# Sustainability Assessment in Aviation Industry: A Mini-Review on the Tools, Models and Methods of Assessment

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## Abstract

Sustainable aviation practices have significantly reduced Greenhouse Gas (GHG) emissions over the years. However, these practices have not shaped the aviation industry in achieving the United Nations Sustainable Development Goals (UN SDGs) to its full potential. The increasing volume of air traffic and the benefits reaped in this sector has hindered sustainable airline operations. This paper brings up a small scale-literature review on several tools and methods used for sustainability assessment in the aviation industry to address this concern, covering all the socio-economic and environmental sustainability dimensions. A review of various models and techniques used in the eco-efficiency assessment for sustainable airline operations are also discussed. Decision Support Systems (DSS) using Artificial Intelligence (AI), Deep learning, and Neural Network (NN) models also formed the basis of this study. This paper's tools and models support strategic and tactical decision-making to foster sustainable operations in the aviation industry; thus, helping mitigate the current challenges.

**Keywords:** Aviation industry, Eco-efficiency assessment, Sustainability, Greenhouse gas emission, United Nations Sustainable Development Goals

## 1. Introduction

Industries in the emerging economies worldwide have sought to considerably reduce Greenhouse Gas (GHG) emissions by adopting sustainable, carbon-neutral development practices (Alsarayreh et al., 2020; Kutty et al., 2020). The airline industry is no exemption in this regard. Among all the other industries, the aviation industry has halved its carbon footprint compared to its operations in the late 1990s (ATAG, 2020). Introducing new technologies such as sustainable fuel alternatives and zero-emission engine designs has promised to cut down the aviation emissions, particulate soot, lead contrails, and cirrus clouds (García-Olivares et al., 2020). A decline in aviation emissions amounts to a simultaneous decline in the climate change-related impacts thus, addressing the Sustainable Development Goal 13: tackling climate-related challenges.

Despite attempts to significantly cut down the $CO_2$ emissions over the next coming years, the GHG emission values are expected to increase drastically due to the airline industry spreading its wings for expansion (Wang et al., 2019). Economic progress through enhanced connectivity, clean and sustainable energy utilization and, improved climatic conditions are some of the targets set forth by the aviation industry for reducing $CO_2$ emissions by 2050 (EU Climate Action, 2020). Promoting development by adopting SDGs across the global aviation sector and building a corporate image can foster sustainable operations.

Reducing the airline industry's carbon footprint is a challenge due to the benefits of air travel (both the passenger and cargo) offers in booming the economy (Hadi-Vencheh et al., 2018). Creating a balance between the non-$CO_2$ related impacts and the impact of aviation emissions remains a question to consider when addressing this industry's sustainability concerns (Kucukvar et al., 2020). A proper understanding of the economics of sustainability and eco-efficiency in the airline industry is felt necessary. Background on the approaches, models, and methods sought to combat sustainability challenges in the aviation industry must be thoroughly examined to create Decision Support Systems (DSS), thus acting as a driver to challenge addressed. The literature in this area spans a broad spectrum. Covering the entire literature goes beyond the scope of the study. This study thus aims to conduct a mini-review

This article's anatomy is planned such that; Section 2 justifies the rationale behind undertaking this area of research. This section highlights the relevance of understanding several methods and application tools used for sustainability assessment in the aviation sector, thus helping foster novelty in this area for future advancements. Section 3 highlights the method used for conducting the mini-literature review. While Section 4 discusses various tools and methods used for sustainability assessment in the aviation industry, covering the Triple Bottom Line (TBL) sustainability aspects in the assessment. Section 5 examines the various models and techniques used in the eco-efficiency assessment for sustainable airline operations. A review covering several Decision Support Systems (DSS) using human programmable languages and cognitive sciences were also discussed in the study through Section 6. Lastly, Section 7 brings out the concluding statements and an overall outlook in this school of thought.

## 2. Research Justification

Advanced zero-emission technologies and hybrid-electric propulsion systems have considerably reduced $CO_2$ emissions during the airline operation stage (Bai et al., 2020). Several ecological impacts still exist at other possible phases of the airline operation life cycle (LC), including; the raw material extortion, manufacturing, and end of product life. This entails utilizing substituent materials and energy resources for sustainable outcomes at alternative phases of the LC. The use of electric energy sources such as a battery for electric-powered aircraft engines provides efficient operations with less maintenance and reduced GHG emissions, thus improving eco-efficiency and reducing possible socio-environmental impacts (Melo et al., 2020). On the other hand, the aircraft's fabrication and recycling that use these alternative energy sources are often expensive than the conventional aviation fuel-powered engines. Thus, possible tradeoffs exist despite efficiency improvements and sustainability practices being adopted within the aviation industry.

Bringing about radical changes to the aviation sector requires continuous monitoring of aviation emissions, eco-efficiency, and operational sustainability (Vela-García et al., 2020). This requires a thorough understanding of several methods and application tools used for assessment to foster novelty in this area of technological advancement. Similarly, understanding the need to replace conventional technologies with alternative sustainable measures requires proper sustainability assessment frameworks with broad categories of indicators, tools, methods, and impact categories. Thus, to develop frameworks and advanced tools, a broader understanding of the existing methods, technologies, and tools are essential.

Risk analysis, fault detection, digital maintenance, and quality control are procedures that require a considerable amount of real-time data to be modeled for supporting proper day-to-day decision-making in the aviation industry (Xue et al., 2020). Due to the complexity of the advanced technologies used in the aviation industry, maintenance procedures can be more challenging, thus causing distortions to sustainable airline operations (Mathaisel, 1996). An effective airline maintenance system enhances efficiency due to the reduced operating costs and GHG emissions related to the system's faults (Zhang et al., 2011). The use of advanced digital maintenance systems with real-time data has forced decision support systems to operate using human programmable languages such as machine learning and artificial intelligence. Thus, a basic idea on the several existing DSS models in the airline industry is necessary to mold an advanced and sustainable DSS better. This justifies the rationale behind undertaking this area of research, thus presenting a mini-literature review.

## 3. Review Method

This paper sheds light on several tools and methods used for sustainability assessment in the aviation industry, covering all the socio-economic and environmental facets of sustainability through a small-scale literature review. The research further spans on examining various models and techniques used in the eco-efficiency assessment for sustainable airline operations. A review covering several Decision Support Systems (DSS) using Artificial

Intelligence (AI), deep learning, and Neural Network (NN) models was also discussed in the study. These models support both the strategic and tactical decision making to foster sustainable operations in the aviation industry.

The study utilized a search technique that involved keywords in the selected research area and searched on the Scopus online database. The document search was organized in four stages, namely; a) Identifying the combination of keywords b) Skimming the title and then scanning the abstract to filter the documents c) Reading the full-length paper after the documents being sorted out based on the abstract reading d) Using another set of keyword combination to refine the search to obtain more articles under each category and subcategory. The search and analysis followed a fixed set of keywords (“Airline”/ “Aviation”/ “Air transport”) along with a variable selection keyword combination (“sustainability”/ “eco-efficiency”/ “decision support system”). The search syntax adopted the style: {TITLE-ABS-KEY (“Airline” OR “Aviation” OR “Air transport” AND “Sustainability”)}

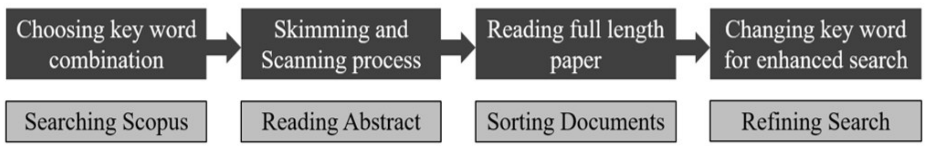


Figure 1. The four-stage Scopus search and analysis technique

Proceedings on international conferences, journal articles, short surveys, book chapters, and review articles were the selection process's document types. The database search resulted in an overall 836 documents that fell directly under the research area. This was then downsized to 326 documents that covered areas under Section 4, 5, and 6. Several e-resources, IATA reports, and ATAG surveys were also used to complement the manuscript process that was not involved in the initial search.

## 4. Sustainability assessment tools and methods

Sustainability in the aviation industry can be achieved by developing systems that can honor the environment, foster economic worth, and enhance social life quality. The three significant aspects of aviation sustainability include a) environmental sustainability consisting of the natural resource-system dependence; b) economic sustainability, which elaborates the economic capability, economic improvement, and financial manageability; c) social suitability, which explains the social righteousness, security, individual health, and superiority of life (Alameeri et al., 2017).

According to Bertoni et al. (2015), the aviation industry can gain sustainability by implementing several efficient alternative technologies with lesser ecological impact. Numerous studies suggest that fuel savings, substitute fuels, air-to-air refills, better aviation engines, environmentally friendly impulsion systems, and well-organized flight routes can help achieve aviation sustainability (Agarwal, 2010; Warwick and Norris, 2010; ICAO, 2012). Over the past two decades, several models and frameworks were presented by scholars to understand aviation sustainability such as the Aviation Environmental Management Systems (AEMS), Cleaner Production System (CPS), Fleet-level Environmental Evaluation Tool, Eco-design, “Life Cycle Assessment (LCA),” “Life Cycle Costing (LCC),” “Social Life Cycle Assessment (S-LCA),” Sustainable aviation fuel LCA model, “slacks-based measure Data Envelopment Analysis (S-DEA)” and Framework for Strategic Sustainable Development (F-SSD) (Pinheiro et al., 2020; Chao et al., 2019; Bertoni et al., 2015). This section aims to profoundly investigate the several sustainability assessment tools and methods in the aviation industry, under all the three pillars of assessment.

### 4.1 Environmental Assessment

According to Pinheiro et al. (2020), a well-established framework used for environmental sustainability assessment is the LCA, which allows assessing the ecological impacts of systems throughout the LC. Lopes (2010) performed an LCA on the manufacturing phase of the Airbus A320-200. The research offers a detailed inventory of the aircraft production system. Lewis conducted an akin study (2013), where an LCA for a commercial jet depending on various flight situations was undertaken. Chen (2013) explained that an AEMS is an effective method to audit measures and resembles the “Plan-Do-Check-Act (PDCA) model” model for quality management systems. This comprises setting goals, quantifiable targets, a comprehensive program, and a monitoring and assessment process to attain the aviation industry’s persistent improvement in environmental behavior and performance. The other well-known framework developed was the “Fleet-level Environmental Evaluation (FLEE)” that evaluated Avionic operations' ecological footprints in the United States. This comprehensive model provided a detailed analysis of airline ticket fairs, airlines’ fleet size and flight mix, and frequent travel destinations and routes across the airlines’ networks using a system dynamics approach (Chao et al., 2019). Chao et al. (2019) applied a "Monte-Carlo simulation" combined with an LCA to assess the impact of multiple policy scenarios on sustainable aero fuel utilization and related emissions. Chang et al. (2014) conducted a study that evaluated the eco-efficiency and economic sustainability of 27 international carriers for 2010. A comprehensive environmental "Slacks-based measure data envelopment analysis model (SBM-DEA)" was developed to examine these airline efficiencies.

### 4.2 Economic Assessment

Several practical approaches for the computation of costs and performances have been developed to assess economic sustainability (Finkbeiner et al., 2010). A well-developed framework for the economic assessment throughout the LC is the "Life Cycle Costing (LCC)" approach that combines all the costs and benefits connected with the product under analysis (Pinheiro et al., 2020). Seemann et al. (2011) conducted an excellent research that evaluated the economic dimensions of sustainability with LCC's help for the protection and maintenance of standard jet engines. The study highlights the fuel consumption and propulsion systems as contributing factors for increased operating costs along the LC. Thokala et al. (2010) built a decision support model based on the LCC approach to understanding the interconnections between the manufacturing, operations, and decommissioning process in the airline sector.

Sustainable Aviation Fuels (SAF)-LCA model is another significant model used in the US aviation industry for environmental and economic sustainability assessment. Despite supporting a multi-dimensional approach, the model was found more helpful in the economic sustainability assessment. The interconnections between the bio-refineries, agronomists, air fleets, and policymakers were modeled using an agent-based approach. Amounting to the aviation industry's objectives to serve the passenger needs and produce profits, the use of SAFs' depends on the aviation fuel costs and policy inducements. Considerable profit reaps can motivate bio-refineries to set up plants that produce SAFs to support the growing demand (Kutty et al., 2020). The choice depends on specific parameters such as the "Internal Rate of Return (IRR)" and "Net Present Value (NPV)" of the investment in addition to the expenses involved in the production process of such SAFs' (Chao et al., 2019).

### 4.3 Social Assessment

The "Social Life Cycle Assessment (S-LCA)" is a commonly used tool for sustainability assessment covering the social domain (Thies et al., 2019). Social shocks are assessed throughout the product's value chain based on a selected set of social attributes using the S-LCA. Activities, including an extraction to the final disposal stage in the life cycle, are covered in this stage related to the social dimension. The social impacts that exist account for the stakeholders' implications due to their actions throughout the life cycle. The other prominent assessment tool is the Corporate Social Responsibility (CSR) reporting. The CSR considers the airline industry's obligations to safeguard and enhance the welfare of both the passenger community and the industry as a whole by adopting proper legal, ethical, and philanthropic actions (Anttila and Kretzschmar, 2010).

## 5. Eco-efficiency assessment on airline operations

Eco-efficiency, a philosophy that supports sustainability by motivating businesses to explore methods, makes a company more environmentally responsible and profitable. Eco-efficiency relates to the negative environmental impacts on the real resource effectiveness (Sun et al., 2019). Mapping eco-efficiency for the airline sector is essential due to the industry being a significant contributor to global $CO_2$ emissions.

Recent statistics by ICCT (2019) revealed a 32% increase in the world $CO_2$ emissions were; 2.4% of the emission reported came from the aviation industry. This amounted to a value of around 918 million tons of $CO_2$ emitted into the atmosphere due to the increased airline operations (ICCT, 2019). Cutting down the resource utilization of individual airlines to maximize their sustainable performance can be termed as airline eco-efficiency. Several methods and frameworks exist in the literature for the eco-efficiency assessment of airline operations. The most common among them is the Data Envelopment Analysis (DEA) models (Wang et al., 2011). Several non-radial frameworks, like the "Network Slacks-Based Measure (N-SBM) models," are being used commonly by sustainability scientists over the years (Chang and Yu, 2014). Skeptics believe that using both the radial and non-radial approaches together can result in a better airline efficiency performance assessment. The Epsilon-Based Measure (EBM) can be used in such situations (Xu and Cui, 2017).

Several approaches have been used over the years to evaluate airline eco-efficiency performance. Li et al. (2015) used a "Network Slack-Based Measure Data Envelopment Analysis (NSBM DEA) model" to compute the eco-efficiency of jetliners. A "Meta-Frontier Dynamic Network Slack-Based Measure Data Envelopment Analysis (MDN-SBM-DEA)" framework was created by Chou et al. (2016) for sustainability performance assessment. The decision-making unit's performance was assessed using a meta-frontier approach that formed the basis of the framework. The networked and dynamic SBM models formed a part of the framework. Wang et al. (2011) proposed a "Dynamic Slack-Based Measure Data Envelopment Analysis (DSBM)" that calculated the eco-efficiency of several international jetliners and was well acknowledged by several aviation industry experts. Xu and Cui (2017) used a unique "Network Epsilon-based Measure (NEBM)" and "Network Slacks-Based Measure (NSBM) Data Envelopment Analysis model" for eco-efficiency assessment in the aviation industry. "A Network Environmental Slack-Based Measure (NSBM) model" with undesired output availability was used by Cui and Li (2020) to assess the impact of the "European Union Emissions Trading System" with fragile unwanted outputs availability on airline eco-efficiency. Yu hang et al. (2019) applied the "Dynamic network DEA (DNDEA) model" to assess the efficiency performance of the essential Indian and Chinese airline operators, considering the airline's internal operations with a successive period that stands as a carryover. The research reveals China's Spring and India's SpiceJet as the most efficient budget airline operators from 2008 till 2015. The analysis reveals that several researchers have examined the aviation industry's efficiency and have applied several DEA models extensively. The SBM models were rarely used to examine the eco-efficiency in the aviation sector.

## 6. Sustainable Decision Support Systems

A Decision Support System (DSS) consists of procedures for designing and evaluating alternatives for enhanced decision making. Decisions are often taken to solve existing challenges. Decisions are either programmed or non-programmed. Programmed decisions are recurring or regular and can be resolved using mechanical methods, such as applying the rules to identify the best possible solution. Approximately 90% of management decisions are scheduled and executed with programmed planning. Non-programmed planned decisions are not regular, and they are usually made due to specific crises, where particular measures are not presented. Using programmed decisions needs a DSS that resolves the problem and proposes the best possible decision (El-Din et al., 2015). DSS's concept is commonly used, although inconsistently employed. At its core, it means support for any "system," which offers essential information essential to sustenance decision making (DM) processes. These systems are highly recognized in extremely multifaceted environments where issues and tasks differ in form, the bulk of them being unstructured or semi-structured (Ivanov and Netjasov, 2014).

The contemporary environment is often complicated and wicked. Uncertainties are a significant factor that drives managers to adopt sophisticated frameworks for decision making. As difficulties and ambiguities exist with the decision situations, the decision model's capabilities should be up to the mark so that extremely non-linear relationships among the various elements can also be analyzed. To handle such situations, the most significant DSS is the Artificial Neural Networks (ANN) model. In general, ANN models can be elaborated as a set of information processing systems that display the ability to learn, recollect and simplify the historical data using a process called "learning" (Delen and Sharda, 2008). Several researchers in the airline industry have used ANN models to achieve sustainability and efficiency. Khardi et al. (2013) applied an ANN model to identify the health risk statistics around the Soekarno Hatta International Airport in Indonesia. The study found ANN as a convenient approach for a better understanding of the multifaceted non-linear correlations. Beulen et al. (2020) analyzed an airline crew planning scenario and suggested "Simulation-trained neural-network" algorithms to assess the flight requests. The study showcased an excellent approach to assess the flight requests and an efficient, low-cost appeal granting system. The algorithms were trained and tested on a leading European carrier as a case study. The results reveal 22% more requests when using algorithms. Thus, algorithms were proved to be a powerful tool over the manual schedule process.

According to Srisaeng et al. (2015), forecasting is considered a promising tool to assess several airline industry developments. A forecast model was constructed by Srisaeng et al. (2015) to identify the domestic travel demands for Australia's budget airlines. Unconfirmed passengers and travel revenue kilometers were used as the driving factor for the air traffic demand. Two frameworks, namely, the classical regression model and the ANN model, were evaluated. Results show that both these models fit best for predicting future demand and supports decision making to a great extend. Dožić, (2019) suggested that the decision making in an airline industry depends on the investments flowing into the sector. Low investments can thus hinder the decision-making process, leading to insignificant outcomes. A "Multi-criteria decision-making method (MCDM)" can be used for enhanced choice selection for better decision making. Dožić, (2019) evaluated the airlines, airports and, air traffic management systems and found that a single DSS is not sufficient for robust decision making. An interconnected system needs to be adopted, such as the Analytic Hierarchy Process (AHP) used for service quality, routes, aircraft, and risk management. On the other hand, TOPSIS was adopted for financial management, service quality, and efficiency ranking. Eurocontrol (2012) provided an "Airport Collaborative Decision Making (A-CDM)" system that uses the combined real-time data received from airport management staffs, air traffic control (ATC), and airfield staffs to decrease the interruptions and optimally deploy resources to avoid chances of unlikely events. The A-CDM system optimizes the runway traffic movement for passengers and cargo handling operations, gate assignment for passengers, and aircraft take-off and landing movements. Thus, this section shows the DSSs' available in the aviation sector that can be used for decision-making processes based on the nature of the problem.

## 7. Conclusion and Future Research

The aviation industry has played a dynamic character in the global development process. Significant growth can be seen in the air transport sector over the past couple of decades. The industry experts have fully recognized the need for sustainability assessment within this industry in a more incorporated manner. This paper conducted a mini literature review covering all the prominent tools and methods used for sustainability and eco-efficiency assessment in the aviation industry. Several methods and frameworks were explored. Among them, Aviation Environmental Management Systems (AEMS), Cleaner Production System (CPS), Fleet-level Environmental Evaluation Tool, Eco-design, "Life Cycle Sustainability Assessment (LCSA)," "Life Cycle Costing (LCC)," "Social Life Cycle Assessment (S-LCA)," Sustainable aviation fuel LCA model, "slacks-based measure Data Envelopment Analysis (S-DEA)" and Framework for Strategic Sustainable Development (F-SSD) were the most commonly used. The research found that despite Slack Based-Measure models being efficient for eco-efficiency assessments, they were rarely used in studies. It is noteworthy that the CSR reporting tool considers the airline industry's obligations to protect and improve the welfare of both the passenger community and the industry as a whole by taking proper legal, moral-ethical, and philanthropic actions.

The three pillars of sustainability can be evaluated deeply with several combinations of LC methods, acknowledged by the mini-literature review conducted. LCA, an ISO tool, is the most commonly used tool to examine the product or material from the production to its end of life stage. The LCA helps in efficient quantitative examination of products or services regarding environmental effect, individual health, and resource utilization perspective. To evaluate the environmental impacts, the LCA framework has been extensively recognized by business and legislative bodies internationally as the most vigorous method. It offers a quantitative approach to evaluate a product system considering all the LC stages, thus helping in enhanced decision making. The LCA approach also uses the scientific basics such as mass and energy conservation laws along with several validated empirical models (Kutty and Abdella, 2020). Hence, the aviation industry needs to achieve environmental sustainability.

For this reason, the aviation industry needs to switch to more fuel-efficient airplanes for their movements. This would significantly decrease carbon emission and assist in sustainably improving the environment. Similarly, fuel-efficient planes consume less fuel and create a better impact on the economic side of sustainability. The "Social Life Cycle Assessment (S-LCA)" is a commonly used tool for sustainability assessment covering the social domain (Thies et al., 2019). Social shocks are assessed throughout the product's value chain based on a selected set of social attributes using the S-LCA. The aviation industry needs to be more socially responsible, and the concept of CSR is very significant to achieve sustainability in every aspect.

For selecting appropriate sustainability indicators for the weighting process in the eco-efficiency assessment, statistical variable selection methods like stepwise regression are suggested (Abdella et al., 2017; Wang and Jiang, 2009). The authors recommend using penalized-based weighting approaches for ruling out multi-collinearity during the indicator aggregation process (Kutty et al., 2020). For future research, thresholding-based selection methods such as an extended "adaptive-least absolute shrinkage and selection operator (A-LASSO)" can be used to improve the approximation on the variance-covariance matrix of the Principal Compound Analysis technique. To better understand adaptive LASSO techniques, the authors suggest referring to Cai and Liu (2011). Integrating empirical methods with sustainability assessment tools can deliver promising results to support decision making. For future research, the authors recommend the use of an integrated LCSA approach (Kucukvar et al., 2018; Sen et al., 2019; Onat et al., 2019; Onat et al., 2015; Onat et al., 2014-A; Onat et al., 2014-B; Tatari and Kucukvar, 2012; Kucukvar and Tatari, 2012; Kucukvar et al., 2016-A; Kucukvar and Samadi, 2015; Park et al., 2017; Kucukvar et al., 2016-B); material footprint analysis (Kucukvar et al., 2017; Kucukvar et al., 2019-A; Kucukvar et al., 2019-B); and "Economic input-output (EIO) analysis" (Egilmez et al., 2013), merged with other DM models, for instance like the Fuzzy-MCDM model (Onat et al., 2016-A), prognosticate approach (Shaikh et al., 2017; Abdella et al., 2019-B; Al-Sheeb et al., 2019), autonomous computational models (Noori et al., 2016; Onat et al., 2017), and system thinking approaches (Ercan et al., 2016; Onat et al., 2016-B; Onat et al., 2016-C; Alirezaei et al., 2017; Kelly et al., 2019) covering the three pillars of sustainability. Additionally, multivariate regression models can be used for selecting response variables to assist the aggregation step while analyzing sustainability Abdella et al., (2016). For a better understanding of statistical computation models and applications in sustainability, the readers can refer Abdur-Rouf et al. (2018); Abdella et al. (2019); Kim et al. (2019); Abdella et al. (2020).

Finally, it is interesting to note that the modern environment is multifaceted, and ambiguity is a crucial element that forces companies to use professional frameworks for decision making. As the complexity and uncertainty increase with the decision situation, the decision model's capabilities should be up to the mark so that extremely non-linear relationships among the various elements can also be analyzed. To handle such situations, the most significant DSS is the ANN model. It can be seen from the literature that airlines around the globe are using several DSS to manage the complex problems which are associated with improving efficiency and performance. Simultaneously, it is noteworthy that, only a few airlines have adopted such frameworks that aid in achieving better sustainability than others. These tools and models discussed in this paper support strategic and tactical decision-making to foster sustainable operations in the aviation industry; thus, helping mitigate the current challenges.

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