DESIGN OF MULTI-DOMAIN MULTI-COPTER

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Abstract - *This paper consists of designing process of Unmanned Ariel Vehicle (UAV). It is recognized as "Multi-domain Multi-copter" which can fly in air and move on the ground, applicable for any exigencies like medical assistance, rescue of natural calamity affected people, spying for enemy countries etc. The paper provides high degree of information about the new concept of quad-copter and design procedure. Also it covers detailed calculations required to fly. The design is developed in CATIA and nick name of this drone is tank-copter.*

Key Words: **TANK-COPTER, UAV, CATERPILLAR, MULTI-DOMAIN**

1. INTRODUCTION

The Tank-Copter is a concept of having multiple domains on single UAV such that as an aerial vehicle primarily it is able to hover above the ground but with the help of extended domain i.e. caterpillar, it is also able to move on ground. This paper gives detailed explanations and study to introduce multi-domain feature on UAV's and quad-copters. The paper also provides the advantages of multi-domain feature and future scope. Here all pros and cons are brought into light with detailed explanations to make the study more informative.

1.1 Concept of Domain

Domain in quad-copter is defined as the mode by virtue of which particular motion can be achieved. Single domain quad-copter implies that it has only one mode of movement i.e. it can only move in air but it is not able to move in ground. So single domain has limited mode of transport and can only fly in air. If there are some restrictions where it is not possible to fly the drone then comes the requirement of optional domain to move the drone to particular location over the ground. Hence having multiple domains increase accessibility on the drone without compromising safety.

1.2 Limitations of Single Domain Quad-Copter

Single domain UAV implies that it can only fly in air. While multi-domain UAV can not only fly as well as move on the ground with help of caterpillar (track) unit. Caterpillar is mechanism which enables drone to move on the ground and can be achieved by motor-wheel-belt or motor-wheel combination.

Limitations of single domain are as follows.

1. Noise due to use of aerofoil.
2. Visible everywhere due to flying.
3. Unable to withstand all climatic conditions.
4. Flying unit uses more power than caterpillar unit.

1.2 Advantages of Multi-Domain Quad-Copter

1. Silent operation with the use of caterpillar.
2. Visibility can be masked at ground level.
3. Caterpillar unit consumes very less power.
4. One optional domain is available in case if another one fails.

1.3 Extended Features And Applications

1. High resolution day vision and night vision camera can be added to transmit live video.
2. Thermal vision camera can be mounted for thermal imaging and security purpose.
3. Distance sensor and altimeter can be used for safe operation of drone.
4. This Tank-Copter can be best tool for surveillance in defense areas.

2. X-CONFIGURATION OVER PLUS-CONFIGURATION

Configuration: It is the arrangement of the propeller used to make the drone. Mainly there are two types of configuration used to make the quad-copter.

X-configuration: This is the most popular configuration used in the drones as it is has more stability and is easy to capture video from this type. Yawning of drone is also avoided due to balancing of couples as the clockwise rotating propellers are opposite to each other and counter-clockwise propellers are opposite to each other.

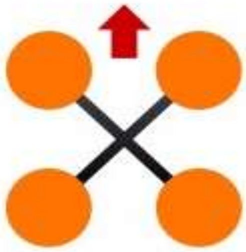

Fig. -1: X-configuration

Plus configuration: The plus configuration feels very similar to the X configuration. When you are performing a normal front or backflip it is actually a cross-axis roll like on the x configuration.

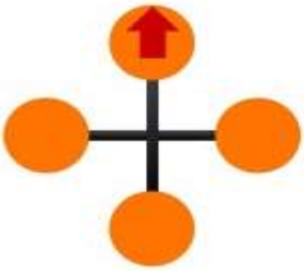

Fig. -2: Plus-configuration

2.1 Advantages Of X Over Plus Configuration

1. According to physics if you have plus configuration then the thrust forces are applied at the distance of r, if you have X configuration then thrust forces are applied at the distance of r*cos 45 approximately 0.71*r. Hence we get 41% more torque in X-configuration than Plus-configuration.

2. Camera arc clearance is necessary in case of surveillance drone; X-configuration is able to provide that clearance.

Hence the tank-copter design is based on X-configuration.

3. CALCULATIONS

3.1 Weight

Assume the total mass of the quad-copter is **5000g** and the payload capacity of the drone is **5000g** the thrust per motor is calculated considering the total weight of the quad-copter.

3.2 Thrust

Equivalent thrust required = **(5000g + 5000g)*1.2**

[Assuming thrust required to lift is **20%** greater than the total mass]

= (10000×1.2)

= **12000** grams

Diameter of wheel = 5 cm

Considering Belt thickness = 0.5 cm

Total diameter = 5+ 0.5+0.5= 6 cm

Max rpm of motor = 300

Top speed = kmph

$$v= *\frac{\pi * D * N}{60}$$

$$= 0.06*\frac{\pi * 300}{60}$$

=0.9424 m/s

=3.39264 km/hr

Time to reach the maximum speed = 5 sec

Maximum angle of inclination = 15^0

3.3 Motor and Propeller calculation

Brushless direct current motors are used for the prototyping of multi-rotors
As we need four motors for our drone so the thrust distributed to each motor is
= 12000/4
= 3000g

So the thrust on each motor is 3000gms.

3.4 Propeller Size Selection

Selection of propeller size depends on the type and power of motor selected for quad-copter. So 1^{st} the motor is selected based on the calculated values. The best motor for required thrust of 3kg is EMAX GT4090/09 with a max thrust of 5.1 kg.The recommended size of propeller by this motor is 16*10 inch. Hence to provide a base for this selection a performance data sheet of 16*10inch propeller was referred. According to the data sheet if the drone motor is operated at 60% thrust capacity i.e. 6000rpm then the propeller at static conditions gives a lifting force of 8.544lbf (3.8448kg) and the required thrust is 3kg so considering factor of safety the selected propeller works up-to the mark.

3.5 Torque Calculations

Notations

m = mass of UAV with payload in kg

M_r = mass of rotating parts in kg

a = acceleration of vehicle m/s^2

μ = co-efficient of friction

θ = gradient of terra-firma in degree

ϱ = air density kg/m^3

C = drag co-efficient

V = velocity of UAV in m/s

U= velocity of air (take negative for favorable air)

Factors affecting required torque

1) Rolling Resistance = μ*m*g

2) Grade Resistance = m*g*sin θ

3) Air Resistance =0.5*ϱ*A*C*$(V+U)^2$

4) Inertia Resistance = ± $(m+m_r)$*a

NOTE: All forces are in newton.

Total tractive effort **T.E.** = sum of all resistances above

Total torque **TT** = **TE*radius of wheel of caterpillar.**

Divide the total torque by number of motors to be used for caterpillar. This will give torque for one motor in N.m. It can further be converted to kg.cm by dividing with g = 9.81 and multiplying with 100.

1) Rolling Resistance

R.R. = μ*m*g μ = 0.3 max (considering sand surface)

= 0.3*12*9.81

= 35.316 N

RR on 1 wheel = $\frac{35.316}{4}$

=**8.829 N**

2) Grade Resistance

GR= m*g* sin θ

= 12*9.81*sin 15

= 30.46 N

GR on 1 wheel = $\frac{30.46}{4}$

= **7.61 N**

3) Air Resistance

V= velocity of vehicle= 3.39 kmph

U= velocity of air = 5 kmph

C = drag co-efficient for car =0.5

$$AR= 0.5*ϱ*A*C*\frac{V+U}{3.6}*\frac{V+U}{3.6}$$

Area A = 0.3*0.6

=0.18 m^2

$$AR=0.5*1.202*0.18*0.5*\frac{8.39*8.39}{3.6*3.6}$$

= **0.2937 N**

4) Inertia Resistance

m= mass of vehicle +mass of rotating parts

t=time to reach top speed

IR = ± m*a

$$a = \frac{V}{t} = \frac{0.9424}{5} = 0.18848 \text{ m/s}^2$$

IR = ± (12+1.5)* 0.18848

= 2.544 N

Total Tractive Force

TF = 35.316 + 30.46 + 0.2937 + 2.544

= 68.6137 N

Total torque = TF * r

=68.6137 *0.03

= 2.0584 Nm

Including losses take 20% extra torque

= 1.2*2.0584

= **2.47 N-m**

Torque in kg cm

$$= \frac{2.47}{9.81} * 100$$

$$= 25.179 \text{kg-cm}$$

Torque on each motor

$$= \frac{25.179}{4}$$

$$= \mathbf{6.294 \text{ kg-cm}}$$

As we considered

1) $\mu = 0.3$ for belt
2) 20% of extra torque
3) 20 % of extra load
4) Maximum area for air resistance 0.18 m^2

Hence motor with torque **8 kg-cm** is suitable.

4. ELECTRONIC COMPONENTS FOR TANK-COPTER

Table No. - 1: electronics components

Brushless direct motor	Is connected to propeller and transmit the motion to propeller	
Flight controller	Synchronizes the function of all motors	
Electronic speed controller	It controls the speed of motors	
Battery	Gives the DC power supply	
Propeller	Converts torque force into thrust	
Altimeter	It measures the height of drone	
Inertia measurement unit	It controls the motion of drone in all axis	
DC geared motor	used to give motion to tracks	
Transmitter and receiver	Receiving and transmitting signals	

- All the components are selected on the base of performance, voltage requirements, endurance, and quality.
- Each component has its specific operation in tank copter.
- Some other components which are needed in tank copter are pulleys and rubber tracks. They have a function in the operation of caterpillar.

5. MODELING OF TANK-COPTER

The modeling of tank-copter is done in CATIA. Each part is separately designed and properly sized according to the aerodynamic laws. The CATIA model shows a rough idea of tank-copter.

5.1 Earlier Trial Models

Before coming to final idea and configuration of design 4 trial models were made in CATIA but failed in some criterion of requirements. The 4 Prototype of failed tank copter are given below:

Trial 1

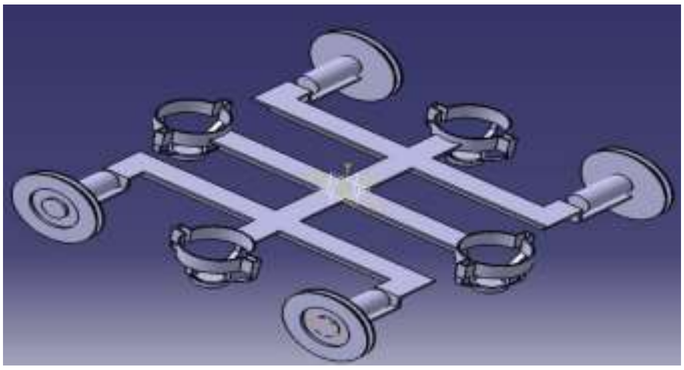

Fig No. – 3: trail 1

Cause of failure: Design was week as per the requirement of payload capacity.

Trial 2

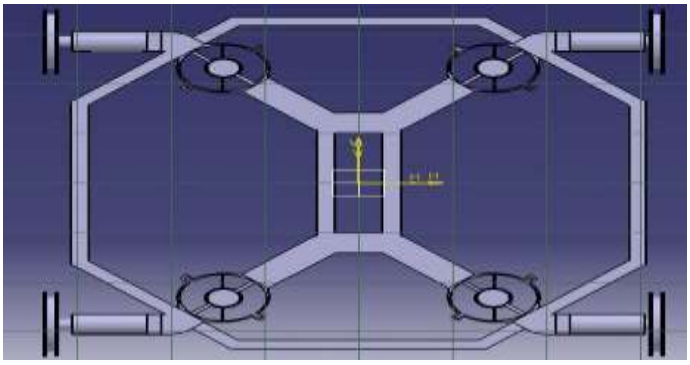

Fig No. – 4 trail 2

Cause of failure: In this model wheel support was very weak.

Trial 3

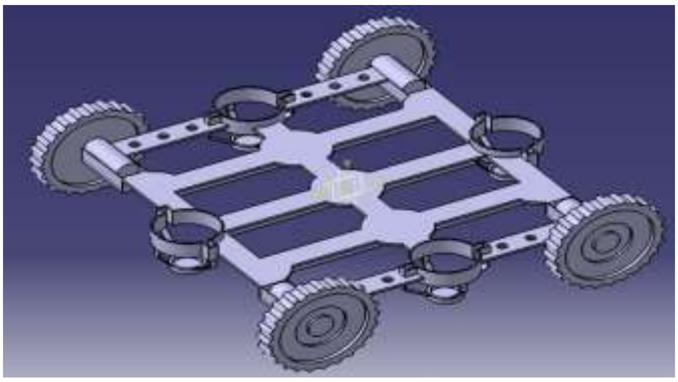

Fig No. – 5: trail 3

Cause of failure: This model was not suitable for aerodynamic motion as it had high resistant area.

Trial 4

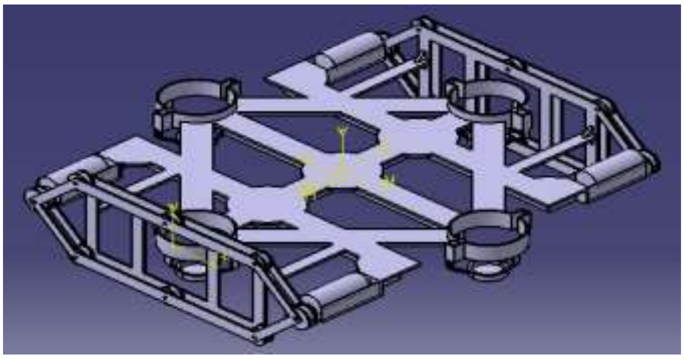

Fig No. – 6: trail 4

Cause of failure: This model was good with the strength point of view but after study it has been observed that using thrusters will not provide efficient control over the UAV.

5.2 Final Model

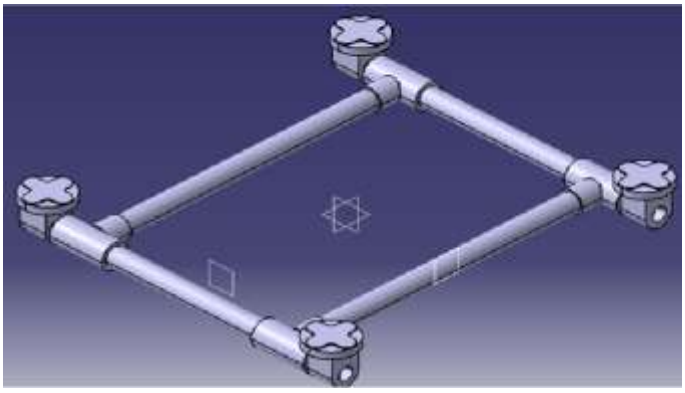

Fig No. – 7: Supporting frame

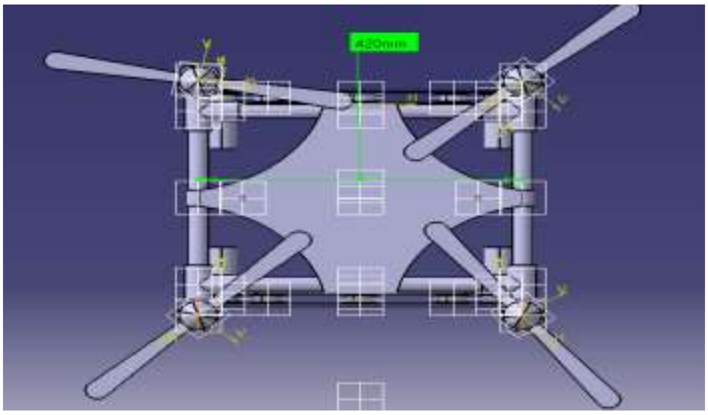

Fig No. – 8: top view of drone

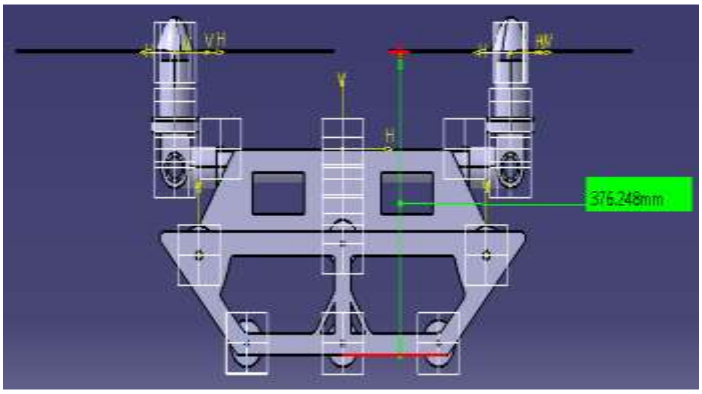

Fig No. – 9: side view of drone

Fig No. – 10: rendered view of tank-copter

6. MATERIAL SELECTION

The main point of this drone is to make it lighter and stronger at the same time. So in this project 3 different types of materials are selected to make the frame very light.

The 3 materials used for tank-copter are:

1. Aluminum 7075 T6
2. Woven carbon fiber
3. Poly-lactic acid(PLA)

All three materials are used in different places of drone such that each material's property is used to its extent.

Aluminum 7075 sheet of 3mm is selected for the tracks and electronic mounting.

Woven carbon fiber hollow rods are selected for supporting the frame.

Poly-lactic acid (a 3-D printing material) is selected for motor mountings and T-section to join carbon fiber rods with each other.

7. FINITE ELEMENT ANALYSIS REPORT

The FEA (finite element analysis) was conducted on ANSYS with the help of all related data described below:

The forces applied on the drone design are given in Fig No. 11.

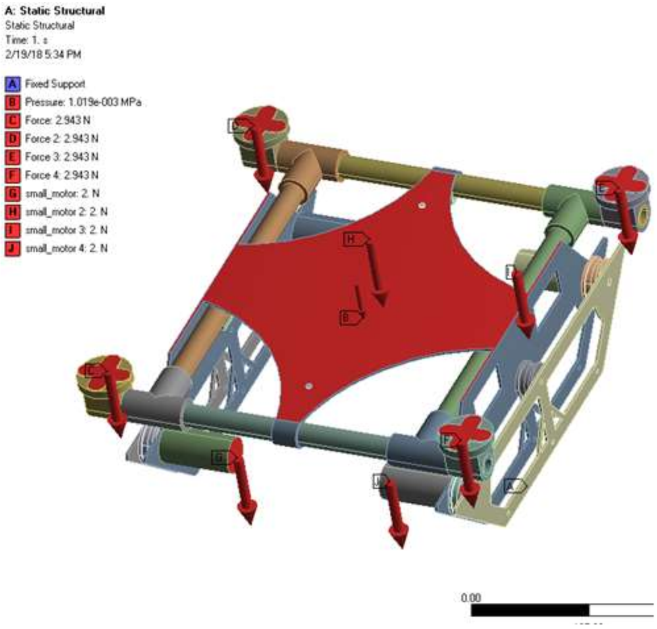

Fig No. – 11: Force diagram

- Total 9 forces were applied on the drone.
- The force applied on 4 motor mountings is 2.94N each.
- The force applied on 4 ground motors is 2N each.
- The pressure applied on the aluminum plate is 0.001019N/mm^2
- Total weight applied on drone frame including max 5kg payload and components is considered as 7.5kg.
- The area of plate on which components are to be mounted is 72198mm^2.

7.1 Solution of FEA

The solution of FEA was obtained as displacement plot and the solution is shown in Fig No – 12.

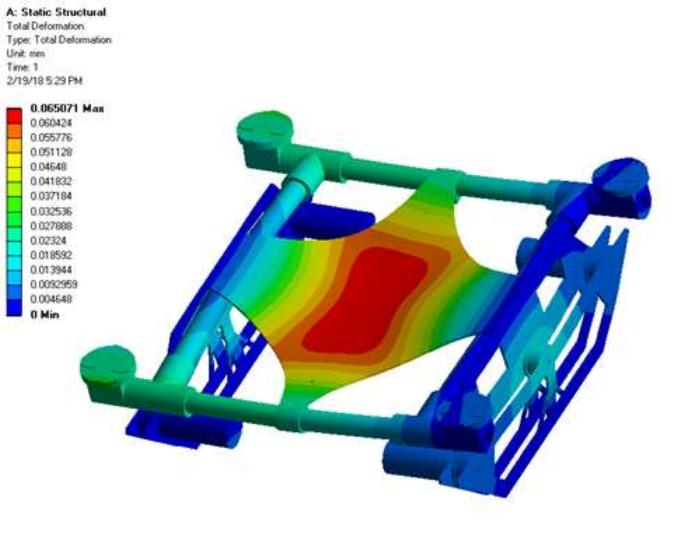

Fig No.-12:Displacement diagram

Above result shows the maximum displacement of aluminum as 0.06507 mm. It also shows the negligible displacement on other supporting members of model that implies the model is safe for loading.

8. ADVANTAGES AND FUTURE SCOPE

1. As optional domain switching is available this makes the Tank-Copter more beneficial enabling it to go anywhere in any terrain.
2. When there is shortage of power in battery the caterpillar can be used to move the Tank-Copter as it consumes very less power as compared to flying domain.
3. Detection of Tank-Copter by enemy can be avoided using caterpillar as it operates silently.
4. As per calculation above Tank-Copter is able to lift payload of 5kg.
5. Tank copter can be used as surveillance tool in military operated zones and it can also help to supply medics to the ongoing war zones.
6. Tank-Copters can also be used to supply ammunition in war zones.
7. In future Tank-Copter can be made smart enough to supply medical assistance at accident occurred place.

9. CONCLUSION

The detailed study over the Tank-Copter and necessary aspects is conducted in order to achieve most efficient and promising facts. After reviewing all aspects it is concluded that Tank-Copter proves to be very promising drone that can be used for multiple purposes in various sectors. In coming future tank-copter can be manufactured with high precision and can prove to be best drone not only in the field of surveillance but also to carry ammunition in war affected zones or to carry medics where human help cannot come as quick as possible.

The conclusions drawn from the design research are as follows:

1. It can carry payload up-to 5kg.
2. It can handle stress very well as after applying all loading factors to maximum extent the deflection plot only shows a max deflection of 0.06mm.
3. It can work on both domains as and when required.
4. Enough space is provided for assembling high resolution camera to capture photos and videos.

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BIOGRAPHIES

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