE SIZING

The major task of empennage is to provide trim, stability and control. Trim refers to balancing of the moment produce by lift forces acting through tail's moment arm with the respect to the center of gravity. The empennage design consists of design of vertical and horizontal tail. The horizontal stabilizer mostly balances the moment created by the wing. It is very important to mount the empennage in the appropriate location. For instance, the stall characteristic of the airplane is directly related to the location of the horizontal tail.

The airfoil selected for tail is NACA 0012 as it is symmetric; comparatively it has high stall angle and low lift.

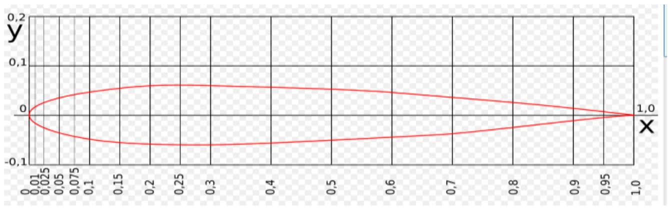


Figure 3.2 shows the geometry of NACA 0012

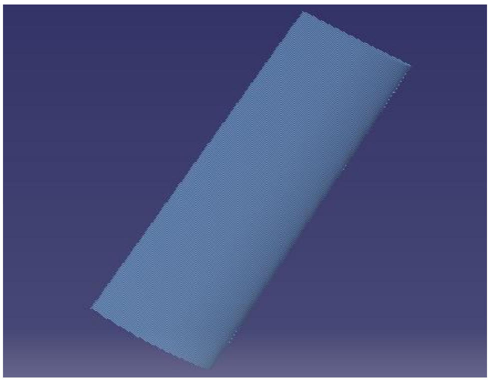


Fig 3.3 shows NACA 0012 airfoil in vertical tail of Tristar UAV

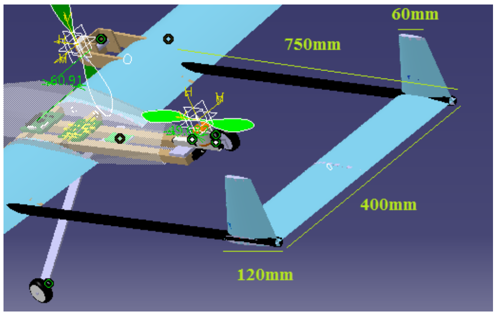


Fig 3.4 shows the final parameters obtained for empennage

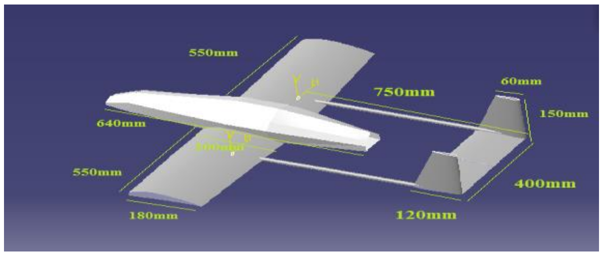


Fig 3.5: shows all the dimensions obtained from preliminary design

3.4 CONTROL SURFACE SIZING

The main control surfaces of a fixed-wing aircraft are attached to the airframe on hinges or tracks so they may move and thus deflect the air stream passing over them. This

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redirection of the air stream generates an unbalanced force to rotate the plane about the associated axis.

3.4.1 Ailerons

The ailerons work by changing the effective shape of the airfoil of the outer portion of the wing changing the angle of deflection at the rear of an airfoil will change the amount of lift generated by the foil. With greater downward deflection, the lift will increase in the upward direction

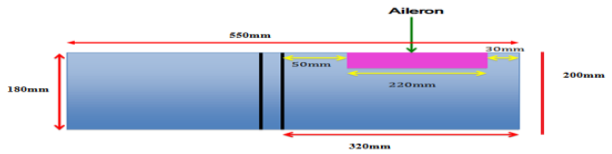


Fig 3.6: Aileron

3.4.2 Elevators

Elevators are flight control surfaces, usually at the rear of an aircraft, which control the aircraft's longitudinal attitude by changing the pitch balance, and so also the angle of attack and the lift of the wing

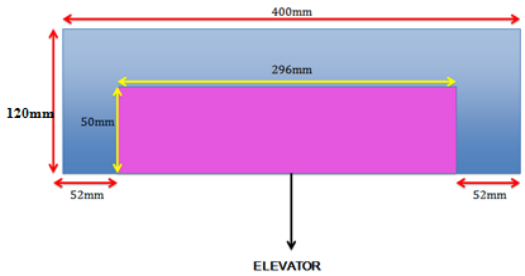


Fig 3.7: Elevator

3.4.3 Rudder

The rudder is a directional control surface (usually attached to horizontal tail structure The rudder is usually attached to the fin (or vertical stabilizer) which allows the pilot to control yaw about the vertical axis, i.e. change the horizontal direction in which the nose in which the nose is pointing.

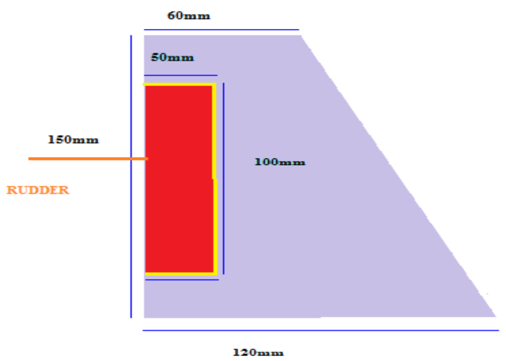
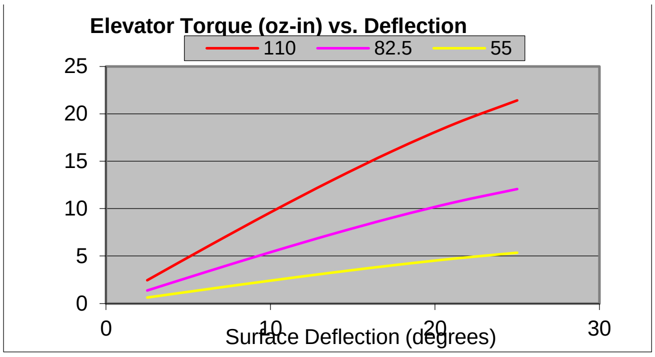


Fig 3.8: Rudder sizing

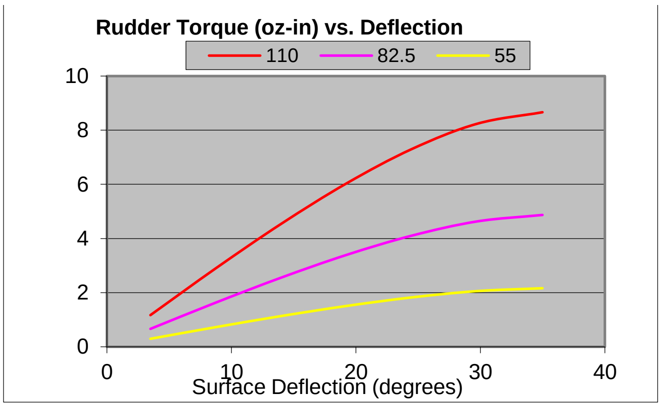
maximum airspeed (mi/hr)	110		
	Ailerons	elevators	rudder
average control surface chord(cm)	5	5	5
average control surface length(cm)	22	29.6	10
maximum available servo torque (oz-in)	21	21	21
maximum deflection of servo arm from center(deg)	35	35	50
maximum deflection of control surface from center(deg)	26	25	35
max required torque at max speed(oz-in)	17.3	21.4	8.7

Table 3.9: Inputs given for the calculation of torque

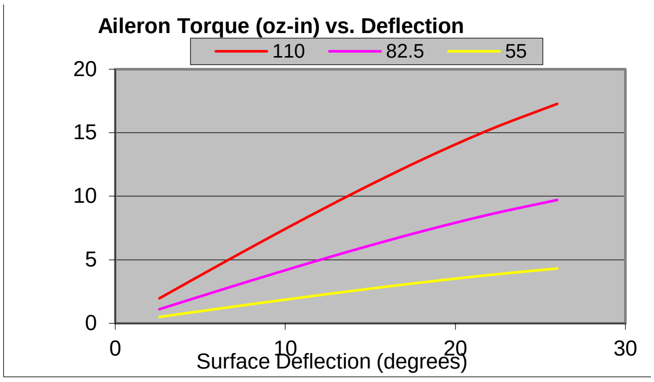
Based on above data; graph is plotted showing the amount of torque required by the control surfaces at respective airspeeds is shown in the graph below



Graph 3.1: elevator torque vs. deflection at different airspeeds



Graph 3.2: Rudder torque vs. deflection at different airspeeds



Graph 3.3: Aileron torque vs. deflection at different airspeeds

motors

4. MODULAR DESIGN

When designing an object, the system could be designed by two broad ways. The first way would be to design the complete system using the known theories, and use the system, as it is designed, in the real conditions. An alternative way would be to design the different components of the system separately, and test each component in separate conditions. Modular design, or "modularity in design", is an approach that subdivides a system into smaller parts (modules or skids) that can be independently created and then used in different systems to drive multiple functionalities. A modular system can be characterized by the following:

1. Functional partitioning into discrete scalable, reusable modules consisting of isolated, self-contained functional elements.
2. Rigorous use of well-defined modular interfaces, including object-oriented descriptions of module functionality
3. Ease of change to achieve technology transparency and, to the extent possible, make use of industry standards for key interfaces.

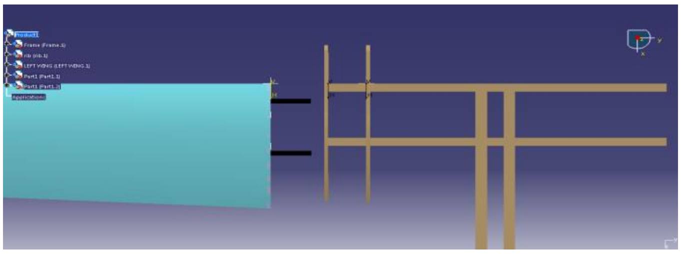


Fig 4.1 : Modularity of wing

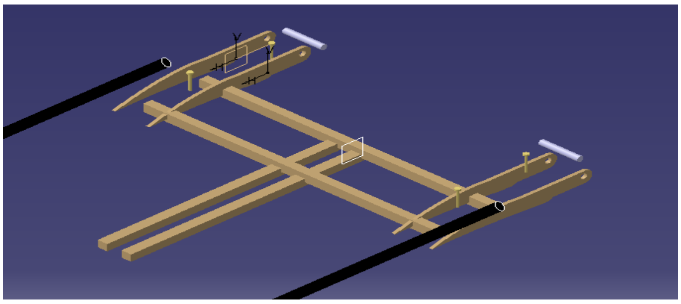


Fig 4.2 :Modularity of Booms

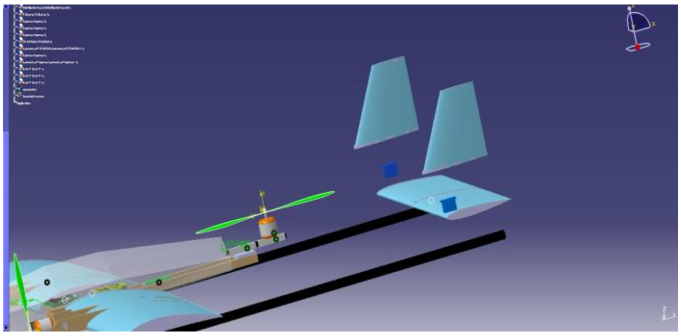


Fig 4.3 : Modularity of tail

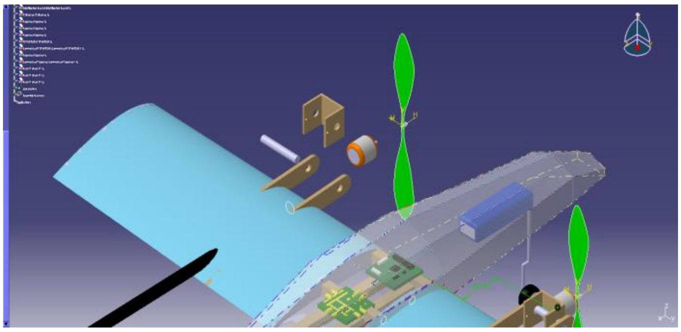


Fig 4.4: modularity of propeller and motor

5. REALIZATION PLAN

Since, all the parameters of TRISTAR UAV are known now, it has to be fabricated and flight tested. Realization plan involves a rational thinking of how to construct a model, what fabrication and manufacturing techniques will be used, how the system will be integrated and other requirements for the successful flight of the model.

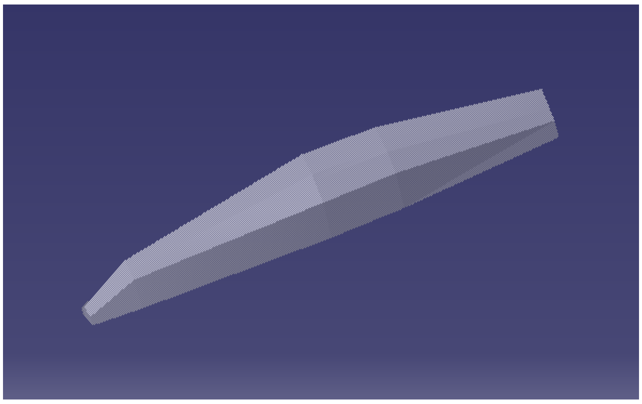


Fig 5.1: fuselage

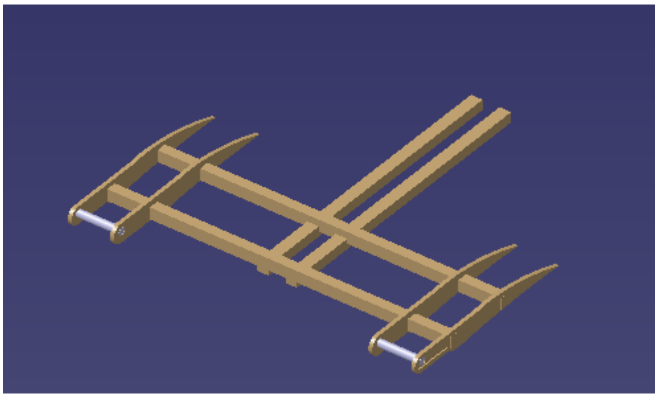


Fig 5.2: frame with spar

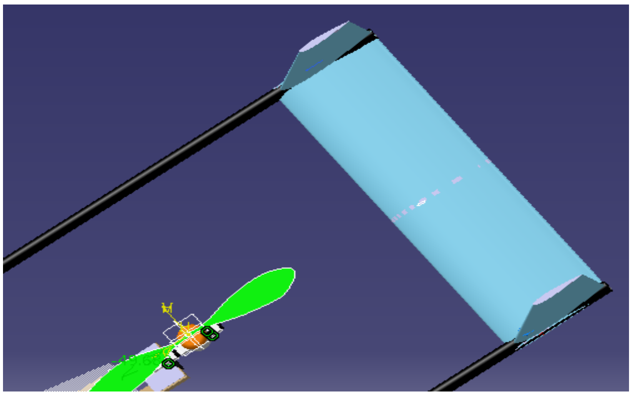


Fig 5.3: tail plan

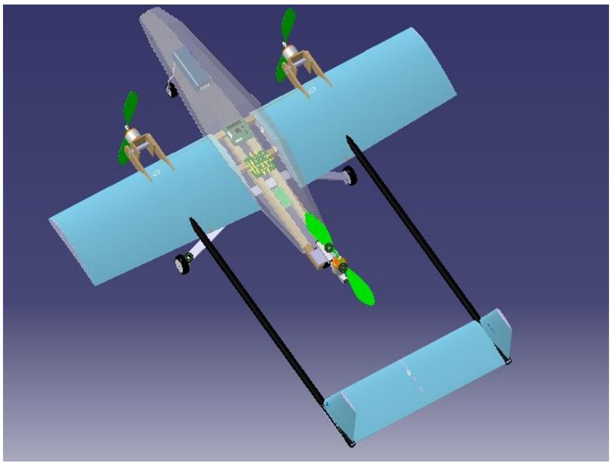


Fig 5.4 complete design of UAV

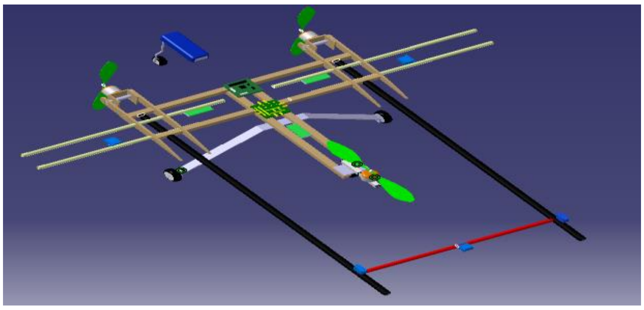


Fig 5.5: Complete design of structure

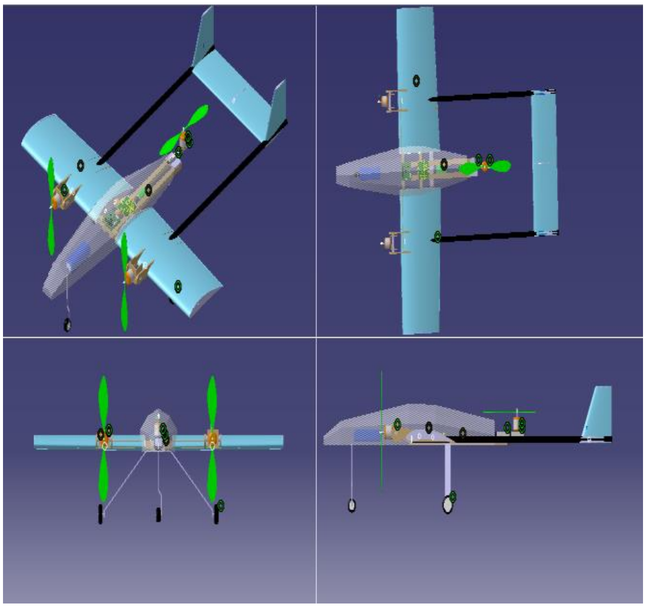


Fig 5.6: Four views of TRISTAR UAV

6. CONTROL SYSTEMS

OpenAero2-VTOL firmware is designed for use with the popular and relatively inexpensive KK2 line of Flight Controllers (FC). It has a unique set of features that make VTOL (Vertical TakeOff and Landing) radio controlled aircraft possible for modelers without the need to write custom firmware. The major features of OA2-VTOL include:

1. Transitional Mixers – If you have an application where aileron becomes rudder, or a similar sort of "axis translation" the OA2-VTOL will get you smoothly and in control from one flight mode to the other.
2. Full Transition Control – You have full control of the transition with an analog input. You can transition at any speed, in any direction, at any time. You can also set up a 3 step timed transition with the flip of a switch.
3. 8 outputs, all with the same functional capabilities.
4. 5 inputs in PPM mode, 8 inputs in CPPM, SPPM and S.Bus mode.
5. 3 point curve for offset adjustment. You can separately trim Hover, Slow Forward Flight, and Fast Forward Flight on each output, and transition smoothly between them.
6. 2 point curve for PID and Accelerometer stability feedback adjustment. You can smoothly change stability feedback values as you transition between Hover and Fast Forward Flight on all 3 axis.
7. 2 point curve for Volume/gain adjustment. You can smoothly vary control throws as you transition between Hover and Fast Forward Flight.
8. Safety Features – Arm and Disarm options that are compatible with all aircraft types.
9. Maximum Flexibility – This is not a "Tell me what kind of aircraft you have" type of interface. It is a "tell me what you want each output (servo/ESC/etc.) to do" type of interface.

10. Off the Shelf KK2 hardware, available for about $30 from HobbyKing.
11. No PC required (except for initially flashing the board). Full configurability via the included LCD interface.
12. No programming (code) required. Only configuration via the LCD display and the menu driven interface.
13. Gyro and Accelerometer based stability. No magnetometer, GPS, or pressure based altimeter.

7. CONCLUSION

1. This work has gone through all the UAV design phases. The layout and design work is completed.
2. The mission profile of work has been drawn. All the dimensions of work are calculated
3. Aerodynamic analysis has been conducted and is found to be apt for work
4. Aerodynamic analysis has been conducted and is found to be apt for work. Performance and propulsion calculations are carried out successfully.
5. Stability and control analysis has been done and it has been determined that work is a stable UAV.
6. Structural analysis has been done which explains that work can withstand all the loads acting on it without any failure. V-n diagram is also been plotted
7. All the design goals have been achieved and work can now be easily fabricated according to the realization plan and flown for the surveillance

8. ACKNOWLEDGMENT

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