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Future Force: Innovation, Sustainability and Performance in Defence

The Frontier Team

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FRONTIER

FRONTIER is a Defence Science and Technology (DS&T) journal formatted under the guidance of the Defence Science and Technology Group (DSTG), for the periodic publication of a curated set of articles, reports and technical papers written by members of the Ministry of Defence (MINDEF) and the Royal Brunei Armed Forces (RBAF), as well as the institutions of higher learning in Brunei Darussalam.

Through publication and hence sharing of DS&T content, FRONTIER aspires to be a platform that creates awareness, generates discussion an inculcates innovation among members of the DS&T community.

In alignment with the ongoing digitisation effort spearheaded by DSTG, FRONTIER will be made available primarily as softcopy via the MINDEF official website. Limited hard copies of FRONTIER will also be distributed to MINDEF and RBAF leaderships and made available in MINDEF and RBAF libraries.

FOREWORD

The Defence Science and Technology Group (DSTG) is pleased to release the sixth volume of *FRONTIER*, themed '**Future Force: Innovation, Sustainability, and Performance in Defence.**'

This edition features four articles showcasing studies conducted by the Ministry of Defence (MINDEF) and Universiti Brunei Darussalam, exploring key areas of defence innovation, sustainability, and performance. The articles cover a range of topics, from digitalising the Royal Brunei Air Force logistics, to addressing environmental challenges and integrating green technologies into defence operations. Additionally, the volume examines the human factors in drone performance, offering valuable insights for enhancing military readiness and resilience.

The first article, '**Innovation in Military Logistics: Air Force Domestic Logistics System (ADLS) Evolution into a Digitalised Inventory Management System**' highlights the need for digital transformation in logistics to improve efficiency and transparency in the Royal Brunei Air Force. **'The Soils of Brunei Darussalam: A Pillar for Sustainability**' underscores the importance of soil health for Brunei's ecosystems, calling for sustainable practices to address environmental challenges. '**Green Technology in Defence Operations: An Air Force Perspective'** explores the integration of renewable energy and sustainable technologies in Air Force operations, emphasising their strategic benefits and the need for alignment with global sustainability goals. Finally, '**Analysing the Relationship Between Self-Assessed Confidence and Simulator Performance: A Quantitative Research Framework**' investigates the alignment between drone simulator performance and pilots' self-assessed confidence, highlighting the complexity of confidence measurement and suggesting the need for refined evaluation methods.

In summary, the articles in this volume reflect significant strides in defence through technological innovation, sustainability, and performance optimisation. They provide a comprehensive view of the evolving defence landscape, where strategic advancements in operations, environmental management, and human factors are crucial to shaping the future of military readiness.

Hasrinah binti Matyassin
Editor-in-Chief

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INNOVATION IN MILITARY LOGISTICS: AIR FORCE DOMESTIC LOGISTICS SYSTEM (ADLS) "EVOLUTION INTO A DIGITALISED INVENTORY MANAGEMENT SYSTEM"

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ABSTRACT

The military relies heavily on efficient inventory management to maintain operational readiness and logistical support. Due to manual existing inventory, issues arise associated with manual processes including lack of visibility, leading to inefficiency in decision-making, lack of accuracy in planning and forecasting of stocks affecting military readiness, lack of cost transparency, leading to stock discrepanices and loss of accountability, affecting operational efficiency, resource allocation and overall trust within the organisation. A digitalised inventory management is a vital tool for Royal Brunei Air Force (RBAirF). It refers to a new system brought about by information technology towards innovation in military logistics. This paper analyses the gaps in using the existing manual inventory processes within the No. 4 Wing, RBAirF. The findings reveal that a well-implemented digital inventory system is important in the military. However, although the implementation of digital inventory system brings many benefits, it may pose several difficulties and challenges. For RBAirF, accelerating digital transformation, overcoming the practical challenges of digital technology landing in the military, and improving the application level of digital technology will become an important development direction in military equipment management in the future.

Keywords:
Logistics, Digital, Digitalised, Inventory Management, Technology, Military, Equipment

1.0 INTRODUCTION

Previously, military inventory management relied on manual tracking and paper-based systems. As operations have becoming more complex and the volume of inventory increased, these methods have proved inadequate [1]. Therefore, modern inventory management is a vital tool in the military where planning of stock levels is critical. Inventory refers to item or resource stock. Inventory management can be defined as a group of rules and controls that detect, manage and maintain inventory levels [2]. The availability of the correct amount of stock can reduce operating costs whilst improving the preparedness, efficiency and responsiveness of No. 4 Wing, Royal Brunei Air Force (RBAirF). On the other hand, unnecessary demands and excessive stock may result in financial losses through damages, stock degradation and stock obsolescence. Currently, RBAirF is in the process of transformation into a digitalised inventory management system called the Air Force Domestic Logistics System (ADLS). In line with His Majesty Sultan Haji Hassanal Bolkiah Mu'izzaddin Waddaulah ibni Al-Marhum Sultan Haji Omar 'Ali Saifuddien Sa'adul Khairi Waddien, Sultan and Yang Di-Pertuan of Brunei Darussalam in a Titah to mark the 38th National Day underscored the need to accelerate the country's digital transformation to adapt to a new norm [3]. With the initiatives of Commanding Officer No. 4 Wing, the ADLS is developed by Information Technology Development (ITD) Section Under Air Engineering Unit, Technical Equipment Maintenance Division (TEMD), and supported by Defence Information Technology Unit (DITU), Ministry of Defence for the domestic store under 41 Squadron, No. 4 Wing. The ADLS will be officially launched on 28th January 2025 with the aims to replace the traditional analog of inventory management, to create real time data for better traceability, transparency, visibility and accountability within the users. Moreover, the implementation of ADLS illustrates the RBAirF's commitment to integrate cutting-edge technologies into its logistics framework.

2.0 LITERATURE REVIEW

The significance of digital transformation in logistics could not be overstated as it is the catalyst that has transformed traditional methods into a more streamlined and agile inventory system [4]. In a study by Robert-Cristian, the growth of research interest has transitioned from traditional supply chain management topics to topics dealing with emerging technology and global issues. Topics in logistics and military operations are also becoming more prominent in literature [5]. Krishnan *et. al* reported that the integration of technology in logistics had led to a reduction in delivery times by up to 30% and an increase in inventory accuracy by approximately 25% [6]. Johnson emphasized that modern military operations require real-time tracking of inventory to ensure efficient deployment of resources. Manual processes, however, fail to provide such capabilities [7].

An Ethiopian Defence Force Logistics Main Department has also conducted a research study on how inventory management has a significant effect on organisational and financial performances as its management is central in military logistics. Military operations depend on supplies, in which the flow of these supplies depends upon the effectiveness of the inventory management for many months prior to issue of the supply. Based on the study, many gaps affecting its logistics performance have been discovered due to lack of computerised management system, lack of proper inventory handling and disposal system as well as lack of training programs in relation to its inventory management practice [8]. Therefore, issues in inventory management are common in every organisation and the military is no exception.

2.1 | Issues in Manual Inventory Management

2.1.1 | *Lack of Visibility in Data Management*

Minimum Stock Level (MSL) is a critical issue that needs to be addressed to overcome unforeseen contingencies that may happen at any time. With the manual processes, maintaining MSL is difficult due to lack of visibility of data management, leading to inefficiency in decision-making and high operational costs. As an example, for a simple reporting purpose, the personnel have to access multiple databases to get the data [9]. This issue arises as manual processes do not adopt a systematic approach to stock multiple items. Hence, modern data system is needed in order to generate and provide correct data in real-time.

2.1.2 | *Lack of Accuracy in Planning and Forecasting of Stocks*

Difficulties in accessing and utilising information will reduce the military's mission in the fastest way possible. Inaccurate forecasting leads to shortages or overstocking, causing delays in delivering critical items to military personnel on the ground [9]. For example, a shortage of essential items such as rations, bedding and fuel could hinder the readiness of military personnel. Hence, with digitalised inventory system will enhance planning and forecasting of stocks as human errors are reduced.

2.1.3 | *Lack of Cost Transparency*

An inventory management system relies on four (4) factors, which are policies control on what quantity to order, holding cost, supply and demand and procurement lead times. Oversupply in inventory level will lead to inadequate controls and price control issues. With lack of cost transparency in the manual processes may affect decision-making processes. The right decision making is important as it directly affects to demand and planning, stock-holding positions, forecasting, equipment optimisation, procurement and also financial control [9].

2.1.4 | *Loss of Accountability*

Loss of accountability in manual inventory management may also affect operational efficiency, resource allocation and overall trust within the organisation. Without accountability, discrepancies in inventory records are becoming more frequent [9]. The time spent on reconciling inventory discrepancies requires extensive manual audits and investigations, and thus, diverting resources and personnel from core tasks.

3.0 METHODS

In order to analyse the main gaps existing in the manual inventory management in the RBAirF, delving into solutions and highlighting the importance of smooth transformation and development of digitalised inventory system at the present stage, a survey was conducted, mainly in the form of questionnaires. A total of 50 respondents under 41 Squadron, No. 4 Wing, RBAirF, including officers and civilian staff participated in the survey. The statistical method was the proportion = the number of votes for a single question, (n)*100%, N=50. Questionnaires were the primary sources of data collection in this study as it is effective in gathering relevant information to the study.

4.0 RESULTS

Table 1. Manual Inventory Management Gaps Focus

Findings	Percentage (%)
Effectiveness in managing and tracking items	32.0
Errors in stock verification	76.0
Responsiveness to items below Minimum Stock Level (MSL)	40.0
Lack of visibility in cost and expenditures	56.0
Shortages or overstock not identified	44.0
Strong need for a digitalized inventory system	98.0
***N*=50**	

From the study findings, several gaps have been identified in using the existing manual inventory management. 32% respondents believed that manual processes are still effective in managing and tracking of items in store. Several gaps identified in manual inventory management practice, whereby, 76% respondents have experienced frequent errors in manual recording and 40% respondents could not respond quickly to items that are below MSL. Meanwhile, cost and expenditure as well as shortages or overstock of items were not shown in manual processes were reported by 56% and 44% respondents respectively. Overall, 98% respondents agreed on the adoption of a digitalised inventory system, such as the new ADLS (**Table 1**).

5.0 DISCUSSION

The RBAirF operates in a highly dynamic and mission-critical environment, whereby inventory management plays a crucial role in ensuring operational readiness and success. The study has shown that there is a need for a transformation from manual into a digitalised inventory system in the RBAirF. This section analyses the considerations that the RBAirF needs to examine before formulating digital inventory system to ensure its effectiveness and alignment within the requirements of its logistics and in line with the mission of No. 4 Wing, which is to provide sufficient and sustainable logistic support for RBAirF.

5.1 | ADLS Conceptual Framework

The ADLS emphasizes on a digitalised method of inventory, whereby currently there are 978 domestic line-items are managed in the system including uniform, Unit Equipment Table (UET) items, miscellaneous items, accommodation and defence stock. The ADLS is a web-based inventory management system that tracks the demands, purchases status and triggers stocks that are below MSL. It also tracks the costs and expenditures of the inventory. The system also involves several key components including advanced software applications to enable real-time tracking and management of inventory as well as data analytics which allow military logistics personnel to make informed decisions regarding inventory levels, demand forecasting and resource allocation. The ADLS framework focuses on five (5) core pillars, which are centralised data management, automated tracking and monitoring, analytics and forecasting, security and resilience as well as user training and integration as shown in **Table 2**.

Table 2. Core Pillars of ADLS Conceptual Framework

Core Pillars	Objectives	Features
Centralised data management	Establish a unified platform for managing all line items in 41 Squadron.	• Centralised database for real-time updates. • Tracking items under running contract. • Role-based access control that only authorised users can track and manage stock.
Automated tracking and monitoring	Minimise human errors and improve accuracy	• Automated calculations of MSL. • Alerts for low stock levels. • In and out transactions of items. • History tracking.
Analytics and forecasting	Optimize inventory levels to prevent shortages or overstock of items and minimize operational costs.	• Predictive analytics to forecast demands based on historical data and current trends. • Real-time data to monitor stock levels. • Automated calculation of cost expenditures.
Security and resilience	Protect data	• Backup recovery plans to ensure system resilience. • Role-based access.
User training and integration	Ensure smooth adoption and effective utilisation of system by all personnel under 41 Squadron.	• Comprehensive training programs. • User-friendly interfaces. • Feedback-loop mechanisms to continuously improve the system.

5.2 | Main Key Players of ADLS

There are three key players in ADLS, which are the front desk administrators, supervisors and managers. The front desk administrators are those responsible to update the database entry such as the daily in and out transactions of items in the store, to monitor stock levels and order status. The supervisors and managers are those responsible to monitor and manage database to make informed decisions. At this level, any changes needed to further improve the system will be reviewed and revised in the policy. **Figure 1** below displays the flow chart of key players in the ADLS.

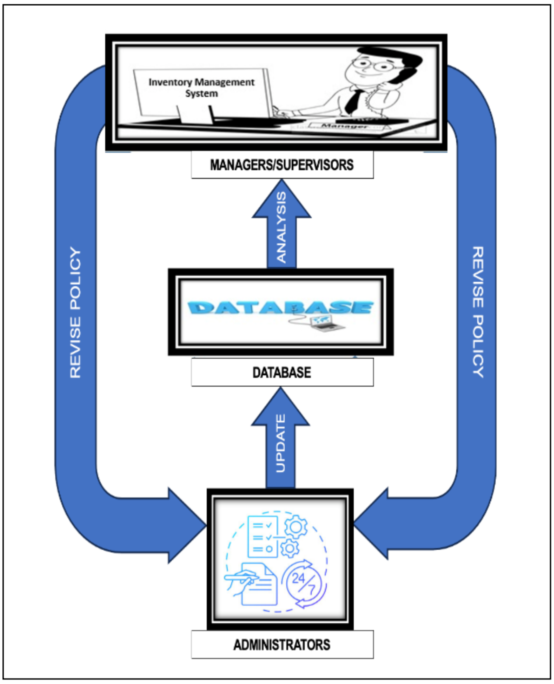

Figure 2. Flow Chart of Key Players in the ADLS.

5.3 | Benefits and Possible Challenges of Digital Inventory System

Previous studies have identified numerous benefits of digital inventory system in military logistics operations. One of the examples is the U.S. Army's use of Logistics Modernisation Program (LMP). The LMP was introduced to replace outdated legacy systems and enhance the Army's ability to manage inventory, maintenance, supply chain, and procurement in real time [10]. This program managed $40 billion worth of inventory to enhance mission readiness and 8entrali logistics support. This program has employed advanced technologies such as GPS, robotics, and automated systems to enhance efficiency and accuracy in logistics operations. The U.S. Army also used predictive analytics to forecast and manage inventory levels effectively. Not only this program has allowed better forecasting and demand planning, but it also significantly reduced costs, improved resource allocation and ensured timely delivery of essential supplies to troops in diverse operational environment [11].

Similarly, ADLS has significantly enhanced inventory visibility by enabling real-time tracking and a centralised data management. This capability supports accurate reporting and better decision-making processes. The cost transparency within the ADLS framework has yet to be explored in relation to holding costs and procurement lead times of domestic line items, as presently, the system only provides detailed cost breakdowns for inventory under contractual suppliers. However, with predictive analytics that automatically monitors the MSL of all domestic line items enables a more effective stock planning and demand forecasting—particularly in ensuring the timely availability of crucial items for military personnel. As a result, this feature allows users to forecast budget utilisation, which contributes to a more efficient financial management and overall operation.

With the role-based access control framework within ADLS, it promotes accountability as users are assigned to specific roles and responsibilities. The system logs all of user activities, including stock updates, stock movements, data modifications or adjustments, fostering transparency across inventory operations. This traceability supports streamlined auditing processes and ensures adherence to regulatory requirements of the system. The adoption of a digitalised inventory system like ADLS has thus, significantly overcome the limitations of previous traditional manual inventory management by providing enhanced data visibility, improved stock accuracy, greater cost transparency, and increased user accountability.

Although ADLS paved the the way to improve readiness, situational awareness and strengthened logistics capabilities of the RBAirF, the adoption of this system may pose several challenges during its implementation. Concerns over data security, the integration of legacy systems, and the need for extensive training and change management may pose significant hurdles. Additionally, the military's unique operational requirements and the need for robust backup systems may add an additional layer of complexity to the implementation process [1,12]. Therefore, it is crucial for RBAirF to explore the potential applications of emerging advanced technologies, particularly artificial intelligence, in order to build a more effective, efficient, robust, and responsive logistics system that can adapt to evolving challenges.

6.0 LIMITATIONS

The significance of the digital transformation could not be underestimated, as military logistics forms the backbone of any military operation, ensuring the timely delivery of essential resources, including basic necessities for military personnel. The scope of this research study, however, has not covered some of the more advanced technologies with potential applications in inventory management, such as big data analytics, digital twin and blockchain technology that have been used by military organisation in other countries [4,13]. As these technologies continues to evolve, it is expected that its applications in the military context will become increasingly sophisticated and widespread, creating potential areas for future research to produce a more comprehensive study.

7.0 RECOMMENDATIONS

With the inherent inefficiencies of traditional manual inventory management and the rapid pace of global technological advancement, it is highly recommended that RBAirF to actively pursue digital transformation, not only in inventory system but logistic system as a whole. However, to successfully achieve this transformation, it is essential to acquire full support and commitment from leadership at the strategic, operational, and tactical levels.

8.0 CONCLUSIONS

This research study has explored the issues in manual inventory management within the RBAirF, highlighting how digital transformation into a systematic logistics sytem is redefining the effectiveness, efficiency, robustness and responsiveness of logistics operations. With the implementation of the ADLS in the near future, it will allow the organisation to handle a large data set and manage stocks effectively, aiming to provide decision-makers with enchanced knowledge to improve analysis and decision-making. The positive impacts are made possible as the ADLS offers innovative solutions to traditional challenges associated with visibility, accuracy, traceability, cost transparency and accountability, that might lead to operational inefficiences. Implementing the ADLS will significantly enhance the RBAirF's military readiness, situational awareness, and logistics capabilities. While a digital inventory system offer significant opportunities for improving military logistics, it may also pose several challenges in terms of data security, the integration of legacy systems, and the need for extensive training and change management especially during the implementation stage. It is crucial that these risks are properly assessed and managed to ensure that the advantages of this system are not overshadowed by its potential negative consequences. In conclusion, it is imperative that the RBAirF needs to stay abreast of technological innovations and proactively integrate them to effectively respond to the dynamic challenges of the modern military environment.

ACKNOWLDEGMENTS

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THE SOILS OF BRUNEI DARUSSALAM: A PILLAR FOR SUSTAINABILITY

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ABSTRACT

Soils form the foundation of terrestrial ecosystems, playing crucial roles in sustaining life on Earth through support for plant growth, regulation of water cycles, and storage of carbon. In Brunei Darussalam, these ecosystems have limited research on their mineralogical and geochemical characteristics. These essential soils face challenges, including highly acidity and the occurrence of potentially toxic elements in agricultural areas and the degradation of peatlands due to anthropogenic activities. Peatlands in Brunei Darussalam are critical for carbon storage, biodiversity conservation, and water regulation; however, anthropogenic activities threaten their stability, turning them from carbon sinks to sources and increasing the risk of forest fires. The growing population in Brunei Darussalam necessitates increased food production, emphasising the importance of sustainable agriculture practices to mitigate environmental degradation. Soil contamination from industrial pollutants and agrochemicals poses risks to food safety and security, requiring proper waste management and pollution control measures. Efforts to address soil challenges include land use regulation, public awareness campaigns, and community engagement, with collaboration between governmental entities and local geoscientists essential for informed decision-making and proactive environmental management. Implementing measures to protect and conserve soil resources is crucial for achieving sustainable development goals and ensuring the well-being of current and future generations, highlighting the importance of research on soil conservation and sustainable land management practices to preserve this invaluable resource and mitigate the impacts of human activities on soil health and ecosystem integrity.

Keywords:
Sustainability, Soil, Organic Matter, Peat, Brunei's Wawasan 2035

1.0 INTRODUCTION

Soils are the foundation of terrestrial ecosystems, providing essential support for life on Earth. From sustaining plant growth to regulating water cycles and storing carbon, soils play a crucial role in supporting various ecosystem services vital for human well-being [1]. Understanding the intricate relationship between soils and the environment is essential for sustainable land management and addressing global challenges such as food security, water scarcity, and climate change. Moreover, by gaining a deeper understanding of soils and their role in supporting life, we can better appreciate the critical need to protect and manage this precious resource for current and future generations [1]. In today's world, it is important to carefully plan human activities as land degradation can lead to adverse effects on the soil quality such as heightened levels of soil acidity, salinity, alterations in soil structure, and depletion of soil organic matter and biodiversity [1,2].

Although healthy soil is essential for productive agriculture and sustainable food production, limited research has been conducted on the mineralogical and geochemical characteristics of the soils of Brunei Darussalam [1,3-10]. However, in recent years, there has been a notable surge in the study of soil, reflecting the increasing awareness of its fundamental significance. The importance of maintaining a clean environment and increasing agricultural productivity also has become one of the sustainable development goals (SDG) in the country's 2035 Vision ("*Wawasan Brunei 2035*"). Universiti Brunei Darussalam (UBD) plays an important role in achieving these goals by conducting research on the global geochemical baselines project [5,9]. This project aims to determine the geochemical background and threshold values which can help in determining the geogenic and anthropogenic sources of any soil-related pollution. By providing robust and reliable data, it can help assist policymakers in creating effective management plans in terms of soil management and remediation. The soils of Brunei Darussalam are highly acidic, with a pH of up to 1.89, rarely exceeding a value of 6 in very localised areas. This acidity is primarily due to the occurrence of pyrite (FeS_2), however, local anthropogenic factors and pollutants may also play a significant role in this effect [3,4,9].

Brunei Darussalam hosts important volumes and areas of peatlands [6-8,11-14]. This ecosystem is widely known for its function as important carbon storage, a medium to attenuate water flow creating waterlogged areas, and acting as hotspots for biodiversity. However, most peatlands in Southeast Asia have been dried out, drained, and completely or partially deforested by anthropogenic influences, releasing the carbon accumulated over thousands of years and becoming extremely combustible. This drainage may lead to the area experiencing the lowering of the water table, encountering land subsidence, and the emergence of carbon dioxide emission, which further leads to forest fires from peat oxidation. As a result, the peatlands in the area have dramatically decreased, changing their role from carbon sinks to carbon sources [12-14].

Agricultural practices are important contributors to the growth of domestic products in Brunei Darussalam and therefore improving and preserving the soil quality in the country is a key aspect of sustainability (**Figure 1**). Soil is also a crucial factor in water quality, as pollutants can infiltrate and contaminate groundwater, with significant adverse effects on public health. This paper will highlight the soil issues of Brunei Darussalam to further improve the understanding of the relevant Sustainable Development Goals for Brunei Darussalam 2035 Vision.

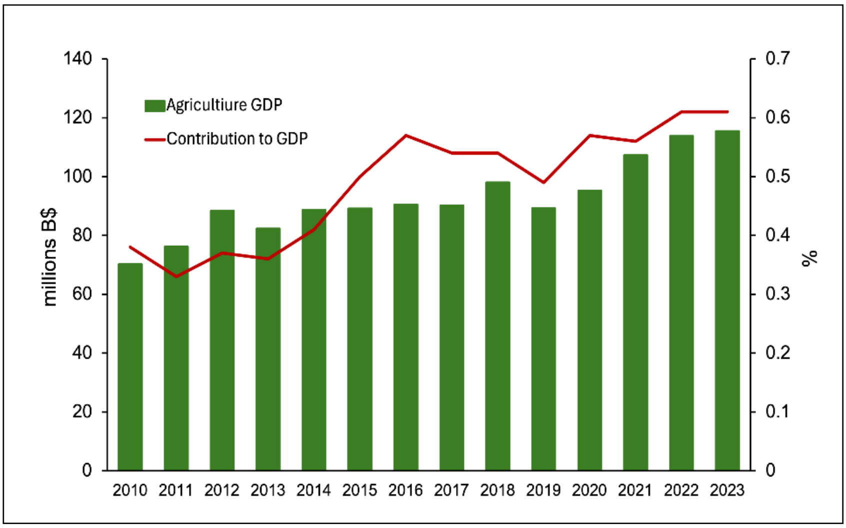

Figure 1. Contribution of the agriculture sector to GDP (2010 - 2023) with data from Agriculture & Agrifood Statistics in Brief 2023, Brunei Darussalam.

2.0 GEOGRAPHIC POSITION AND GEOLOGICAL SETTING OF BRUNEI DARUSSALAM

Brunei Darussalam is located in the northwest region of Borneo Island. The country has two seasons, where the mean annual temperatures of the dry season and rainy seasons range from 24 to 36°C and from 20 to 28°C, respectively. Brunei Darussalam experiences high annual precipitation averaging at 2,900 mm. Geologically, the area comprises three significant deltaic systems: the Meligan Delta which is the oldest and active during Middle Oligocene to Early Miocene, the Champion Delta (Middle Miocene to Pliocene), and the Baram Delta, which is active from Late Miocene till today. The sedimentary sequences produced by these active deltaic systems frequently exhibit variations in facies types, characterised by alternations of sandstone and claystone [15,16].

3.0 SOIL TYPES IN BRUNEI DARUSSALAM

Soil is a complex mixture of minerals, organic matter, water, air, and living organisms. One way to categorise soil is based on its composition of organic and inorganic components.

3.1 | Inorganic soils

Inorganic soils are predominantly comprised of mineral particles originating from the weathering of pre-existing rocks and minerals. Unlike organic soil, which contains a significant amount of decomposed plant and animal matter, inorganic soil consists mainly of sand, silt, and clay. The composition and characteristics of these soils vary greatly depending on factors such as parent material, climate, and geographic location.

Their significance extends beyond mere physical attributes, playing a crucial role in sustaining ecosystem functions and human endeavors. The mineral particles form a supportive framework for plant roots and facilitate the movement of water and nutrients within the soil profile. These mineral particles provide the physical structure and texture of the soil, influencing its properties such as drainage, water retention, and nutrient availability. Moreover, inorganic soils act as both a sink and a reservoir, not only for vital plant nutrients but also for a myriad of chemical pollutants. This dual role underscores their importance in environmental processes and underscores the need for their careful management and conservation [17,18].

3.2 | Organic soils

Organic soils contain plant organic matter, which is typically partially decomposed under waterlogged and oxygen-depleted conditions. If the organic matter exceeds 50%, the soil is known as peat, and the relevant ecosystem is referred to as peatland. This ecosystem develops when there is an excess of organic matter production over decomposition and predominance of humification over bacterial respiration and decomposition, thus leading to net accumulation of organic matter [13,14]. Peat enriches the soil with nutrients, improves its structure, and enhances water retention capacity.

Peatlands are globally known for their function as important carbon storages, a medium to attenuate water flow creating waterlogged areas, and acting as a host to various biodiversity. Notably, tropical peatlands emerge as substantial reservoirs of near-surface organic carbon, underscoring their critical importance in shaping climate dynamics and ensuring environmental stability. Continuous changes in the environment, especially through activities like draining and clearing forests, pose a serious threat to the stability of these peatlands, releasing carbon into the atmosphere and becoming extremely combustible. Brunei Darussalam hosts some of the last pristine peatlands in the world, which are significant biodiversity hotspots. Despite their ecological importance, these peatlands are generally geologically understudied and often overlooked [13].

4.0 DISCUSSION

The population of Brunei Darussalam has been steadily increasing since the 1950s, with recent growth rates ranging from 0.7% to 0.8% (**Figure 2**), leading to a rising demand for food. However, agricultural activities and arable land have remained nearly constant in recent years (**Figure 3**). The Food and Agriculture Organization of the United Nations defines arable land as land utilised for seasonal crops (areas with double cropping counted once), temporary meadows for mowing or grazing, plots dedicated to market or kitchen gardens, and land left fallow temporarily are included. Land abandoned due to shifting cultivation is not considered.

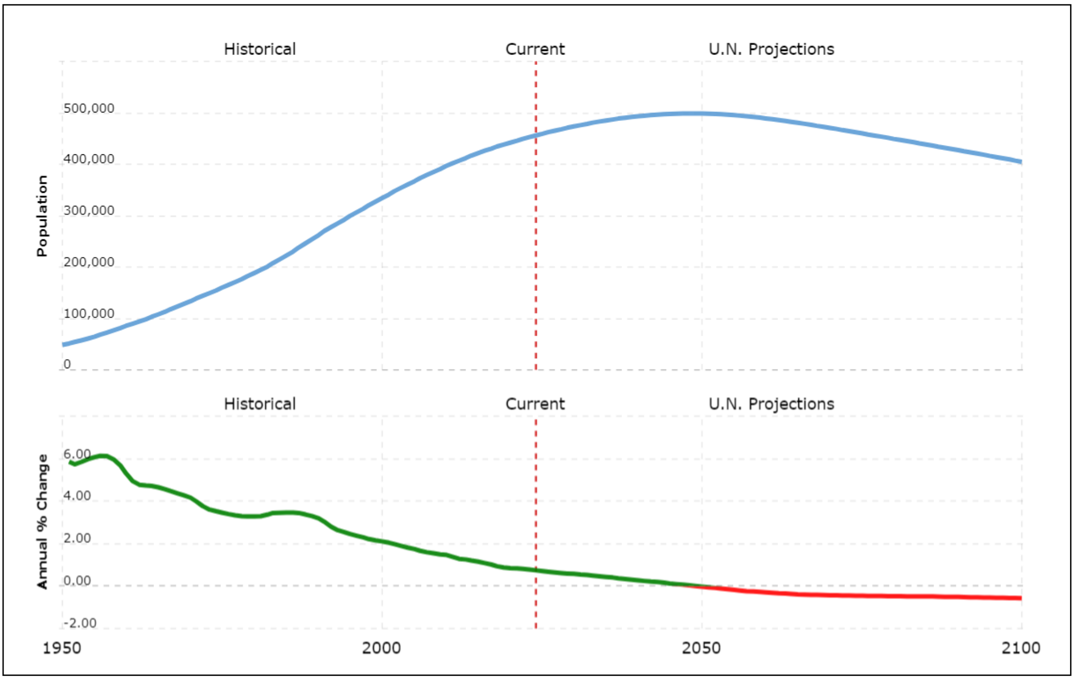

Figure 2. Chart showing Brunei Darussalam population from 1950 to 2024. United Nations projections are also included through the year 2100 (modified from [19]).

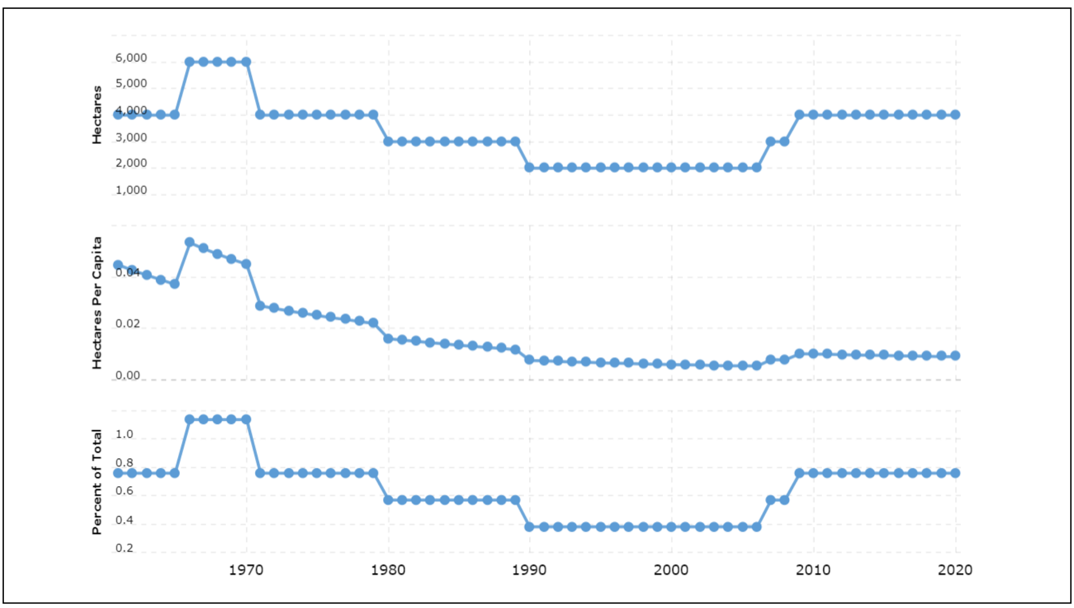

Figure 3. Brunei Darussalam's arable land (in hectares) includes land defined by the Food and Agriculture Organization of the United Nations (modified from [20]).

4.1 | The influence of inorganic soils to agriculture, public health and the economy

The growing awareness of the need to increase food production by 2050 has spawned numerous studies. An increase in crop yield is crucial to feed the constant rise in the global population. Utilising more land for farming is a viable solution to meet growing food demands and it is essential to approach this expansion with careful planning and knowledge to ensure sustainability and minimise environmental degradation. Proper nutrient management, such as crop rotation to replenish soil nutrients and maintain soil fertility and wise use of fertilisers and pesticides are important for optimising crop yield and ensuring food security. It has been demonstrated that increasing yield potential through photosynthesis is another way forward to increase crop production without needing more land [21,22]. However, light can never be excessive to a plant, and this leads to the inhibition of photosynthesis itself [22]. Another way to improve crop yield is by using sustainable agriculture methods, such as utilising smart farming by implementing a SWOT analysis to determine strengths, weaknesses, opportunities, and threats [23].

As soil plays a crucial role in public health, whether through residential connections or the food chain, it is imperative to conduct research to monitor pollutant concentrations and the overall condition of the soil. Previous research indicates that elevated values of potentially toxic elements (PTE) such as lead (Pb), arsenic (As), copper (Cu), chromium (Cr), zinc (Zn), manganese (Mn), and nickel (Ni) are spatially associated with agricultural areas in the Brunei-Muara District [9]. Industrial pollution and the road network contribute to elevated levels of potentially toxic elements (PTE) in the area, highlighting the need for increased awareness. The spatial association of PTE with agricultural regions (**Figure 4**) indicates that their potential sources are fertilisers and pesticides, which contain a significant amount of these toxic metals [9]. Continuous and uncontrolled usage of fertilisers and pesticides can lead to the accumulation of PTE which disrupts the soil quality and progressively makes it less arable [24]. Addressing soil contamination issues, such as pollution from agrochemicals or industrial pollutants, is essential for ensuring food safety and security. Local farmers must adopt sustainable farming practices and seek experts' advice when using fertilisers and pesticides. In addition, they must only use the approved brands of fertilisers and pesticides and must only use fertilisers with the element concentration not exceeding the approved limits. Controlling the usage of fertilisers and pesticides helps also to protect aquatic life from pollution from the elements carried by groundwater. Remediation measures and sustainable land use practices can help mitigate the impacts of soil contamination on food production. In addition, policymakers must consider the implementation of mitigation and preventive plans for proper waste management to prevent severe soil contamination.

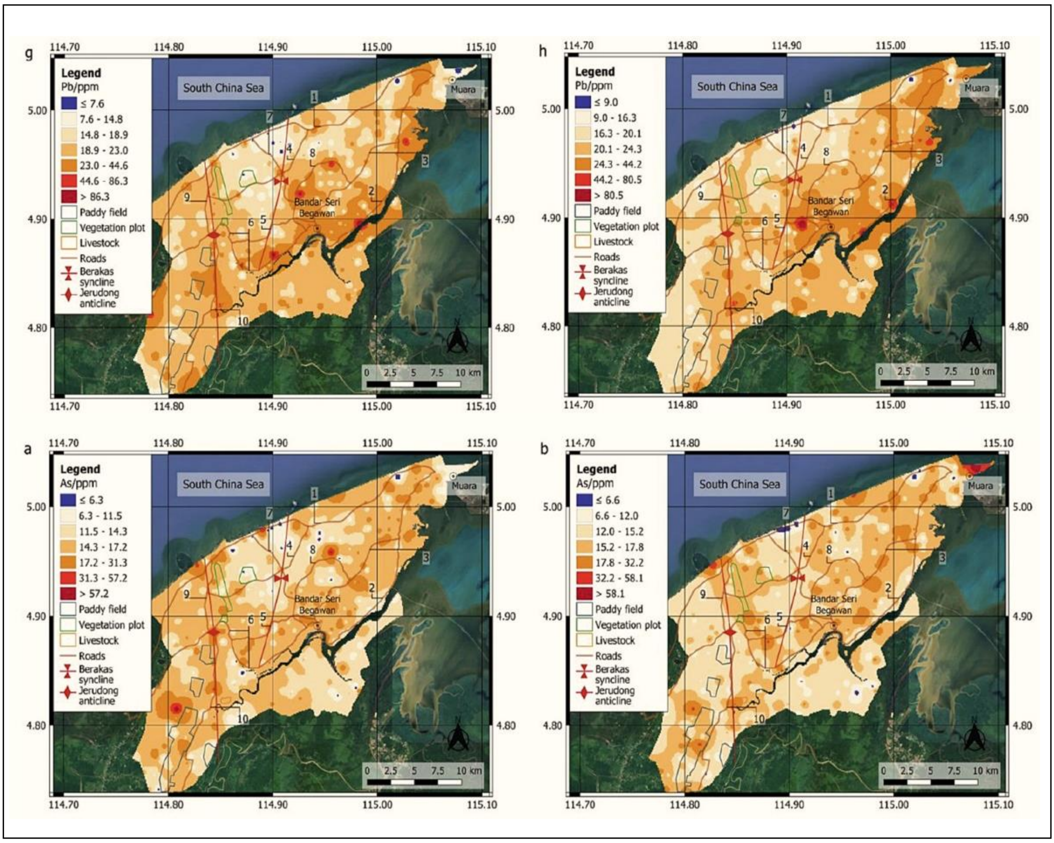

Figure 4. Geochemical maps indicate the threshold values for: a) Arsenic topsoil b) Arsenic subsoil, g) Lead topsoil, and h) Lead subsoil (modified from [9]).

Naturally, acid-sulphate soils can form in various physical settings, including organic matter fractions (such as those found in lowland peat domes) and minerals like pyrite. [3,25]. In Brunei Darussalam, pyrite has been identified in the shale layers of the soil and in several estuaries [3,25]. During the monsoon rain season, the estuary system is prone to acidification as the groundwater emanates from pyrite-rich acid-sulphate soils [26,27]. Dating from 5,400 years ago, the mudflats in the Brunei estuarine system have been influenced by the acidic inflow from the freshwater derived from acid-sulphate soils containing pyrite [27]. When acid-sulphate soil is exposed to the air due to erosion or excavation, the sulphide minerals oxidise and leach sulphuric acid, resulting in a decrease in soil pH [3]. Consequently, the soils of Brunei-Muara District are very acidic with pH levels generally below 5.5 and reaching values below 3 in agricultural areas [9]. Challenging acidic conditions hinder the development of areas for agricultural purposes by diminishing crop yields and favouring the mobility of potentially toxic metals. Consequently, it becomes crucial to devise methods for soil amendment and conditioning that can augment the productivity and overall health of paddy rice and other crops. Decreased pH can have a negative impact not only on plants and animals but also directly on humans. This is because under these conditions, the PTE can be absorbed by the crops which will eventually be consumed by humans and constant consumption can lead to health risks and food safety issues [24].

The primary threats to agricultural development on acid-sulphate soils include the lowering of the water table, which exposes sulphide minerals to increased oxidation and acidification, as well as subsidence caused by the oxidation of organic soils, leading to the depletion of valuable soil resources. A lack of control over the water table can result in increased acidification, decreased productivity, environmental degradation, and ultimately, the depletion of soil resources. Acidification, or the presence of sulphuric materials, poses a significant risk due to the limited acid-neutralising capacity observed in wetland soils containing sulphide minerals. Typically, soil acidity is mitigated by carbonate minerals and clays; however, Brunei Darussalam, where the rainfall is high and has heavily leached acid soils, lacks carbonate rocks that may raise the soil pH.

To utilise and have a sustainable production on acidic soil due to the presence of pyrite, it is important to have appropriate management practices. The best optimal management of regions containing acid-sulphate soils involves minimising risk by avoiding development in these areas [4]. Moreover, in instances where land utilisation is deemed necessary, fostering a formal collaboration between governmental entities and local geoscientists emerges as a best practice. This collaborative endeavour serves to yield promising and viable geochemical baselines, facilitating informed decision-making and the implementation of proactive measures to mitigate potential environmental ramifications. The government has introduced measures aimed at regulating land use practices, limiting deforestation and land clearing activities, and advocating for sustainable land management approaches. Furthermore, efforts such as public awareness campaigns and community engagement endeavours have been initiated to inform stakeholders about the significance of conserving peatlands and the potential hazards linked to fires.

4.2 | The importance of peatlands

Peatlands in Brunei Darussalam play a crucial role in maintaining ecological balance and supporting biodiversity, particularly in the face of climate change. These unique ecosystems, which cover approximately 16% of the country, are highly susceptible to forest fires, especially during dry periods when the water table drops [13]. This reduction in moisture causes the upper layers of peat to become more combustible, leading to smoldering combustion that can persist for extended periods, even with limited oxygen availability [28].

The significance of peatlands extends beyond their susceptibility to fire. They act as vital carbon sinks, storing substantial amounts of carbon accumulated over thousands of years. This carbon storage is essential for mitigating climate change, as drained or disturbed peatlands can release greenhouse gases like carbon dioxide and methane, exacerbating global warming. Furthermore, Brunei Darussalam's peat swamp forests are among the most pristine in Southeast Asia, housing diverse flora and fauna that contribute to the region's rich biodiversity [13]. Protecting these habitats is critical not only for preserving species but also for maintaining ecosystem services that support human livelihoods. Fire breaks are essential tools in preventing and controlling peat forest fires by creating barriers that interrupt the spread of flames. By limiting fire spread, these breaks facilitate more effective suppression efforts, protect valuable ecosystems, and promote landscape resilience. Their establishment encourages proactive fire management practices, such as regular maintenance and monitoring, contributing to sustainable land stewardship. Integrating fire breaks into land management plans enhances the capacity to mitigate the devastating impacts of peat forest fires, safeguarding ecological integrity and promoting long-term environmental sustainability.

In addition to fire management, ongoing research on peatlands is vital for understanding their geological evolution and the conditions necessary for their formation. This knowledge can inform conservation strategies aimed at preserving biodiversity and peatland ecosystems. Collaborative research initiatives involving local and international experts can further enhance our understanding of peatland dynamics and their response to environmental changes. Overall, safeguarding Brunei Darussalam's peatlands is not only crucial for climate change mitigation and biodiversity conservation but also for ensuring the resilience of local communities that depend on these ecosystems for their livelihoods. By prioritising peatland protection and sustainable management practices, Brunei Darussalam can enhance its role as a leader in environmental stewardship in Southeast Asia.

4.3 | The critical role of soil studies in military strategy

Understanding local soil conditions and integrating sustainable practices are essential for military forces to enhance food security, promote environmental sustainability, and improve operational effectiveness. By analysing soil properties, military operations can implement sustainable land management practices that prevent land degradation, reduce flood risks, and enhance resilience to natural disasters. This knowledge supports strategic land use planning, efficient resource allocation, and optimal site selection for military operations, ensuring the efficient deployment of equipment and personnel. Additionally, addressing soil contamination risks and adopting remediation strategies can lessen the environmental footprint of military activities.

In remote areas, these practices facilitate the development of self-sufficient food systems, minimising dependence on external supply chains while allowing for the cultivation of food and medicinal plants. Unfortunately, military operations often overlook long-term environmental impacts, addressing related issues only after significant damage has occurred. This oversight tends to prioritise short-term gains over long-term sustainability goals [29]. However, incorporating sustainable practices into initial operational plans can prevent environmental damage and reduce rehabilitation costs.

Implementing sustainable practices in military organisations may seem straightforward, but several challenges can arise. For example, the lack of knowledge and understanding of sustainable practices among personnel [30]. Additionally, even when these practices are implemented, the long-term benefits may not be immediately apparent, making it difficult to evaluate and report the tangible outcomes and effectiveness [29,31]. To overcome these challenges, military organisations can start by providing training on sustainable practices to their personnel. Such initiatives would equip the personnel with necessary skills and foster a culture of sustainability operations within the organisation. By embedding these practices into the organisational norm, military operations can become more environmentally conscious and

efficient. This highlights the growing recognition of the global nature of environmental challenges and the potential for militaries to collaborate in sharing best practices and developing innovative solutions [32]. An effective strategy is to foster partnerships between military organisations and researchers. Such collaborations can aid in the transition to sustainable operations and drive continuous improvement in national sustainability efforts. One particularly valuable area of collaboration involves investigating the effects of neighbouring countries' agricultural or farming activities on local soil conditions. Transboundary agricultural practices, such as the use of chemical fertilisers, pesticides, or intensive farming techniques, can have far-reaching impacts on soil health, water quality, and ecosystem stability in adjacent regions. By engaging in joint research initiatives, military organisations and academic researchers can monitor and assess these impacts, identify potential risks to local soils, and develop mitigation strategies to prevent land degradation. These collaborative efforts can also inform policies on sustainable land management and foster regional cooperation to address shared environmental concerns.

Brunei Darussalam forces could greatly benefit from adopting an innovative outreach program similar to the "Frontline to Farm" (F2F) initiative by Appalachian State University. This program is designed to support veterans in transitioning to sustainable agricultural practices, providing them with the skills and knowledge necessary for successful farming careers. The F2F program offers a comprehensive range of resources, including internships, intensive training sessions, and conferences that focus on sustainable farming practices [32]. Participants engage in hands-on learning experiences, collaborating with experts in various agricultural fields such as soil management, crop production, and business planning. This immersive approach not only equips veterans with practical skills but also fosters a strong sense of community among participants. In the long term, the skills and insights gained through such training can empower veterans in Brunei to contribute significantly to the remediation of degraded land, enhance local food security and raise awareness for environmental sustainability. By promoting sustainable agricultural practices, Brunei's military forces can play a pivotal role in environmental stewardship while supporting the livelihoods of former service members. Implementing a program like F2F could also encourage collaboration between military organisations, Academia and local agricultural experts, creating a network that supports sustainable practices across the region. This initiative would not only benefit veterans but also contribute to the overall resilience of Brunei Darussalam's agricultural sector, ensuring that it meets the challenges posed by climate change and food security concerns.

5.0 CONCLUSIONS

The significance of soil is unequivocal as it serves as the foundation of life on Earth, underpinning agriculture, biodiversity, water regulation, and climate stability while providing habitat for myriad organisms. Beyond its ecological functions, soil holds cultural, historical, and economic value. However, it is increasingly threatened by erosion, degradation, and pollution driven by human activities. In Brunei Darussalam, soils are particularly vulnerable to natural acidification, exacerbated by anthropogenic factors, necessitating urgent mitigation efforts.

To promote sustainable agricultural development, it is essential to exercise caution in the widespread use of fertilisers and pesticides. Moreover, effective management of industrial waste is critical to prevent the accumulation of potentially toxic elements that could jeopardise public health. Therefore, further research into soil conservation and sustainable land management practices is vital to safeguard this invaluable resource for present and future generations. Implementing protective measures can help achieve sustainable development goals.

Peatlands are integral to carbon storage, biodiversity conservation, and water regulation, aligning with various Sustainable Development Goals, such as climate action and clean water and sanitation. Understanding the dynamics of peat ecosystems, along with their susceptibility to degradation and fire, is crucial for developing effective management strategies that contribute significantly to these goals. By prioritising research and investing in sustainable peatland management practices, we can harness their potential to mitigate climate change, preserve biodiversity, and secure essential resources for future generations.

Conducting comprehensive studies on both inorganic and organic soil components can aid policymakers and farmers in formulating more sustainable soil and nutrient management strategies. Collaborative efforts involving military organisations, researchers, and local stakeholders are essential for monitoring and managing soil health effectively, ensuring that regional environmental challenges are addressed collectively.

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GREEN TECHNOLOGY IN DEFENCE OPERATIONS: AN AIR FORCE PERSPECTIVE

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ABSTRACT

The growing environmental challenges of the 21st century have necessitated significant shifts in global operations, including defense. With a focus on sustainability, the military has increasingly turned to green technologies to reduce its environmental footprint while maintaining operational efficiency. This paper explores the integration of green technologies within Air Force operations, addressing the adoption of renewable energy sources, sustainable mobility, eco-friendly infrastructures, and innovative material use. Through case studies, this paper highlights the strategic advantages of these technologies, from reduced dependence on fuel supply chains to enhanced global cooperation. Despite the clear benefits, challenges such as high initial costs and logistics remain obstacles to full implementation. This paper concludes by outlining the future of green technology in military operations and the importance of aligning defence strategies with global sustainability goals.

Keywords:
Green technology, Sustainability, Renewable energy, Biofuels, Energy security, Operational efficiency, Sustainable mobility, Eco-friendly infrastructure, Military sustainability.

1.0 INTRODUCTION

Climate change is currently becoming a growing concern in Brunei Darussalam and we started to see the publication of Brunei Darussalam National Climate Change Policy in 2020. The nation has now seen the importance of incorporating green technology as part of its commitment to reducing environmental footprint and sustainable development. Brunei recognizes the importance of addressing global environmental challenges such as climate change, resource scarcity, and environmental degradation. This can be proven with the establishment of the Centre for Green Technology and Sustainability Research at Universiti Teknologi Brunei (UTB). This recognition is a vital step to achieving sustainability in achieving *Wawasan* Brunei 2035, aimed at reducing environmental impact through integrating eco-friendly solutions.

The defence organisation plays a huge role in recognising the need to adapt to green technology. As stated in the Defence White Paper of 2021, the Royal Brunei Armed Forces have shifted their defence posture aligned with the evolving non-conventional threats that the world is facing. Adopting green technologies in this context is crucial in ensuring operational readiness while also mitigating the environmental impact of defence activities. The Royal Brunei Air Force (RBAirF), in particular, is constantly looking into enhancing its strategic capabilities, thus, cooperating with green technology in the development of their assets ensures that the organisation would not need to rely heavily on fossil fuels, which may cause detrimental effects to our environment. The RBAirF can start to look at the use of renewable energy sources, energy-efficient systems, and sustainable practices that reduce the carbon footprint of air operations. We can start to learn from our friendly forces, the Republic of Singapore Air Force (RSAF) has started designing eco-friendly solutions for their aircraft hangar by using solar power panels uses LED lighting.

This article explores how green technology is being integrated into air operations with a focus on:

1. Energy solutions in terms of integrating renewable energy
2. Sustainable mobility for transportation in military transport
3. Eco-friendly infrastructure to emphasize green building
4. Material innovation for future development

Additionally, it delves into the benefits and challenges associated with these technologies, offering insight into the future of defence strategies that harmonize military effectiveness with environmental responsibility.

2.0 BACKGROUND

Historically, air operations have relied heavily on conventional energy sources, such as fossil fuels, as the operations mainly dealt with aircraft. Aircraft such as S70i, C295W and previously C295 burn large amounts of fossil fuels, especially with the increased amount of taskings and training period. These fuels release high amounts of gas namely carbon dioxide (CO_2), which in turn becomes a major contributor to global warming. Additionally, supporting assets such as Iveco Medium Trucks and small engine generators that rely on combustion engines contributed to pollution as they burn diesel fuels and produce CO_2. The detrimental impact of CO_2 on the environment can be shown in **Figure 1**.

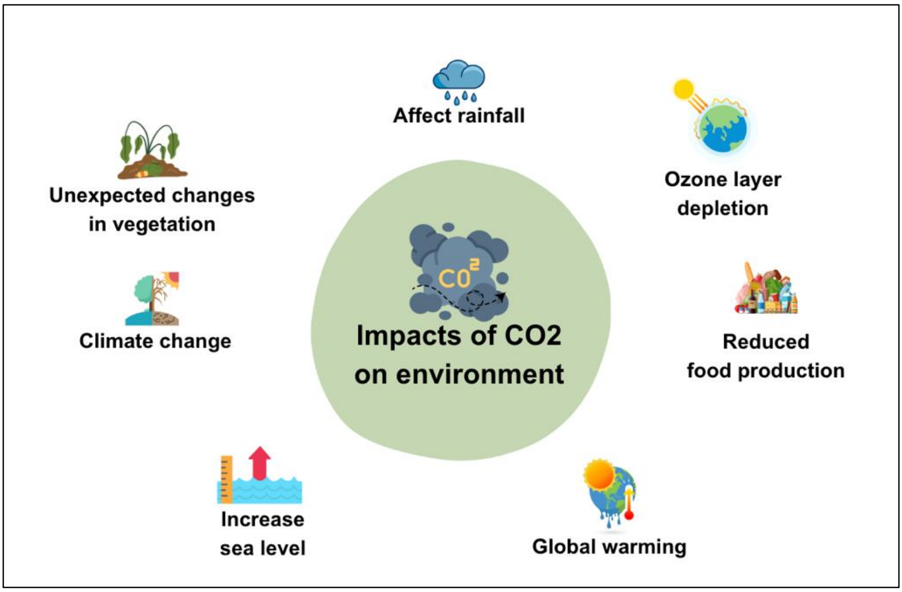

Figure 1. Impacts of CO_2 on the Environment.

These impacts necessitate the drive for the Air Force to adopt green technology in defence operations for operational resilience, preserving our ecosystem, reducing costs in the long run through streamlined systems, and proving to the public their commitment to environmental goals. It showcased the defence preparedness to counter future challenges and concurrently, contributes to global efforts in combating climate change.

Traditional Energy Usage in the Air Force

Historically, the Air Force is known for its dependency on fossil fuels to power aircraft, ground vehicles, and base infrastructures have contributed to significant greenhouse gas emissions and logistical vulnerabilities, such as securing fuel supply chains in contested regions. Key areas of these traditional usages are as such:

1. Aircraft Operations
2. Ground Vehicles and Equipment
3. Base Operations
4. Emergency and Back-up Systems

The aforementioned above has presented significant challenges on environmental impact, operational risks, and concerns on long-term sustainability.

It is well known that jet fuel is primarily used to power transport aircraft and unmanned aerial systems (UAS). Using RBAirF as an example, a list of the fuel consumption per hour and CO_2 emissions per liter of fuel burned are shown in **Table 1** below:

Aircraft Type	Fuel Burn Rate/Hour	CO2 Emissions Per Liter of Fuel Burned
S70i	757 – 946 liters	~2,392 kg/hour
C295	750 – 1,000 liters	~2,520 kg/hour
UAS Integrator X300	1.5 – 3 liters	~7.56 kg/hour

Table 1. Fuel Consumption and CO_2 Emissions.

Apart from that, the ground support equipment is not exempted from presenting environmental challenges through its heavy reliance on fossil fuels to meet the demands of logistics and mobility. Air operations commonly require tow vehicles, generators, and transport trucks at the Air Force bases. One of the impacts of fossil fuel dependency is the environmental impact it has from air and noise pollution as these engines emit nitrogen oxides (NOx) that harm the air quality. Meanwhile, the vehicle noise from the fuel engines created sound pollution, especially when the airbases were located near residential and civilian areas.

Environmental Impact

The burning of jet fuel and other petroleum-based products releases large amounts of carbon dioxide and pollutants into the atmosphere, intensifying climate change. In addition to this, the Air Force bases and operations generate significant waste, which can disrupt and harm the nearby ecosystems. The reliance on fossil fuels not only accelerates global warming, but it also creates logistical challenges, such as transporting and storing fuel, particularly during missions. A few disadvantages of fossil fuels are shown in **Table 2**.

Disadvantages	Impact	Method
Land degradation	Destroying wild life habitat	Unearthing and processing of underground oil and gas
Water Pollution	Contaminated water and jeopardize ecosystems	Coal mining operations and oil spills leak during extraction
Emissions	Impacted health	Burning fossil fuel

Table 2. Disadvantages of Fossil Fuels.

However, with the global shift towards cleaner, sustainable energy and the growing pressure on governments and institutions to reduce greenhouse gas emissions, military organisations are beginning to explore alternative, environmentally friendly technologies. Several examples are the Terrex S5 infantry fighting vehicle, which was introduced by the Singapore Armed Forces during the Singapore Airshow 2024, and the Leh Indian Air Force Station solar farms established in 2020. Other military organisations now starting to see the benefits it possesses and the growing importance of adopting green technologies into their missions and day-to-day operations.

Growing Need for Green Technology

As the Air Force is known to be one of the largest consumers of energy within the military, transitioning to green technology presents both opportunities and challenges. This section explores the broader landscape of green technology adoption, from global sustainability trends to the specific environmental targets set by military institutions, and the operational goals driving the integration of these technologies. Green technology offers a dual advantage:

1. **Mitigating environmental damage**

   Combating climate change is a global responsibility as it is not only beneficial to the surroundings but to the military personnel as well, and it improves the air quality that they live in. Efforts to mitigate these environmental damages will gain public trust in the military and align themselves with regional and international goals for a sustainable future.

2. **Enhancing the Air Force's strategic resilience by reducing reliance on finite resources**

   The reliance on fossil fuels creates logistical challenges and vulnerabilities, especially during conflicts. Fuel supply chains became an easy target for adversaries, and this poses risks to the air operations and their personnel. Knowingly, the air operations' main modus operandi is to execute power by securing air superiority through surveillance and support to the ground and maritime forces. Any disruptions in the fuel supply may jeopardize missions which in turn undermine operational effectiveness and thus, fail to meet mission objectives. The need for green technology will drive the Air Force to develop self-sustaining operations reducing dependency and vulnerabilities.

3.0 APPLICATIONS OF GREEN TECHNOLOGY IN DEFENCE

There are several initiatives that the Air Force can start to think of in reducing these harmful impacts on the environment. The RBAirF can start to develop these ideas to be included in the future National Development Plan in order to show their efforts in being one of the leading organisations in the nation to see the importance of green technology, aligning with the *Wawasan* Brunei 20235 goal 2 as shown in **Figure 2.**

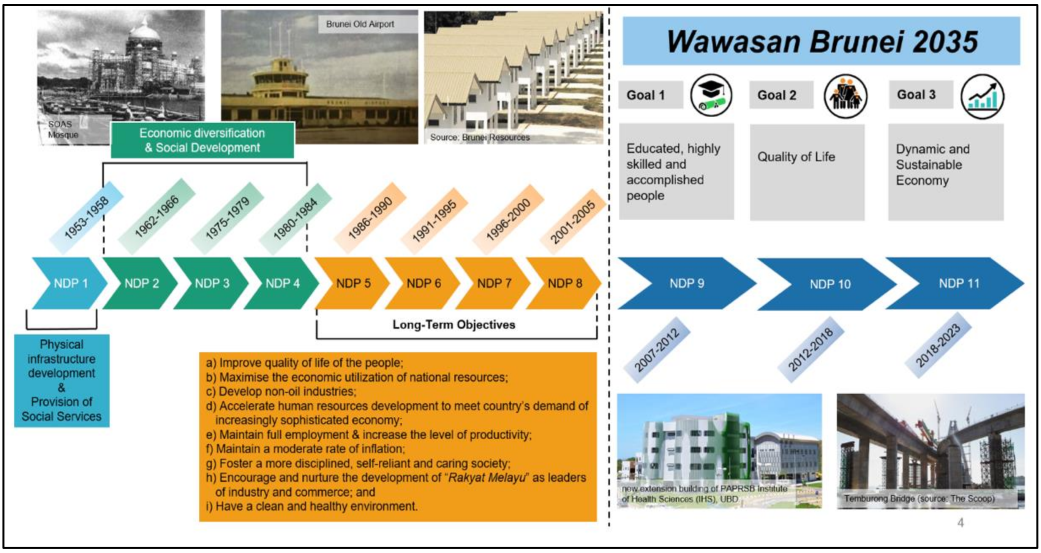

Figure 2. Overview of the NDPs.

► ***Renewable Energy Solutions***

One of the most significant shifts in military operations has been the increasing adoption of renewable energy solutions. Renewable energy sources such as **solar power** and **biofuels** are proving to be viable alternatives to traditional fossil fuels. For instance, solar panels have been integrated into remote airbases and Forward Operating Bases (FOBs) to provide power for communication systems, lighting, and other essential functions. Having these panels provides constant electricity for base operations to operate critically on their medical facilities and command centers without worrying about electricity failure or limited water supply for the electrical system. Electricity power can be generated through the amount of sunlight captured by the solar panels, producing sufficient electricity to bases. Additionally, the Air Force can reduce its dependency on fuel convoys and power generators.

Solutions such as the use of wind turbines in strategic locations allow the Air Force to diversify its energy sources, ensuring operational continuity even in areas where traditional energy supplies are limited or unreliable. This is of crucial importance to the Royal Brunei Armed Forces (RBAF) as most of Brunei Darussalam is covered with tropical green forest, making it difficult when there is a requirement to operate FOBs and Forward Arming and Refueling Point on the edge of Brunei's borders that are dense in vegetation as shown in **Figure 3**. Future technological initiatives to cut waste and pollution must be planned for in order to protect the nation's pristine rainforest from environmental damage, particularly from carbon emissions. Furthermore, **biofuels** derived from renewable organic materials have been tested for use in aircraft and ground vehicles, offering a cleaner alternative to conventional jet fuel.

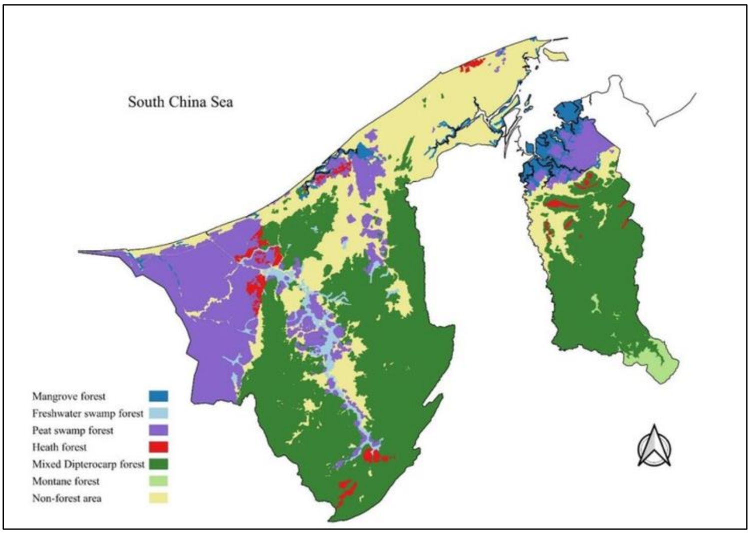

Figure 3. Distribution of Forest in Brunei.

► ***Sustainable Mobility***

The Bruneian government has recently started to show an interest in promoting electric vehicles (EVs) which shows the importance of having sustainable mobility to adapt to the current trends and challenges. Similarly, Air Forces all over the world have developed its efforts to focus on the electrification of ground vehicles to achieve sustainable mobility. The integration of **electric vehicles (EVs)** and **hybrid technologies** into the military fleet represents a significant step toward reducing fuel consumption and emissions. These vehicles are particularly useful for base operations, where they can replace traditional fuel-powered vehicles with lower-emission alternatives. This is crucial in achieving the reduction goals as stated in the Paris Agreement which Brunei Darussalam is a part of. Developing initiatives for the nation’s defense to transition towards lower-emission vehicles will help to reduce greenhouse gas emissions by 20%.

The Air Force has also been experimenting with electric-powered ground support equipment (GSE) for aircraft, reducing the need for diesel-powered GSE and improving the overall energy efficiency of air bases. In the aviation sector, the transition to **biofuels** is gaining momentum. Several military aircraft have already successfully flown using biofuels, demonstrating their potential for reducing reliance on traditional petroleum-based fuels. In the long term, the use of biofuels, hydrogen, and hybrid engines could drastically lower the Air Force's carbon footprint, particularly in non-combat operations such as training and logistics.

► *Eco-Friendly Infrastructure*

The adoption of green building practices is essential for creating more sustainable military installations. **Eco-friendly infrastructure** includes the use of **energy-efficient building designs**, **water conservation systems**, and **sustainable materials**. The Air Force has begun incorporating these elements into the design and construction of new facilities, such as airfields and barracks. Features like **solar-powered lighting**, **rainwater harvesting**, and **green roofs** contribute to reducing the overall environmental impact of military bases.

Furthermore, energy-efficient **cooling and heating systems** powered by renewable energy sources are being integrated into both new and existing facilities. These systems help reduce energy consumption and enhance the overall sustainability of military operations.

► *Advanced Recycling and Materials*

The use of **advanced materials** and **recycling initiatives** in the Air Force is an essential part of reducing waste and promoting sustainability. The military has long been a significant consumer of materials, from metals to plastics, and recycling programs have been established to ensure that materials from decommissioned equipment, such as aircraft and vehicles, are repurposed or recycled. For instance, the Air Force has started using **lightweight, eco-friendly composite materials** in aircraft construction, which not only reduce the environmental impact but also improve fuel efficiency.

Furthermore, efforts to recycle aviation fluids, metals, and even electronic waste have been integrated into operational procedures to minimize waste generation and reduce the need for raw material extraction.

4.0 CASE STUDIES

Case Study 1 | *Solar-Powered Airfields in Remote Locations*

One of the most notable initiatives in green technology within the Air Force has been the use of **solar energy** to power remote airfields. The **U.S. Air Force** has implemented solar panel installations in forward operating bases (FOBs) in areas like the Pacific Islands and the Middle East. These airfields often face logistical challenges in maintaining fuel supplies, which can be costly and vulnerable to attack. By installing solar panels, the Air Force has reduced its reliance on fuel deliveries, while simultaneously decreasing the carbon footprint of its operations. In some locations, solar energy has provided power for critical systems, such as lighting, communications, and airfield operations, making it a key component of sustainable military operations in these regions.

Case Study 2 | *Biofuel Testing and Integration*

The Air Force has also taken significant steps toward integrating **biofuels** into its aviation fleet. In 2008, the **U.S. Air Force** conducted its first successful test flight of a **C-17 Globemaster** using a 50/50 blend of traditional jet fuel and **biofuels** derived from algae and other renewable resources. This was a landmark achievement in the effort to reduce the military's dependency on fossil fuels. Since then, the Air Force has continued to test and integrate biofuels into its operations, focusing on ensuring that they meet military standards while providing a cleaner alternative to conventional aviation fuels. In 2016, the Air Force achieved another milestone by performing routine operations with biofuels at several airbases, paving the way for a broader adoption of sustainable aviation fuels.

Case Study 3 | *Electric Ground Support Equipment (GSE)*

Electric-powered Ground Support Equipment (GSE) has been successfully adopted at several U.S. Air Force bases. Traditionally, GSE, such as tugs, forklifts, and aircraft tow vehicles, have relied on diesel and gasoline engines. However, in recent years, the Air Force has begun transitioning to electric-powered GSE to reduce fuel consumption and emissions. For example, at **Nellis Air Force Base**, electric-powered aircraft tow vehicles have been implemented, reducing the need for diesel fuel and contributing to a cleaner base environment. The shift to electric GSE also reduces maintenance costs and enhances the energy efficiency of base operations.

5.0 BENEFITS IN GREEN TECHNOLOGY IN DEFENCE

The adoption of green technologies in defence operations provides a wide range of benefits that extend beyond environmental conservation. These benefits impact military strategy, operational efficiency, cost-effectiveness, and international relations.

- ***Environmental Impact Reduction***

The most obvious benefit of green technology in defence is the reduction of the military's environmental footprint. The Air Force’s shift towards **renewable energy sources**, such as solar and wind, reduces its reliance on fossil fuels, which in turn decreases greenhouse gas emissions. This not only helps combat climate change but also reduces the ecological damage caused by large-scale fuel transport and consumption. By adopting sustainable practices, the military can contribute to global environmental goals, positioning itself as a leader in sustainability.

- ***Increased Operational Efficiency***

Green technologies, such as **solar energy**, **biofuels**, and **energy-efficient aircraft**, can significantly improve the operational efficiency of military operations. For example, renewable energy systems allow the Air Force to become more energy-independent, reducing the logistical burden of fuel supply chains. Solar-powered airfields and military bases can operate autonomously, even in remote areas, minimizing the risks of fuel shortages or disruption. Additionally, **electric vehicles** and **hybrid systems** improve mobility within bases and reduce the need for traditional fuel-powered vehicles, further enhancing energy efficiency.

► ***Cost Savings***

Although the initial costs of green technologies can be high, the long-term financial benefits are substantial. The Air Force can achieve significant savings through reduced fuel consumption, lower maintenance costs for energy-efficient equipment, and longer lifespans for renewable energy systems. For example, switching to **biofuels** may reduce the cost of aviation fuel over time, while **solar panels** can provide free energy once installed. In the long term, these investments can save the military millions of dollars in fuel costs and maintenance, which can be reallocated to other critical operational needs.

► ***Energy Security***

Green technology offers improved **energy security** for military operations, especially in remote locations where fuel supply chains are vulnerable to disruption. For example, by using **solar power** to supplement traditional energy sources, the Air Force reduces its reliance on centralized power grids and ensures a more resilient energy supply. This is especially important in conflict zones where fuel deliveries can be delayed or intercepted, putting military operations at risk. The ability to generate and store energy on-site provides operational flexibility and enhances mission success.

► ***Enhanced Global Cooperation and Reputation***

The adoption of green technologies also strengthens **international partnerships**. Many countries are signatories to international climate agreements, such as the **Paris Agreement**, and the military's commitment to sustainability can enhance diplomatic relations. The U.S. Air Force, for instance, has collaborated with allied nations on joint renewable energy projects, reinforcing its leadership in environmental stewardship. By aligning military strategies with global environmental initiatives, the Air Force improves its reputation and contributes to global peace and stability.

6.0 CHALLENGES AND LIMITATION

While the integration of green technology into Air Force operations offers numerous benefits, it is not without its challenges and limitations. These challenges must be carefully considered to ensure that the adoption of green technology does not compromise operational readiness or overall effectiveness.

► ***High Initial Costs***

One of the primary barriers to adopting green technologies in the military is the **initial cost**. Technologies such as solar panels, energy-efficient equipment, and biofuel production require significant investment upfront. While these technologies often lead to long-term savings, the high costs associated with their integration can be a deterrent, particularly in a sector that demands constant readiness and operational flexibility. The military must weigh the short-term financial impact against long-term sustainability goals and operational efficiency.

- ***Reliability in Harsh Environments***

The Air Force operates in some of the most challenging environments on Earth—deserts, mountains, and arctic conditions, where the reliability of renewable energy sources can be uncertain. For example, **solar power** is heavily dependent on sunlight, which may be limited in polar regions or during cloudy weather. Similarly, **wind turbines** may not generate sufficient energy in areas with low wind speeds. Ensuring that green technologies remain reliable and capable of meeting operational demands in such environments requires ongoing research and technological advancements.

- ***Infrastructure and Logistics***

The logistical challenges of implementing green technology in the military are significant. The Air Force requires vast quantities of fuel for its aircraft and other assets, which are often stationed in remote locations. The transition to biofuels or solar power can complicate supply chains and infrastructure, particularly in areas where these technologies are not yet established. In such cases, military operations might face difficulties in sourcing and distributing green energy solutions, which could disrupt mission effectiveness.

- ***Integration with Existing Systems***

Another limitation lies in the **integration** of green technologies with legacy military systems. Many aircraft, vehicles, and other essential equipment were designed to run on fossil fuels and were not built with green technology in mind. Retrofitting these systems with alternative energy solutions can be costly and time-consuming. The military must find ways to balance the integration of modern, sustainable technologies with the operational demands of older equipment.

- ***Political and Bureaucratic Resistance***

Adoption of new technologies often faces resistance due to bureaucratic inertia or lack of political will. There may be resistance from traditional sectors of the military that view green technologies as untested or secondary to combat capabilities. Overcoming such resistance requires strong leadership, clear communication of the benefits, and a shift in organizational culture that embraces sustainability alongside operational readiness.

To overcome these challenges, governments and defense organizations must prioritize investments in green technology for aviation. Public-private partnerships can accelerate innovation, leveraging the expertise of the private sector. International collaboration is also vital, enabling nations to share knowledge, pool resources, and establish standards for green aviation practices. Additionally, incorporating sustainability goals into defense policies and strategies can drive cultural change within military organizations.

7.0 FUTURE OUTLOOK

The future of green technology in Air Force operations looks promising, but the journey towards a fully sustainable and energy-efficient military is complex. As technological advancements continue, the potential for greater integration of renewable energy and sustainable practices into the Air Force will increase.

► *Advancements in Renewable Energy*

As the global energy market shifts toward cleaner sources, advancements in **solar technology**, **wind power**, and **energy storage** will play a crucial role in making military bases more self-sufficient. Next-generation solar panels, with higher efficiency and more durable materials, will enable the Air Force to harness solar energy even in challenging environments. Additionally, **energy storage solutions**, such as advanced batteries and supercapacitors, will help store excess energy for use during times of low renewable production, ensuring continuous power supply.

► *Hydrogen and Biofuels*

In the aviation sector, **hydrogen** and **biofuels** hold significant potential to replace fossil fuels. Hydrogen-powered aircraft are already in development, and in the future, hydrogen could be a viable option for long-range flights, providing a carbon-neutral alternative to traditional aviation fuel. Meanwhile, biofuels are likely to become more refined and widely available, allowing for broader use in military aircraft, vehicles, and ships. This transition could dramatically reduce the Air Force's carbon emissions while maintaining high levels of operational performance.

► *Artificial Intelligence (AI) in Energy Management*

The integration of **AI** and **machine learning** could revolutionize how the Air Force manages energy consumption. AI could optimize the use of renewable energy across military installations, adjusting the energy load in real-time based on weather conditions, energy demand, and operational requirements. This would allow for more efficient energy distribution, reducing waste and increasing the overall resilience of military operations.

► *Sustainable Aircraft and Fleet Design*

Future Air Force fleets may be designed with sustainability at the forefront. Lightweight materials, more energy-efficient engines, and hybrid propulsion systems will be incorporated into new aircraft designs, reducing fuel consumption and emissions. Moreover, efforts to increase the **fuel efficiency** of existing aircraft through design modifications and the adoption of alternative fuels will continue to play a key role in reducing the military's environmental impact.

► *Global Collaboration and Policy Integration*

As nations worldwide commit to addressing climate change, global collaboration on military sustainability will become more critical. The Air Force, along with other branches of the military, will need to align its strategies with international environmental agreements, such as the **Paris Agreement**. This will require not only adopting green technologies but also fostering cooperation with allied nations to ensure that military operations are both effective and environmentally responsible.

8.0 CONCLUSION

Green technology in defence operations is not just a trend—it is a strategic necessity. As the world faces pressing environmental challenges, the military must evolve to balance operational efficiency with sustainability. For the Air Force, adopting green technologies like renewable energy solutions, biofuels, and eco-friendly infrastructure is critical for maintaining operational readiness while reducing environmental impact. Despite the challenges, such as high initial costs, infrastructure limitations, and the need for integration with existing systems, the long-term benefits far outweigh the obstacles.

The adoption of green technology offers not only environmental advantages but also strategic ones. By reducing dependency on fossil fuels, the Air Force can enhance energy security, improve operational efficiency, and decrease logistical vulnerabilities. Furthermore, as the military continues to integrate cutting-edge green technologies into its operations, it will be better positioned to lead by example, demonstrating how environmental responsibility can coexist with military power.

Looking to the future, advancements in renewable energy, hydrogen fuel, AI, and sustainable fleet design will transform Air Force operations. These developments will not only contribute to a more sustainable military but also help the global community in the fight against climate change. Ultimately, the future of defence operations will be one that combines military strength with environmental stewardship, ensuring that the Air Force remains prepared for the challenges of tomorrow while preserving the planet for future generations.

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ANALYSING THE RELATIONSHIP BETWEEN SELF-ASSESSED CONFIDENCE AND SIMULATOR PERFORMANCE: A QUANTITATIVE RESEARCH FRAMEWORK TO EVALUATE CONFIDENCE METRICS

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ABSTRACT

This study explores the relationship between drone simulator performance and self-assessed confidence levels among drone pilots, using a two-day evaluation process involving self-assessment surveys and a drone simulation environment. Confidence levels were assessed via linear scale questions (1–5) conducted at the conclusion of third-person and first-person drone racing simulation stages. Performance metrics, including normalized time, consistency of velocity, completion rate, and error penalties, were integrated into a Confidence Score (CS) formula, designed to quantitatively represent pilot performance. Spearman's rank correlation was employed to examine the alignment between CS and self-assessment scores. The results revealed weak positive correlations (ρ=0.083 for third-person view racing and ρ=0.173 for first-person view racing), suggesting minimal alignment between performance-based metrics and self-perceived confidence. The study was conducted in a controlled environment using the DJI Flight Simulator with a DJI Mavic 2 Zoom drone, ensuring consistency and reducing biases. These findings highlight the complexity of assessing confidence in drone operations and the potential need for refined evaluation frameworks to better understand the interplay between self-assessment and performance. Future research should consider broader samples and qualitative data to enhance insights into pilot confidence dynamics.

Keywords:
drone safety, flight safety, DJI Flight Simulator, drone training simulator, drone anxiety, drone racing, flying with confidence

1.0 INTRODUCTION

The increasing adoption of drone flight simulators in training and competitive settings has underscored the need for reliable metrics to evaluate pilot performance and confidence. In high-speed, precision-critical tasks such as drone racing, confidence plays a pivotal role in decision-making, task execution, and overall performance. However, quantifying confidence objectively remains a challenge, particularly in contexts where subjective self-assessments may not accurately reflect a pilot's true capabilities or limitations.

Drone flight simulators provide a controlled environment to assess pilot performance under varied conditions, offering a wealth of data that can be analysed to evaluate confidence objectively. Metrics such as task completion rates, consistency, speed, and error frequency offer valuable insights into a pilot's reliability and decision-making efficiency. By integrating these performance indicators into a structured framework, it becomes possible to derive a confidence score that objectively reflects a pilot's ability to meet performance demands.

This study presents a quantitative framework to evaluate confidence metrics based on measurable performance data collected from drone flight simulators. The framework combines metrics such as task completion, timing, variability, and error frequency into a weighted scoring model to generate a comprehensive confidence score. Additionally, the study explores the correlation between this objective score and subjective self-evaluations to assess the alignment between perceived and actual performance.

By providing a systematic approach to confidence evaluation, this research contributes to the development of more effective training protocols, performance assessments, and system designs. The findings have implications not only for drone racing but also for applications in broader fields, such as autonomous systems, aviation training, and human-computer interaction.

2.0 LITERATURE REVIEW

The relationship between confidence and performance has been well-studied in high-pressure domains such as aviation, sports, and surgery [1,2]. In these settings, confidence influences decision-making, risk-taking, and error correction. Bandura's (1997) self-efficacy theory suggests that individuals with higher confidence tend to perform better because they believe in their ability to handle challenging tasks. However, overconfidence can lead to poor or reckless decision-making, while under-confidence may result in hesitation and missed opportunities.

In high-stakes environments, confidence is particularly crucial because it directly affects a pilot's ability to navigate complex courses, recover from errors, and make swift decisions under pressure. A pilot's confidence in their own abilities may lead to faster and more accurate decisions, as well as the willingness to take calculated risks to complete tasks in record time.

Previous studies have suggested that misalignment between subjective self-assessments and actual performance can lead to significant discrepancies in the pilot's behaviour. Buehler *et al.* (1994) found that self-perceived confidence in decision-making often does not correlate with actual performance, leading to the concept of "confidence bias" [3]. This misalignment is particularly relevant in unmanned aerial missions, where a drone pilot's perceived confidence can heavily influence their performance but may not always align with the objective data.

Various performance metrics are commonly used to evaluate drone pilots' skills and abilities, such as lap time, completion rate, and error frequency. These metrics are crucial for understanding a pilot's proficiency and consistency, especially in environments where high performance is critical.

- ***Time-based Metrics***: For drones, the most common performance metric is time. A pilot's ability to complete a course in the shortest time possible is often the key determinant of success. Researchers have emphasized that speed alone is insufficient to determine overall performance, as it does not account for the pilot's consistency or error management [4].

- ***Consistency***: Consistency, often measured as the coefficient of variation (CV) in lap times, plays a significant role in performance evaluation. Consistent pilots are less likely to make major mistakes and can adapt to changing conditions during the race [5]. High variability in lap times is typically a sign of fluctuating confidence and skill, whereas consistent performance reflects a stable and confident pilot.

- ***Completion Rate***: Task completion rate (CR) measures the percentage of tasks successfully completed by a pilot. In drone racing, this metric could reflect a pilot's ability to navigate obstacles without crashing, highlighting their skill in maintaining control over extended periods. Griffiths *et al.* (2018) found that task completion rates were significantly correlated with real-world performance in aviation, suggesting that this metric is a valid indicator of skill and reliability [6].

- ***Error Frequency***: The frequency of errors is another crucial factor in evaluating a pilot's performance. A high error rate is typically associated with lower confidence, as it indicates a lack of control and decision-making under pressure [7]. Conversely, pilots who make fewer mistakes tend to have higher confidence, as they can navigate challenges effectively without losing control. Error frequency can be a key indicator of how well a pilot manages stress and unexpected situations.

3.0 METHODS

This study investigates the development of a comprehensive confidence score for drone pilots using a flight simulator, with a focus on performance metrics such as task completion, consistency, error frequency, and timing. The methodology is divided into three stages: *basic drone control*, *third-person view (TPV) drone racing*, and *first-person view (FPV) drone racing*. Each stage progressively increases the complexity of the tasks, mimicking real-world scenarios where pilots are required to demonstrate skill, confidence, and adaptability in various flight environments.

3.1 | Participants

The study involved 17 participants from 262 Squadron, all holding ranks between Private (Pvt) and Sergeant (Sgt). The mean age of the participants ranged from 25 to 30 years, representing a typical demographic within this operational group.

On average, participants had logged 225 minutes of operational flying hours; however, it is noteworthy that 40% of the participants had no prior experience with real-world operational flying and had only undergone training using the DJI Flight Simulator. This mix of operational and simulator-only experience provided a diverse dataset for assessing the correlation between flying proficiency and confidence.

3.2 | Study Design

The study was conducted over a two-day period, combining an online survey and drone simulator sessions to evaluate the confidence levels of participants. The study was designed to minimize external influences and ensure consistency across all evaluations.

Self-Evaluation of Confidence Levels: Confidence levels were assessed using a self-evaluation method on a scale of 1–5 to evaluate participants' confidence: Participants assess their confidence level post-stages to capture any changes following the simulator experience.

Simulator Description: The DJI Flight Simulator was utilized to replicate real-world drone operations. The simulator provided a controlled and immersive experience, offering participants exposure to tasks such as basic flying and control manoeuvres, navigation through obstacles. Drone racing in third-person and first-person views. The simulator's design helped replicate high-pressure conditions, providing insights into pilot performance and confidence under operational scenarios.

Controlled Environment: To eliminate potential biases, the study was conducted in a controlled environment to ensure uniform testing conditions. Only one drone model—the DJI Mavic 2 Zoom—was used throughout the evaluation. This ensured consistency in drone characteristics and performance. The remote controller used was the actual controller for the DJI Mavic 2 Zoom, maintaining familiarity and muscle memory for participants.

This standardized approach ensured that all participants were subjected to the same conditions, enabling a fair and reliable comparison of confidence levels before and after the simulation tests.

3.3 | Structured Stages of Testing

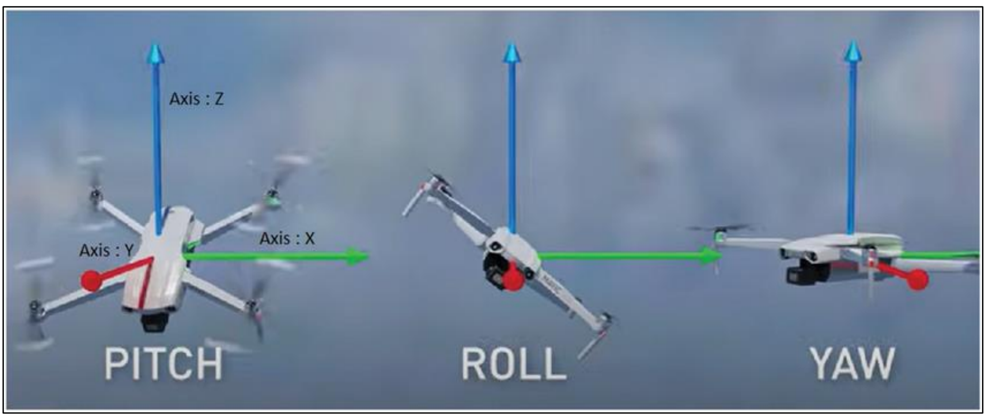
Stage 1 | *Basic Drone Control*

Objective:
The first stage is an introductory stage, aiming to evaluate the pilot's basic drone operating abilities. This stage introduces participants to fundamental drone controls and navigation in a controlled, non-competitive environment.

Procedures:

- **Pilot Training:** Participants are given a brief refresher session on the controls and features of the drone simulator.
- **Task Assignment:** Participants are tasked with performing basic controls and manoeuvres. The controls include throttle up/down, pitch forward/backward, yaw right/left, and roll right/left whilst manoeuvres include tracking a static point of interest and performing figure eight (8) maneuver. Each participant undergoes a basic

calibration exercise to ensure they are familiar with basic drone manoeuvres such as ascending, descending, and turning. The task difficulty is designed to allow the pilot to become comfortable and familiar with the drone and develop their control skills.



- **Performance Metrics**: During this stage, no performance metrics were collected.
- **Confidence Evaluation**: During this stage, confidence was not evaluated.

Stage 2 | *Third-Person View (TPV) Drone Racing*

Objective:
The second stage introduces a more competitive element with third-person view (TPV) drone racing. Pilots now face a course with obstacles and must navigate through gates and avoid barriers, all while managing speed and accuracy. TPV allows pilots to view the drone from a third-person perspective, offering a wider field of vision compared to FPV.

Procedures:

- **Course Setup**: A complex race course is designed, with multiple obstacles, sharp turns, and gates. The course is timed to a maximum limit of 3 minutes, and pilots are tasked with completing it as quickly as possible while maintaining accuracy and avoiding crashes.

- **Pilot Training**: 1x practice run using TPV mode.

- **Task Assignment**: Each participant is required to complete three race courses with increasing complexity i.e. 10 gates, 14 gates and lastly 17 gates. Timing and errors are tracked throughout. They are also asked to take part in a practice round before the official timed runs.

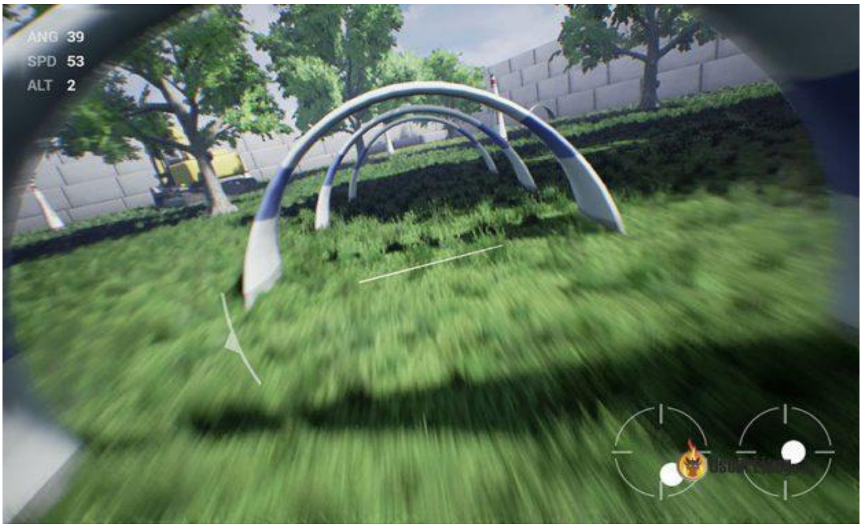
- **Performance Metrics**:

Metric	Description	Measurement Method	Indication of Confidence
(a)	(b)	(c)	(d)
Completion Rate	Percentage of tasks successfully completed during simulation.	Calculate tasks completed / total tasks assigned.	Higher completion rate indicates higher confidence, and vice versa.
Lap Time	Time taken to finish a course.	Measure time (seconds) from start to finish.	Faster completion time suggests greater confidence. Failure to complete or lower completion time suggest lower confidence.
Error Frequency	Number of errors such as crashes, incorrect manoeuvres, or failed objectives.	Count errors during each simulation session.	Fewer errors correlate with improved confidence, and vice versa.
Consistency	Stability of performance across multiple simulation sessions.	Compare performance metrics (completion rate and time) across sessions.	Consistent performance reflects higher confidence levels, and vice versa.
Self-Assessment Survey	Participant's own evaluation of their confidence before and after completing tasks.	Survey or questionnaire using a Likert scale (1–5). Difference of final and initial scores indicate the result.	Higher / Positive scores align with increasing confidence. Lower / Negative scores suggest decreasing confidence.

- **Confidence Evaluation**: At end of stage 2, participants are required to answer a self-assessment question rating his confidence level.

Stage 3 | *First-Person View (FPV) Drone Racing*

Objective:
The third stage shifts to first-person view (FPV) racing, where the pilot views the race course directly from the drone's perspective. This stage simulates the true racing environment and places higher cognitive and spatial demands on the pilot.



Procedures:

- **Course Setup**: The race course in Stage 3 remains similar in complexity to Stage 2 but is viewed entirely from the FPV perspective. Pilots no longer have a third-person perspective, which requires them to rely entirely on their perception of the drone's surroundings as seen from the on-board camera.
- **Pilot Training**: 1x practice run using FPV mode.
- **Task Assignment**: Pilots complete the same race course multiple times, but this time, they must complete it from the FPV perspective. As in Stage 2, the race is timed, and errors are tracked.
- **Performance Metrics**: The same set of metrics from the previous stages is applied.
- **Confidence Evaluation**: At the end of stage 3, the participant is required to answer a follow up question rating his current confidence level.

3.4 | Data Analysis

After the completion of all three stages, the performance data will be analysed to generate a comprehensive confidence score. A weighted composite scoring model will be used to evaluate the participant's confidence based on the performance metrics of completion rate, lap time, consistency, and error frequency. These metrics will be used to calculate the Confidence Score (CS) that reflects both objective performance and confidence.

A correlation analysis will also be conducted to assess the relationship between the objectively calculated Confidence Score (CS) and subjective Post-Stage Self-Evaluation (SE) scores recorded after the completion of Stage 2 (third-person view racing) and Stage 3 (first-person view racing). It will be analysed using the Spearman's rank correlation coefficient. The aim is to understand the alignment (or misalignment) between subjective and objective confidence assessments.

Procedure – *Deriving CS*

To quantitatively derive a CS from the data collected, the following functions were used:

$$T_{norm} = \frac{T - T_{min}}{T_{max} - T_{min}} ,$$

where T_{norm} is the lap time normalized to a scale of 0 to 1, T is the average lap time, T_{min} is the fastest (best) time, and t_{max} is the slowest (worst) time. If lap failed, lap time is assumed to be 180s. 1 - T_{norm} represents the normalised "performance efficiency" where higher values are better.

$$CV = \frac{\sigma}{\mu} ,$$

where Correlation of Variation (CV) is a normalised measure of variability: a lower value reflects higher confidence; Standard Deviation (σ): smaller value indicates more consistent performance; μ is the mean time. 1 – CV represents consistency, where higher values indicate more stable performance.

$$CR = \frac{Tasks\ Completed}{Tasks\ Assigned} ,$$

where Completion Rate (CR), ranges from 0 (no task completed) to 1 (all tasks completed). Higher CR value indicates better performance.

$$EP = \frac{EF_{avg}}{EF_{max}},$$

where Error Penalty (EP) is a penalty term introduced for higher value of Error Frequency (EF). Where EF_{avg} is the average error frequency of each stage (consisting of three courses). EF_{max} is the maximum observed error frequency, normalizing this term between 0 and 1. Lower EP signifies better performance.

All data are measurable metrics; thus, the equation becomes more objective. A suggested model to calculate the Confidence Score (CS) is as follows:

$$CS = \alpha x\ (1-\text{Normalized Time}) + \beta\ x\ (1-CV) + (\gamma\ x\ CR) - (\delta\ x\ EP)$$

where α, β, γ, δ are weightages that sums to 1; δ penalizes for errors to balance the impact of errors against other metrics. Values allocated for the weightages are solely based on the author's school of thought, whereby task completion is of highest priority followed by timing, consistency and lastly error.

α – emphasizes timing = 0.3
β – rewards consistency = 0.2
γ – prioritizes task completion = 0.4
δ – penalizes errors = 0.1

Procedure – *Deriving correlation between CS & SE*

Definition of variables:

- CS_2 – Confidence Score for Stage 2
- CS_3 – Confidence Score for Stage 3
- SE_2 – Self Evaluation after completing Stage 2
- SE_3 – Self Evaluation after completing Stage 3

For each stage, rank participant's CS out of the total number of participants. Calculate the rank difference (*d*) between his CS rank & SE rank. Due to SE scores are constrained to a small ordinal range (1–5) and multiple participants have the same SE score, ranking all participants becomes ambiguous due to tied ranks. Thus, for tied scores, assign the average of the ranks, for example, if three participants have the same SE score of 4 and occupy positions 5, 6, and 7 in the sorted list, assign each a rank of (5+6+7)/3 = 6.

Example:

CS_2 rank 4th / 17
SE_2 rank 6th / 17 (after averaging scores)
d *= 6 – 4 = 2*

Thus, the formula to calculate Spearman's rank correlation:

$$\rho = 1 - \frac{6\ x \sum d^2}{n\ x\ (n^2 - 1)}$$

where,

n is the total number of participants (17 in this case) and $\sum d^2$ is the sum of squared differences between the ranks of CS and SE.

4.0 RESULTS

4.1 | Performance Metrics Comparison

Table 1 summarizes the performance metrics recorded for all participants across the two stages of the study: Third-Person View (Stage 2) and First-Person View (Stage 3).

Stage	T_{norm} (Mean ± SD)	CV (Mean ± SD)	CR (%)	EP (Mean ± SD)
(a)	(b)	(c)	(d)	(e)
2	0.81 ± 0.19	0.13 ± 0.14	21%	0.62 ± 0.08
3	0.70 ± 0.12	0.18 ± 0.12	37%	0.67 ± 0.09

Table 1. Comparison of mean performance metrics.

The results show improved performance in Stage 3, with reduced T_{norm}, higher consistency and higher CR, but there is a slight increase in error penalties reflecting the added complexity of first-person drone control.

4.2 | CS Comparison

The CS for each participant were calculated using the weighted model in **Table 2**.

$$CS = \alpha x\ (1 - \text{Normalized Time}) + \beta\ x\ (1 - CV) + (\gamma\ x\ CR) - (\delta\ x\ EP)$$

Stage	CS (Mean ± SD)
(a)	(b)
2	0.25 ± 0.13
3	0.34 ± 0.12

Table 2. Comparison of mean CS.

Although task complexity increased, participants exhibited a higher CS in Stage 3 (first-person view), indicating an increase in confidence, suggesting that the participants are familiar and had adapted with the race course.

4.3 | SE Scores Comparison

SE scores were collected post-Stage 2 and Stage 3 on a scale of 1–5. Descriptive statistics for SE are presented in **Table 3**.

Stage	SE (Mean ± SD)
(a)	(b)
2	3.68 ± 0.94
3	3.04 ± 1.00

Table 3. Comparison of mean SE scores post-stage 2 and 3.

The decline in SE from Stage 2 to Stage 3 suggests that participants perceived lower confidence when transitioning to first-person view.

4.4 | Correlation Between CS and SE

Spearman's rank correlation was used to assess the relationship between CS and SE for Stage 2 and Stage 3. The results are summarized in **Table 4.**

Stage	Spearman's ρ
(a)	(b)
2	0.083
3	0.173

Table 4. Spearman's ρ correlation between CS and SE.

A very weak positive correlation was observed in both stages. Essentially, this suggests that as one variable increases, the other tends to slightly increase, but the relationship is extremely weak and possibly negligible. The weak correlation suggests that CS and SE do not strongly align, indicating that participants' self-evaluations may not reflect their simulator-based performance.

5.0 DISCUSSIONS

Why Are the Correlations Weak?

- **Human Factors**:
  - Participants might base SE on subjective feelings rather than actual performance.
  - There may be inconsistencies in interpreting the SE scale (1–5). Each participant may view it differently.
- **Varying Task Difficulty**:
  - The variability introduced from Stage 2 to Stage 3 may weaken the alignment between CS and SE.
- **CS Model:**
  - The weightages (α, β, γ, δ) in the CS model might not fully reflect participants' perceptions of confidence.
  - The performance metrics used to derive the CS model may not be comprehensive enough.

6.0 RECOMMENDATIONS

Consider to explore adjustments for both the CS model and SE methodology. Doing so might yield stronger correlations in future studies. While confidence is intangible, these are some suggestions of key performance metrics that may need to be included for the CS model:

Metric	Description	Measurement Method	Indication of Confidence
(a)	(b)	(c)	(d)
Reaction Time	Time taken to respond to simulated challenges or unexpected scenarios.	Measure time (seconds) from stimulus to action.	Faster reaction times suggest greater confidence.
Risk-Taking Behaviour	Willingness to attempt challenging tasks without excessive hesitation or withdrawal.	Record observations or assign difficulty ratings to tasks.	Balanced risk-taking shows confidence, not recklessness.

Decision-Making Speed	Time taken to decide on a course of action during complex scenarios.	Measure time from task presentation to pilot action.	Quicker, accurate decisions indicate confidence.
Instructor Evaluation	Observations from instructors on pilot behaviour, composure, and adaptability during simulation.	Use a standardized rubric to score behaviours (e.g., 1–10).	Positive instructor feedback reflects confidence.

Future studies should also increase the sample size to a minimum of 50 participants. There should be zero to minimum bias, thus all participants must have zero background in drone flying and within the same age group.

6.0 CONCLUSIONS

This study investigated the relationship between drone pilot performance, measured using a Confidence Score (CS), and self-assessed confidence (SE) across two simulation stages: third-person view racing (Stage 2) and first-person view racing (Stage 3). Spearman's rank correlation was used to assess the alignment between these metrics.

The results showed weak positive correlations in both stages, with ρ=0.083 for Stage 2 and ρ=0.173 for Stage 3. These findings suggest a minimal relationship between CS and SE, indicating that self-assessed confidence may not strongly reflect measured performance in drone simulation tasks. The slightly higher correlation in Stage 3 may reflect increased alignment between confidence and performance as participants adapt to more challenging first-person view tasks, but the relationship remains weak overall. This finding could imply that self-assessed confidence may not reliably indicate performance in drone simulation tasks.

The weak correlations highlight the complexity of quantifying confidence and its relationship to performance in drone simulation contexts. Factors such as individual differences in self-perception, task difficulty, and the weighting of metrics in the CS formula may have contributed to the observed results. Future studies should explore alternative scoring methods, larger participant samples, and additional qualitative measures to gain a deeper understanding of the factors influencing confidence and performance alignment in drone operations.

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