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Case study on vertical take-off and landing capabilities in unmanned aerial vehicles for defense applications

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ABSTRACT:

The need to take-off and land in stringent battlefield conditions necessitates the need for Vertical Take-Off and Landing (VTOL) capabilities in Unmanned Aerial Vehicles (UAV). Also, a major issue associated with UAVs is that these aircrafts are not suitable for operations in limited airspace. This problem becomes huge especially in urban areas where the usage of runway is not possible, and UAVs usually have to fly at a relatively low speed and altitude. VTOL UAVs require less investment in infrastructure and geographical area for their operations as compared to other traditional aircrafts. Development of VTOL technology would not only strengthen our military but also eliminate the requirement of big airstrips. This paper focuses on the introduction, classification, applications and basic design process of VTOL UAVs keeping in mind the military requirements.

KEYWORDS: VTOL, Tilt-rotor, UAV, Medium Caliber Canon

INTRODUCTION:

VTOL stands for Vertical, Take-Off and Landing. These aircrafts have the capability of taking-off, landing and hovering above the ground vertically. Now talking about the history of VTOLs, they first came into existence during the years ***1950-1970,*** and almost every experiment failed. These experimental aircrafts used to have short run before take-off and were also referred as ***Short-Run, Take-Off*** and ***Landing*** vehicles (***STOL***). The majority of work done by aerospace companies on the design and construction of VTOL aircraft occurred between the 1950 and 1980, during which time a variety of approaches were used for vertical take-off. These lifting approaches incorporated a wide variety of propulsion concepts in an effort to gain greater propulsive efficiencies and higher thrust-to-weight ratios. These propulsion approaches have been broken down into four distinct categories in order to better classify the historical VTOL aircraft and provide commonality for comparison. In addition to the appeal of a VTOL vehicle's capabilities, the maturation of unmanned aerial vehicle (UAV) and unmanned aerial combat vehicle (UCAV) technologies allows manoeuvrable drones the capability to autonomously access isolated terrains, increasing capabilities within both the commercial and military sectors. While a few VTOL UAV designs have reached the flight test phase, this sector of unmanned aerial vehicles as a whole is still considered to be in its infancy, while propulsion offerings continue to arise along with more capable autonomous technologies. The now infamous VTOL "wheel", depicting historical VTOL flight vehicles and their lifting approaches, was recently modified ***by ANSER Research Institute during the Joint Strike Fighter competition*** in order to compare historical VTOL vehicles and the similarities that exist between them. This research proposes a methodology for use of UAVs in combat. The proposed design consists of a medium caliber canon mounted on the fuselage with additional sensors and further improvements such as power to weight ratio by use of alternate propulsion source and a well-balanced System.

HISTORY OF UAV's:

Operation in helicopter mode makes the aircraft possible to Vertical Take-off and Landing (VTOL), fly at low speeds in any direction (e.g., forward and sideways), hover and perform some difficult manoeuvres. In the fixed-wing mode, due to stall problems on the lifting surfaces, low speeds are not possible. However, this type of UAV can have increased range, endurance, payload carrying capacity and stability. and performance of a typical aircraft by incorporating the characteristics of Throughout the last decades, numerous attempts have been devoted in developing Traditional Aircraft. Diverse concepts have been examined in previous works in an attempt to find better designs. [13]

Following are some of the traditional Tiltrotor designs:

Fig 1: Bell Eagle Eye Tilt-rotor UAV [17]

Fig 2: NASA's GL-10 Tilt Wing UAV [18]

TYPES OF UAVS:

- **Target and decoy** – This type is used to provide firing at higher elevations (aerial ammunition; where the UAV carries a semi-automatic gun)
- **Reconnaissance**- This type is mainly associated with gathering of images of enemy battlefield and also conduct and provide real-time surveillance.
- **Combat** – This type is also known as UCAV i.e. unmanned combat aerial vehicle. This type of UAV provides assistance to combat by carrying ammunition and missiles for surgical strikes.
- **Civil and Commercial UAVs** – These UAV's are being made to be used by various industries to increase the efficiency of their work cycle. [13]

RESEARCH AND FINDINGS:

In order to properly establish weight trends for the three categories of power plant configurations, a reasonable amount of data is gathered so that equations are created with higher precision. While conducting this research, all data relating to the weights of the historical vehicles is noted, with particular attention paid to the two main aircraft weight values and their ratio:

1. Takeoff Gross Weight
2. Empty Weight
3. Empty Weight Fraction

These weight values are of great importance as they have a direct impact on the stability of the UAV and the amount of payload that can be added to avoid imbalance in the system. In addition, the vehicles considered in this study typically transition into a more efficient flight configuration for forward flight. [1]

CONSTRAINTS FOR UAV DESIGN:

Once the empty weight and takeoff gross weight of the VTOL UAV are determined, the preliminary sizing of the vehicle's wing (primarily used for forward, conventional flight in this case) and the general sizing of the power plant are required in order to fully define the preliminary size of the VTOL UAV.

Sr. No	Constraint
1	Takeoff
2	Landing
3	Stall Speed
4	Range
5	Cruise Speed
6	Altitude

While some of the above constraints are applicable to a VTOL UAV, the takeoff and landing constraints are not. The method by which the VTOL UAV transitions to forward flight greatly determines what the stall speed of the aircraft is. In addition to the constraints that are applicable to this study, constraints depicting the requirements of a VTOL aircraft are also necessary. In order to approach the rapid development of a constraint for VTOL UAVs, a similar approach will be taken as was taken with the weight trends; the takeoff gross weight of the historical aircraft located on ANSER's VTOL "wheel" will be used in conjunction with the aircraft's installed power and/or thrust to develop a trend for the aircraft. Installed power rather than installed thrust will be focused on for the development of this constraint, as a vehicle that relies on installed turbojet/turbofan engines for direct lift the UAV will need to have a ***thrust-to-weight ratio of greater than 1.0.*** [1][14]

$$W / P = 8.18 \quad \text{(Eq. 1)}$$
$$T / W = 1.15 \quad \text{(Eq. 2)}$$

Where,
W= Weight of the UAV
P= Power Output of the UAV
T= Thrust required to lift the UAV

There are two items to note about the equations presented above. First, ***the thrust-to-weight ratio of 1.15*** is chosen as a historical aircraft design estimation, allowing for a buffer of thrust for the aircraft as well as a slight amount of leniency for the takeoff gross weight of the aircraft to increase over design iterations. Secondly, the weight-to-power ratio for the Combined Powerplants for Hover ***(Eq. 1)*** is a rudimentary estimate. Because of this, additional factors may need to be considered when designing a VTOL UAV of this type and determining where, on a constraint plot, is a viable location to begin an aircraft design.
Based on a Research carried out by the American Institute of Aeronautics and Astronautics following has been formulated:

$$W_{empty\,(UAV)} = 0.8872 * W_{empty(manned)} + 558.7$$

Where,
$W_{empty\,(UAV)}$ -Weight of the UAV while carrying no ordnance
$W_{empty(manned)}$ – Weight of a manned aircraft while carrying no load (passenger or goods)
The equation should only be used for vehicles greater than 2,500 pounds as any vehicle smaller than this is outside of the scope of what the final trend line from this study can effectively account for.

Important Points related to Design Considerations:

- Weight reduction
- Maximum Payload Carrying Capacity

- Hovering Capability of UAV
- Maximum weight of UAV with Payload

In this context, ***Payload includes a Medium caliber canon, Battery Management System, On-board Computers, High- Resolution Cameras, and various Sensors*** and devices which help in proper functioning of the Vehicle. Following is a brief description on an attempt to use UAV in Combat with proper recoil control in order to maintain stability of the vehicle.

ARMAMENTS:

UAVs are currently used for a number of military operations including reconnaissance and Combat assistance**.** UCAVs (Unmanned Aerial Combat Vehicles) have emerged as a successful support for carrying a variety of missiles, like the **Hellfire.** The Hellfire is supposed to be the best in its class for precise drone strikes**.** However, unlike the traditional UCAVs, the proposed design boasts of a **Medium Caliber Canon** that can be used for various purposes like engaging targets from a safer distance, providing tactical assistance to troops under fire, crowd control etc. Since using a small canon requires high stability, the highly stable hovering capability of a VTOL was instrumental to the design. The UAV can hence can travel for a longer distance and carry a higher payload due to its fixed wing design as well as deliver efficient blows to the target with its VTOL mode.

The available choices of ammunition were:

- ***NATO 5.56 x 45 mm***
- ***NATO 7.62 x 51 mm***
- ***.50 Cal BMG***

The recoil forces generated for a net 2.5 kg were calculated.

Fig 3: Medium Caliber ammunition [20]

Ammunition	*Recoil Impulse(lbs./sec)*	*Recoil Force (ft.lb)*	*Recoil Velocity(fps)*	*Bullet Energy(ft.lb)*
NATO 5.56x45mm	1.34	5.93	8.87	1005
NATO 7.62x51mm	2.79	25.73	18.48	2473
.50 Cal BMG	12.68	75.1	482.98	13314

Hence from the above data it is evident the **7.62x51 mm** is the ideal ammunition choice owing to its ***moderate penetration power and moderate recoil***. Although the 0.50 Cal boasts of a very high bullet energy its high recoil characteristics makes the UAV prone to flinching.[22][23][24]

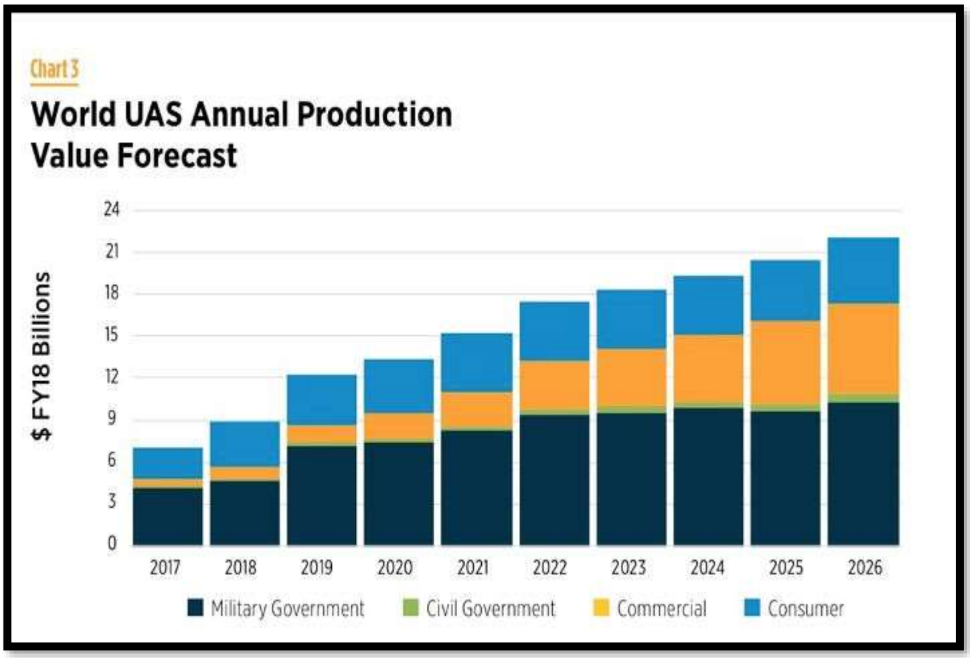

Fig 4: Graph of Estimated production of UAVs in following years [19]

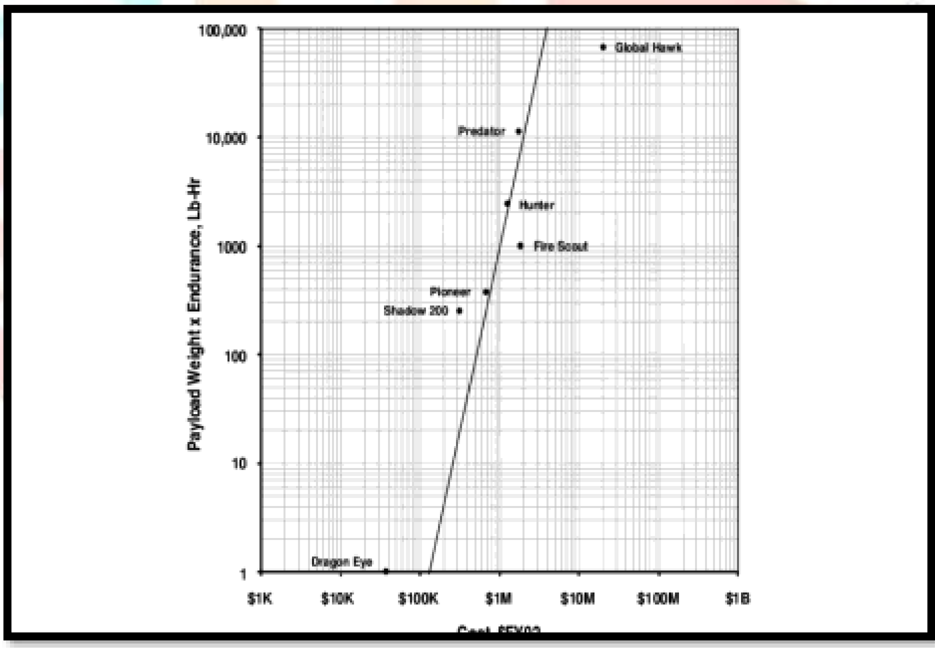

Fig 5 : A Graphical Representation indicating how overall cost of UAV increases with its payload carrying capacity [4]

POWER SUPPLY:

The propulsion system used these days is mostly fed by fossil fuels and is in a way a different configuration s of an Internal Combustion Engine. Preceded by the energy crises of the 70s and strategic incentives to make alternative propulsion systems, renewable sources are slowly being introduced. These have advantages in terms of endurance, efficiency, emissions, and stealth which make them ideal for UAV applications. [5]

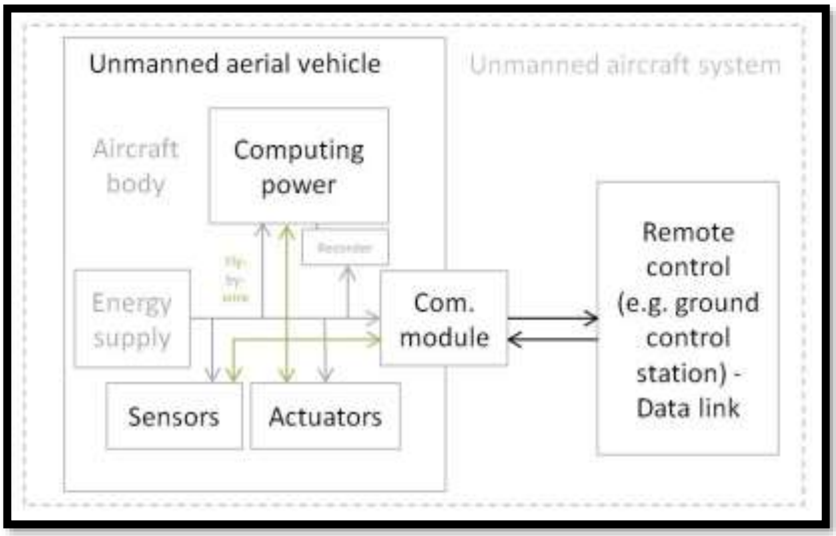

Fig 6: Power Supply System for UAV

UAV SENSORS:

- **Hyperspacial Sensors**

They utilize reflections of various ***IR wavelengths*** to determine the material that the target is made of. Every object has its own '***fingerprint'*** and Hyperspacial Sensors collect the data and help match it up to those '***fingerprints'.*** Today the military applications of Hyperspacial Sensors include ***detecting roadside bombs*** and ***fields of illegal drugs. [1]***

- **Multi-spectral Targeting System**

It is a combination of infrared sensors, a color/monochromatic daylight TV camera, and an image-intensified TV camera. It allows video from individual sensors to be viewed or can combine all of the images from the multiple sensors into one large image. It enables the military for ***long-range surveillance*** and ***high-altitude acquisition, tracking and laser designation for surveillance, target acquisition, tracking*** and ***range tracking.[1]***

Fig 7: A Multi-spectral Targeting system developed by Raytheon [21]

- **Light Detection and Ranging (LIDAR)**

A remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. LIDARs are mostly used for making high resolution maps for the military.

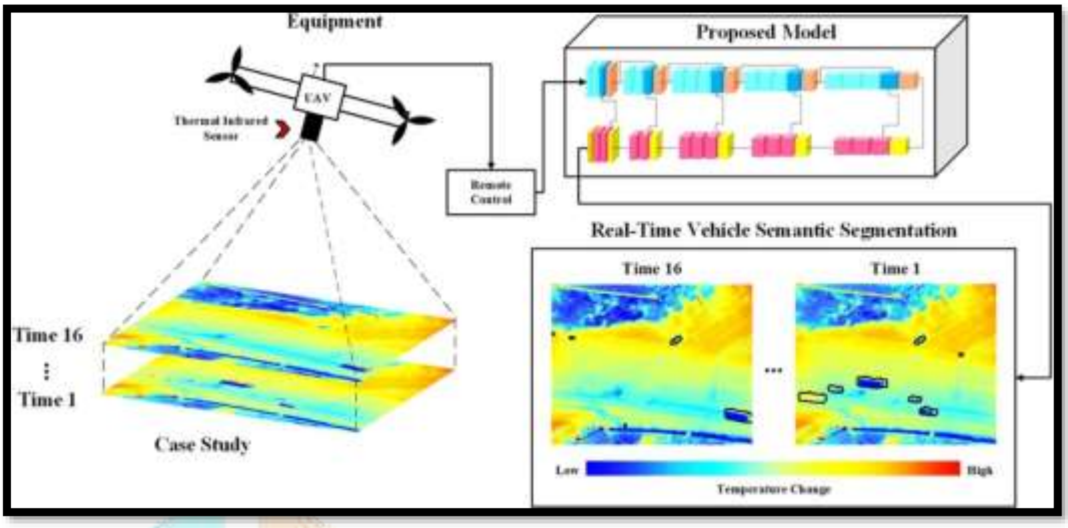

Fig 8 : An example of how a thermal image sensor produces real-time image [3]

UAV PROPULSION SYSTEMS:

The propulsion system of a UAV consists of the following elements:

- energy source: chemical fuels (fossil fuels, biofuels, and chemicals), electricity, solar energy (in conjunction with photovoltaic cells), hydrogen, methanol, and energy mechanics;
- storage media: tanks, batteries, capacitors, metal hydrides, and so forth;
- mechanical energy converter: internal combustion engine, and fuel cell + electric motor;
- lift/thrust converter: rotor, fan, propeller, jet engine, and so forth.

Lift/thrust conversion systems are closely linked to the type of aircraft (fixed wing, rotary, lighter than air, etc.). In addition, propulsion systems usually include power control, rpm control, heat management system, and an auxiliary electrical power generator.

In this context we will be focusing on electrically powered UAVs with the help of a stable Battery management system.

Electric Motors convert electricity into mechanical energy by moving a propeller, fan, or rotor. Electrical energy is supplied by a battery. They have the advantage of being the quietest and having one of the lowest thermal signatures. Currently, mainly Micro- and Mini-UAVs are powered by batteries and electric motors. Although there is a significant scope of improvement, electricity demand comes not only from the engine, but also from the payload and communication systems, limiting the endurance or speed. Newer sources such as Fuel cells and photovoltaic cells have already been tested in UAVs, but they remain far from being mature technologies.[6]

The power comes from a lithium polymer battery which is rechargeable and has a ***polymer electrolyte such as poly (ethylene oxide) (PEO), polyacrylonitrile) (PAN), poly(methyl methacrylate) (PMMA) or poly(vinylidene fluoride) (PVDF).*** These have very high specific energies as compared to conventional lithium-ion batteries.
Also, these have a very good power to weight ratio as compared to lithium-ion cells and are used in lightweight applications as in a Combat UAV. Lithium polymer batteries are a popular choice for unmanned aerial systems, as these cells can be enclosed in thin, flexible aluminium pouches. These batteries have high energy density in accordance to their size and weight. The voltage rating per cell is also high in case of Li-Po batteries which are used in UAVs.

In UAVs, the duration of flight is largely dependent on the battery life, and a condition in which the battery becomes completely drained during flight can be disastrous. In order to avoid this, a ***battery management system (BMS)*** is important. The battery management system acts as the brain and monitors battery voltage, current, temperature, state of charge, state of health and other parameters. It also calculates additional information based on these bits of data. In addition to managing the battery usage, the battery management system also safeguards the battery against conditions such as over-current or over-voltage.

FUNCTIONING OF UAVS:

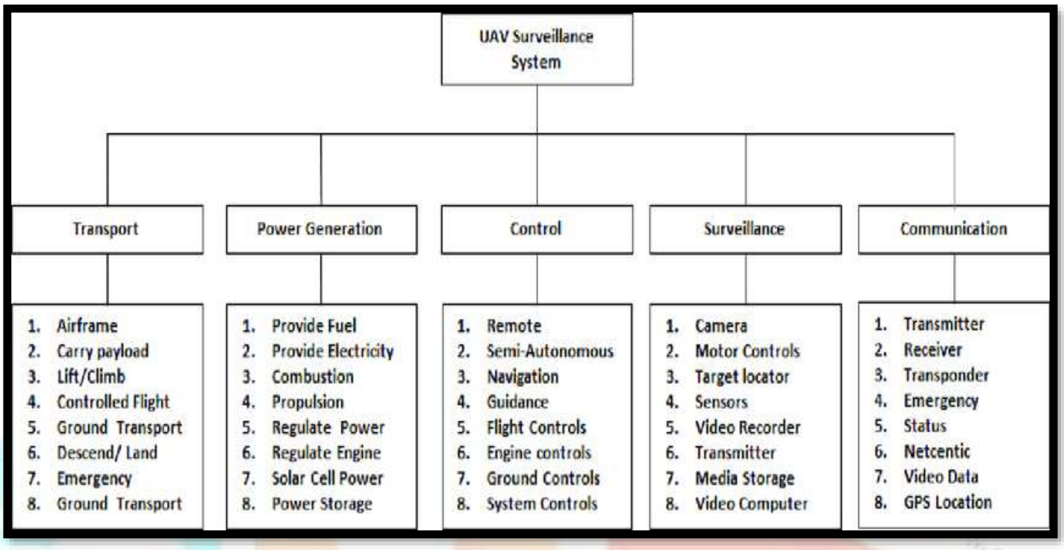

Fig 9 : Conjugation of components for effective working of a UAV [2]

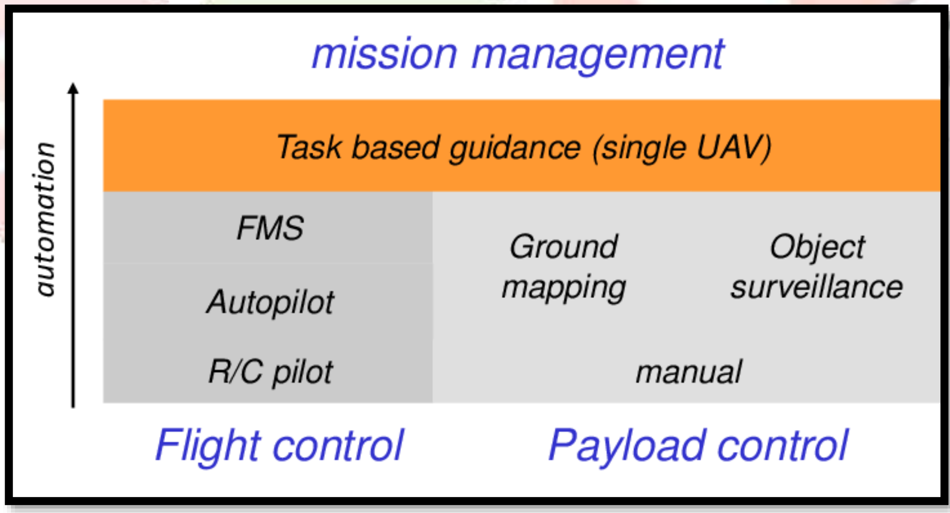

Fig 10: Functioning of UAV [5]

FUTURE IMPROVEMENTS:

When it comes to technology, the scope of its advancements has been proven limitless. From physical maneuvering aircrafts to get a lock to simply using the helmet mounted sights for target selection and handling the gun turret we have come a long way and we have a long way to go.

When it comes to UAV craft there are several sectors which can be improved:

- Transmission speeds of Camera feed from UAV to ground Stations. The newer versions of UAVs are focusing at higher quality live feeds from the Drone at higher speeds which will help in faster target identification and assessment.
- The "Swarm UAV" a new concept that has been floating around for a while is a system which aims at interlinking several smaller UAVs at the same time such that each drone can operate with the other and the ground station simultaneously.

- There has been a lot of development in the micro UAV sector the prime example of which is the FLIR Black Hornet which is basically a small camera drone that can be easily carried by a single soldier into combat.
- The UAVs can be covered with retro-reflectors / retro-reflective panels which tend to bend light around the object so as to make it invisible to the human eye. This results in increased stealth.

HOW UAVS CAN BE USED TO HIT TARGETS PRECISELY:

UAVs can be incorporated with Systems to suppress enemy air defenses, which not only includes surface –to-air missiles but also early-warning radars and command center communication. This can be done by disrupting the surface-based systems. Electronic attacks involve use of electromagnetic energy to destroy enemy facilities such as radars and communication systems which may give the home side a better advantage.
An anti-radiation missile directly targets the radio emission source which can also be used against jammers and communication systems.
The above proposed systems may increase the accuracy of a successful strike with medium interference of the Rival nation.

CONCLUSION:

Thus, the research is done to propose a methodology to be implemented in modern UAVs i.e., Vertical Take-off and Landing (VTOL). Additionally, future studies may include methodologies beyond weight, engine, and wing sizing, potentially including preliminary stability calculations and drag estimations as they relate to a vertical takeoff and landing unmanned aerial vehicle. This methodology eliminates the use of a conventional engine which increases the power-to-weight ratio and also payload carrying capacity is increased by a significant amount.

REFERENCES:

1. *Kadir Alpaslan Demir, Halil Cicibas, Nafiz Arica*. "Unmanned Aerial Vehicle Domain: Areas of Research". Defence Science Journal, Vol. 65, No. 4, July 2015, pp. 319-329, DOI: 10.14429/dsj.65.8631 2015, DESIDOC.
2. *Andrew Renault*. "A model for Assessing UAV System Architectures". 1877-0509 © 2015 Published by Elsevier B.V. DOI: 10.1016/j.procs.2015.09.180.
3. *Mehdi Khoshboresh Masouleh, Rexa Shah-Hosseini.* "Development and Evaluation of a deep learning model for real-time ground vehicle semantic segmentation from UAV-based thermal infrared imaging". ISPRS Journal of Photogrammetry and Remote Sensing. Volume:155, September 2019, Pages 172-186.
4. *Johann Uhrmann, Axel Schulte.* "Task-based Guidance of Multiple UAV using Cognitive Automation". COGNITIVE 2011: The Third International Conference on Advanced Cognitive Technologies and Applications.
5. *Ricardo Valerdi.* "Cost Metrics for Unmanned Aerial Vehicles". American Institute for Aeronautics and Astronauts.
6. *Mohamed Kara Mohamed, Sourav Patra, Alexander Lanzon.* "Designing Electric Propulsion Systems for UAVs". Springer, Berlin, Heidelberg. DOI: https://doi.org/10.1007/978-3-642-23232-9_41
7. *Aditya Intwala, Yash Parikh.* "A review on Vertical Take-off and Landing (VTOL) vehicles". International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163 Issue 2, Volume 2 (February 2015).
8. *Md Saifuddin Ahmed Atique, Nafisa Nawal Probha, Asif Shahriar Nafi.* "Vertical (VTOL) and Short (STOL) take-off and landing for modern jet powered aircraft: A problem to carry heavy payload and its solution". International Conference on Mechanical, Industrial and Energy Engineering 2014 26-27 December, 2014, Khulna, Bangladesh.
9. *Chipade, V., Abhishek, Mangal, K. and Chaudhari, R.* "Systematic design methodology for development and flight testing of a variable pitch quadrotor biplane VTOL UAV for payload delivery," Mechatronics, Vol. 55, Nov. 2018, pp. 94-114.
10. *Win Ko Ko Oo, Hla Myo Tun, Zaw Min Naing, Win Khine Moe.* "Design of Vertical Take-Off And Landing (VTOL) Aircraft System".
11. *Jian Zhang, Zhiming Guo, Liaoni Wu.* "Research on control scheme of vertical take-off and landing fixed-wing UAV". Published in 2017 2nd Asia-Pacific Conference on Intelligent Robot Systems (ACIRS).
12. *Roman Czyba, Marcin Lemanowicz, Zbigniew Gorol, Tomasz Kudala.* "Construction Prototyping, Flight Dynamics Modelling, and Aerodynamic Analysis of Hybrid VTOL Unmanned Aircraft". Volume 2018 |Article ID 7040531 | 15 pages | https://doi.org/10.1155/2018/7040531.
13. https://www.theuav.com/
14. https://www.isro.gov.in/applications-of-unmanned-aerial-vehicle-uav-based-remote-sensing-ne-region
15. https://www.avinc.com/uas/view/puma
16. https://www.sciencedirect.com/topics/engineering/unmanned-aerial-vehicles
17. https://www.naval-technology.com/projects/belleagleeyeuav/
18. https://www.nasa.gov/aero/testing-electric-propulsion.html
19. https://insideunmannedsystems.com/military-uav-market-to-top-83b/

20. https://www.rheinmetall-defence.com/en/rheinmetall_defence/systems_and_products/weapons_and_ammunition/direct_fire/mittelkalibermunition/index.php
21. https://www.raytheon.com/sites/default/files/styles/lightbox_gallery/public/2018-01/rtn_251213.jpg?itok=E5fcP89c
22. https://www.nosler.com/cartridge-data/
23. http://www.shooterscalculator.com/bullet-kinetic-energy.php
24. https://www.pewpewtactical.com/bullet-sizes-calibers-and-types/