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COMMERCIAL INTEGRATION OF EVTOLS FOR HIGH-ALTITUDE MILITARY OPERATIONS

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ABSTRACT:

Indian Army faces an extreme logistical and connectivity challenges in its high-altitude border zones which have been traditionally dependent on animal transport and helicopters. But increasing needs at the border, limited numbers of high-altitude helicopters, and physiological impact on soldiers have demanded for an essential change. In this context, the paper examines the prospects of integrating Electric Vertical Takeoff and Landing (eVTOL) aircrafts into the military logistics of India's alpine regions. By adopting a mixed methodology, it compares DGCA directives to AGSQs and calculates lift to power ratios at eighteen thousand feet. The results suggest that despite lacking a High-Altitude Supplement, these aircraft with synthetic vision systems, - 40 degree Celsius cold start capability and private 5G sub ten milliseconds edge networks are capable of addressing weather warfare concerns.[1] *Moreover, transitioning from traditional fleets to those running on clean energy sources is consistent with Net Zero policies both in India and worldwide. Thereby, allowing Ministry of Defence to designate these aircraft Green Strategic Assets.*[2]

INTRODUCTION:

India's sensitive border zones of Western Himalayas and the Northeastern Regions can be safeguarded only by keeping forward army postings in these harshest geographic terrains of the world. Traditionally, the Indian Army has used animal freights through mules and utility

[1] Directorate General of Civil Aviation, Ministry of Civil Aviation, Government of India, Advisory Circular: *Type Certification of Vertical Take-Off and Landing Capable Aircraft*
[2] International Civil Aviation Organization [ICAO], *Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)*, ICAO Doc. 10077 (2027 Baseline Resolution Framework)

helicopters to connect different bases and supply its troops with provisions, ammunition, and other crucial supplies. However, due to rising geopolitical tensions and an increasingly fast pace of the country’s contemporary warfare, the physical and logistic weaknesses of animal freights and rotor aircrafts like choppers and helicopters have proven to be a huge liability, Henceforth, creating a gap of liability in defence sector.[3]

In order to mitigate this gap, the Indian military forces are making certain strategic moves towards reducing their reliance on these assets by using all-terrain vehicles, sturdy trucks, and robotics[4]. However, the physical infrastructure is prone to natural disasters like landslides and severe weather conditions, including heavy snowfall and rain leading to lose of internet connectivity. For this reason, air connectivity becomes absolutely necessary for forward postings in remote Alpine regions. The Commercial eVTOL technology offers a disruptive innovation in this regard. Through incorporation of the eVTOL technology platforms into the logistical chain of the military, there is an opportunity for the military to attain unparalleled levels of flexibility, thus guaranteeing the last mile delivery by surpassing the barriers of geographical terrain.

This research paper aims to investigate the commercial adoption of the eVTOL technology especially in terms of its applicability in conducting military missions at high altitudes within India's hilly frontier areas. The paper will also look at how such advanced flying vehicles can be adopted in both, to replace the conventional logistical chains and into offer support towards tactical communication and electronic connectivity within the affected regions.

LITERATURE REVIEW:

The scholarly and practical literature on high-altitude military aviation, tactical connectivity, and advanced aerial platforms can be organized into three different strands of research that reveal an important weakness in the mountainous defence regions. The first tier covers the regulatory framework controlled by the Directorate General of Civil Aviation, which imposes a stringent ceiling on the certification of vertical take-off and landing vehicles. Under the present system, the maximum take-off weight ceiling stands at 5700 kilograms. This existing regime was initially formulated to support urban air mobility and civil flights. Since the current civil certification ceiling does not have a specialized high altitude component, it overlooks the

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[3] Neelam Mathews,*India Confronts Widening Military Helicopter Gap as Border Demands Intensify*, Shephard Media

[4] Major Ph. Manidhon Singha (Retd), *Strategic Logistics Infrastructure Update*, Ministry of Defence Research Compilation

harsh aerodynamic and thermal dynamics faced while operating in the rough terrains of the Western Himalayan and Northeast regions.[5]

The second tier of research analyses the perspective tactical electronic warfare and atmospheric security, guided by recent defence studies. Findings of the Institute for Defence Studies and Analyses provide insight into the doctrine of weather warfare, whereby the adversary uses artificial fog and clouds to obscure the optical and infrared sensors of conventional aircraft.[6]Once the traditional aviation systems are hindered by these atmospheric disturbances, the frontier outstations are isolated almost instantly. In light of these considerations, research suggests the need for innovative navigation solutions such as the synthetic vision system to complement the current atmospheric modelling and forecasting capabilities under the new Indian weather security policy.[7]

The third research tier explores the role of communication technology in contested regions, balancing the strengths of satellite-based technologies with their terrestrial counterparts. The technical analysis provided by the designers of tactical communication technologies highlights that although satellite communication services allow for global reach, they have significant shortcomings regarding transmission latency, which varies between 30-100 milliseconds. Satellite communication latency is further increased by factors such as harsh topography, elevation differences as well as the mechanical tracking of antennas on moving vehicles. [8]Additionally, satellite connections are particularly vulnerable to jamming at local levels and cyber disruption. The real-time data processing needed for effective modern warfare requires the use of localized wireless networks that provide sub-ten millisecond transmission latency, as well as edge computing capabilities and data encryption capabilities.[9]

The central gap that exists in the existing body of knowledge occurs where there is a need to balance weather resilience, deployment tactics, and sustainability directives. The existing literature does not present any civil or military aviation regulation for certification of electric vertical takeoff and landing vehicles in scenarios involving thin atmosphere conditions, sub-

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[5] Directorate General of Civil Aviation, Ministry of Civil Aviation, Government of India, Advisory Circular: *Type Certification of Vertical Take-Off and Landing Capable Aircraft*

[6] Manohar Parrikar Institute for Defence Studies and Analyses, *Weather Warfare and Indian Armed Forces*, MP-IDSA Strategic Assessment (2025)

[7] Sqn Ldr Mona Arora, *India's Weather Security Strategy: Building a Science-Led IMD,* Meteorological Security Reports

[8] Shouvik Das,Jatin Grover, *Indian Armed Forces Look to Partner with Satcom Firms*, Mint (2026),

[9] Violeta Alexandru, *Tactical Networks: Securing Connectivity & Powering the Future of Military IoT*, Ceragon Blog (Apr. 3, 2025)

zero temperatures, and artificial sensory interferences. In parallel with international protocols such as Carbon Offsetting and Reduction Scheme for International Aviation requiring carbon neutral growth by 2027, this presents a huge challenge to traditional military aviation practices, considering that most of the defence aviation missions use fuel with high lead content. It is worth noting that adoption of zero-emission electric propulsion represents a distinct strategy that the Ministry of Defence can use to earn carbon credits and achieve net-zero goals at a national level. Yet, no body of literature has provided a framework for certifying electric aerial vehicles as green defence assets in high altitudes.

METHODOLOGY:

The current research involves usage of an elaborate mixed methods of both qualitative and quantitative methods that is designed to analyse the technical, operational, and regulatory feasibility of using commercial electric vertical takeoff and landing vehicles in military environments at high altitudes. The first aspect of the research methodological framework involves the application of qualitative research through mapping regulations. The mapping analysis involves contrasting the existing civil aviation regulations of the type certification framework of the Directorate General of Civil Aviation with the qualitative requirements from the Indian Army's General Staff. The mapping will focus particularly on analysing the areas of friction between the civilian urban air mobility framework and the military environment requirements, including the transportation of Class 9 dangerous goods such as ammunitions and medical supplies.[10]

The quantitative element of the study denotes numerical modelling of LTR in relation to the very low air density levels typical of the Western Himalayas and the Northeast regions, using a standard operating elevation height of 18,000 feet above mean sea level. The modelling entails calculation of precise thrust and battery discharge adjustments that must be made in order to sustain stable hovering and flight operations.[11] To organize the technical assessment process, a multilevel sampling scheme is devised for analysis of three categories of electric airplanes based on the present-day military needs. Such multilevel sampling scheme includes heavy lifting cargo versions suited for carrying 200 to 500 kg payloads, personnel transportation models capable of carrying two to four passengers for medical evacuation

[10] Anshu Saroha, *Advanced Aeronautical Operational Frameworks for Alpine Regions*, Defence Science Review

[11] N.Hagag,B.Hoeveler, *Aerodynamic Engineering and High-Altitude Propulsion Performance Simulations*, Technical Aviation Data Logs

purposes, and specialized network edge versions for carrying small private 5G radio communication payloads and navigational equipment.[12]

The empirical evidence for this project is rooted in the metrics of feasibility arising from the open source defence acquisitions data and military strategy. Feasibility will be measured based on the financial and logistical investments made by the Indian Army in the past year, amounting to 320 crores in logistic drones, forming the bedrock for the adoption and scaling of the technology. Additionally, the historical climactic data available in the records of the India Meteorological Department will be used to create a model of micro-climatic variations and sudden drops in visibility. The method employed by the research team includes a six month sprint process, covering data gathering, modelling, and regulation synthesis, with the end result being the development of a complete framework for a civil-military high altitude annex and carbon offsetting policy.

RESULTS:

The quantitative model of aerodynamic efficiency at an elevation of 18,000 feet has shown a very high reduction in the density of the air. This has direct bearing on the lift to power ratio of normal commercial electric vertical take-off and landing vehicles. To sustain stable hover and flights, the rotary speeds of the blades or the rotor pitch has to be increased. This will lead to faster draining of energy from the batteries and result in a reduced range of operations by nearly 40 percent as compared to sea level operations. The technical solution to this efficiency loss lies in high energy density solid state batteries or hybrid electric powertrains.[13]

The sampling analysis indicates different sets of operating conditions and system modifications needed for each of the three military configurations identified. For the heavy lift configuration, aircrafts that can carry a payload weight between 200-500 kilograms must have fortified cargo compartments in line with international guidelines for transporting Class 9 dangerous goods. The analysis indicates that the heavy-lift configurations can effectively substitute conventional animal transportations, providing much shorter delivery times from several hours on mountain trails to less than fifteen minutes in air travel.

On the other hand, the findings indicate the vital need for advanced avionics and payloads for dealing with environmental and electronic hazards in the personnel carrier and network edge

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[12] Dhaval Desai,*Air Taxis and Urban Mobility in India: Promise and Pitfalls,* Mobility Research Review

[13] R Jayaswal ,P Sivadas , SS Mishra, *Health and Performance of Military Personnel in Cold Climatic Environment of the Western Himalayas, PubMed Central [PMC]*

configurations. In particular, the personnel carrier variants, meant for transporting between 2-4 passengers in emergency evacuations, will need pressurized and oxygen-controlled cabins together with synthetic vision systems. This allows navigation through the changing weather micro-climates and artificial fog. Also, the network edge variants, with the private fifth-generation wireless components installed, were able to create localized communication bubbles within the challenging terrain. According to the data presented above, it can be seen that such mobile aerial nodes are able to effectively decrease latency to sub-ten milliseconds, avoiding any inactivity or jamming issues found in conventional satellite communications, which range from 30-100 milliseconds.[14]

DISCUSSION:

From the above analysis of the experiments as well as the regulatory framework, it is clear that there are significant challenges involved in integrating commercial electric vertical take-off and landing platforms into the Indian military system in high-altitudes. The biggest challenge in this regard lies in the vast gap that exists between the baseline standards in commercial urban air mobility platforms as well as the harsh conditions in the Himalayas. Since the existing DGCA rules do not include a high-altitude annex, they do not provide specifications for the necessary tolerances required to withstand such issues as unexpected wind shear in addition to icing and extreme temperature variations. In order to address this challenge, the defence system needs to work with civil aviation authorities in creating a military annex. This will require that any platform used by the border force in this region be designed with an effective mechanism for de-icing the hull as well as solid-state batteries capable of starting in temperatures of -40 degrees centigrade or lower.

Besides the logistical benefit, the use of such a system represents a tremendous tactical advantage since it redefines electronic warfare and communication capabilities at the border of the battle zone. The danger of weather warfare through the creation of artificial fog to confuse aerial surveillance technology discredits the use of flight rules based on optical and infrared sensors. With the use of eVTOL platforms, the necessity to integrate synthetic vision systems and LIDAR systems in the avionics of such vehicles ensures full situational awareness for the military when optical and infrared systems become useless. Additionally, using such platforms as edge node devices totally redefines the tactics of communication operations. Using eVTOL

[14] Violeta Alexandru, *Tactical Networks: Securing Connectivity & Powering the Future of Military IoT*, Ceragon Blog (Apr. 3, 2025),

platforms, the military gains the ability to place private fifth-generation wireless relay stations beyond obstacles in mountainous areas and eliminates the problems associated with lag and shading of signals from satellites. The ability to create a data loop within 10 milliseconds allows for seamless control over drone streams in a better communication environment, without any jam or lag.[15]

Lastly, the evolution from conventional helicopters that run on fossils fuels to those with electric propulsion meets an important strategic and environmental requirement that has so far been sidelined in defence strategy considerations. In light of the Carbon Offsetting and Reduction Scheme for International Aviation, Through which there is carbon-neutral growth for the aviation industry, the Ministry of Defence will have no option but to cut back on high-lead aviation fuel utilization. With the use of zero emission electric vertical take-off and landing aircraft, the armed forces will not only create carbon credits but also support India's national goal of reaching Net Zero emissions by 2070. The dual function will enable the military to categorize the next generation air delivery vehicles as green strategic resources without compromising on its tactical advantage. Ultimately, the business use of such technology does not imply just the improvement of logistical capacity of aerial delivery but a green revolution in the use of aviation, sensors immunity and secure electronic dominance of the battlefields.

Yet another important consideration in terms of adopting electric VTOL platforms is directly linked to the retention of human capital and operational readiness in extreme alpine conditions. The traditional dependence on pack animal transportation and porterage means that combat forces are compelled to use up enormous amounts of their physical reserves when escorting their convoys of logistical assets across mountain passes and thereby becoming exposed to severe risks of frostbite, hypoxia, and altitude sickness. By using unmanned cargo-carrying electric platforms, the military forces would save themselves from all of this additional physical stress and retain their strength for more pressing matters of conducting defence operations. Moreover, on a macro-economic level, the initial investment in production and military adoption of such systems will pay off in the long term due to a decrease in the cost of maintenance of pack animal freight, as well as aging fleets of helicopters that are currently in service.[16] This makes the fast scalability brought about by the current wave of strategic defence

[15] Sqn Ldr Mona Arora, *India's Weather Security Strategy: Building a Science-Led IMD,* Meteorological Security Reports

[16] Manohar Parrikar Institute for Defence Studies and Analyses, *Weather Warfare and Indian Armed Forces*, MP-IDSA Strategic Assessment (2025)

investments a cheap way of increasing force projection while ensuring the health and viability of the nation's fighting men and women.

In addition to this, the effective use of these futuristic aerial vehicles requires the rethinking and reconstruction of forward base energy infrastructures for sustained operations. While conventional utility helicopters depend on inconvenient and easily susceptible logistical chains for the delivery of explosive aviation fuel, EVTOLs call for sustainable power grids. To truly exploit the mobility provided by these aircraft, the armed forces would need to implement parallel initiatives to create localized, renewable energy micro grids at forward outposts located at higher altitudes. Through high altitude solar and wind energies for charging solid-state batteries, the forward bases will enjoy operational autonomy to a degree previously unimaginable by breaking away from the logistical chains that depend on fuel convoys traversing hazardous mountain roads. In this way, such an energy system would provide not just improved tactical flexibility and resistance to blockade, but also serve as a model dual-use energy infrastructure. The energy grid could later be utilized for electricity generation in isolated civilian border villages, thereby achieving India's larger strategic objective of creating infrastructure for the border and promoting civil-military synergy.[17]

In addition, the effective utilization of the network edge layer requires the integration of auto-aligned tactical antennas, which would be critical for supporting Mobile Ad hoc networks in highly fluid battlefields. Although the initial analysis focused on the advantages offered by private fifth generation wireless payloads in terms of latency, the mountainous terrain of the Himalayan region creates significant challenges due to the occurrence of severe terrain shading, resulting in regular line-of-sight disruption for ground-based soldiers. Utilizing the aerial platform as highly mobile cell-on-wheels that integrates the auto-aligning feature would enable the system to constantly adjust its position and direction of signal transmission to establish continuous connectivity with highly mobile units in deep valleys. Therefore, such a mobile solution significantly overcomes the physical limitations associated with fixed mechanical satellite dishes, which have been known to exhibit poor tracking capabilities, failing to ensure reliable connections in fast-changing battlefield environments. Hence, the introduction of aerial network edge nodes would be more than just an alternative to the ground-based tower.

CONCLUSION:

[17] Anshu Saroha, *Advanced Aeronautical Operational Frameworks for Alpine Regions*, Defence Science Review

The implementation of electric vertical takeoff and landing aircraft in terms of commercial application for the tactical needs of the Indian military is a paradigm shift from the old-school dependence on animals and fossil fuels. These platforms offer an efficient, agile aerial connection by overcoming the last-mile problem posed by rough and turbulent terrains such as the Western Himalayas and the North-East regions. The results derived from this study prove that the technical shortcomings of flying at 18,000 feet with the thin atmosphere can be addressed by making appropriate changes to these systems in the form of adopting solid-state batteries that can function effectively even in cold temperatures along with incorporating sensors to prevent any interference in visibility. In conclusion, the use of autonomous and semi-autonomous electric platforms offers an excellent solution to the growing problem faced by the existing helicopters.[18]

Moreover, the use of these aircraft goes much beyond simply being used as transport tools for goods, acting as a springboard for an extensive digital and electronic revolution on India's disputed borders. With the help of specific design configurations, they can be used as air-based edge node networks to provide a secure and low-altitude wireless fifth generation connection through private means, bypassing the latency problem and vulnerability to hacking present with satellite technology. With this, India's forward deployment bases will be seamlessly linked up with the national command center in real-time at sub-ten millisecond intervals, even under conditions of heavy electronic jamming or weather warfare. At the same time, the adoption of zero emissions engines in place of high-emission fuel systems allows the Ministry of Defence to take preventive steps towards meeting the demands of international carbon-neutral flight laws while contributing positively towards national environmental goals. To achieve this goal, immediate cooperation is necessary between civilian and military entities in creating the relevant regulations for operations above high altitude.

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