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Heating the Battle Space: Consequences of Climate Change on Air Operations

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Abstract *- Climate change is not a prediction, it is a present-day ground reality. It has been accelerated by man-made reasons primarilyby the emission of greenhouse gases and deforestation. This study is focused on the consequencesof globalwarming specificallyon airoperations. Objectives of the study are to find out the consequences of global warming, particularly on air operations, to identify the measures taken by different stakeholders to address the issues due to global warming, to determine the level of commitment of aviators in adopting the measures to address global warming and potential inputs of technology to mitigate adverse effects of global warming on air operations. The methodology of the study adopted an inductive approach to this exploratory qualitative study and pragmatism was the philosophy. Grounded theory was the strategy and the time horizon was cross-sectional. Data collection and analysis happened to be the technique. Primary data were collected through a sample of aviators operating in tropical regions, selected through purposive sampling. There were two recommendations based on the research outcome namely,to encourage global-level discussions for seeking long-term solutions, continue researchon sustainable solutions and develop a combined strategy.Humans kind have already joined the vicious cycle of climate change and accelerated it through a variety of activities, essential for modern-day living. Yet there are ways and means to slow down the process of global warming, which require short-term and long-term solutions. Collective effort through genuine collaboration could yield better results than working in isolation.*

Keywords **– Air operations, Global Warming, Climate Change, Sustainable solutions**

I. INTRODUCTION

Climate change is a novel notion. It is not a prediction buta ground reality today. It has been there at the outset. Then the question arises, why the world has paid more attention toclimate change in the latter decades? It has been identified that man-made reasons have accelerated the rate of climate change significantly and in turn, there will be a dramatic change to the livelihood onplanetEarth(Zandalinas, Fritschi and Mittler, 2021). Despite the way too different contributionsto climate change by different stakeholders, the price for the same would have to be paid collectively. Nonetheless, certain states, regions, and entities would have more impact than others such as coastal regions and islands. Air space could be considered one of the most affected due to climate change. Thus, the study is focused on the inevitable consequences of one specific segment of climate change namely the global warming on air operations by military elements, which predominantly behaves across the atmosphere.

II. METHODOLOGY

Researchers adopted an inductive approach to explore the research gap between the expected effectiveness of the measures taken for addressing global warming and the actual effectiveness of those measurements. During the exploratory qualitative study, pragmatism has been the philosophy whilst adopting grounded theory as the strategy. The time horizon was cross-sectional.The collection of primary data was through interviews with aviators of the Sri Lanka Air Force, Royal Omanian Air Force, Indian Air Force and Pakistan Air Force selected purposively.The study population was aviators operating in tropical regions, where atmospheric temperatures are relatively higher. The theoretical population is all aviators operating under a heated-up atmosphereas of now and in the future. Secondary data were collected through literature and related conference proceedings. Data collection and analysis was the technique adopted.

A. Conceptualization

The conceptual framework has been formulated based on the theoretical framework as follows.

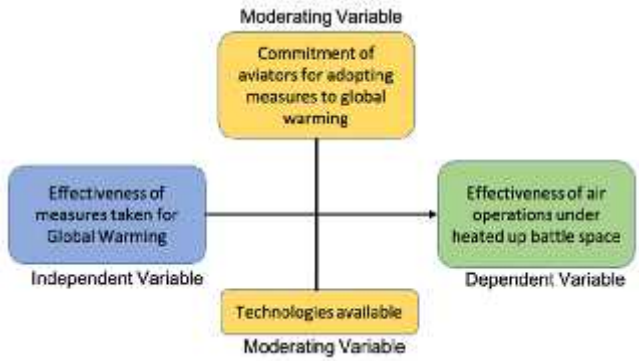

Figure 1: Conceptual Framework

Source: (Authors, 2023)

CLIMATE CHANGE AND GLOBAL WARMING

Climate change and global warming have emerged as two of the most pressing and inseparable environmental challenges today(Zandalinas, Fritschi and Mittler, 2021). The scientific consensus is clear: natural and man-made reasons. As far as human activities are concerned, particularly the burning of fossil fuels, emission of greenhouse gases and deforestation, are the primary drivers of these phenomena.The consequences of climate change and global warming are far-reaching and pose significant threats to global ecosystems, economies, industries and future generations.

One of the most evident impacts of climate change is the rise in global temperatures. Over the past century, the Earth's average temperature has increased by approximately 1 degree Celsius (Kerr, 2007). One degree may seem like a small change, but it has profound implications. Rising temperatures lead to the melting of polar ice caps and glaciers, causing sea levels to rise. Coastal regions are already experiencing more frequent and severe flooding, displacing communities and threatening infrastructure (Masson-Delmotte et al., 2018).

This paper intends to discuss the consequences of global warming rather than the reasons behind it. Even though the consequences of global warming are multifaceted, this paper will limit its focus on the impacts particularly upon air operations as follows:

A. Disrupted weather patterns
B. Effects on aircraft performance
C. Effects on human performance
D. Sustainability of aircraft and associated equipment
E. Risk of fire hazard
F. Rise of sea level

Several organizations are monitoring and studying climate change and global warming. United Nations (UN), National Aeronautics Space Administration (NASA), Climatic Research Unit of the United States of America (USA), and National Oceanic and Atmospheric Administration of the USA…etc are among key such organizations. The statistics analyzed by these organizations unanimously represent a continual and sharp rise in global temperature. Two following indexes are depicting the rise of global surface temperature as well as the ocean temperature.

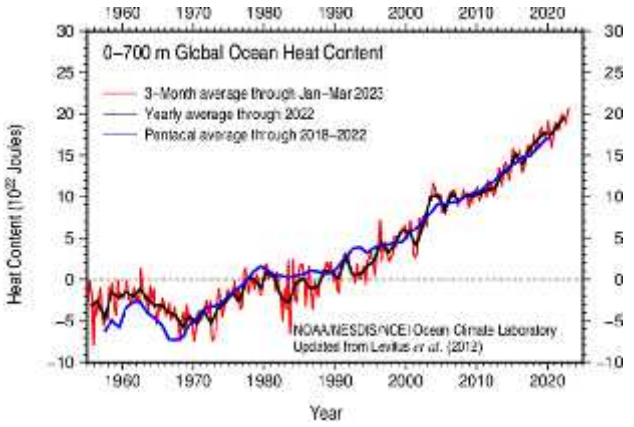

Figure 2: Global AverageSurface Temperature Index

Source: www.climate.gov

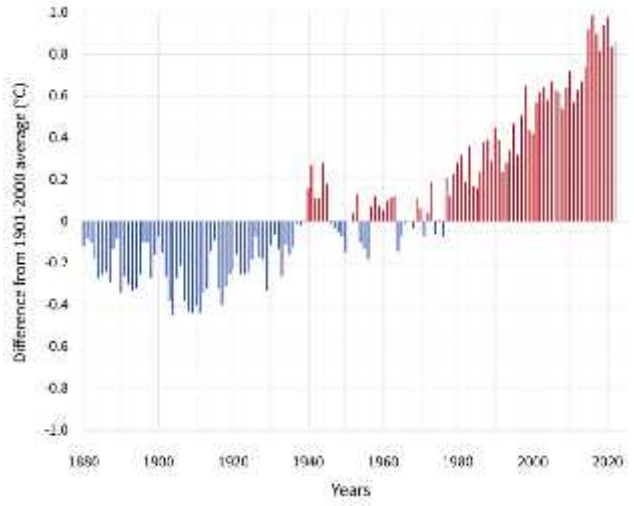

Figure 3: Global Average Ocean Heat Content

Source: www.ncei.noaa.gov

The empirical data reveal that the hottest years as far as the average global temperature is concerned are 2016 and 2020. Nonetheless, 7-11Jun 2023 had been recorded as the highest ever average global temperature recorded trussing previous data by a substantial margin as highlighted by European Uion's Climate Monitoring Unit.

> " The world has just experienced its warmest early June on record"
>
> -SamathaBurgess, Deputy Director of the Copernicus Climate Change Service-

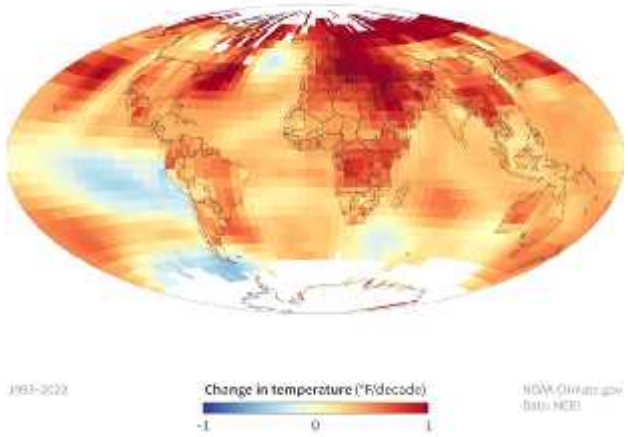

Figure 4: Recent Temperature Trends (1993-2022)
Source: www.ncei.noaa.gov

It is more than 1.5 degrees Celsius than the pre-industrial era for the first time in history. These events haveculminating effects on intense and long-lasting climatic changes in the future.

IV.FINDINGS AND DISCUSSION

B. Disrupted Weather Patterns

The atmosphere is the medium for air operations. Thus at the outset,favorable weather conditions have been a decisive factor for the safety and success of air operations. Weather Radars, autopilot systems, and many other systems are been developed through modern technology to conduct air operations amidadverse weather (Beckwith, 1971). Nevertheless, extreme weather conditions such as storms, hurricanes, volcanic eruptions, heat waves, different forms of heavy precipitation…etc are still posing significant disruptions for air operations(Gultepe et al., 2019).

One of the most striking manifestations of disrupted weather patterns is the increasing frequency and intensity of extreme weather events. Rising global temperatures create favorable conditions for the formation and intensification of hurricanes and tropical storms. Warmer ocean waters provide the energy necessary for these systems to grow stronger, resulting in more destructive storms with higher wind speeds and heavier rainfall(Wuebbles et al., 2014).

Global warming further leads to the exacerbation of heat waves. Heatwaves are becoming more prolonged and intense, posing severe threats to humans, natural ecosystems and even man-made infrastructure. The combination of high temperatures and increased humidity creates a dangerous heat index, pushing the limits of human tolerance beyond the red line(Delworth, Mahlman and Knutson, 1999). The impact on human performance, aircraft and associated equipment due to higher temperatures is discussed subsequently.

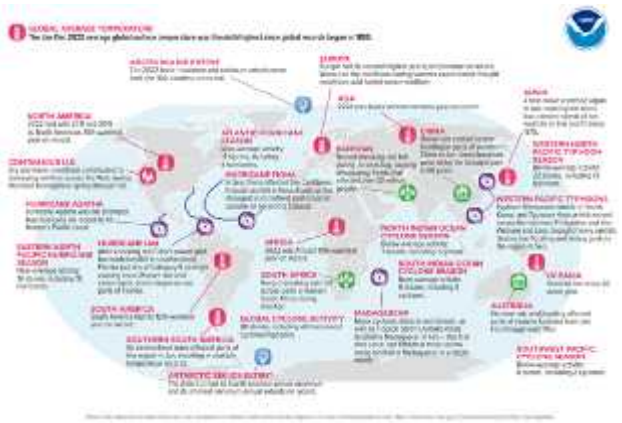

Figure 5: Selected Significant Climate Anomalies and Events in 2022
Source: www.ncei.noaa.gov

C. Effects on Aircraft Performance

Global warming results in heating air than usual, which makes the air less dense causing numerous challenges to air operations. Mainly the effects of less dense air are twofold. On one hand, it affects the propulsion system. Air-breathingengine performance heavily depends on the quality of air it consumes(Wei et al., 2022). As per the gas laws, the density is proportional topressure. Low pressure at the inlet results inlow-pressure air at the combustion. With a drop in density and pressure, the partial pressure of oxygen also drops, which affects the fuel-air mixer adversely. All these phenomena are contributing to less efficient propulsion output(Whalley and Ebrahimi, 2002).

On the other hand,lessdense air affects the aircraft's aerodynamic performance. Heavier than air machines are flown according to the laws of physics(Webster, 1920). There are several theories in combination that describes the principles of flight such as Bernoulies' theorem, Newtons' laws, Circulation theory, Magnus effect, Momentum theory…etc. Qualities of air and aerodynamics form the cornerstone of almost all these theories. Less dense air creates low pressures than expected by the aerodynamics at respective places of the aircraft, thus adversely affecting the creation of lift(Grauer and Morelli, 2015). Pilots experience a significant drop in aircraft performance in terms of payload, maneuverability, rate of climb…etc as the atmospheric temperature rises.

In combination, under higher atmospheric temperatures the engine performance and aircraft performance

allowslesserpayload, demand longer runwayfor take-off and landing(Coffel, Thompson and Horton, 2017;Zhou et al., 2018), truncate the operational range and endurance of the flight, restrict the maneuverabilityway below the full potential…etc(Sun et al., 2016). Even an increment of one degree of Celsius can significantly affect the aircraft performance as per the aircraft performance charts provided in flight/performance manuals.

During the gulf war, American aviators experienced a significant drop in their aircraft performance due to comparatively higher temperaturesthey were used toand as a result, they had to conduct more sorties than usual for airlift and strike. This is contributing tothevicious cycle of climate changespeeding up by emitting more carbon and consuming more fossil fuels(Khordagui and Al-Ajmi, 1993). For usage in Africa and the Gulf region, the aircraft is specially designed to operate under higher atmospheric temperatures. What-so-ever done, their operational efficiency and performances are comparatively lesser than in colder regions.

D. Effects on Human Performance

Human performance is greatly influenced by environmental factors, and one such factor that has a significant impact is temperature. Hyperthermia has adverse effects on human physiology, cognitive function, and physical performance(Turner, 2020). In general, the rise of the human body's core temperature beyond 38 degrees Celsius, forces the individual into hyperthermia region and if the core temperature rises beyond 41 degrees Celsius the probability of death due to hyperthermia sets in(Desforges and Simon, 1993). Of course, different individuals have different tolerances for these environmental factors. Usually, the aviators' ground working environment is tarmac, which is having higher temperatures compared to other ordinary working environments. The rise of temperature is, therefore, more phenomenalon-air operators than that of other professions. Elevated temperatures affect various physiological processes in the human body. One of the most critical mechanisms is thermoregulation, which allows the body to maintain its core temperature within a narrow range. As ambient temperatures rise, the body must work harder to dissipate heat and prevent overheating(González-Alonso, 2012). This increased strain can lead to dehydration, heat exhaustion, and even heatstroke.

Dehydration negatively affects cognitive function and physical performance. When the body loses water through sweating, blood volume decreases, which reduces the delivery of oxygen and nutrients to the brain and muscles,consequently, cognitive abilities such as memory, attention, and decision-making are impaired, leading to reduced productivity and increased errors(Cheuvront and Kenefick, 2014; Pross, 2017).

Furthermore, higher temperatures can affect sleep patterns, resulting in sleep deprivation. Sleep is essential for cognitive restoration and consolidation of memory. Sleep deprivation caused by excessive heat can further impair cognitive function and alertness, leading to decreased productivity and increased accidents.(Pross, 2017)

In addition, hyperthermia has a detrimental effect on cognitive function. Heat stress can impair short-term memory, attention, and problem-solving abilities. In an environment with increased temperatures, individuals may experience difficulty in concentrating, reduced information processing speed, and diminished decision-making capabilities(Cheuvront and Kenefick, 2014). Such cognitive impairments can have significant consequences in various settings, including work, learning, and other cognitive-demanding activities.

Higher temperatures also impact physical performance. Heat stress increases the perceived effort during physical tasks, leading to decreased endurance and reduced strength and power output(Pontiggia et al., 1990). The body's natural response to heat is to divert blood flow to the skin for cooling purposes, which can compromise muscle perfusion and oxygen delivery.Exercise in hot environments can also lead to muscle fatigue and an increased risk of heat-related injuries, such as cramps, heat exhaustion, and heatstroke(Loeschcke and Sørensen, 2005). These conditions can be debilitating and, in severe cases, life-threatening.

All these conditions limit the full potential of a human being physically and psychologically. These conditions could be detrimental during a high-intensity air operational demand. Ground troops in far distances could be deprived of critical aerial support.

E. Sustainability of aircraft and associated equipment

Aircraft and the associated equipment in air operations are delicate unless otherwise developed for specific robust conditions. Air assets and related ground equipment are usually stationed on the tarmac or inside a shelter (hangar/soft shelter/hardened shelter). All these places except the shelters with air conditioning will be subjected to a rise in temperature. The aircraft are usually designed to operate for decades than years. Avionics packages of modern aircraft are comparatively complex and mission-

critical. These systems contain electronic circuits, crystal liquid displays, and materials such as rubber, plastic fabrics…etc. When exposed to higher heat, these parts and materialsstart deforming more than usual(Kitto and Robertson, 1989). A higher number of avionics-relatedunserviceability in hotter regions are commonplace. In Furtherance, deforming of materials such as rubber, plastic, and fabric due to higher heat could seriously truncate the usable life. For example, the life of a drag chute, in terms of the number of deployments, used to maximize aerodynamic breaking in fighter platforms drastically reduces, when exposed to high heat during deployments.Wearing of tires would be pronounced under heated-up conditions.When the environment is more humid the conditions start to exacerbate. All the solutions other than parking/placing in an air-conditioned environment have not yielded effective results.

F. Risk of Fire Hazards

The fire triangle is fundamental in fire science, explaining three essential components for a fire to ignite and sustain. Namely, they are fuel, oxygen and heat. It is understood that there is a significant difference between flashpoints and autoignitionpoints. Nevertheless, fire hazards increase with the rise of atmospheric temperature. However, the possibility of escalating a started fire under higher temperatures rises exponentially(Carnicer et al., 2022). The aviationenvironment itself is fire-prone, thus more emphasis to fire cover is given. The effectiveness of thesefire extinguishing and control measures would be undermined by a significant rise in atmospheric temperatures.

G. Rise of Sea Levels

The rise of sea levels due to global warming is a critical consequence that poses significant threats to coastal regions and low-lying areas around the world. As the Earth's average temperature continues to increase, the polar ice caps and glaciers are melting at an accelerated rate, leading to the ingress of significant amounts of water into the oceans(Raper and Braithwaite, 2006).

The primary cause of rising sea levels is the expansion of seawater as it warms. This thermal expansion alone contributes to a portion of the sea level rise. However, the melting of land-based ice, particularly in Greenland and Antarctica, is the primary driver of the drastic increase in sea levels.These ice masses have been stable for centuries, but with global temperatures on the rise, they are melting at an alarming rate. The sheer volume of water released into the ocean exacerbates the problem, causing sea levels to steadily rise year after year(Raper and Braithwaite, 2006; Shukla, Verma and Misra, 2017).

Despite the serious consequences on the population living in coastal regionsand coastal ecosystems in general, aviation has particular issues from this phenomenon. There aremany airfields located in coastal areas, with marginal airfield elevation. The current rate of sea level rise is approximately 3.4 ±0.4 millimeters per year. Further, the rate itself has accelerated from 2.5 millimetersto 3.4 millimeters within the past three decades.

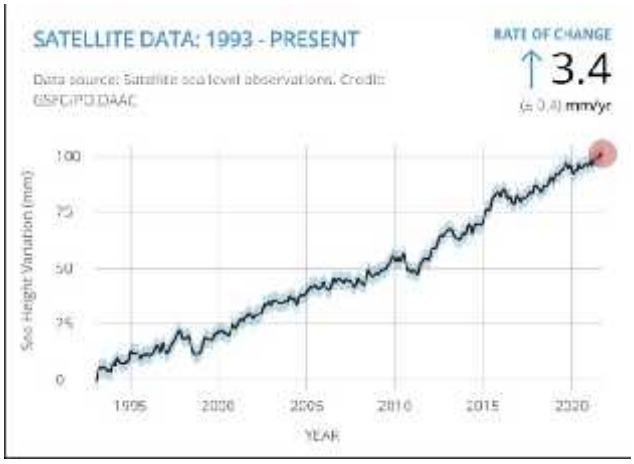

Figure 6: Rate of Sea Level Rise
Source: www.sealevel.nasa.gov

For example in an island like Sri Lanka, 07 airfields including three out of fourprimary international airfields will be affected due to the rise of sea levels soon if the sealevels continue to rise. Loss of available infrastructure would seriously undermine the operational capacity. Relocating/rebuilding this infrastructure would incur exponential costsfor the relevant authorities as well as consume a significant amount of time and effort to regain the operational status.

III. SOLUTIONS IN AVIATION FOR GLOBAL WARMING

As one of the most affected industries by climatechange, air operators are compelled to find solutions for effective and efficient air operations amidst global warming. These solutions could be categorized as long-term and short-term. Short-term solutions are predominantly focused on how to retain efficiency and effectiveness under existing conditions with existing assets, while long-term solutions focus on how to reduce contribution to global warming in aviation as well as to design future temperature level compatible air assets.

A. Short-term Solutions

The changes in aviation demanda significant amount of time, effort, and money. As far as the aircraft performanceis concerned, except for mission-criticaloperations, routine operations, training, and non-mission critical air operations could be planned during the time of favorable temperature

slots in diurnal temperature variation forecast reports. This practice has been already implemented by many air forces located in tropical and heated-up areas, especially during summer. The humidity levels are also to be a concern since the higher levels of humidity could produce the feel of a higher temperature than the actual. This step has been taken predominantly considering the human factor, which has more delicate and serious limitations than the machines. Keeping the people hydrated and continuous education regarding the adverse effects of higher temperatures would be beneficial to keep the physical and mental health of the air/ground crew infavorable conditions for safe and efficient air operations. Heat acclimatization programs, where individuals gradually expose themselves to higher temperatures over time, can also improve tolerance and performance in hot conditions.

The sustainability of the air assets and associated equipment could be enhanced by restricting exposureto direct sunlight and higher temperatures during non-operational periods. Soft/hardened shelters and hangars are reasonable solutions for areas with moderately high-temperature regions. In furtherance, additional cooling/air conditioning systems are required for high-temperature regions. For example, the Gulf region operators have implanted airconditioning systems in aircraft hangars, with substantial capital and recurring cost.

The risk of fire hazards could be mitigated by implementing best fire preventive practices and introducing more effective fire extinguishing measures. Further, inculcating a developed fire safety culture among the crew would yield better results in the long run.

Unfortunately, there are no short-term solutions for addressing disruptive weather changes and the rise of sea levels. During unfavorable weather conditions, air operations should seize to ensure the safety of the crew and air assets.

B. Long-term Solutions

Responsibility for finding long-term solutions has been shouldered by key aviation industries as well as major global air forces. Moving towards renewable energies to power aircraft is still inthe developing stage.

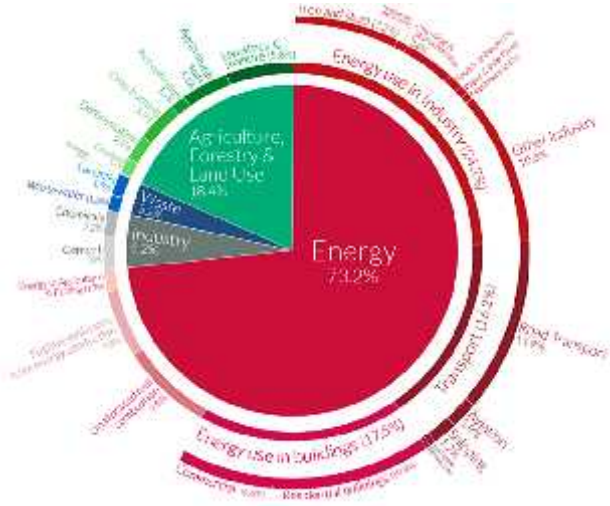

Figure 7: Global Greenhouse Gas EmissionsBy Sector-2016
Source: www.ourworldindata.org

Aviation accounts for 1.9 % oftotal greenhouse gas emissions as an industry. Themovement towards renewable energies such as solar power could reduce the carbon footprint of the aviation industry.

Further, respective authorities could plan for the relocation of endangered airfields due to the sea level rising to viable locations. Gradual transition would permit controlled effort and cost, rather than sudden shifts.

VI. RECOMMENDATIONS

Based on the findings of the study following recommendations could be put forward to face the adverse consequences of climate change in general and global warming in particularon-air operations.

A. Encourage Global Level Discussions for Seeking Long-term Solutions

As the consequences of climate change become more prominent, global leaders have taken the initiative to open up forums to discuss the future cause of actions to address climate change. Global Air Forces Climate Change Collaboration was held in London in line with a two days event of Global Air and Space Chief's Conference 2022, where they pledged to commit to innovative solutions to reduce dependency on fossil fuels and carbon footprint, thus moving to sustainable and alternative sources of energy through sharing of expertise, best practices, resources and research capacities. This is the first of this kind of agreementamongglobal-level military aviators. The forum could be expanded to accommodate the voices of developing and affected nations to have more productive sessions. Nevertheless, the forum is to beopened to

developing and affected nations to accommodate their experience and concerns.

B. Continue Research on Sustainable Solutions

As agreed upon by the air chiefs of global air and space forces, research effort in finding solutions to this issue is of paramount importance. The seriousness of the issue demands serious attention for research. The technology could provide better solutions to reduce the dependency on fossil fuels and find sustainable alternatives. Already there aresome studies, which have gone a reasonable distance in findingsolar and battery-powered solutions. Additionally, improving aircraft designs and aerodynamics, optimizing flight routes, and implementing air traffic management systems can further enhance fuel efficiency and reduce carbon emissions. All these are time-consuming and resource-intense efforts, where rich air forces could take the lead.

C. Develop a Combined Strategy

As the impact of global warming is common to all stakeholders in varying degrees, the participation of all parties is required. Steps taken in isolation would not yield much results. Hence, a combined strategy could be developed to take a collective effort in battling the common cause. This strategy could include how each stakeholder can contribute within their capacities to optimize the output. Humankindhas speedup the vicious cycle of climate change in isolation, seeking development. Now it's time to get together and slow down the process to ensure livable conditions for the future.

VII. CONCLUSION

Climate change has been accelerated due to man-made reasons collectively. Nevertheless, certain states, industries and regions have to pay more to the consequences of the same despite their degree of contribution. Conducting a postmortem to find out who is responsible more would not provide the answer to the existing issues. In contrast, a collective and collaborative effort would yield better results than working in isolation in this regard. Humans have already entered into the vicious cycle of climate change and inadequate measures to slow down would result in detrimental impacts on future generations. Dialogues for discussing the issues and finding solutions have already started, which is a very positive sign for future generations and particularly for the future sustainability of the aviation industry. The steps taken today would decide the fate of the aviation in future as well as it would slow downthe global warming process and climate change.

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AUTHOR PROFILE

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