

عنوان البحث

تأثير البيئة الحارة والقاسية على أداء الطائرات

دراسة على شركات الطيران في المملكة العربية السعودية

إعداد الطالب/

م. الوليد أحمد بغلف

م. زامل عيسى زامل

إشراف/

د. الفیصل عبد الحمید

د. فايز جراد

العام الدراسي:

2024

Research Title:

The Effect of The Hot and Harsh Environment on Aircraft Performance

A Study on The Operators in The Kingdom of Saudi Arabia

Prepared by:

Engr. Alwaleed Ahmad Baghlaf

Engr. Zamil Essa Zamil

Supervision:

Dr. Alfaisal Abdelhameed

Dr. Fayez Ali Jrad

Year:

2024

0.1 Copyright Notice:

This research is submitted to Midocean University in partial fulfillment of the requirements for the Master of Management and Master of Business Administration degree. Midocean University owns the copyright of this research. This work is permitted under the terms and conditions set by Midocean University. Any use, reproduction, or distribution of this work must acknowledge Midocean University as the copyright holder.

0.2 Abstract:

The Kingdom of Saudi Arabia plays a pivotal role in global aviation due to its strategic geographic location, significant religious travel demands, and ambitious economic goals outlined in Vision 2030. This study investigates the profound impact of the Kingdom's extreme environmental conditions—high temperatures, dust, and humidity—on aircraft performance and maintenance. The harsh climate accelerates wear and tear on critical aircraft components. It exacerbates issues such as corrosion and sand build-up, which can compromise the integrity of aircraft systems and reduce engine efficiency.

This research employs a theoretical framework integrating environmental performance theory, operational resilience, systems theory, and risk management to analyze how extreme heat and ecological stressors affect aircraft operations. The study focuses on two of the largest commercial airlines in Saudi Arabia, examining their operational practices and preventive maintenance strategies in response to these challenges.

The sample includes operational data from various flight routes and aircraft models these airlines use. The study highlights the importance of robust preventive maintenance programs in mitigating the effects of extreme environmental conditions, emphasizing early problem detection and effective management practices to enhance aircraft safety, performance, and longevity.

This research aims to offer actionable insights for improving operational resilience and efficiency in similar challenging climates by providing a comprehensive analysis of how harsh environmental factors impact aircraft operations and the effectiveness of preventive maintenance.

0.3 Acknowledgement:

Gratitude is extended to everyone who has supported and guided this research journey.

Special thanks are due to the advisors for their invaluable guidance, encouragement, and support. Their expertise and insight have been instrumental in shaping this research, and their patience and dedication are deeply appreciated.

Appreciation is also extended to all who have contributed to this work, directly or indirectly. Your contributions have been indispensable, and heartfelt thanks are offered to each of you.

0.4 Table of Contents:

0.0	Front Matter.....	-
0.1	Copyright Notice.....	A
0.2	Abstract.....	B
0.3	Acknowledgment.....	D
0.4	Table of Contents.....	E
0.5	List of Tables.....	F
0.6	List of Figures.....	F
0.7	list of Terminology.....	F
0.8	List of Abbreviations.....	L
1.0	Chapter I Introduction.....	1
1.1	Introduction.....	2
1.2	Study Problem.....	5
1.3	Importance of The Study.....	7
1.4	Objectives of The Study.....	9
1.5	Study Questions.....	11
1.6	Research Hypotheses.....	13
1.7	Theoretical Model.....	14
2.0	Chapter II Literature Review.....	16
2.1	Introduction.....	17
2.2	Dependent Variable.....	18
2.3	Independent Variable.....	20
2.4	Previous Studies.....	21
2.5	Theoretical Framework.....	22
3.0	Chapter III Study Methodology.....	24
3.1	Introduction.....	25
3.2	Research Design.....	26
3.3	Population of The Study.....	27
3.4	Sample Characteristic.....	28
3.5	Sample Size Determination.....	30
3.6	Data Collection Procedure.....	31
3.7	Study Limitation.....	33
4.0	Chapter IV Practical Study.....	36
4.1	Introduction.....	37
4.2	Data Analysis.....	39
4.3	Research Findings.....	46
4.4	Research Recommendations.....	49
4.5	References.....	54
5.0	Appendixes.....	55
5.1	Abstract.....	56
5.2	Arabic Abstract.....	58

0.5 List of Tables:

- Table 1: Engine LLP & MTBF Data

0.6 List of Figures:

- Graph 1: Engine MTBF per years

0.7 list of Terminology:

- Maintenance Planning Document (MPD)** is a crucial publication issued by the type certificate holder within the aviation industry. This document is a comprehensive compilation of all the requirements that must be followed and implemented in the Aircraft Maintenance Program. By outlining these requirements, the MPD plays a vital role in the safety and airworthiness of the aircraft throughout its service life.

One of the critical aspects of the MPD is its connection and integration with other essential manuals and publications, such as the Aircraft Maintenance Manual (AMM) and Structure Repair Manual (SRM), which the manufacturer also issues. The MPD, along with these related documents, collectively provides detailed guidelines and instructions for the maintenance and repair of the aircraft.

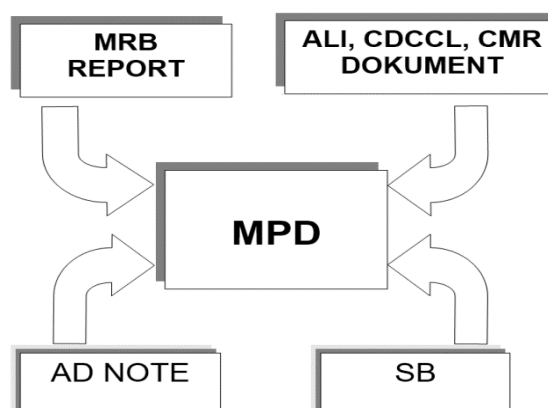
The MPD and associated manuals typically utilize the ATA 100/AMTOSS task numbering system to facilitate efficient referencing and task

identification. This standardized system allows maintenance personnel to quickly locate specific tasks and procedures within the various manuals, ensuring consistency and clarity in the maintenance process.

Overall, the Maintenance Planning Document is crucial for operators, maintenance personnel, and regulatory authorities in guaranteeing aircraft.

Overall, the Maintenance Planning Document is a vital tool for operators, maintenance personnel, and regulatory authorities in ensuring aircraft's proper maintenance and airworthiness. Through its detailed requirements and linkages with other manuals, the MPD plays a vital role in safeguarding the safety and dependability of aircraft operations, thereby significantly influencing the overall prosperity and longevity of the aviation sector's proper maintenance and airworthiness. Through its detailed requirements and linkages with other manuals, the MPD plays a vital role in the safety and dependability of aircraft operations, thereby significantly influencing the overall prosperity and longevity of the aviation sector. (EASA Part M)

Integration of sources in MPD:



b. Mean Time Between Failure (MTBF) is crucial in reliability engineering and analysis. It refers to the average time interval between failures in a system or a subsystem. In other words, MTBF estimates how long a system is expected to operate without experiencing a failure. MTBF is a key metric used by engineers and designers to assess a system's reliability. A higher MTBF value indicates that a system is more reliable and has a lower probability of failure within a given time frame.

On the other hand, a lower MTBF value suggests that the system is more prone to failures and may require more frequent maintenance and repair. It is important to note that MTBF does not guarantee how long a system will operate without failure. It is an average estimation based on historical data and analysis. Factors such as operating conditions, environmental factors, quality of components, and maintenance practices can all influence the actual reliability of a system.

In contrast to MTBF, Mean Time Between Outages (MTBO) is a term more commonly used in the context of services and facilities. While MTBF focuses on the reliability of hardware systems, MTBO measures the average time interval between service outages or disruptions. For example, MTBO provides insights into a service's overall availability and uptime in telecommunications or utility services.

MTBF and MTBO are essential metrics for assessing the reliability and availability of systems and services. By understanding and monitoring these

metrics, engineers and operators can make informed decisions to improve reliability, minimize downtime, and enhance overall system performance.

(FAA Handbook 006D)

c. Hot and harsh environments in aviation industries refer to conditions that pose significant challenges and potential hazards to aircraft and personnel.

These conditions can arise from various factors, such as extreme temperatures, high altitudes, rugged terrain, and harsh weather patterns.

Understanding and effectively managing hot and harsh environments is essential for ensuring aviation operations' safety, efficiency, and success.

One key aspect of an aviation environment is high temperatures. Extreme heat can adversely affect aircraft systems, engines, and components, leading to decreased performance and potential malfunctions. Heat can also impact personnel's operational capabilities, as working in sweltering conditions can be physically taxing and increase the risk of heat-related illnesses. Proper cooling systems and maintenance procedures are critical for mitigating the effects of high temperatures in aviation environments.

Additionally, a harsh environment in aviation can be characterized by challenging terrain or weather conditions. For example, mountainous regions, deserts, and Arctic environments present unique challenges to aircraft operations due to multiple factors, such as limited navigational aids, unpredictable weather patterns, and extreme wind conditions. Pilots and

maintenance personnel must be well-trained and equipped to handle these challenges effectively.

Proper planning and risk management are essential in navigating hot and harsh aviation environments. This includes conducting thorough weather assessments, considering the limitations of aircraft and personnel, and implementing contingency plans to address unforeseen circumstances. Regular maintenance and inspections of aircraft systems are crucial for detecting and addressing potential issues in advance.

In conclusion, a hot and harsh environment in aviation industries encompasses a range of challenging conditions that require careful attention and proactive management. Aviation professionals can ensure safe and successful operations in diverse and demanding environments by understanding the risks and implementing mitigation measures. (Saudia Airline Engineering)

d. On-Time Performance (OTP) is a widely used metric to measure punctuality across various public transportation systems, most notably aviation. It tells how well a service adheres to its published schedule. It compares the number of on-time arrivals or departures with the total number. An arrival or departure is typically considered on time if it occurs within a specific window (usually 15 minutes) of the published schedule. This

standardized approach allows for fair comparisons between different service providers.

OTP is generally expressed as a percentage. A higher percentage signifies a more reliable service with fewer delays.

It does not necessarily reflect the entire journey experience, such as delays within the travel itself. (Saudia Airline Engineering)

- e. **Maintenance:** The performance of tasks on an aircraft, engine, propeller, or associated part required to ensure the continuing airworthiness of an aircraft, engine, propeller, or associated part, including any one or combination of overhaul, inspection, replacement, defect rectification, and the embodiment of a modification or repair, except transit/preflight inspection/preventive maintenance. (GACA Regulations Part 1)

- f. **Aircraft Engine:** A unit used for aircraft propulsion. It consists of at least those components and equipment necessary for functioning and control. (GACA Regulations Part 1)

- g. **Repair:** The restoration of an aircraft, engine, propeller, or associated part to an airworthy condition in accordance with the appropriate airworthiness requirements after it has been damaged or subjected to wear. (GACA Regulations Part 1)

0.8 List of Abbreviations:

A/C	Aircraft
AD	Airworthiness Directive
APU	Auxiliary Power Unit
BSI	Bore scope Inspection
KSA	Kingdom Of Saudi Arabia
LLP	Life Limited Parts
SB	Service Bulletin
FC	Flight Cycle
FH	Flight Hour
HPC	High Pressure Compressor
HPT	High Pressure Turbine
CC	Combustion Chamber
TOW	Time on Wing
EGT	Exhaust Gas Temperature
RPM	Revolution Per Minute
HPTACC	High pressure turbine air cooling control
MPD	Maintenance planning Document

Chapter I

Introduction

1.1 Introduction:

The Kingdom of Saudi Arabia is a significant player in the world of aviation for a couple of key reasons:

- **Hajj & Umrah:** Millions of Muslims travel to Saudi Arabia each year for the Hajj, the obligatory pilgrimage for all Muslims who are able. Umrah, a shorter pilgrimage, also attracts a significant number of visitors. This massive influx of pilgrims necessitates a robust and efficient aviation industry to handle the transportation needs. Saudi Arabia plays a critical role in facilitating these journeys of faith.
- **Geographic Location:** At the crossroads of three continents—Asia, Africa, and Europe—Saudi Arabia is a natural stopping point for flights between these regions. This prime location makes it a crucial link in global air travel.
- **Economic ambitions:** The country's Vision 2030 plan heavily emphasizes developing its aviation sector. This includes expanding existing airports, building new ones, and establishing Saudi Arabia as a major tourism hub. The country is investing heavily in creating a modern and efficient aviation infrastructure.

In essence, Saudi Arabia's importance in aviation stems from its religious significance, geographical advantage, and future-oriented economic plans. These factors combine to make it a crucial player in the global aviation landscape.

Modern aviation's safety and efficiency hinge on a delicate balance between cutting-edge technology and meticulous maintenance practices, especially for aircraft operating in hot and harsh environments. These environments, characterized by extreme temperatures, dust, sand, or high humidity, significantly threaten aircraft performance and longevity.

The unrelenting heat can lead to accelerated wear and tear on critical components of the aircraft, while harsh elements like dust and sand exacerbate this effect. Furthermore, hot and humid conditions create a breeding ground for corrosion, jeopardizing the integrity of aircraft modules (fuselage, powerplant, auxiliary power unit, landing gears, wings, and harnesses). These factors, combined with the potential for reduced engine thrust due to sand build-up on the high-pressure compressor (HPC) and high-pressure turbine (HPT). In addition, the increase in the engine exhaust gas temperature (EGT) because of the sand and corrosion build-up and the high outside temperature highlights the critical need for a robust and proactive approach to preventive maintenance.

The Kingdom of Saudi Arabia is in the Middle East region, and the weather environment is considered as hot and harsh due to the extremely high temperature in the summer and the high volume of sand in the air in all seasons of the year, even in mid-altitude like 20,000 ft, the air is carried of sand. Also, The Kingdom of Saudi Arabia has airports in sea cities, especially the main cities with an international airport like (Jeddah and Dammam). The aircraft ground time is very

high, which is an excellent opportunity for corrosion to build up on the aircraft modules.

This research paper delves into the impacts of hot and harsh environments on aircraft, exploring the detrimental effects on components and overall performance. We will then examine the significance of preventive maintenance programs in mitigating these challenges. By analyzing the benefits of early problem detection, improved safety, and extended aircraft lifespan, this paper sheds light on preventive maintenance's crucial role in ensuring aircraft's safe and efficient operation in demanding environments.

1.2 Study Problem:

The environment of the Kingdom of Saudi Arabia poses formidable obstacles to aircraft performance and maintenance, with temperatures soaring above 45°C and occasionally surpassing 55°C for prolonged periods annually. These extreme conditions not only test the limits of aircraft systems and materials but also burden maintenance operations substantially. Despite this critical issue, there is a notable shortage of comprehensive studies addressing the specific challenges aviation professionals face in the Kingdom of Saudi Arabia's unique environment. The scarcity of research in this area underscores the importance of investigating the impact of such environments on aircraft safety, reliability, and maintenance practices, prompting the need for a detailed examination to enhance operational efficiency and safety in the region.

Moreover, the environment of the Kingdom of Saudi Arabia is characterized by extreme heat and harsh conditions for about six months of the year, with temperatures frequently surpassing 45°C and occasionally exceeding 55°C in certain regions. These extreme environmental conditions significantly challenge the region's aircraft performance and maintenance operations. High temperatures can impact aircraft aerodynamics, leading to reduced lift and engine performance, which may affect the overall safety and efficiency of flights. Additionally, the scorching heat can accelerate wear and tear on aircraft components, increasing the frequency of maintenance checks and repairs. The harsh desert environment,

dust storms, and sand particles can also contribute to engine abrasion and corrosion. In addition, the high humidity, which is very high and reaches approximately 99% in the sea cities, is a significant factor in producing corrosion in the aircraft parts, necessitating specialized maintenance practices to ensure the longevity and airworthiness of aircraft operating in the Kingdom of Saudi Arabia. Understanding and mitigating the effects of these environmental factors on aircraft performance and maintenance are critical for ensuring the safety and reliability of aviation operations in this challenging region.

1.3 Importance of The Study:

The Kingdom of Saudi Arabia's geographical location in a dry and hot region exposes it to formidable environmental challenges, with certain cities experiencing high humidity levels, further impacting aircraft and engine performance and maintenance procedures. Understanding the specific risks and strains of these extreme conditions on aviation operations is crucial for ensuring the safety and efficiency of aircraft operations in such environments. This study is essential to identify the human factor risk associated with maintenance personnel working under these conditions, ensuring their well-being and the longevity of aircraft components subjected to the harsh climate of the Kingdom of Saudi Arabia. By delving into these intricate dynamics, the study aims to offer insights that can enhance the maintenance protocols and operational strategies tailored to the unique environmental demands of the region, ultimately contributing to safer and more reliable aviation practices. Notably, previous studies have yet to address this specific matter.

Moreover, the Kingdom of Saudi Arabia faces significantly challenging environmental conditions, particularly during the scorching summer months when the maximum temperature can reach 50 to 60 degrees Celsius. These unique ecological characteristics directly impact aircraft operational performance, affecting reliability, serviceability, availability, and maintenance costs. Failure to address the hot and harsh environment in the Kingdom of Saudi Arabia can lead to

issues such as maintenance difficulties, reduced aircraft availability, and disruptions to flight schedules. This study endeavors to understand and mitigate the impact of the challenging environment, supporting operators in optimizing aircraft performance, on-time performance, and flight availability in the Kingdom of Saudi Arabia.

1.4 Objectives of The Study:

This study aims to provide an in-depth and meticulous analysis of the numerous and intricate effects of the hot and harsh environment in the Kingdom of Saudi Arabia on various aviation operations. In this extensive investigation, the study will delve into evaluating the influence of challenging environmental conditions on:

- Aircraft performance efficiency.
- Maintenance costs and reduced unscheduled maintenance intervals.
- Engine deterioration rates and classify the engine before unscheduled removal (MTBUR).
- Potential maintenance personnel errors due to the adverse environment.
- The durability of aircraft components under such harsh operating conditions.
- Examining the impact on fuel consumption and emission rates.

The continuous endeavors of aircraft operators in the region to develop and implement predictive maintenance strategies accentuate the critical and immediate necessity to delve into and resolve the efficiency challenges commercial aircraft operating in this specific geographical area face. This comprehensive research initiative offers invaluable insights to enhance aircraft performance, optimize maintenance practices, mitigate environmental risks, and elevate operational efficiency in this demanding environment. By thoroughly evaluating the multifaceted effects of the ecological conditions in the Kingdom of Saudi Arabia

on aviation operations, this study not only aims to bridge the existing research gaps but also intends to provide innovative solutions to tackle the complexities associated with operating aircraft in such arduous circumstances.

1.5 Study Questions:

- What is the specific temperature range experienced at the major airports in the Kingdom of Saudi Arabia, and how does this impact engine thrust, takeoff performance, and fuel efficiency?
- How do dust and sandstorms prevalent in the Kingdom of Saudi Arabia affect aircraft engines?
- Does the humidity level in different regions of the Kingdom of Saudi Arabia contribute to corrosion or other performance issues for aircraft?
- How significantly do hot air and sand/dust at the Kingdom of Saudi Arabia airports reduce an aircraft's thrust-to-weight ratio, affecting takeoff weight limitations and runway requirements?
- To what extent does the hot environment decrease fuel efficiency for aircraft operating in the Kingdom of Saudi Arabia, and how does this translate into airline operational costs?
- Do hot and harsh conditions increase the risk of in-flight malfunctions or equipment failures for aircraft operating in the Kingdom of Saudi Arabia?
- How do the Kingdom of Saudi Arabia operators employ the existing preventive maintenance practices to mitigate the effects of harsh environments on aircraft performance?
- Are there opportunities to optimize preventive maintenance schedules or techniques to better address the specific challenges of the Kingdom of Saudi Arabia's environment?

- How do the costs associated with more frequent or specialized maintenance procedures compare to the potential savings from preventing performance degradation and equipment failures?
- Do the specific environmental challenges differ between regions within the Kingdom of Saudi Arabia (coastal vs. desert), and how does this impact aircraft performance and maintenance needs?
- How do the effects of hot and harsh environments vary depending on the aircraft type operated by the Kingdom of Saudi Arabia airlines (commercial jets, cargo planes, helicopters)?
- Are there any specific regulations or guidelines from the Kingdom of Saudi Arabia aviation authority regarding aircraft maintenance practices in harsh environments?

1.6 Research Hypotheses:

The research hypotheses suggest that operating an aircraft in the hot and harsh environment of the Kingdom of Saudi Arabia, in comparison to a clean environment, will substantially impact aircraft performance and operation. It is postulated that maintenance costs may escalate by an estimated 30%, fuel consumption could significantly increase by around 40%, and engine deterioration may rise by approximately 50%. Due to the challenging environmental conditions, maintenance personnel could experience a notable elevation in the risk associated with human factors. This increased risk may contribute to a higher occurrence of maintenance errors and potentially lead to extended maintenance intervals, further impacting aircraft efficiency and safety standards. Combining these factors emphasizes the need to comprehensively evaluate the implications of operating aircraft in such demanding environmental conditions to ensure optimal performance and safety measures are maintained.

1.7 Theoretical Model:

The theoretical model for this study integrates vital concepts from environmental performance theory, operational resilience, and systems theory to analyze the impact of extreme environmental conditions on aircraft performance. This model provides a structured approach to understanding and evaluating how harsh climatic conditions affect various aspects of aviation operations.

- a) Environmental Stressors:** This model component focuses on the extreme environmental conditions prevalent in the Kingdom of Saudi Arabia, such as high temperatures exceeding 40°C. It examines how these stressors impact aircraft systems, including engine performance, fuel efficiency, and reliability.
- b) Operational Response Mechanisms:** The model incorporates the strategies and practices employed by airlines to manage the effects of extreme heat. This includes adaptive maintenance procedures, modifications to operational protocols, and specialized training for personnel to handle the challenges posed by the harsh environment.
- c) Performance Outcomes:** This component assesses the operational response mechanisms' outcomes. It includes metrics related to aircraft performance, safety incidents, maintenance needs, and overall operational efficiency. Performance outcomes are evaluated to determine the effectiveness of the strategies implemented to mitigate the impact of environmental stressors.

d) Resilience and Adaptation: The model's central concept is resilience, which reflects airlines' ability to adapt to and recover from the adverse effects of extreme environmental conditions. The model examines how resilience is built through proactive measures and how it contributes to sustained operational effectiveness.

This theoretical model guides the study in analyzing the interplay between environmental stressors, operational responses, and performance outcomes. The research aims to comprehensively understand how extreme heat affects aircraft performance and develop actionable recommendations for enhancing operational resilience in challenging climates.

Chapter II

Literature Review

2.1 Introduction:

The literature review is a foundational element of this research, providing a comprehensive overview of the existing knowledge related to the topic. This chapter synthesizes previous studies, theoretical frameworks, and empirical findings, highlighting key themes and trends within the field. By critically examining relevant literature, this chapter aims to contextualize the current research, identify gaps in the existing knowledge, and justify the need for further investigation.

2.2 Dependent Variable:

The dependent variable in this study is aircraft performance, specifically focusing on the impact of extreme environmental conditions on various performance metrics. Aircraft performance is assessed through several critical indicators, including:

- a) Engine Efficiency:** Metrics such as engine thrust, fuel consumption, and engine exhaust gas temperature (EGT) are measured to evaluate how extreme heat and sand accumulation affect engine performance.
- b) Component Wear and Tear:** The rate of deterioration and failure of critical aircraft components (e.g., fuselage, powerplant, auxiliary power unit, landing gears, wings, and harnesses) is analyzed to understand the impact of harsh environmental conditions on their longevity and functionality.
- c) Maintenance Requirements:** The frequency and type of maintenance interventions required, including preventive and corrective measures, are examined to assess how environmental factors influence maintenance needs and costs.
- d) Operational Efficiency:** This includes metrics related to flight delays, cancellations, and overall operational disruptions caused by environmental stressors.

e) Safety Incidents: The incidence of safety-related events or issues linked to environmental conditions is evaluated to determine the impact on overall flight safety.

By analyzing these performance metrics, the study aims to quantify the effects of extreme environmental conditions on aircraft performance and to assess the effectiveness of preventive maintenance strategies in mitigating these impacts.

2.3 Independent Variable:

The independent variable in this study is extreme environmental conditions. This variable encompasses several specific factors that are hypothesized to influence aircraft performance. Critical aspects of the independent variable include:

- a) **Temperature:** The effect of high ambient temperatures, typically exceeding 40°C, on aircraft systems and components. This includes the impact on engine performance, fuel efficiency, and the overall thermal stress experienced by aircraft parts.
- b) **Dust and Sand Accumulation:** The presence and concentration of dust and sand in the environment can lead to their accumulation on aircraft surfaces and in engine components, affecting performance and maintenance needs.
- c) **Humidity:** The air's humidity level can contribute to corrosion and affect various aircraft systems and materials.

These independent variables are measured and analyzed to determine their impact on the dependent variable, aircraft performance. The study investigates how variations in these environmental factors affect operational efficiency, component wear, maintenance requirements, and safety outcomes.

2.4 Previous Studies:

The essentiality of thoroughly investigating prior studies and constructing a sturdy theoretical framework for this research is underscored by the critical need to expand on established knowledge, bridge existing gaps within current literature, and establish a firm groundwork for the study. Regrettably, despite exhaustive efforts, no previous studies specifically addressed the impact of the hot and harsh environment on aircraft performance in the Kingdom of Saudi Arabia or analogous environmental conditions in other countries. This scarcity of literature clearly emphasizes the novelty and importance of this study in offering pioneering insights and a deeper comprehension of this specialized area of research.

2.5 Theoretical Framework:

The theoretical framework for this study is grounded in the principles of environmental performance theory and operational resilience. This framework provides a foundation for understanding how extreme environmental conditions affect aircraft performance and guides operational strategies and adaptation analysis.

- a) Environmental Performance Theory:** This theory posits that ecological factors, such as extreme temperatures, significantly impact complex systems' operational efficiency and safety. In aviation, this theory helps explain how harsh climatic conditions in the Kingdom of Saudi Arabia, with temperatures exceeding 40°C, influence aircraft performance, maintenance needs, and overall operational effectiveness.
- b) Operational Resilience Framework:** Operational resilience theory focuses on organizations' ability to withstand and adapt to adverse conditions. This framework examines how airlines develop and implement strategies to manage and mitigate the effects of extreme environmental conditions. It encompasses adaptive maintenance practices, training protocols, and emergency response strategies to enhance operational efficiency and safety.
- c) Systems Theory:** Systems theory provides insights into the interaction between various components of an aviation system, including aircraft,

personnel, and environmental factors. This theory helps analyze how changes in one component, such as extreme temperatures, affect the performance and integration of other components, offering a holistic view of the impact on overall operational efficiency.

d) Risk Management Theory: Risk management theory is applied to understand how airlines assess, prioritize, and manage risks associated with extreme environmental conditions. It addresses the processes for identifying potential hazards, evaluating their impact, and implementing mitigation strategies to ensure continuous, safe, and efficient operations.

By integrating these theoretical perspectives, the study aims to comprehensively understand how extreme heat and environmental conditions affect aircraft performance and operational practices. This theoretical framework informs the research design and methodology and provides a basis for analyzing findings and developing actionable recommendations for improving operational resilience and performance.

Chapter III

Study Methodology

3.1 Introduction:

The chapter outlines the methodology employed in this study, detailing the research design, study population, sample characteristics, data collection techniques, study limitations, and analytical approaches used to investigate the effect of the hot and harsh environment on aircraft performance.

This methodology chapter provides a roadmap for the research conducted and ensures that the study's findings are grounded in a robust and rigorous methodological framework. Through a detailed exposition of the study design and procedures, this chapter establishes the foundation for the analysis and discussion of results presented in subsequent chapters.

3.2 Research Design:

This comprehensive study significantly emphasizes the pivotal objective of meticulously quantifying and critically analyzing the profound impact of the environment on aircraft performance when confronted with the intense heat and harsh conditions prevailing in the Kingdom of Saudi Arabia, known for its extreme temperatures exceeding 40°C. The research is meticulously structured to engage with actual operators in the Kingdom of Saudi Arabia, with a deliberate intention to glean invaluable insights and proffer actionable recommendations to enhance these operators' operational efficiency and preparedness.

By profoundly investigating this unique and challenging environment and its consequential effects on aircraft operations, the study imparts indispensable information that can refine operational strategies and optimize performance under prevailing climatic adversities. This study endeavors to push boundaries in understanding the intricate nuances of aviation operations within such demanding environments, contributing significantly to the overall resilience and effectiveness of aircraft operations.

3.3 Population of The Study:

The population for this study consists of actual aircraft operators working within the Kingdom of Saudi Arabia, a region known for its extreme temperatures, often exceeding 40°C. This group was selected due to their direct experience and involvement in aircraft operations under such harsh environmental conditions, central to the study's focus on understanding and improving performance in challenging climates. The study targets operators from commercial airlines, ensuring a comprehensive representation of those affected by the region's unique climatic challenges. This diverse population enables the research to capture a wide range of operational experiences and insights, which are crucial for formulating actionable recommendations to enhance operational efficiency and resilience in the face of extreme heat and environmental stresses.

3.4 Sample Characteristic:

The sample for this study comprises operational personnel from two of the largest commercial airlines in the Kingdom of Saudi Arabia. SAUDIA and FLYNAS Airlines are known for their extensive domestic, regional, and international flight operations. The sample includes individuals involved in various airline operations, encompassing different roles and specializations.

- a) Occupational Roles:** The sample consists of maintenance mechanics and engineers from both airlines. This range of roles ensures a comprehensive understanding of how extreme environmental conditions impact different facets of airline operations.
- b) Experience Levels:** Participants are selected to represent varying levels of experience, including seasoned professionals with extensive experience in the region's climate and newer employees who bring fresh perspectives on operational challenges.
- c) Aircraft Types:** Since airlines operate different aircraft types, the sample includes individuals who work with various aircraft models, from narrow-body to wide-body jets. This diversity helps in understanding how different aircraft types are affected by extreme temperatures and environmental conditions.

d) Geographic Locations: The sample includes personnel from various operational bases within the Kingdom of Saudi Arabia, capturing the experiences and challenges faced in different geographic locations.

e) Demographic Factors: While not the primary focus, demographic factors such as age and educational background are noted to explore any potential correlations with operational challenges and responses to extreme conditions.

These sample characteristics are designed to provide a detailed and nuanced understanding of how extreme heat and environmental conditions affect aircraft performance and operational efficiency across different roles, aircraft types, and flight operations.

3.5 Sample Size Determination:

The sample size for this study is determined based on the need to capture comprehensive insights from the two largest commercial airlines operating in the Kingdom of Saudi Arabia. Given these airlines' extensive operations, which include domestic, regional, and international flights with a variety of aircraft types, the sample size is designed to be representative of their diverse operational contexts.

- a) Scope of Study:** To ensure that the study reflects the impact of extreme environmental conditions on a broad range of flight operations, the sample includes data from multiple flight routes and aircraft models used by both airlines.
- b) Practical Constraints:** The sample size balances statistical requirements with practical considerations, including data accessibility and resource availability. The aim is to gather sufficient data to provide meaningful insights while maintaining feasibility.
- c) Target Size:** The final sample size is set to include operational data of flights and aircraft across both airlines, ensuring a robust representation of their operational environments and performance under extreme conditions.

This approach ensures that the study thoroughly understands how environmental factors impact aircraft performance across different operational scenarios and aircraft types.

3.6 Data Collection Procedure:

Data collection is critical to any research study, as it provides the foundation for analysis and conclusions. The data collection involved directly engaging proficient operators to gather valuable insights on internal operations within engineering and operational departments. This essay will delve into the methods and tools used to collect data, highlighting the importance of operator engagement in enriching the study.

The first step in the data collection process was to engage proficient operators responsible for internal data collection within their respective departments. These operators played a crucial role in providing firsthand insights and perspectives essential for understanding the intricacies of the operational processes being studied. By involving those directly involved in data collection daily, the study captured a more authentic and comprehensive view of the subject matter.

To gather data

effectively, direct interviews were conducted with the operators' engineering team. These interviews served as a platform for exchanging information, sharing experiences, and eliciting feedback that was instrumental in shaping the direction of the study. A semi-structured questionnaire was developed as the primary data collection tool, with careful consideration given to its construction and refinement.

The questionnaire underwent a meticulous refinement process involving iterative feedback loops with the operators and other stakeholders. This iterative approach ensured that the questionnaire was tailored to suit the study's specific needs and designed to collect valid and reliable data. By incorporating operator feedback and refining the questionnaire, the study enhanced the quality and depth of the data collected.

This study tool facilitated valuable data collection and fostered a sense of collaboration and engagement between the researchers and the operators. By involving the operators in the data collection process, their expertise and insights were leveraged to enrich the study and provide a more nuanced understanding of the subject matter. This participatory approach enhanced the study's credibility and helped build a rapport with the operators, ensuring their continued cooperation and support throughout the research process.

In conclusion, using proficient operators as crucial stakeholders in the data collection proved invaluable in enriching the study. The study gathered relevant and reliable data by directly engaging with operators and utilizing a carefully constructed questionnaire, contributing to a more comprehensive analysis of the subject matter. This approach strengthened the research findings and established a collaborative relationship between the researchers and the operators, paving the way for future cooperation and knowledge-sharing endeavors.

3.7 Study Limitation:

Data Availability:

- **Limited Local Data:** Research specific to the Kingdom of Saudi Arabia's climate and aircraft types might be scarce. We might need to rely on data from other hot and arid regions, which may not perfectly match Saudi Arabia's specific conditions.
- **Proprietary Data:** Detailed performance data from airlines might be considered commercially sensitive and challenging to obtain.

Environmental Factors:

- **Variability Within the Kingdom of Saudi Arabia:** Climate conditions can vary. Generalizing results from one region to the entire country might not be accurate.
- **Focus on Temperature:** Hot temperatures are a significant concern, but other factors like sandstorms and high humidity can also impact performance and might not be well-represented in existing research.

Aircraft Factors:

- **Aircraft Model Specificity:** The impact of hot environments can vary depending on the specific aircraft model and engine type. Research might not be directly applicable to our target aircraft fleet.

- Limited Testing Data: Finding data on how specific aircraft models perform under sustained hot and harsh conditions might be challenging.

Operational Factors:

- Flight Procedures: Airline practices like takeoff weight restrictions or adjusted climb profiles in hot weather might need to be well-documented or publicly available.
- Maintenance Practices: Quantifying the impact of more frequent inspections or specific maintenance procedures in hot climates might require more work.

General Limitations:

- Cost and Time: Conducting tests or simulations to gather data can be expensive and time-consuming.
- Focus on Averages: Research might focus on average performance impacts, but real-world scenarios can involve various factors, leading to more variable outcomes.

Here are some suggestions to mitigate these limitations:

- Collaboration: Consider contacting the Kingdom of Saudi Arabian airlines, aviation authorities, or research institutions to see if they have relevant data.

- Focus on Available Data: While specific Saudi data might be limited, use data from other hot regions, acknowledging the potential for geographical variations.
- Case Studies: If detailed performance data is unavailable, consider case studies that analyze specific hot weather operational challenges airlines face.
- Expert Interviews: Talk to the Kingdom of Saudi Arabian pilots, mechanics, and airworthiness experts to gain practical insights.
- Focus on Mitigation Strategies: Even if quantifying performance impacts is complex, research existing airline strategies to mitigate hot weather effects on aircraft in other regions.

Chapter IV

Practical Study

4.1 Introduction:

The Kingdom of Saudi Arabia has vast desert terrain and extreme climatic conditions, including high temperatures and low humidity. These environmental factors pose significant challenges to the aviation industry, particularly regarding aircraft performance. During interviews with operators' engineers, it was revealed that the primary impact of the hot and harsh environment is on aircraft engines. This significantly affects aircraft availability, increases maintenance burdens, raises fuel consumption, and escalates maintenance costs.

This practical study is designed to investigate the effects of the hot and harsh environment on aircraft performance within the KSA aviation industry. By examining the experiences and data of regional operators, this research seeks to identify the key challenges, impacts, and mitigation strategies employed to address these environmental factors. The study's practical nature ensures that the findings will be applicable to the challenges faced by the aviation industry in the KSA, providing reassurance and confidence in its relevance.

The findings of this study contribute to understanding complex relations. The Kingdom of Saudi Arabia's environmental factors present significant challenges to the aviation industry, particularly regarding aircraft performance. Interviews with operators' engineers revealed that the main impact of the hot and harsh environment is on aircraft engines. This significantly affects aircraft availability, increases

maintenance requirements, raises fuel consumption, and escalates maintenance costs.

This practical study is designed to investigate the effects of the hot and harsh environment on aircraft performance within the KSA aviation industry. By examining the experiences and data of regional operators, this research seeks to identify the key challenges, impacts, and mitigation strategies employed to address these environmental factors. The study's practical nature ensures that the findings will be applicable to the challenges faced by the aviation industry in the KSA, providing reassurance and confidence in its relevance.

This study's findings will help understand the complex relationship between climate and aircraft performance, providing valuable insights for both operators and aviation authorities in the KSA. Ultimately, the research aims to support the development of effective strategies to enhance aircraft performance, improve safety, and optimize operational efficiency in the challenging environmental conditions prevalent in the region. Hip between climate and aircraft performance, providing valuable insights for operators and aviation authorities in the KSA. Ultimately, the research seeks to support the development of effective strategies to enhance aircraft performance, improve safety, and optimize operational efficiency in the challenging environmental conditions prevalent in the region.

4.2 Data Analysis:

The analysis of operators' data for the primary aircraft types operating in the Kingdom of Saudi Arabia, equipped with five different engine models, reveals that the hot and harsh environment predominantly impacts the following aspects of engine performance:

- Engine Mean Time Between Failures (MTBF).
- Engine Efficiency.
- Engine Maintenance Frequency.
- Engine Repair Costs: The increased maintenance frequency and severity of environmental stressors result in higher engine repair costs

4.2.1 Engine Mean Time Between Failures (MTBF):

The extreme conditions in the Kingdom of Saudi Arabia significantly reduce the Mean Time Between Failures (MTBF) of aircraft engines, resulting in more frequent failures. This accelerated failure rate is primarily attributed to the rapid deterioration of core modules, including the High-Pressure Compressor (HPC), Combustion Chamber (CC), and High-Pressure Turbine (HPT).

In a standard operating environment, engines are designed to achieve the first limit of their Life Limited Part (LLP). However, under the harsh conditions prevalent in the KSA, engines often fail at approximately 33% of their LLP on average. The high temperatures and abrasive sand particles lead to increased wear and tear,

causing components to degrade much faster than anticipated. This shortens the lifespan of critical engine parts and necessitates more frequent inspections, repairs, and replacements.

Moreover, the high frequency of engine maintenance required in such an environment significantly drives up operational costs. Elevated temperatures and particulate matter cause extensive damage, leading to frequent unscheduled maintenance events and increased downtime, further affecting aircraft availability and operational efficiency.

Table 1 provides a detailed breakdown of MTBF data for each engine type, highlighting the substantial impact of the harsh environment on engine performance.

Aircraft Type	Engine Model	LLP First Limiter [FC]	MTBF [FC]	MTBF/LLP
AIRBUS A320ceo	CFM56-5B	20,000	10,150	51%
AIRBUS A320neo	CFM LEAP-1A	9,900	3,180	32%
AIRBUS A321ceo	CFM56-5B	20,000	5,300	27%
BOEING B777	GE90-115B	8,800	3,250	37%
BOEING B787	GENx1B	10,150	1,600	16%

Table 1: Engine LLP & MTBF Data

4.2.2 Engine Efficiency:

The hot and harsh environment profoundly impacts engine efficiency, mainly due to the accumulation of sand and dust. The sand build-up is evident from the first borescope inspection (BSI) compliance, and its effects on engine components are detrimental.

The accumulation of sand plays a pivotal role in altering the airflow direction and changing the airfoil shape, which significantly reduces engine efficiency. This alteration forces the engine to burn more fuel to compensate for the required thrust, thereby increasing operational costs and reducing overall efficiency.

Additionally, cooled air is essential for protecting the combustion chamber (CC) and high-pressure turbine (HPT) from heat stress. This cooled air is sourced from the high-pressure compressor (HPC) and routed through the high-pressure turbine air cooling control (HPTACC) system to feed the HPT. However, in harsh environments, the cooling holes in the CC and HPT become clogged with sand and debris.

This clogging not only disrupts the cooling process but also removes protective coatings on the components. The absence of these coatings leads to material discoloration and subsequent oxidation. Over time, this oxidation can cause the formation of cracks or the loss of material, severely compromising the structural integrity of the engine parts.

The combination of these factors—altered airflow, increased fuel consumption, and material degradation—significantly decreases engine efficiency. The need for more frequent maintenance to address these issues further exacerbates the operational challenges aircraft face in such environments.

Ultimately, the hot and harsh environment leads to a vicious cycle of reduced efficiency, increased fuel consumption, higher maintenance costs, and shorter engine lifespans. However, effective mitigation strategies and, more importantly, advanced maintenance techniques are crucial in breaking this cycle and ensuring the sustained performance and reliability of aircraft engines operating in extreme conditions.

4.2.3 Engine Maintenance Frequency:

The hot and harsh environment in Saudi Arabia necessitates significantly increasing maintenance activities. These increased maintenance requirements involve frequent inspections, part replacements, cleaning, and relubrication. The cumulative effect of these activities is higher operational costs, increased aircraft ground time, and greater resource allocation, all of which highlight the critical need for robust maintenance strategies to manage the challenges posed by such an environment.

Key points highlighting the increased maintenance demands are:

- **Borescope Inspections (BSI):** BSIs are the primary method for monitoring and detecting engine hardware wear and tear. In the harsh environment of the Kingdom of Saudi Arabia, the frequency of BSIs increased by approximately 50% compared to the standard requirements outlined in the Maintenance Planning Document (MPD). This increase is necessary to keep up with the accelerated deterioration of engine components caused by extreme temperatures and sand accumulation.
- **Engine Replacements:** The reduced Mean Time Between Failures (MTBF) due to the harsh environment results in more frequent and costly engine replacements. This requires costly parts and consumables, as well as increased ground time and manpower. The frequent need for engine replacements underscores the significant financial impact of the harsh environment on engine longevity and operational costs.
- **Fan Blade Relubrication:** Due to the dusty environment, fan blade cleaning and relubrication frequency increased by approximately 50% compared to MPD requirements. Maintaining the efficiency of the fan blades is essential for engine performance.

- **Engine Gas Path Cleaning/Washing:** The frequency of engine gas path cleaning or washing has increased by approximately 50% compared to MPD requirements. This cleaning is crucial to remove accumulated dust and debris from the core hardware, which clogs cooling holes and alters the blades' aerodynamic properties. Regular cleaning helps maintain engine efficiency and prevent overheating and material degradation.

4.2.4 Engine Repair Costs:

The severe environmental stressors in Saudi Arabia result in significantly higher engine repair costs. These costs are driven by several factors, including severe damage to core hardware, increased scrap rates, and the necessity for more extensive part repairs. Additionally, the likelihood of upgrading the work scope due to unexpected findings during inspections often leads to the disassembly of modules not initially planned for maintenance.

Key points highlighting the increased repair costs are:

- **Damage to Core Hardware:** The extreme heat and abrasive sand particles cause severe damage to critical engine components, increasing their scrap rate. This raises the cost of repairs and requires the procurement of expensive replacement parts.

- **Unexpected Findings:** The harsh environment increases the probability of unexpected findings during inspections and maintenance. These findings often necessitate unplanned disassembly of engine modules, further escalating repair costs and downtime.
- **Modifications and Upgrades:** To improve reliability and extend the engine time on wing, modifications and configuration upgrades developed explicitly for hot and harsh environments are often required. Implementing these upgrades adds to the overall repair costs but is essential for maintaining engine performance and longevity in such conditions.
- **Life Limited Part (LLP) Replacement:** The harsh environment makes meeting the average MTBF after engine repair challenging. The remaining LLP life must align with MTBF goals, but the reduced MTBF in these conditions often results in early LLP replacement. This early replacement leads to wasted LLP life and increased costs, as parts are discarded before reaching their potential lifespan.

4.3 Research Findings:

The hot and harsh environmental conditions in the Kingdom of Saudi Arabia profoundly impact aircraft engine performance, leading to significant operational and financial consequences for airlines. The intense heat, coupled with the pervasive presence of sand, accelerates engine deterioration, resulting in increased maintenance costs, the need for more frequent repairs, and a higher demand for spare parts and additional engines to sustain operations. This also necessitates a more significant, skilled workforce, particularly in maintenance and engineering departments, to manage the elevated maintenance demands and minimize operational disruptions. Expertise and dedication are crucial in this process.

One of the critical issues is the increased risk of engine failure due to the accumulation of sand on critical components like the High-Pressure Compressor (HPC) and High-Pressure Turbine (HPT) blades. This buildup can lead to issues such as high vibration levels and impaired fan blade lubrication, which elevate the likelihood of in-flight engine failures. If core engine deterioration goes undetected, the risk of an in-flight shutdown (IFSD) significantly increases, potentially forcing the aircraft to return and land with only one operable engine, a hazardous scenario that poses serious safety risks.

Furthermore, the combination of high temperatures and sand accumulation, particularly on the HPC and HPT blades, subjects these components to extreme stress. If this stress is not detected and mitigated, it can lead to catastrophic failures

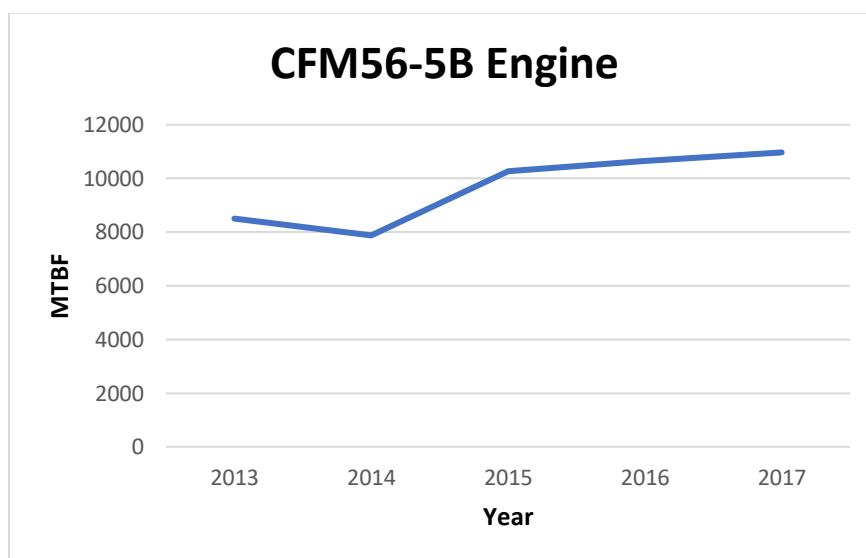
such as blade liberation, which can cause severe damage to the entire engine. The potential for such catastrophic failures underscores the urgency of the issue and the need for robust preventive maintenance strategies.

The harsh environment also rapidly diminishes engine efficiency, increasing fuel consumption. This drives up operational costs and has negative environmental implications due to higher emissions. Consequently, airlines operating in these conditions face economic and environmental challenges, necessitating robust maintenance strategies to manage and mitigate the impact.

Operators have implemented several preventive maintenance actions to combat these issues and improve the engine's time on the wing (TOW). Among the most effective measures are enhanced engine gas path washing and the installation of modified hardware designed specifically for hot and harsh environments. For example, using chemical foam in engine washes, as opposed to pure water, has proven more effective in cleaning the blades, leading to better recovery of engine efficiency and a slower rate of deterioration. Additionally, modifications recommended by the engine manufacturers, such as installing High-Pressure Turbine (HPT) blades with more cooling holes and thicker coatings, have also contributed to improved engine performance.

Graph 1 illustrates the effectiveness of these preventive measures. It shows a significant improvement in the Mean Time Between Failures (MTBF) for the

CFM56-5B engine following the implementation of these enhanced maintenance practices. Specifically, the MTBF improved by approximately 37% after adopting more frequent engine washes and installing modified HPC, Combustion Chamber (CC), and HPT hardware. These improvements underscore the critical importance of proactive maintenance strategies in mitigating the adverse effects of hot and harsh environments on aircraft engines.



Graph 1: Engine MTBF per years

4.4 Research Recommendations:

This study underscores the urgent need for airlines to address the significant operational and financial challenges posed by hot and harsh environments, such as those prevalent in the Kingdom of Saudi Arabia. Successfully navigating these challenges necessitates a holistic strategy that fuses cutting-edge technology, strategic maintenance best practices, and proactive risk management. The following recommendations are designed to assist airlines in mitigating the adverse effects of these environments on aircraft engine performance, thereby ensuring long-term operational efficiency, safety, and cost-effectiveness.

(1) Advanced Engine Monitoring and Predictive Analytics:

Airlines should invest in top-of-the-line engine monitoring systems to address the accelerated engine wear caused by high temperatures and sand infiltration. These systems provide real-time data on engine health and utilize predictive analytics to forecast potential failures before they happen. By continuously monitoring key parameters such as engine vibration levels, exhaust gas temperature (EGT), and oil pressure, airlines can detect early signs of wear, such as sand build-up on High-Pressure Compressor (HPC) and High-Pressure Turbine (HPT) blades. This proactive approach reduces the risk of in-flight engine failures and extends the engine's operational life, ultimately lowering maintenance costs.

(2) Tailored Preventive Maintenance Programs:

The harsh environmental conditions in regions like the KSA require reevaluating standard maintenance schedules. Airlines should implement a customized preventive maintenance program that enhances the frequency of essential activities such as borescope inspections (BSI), engine gas path cleaning, and fan blade relubrication. These adjustments are crucial in addressing the accelerated wear and tear caused by sand and high temperatures, which can significantly degrade engine components if left unchecked. For example, increasing the frequency of engine washing with chemical foam instead of pure water can more effectively remove debris, thus restoring engine efficiency and reducing fuel consumption.

(3) Strategic Engine Modifications and Upgrades:

Working with engine manufacturers to implement modifications tailored to specific environments is essential for enhancing engine durability in hot and harsh conditions. Airlines should prioritize adopting upgraded components, such as HPT blades with improved cooling holes and thicker protective coatings, specifically designed to withstand the extreme heat and abrasive particles commonly found in desert environments. Furthermore, these upgrades should be installed on existing engines throughout the fleet to standardize performance enhancements. By making these modifications, airlines can prolong the engine's time on wing (TOW) and reduce the

frequency and severity of maintenance events, resulting in significant cost savings over time.

(4) Improving Fuel Efficiency and Reducing Environmental Impact:

Engine inefficiency caused by sand accumulation and high temperatures increases fuel consumption, raising operational costs and carbon emissions. To address this, airlines should implement fuel efficiency optimization programs. These programs could include optimizing flight routes to avoid extreme conditions, adopting fuel-saving technologies, and using advanced engine tuning methods. These measures are crucial for reducing the carbon footprint, aligning with sustainability goals, and decreasing fuel costs.

(5) Comprehensive Training and Capacity Building:

Operating in challenging environments requires a highly skilled maintenance workforce capable of addressing the unique issues posed by extreme conditions. Airlines should invest in comprehensive training programs focusing on the latest diagnostic techniques, advanced maintenance procedures, and best practices for working in hot and harsh environments. This training should be ongoing to ensure that maintenance and engineering teams are continually updated on new technologies and methods. Promoting the culture of continuous improvement and knowledge

sharing within maintenance teams can further enhance their ability to effectively address the challenges these environments pose.

(6) Collaborative Research and Development (R&D):

To overcome the challenges of operating in hot and harsh environments, continuous research and development efforts are essential. It is crucial for airlines to actively participate in R&D collaborations with engine manufacturers, academic institutions, and industry organizations to create new materials, coatings, and technologies capable of withstanding extreme conditions better. This collaborative approach can result in developing more durable engine components, innovative maintenance techniques, and advanced diagnostic tools, all of which enhance engine performance and reliability. Airlines can ensure their competitiveness and resilience amid environmental challenges by staying ahead in technological advancements.

(7) Proactive Operational Risk Management:

With an increased risk of engine failures in harsh environments, developing solid operational risk management strategies is essential. Airlines should create detailed contingency plans for in-flight engine shutdowns, emergency landings, and rapid engine replacements. These plans include ensuring adequate spare engine capacity, pre-positioning critical parts and equipment at key locations, and maintaining a well-trained ground support team capable

of executing repairs and replacements quickly. Proactive risk management will minimize operational disruptions, protect passenger safety, and maintain schedule integrity, even during unexpected engine failures.

(8) Industry-Wide Standards and Regulatory Advocacy:

The aviation industry would benefit from developing specific standards and regulations addressing the challenges of operating in hot and harsh environments. Airlines should advocate for establishing industry-wide guidelines that set forth best practices for maintenance, engine modifications, and performance monitoring in extreme conditions. These standards should be developed in close collaboration with regulatory authorities, engine manufacturers, and industry experts to ensure they are both practical and effective. By promoting and adopting these standards, airlines can help develop a safer and more efficient operating environment for all carriers operating in similar conditions.

By implementing these comprehensive recommendations, airlines can improve their ability to deal with the challenges of hot and harsh environments. This will ensure sustained engine performance, reduce operational costs, and enhance safety. These strategies are essential for maintaining the reliability of aircraft engines and securing the long-term viability and competitiveness of airlines operating in regions with extreme climatic conditions.

4.5 References:

- European Union Aviation Safety Agency EASA, Part M - AMC M.A.302(d)
Aircraft maintenance program.
- Federal Aviation Administration FAA, FAA-HDBK-006D October 8, 2020.
- Saudia Airline, 2024 Engineering Team.
- Flynas Airline, 2024, Engineering Team.
- General Authority of Civil Aviation GACA, 2024, GACAR Part 1 Version 12.0.

Appendixes

5.1 Abstract:

The Kingdom of Saudi Arabia plays a pivotal role in global aviation due to its strategic geographic location, significant religious travel demands, and ambitious economic goals outlined in Vision 2030. This study investigates the profound impact of the Kingdom's extreme environmental conditions—high temperatures, dust, and humidity—on aircraft performance and maintenance. The harsh climate accelerates wear and tear on critical aircraft components. It exacerbates issues such as corrosion and sand build-up, which can compromise the integrity of aircraft systems and reduce engine efficiency.

This research employs a theoretical framework integrating environmental performance theory, operational resilience, systems theory, and risk management to analyze how extreme heat and environmental stressors affect aircraft operations. The study focuses on two of the largest commercial airlines in Saudi Arabia, examining their operational practices and preventive maintenance strategies in response to these challenges.

The sample includes operational data from various flight routes and aircraft models these airlines use. The study highlights the importance of robust preventive maintenance programs in mitigating the effects of extreme environmental conditions, emphasizing early problem detection and effective management practices to enhance aircraft safety, performance, and longevity.

This research aims to offer actionable insights for improving operational resilience and efficiency in similar challenging climates by providing a comprehensive analysis of how harsh environmental factors impact aircraft operations and the effectiveness of preventive maintenance.

5.2 Arabic Abstract (الملخص العربي)

تلعب المملكة العربية السعودية دورًا محوريًا في الطيران العالمي نظرًا لموقعها الجغرافي الاستراتيجي، ومتطلبات السفر الديني الكبيرة، والأهداف الاقتصادية الطموحة التي تحددها رؤية 2030. تستكشف هذه الدراسة التأثيرات العميقة لظروف البيئة القاسية في المملكة، التي تتميز بالحرارة الشديدة، والغبار، والرطوبة، على أداء وصيانة الطائرات. المناخ القاسي يسرع من تآكل مكونات الطائرات الحيوية ويزيد من مشكلات مثل التآكل وتراكم الرمل، مما يمكن أن يهدد سلامة الطائرات ويقلل من كفاءة المحركات.

تستخدم هذه الدراسة إطارًا نظريًا يجمع بين نظرية الأداء البيئي، ونظرية المرونة التشغيلية، ونظرية النظم، وإدارة المخاطر لتحليل كيفية تأثير الحرارة الشديدة والعوامل البيئية على عمليات الطائرات. تركز الدراسة على اثنين من أكبر شركات الطيران التجارية في المملكة العربية السعودية، وتفحص ممارساتها التشغيلية واستراتيجيات الصيانة الوقائية استجابةً لهذه التحديات.

يشمل العينة بيانات تشغيلية من مسارات الرحلات المختلفة ونماذج الطائرات المستخدمة من قبل هاتين الشركتين. تسلط الدراسة الضوء على أهمية برامج الصيانة الوقائية القوية في التخفيف من آثار الظروف البيئية القاسية، مشددة على الكشف المبكر عن المشكلات والممارسات الإدارية الفعالة لتعزيز سلامة الطائرات وأدائها وطول عمرها.

من خلال تقديم تحليل شامل لكيفية تأثير العوامل البيئية القاسية على عمليات الطائرات وفعالية الصيانة الوقائية، تهدف هذه الدراسة إلى تقديم رؤى قابلة للتنفيذ لتحسين المرونة والكفاءة التشغيلية في الظروف المناخية المماثلة.