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Perception-Based Monitoring and Prediction of Aircraft Fatigue and Fracture

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Abstract
Fatigue and Fracture on aircraft are vital threats to aviation safety, these directly impact structural integrity which are contributors to both incidents and accidents. This research investigates the link between aircraft safety, fatigue, and fracture, while also scrutinizing the outturn of environmental, operational, and structural factors and aircraft age. With Licensed Aviation Maintenance Technicians as the target participants, the researchers used a mixed method technique while data was collected through surveys and interviews by convenience and snowball sampling. This study accentuates the importance of the role of environmental factors and human practices in aircraft safety and structural integrity. The factor that was pointed out as a primary contributor to aircraft fatigue and fracture is both changes in pressure and altitude; this emphasizes the need for rigorous standards in maintenance and strategies to alleviate the risks. In addition, support in system thinking, incident pattern analysis, and structural modeling is heavily pushed to increase aircraft safety. Finally, combining the findings into operations and aircraft design can assist in aircraft safety.

Keywords: Aircraft, Fatigue , Fracture , Environmental Factors, Operational Factors, Structural factors.

1. INTRODUCTION

As the aviation industry evolved, challenges with safety concerns pushed the sector into developing the highest possible safety regulations for both passengers and crew. Habitually, aviation safety is heavily correlated to the age of the aircraft, the older the plane the more it is prone to accidents due to wear and tear, and also its outdated technology. Despite that, research has created evidence suggesting that it is not the age but rather the untreated fractures in an aircraft that play a critical role in aircraft safety.

According to (Murray et al., 2021), who stated that the risk of loss of life in aircraft accidents due to catastrophic fatigue failure is huge. A study by (Stamoulis et al., 2016), identified the key environmental factors causing the failure modes of aircraft that result in major accidents to be fatigue and corrosion. Moreover, it enumerates the most frequent modes of failure concerning several landing gear components as fatigue, overload failures, and stress corrosion cracking.

(Diltemiz, 2021) addressed the interests of metal fatigue specialists concerning design specifications, life prediction, and evaluation methodologies. As stated by (Wanhill et al., 2021), specific accidents have been linked to the aging of aircraft and outdated safety standards, and that it may compromise aviation safety.
The author of "What Is Aircraft Fatigue, and How Can Fatigue Failure Be Prevented?" (2019) stated that overexposure to high altitudes with changes in pressure depressurizes the plane, hence weakening its metal. On the contrary, the review by (Pfingstl et al., 2022) claims that apart from the various load types. It also depends upon operational variables such as cruise altitudes and seat loads that will affect the wear and tear of aircraft structures.
On the other hand, a study done by (Hansman, 2014) affirms that so long as National Aviation Authorities oversee aircraft design and its certification, the age of aircraft is not a big safety concern. A study on the effects of corrosion on fatigue life for aluminum alloys in aircraft structure were studied by (Kamath et al., 2022), who researched both pre-corroded materials and on-going corrosion with crack models and fatigue analysis to determine the component durability. (Jones et al., 2015) also mentioned that special tools to predict the small cracks from getting bigger so that people can know the durability of the aircraft from the small cracks.
The author of "Ageing aircraft - structural failure" (2024) specified that specific aircraft age has been blamed for certain accidents, and old standards relating to safety could pose a threat to aviation safety since they have been set based on outdated criteria. Despite that, the author of "What Determines the Life Span of an Airplane" (2021) consolidates the fact that the life span of an aircraft is not directly related to the safety of the aircraft. Moreover, (Grbović et al., 2019) stated that there are two most critical concerns regarding aviation safety: one is fatigue, while the other pertains to fractures in the wings.
(Grant et al., 2018) claim that some basic precepts of "systems thinking" might be used to explain a few simple concepts about understanding and trying to prevent accidents.
(Cankaya et al., 2019) support the fact that Bayesian Belief Networks together with an advanced decision support system, it would help in forecasting aircraft incidents but also in creating all sorts of preventive measures depending on the patterns formed at the time the incidents occurred. (Ancel et al., 2015) further confirm the fact that OOBNs are indispensable in the determination of the multifactorial causes of accidents.
The study by (Zhang et al., 2019) discussed a hybrid model that includes the integration of Support Vector Machines with Deep Neural Networks for determining the severity of unusual aviation events and related risks to further improve aviation safety. (Rios Insua et al., 2019) discussed decision analysis in aviation based on risk management; incidents are identified by analyzing the decisions, after which extra resources are pumped to mitigate the risks involved in those incidents.
(Omrani et al., 2024) investigated various machine learning techniques in accident prediction and determination of influential factors. (Flores et al., 2022) pointed out that multiple countries are now moving to apply aviation safety event forecasting in the hope of making accidents less severe. Governments are investing in predictive models, particularly those based on Bayesian decision analysis, which show promise for enhancing future aviation safety. This is supported by (Wagh et al., 2023), which states that although the past may have been unfortunate, these events serve as a great chance to document the lesson learned from the same mistake, thus increasing the strength of the prediction and avoiding similar events in the future. In addition, (Venugopal et al., 2021) reported that the airframes for the Royal Malaysian Air Force made of aluminum 2024 are prone to corrosion at high temperatures and humidity but their periodic maintenance will prevent them probably to that extent. Compared with earlier research

on the management of large cracks.

(Main et al., 2024) developed cold expansion techniques for the small crack management of aircraft. (Nejad et al., 2021) indicate that the poor repairing quality which may be the result of inexperience and environmental conditions, while (Dalkilic, 2017) speaks of the fact that poor maintenance is one of the causes that leads aircrafts to accidents.

The study will emphasize the relationship between aircraft fracture and fatigue, and the importance of handling the uprising issues without regard to old or new aircrafts. Through looking into the advancements in technology because of previous accidents, and by studying past cases, this paper will justify that to enhance aviation safety it is crucial to focus on the preventive measures for aircraft fracture. The study will also look at how existing safety guidelines and rules should be modified to better manage the dangers of aircraft fractures, and to guarantee the dependability of one aircraft irrespective of age.

1.1. Background of the Study

An aircraft starts to age the moment it takes off to fly, and different aging effects start to show just about instantly. Still, the phrase "aging aircraft" is typically used to describe problems that can surface when the period since new exceeds the average age of aircraft in the same class and starts to become substantial. To determine the impacts of accidental, environmental, or fatigue damage, proper inspection techniques and inspection intervals are devised. Damage tolerance and safe life design philosophies are utilized nowadays. Additionally, it is increasingly customary to set up a corrosion prevention and control program and an inspection program for fatigue-related samples. An aircraft that is continuously used without the necessary fatigue inspection and maintenance may have microscopic damage that manifests as noticeable cracks in the body of the aircraft that widen with exposure to flight conditions.

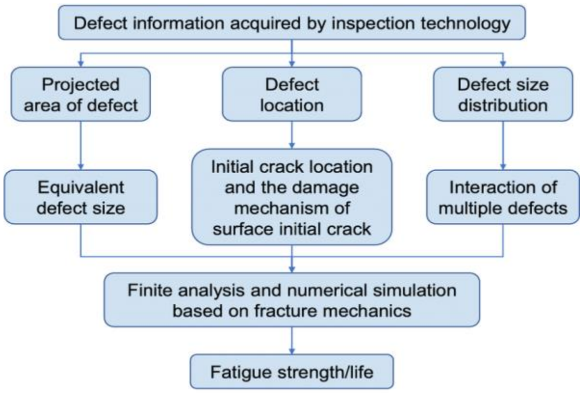
To provide effective and timely maintenance to aircrafts, maintenance personnel must know when an aircraft is already experiencing fatigue and is already prone to failure and accident. To resolve these problems, airlines and researchers have been developing ways and programs to provide accurate predictions and fatigue analysis. As of today, there are various software and projects used for comprehensive analysis of structures; systems such as Hexagon's MSC Nastran and ANSYS are some of the software used for predictive maintenance not just in aviation, but in other industries as well. MSC Nastran created by Hexagon used by NASA and Boeing is a software that analyzes multidisciplinary structures with automated structural optimization and fatigue analysis is one of the used software around the world.

Many countries have attempted to develop programs that would predict aircraft fatigue and failure that can provide effective and efficient safety measures in ensuring aircraft integrity and passengers welfare, aiding the growth in demand for air transport. The Philippines is one of those countries that tries to sustain and keep up with the innovation and development of other nations. Lufthansa Technik Philippines, one of the providers of MRO in the Philippines, has been encouraging the need for AI programs that aim to develop such programs.

As stated by the (JETechnology Staff, 2019), when aircraft fatigue is ignored or not identified on time, structural failure results. Detecting cracks is particularly difficult because most of them are initially undetected to the naked eye, thus the development of programs and software that can make it possible for machines and computers to see cracks and be able to see failure can prevent accidents and incidents from happening.

1.2. Theoretical Framework

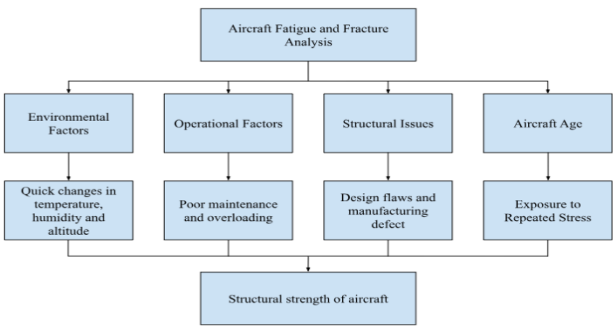
Figure. 1: Flow Chart for Fatigue Strength/Life Assessment Under Defects



Inspection may be required in evaluating fatigue life components based on the information obtained. Information about the identified flaws is gathered in the first step of the process using a variety of techniques, including the expected area of the defect, the location of the defect, and the distribution of defect sizes. To identify its type and severity, the collected data is analyzed to ascertain its size, the location of the initial crack, the damage mechanism, and the way multiple faults interact. A defect size is chosen to make the analysis easier to understand, even though the fault would have the same expected lifespan.
As stated by (Murakami and Endo, 1994), manufacturing defects, especially those found on or near the surface, are a primary cause of fatigue cracks in engineering components. These defects can lead to fatigue crack propagation, which can ultimately fail. The size and number of these defects are often used to estimate the fatigue life components, as seen in methods like the Katigawa-Takashi diagram.
The provided flowchart outlines a general modeling process for evaluating fatigue strength and life under the influence of defects. It highlights that previous studies primarily focused on the impact of geomagnetic discontinuities or cracks caused by fatigue while neglecting the effects of defects or non-metallic inclusions within the material. The advancement of fracture mechanics theory has proven to be crucial in accurately assessing strength under the influence of critical defects, particularly when considering size effects, (Frost and Greenan, 1969).

1.3. Conceptual Framework

Figure. 2: Flow Chart for Structural Strength of an Aircraft Under Fatigue and Fracture Analysis



One of the major key portions of the modern transportation industry is the aviation sector, making aircraft a critical part of the whole industry of transportation. Rigorous assessment and close inspection of the aircraft body and engine are needed to support its continuous safe operations making sure that fatigue and fracture do not catch up to it. This conceptual framework aims to outline the essence of assessing and monitoring the aircraft quality for preventive measures. By extracting the important elements in the theoretical framework, the researchers were able to create a conceptual framework that highlights the relationship between the factors that are affecting the aircraft integrity and structural strength. The elements were connected based on the relationship between the factors stated by the researchers and the extracted elements of the theoretical framework.

Figure 2 shows that fatigue and fracture of an aircraft happen whenever an aircraft is continuously used, over time the "wear and tear" starts to appear which is caused by factors such as environmental factors, operational factors, structural issues, and Aircraft age. These factors are necessary in determining the structural strength of an aircraft. First, the environmental factors include the sudden changes in temperature, humidity, and altitude during flight operations which can gradually affect structural integrity. Operational factors such as poor maintenance and overloading can increase stress on the aircraft components and damages may be overlooked that could cause more harm than good to the aircraft. Structural issues which include design flaws and manufacturing defects could cause increased aircraft stress that may lead to potential fractures. Lastly, the age of an aircraft which reflects its exposure to repeated stress during landing and takeoff can lead to material degradation over time.

The safety of the aviation industry heavily relies on Fatigue and Fracture Assessment. All of the aforementioned factors are contributory elements in analyzing the fatigue and fracture of an aircraft.

1.4. Statement of the Problem

This study aimed to examine the relationship between fatigue and fracture in aircraft and how these factors impact safety and incidents. Specifically, the study sought the answers to the following questions:

1. Is there any significant relationship between Aircraft Fatigue and Fracture in safety incidents and accidents?
2. What are the effects of the following factors on aircraft fatigue and fracture:

- Environmental Factors;
- Operational Factors;
- Structural Factors; and
- Aircraft Age?

3. How can aircraft incidents and accidents predict similar scenarios?
4. How do rapid changes in temperature, humidity, and altitude affect the structural integrity of aircraft, leading to fatigue-related issues?
5. What role do poor maintenance practices and overloading play in contributing to aircraft fatigue and the potential for fractures?
6. Why are Environmental factors considered to be highly significant compared to other variables? (As per results and analysis of SOP 1 and 2)

1.5. Hypothesis

The study aims to provide a deeper understanding of the importance of aircraft monitoring, fatigue prediction, and fracture assessment. To determine whether aircraft fatigue and fracture in accidents and incidents have a significant relationship, many aspects must be considered. Dependent variables such as environmental, operational, and structural factors are used to fully analyze the independent variables. The null hypothesis proposes that there is no significant relationship between aircraft fatigue and fractures in accidents and incidents.

1.6. Significance of the Study

This study will be conducted to determine the relationship between aircraft fatigue and fractures in accidents and incidents. The findings of this study will be beneficial to the following:

1. Aircraft Manufacturers - This study will benefit aircraft manufacturers to innovate better aircraft designs comprised of improved materials that can withstand extreme stresses.
2. Aircraft Maintenance Technicians - This study will benefit aircraft maintenance technicians in being knowledgeable of the prevalent aircraft structural failures in the present time, which calls for more proficient measures in terms of enhancing aircraft maintenance.
3. Aircraft Operators - This study will benefit the aircraft operators in terms of maintenance cost which could be reduced if proper measures are followed to achieve aircraft operational integrity.
4. Passengers - This study will be able to give passengers enhanced safety, and reliability of aircraft, it will minimize the risk of fatigue and structural failure through meticulous maintenance and monitoring.
5. Future Researchers - Scholars and engineers that will be carrying out their research that might fall under the information within this paper, can use this to further advance their studies.

2. Methodology

2.1. Research Design

The research aims to rule out the significance of the weight of aircraft monitoring and the prediction of fatigue and fracture within the industry of aviation, furthermore assessing the influence of several factors such as operational, environmental, aircraft age, and structural conditions on the fatigue and fracture of an aircraft.

The study mainly focused on graduates of the Bachelor of Science in Aircraft Maintenance Technology. The respondents were recruited through convenience sampling and snowball sampling techniques, types of non-probability sampling. The data collection was utilized through the snowball technique using questionnaires, surveys, and one-on-one interviews. The data analysis included quantitative and qualitative or what we call the mixed method. Thematic analysis was employed during the interview to pinpoint the key factors that are influencing aircraft fatigue and fracture.

The outcome to be expected is the identification of key factors that are contributing to the key reason why monitoring and predicting aircraft fatigue and fracture is important.

2.2. Respondents

The study focused on individuals who are graduates of Bachelor of Science in Aircraft Maintenance Technology and licensed AMT personnel. These respondents were chosen based on their willingness to participate and accessibility. The respondents were invited to participate through a non-probability method which is a convenience sampling method that includes personal connections and their existing networks.

The researchers conducted an external survey with a sample size of 30. As a result of the survey, the researchers gathered 17 responses using the formula for the acceptable response rate. The computed response rate is 56.67%. The acceptable response rate for external surveys is 10% to 15% therefore the result of the survey is above the accepted response rate.

Table 1: Frequency and Percent Distribution of the Respondents that do or don’t have Professional AMT License

To get the different aspects of the respondents, the researchers set choices to identify if the respondents do or do not have a professional AMT license. Through the Snowball Technique, the researchers successfully achieved their respondents. After tallying the results, the researchers conclude that most of their acquired respondents do not have their AMT licenses at the time being. According to the results, the majority of respondents are currently pursuing their licensure training to obtain their licenses in the industry.

Table 2: Frequency and Percent Distribution of the Age Bracket of the Respondents

The researchers developed a bracket to rapidly determine the respondents' age group to gather information about their various characteristics. The following age groups can be selected: 21 - 25, 26 - 30, 31 - 35, and 36 - 40 years old. The researchers were effective in reaching their responders by using the Snowball Technique. Ages 21 to 25 had the greatest number of respondents, However, the least number are Ages 31 to 35 and 36 to 40, which have the same frequency, according to the statistics. According to the findings, the respondents are now enrolled in their licensure training and are between the ages of 21 and 25.

Table 3: Frequency and Percent Distribution of the Respondents' Years of Experience Working on the Field

The researchers developed a bracket to classify the years of experience of the respondents, thus assessing different aspects of the characteristics the respondents possessed. This bracket illustrates the distribution of respondents' years of experience among the 17 Aircraft Maintenance Technicians who participated in the research. Notably, 82.4% (14 respondents) have between 1 to 5 years of experience, indicating that most of those who took part are still at the initial stage of their careers. On the other hand, 5.9% (1 respondent each) have 5 to 10 years, 11 to 15 years, and 16 to 20 years of experience, showing that there are very few experienced technicians. The bracket reveals that the population under the survey comprises mainly technicians with 1 to 5 years of experience in the field.

The researchers have also carefully selected three informants for the interview to discuss and explain the last statement of the problem. The researchers decided to choose three Aircraft Maintenance Technicians informants on the field that can further give a more definitive explanation of the study.

2.3. Settings

This research focused on determining how vital monitoring of aircraft and prediction of fatigue and fracture assessment is in the aviation industry, and how it can assist the flight operations occurring worldwide.

The respondents of this study focused on Aircraft Maintenance Technicians, whether a license holder or not. Other personnel such as Flight Dispatcher Officers, Air Traffic Controllers, and Avionics Maintenance Technicians were not included in the scope of conducting the survey.

2.4. Instrumentation

The researchers utilized Questionnaires, Surveys, and Interviews. As for the data analysis, the researchers used Thematic Analysis and conducted a one-on-one interview with AMT professionals. The researchers used the Snowball and convenience sampling technique to gather data by asking respondents to pass on the questionnaire given to them. The instrument and procedures utilized helped guarantee the accuracy and dependability of the findings in this study. According to the information gathered from the interviews, the three licensed professionals consider environmental factors to be quite important. This only indicates that the most influential component in an aircraft was the environmental factors. As a result, the researchers developed a statement of the problem and three interview questions in regard to environmental factors.

2.5. Data Analysis

The data gathered from the respondents' answers were analyzed using a Convenience Sampling Method that relies on the accessibility of the participants to the researchers in this field. In addition, the snowball technique was used to spread the survey to reach existing communications within their reach. Moreover, the data on the interviews were analyzed using thematic analysis to know whether the following factors affect aircraft fatigue and fracture: 1) environmental 2) operational 3) structural 4) aircraft age. The same tools and method were used to determine if aircraft incidents and accidents predict similar scenarios and how rapid changes in temperature, humidity, and altitude affect the structural integrity of the aircraft and can lead to fatigue-related issues. The researchers used SPSS to measure the data they have gathered from the surveys. The frequency and percentage distribution were used to measure the respondents' frequency. As for the weighted mean, it was utilized in measuring the average of the data gathered from the surveys. To measure the relationship between aircraft fatigue in safety incidents and accidents the researchers used the Pearson correlation. Lastly, the researchers still used the same method in evaluating the data as well as thematic analysis that were gathered to know what role poor maintenance practices and overloading play in contributing to aircraft fatigue and fractures.

2.6. Ethical Considerations

The researchers credited all sources properly to ensure originality in their paper and avoid plagiarism. The researchers also assured the originality of work through verification using AI detection tools. On privacy, all the personal information that was collected was anonymous and secure. This protects both the respondents as well as encourages them to participate. All the participants were notified to ensure their comfort and then approached to ask for approval as per ethical standards.

The researchers ensured that all personal data was given confidentiality and assured participants that the research did not pose risks to their health or safety when the data seemed to be in disagreement. Locked storage ensures protection against hacking and other forms of unauthorized access to their data.

The researchers ensured all the permissions and clearances needed from the institution or company before conducting the research. There is a site representative available during the activity to assure safety and compliance. From a procedural viewpoint, all on-site procedures conform to the institution's standards in terms of safety.

Participation in this survey was strictly voluntary, although some sensitive topics would have emerged. The researchers handled discussions responsibly so no harm occurred to participants, company, or institution.

The researchers performed their research in a room with proper lighting and indicated an emergency exists. Places with industrial hazards especially those with gases and noise or oil spillage should be avoided so that everyone leaves the site of research safely. The researchers were set to have a quick response to any safety concerns so that there is minimal risk as the researchers do not bring valuables to the research site. The researchers brought their problems to the attention of representatives, school clinics, and security for prompt action. The participants were comfortable and well-informed.

The researchers realized that their presence does impact the company's or the institution's running. The researchers thus strived to introduce minimum distortion and provided inputs that may find an improvement in their processes and total functioning.

3. Results and Analysis

3.1. Statement of the Problem 1

Table 4: The Significant Relationship Between Aircraft Fatigue and Fracture and the Factors Affecting the Aircraft with Regard to License

License		
Variable	Sig.	Decision
Environmental Factors	0.008	REJECT
Operational Factors	0.195	ACCEPT
Structural Factors	0.488	ACCEPT
Aircraft Age	0.678	ACCEPT

Legend: = or < 0.05 Reject; > 0.05 Accept

The data in Table 4 shows that licensed individuals see environmental factors as heavily significant, proven by its indicated value of 0.008 and concerning the null hypothesis. On the other hand, operational factors, structural factors, and aircraft age show no significance with values of 0.195, 0.448, and 0.678 respectively. The author of "What is Aircraft Fatigue, and How Fatigue Failure Be Prevented?" (2019) stated that overexposure to high altitudes with changes in pressure depressurizes the plane hence weakening its metal. However, by the literature gathered by the researchers, it is stated that all the other factors are relevant in aircraft fatigue and fracture. This has been proven wrong by the data gathered by the researchers which shows that only environmental factors have a significant effect on the build-up of aircraft fatigue and fracture. This simply means that the most influential element in an aircraft is the environmental factors such as the pressure and weather due to high altitudes.

3.2 Statement of the Problem 2

Table 5: Standard Deviation, Weighted Mean, and Remarks of the Respondents on the Effects of the Following Factors on Aircraft Fatigue and Fracture

	Statement	SD	Mean	Remarks
Environmental Factors	There is a correlation between high altitude, changes in pressure, and the development of fatigue in aircraft metal.	0.49459	3.65	Strongly Agree
Operational Factors	There is a big factor in aircraft fatigue and airworthiness when considering seat loads and cruise altitudes.	0.62426	3.47	Agree
Structural Factors	There is a determinant in aircraft accidents and incidents when considering aircraft design.	0.61835	3.41	Agree
	There is a significant correlation between corrosion and fatigue life in aluminum alloys used in aircraft's structures.	0.70189	3.35	Agree
	There are tools to accurately predict the growth of small cracks.	0.50730	3.59	Strongly Agree
Aircraft Age	There is a strong correlation between aircraft age and the likelihood of accidents and incidents.	0.77174	3.29	Agree
	There is a crucial link between proper maintenance on older aircraft and the prevention of accidents and incidents.	0.79521	3.41	Agree
	There is a vital role for wing fracture assessment in ensuring aviation safety.	0.62426	3.47	Agree

Legend: 3.51 - 4.00 Strongly Agree; 2.51 - 3.50 Agree; 1.51 - 2.50 Disagree; 1.00 - 1.50 Strongly Disagree

The table represents the Statement of the Problem which focuses on what are the effects of the following factors on aircraft fatigue and fracture. The content of the table is the following statements that could help the researchers in determining what are the effects of the factors on aircraft fatigue and fracture. Based on Table 5, most of the statements agreed except that the first statement has the highest mean with 3.65 which indicates that most of the respondents have the same response in stating that there is a correlation between high altitude, changes in pressure, and the development of fatigue in aircraft metal. On the other hand, the sixth statement has the lowest mean result with 3.29 which indicates that respondents have the same response. With the results gathered, it can be concluded that there is a correlation between high altitude, changes in pressure, and the development of fatigue in aircraft metal. A study by (Stamoulis et al., 2016), identified the key environmental factors causing the failure modes of aircraft that result in major accidents to be fatigue and corrosion. Additionally, the author of "What is Aircraft Fatigue, and How Can Fatigue Be Prevented?" (2019) stated that overexposure to high altitudes with changes in pressure depressurizes the plane, hence weakening its metal.

3.3. Statement of the Problem 3

Table 6: Standard Deviation, Weighted Mean, and Remarks of the Respondents on How Aircraft Incidents and Accidents Predict Similar Scenarios

Statement	SD	Mean	Remarks
There is a strong consensus that system thinking is invaluable in understanding and preventing accidents.	0.77174	3.30	Agree
There is a need to study incident patterns so that it can become helpful in preventing accidents.	0.50730	3.59	Strongly Agree
There is a strong correlation between creating effective structural models and understanding aircraft safety incidents.	0.46967	3.71	Strongly Agree
There is an importance in the study and analysis of aircraft fractures to help prevent aircraft accidents.	0.49259	3.65	Strongly Agree
There is an integration of decision support systems (ex. Bayesian Belief network) that is helpful in managing risks in aircraft fatigue and fracture.	0.69663	3.12	Agree
There is a significant benefit to using predictive measures based on past incidents to prevent similar accidents, especially in the realm of aircraft fatigue and fracture.	0.68135	3.42	Agree
There is a possibility to avoid undesirable consequences, such as death, through the use of predictive decision analysis.	0.79521	3.42	Agree
There is a possibility for improved decision support systems, like DSSs, to accurately predict aircraft incidents.	0.50730	3.59	Strongly Agree

Legend: 3.51 - 4.00 Strongly Agree; 2.51 - 3.50 Agree; 1.51 - 2.50 Disagree; 1.00 - 1.50 Strongly Disagree

Based on Table 6, most of the statements agree except for the third statement with the highest mean of 3.71 in which respondents agree indicating that most of the respondents have the same response in stating that there is a strong correlation between creating effective structural models and understanding aircraft safety incidents. On the other hand, the fifth statement has the lowest mean result with 3.12 which indicates that respondents have the same response. With the results gathered, it can be concluded that there is a strong correlation between creating effective structural models and understanding aircraft safety incidents. A study on the effects of corrosion on fatigue life for aluminum alloys in aircraft structures was conducted by (Kamath et al., 2022), who researched both pre-corroded materials and ongoing corrosion with crack models and fatigue analysis to determine the component durability.

3.4. Statement of the Problem 4

Table 7: Standard Deviation, Weighted Mean, and Remarks of the Respondents on How Rapid Changes in Temperature, Humidity, and Altitude Affect the Structural Integrity of Aircraft, Leading to Fatigue-Related Issues

Statement	SD	Mean	Remarks
There is a combination of environmental factors and aging aircraft construction materials leading to more frequent maintenance issues.	0.51450	3.53	Strongly Agree
There is a phenomenon known as cold expansion, which is a key factor in the study of crack growth.	0.51450	3.53	Strongly Agree

Legend: 3.51 - 4.00 Strongly Agree; 2.51 - 3.50 Agree; 1.51 - 2.50 Disagree; 1.00 - 1.50 Strongly Disagree

This table represents the Statement of the Problem which focuses on the frequency of maintenance issues and their contributing factors. The statements in the given table helped researchers identify how rapid changes in temperature, humidity, and altitude affect the structural integrity of aircraft, leading to fatigue-related issues. Both statements have the same mean value of 3.53, suggesting that the respondents of the survey strongly agree with the statements about environmental factors and aging aircraft construction materials that contribute to maintenance issues. The standard deviation of both statements is equal to each other indicating a moderate level of agreement that may vary on the responses. A study by (Main et al., 2024) develops cold expansion techniques for the small crack management of aircraft. In addition, according to the study by (Venugopal et al., 2021), the airframes are susceptible to corrosion in high-temperature and humid environments. However, thorough maintenance can likely prevent it from adding up to other maintenance issues.

3.5. Statement of the Problem 5

Table 8: Standard Deviation, Weighted Mean, and Remarks of the Respondents on What Role Poor Maintenance Practices and Overloading Play in Contributing to Aircraft Fatigue and the Potential for Fracture

Statement	SD	Mean	Remarks
There is a result of lack of experience and unfavorable environment that contributes to poor quality maintenance.	0.51450	3.53	Strongly Agree
There is inadequate maintenance, which is another leading factor in aircraft accidents.	0.51450	3.47	Agree

Legend: 3.51 - 4.00 Strongly Agree; 2.51 - 3.50 Agree; 1.51 - 2.50 Disagree; 1.00 - 1.50 Strongly Disagree

The given table, which constitutes the Statement of the Problem aimed at understanding the factors that can contribute to aircraft fatigue and fractures. This table focused on the roles of poor maintenance practices and overloading. The statements in the given table helped the researchers identify what role poor maintenance practices and overloading play in contributing to aircraft fatigue and the potential for fractures. By analyzing the table, it was seen that both statements received an agreement from the respondents. It highlighted the negative impact of lack of experience and unfavorable environment on maintenance quality which has a weighted mean of 3.53. Similarly, the second statement emphasized the inadequacy of maintenance as a contributing factor to accidents. The weighted mean on this statement is generally lower with a result of 3.47. (Nejad et al., 2021) indicate poor repairing quality which may be the result of inexperience and environmental conditions.

3.6. Statement of the Problem 6

Table 9: Master Themes Based on the Data Gathered from the Respondents, why are Environmental Factors Considered to be Highly Significant Compared to Their Neighboring Variables

Master Theme	Superordinate Theme
Environmental factors are impactful in the efficiency and safety of an aircraft.	Safety
Weather, air quality, and temperature significantly deteriorates the integrity of an aircraft.	Fatigue
Environmental factors are much more significant than operational factors, structural factors, and aircraft age.	Unpredictable

Master Theme 1: Environmental factors are impactful in the efficiency and safety of an aircraft.

Superordinate Theme 1.1: Safety

Informant 1: "… safety, making them critically important in aviation."

Informant 2: "… compromising both safety and performance of the aircraft."

Informant 3: "…greatly impact aircraft safety and reliability…"

The first interview question is about environmental factors that are impactful in the efficiency and safety of an aircraft. The informants all concurred that environmental factors affect aircraft safety. For example, takeoffs and landings are dangerous during high winds due to the aircraft structure being subjected to excessive stress, which could cause deformation or cracks. The three informants collectively said that weather, temperature, and air pressure are key environmental factors in aviation since they have a direct impact on engine performance, flight dynamics, fuel efficiency, and safety.

The production of decision support tools in the aviation industry is vital in predicting occurrences to establish safety in airport operations (Flores et al., 2022). These tools can be used for medium to long-term forecasts, from predicting turbulence to forecasting weather. Nonetheless, these tools are not meant for the industry to be solely dependent on it, as it only serves as a guiding tool to enhance aviation safety.

Master Theme 2: Weather, air quality, and temperature significantly deteriorate the integrity of an aircraft.

Superordinate Theme 2.1: Fatigue

Informant 1: "…..that lead to material fatigue."

Informant 2: "......exposed to moisture and fatigue….."

Informant 3: ".....can affect aircraft components and maintenance…."

The responses gained from the informants pertain that environmental factors such as weather, air quality, and temperature produce a higher risk of aircraft fatigue during flight operations, which greatly affects the integrity of an aircraft.

Stretching the discussion, severe weather, unpredictable environment, and exposure to moisture can cause weakening in the components and also the electrical system of the aircraft. Severe environment pushes engines to perform at full capacity leading to stress and constant exposure to fatigue. By common understanding, a material that is overly exposed to stress leads to fatigue that later on poses a great threat to safety.

To strengthen the claim the research titled "What is Aircraft Fatigue, and How can Fatigue Failure be Prevented?" (2019) that weather, air quality, and temperature significantly deteriorate the integrity of an aircraft, because of the atmospheric conditions, for instance the fluctuating pressure differences and extreme temperature. This further deteriorates the integrity of an aircraft.

Master Theme 3: Environmental factors are much more significant than operational factors, structural factors, and aircraft age.

Superordinate Theme 3.1: Unpredictable

Informant 1: "…more dynamic and unpredictable…"

Informant 2: "...uncontrolled and unreliable…"

Informant 3: "... can't control external events…"

The third interview question aims to know why environmental factors are much more significant than the other factors stated in the research. All the responses collected by the researchers state the same idea about environmental factors and why it is much more significant than the other factors in this research. The informants all assert that this is because environmental factors are unpredictable and are hard to foresee since they vary from time to time. Moreover, the respondents stated that the other factors are much more predictable and controlled. The informants articulated that aircraft structure is built to withstand environmental changes and that aircraft age is not as significant because aircraft are maintained on a routine basis.

"What is Aircraft Fatigue, and How Can Fatigue Failure be Prevented?" (2019) directly supports the master theme 3 as environmental conditions impose distinct types of stresses on aircraft structure. Compared to aircraft age, operational factors, and structural factors, environmental factors can introduce complications that are harder to mitigate, such as pressure and altitude which can be considered to be a significant contributor to aircraft deterioration.

4. Discussion

4.1. Conclusions

Based on the results and analysis, the following were concluded:

1. The presented results of this study effectively explain safety incidents and accidents that contributed to understanding the aircraft fatigue and fracture relationship. Aircraft fatigue and fracture are significantly influenced by operational, structural, and age-related factors. However, researchers found no significant link between environmental factors and fatigue-related fractures in aviation accidents and incidents.
2. According to statistical analysis done in the study, the researchers conclude that the environment-based causes of aircraft fatigue and fracture are primarily high altitude and pressure variations. This is in light with other literature that captured environmental effects to have weakened aircraft structural capacity through fatigue and corrosion.
3. The findings of the research are therefore perceived to substantiate the role of system thinking, the pattern of incident analysis, and structural modeling to enhance the air safety of aircraft. It also identifies the importance of aircraft fracture analysis and the effectiveness of decision support systems for risk management and the avoidance of mishaps emanating from fatigue and fracture of aircraft.
4. Based on the findings, environmental influences and aging of the aircraft constructional materials are the two sources that increase maintenance. Further, the study has identified the need to understand cold expansion technology in connection with cracks in the evaluation of an aircraft's structure. These findings suggest precautionary measures concerning aircraft maintenance as well as elaborate visual assessment methods that minimize the hazards of aircraft degradation and the environment.
5. As for the poor maintenance, it can be assumed that it could be caused by several complex factors including the insufficient experience of organizations and unfavorable conditions under which people operate, as well as the poor maintenance management. This would still further increase the level of aircraft accidents. These findings, therefore, have outlined it as containing innovative importance which must be addressed with overall skill development, enhancement of working conditions, and adherence to maintenance regimes. The factors being highlighted above can complement the quality of the practice of maintenance and significantly cut down on accident risks.
6. The results of the study highly indicate that environmental factors indeed induce important safety and efficiency degradations of aircraft. Precisely, weather, air quality, and temperature are the crucial deteriorating elements that accelerate the crash condition of aircraft integrity. Further research studies indicated that environmental factors have a significantly influential effect compared to operational, structural, and age-related factors. Such research findings appealed to careful consideration of environmental conditions in aircraft maintenance, operations, and design for ensuring safety and longevity.

4.2. Recommendations

Based on the discussed conclusions, the recommendations are as follows:

1. The study encourages aircraft manufacturers to further research and develop innovative solutions to

address any problems that can impose danger to the aircraft with the use of Bayesian decision analysis, machine learning techniques, and decision support systems. By choosing materials that are resistant to both stress and fatigue, the designers of an aircraft can create different structures that can adapt quickly to the changes in environmental factors.

2. The study urges aircraft manufacturers to develop real-time monitoring systems to track the aircraft's structural integrity and to prevent aircraft accidents and incidents. Through this research, aircraft manufacturers can gain valuable information that can help with the development of the long-term performance and durability of an aircraft.
3. By analyzing real-time data on aircraft's health, aircraft maintenance technicians can make informed decisions and allow time for repairs reducing catastrophic failures. Moreover, aircraft maintenance technicians can seek recommendations from experts in the field who can provide knowledge and valuable feedback that will assist the aircraft maintenance technicians in the prevention of accidents and incidents.
4. The study motivates airline operators to invest in advanced technologies to improve the accuracy and reliability of data that can assist in the prevention of disasters. It promotes detailed studies of the effects of external factors on aircraft materials and structures. Additionally, to develop a set of guidelines for maintenance routines to prevent the accumulation of fatigue.
5. Maintenance of aircraft must be meticulous in ensuring the safety of passengers. Minimizing the risk of both fracture and fatigue in aircraft, as this is the foundation of trust between the aviation industry and passenger relationship.
6. This study will be an encouragement to researchers to act as a foundation for further and deeper research towards the study of aircraft safety and aviation development for safety and efficiency. Furthermore, to develop a more efficient and effective way of monitoring and assessing aircraft fatigue and fractures.

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