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Conceptual Design and Non-Linear Analysis of Triphibian Drone

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Abstract

Drones are increasingly used to replicate human presence and are extremely capable whether it is in terms of delivering aid to war torn areas or carrying reconnaissance missions beyond borders. Due to their increasing demand in all forms, an arsenal of drones has to be maintained and there is a need to make existing drones capable of maneuvering wherever the need be. Design of drone with land, water and air affinity is proposed along with non-linear analysis of drone structure. Physical contacts in the drone structure and gravity is accounted for and simulated. Weight carrying capacity of the drone is measured by increasing the weight of the components in each simulation run till the point of failure. Landing capability, structural integrity and stress is studied to ensure the structure doesn't collapse. Effective visualization tool for variable thrust, rpm and forward speed of the drone is developed, which is able to generate real time data regarding the drone's flight by plotting a three dimensional surface plot of varying thrust, rpm and forward flight speed. Model of the drone is used to study the flight plan of the drone with gravity considerations in non-linear analysis.

Keywords: Design of air-water-land capable drone; non-linear analysis; thrust-rpm-forward speed plotter; structural simulation; landing test.

Nomenclature & Abbreviations

Triphibian	Designed to operate on land, under water and in air
UAV	Unmanned Aerial Vehicle
3D	3 Dimensional
GUI	Graphic User Interface

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FAA	Federal Aviation Administration
Kv	Constant Velocity of the motor
DC	Direct Current
ABS	Acrylonitrile Butadiene Styrene
MPa	Megapascal

1. Introduction

Military applications or for the purposes of civilian use, drones are the need of the present and the future. Whether it is a matter of delivering humanitarian aid in war torn areas or carrying out surveillance behind enemy lines, carrying out inspection of fault lines under the bed of the ocean or crawling on land to go undetected inside the enemy's territory. Drones are the ultimate solution to all our problems, a machine designed by humans to replicate their presence in several areas. A Drone that combines the likes of a drone that can walk, a drone that can fly and a drone that can swim. Combining all the abilities of a modern drone into making one UAV that can do everything on its own and we no longer have to limit ourselves or our expectations. A major problem in successful drone flight is the accurate calculation of thrust [1]. A thrust measurement apparatus is designed and developed which could affordably measure the torque and efficiency of motors, in an attempt to simplify the process of finding torque and making it cost effective [2]. However, there's a need for simplification and development of a model that generates a 3D plot of thrust, rpm and forward speed as that will enable us to visualize and predict the behavior and stability of our drone without the need for an apparatus. Quad copter frame modeling and analysis is critical to determining the structural integrity of the model and to be able to determine the correct gap between the propellers, the right size of the frame and the weight of the components.

The drone model is analyzed for the right frame size and also for the structural integrity of the body. However, drones cannot just be analyzed with a linear model and in a static manner. This model needs to be extended to do the analysis of drones in a non-linear manner since in reality the drone is actually an assembly and not a single body and has numerous physical contacts that need to be taken into account. Analyzing a drone in terms of its load carrying capacity and its ability to handle damage is an important factor that leads to the making of a stable drone [3]. The efficiency of drones is studied with different propellers in terms of the optimum thrust generated to support the payload. It helps in predicting the drone's ability to withstand load during flight. The experimental work carried out with measurement of thrust for propellers of varying diameter and pitch proved useful in the development of GUI for thrust-rpm-speed plotter [4]. A tool that relates rpm, thrust, forward flight speed of drone is designed with the diameter and pitch of the propeller which led to the development of an excel based calculator capable of drawing the curve for fixed rpm and flight speed values [5]. The existing model needs to be extended to solving thrust equations with not just a fixed value of rpm or forward speed but a range of both the variables. In real time flight plan of drones, the entire duration comprises of range of rpm and speed as the drone has to maneuver its way through the obstacles to reach its target. Hence, an evaluation at range instead of fixed value will paint the actual picture.

An amphibious drone is designed which helped in multiplying the applications of a drone and created a system that has enhanced maneuverability [6]. The design principles used also help in understanding the difficulties that can be faced while combining capabilities of a drone (land and water). Extending the model for designing a triphibian drone cannot serve the purpose as the use of multi-functional components and parts is extremely critical to developing a design that not only weighs less but can lift or carry more as a result. Drone design needs to be modified in a way that the same quad rotor frame is able to maneuver on land, water and air. Thereby allowing the drone to carry goods or carry out surveillance without any barrier. The design of the air-water-land capable drone is proposed, taking into account the existing advancements in the field of UAV's along with a tool that provides useful insight in the real time behavior of the modern UAV.

2. GUI for thrust-rpm-forward speed plotter

The analytical relations developed for finding out the value of thrusts based on rpm and forward flight speed of the drone [6] were used to arrive at the resultant equation that yields the thrust force generated. The equations along with all the parameter and constants were fed into the Matlab GUI code to integrate and develop an interface that can not only generate the thrust value but also helps in analyzing the 3D view or the three-way-relationship between rpm, thrust and forward flight speed. The major milestone achieved with the Matlab integration is that the new mode operates for a range of rpm and forward flight speed. By entering the blade specifications i.e. the blade pitch and the diameter and further specifying the range of rpm and filling in the forward flight speed range of the drone, one can click on 'update' button which appears in the interface and it will generate a 3D plot that represents the thrust, rpm and forward speed on y, z and x-axis respectively. It helps in analyzing the effect of two parameters combined on the third one, for e.g. the effect of increase in rpm and forward speed on the thrust produced. The tool is also ideal for obtaining optimum value of thrust at any instant during the entire flight of the drone.

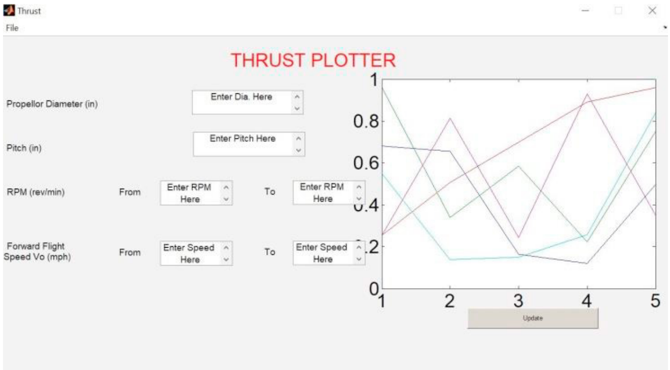


Fig 1: The interface of thrust plotter.

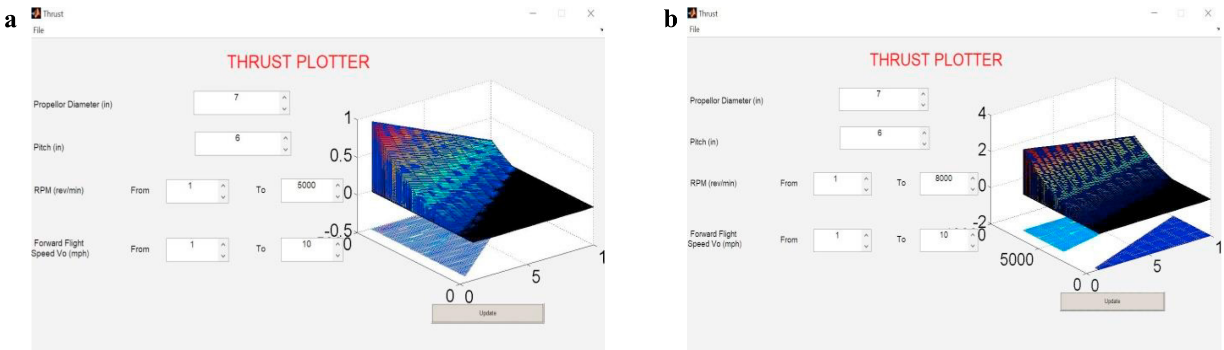


Fig. 2. Thrust plotter for (a) 7x6 blade at 1-5000 rpm & speed at 1-10 m/s; (b) 7x6 blade at 1-8000 rpm & speed at 1-10 m/s.

3. Simulation and analysis of the drone

3.1 Design of a quad rotor frame in solidworks

Figure 3 shows the model of the drone was designed in SolidWorks using the FAA prescribed standards for Unmanned Aerial Vehicles (UAV's). The drone was made in a way that it is symmetric across all ends so that only a quarter of the entire model needs to be simulated to arrive at the final results, saving computational time and effort. The designed propellers are of 1045 series while the motors are 1000kv brushless dc motors. Landing arms are provided at the bottom of the structure in order to allow the drone to make a stable landing and avoid damage. The hollowed out portions of the design are due to weight reduction, in order to have the least total weight of components possible so that the generated thrust can easily lift the drone with the scope for additional load.

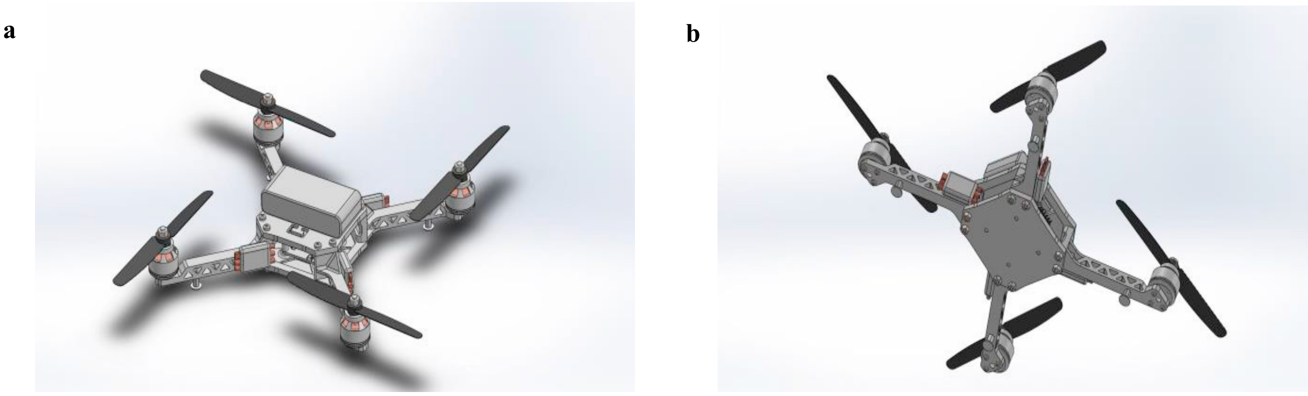


Fig. 3. Drone design in SolidWorks (a) isometric view; (b) bottom view.

3.2 *Structural simulation of drone frame*

Drones are assemblies consisting of a large number of components, hence they can't be treated as single body units and have to simulated while considering all the individual components and their interactions with the assembly. The load conditions used in the simulation are specified in Figure 4. Structural simulation in this manner helps in identifying the components under maximum stress as well as assists in evaluating the drone design as a whole.

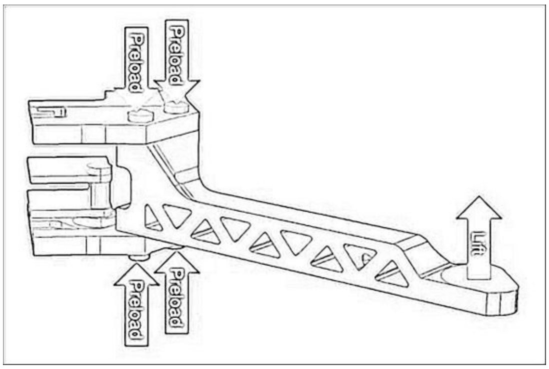


Fig 4: The loading condition in the simulation

Mesh refinement was applied in the portions where stresses higher than the rest of the body were expected as shown in Figure 5. The loading condition in (Figure 5a.) makes certain areas prone to large stresses as compared to others and refining mesh saves computational effort as well as helps in evaluating those regions with much more clarity. The physical contacts between the spider top, arm and the spider base as well as the contacts between the screws and the surfaces were defined to ensure a non-linear analysis that takes into account physical contacts and doesn't take model as single body. The displacement produced in the drone arm due to the preload and lift is well within the permissible limits. The maximum von mises stress developed in the structure is about 34.3 MPa whereas the yield stress of ABS is approximately 42-45 MPa. The major stresses developed in the structure have been produced in the steel parts i.e. the screws indicating that the body will be able to sustain the load comfortably and the screws can be replaced when worn out or can be made from a better performance material.

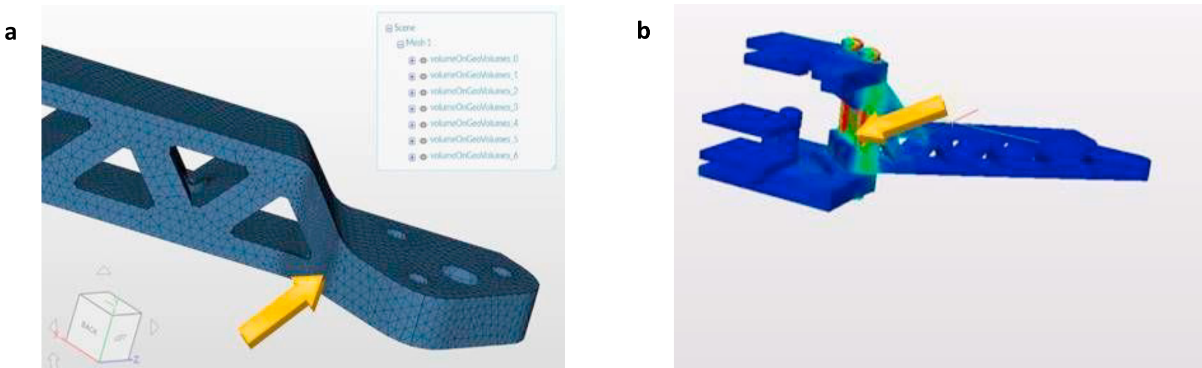


Fig. 5. (a) One of the mesh refinement zones; (b) 3D view of maximum stress regions.

3.3 Landing and weight testing of the drone

The landing effect of the drone on land was studied. The weight of the structure was supplemented each time. The landing of the drone was simulated as shown in Figure 6 to identify the maximum stresses developed during crash or landing. Additionally the increment in mass helps in identifying the weight of components that can be successfully carried by the drone. Geometric behaviour and gravity were defined to carry out non-linear analysis. The simulation run was carried out to identify stresses before and after hitting the ground. The simulation run carried out at increased mass and analysis of results shows that the maximum stresses developed in the structure is 38.5 MPa while the yield stress value for ABS (material used in simulation) is 42-45 MPa, reflecting that the designed structure is safe from damage in case of an increase in the weight of the component or from sudden landing or crashing as well.

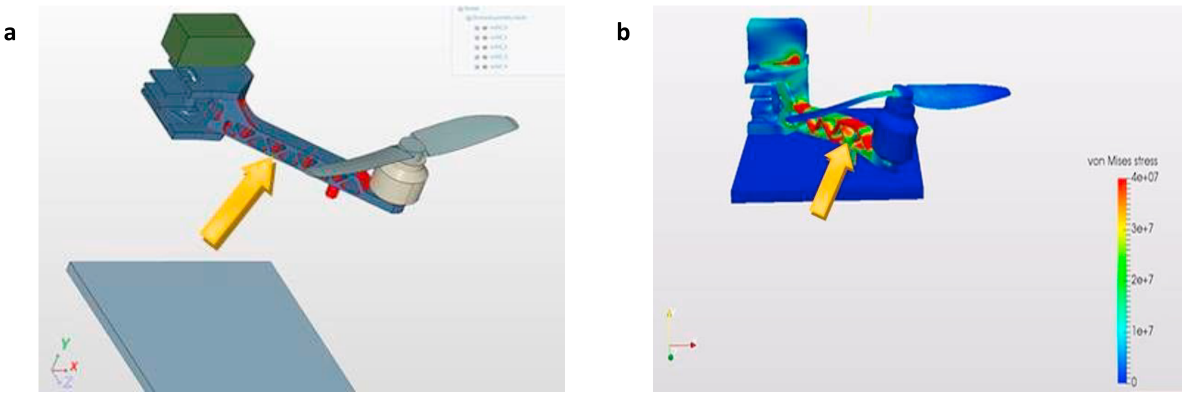


Fig. 6. (a) One of the mesh refinement zones; (b) 3D view of simulation.

3.4 Aerodynamics of propellers of the drone

From Figure 7, the production of thrust force can be clealry visualized. While studying the aerodynamics of the propeller, the thrust vs. speed variation was also examined for two and three blade propellers in order to get insight regarding the efficiencies of both propellers at various values of drone speed.

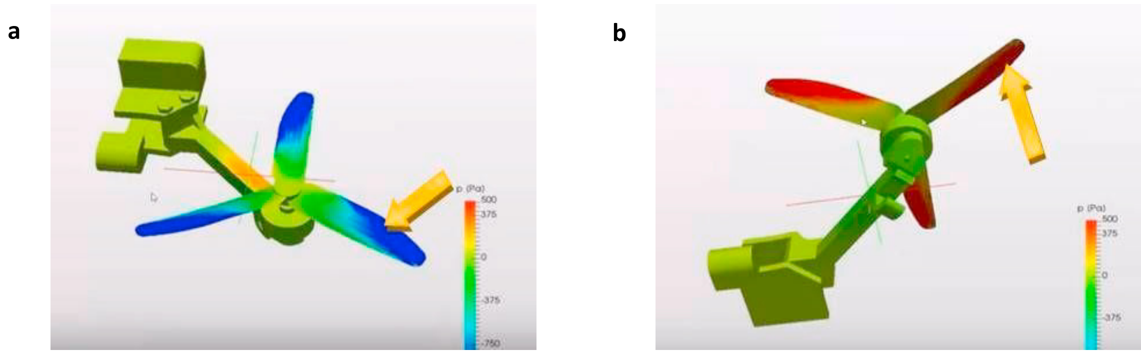


Fig 7: (a) Top region of the propeller; (b) Bottom region of the propeller.

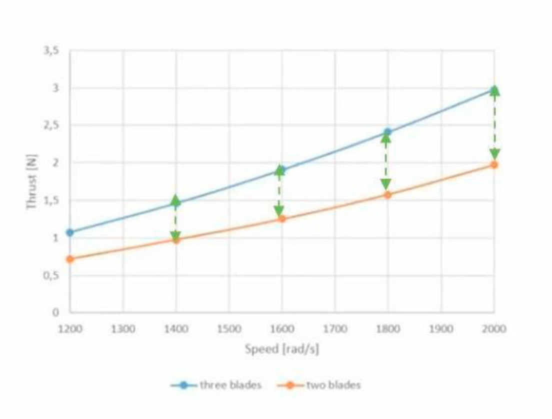


Fig 8: Graph of Thrust vs. Speed for 2 & 3 blade propeller.

From the Figure 8, the steadily increasing gap between the thrust produced by a two blade propeller as compared to a three blade propeller shows helps in comparing the efficiency of both blades at high speeds. The decrease in efficiency can be compensated by a variety of factors such as chord length and diameter of the blade. Though a three blade propeller generates a more concise vortex yet two blade propellers can also turn out to be more efficient with different specifications.

4. Concept design of the drone

The important components of air-water-land capable drone concept design: Landing gears have additionally flexibility in order to minimize the stresses induced during landing as shown in Figure 9. The ability to stretch is provided in the landing gears which serves as a suspension system for the entire drone frame and helps it in absorbing all the stresses and thus minimizing the displacement and stresses. Hence, the drone was designed with gears that are free to move in a V-shape (relating to a knuckle joint with limit) and form the cushion for the drone. To enable the drone to float or swim in water, additional movement is required in the drone arms so that they can serve as the fins for the movement of the drone under water. The drone arms can maneuver freely about their axis and thus can move in a front-back motion as illustrated in Figure 10 to function as the fins of the drone. The presence of moving arms not only provides water borne capabilities but also enables the drone to use its ducts as wheels to move on land.

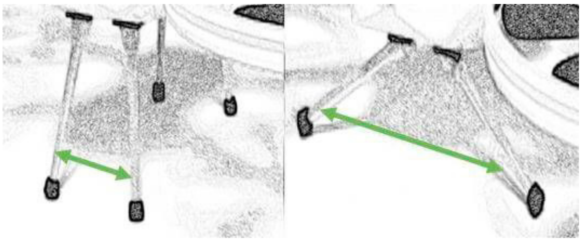
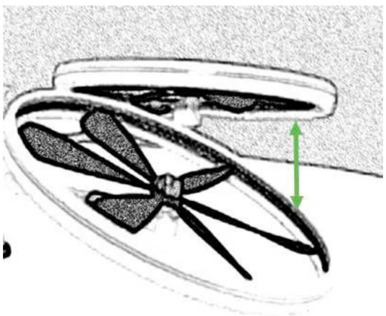


Fig. 9. Flexible landing gears.

Fig. 10. The up and down arrow signify movement of frame.

The ducts around the drone serve as the wheels for the structure (are able to move with the help of a ball joint) and hence enable to move on land and maneuver easily. Addition of components like wheels (for land) and fins (for underwater) adds weight to the drone structure, since there are always limitations to the amount of weight that a drone can carry, additional components imply a reduction in the ‘package’ carrying capacity of the drone. Wheels require additional motors and shafts that add on to the load on the drone frame and hence instead providing additional movement to the arms serves better in terms of minimal weight of components and maximum functionality as shown in Figure 11.

a



b

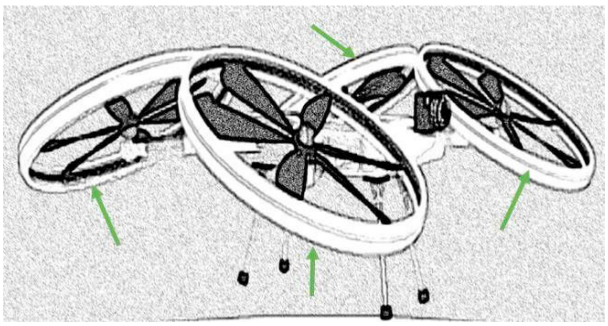


Fig. 11. (a) Independent movement of the drone arms; (b) Independent movement of propeller ducts for wheel conversion.

5. Results

Thrust-rpm-speed plotter enables a clear visualization of the entire drone flight plan and also helps in predicting the exact value of thrust at any given point of instant in the flight. It paints a clear picture of the drones thrust capacity. The structural simulation of the drone frame provided a stress value of 34.3 MPa, while the yield limit for ABS is 42-45 MPa. Thus, providing a clear indication about the structural integrity of the drone frame under conditions of static load. The landing and weight testing of the drone resulted in the maximum stress being 38.5 MPa while material used has a higher yielding limit (42-45 MPa) and thus no yielding or displacement is expected to occur when the drone is making a landing. The simulation of the drone at increased weight resulted in a rise in the maximum stress but well within the permissible limits (stress value- 37 MPa, limit- 45 MPa). The analysis of the load carrying capacity indicates that the drone can successfully handle an increase in the amount of components loaded on it without any visible failure. The aerodynamics of propellers clearly indicates the normal functioning of the blades. The comparison between the two and three blade propellers is indicates that in terms of constantly increasing speed, a three blade propeller produces much more thrust as compared to a two blade propeller and thus is more efficient, however blade efficiency can be tailored by altering the chord length and diameter of the blades. The concept design of the drone is developed keeping in mind the importance of weight reduction. Removal of additional components such as wheels, shafts saves the amount load imparted on the drone frame and thus enables it to carry more and weigh less and fly with efficiency. The additional flexibility in the drone arms provides it with the means to easily maneuver on land, in air and under water. The presence of flex-landing gears provides the cushion required for safe landing and minimum stresses.

6. Conclusion

Based on the conceptual design and non-linear analysis of Triphibian drone, the following points are concluded,

- The development of the Matlab based GUI for thrust-rpm-forward speed plot, simplifies the process of calculation of thrust and its visualization in terms of forward flight speed and propeller rpm. Its capacity to take rpm and forward flight speed of the drone in the form of a range rather than a fixed number is what helps in a clear visualization of the entire flight. It eliminates the need for any apparatus to test and measure the thrust of the propellers, minimizing effort and maximizing precision.
- The non-linear analysis of the drone frame for its structural integrity, landing stability provides real time insight about the drone frame. Taking account of geometric entities, physical contacts and gravity results in a simulation that has close proximity with actual conditions. The maximum values of stresses are all in the range of 32-38 MPa which is well within the allowable limit as the chosen material has a higher yielding range. Further, it gives a clear indication about the robustness of the frame and the amount of weight it can carry without any failure.
- The conceptual design of the drone stands out in terms of its ability to maneuver under water, on land and in air. It eliminates the presence of any unnecessary component in the assembly, thereby reducing the overall weight of the structure. The air-water-land capable drone can be used to carry out surveillance beyond borders undetected or deliver aid-packages in war struck areas. Due to the fin-like movement of its arms, the drone can also be used to carry out inspection of oil rigs. The existence of a single drone that can maneuver in all three medium eliminates the need to maintain an arsenal of drone and gives rise to endless applications.

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