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AERODYNAMIC STUDIES OF FLOW CONTROL METHOD USING UTM AEROLAB NACA-0012 AIRFOIL

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Abstract: Many studies have shown that boundary layer tripping is able to delay separation and remove separation bubbles at low Reynolds numbers. However, the effects of boundary layer trip at moderate Reynolds numbers have not yet been well documented. In conjunction to this, the primary objective of this study is to investigate the effect of different transition strip (TS) locations on flow topology on the upper NACA-0012 airfoil and also its corresponding aerodynamic performances at Reynolds number of 1 million. The smooth tape surface is attached at three different locations: 0.0%, 3.8% and 8.8% x/c of the NACA-0012 airfoil. Pressure across the airfoil was measured through electronic pressure scanner. From the results, different strip locations had been shown to affect the flow control above airfoil, which was either to delay or promote separation. Delaying the flow separation can improve lift performance of the wing.

Keywords: flow control; transition strip; flow separation; NACA-0012

1. Introduction

The presence of boundary layer will have some effects on any objects passing through fluid. These viscous fluid effects contribute towards skin friction drag where the drag effects are more pronounced for higher turbulent flows [1]. Moreover, due to adverse pressure gradient across the object's surface and the nature of laminar instability, an abrupt flow separation might occur that significantly increases the pressure drag and results in stall conditions. In this case, the boundary layer might be fully detached from the surface or reattached back on the surface forming laminar separation bubble. To date, various methods have been implemented to control the boundary layer [2]. When manipulating boundary layer, the applied control method can be categorized as either active or passive. In general, the passive flow control has the main benefits of not requiring any external energy. For instance, mechanical turbulators have been applied since the early 20th century to prevent flow separation and laminar separation bubble [3]. This mechanical turbulator could be in the form of vortex generator, transition strip and riblets. It trips the boundary layer, which causes an early transition from laminar to turbulent flow and therefore preventing laminar flow instability across airfoil surfaces [4].

At the moment, the transition strip has found numerous applications in manipulating the boundary layer [5]-[7]. Transitioning boundary layer at the leading edge helps to reduce the risk of laminar bubbles bursting into flow separation [8]. In addition, the emerging utilization of unmanned aerial vehicle (UAV) and wind turbines that operate up to Reynolds number of 2×10^6 has led researchers to investigate the effects of strip at low Reynolds number [9]-[10]. At low Reynolds number, the focus has been to prevent

any occurrences of laminar separation bubbles and flow separation. Many of such studies have already been conducted but they mostly cover only Reynolds number ranges between 50,000 to 500,000. In the meantime, NACA-0012 airfoil has been well-established in academic researches for the boundary layer studies. However, it can be noted that the effects of the transition strip on separation bubble and flow separation have been less documented on NACA-0012, particularly at Reynolds number above 500,000. It is believed that the proper settings of strips location, heights and surface properties can lead to a wide range of possibilities in optimizing the prevention of separation and the improvement of aerodynamic performances. In conjunction to this, the objective of this research is to study the effect of transition strip on flow characteristics of NACA-0012 and its performances at moderate Reynolds number.

2. Methodology

In this study, NACA-0012 airfoil model with a chord length of 500 mm and a span of 1498 mm is used as shown in Figure 1. It has a maximum thickness 12% that is located at 30% of the chord length. A total of 32 pressure taps are used to measure the pressure distribution across this NACA-0012 model, in which 16 taps are dedicated to each upper surface and lower surface. This airfoil model is then tested using the wind tunnel facility at Universiti Teknologi Malaysia Aerolab. Test section of the wind tunnel has dimensions of 5.8 m length, 2.0 m wide and 1.5 m height. It should be noted that, since the height of the test section is approximately equals to the span of the airfoil model of 1.48 m, the air flow through the airfoil can be considered as two-dimensional (2D).



Figure 1: NACA-0012 model used for this flow control study

As depicted in Figure 2, an electronic pressure scanner of FlowKinetics LLC-FKPS series with 30 independent pressure scanners are used in this study. Pressure taps from the airfoil model are connected to the pressure scanner through a long small tube. A single pressure tap from pre-wind tunnel section is set up to measure the freestream static pressure. 29 out of the 32 taps on airfoil's surface are used to obtain the pressure across the airfoil. One pressure tap located on the top surface and two taps at the lower surface located at the trailing edge have been chosen to be sacrificed since major adverse pressure gradient occurs at leading edge.

The room temperature at the wind tunnel facility during the experiment is measured at 29°C using a barometer. Given this air temperature, both the air density, ρ and kinematic viscosity, μ are calculated as 1.168 kg/m³ and 1.855 kg/m-s, respectively. The freestream velocity is set to be 30 m/s, which results in a Reynolds number of 945,000. In case of angle of attack, α , the selected values are within the range from -4° to 18° with 2° increment. Transition strip utilized is a smooth surface tape type with 1.5 mm

(height) and 25 mm (width). The considered locations of the transition strip for parametric study are 0.0%, 3.8% and 8.8% x/c as shown in Figure 3.

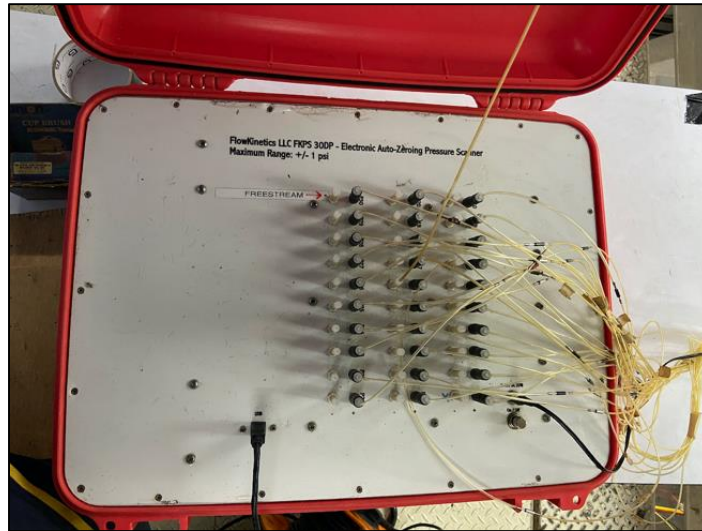


Figure 2: Instrumentation used to measure pressure across the airfoil



Figure 3: Considered strip locations for the parametric study

The wind tunnel experiment has been first conducted with a clean airfoil model. Subsequently, the experimental procedures are repeated for several different strip locations. The reading from the pressure scanner for each of the iterations, a is recorded for 10 seconds through the LabView application and they are then averaged for analysis. The pressure measurement, P is then converted to dimensionless pressure coefficient, C_p . The comparison between the clean and attached strip conditions is then made through the constructed graphs of pressure distribution and lift coefficient performance.

3. Results and Discussion

Figure 4 shows the pressure distribution for clean airfoil condition at specified range of angles of attack. Minimum pressure points are reached when $\alpha = 14^\circ$ at C_p of -3.75. Separation bubbles condition is observed at $\alpha = -4^\circ$. On the other hand, flow separation occurs at 20% x/c when $\alpha = 14^\circ$ and full separation occurs when $\alpha = 16^\circ$. The separation phenomenon on this airfoil has a short range of angles of attack with small ranges of separation point values.

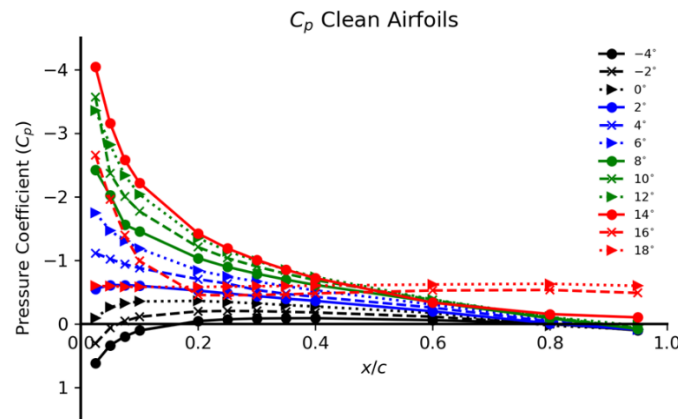


Figure 4: Pressure distribution of upper surface for clean airfoil condition

Meanwhile, Figure 5 to Figure 8 show the pressure distribution of clean versus trip conditions. The vertical dashed blue and green color represent the strip location at 3.8% x/c and 8.8% x/c , respectively. It can be seen that the pressure distribution shape behaves differently near the strip area when compared to the clean condition. The pressure distribution pattern indicates that the pressure increases before the strip and then decreases after the strip. The pressure increment before the strip area is due to reduction in the flow velocity caused by the obstruction of the strip and the pressure will reach to stagnation point locally. When the flow is about to pass through the strip, its velocity will increase and subsequently, the pressure decreases.

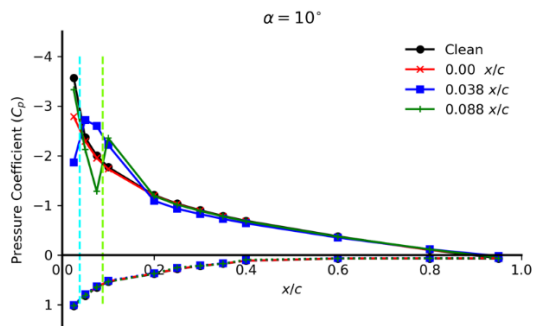


Figure 5: Pressure distribution on clean versus trip at angle of attack of 8°

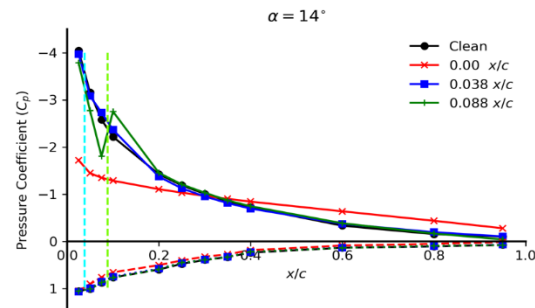


Figure 6: Pressure distribution on clean versus trip at angle of attack of 14°

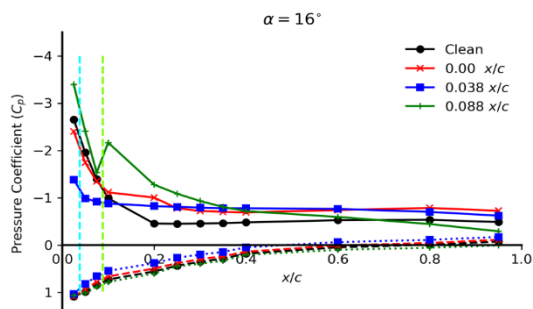


Figure 7: Pressure distribution on clean versus trip at angle of attack of 16°

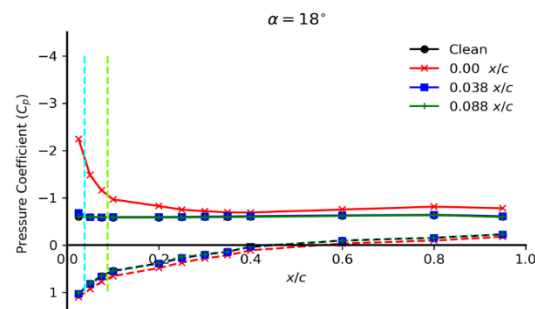


Figure 8: Pressure distribution on clean versus trip at angle of attack of 18°

The most significant effects of transition strip on pressure distributions can be observed when $\alpha = 14^\circ$ to $\alpha = 18^\circ$. For transition trip at 0.0% x/c, the minimum pressure point is lower when compared to clean condition, which is at 2.5% x/c as depicted in Figure 6. However, the minimum points might reach before 2.5% x/c, which is unknown. Referring Figure 7, which at $\alpha = 16^\circ$, transition trip at leading edge has separation bubble between 10% to 20% x/c, and the flow is entirely separated at 25% x/c. The transition strip at 3.8% x/c causes the flow to separate earlier at 5% x/c while when the transition strip at 8.8% x/c, there is no flow separation. Referring Figure 8, which at $\alpha = 18^\circ$, the transition strip at leading edge has delayed separation to 10% x/c. On the other hand, transition strip at 3.8% and 8.8% show full separation similar to clean condition, hence no effect on flow control is observed.

From Figure 9, transition strip at 0.0% x/c shows a lift improvement by 3.1% and 45.6% for $\alpha = 16^\circ$ and $\alpha = 18^\circ$, respectively, when compared to clean condition. For transition strip at 3.8% and 8.8% x/c, lift improvement/reduction is found to be -18.3% and 26.5%, respectively, for $\alpha = 16^\circ$. For $\alpha = 18^\circ$, there is no lift improvement from these two latter locations. In both conditions, there is a full flow separation that is similar to clean condition, thus no flow control effect is expected. Any transition strip attached after 0.0% x/c will not provide any improvement of lift performance since the transition strips are unable to provide any benefits of flow control if it is located at the separated flow regions. Moreover, the C_L and separation point trend with respect to strip location is similar as shown in Figure 10. This shows a correlation between C_L and flow separation point. As separation point increases, i.e. delayed, the lift coefficient is also increased and vice versa. Referring to Figure 10, the best strip location at $\alpha = 16^\circ$ is found to be 8.8% x/c since it has the highest lift improvement and highest separation delay while the best strip location at $\alpha = 18^\circ$ is 0.0% x/c since it is the only location that provides lift improvement and separation delay.

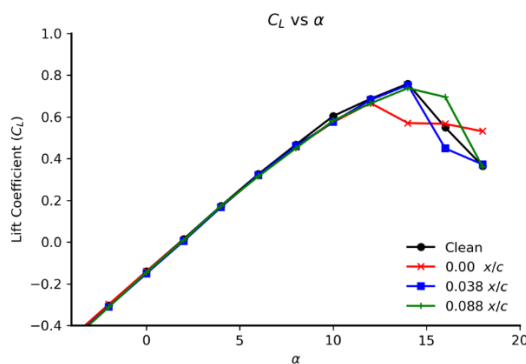


Figure 9: Lift performances clean versus trip conditions

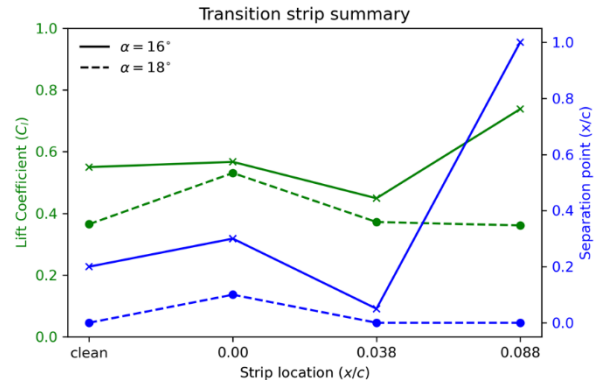


Figure 10: Lift coefficient and separation point on NACA-0012 using transition strip

4. Conclusion

Based on the obtained results in this study, the flow control using the transition strip at low angle of attack, α has been shown to have minimal change to lift performances. However, its relation to drag performance is unknown since this is not covered by this study. By moving the transition strip further behind, no linear pattern of improvement or reduction of the lift performance can be observed. For $\alpha = 16^\circ$, the transition strip's location possibilities may be varied from 0.0% to 20% x/c where separation occurs at 20% x/c. On the other hand, for $\alpha = 18^\circ$, the possible location of the transition strip might be limited to 0.0% x/c in order to ensure that applied transition strip is located before the full separation region. In future, further studies might be pursued by implementing drag measurement, additional strip design and considering additional strip locations and Reynolds numbers.

Acknowledgement

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References

- [1] L. Prandtl, Motion of Fluids with Very Little Viscosity, National Advisory Committee for Aeronautics, 1928.
- [2] M. Gad-el-Hak, 'Control of Low-Reynolds-number Airfoils: A Review', Presented at Conference Notre Dame, Indiana, USA, 1989.
- [3] C. D. Donaldson, Investigation of a Simple Device for Preventing Separation due to Shock and Boundary-layer Interaction, National Advisory Committee for Aeronautics, 1950.
- [4] B. H. Carmichael, Low Reynolds Number Airfoil Survey, National Aeronautics and Space Administration, 1981.
- [5] W. J. McCroskey, A Critical Assessment of Wind Tunnel Results for the NACA 0012 Airfoil, National Aeronautics and Space Administration, 1987.
- [6] M. Selig, J. Guglielmo, A. Broern and P. Giguere, 'Experiments on Airfoils at Low Reynolds Numbers,' Presented at 34th Aerospace Sciences Meeting and Exhibit, 1996.
- [7] W. A. Timmer and A. P. Schaffarczyk, 'The Effect of Roughness at High Reynolds Numbers on the Performance of Aerofoil DU 97-W-300Mod,' Wind Energy: An International Journal for Progress and Applications in Wind Power Conversion Technology, vol. 7, no. 4, pp. 295-307, 2004.
- [8] C. Lyon, M. Selig and A. Broeren, 'Boundary Layer Trips on Airfoil at Low Reynolds Numbers,' Presented at 35th Aerospace Sciences Meeting and Exhibit, 1997.
- [9] L. W. Traub, 'Experimental Investigation of the Effect of Trip Strips at Low Reynolds Number,' Journal of Aircraft, vol. 48, no. 5, pp. 1776-1784, 2011.
- [10] B. K. Sreejith, A. Sathyabhama and S. S. Kumar, 'Comparative Study on the Aerodynamic Performance of Airfoil with Boundary Layer Trip of Various Geometrical Shapes,' Journal of Physics: Conference Series, vol. 1854, no. 1, 012003, 2021.

RPAS TECHNOLOGY FOR ENHANCED FOD DETECTION: KLIA CASE STUDY

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Abstract: This paper is focused on the issues of Foreign Object Debris (FOD) detection on the airport runways, specifically at Kuala Lumpur International Airport (KLIA) Aerodrome. Current manual FOD detection methods are rather time-consuming, error-prone and pose risks to the aviation safety, causing operational disruptions, financial losses and possible fatal risks. The current manual procedure includes the time taken by runway safety officers to reach the search area, perform the FOD search, detect and remove the foreign objects, and potentially conduct full-length runway inspection before notifying the Aerodrome Air Traffic Controller (ATC) that the “Runway is Clear from FOD”. These procedures can lead to operational disruptions that subsequently result in unscheduled runway closures. In this study, an improved solution is proposed, which involves integration of the Remotely Piloted Aircraft Systems (RPAS) or drones, particularly those with the Beyond Visual Line of Sight (BVLOS) capabilities, into air traffic management (ATM) for immediate, accurate and reliable runway FOD detection. However, designing the safe and efficient BVLOS RPAS system within the ATM framework also presents few challenges. This research aims to develop an effective runway inspection approach within the context of ATM, considering both RPAS and traditional methods. Through comprehensive analysis, the study seeks to enhance runway safety, optimize the inspection procedures and improve the airport operation. Successful implementation of this proposed innovative FOD detection approach will maintain runway conditions, enhance capacity, minimize disruptions and improve operational efficiency.

Keywords: aviation safety; foreign object debris; RPAS; air traffic management; runway inspection

1. Introduction

The aviation industry, a testament to human ingenuity and technological progress, grapples with a range of safety and also operational challenges. Among these, the detection and management of foreign object debris (FOD) on airport runways stands out as a critical concern [1]. FOD encompasses a wide array of objects, from metallic fragments to wildlife, that capable of posing severe risks to aircraft during take-off and landing. To address these risks, airports typically rely on current conventional practices for FOD management such as employing ground vehicle inspections that depend merely on human visual capabilities. This inspection is vital for ensuring day-to-day flight safety in areas like runways, taxiways and aprons. Indeed, current FOD management practice is overseen by international aviation authorities such as the International Civil Aviation Organization (ICAO) and the Federal Aviation Administration (FAA) [2]. However, the current practice typically involves multiple steps that are time-consuming. The procedure could lead to operational disruptions, resulting in unscheduled runway closures, particularly at densely populated airspace areas such as KL International Airport (KLIA) aerodrome, which features three runways with each measuring at four kilometers in length and approximately 60 meters wide. One

of the most tragic reminders of the dangers posed by FOD on the runway is the Concorde Air France Flight 4590 near airport air disaster in the year 2000 at Charles de Gaulle Airport, France, that killed all 109 persons on board [3]. In this instance, a stray piece of metal on the runway, which was identified as a fallen FOD from a DC10 aircraft that took-off 5 minutes earlier, has led to a tire blowout, triggering a catastrophic chain of events. Modern aircraft engines, with their increasing power and also efficiency, elevate potential consequences of the FOD ingestion, therefore making the FOD management as an integral component of aviation safety [4].

The guidelines and recommendations from the ICAO and FAA emphasize systematic inspections, early detection mechanisms and immediate removal procedures to mitigate risks associated with FOD [5]. However, the guidelines normally offer a starting point, and further continuous improvement and adaptation by the local authorities are often essential. FOD management remains central to the aviation safety, demanding constant vigilance and also adaptation to technological and regulatory advancements [6]-[7]. Traditional FOD management practices, which are relying on manual ground vehicle inspection, routine patrol and human vigilance, have served the industry well but are not without some limitations [8]. Manual inspections are labor-intensive and time-consuming, which will greatly affect the operational efficiency [9]. Human error remains a big concern as many reports have shown missed FOD items [10]. Routine patrols and inspections may necessitate runway closures, disrupting aviation's tight scheduling [11]. Despite existing protocols and guidelines set forth by aviation authorities such as ICAO and FAA, the traditional methods of runway inspection, and FOD detection and removal by using ground vehicle inspection with full human intervention have demonstrated limitations in terms of speed, efficiency and accuracy, which pose a significant risk to aviation safety, particularly considering the robust rebound in recorded passenger air traffic following the post-pandemic COVID-19 period.

The advent of Remotely Piloted Aircraft Systems (RPAS) technology, commonly known as drones or Unmanned Aircraft System (UAS), has introduced a disruptive element into the FOD management. These autonomous or semi-autonomous aerial vehicles offer rapid and precise inspections of critical airport zones, including runways, taxiways and aprons. Integrating RPAS into the ATM for immediate FOD detection represents a paradigm shift in FOD management. While RPAS technology with Beyond Visual Line of Sight (BVLOS) capabilities also presents challenges, the potential benefits make it worth pursuing with several careful considerations [12]. The systematic methodology is critical to develop an effective domain-system architecture that balances safety, efficiency and also regulatory compliance. To this end, this study employs comprehensive framework that is combining Systematic Literature Review (SLR) and meta-analysis to explore the possibility and potential approach to effectively and efficiently integrate BVLOS RPAS technology into the FOD management.

2. Methodology

This study explores the integration of BVLOS RPAS technology for FOD management at KLIA through comprehensive and systematic methodology that combines SLR and meta-analysis. In general, SLR allows for the synthesis of a vast body of knowledge while meta-analysis quantitatively examines the available data to extract any valuable trends, patterns and critical insights. The overall framework is illustrated in Figure 1.

2.1 Data collection

The data collection process in this study involves gathering relevant information from published literatures and domain experts to aid in the development of effective BVLOS RPAS system architecture.

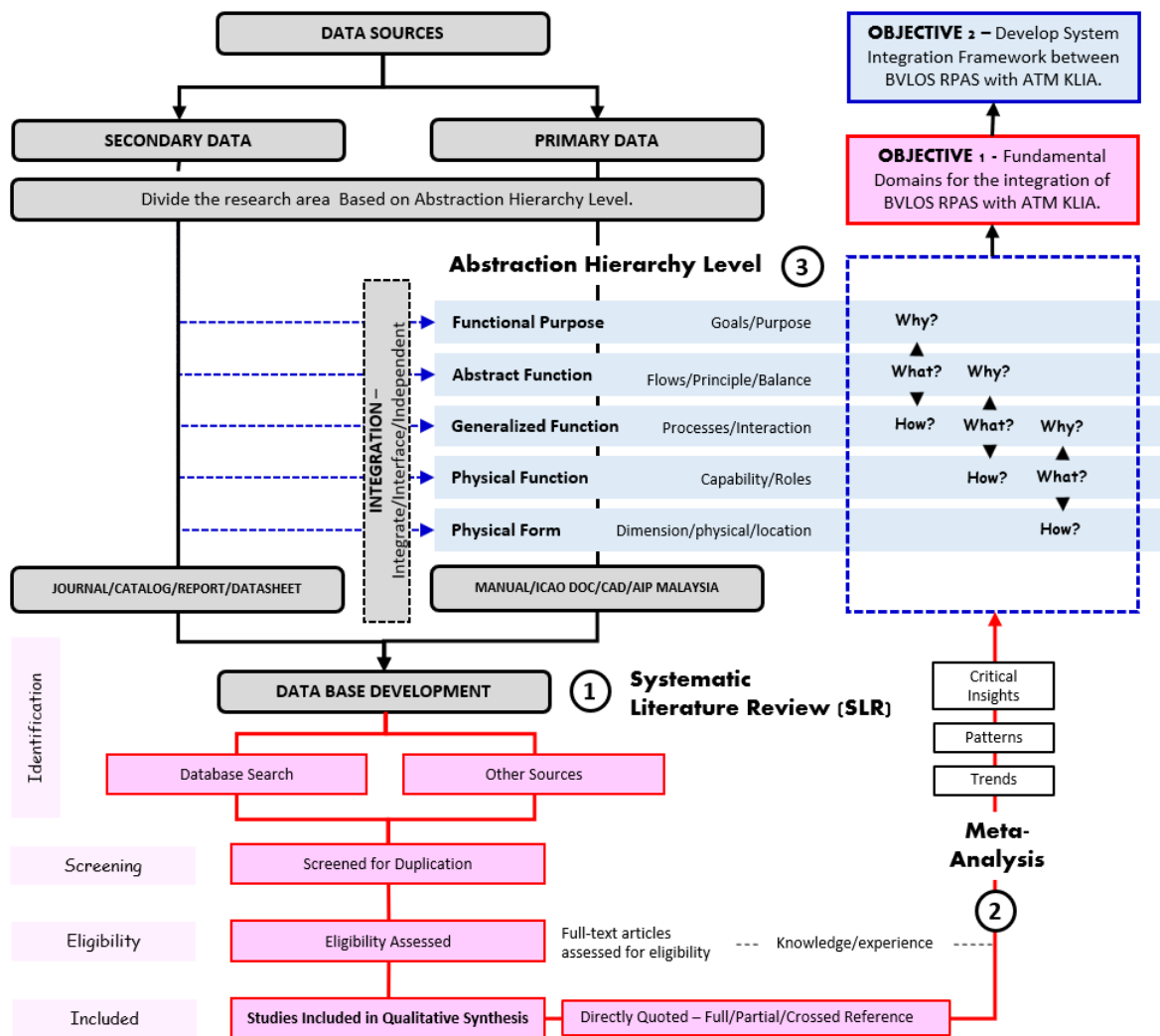


Figure 1: The overall research framework for this study

The SLR method is a rigorous approach involving setting clear inclusion and exclusion criteria and systematically extracting essential insights and findings from selected studies. In this study, it should be noted that the primary data comes from the regulators and authorities that are closely associated with the current operational procedures, representing the existing regulations for integrating BVLOS RPAS, particularly for runway FOD detection. Primary Data takes precedence over the Secondary Data, which focuses on BVLOS RPAS applications across domains, as aligned to primary data requirements. It aims to align with the requirements of Primary Data, maintaining aerodrome safety standards.

Building on the SLR findings, abstraction hierarchy theory is then applied to develop a specialized BVLOS RPAS domain framework. This involves delineating five levels of abstraction, from high-level characterizations to detailed physical forms. Such hierarchy process ensures a structured methodology that is aligned with safety, airspace management and operational procedures.

2.2 Data sources

In conducting the SLR for both primary and secondary data, a comprehensive set of data sources has been utilized, which include the following list:

- Academic databases such as PubMed, IEEE Xplore and Google Scholar to cover diverse research areas including life sciences, engineering, technology and aviation
- Authoritative documents from aviation regulatory bodies like ICAO, CAAM, FAA and EASA to incorporate guidelines and regulations
- International organizations for insights into aviation standards and recommended practices
- Specialized aviation-related websites and industry news sources for current perspectives

The reliability and validity of data sources are important selection criteria in conducting the SLR. By consolidating a wide range of literatures, this approach has enabled a holistic synthesis of knowledge from multiple disciplines that are relevant to BVLOS RPAS integration.

2.3 Data analysis

A systematic data analysis process is applied to extract the meaningful insights from the collected literature. This involves two key techniques that are tailored to specific data types. Firstly, meta-analysis is conducted systematically within the SLR to extract and synthesize information from selected studies. Key steps include data extraction, synthetization and categorization of RPAS applications into distinct domains. This process aims to provide a clear overview of BVLOS RPAS applications, together with possible integration with ATM, enhancing the understanding of their multidimensional uses. Secondly, the Abstraction Hierarchy method is applied to guide the development of the domain framework, which structures the framework into five hierarchical levels, ensuring the alignment with research objectives, addressing safety concerns, optimizing airspace management and streamlining operational procedures. Since an effective RPAS integration faces numerous challenges, including regulatory compliance, safety considerations, weather conditions, technology limitations, cost and privacy concerns [13], the resulting framework offers a holistic and adaptable solution for BVLOS RPAS usage in runway inspections at KLIA through ATM integration. In short, this method operates on five-level hierarchical structure as highlighted in Figure 2 and detailed as follows:

- **Functional Purpose:** At the highest level, it defines “Why?” the framework is needed, addressing its primary objectives in RPAS utilization for runway inspections
- **Abstract Function:** Outlines key functionalities the framework must achieve in terms of core functions and features
- **Generalized Function:** Focusing on broader operational aspects, it begins to answer “How?” the framework should operate practically
- **Physical Function:** Focus on the tangible components and operational procedures required for successful framework implementation
- **Physical Form:** Deals with specific physical forms and configurations the framework may take, addressing practical implementation and technological aspects

On the whole, the Abstraction Hierarchy method ensures a structured development, aligning with safety, airspace management and operational objectives. It facilitates a holistic approach, resulting in a comprehensive solution for BVLOS RPAS usage in KLIA runway inspections via ATM integration.

This multifaceted research strategy allows in-depth investigation into FOD management practices, exploration of the RPAS technology potential, evaluation of system architecture significance and also meticulous examination of factors influencing BVLOS integration feasibility [14]-[15]. It is essential to acknowledge inherent limitations of this study, including exclusive focus on KLIA, regulatory variances, technological and resource constraints. However, the aim is to remain steadfast in the commitment to provide invaluable insights that enhance the FOD detection and contribute to aviation safety, efficiency, RPAS integration knowledge, particularly within ATM context. This research establishes a framework that can potentially serve as an airport blueprint.

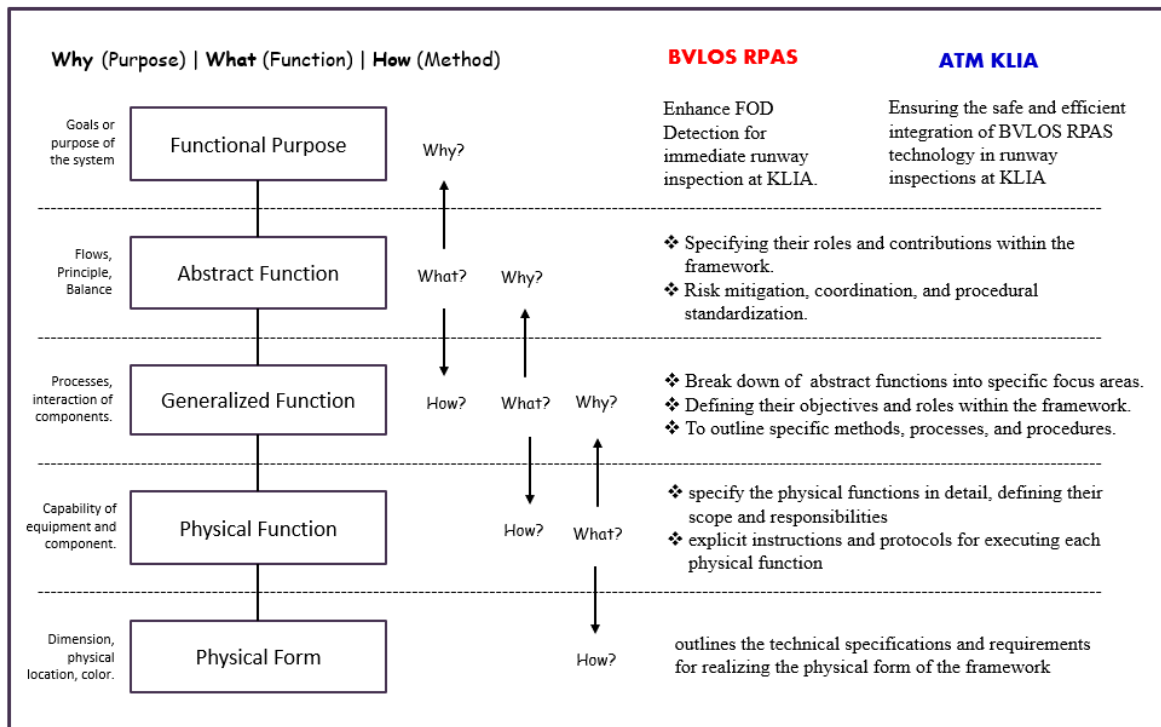


Figure 2: Schematic representation of the systematic identification of fundamental domains using Systematic Literature Review (SLR) based on the 'Why?', 'What?', and 'How?' aspects of the Abstraction Hierarchy level frameworks, contributing to the development of an integrated system architecture design

3. Results and Discussion

Figure 3 illustrates the fundamental domains identified through the combined analysis of SLR and Abstraction Hierarchy, as detailed in the methodology framework in previous Figure 1 and Figure 2. In brief, this investigation has unveiled 30 critical fundamental domains within the two major categories of core domains: BVLOS RPAS and ATM at KLIA. The findings have affirmed that the integration of the automated BVLOS RPAS technology, securely coordinated through the KLIA's ATM systems and procedures, holds the potential to significantly enhance FOD detection capabilities on runways.

The SLR has uncovered the pivotal capabilities of BVLOS RPAS that directly address limitations of current FOD detection methods. A notable limitation lies in the time required for manual inspection of lengthy runways, necessitating personnel travel and visual surface scanning. BVLOS RPAS efficiently overcomes this challenge through the rapid response, reduced inspection times and advanced sensors automating the FOD detection as highlighted by Ref. [16]. Among others, the identified key advantages include the following:

- Swift reaction and immediate response to FOD incidents, minimizing risks
- Shortened inspection and search times via wide aerial coverage and auto-pilot control
- Precision damage and FOD detection using digital imagery and advanced analysis like artificial intelligence (AI)
- Provision of live-feed data for real-time assessments by operators

The detailed insights into BVLOS RPAS technology and KLIA ATM Integration are tabulated in Table 1 and Table 2, respectively.

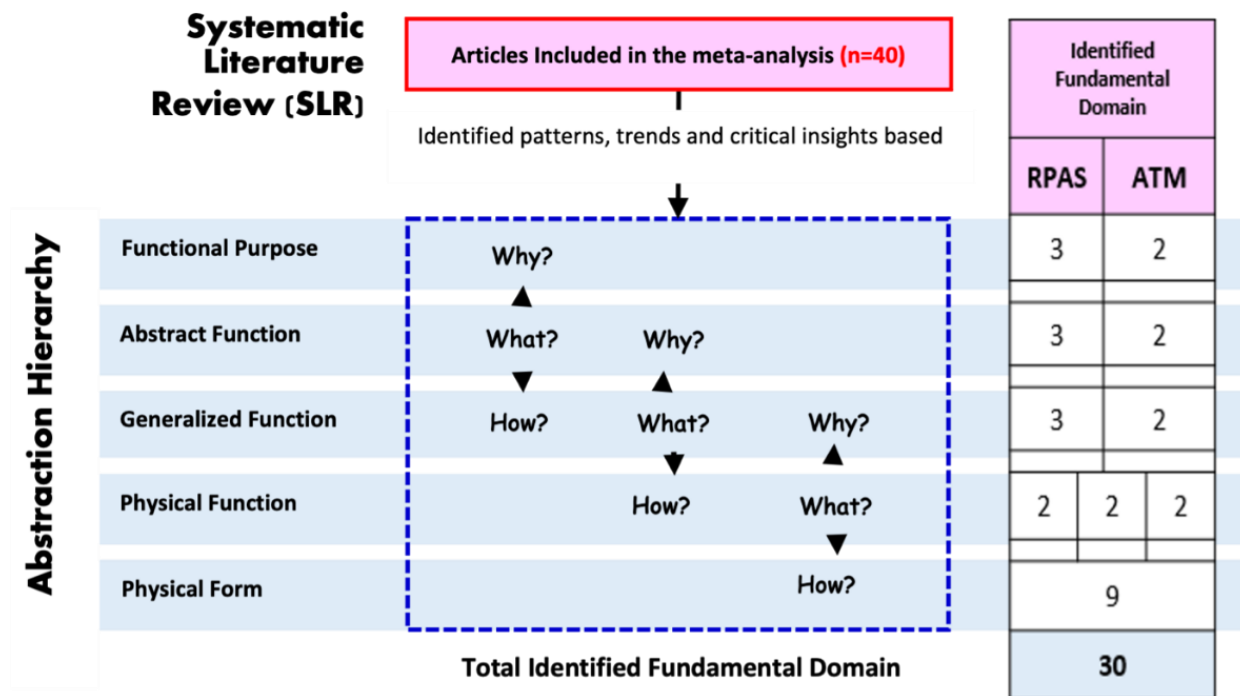


Figure 3: The recorded of fundamental domain for BVLOS RPAS and ATM KLIA

Table 1: BVLOS RPAS Technology

Findings	Implications
Swift Reaction	Rapid response to incidents, reducing assessment and mitigation times
Enhanced Efficiency	Improved runway inspections and FOD detection, minimizing closures
Precision	Detailed runway condition information for enhanced safety
Immediate Response	Swift response to FOD incidents, reducing aircraft damage risks
Reduced Inspection Time	Significant reduction in runway inspection and FOD detection time
Surface Damage Detection	Efficient detection of surface damage and FOD, enhancing runway safety
Remote Control Autopilot	Precise remote control and navigation features
Wide Field of View	Comprehensive aerial view coverage during inspections
Digital Image Analysis	Advanced analysis enhancing FOD detection accuracy
Live-Feed Data	Real-time data provision for operators, enabling timely decision-making
Flight Procedure Integration	Integration into instrument flight procedures for efficient and safe inspections
Geo-Fencing	Enhanced safety and control by restricting RPAS operations to specific areas

Table 2: KLIA Air Traffic Management (ATM) Integration

Findings	Implications
Safety Focus	Prioritization of airspace safety in aerodrome ATM procedures
Efficiency Focus	Avoidance of disruptions through coexistence with manned aviation
Situational Awareness	Necessary for safe and orderly air traffic flow, especially in mixed operations
Aerodrome Surveillance Display	Provides visual position display for ATCs, enhancing situational awareness
ATC Voice Coordination	Real-time communication between ATCs, manned aviation and RPAS operators
Report / Give Instruction	Facilitation of RPAS activities through reporting and instructions to aerodrome users
Visual RPAS Live Feed	Displays aid controllers with real-time runway condition information
Radio Communication	Ensures reliable contact between ATCs and aerodrome users

In the meantime, the Abstraction Hierarchy analysis has further delineated critical ATM integration requirements for safe and efficient BVLOS RPAS runway operations. Table 3 details the five hierarchy levels - Level 1: Functional Purpose, Level 2: What and Why, Level 3: How, What, and Why, Level 4: How and What, Level 5: How. It must be noted that a coordinated framework can provide situational awareness and communications between ATCs and remote pilots [17]. Several other elements including surveillance displays, radio voice communications, flight plans and also geo-fencing further facilitate a seamless integration. A significant finding is the efficacy of a nesting drone approach, which can enable immediate ATC activation of drones for faster FOD sites inspections as compared to traditional ground crews. Auto-pilot capabilities also precisely navigate pre-planned missions within geo-fenced areas.

Table 3: Abstraction Hierarchy Results

Level	Functional Purpose
Level 1	BVLOS RPAS: Promises fast reaction, increased efficiency and detailed accuracy ATM KLIA: Ensures safe coexistence and operational efficiency
Level 2	BVLOS RPAS: Immediate search response, shortened inspection time, surface damage detection ATM KLIA: Visual situational awareness, ATC voice coordination
Level 3	BVLOS RPAS: Digital data analysis, remote control autopilot, wide aerial view ATM KLIA: Aerodrome surveillance, report/give instruction, radio communication
Level 4	BVLOS RPAS: Robust communication, RPAS position, flight procedure design, geo-fencing, capture live feed ATM KLIA: Visual surveillance, radio voice communication
Level 5	BVLOS RPAS: Multiple nested drone units, geo-fencing, capture live feed images ATM KLIA: DPSD, Air to Ground Radio, collaboration, and communication for safety

In summary, BVLOS RPAS significantly improves the speed, accuracy and efficiency of the runway FOD detection. Integration with KLIA ATM safely coordinates their operation in active aerodromes. These findings have demonstrated that the proposed solution successfully addresses the limitations in current FOD detection practices.

4. Conclusion

This research is aimed to develop an integrated framework for BVLOS RPAS to enhance the FOD detection capabilities at KLIA airport. The limitations of current manual inspection methods include long detection times, visual scanning errors and delays responding to FOD incidents. The key findings demonstrate that an automated BVLOS RPAS integrated with KLIA ATM systems and procedures can effectively address these limitations. BVLOS RPAS can enable rapid and frequent inspection of runways with advanced sensors providing detailed damage and FOD detection data. Coordination through ATM elements like surveillance, communication protocols and flight plans is necessary to allow safe operation in active aerodromes. A major innovation is the proposed nesting drone approach, which allows ATCs to immediately dispatch drones to inspect FOD sites faster than waiting for ground crews. This reduces occupancy times and risks. The comprehensive framework integrates the strengths of BVLOS RPAS and KLIA ATM to optimize FOD detection capabilities.

In conclusion, this research lays a strong foundation for enhancing the airport's FOD management through leveraging BVLOS RPAS technologies and systems. The framework provides a valuable basis for guiding effective integration to maximize improvements in speed, accuracy and efficiency. Further research can build on these findings to quantify performance gains, optimize coordination procedures, and progress towards full operational implementation at KLIA and other airports. In addition, the long-term potential is a paradigm shift in runway safety management practices through use of BVLOS RPAS capabilities.

References

- [1] R. Hussin, N. Ismail and S. Mustapa, 'A Study of Foreign Object Damage (FOD) and Prevention Method at the Airport and Aircraft Maintenance Area,' IOP Conference Series: Materials Science and Engineering, vol. 152, no. 1, 012038, 2016.
- [2] A. K. Ahmed Al Majizi, A. A. Khan and T. Hussain, 'Foreign Object Damage Detection and Elimination,' Presented at International Conference on Aeronautical Sciences, Engineering and Technology, Muscat, Oman, 2023.
- [3] E. D. Solomon and D. L. Relles, 'Criminalization of Air Disasters: What Goal, If Any, is Being Achieved,' Journal of Air Law and Commerce, vol. 76, no. 3, pp. 407-456, 2011.
- [4] J. Zhong, K. Zhang, Q. Zeng and X. Liu, 'A False Alarm Elimination Algorithm of Foreign Objects Debris Detection Based on Duffing Oscillator,' IEEE Access, vol. 10, pp. 7588-7597, 2022.
- [5] H. Yao, R. Qin and X. Chen, 'Unmanned Aerial Vehicle for Remote Sensing Applications – A Review,' Remote Sensing, vol. 11, no. 12, 1443, 2019.
- [6] K. Jeong, J. Kwon, S. L. Do, D. Lee and S. Kim, 'A Synthetic Review of UAS-Based Facility Condition Monitoring,' Drones, vol. 6, no. 12, 420, 2022.
- [7] E. V. Butilă and R. G. Boboc, 'Urban Traffic Monitoring and Analysis using Unmanned Aerial Vehicles (UAVS): A Systematic Literature Review,' Remote Sensing, vol. 14, no. 3, 620, 2022.
- [8] J. Pyrgies, 'The UAVs Threat to Airport Security: Risk Analysis and Mitigation,' Journal of Airline and Airport Management, vol. 9, no. 2, pp. 63-96, 2019.

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- [9] Y. Zhongda, L. Mingguang and C. Xiuquan, 'Research and Implementation of FOD Detector for Airport Runway,' IOP Conference Series: Earth and Environmental Science, vol. 304, no. 3, 032050, 2019.
- [10] W. Chen, 'Runway Foreign Object Detection using RGB,' The Aeronautical Journal, vol. 119, no. 1212, pp. 229-243, 2015.
- [11] G. Fizza, 'Review on Foreign Object Debris Detection Technologies and Advancement for Airport Safety and Surveillance,' Turkish Journal of Computer and Mathematics Education, vol. 12, no. 3, pp. 1431-1436, 2021.
- [12] O. Fontaine, A. Martinetti and S. Michaelides-Mateou, 'Remote Pilot Aircraft System (RPAS): Just Culture, Human Factors and Learnt Lessons,' Chemical Engineering Transactions, vol. 52, 2016.
- [13] K. Dalamagkidis, K. P. Valavanis and L. A. Piegł, 'On Unmanned Aircraft Systems Issues, Challenges and Operational Restrictions Preventing Integration into the National Airspace System,' Progress in Aerospace Sciences, vol. 44, no. 7-8, pp. 503-519, 2008.
- [14] L. Tomić, O. Čokorilo and D. Macura, 'Runway Pavement Inspections using Drone – Safety Issues and Associated Risks,' International Journal for Traffic & Transport Engineering, vol. 10, no. 3, pp. 278-285, 2020.
- [15] H. Liang, S. Lee, W. Bae, J. Kim and S. Seo, 'Towards UAVs in Construction: Advancements, Challenges, and Future Directions for Monitoring and Inspection,' Drones, vol. 7, no. 3, 202, 2023.
- [16] Z. Gui and H. Li, 'Automated Defect Detection and Visualization for the Robotic Airport Runway Inspection,' IEEE Access, vol. 8, pp. 76100-76107, 2020.
- [17] R. Fusaro, N. Viola, S. C. Aleina and G. A. Di Meo, 'Innovative Time-Based Separation Procedures for Civil RPAS Integration,' Aircraft Engineering and Aerospace Technology, vol. 91, no. 5, pp. 728-735, 2019.

A CASE STUDY OF AIRCRAFT COMPOSITE COMPONENT REPAIR UTILIZING AUTOCLAVE CURING

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Abstract: This paper presents the evaluation process of aircraft composite component structural repair of flap fairing origin for Boeing 737-800 aircraft. The intended repair has been carried out due to a wide area of damage that requires utilization of an autoclave. All preparations are carried out in accordance to the aircraft structural repair manual of Boeing 737-800 aircraft. The damage is removed via the step cutting method on the outer surface of the component prior to the inspection verification via tap test inspection. In order to prevent profile bending and torsion, the part is placed on a male mold that will be vacuumed together. The damaged area is repaired using similar materials and orientation, but with an additional layer as per prescribed in the manual. The component is then cured inside the autoclave at 121°C for two hours at a pressure of four bars. Once cured, the component is inspected through the post-repair inspection for visual and structural integrity prior to painting. The post-repair inspection has indicated that the repair has preserved the component and it is now fit to be used.

Keywords: aerospace structure; aircraft maintenance; advanced composite; curing process

1. Introduction

The utilization of advanced composite materials has increased tremendously in aircraft structural application. The capability to offer high strength and high stiffness to weight ratio, resistance to fatigue and corrosion resistance are some of the benefits acquired in utilizing these materials. As for structure materials, the carbon fiber reinforced plastic (CFRP) has been mostly used due to its reduced structural weight compared to the aluminum alloy material. Although CFRP offers significant benefit, however, it is also highly susceptible to the impact and heat damage, especially when it is used near to the aircraft engine exhaust. In general, the advanced composite materials pose challenges compared to traditional metallic material used in aircraft structure. Their failure characteristics behave differently and there is a need for new set of skills in order to repair the components. A damaged composite part will require an extensive assessment, competent staff and advanced materials to be dealing with. This paper looks into the process in carry out such repair.

The world's aircraft fleet is expected to increase from 25,900 to 49,405 aircraft between 2019 and 2039. While the more established markets of Europe and North America are predicted to increase by around 76 and 42 percent, respectively, within that period, the Asia Pacific fleet has also been expected to increase by about 139 percent to 18,770 aircraft in 2040 [1]. It should be noted that new generation aircraft are having more than 50% of its structural weight contributed by advanced composite materials. With the increasing percentage of these materials, more aircraft structural parts or components made from composites need to be maintained and repaired. Damages can be found during the manufacturing

and in service of the aircraft, in which the latter will accumulate the largest portion of defect findings and rectification. During manufacturing, defect on composite parts can be originated from micro-cracks and delamination, scratches, gouges, hole damage and impact damage [2]-[3]. These damages cannot be prevented and therefore, the acceptable thresholds are incorporated in the design by demonstrating the attainment of the intended ultimate strength with the damage present in the component through the principle of fracture mechanics. Some of these damages may go undetected or beyond the specification limits. Hence these damages should be assumed to exist within a composite component with a damage tolerant design [4]-[5]. In the meantime, during operation, aircraft are subjected to both scheduled and unscheduled maintenance inspections. For scheduled inspection, the aircraft will undergo a periodical inspection as part of a maintenance schedule to look for possible defect or damage. These maintenance interval inspection is categorized as Check A, Check B, Check C and Check D or Heavy Maintenance Visit (HMV) for continuing airworthiness. For unscheduled inspection, the aircraft need to be grounded and inspected to evaluate and rectify any identified damage for assessment. For example, impact damage such as due to foreign object debris (FOD) on the runway, ground handling, dropped parts, aircraft-handling accidents, collisions with airport structures and/or environmental factors are among the main causes of the defects [6]. More than 80% of damages to composite structures have been attributed to impact, with the remainder being attributed to environmental factors [7]. Moreover, damages occurred on the aircraft's wing area accounted for up to 13% of the total area damages, which is the fourth from the accounted location of damaged structure of a typical aircraft [8]. Figure 1 shows the typical damage extended to the laminated structure.

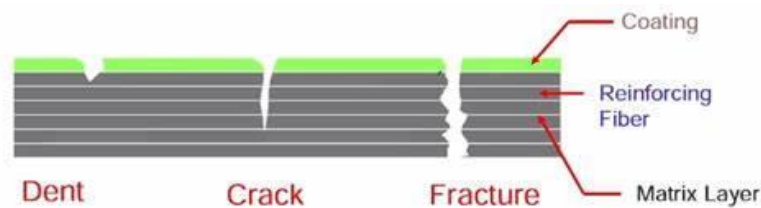


Figure 1: Typical damage on a laminated composite structure

It should be noted that the traditional repair methods based on the sheet metal philosophy cannot be used for composite parts or composites as they have transformed from drilling and cutting to laying up and trimming. A new set of skills are required and during one of the trainings conducted in UniKL MIAT, sheet metal technicians have been trained to do composite repair. This is to ensure an effective and optimum manpower usage. Furthermore, the authorities such as Federal Aviation Administration (FAA), European Union Aviation Safety Agency (EASA), Society of Automotive Engineers (SAE) have produced documents to recommend the competencies, facilities and requirement to carry out the repair of composite structure [8]-[10]. In this study, the presented case study of Flap Support Forward Fairing Panel of a Boeing 737-800 aircraft is used to demonstrate an example of repair process of the composite aircraft parts.

2. Methodology

As previously mentioned, the component of interest in this study is Flap Support Forward Fairing Panel that is situated at the bottom of the wing, which is housing the flap tracking system in order to control deployment and retraction of the flap. Due to its location, which is underneath the aircraft wing, the component is facing debris during taxing, landing and taking off, in which a high projectile of FOD can easily damage the structure. Figure 2 shows the location of the Inboard Forward Flap Fairing (IFFF) section.

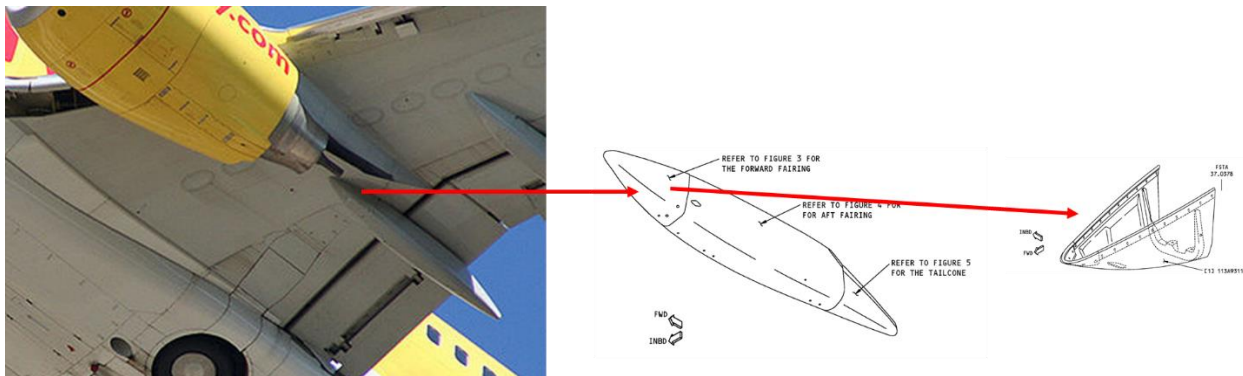


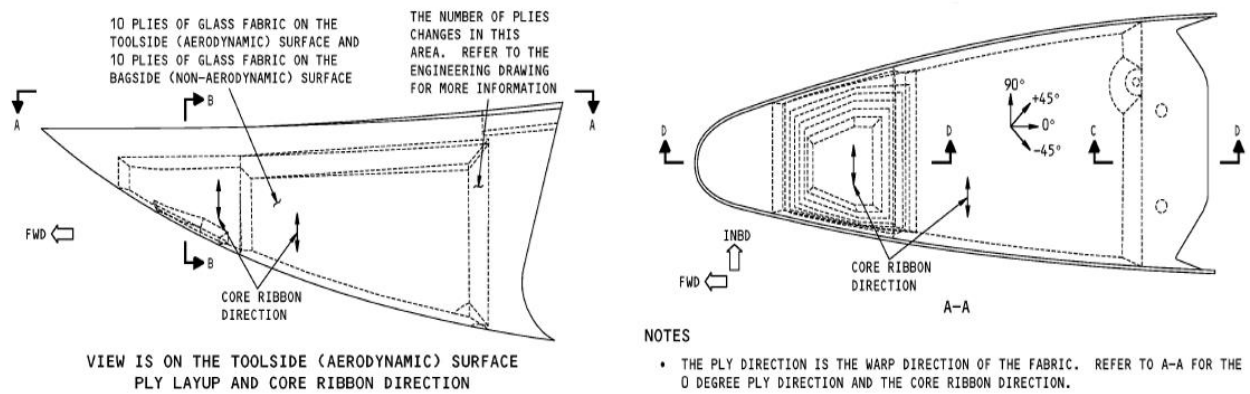
Figure 2: Location of the IFFF with respect to Boeing 737 series aircraft [11]

Upon inspecting the IFFF component, it has been found that the inboard side of the component is affected by heat damage due to its close vicinity of the exhaust area. The prolonged exposure has led to diminishing the component integrity and thus it is required to be repaired. Therefore, the objective of the task is to carry out the repair as outlined by Aircraft Structural Repair Manual (SRM) requirement. This involves utilization of the autoclave as the curing mechanism and the comparison of the outcome of curing with respect to the post-repair inspection. In short, the damage is evaluated in accordance to the corresponding SRM [10] and upon evaluation, the area subjected to damage is found to be repairable as documented in the SRM. Damage due crack has been found at the rear section of the component. It has been suggested that a major repair need to be carried out due to the fiber damage and the damage size. A preliminary evaluation is carried out to determine the extent of the damage through both physical and non-destructive testing. The damaged component is shown in Figure 3.



Figure 3: Extent of damage that is observed on the IFFF component

Furthermore, assessment from non-destructive testing has indicated that the damage is feasible to be repaired. However, due to its size characteristic, autoclave curing has been suggested for the curing of the component. This is to ensure the compaction from the pressure can assist in consolidating the repaired plies and subsequently provide a stronger and intact bonding between the original and repair layers. Further information is retrieved pertaining to related material specification and curing parameter. Figure 4 shows the configuration of the component. Upon investigation, P1 to P10 have been removed in order to go for the preparation process. Once the damaged plies have been removed, a male mold is fabricated using layer of fiberglass laminates saturated with high temperature curing resin in preparation for autoclave curing. Six layers of 400 gsm woven roving fiber glass are used, which lead to an average thickness of approximately 8 mm as depicted in Figure 5. It should be noted that the use of the male mold is to provide a positive pressure and reduce distortion whilst curing.



PLY MATERIAL AND DIRECTION OF THE FORWARD FAIRING BONDED SKIN FOR FIGURE 3 ^{T1}		
PLY	DIRECTION	MATERIAL
P1, P10, P11, and P20	0 or 90 degrees	Epoxy impregnated glass woven fabric as given in BMS 8-79, Class III, Grade B, Style 120 (Optional: Style 220)
P2 thru P4, P6, P8, P13, P15, and P17 thru P19	0 or 90 degrees	Epoxy impregnated glass woven fabric as given in BMS 8-79, Class III, Grade B, Style 1581 (Optional: Style 7781)
P5, P7, P9, P12, P14, and P16	+ or - 45 degrees	Epoxy impregnated glass woven fabric as given in BMS 8-79, Class III, Grade B, Style 1581 (Optional: Style 7781)
Filler Plies	0 or 90 degrees	Epoxy impregnated glass woven fabric as given in BMS 8-79, Class III, Grade B, Style 1581 (Optional: Style 7781) or Style 120 (Optional: Style 220)

Figure 4: Information pertaining to the component configuration [11]



Figure 5: Fabrication of in-house male mold to support the part during curing

The damaged area is removed by manually step sanded the affected area with respect to the outlined SRM procedure. The purpose of step sanding is to allow the stresses to be transferred from the original towards the repair areas and back to the original, thus minimizing stress concentration. The information with respect to the total number of layers and orientation are retrieved to replace the removed layers, inclusive with the repair plies and honeycomb material specifications. Once the plies and honeycomb have been replaced, the area are prepared for the vacuum bagging layers. In order to prevent distortion

of the part during curing, the part has been placed on top of the mold for stabilization. The material of the mold needs to be fabricated by using high temperature resin to suite with the curing environment. This is to ensure that the resin works well with high temperature curing of the part. Figure 6 shows the placement of the part on the mold and the envelope type of vacuum bagging system used to encapsulate the part for curing. The curing has taken place in an autoclave with parameters set accordingly. Prior to curing in the autoclave, the part is vacuumed at 0.75 bar (25 in Hg). After that, the consolidated set up is transported to the autoclave.



Figure 6: Positioning of the repaired panel on top of the mold and the vacuum bagging encapsulation during curing

3. Results and Discussion

Table 1 shows the setup of the curing parameters for the autoclave. The autoclave applied in this study is located at UniKL MIAT Subang, which is manufactured by ARKAMAK Inc. with an internal size of 1 m x 2 m (i.e. diameter x depth). Once the part has cured, it is removed from the autoclave and ready for post-repair inspection. A tap test, which is then followed by ultrasonic NDT, has been carried out to ensure that the part is well-cured and also consolidated. The tap test is performed by tapping from the original surface to the repaired areas and back to the original surface. In this test, a consistent thudding sound registered shows an intact bond between the repair plies to the original surface.

Table 1: Curing parameters and actual comparison

	Setup	Actual (Average)
Curing Temperature	250 °C ± 10 °C	247 °C ~ 260 °C
Curing Time	120 min	120 min
Rate of Curing	5 °C/min	5 °C/min
Rate of Cooling	5 °C/min	3 °C/min
Pressure	5 bars	4.97 bars

Figure 7 shows the curing cycle during the process. The actual and estimated curing cycles show a good argument within the boundaries result. Therefore, the process is valid and in accordance with the desired perimeter. Once the vacuum bag system is separated from the part, crevices due to resin ridge presence on the outer surface of the part can be observed as shown in Figure 7. This line is caused by the wrinkling of the peel ply and it does not dislocate the fiber. A sanding process is later carried out to smoothen the surface. Dimension-wise, the component is undistorted due to the mold holding on its position from the surrounding pressure exerted on the surface. Finally, the tap test is carried out at the locality of the repair cured area. Neither disbonding nor delamination is found to be present within the component. Overall, the process shows positive result and the component is proceeded for painting.

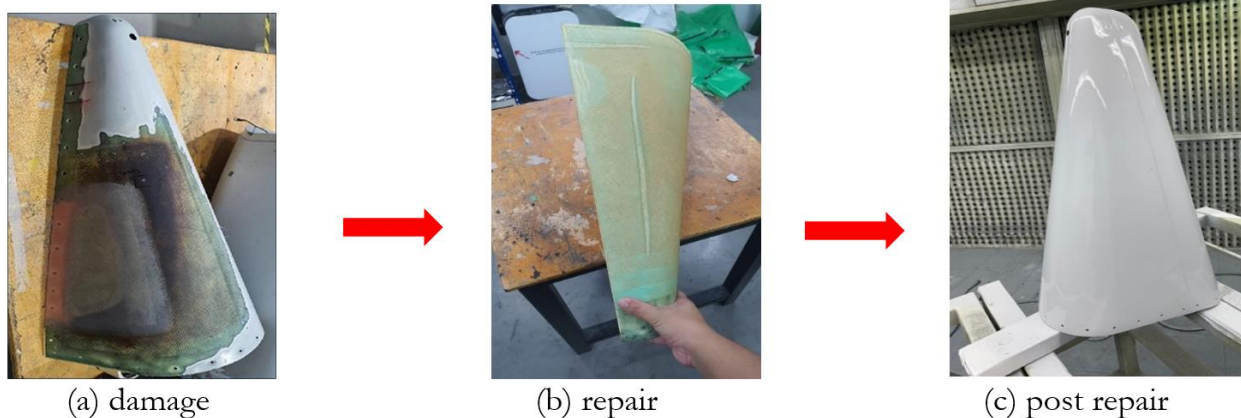


Figure 7: The repair process from damaged, repaired and post-repaired

4. Conclusion

The repair process has been carried out successfully within the set parameter. The outcome of the repaired surface shows crevices but this does not affect the strength of the component as it is within the aircraft structural repair limits. All objectives are attained and the parts have been certified to be put back in service. The part has undergone a permanent repair and have been installed back to the original position and location. The defect report has been closed and the certificate release to service is issued for it to be returned back to the respective aircraft safely. An interim inspection has been set to monitor for any degradation during its operation. Therefore, the process has been conducted successfully with respect to the manual procedures.

References

- [1] M. Y. Mohd Haris, K. D. Mohd Aris, M. Zulkifli, T. A. Abdul Razak and N. Z. Mahmud Zuhudi, 'Vacuum Infusion Simulation for Radome Manufacturing using Woven Flax Fibre and Glass Fibre,' *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, vol. 88, no. 3, pp. 49-56, 2021.
- [2] S. Dubinskiy, Y. Feygenbaum, V. Senik and E. Metelkin, 'A Study of Accidental Impact Scenario for Composite Wing Damage Tolerance Evaluations,' *The Aeronautical Journal*, vol. 123, no. 1268, pp. 1724-1739, 2019.
- [3] J. B. Robles, M. Dube, P. Hubert and A. Yousefpoura, 'Repair of Thermoplastic Composites: An Overview,' *Advanced Manufacturing: Polymer & Composites Science*, vol. 8, no. 2, pp. 68-96, 2022.
- [4] P. Boisse, *Advances in Composites Manufacturing and Process Design*, Woodhead Publishing, 2015.
- [5] K. D. Mohd Aris, F. Mustapha, S. M. Sapuan and D. L. Abang Haji Abdul Majid, 'Condition Structural Index using Principal Component Analysis for Undamaged, Damage and Repair Conditions of Carbon Fiber-Reinforced Plastic Laminate,' *Journal of Intelligent Materials System and Structures*, vol. 25, no. 5, pp. 575-584, 2013.
- [6] Q. Deng and F. B. Santos, 'Lookahead Approximate Dynamic Programming for Stochastic Aircraft Maintenance Check Scheduling Optimization,' *European Journal of Operational Research*, vol. 299, no. 3, pp. 814-833, 2022.
- [7] Z. Liang, Y. Feng, X. Zhang, T. Wu and W. A. Chaovalitwongse, 'Robust Weekly Aircraft Maintenance Routing Problem and the Extension to the Tail Assignment Problem,' *Transportation Research Part B*, vol. 78, pp. 238-259, 2015.

- [8] M. J. Davis, 'A Rigorous Approach to Certification of Adhesive Bonded Repairs,' Presented at FAA Workshop on Certification of Adhesive Bonded Structures and Repairs, Seattle, USA, 2004.
- [9] K. B. Katnam, L. F. M. Da Silva and T. M. Young, 'Bonded repair of composite aircraft structures: A review of scientific challenges and opportunities,' Progress in Aerospace Sciences, vol. 61, pp. 26-42, 2013.
- [10] C.H. Wang and C. N. Duong, Bonded Joints and Repairs to Composite Airframe Structures, Academic Press, 2016.
- [11] Boeing Inc., Boeing 737-700/800/900 Structural Repair Manual, 2013.

EMPLOYABILITY TREND OF AVIATION GRADUATES IN MALAYSIA: PRE- AND POST-COVID-19

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Abstract: At the pinnacle of the COVID-19 pandemic, aviation graduates faced substantial setbacks as numerous aviation companies were compelled to downsize their workforce due to heightened financial pressures. Notably, graduates from the class of 2020 encountered the need to pivot towards alternative fields, whether related to engineering or not, in their pursuit of employment. During this period, the efficacy of Universiti Kuala Lumpur – Malaysian Institute of Aviation Technology (UniKL MIAT) as a teaching factory initiatives was scrutinized, which was aimed to assess their practicality in mitigating the employment crisis amid the pandemic's turmoil. Nevertheless, a noticeable shift has emerged in the trajectory of aviation graduate employment as the years progressed beyond 2020. By 2021 and 2022, the sector has displayed encouraging signs of recovery. The year 2022 has witnessed significant upsurge in number of graduates successfully securing positions within the aviation industry. This phenomenon suggests two important aspects. Firstly, aviation companies are evidently ramping up their recruitment efforts to address the workforce gaps created by the measures taken to downsize during the pandemic. Secondly, the furloughed staff appears to be reluctant to rejoin the workforce, thereby creating avenue for young talents to commence their careers within the aviation sector.

Keywords: graduate employability; aviation; teaching factory; MRO; training

1. Introduction

The rapid onset and the subsequent widespread transmission of the COVID-19 pandemic have profoundly impacted many businesses. For instance, the hospitality industry, which is depending heavily on tourists and travelers, has been greatly disrupted. The effect of that leads to adverse consequences for the performance of hotels [1]. The healthcare landscape has also undergone a major transformation due to the pandemic, leading to a fresh set of obstacles that the healthcare workers have to navigate in both their professional and social spheres [2]. Furthermore, the food industries alike are also vulnerable and impacted by the profound consequences of the coronavirus pandemic as the societies practice new norms [3]. Safeguarding food safety and mitigating the transmission of the virus in the food service and retail sector has emerged as a significant challenge. This is particularly critical as this sector deals with the handling and delivery of perishable and delicate food items. These items undergo a series of crucial operational procedures, including order taking, food receiving, food preparation, packaging and delivery to customers. Fortunately, the rigid procedures and operation undertaken during the COVID days have slowly been released and uplifted as the situation gets better.

In different perspective, aviation industry is among the primary sectors that have had a devastating impact due to COVID-19, causing unprecedented disruptions and challenges. The furlough of aviation workers has been one of the most distressing consequences of the pandemic's impact on the aviation

industry. As travel demands plummeted and most airlines faced a significant financial strain, they were compelled to take drastic cost-cutting measures to survive. During the height of the pandemic, airlines had to ground substantial portion of their fleets and suspend numerous flights due to travel restrictions and border closures. As a result, the need for a full workforce diminished significantly. Many airlines had to furlough pilots, flight attendants, ground staff, maintenance crews and some other operational personnel as they could not sustain their regular workforce due to drastically reduced flight schedules [4]-[6]. The situation has also profoundly impacted the broader aviation ecosystem, including airports, aircraft manufacturers and travel-related businesses. In a 2020 report by the International Civil Aviation Organization (ICAO), there is steep decline in global air travel with a significant drop of 60% compared to the previous year 2019, which is highlighted in Figure 1. This sharp decrease equated to about 2,703 million passengers who would have travelled in 2020 if the pandemic had not occurred. The impact of this decline was substantial, with airlines suffering a staggering loss of approximately USD 273 billion in 2020 [7].

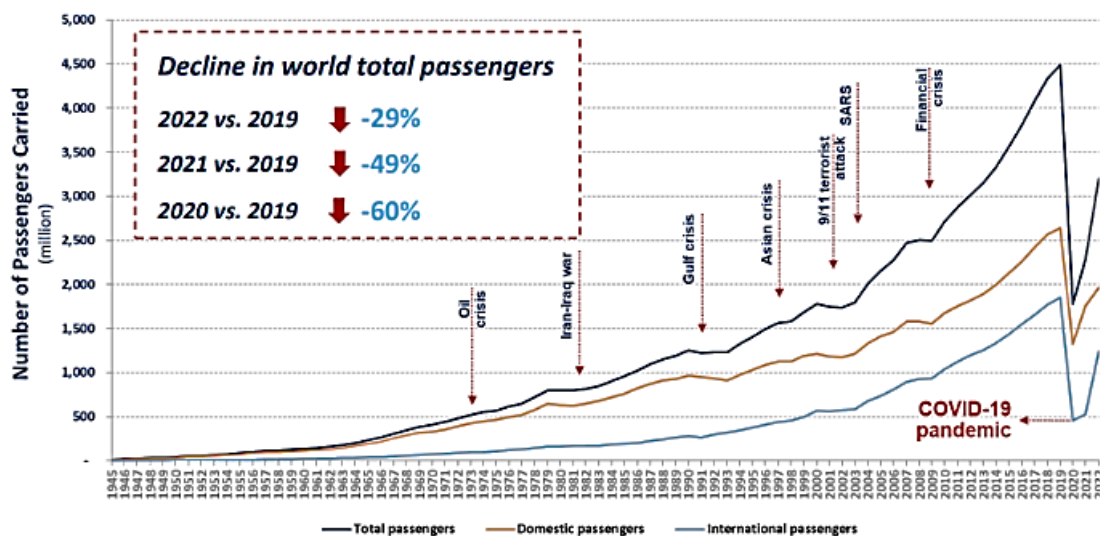


Figure 1: World traffic evolution between years 1945 to 2022 [7]

According to recent report by Malaysian Aviation Commission (MAVCOM), Malaysia’s passenger traffic has experienced a significant recovery in 2022, reaching 54.8 million passengers compared to 11 million in 2021, showing an impressive year-on-year growth rate of 399% as depicted in Figure 2. This remarkable rebound in the aviation industry can be attributed to the government of Malaysia’s decision to open borders and lift the movement control order towards the end of 2021. The easing of the travel restrictions, combined with increased vaccination efforts and restored confidence in travel, contributed to this sharp increase in passenger traffic [8]. In general, the aviation industry’s strong recovery in 2022 has demonstrated its resilience in overcoming the challenges posed by the pandemic.

However, despite the forecast of continued growth in 2023 with estimated passenger traffic ranging between 74.6 to 80.8 million, it still falls short compared to pre-pandemic level in 2019, which recorded about 109.3 million passengers. The growth of aviation industry in 2023 is impeded by several factors and among these hindering factors, the lack of staffing has been a significant issue [9]. The airlines have faced challenges rebuilding their workforce after substantial staff reductions during the pandemic. Re-employing laid-off staff has proven to be difficult, further exacerbating staffing shortage. Additionally, the Maintenance, Repair and Overhaul (MRO) industry also suffers from the shortage of maintenance manpower. As a result, airlines encounter difficulties returning aircraft to service after extended parking periods during the pandemic. These grounded planes require extensive maintenance checks but the lack of skilled personnel in the MRO industry slows down the process. Furthermore, the global geo-political

tensions have added to the slowdown in the aviation sector's growth in 2023. These tensions have had an adverse impact on the industry's supply chain, creating disruptions and uncertainties that hinder its recovery and expansion.

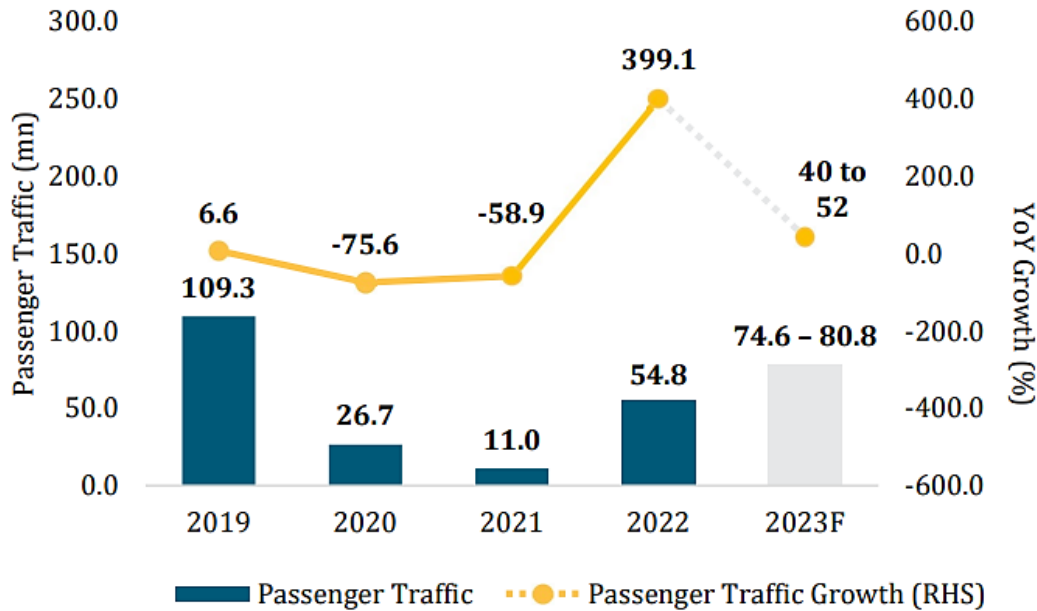


Figure 2: Malaysia passenger traffic 2019 – 2023 (forecast) [8]

In a broader context, the COVID-19 pandemic has brought significant vulnerabilities across nearly every global industry to the forefront, exposing both their structural weaknesses and also the fragility of employment. The worldwide income landscape bore the brunt of COVID-19 and the subsequent 2020 economic crisis has resulted in the substantial rise in unemployment rates [10]. Implementing the movement control orders (MCOs) by different nations has led to workforce reductions and operational cutbacks, exacerbating the financial turmoil [11]. Various enterprises and industry leaders responded by requesting unpaid leaves and layoffs to curtail operational costs and weather the pandemic's impact on their businesses [12]. This situation has endangered economic upheaval in Malaysia and escalated the vulnerability of recent graduates to unemployment risks [10]. Furthermore, the pandemic added a layer of complexity for university graduates aiming to secure positions in their respective fields.

At the same time, the shrinking of aviation job market has significantly impacted aviation graduates seeking employment. The situation could well be exacerbated by the large pool of experienced aviation workers who already furloughed, seeking re-employment when the industry began recovering [13]. This competition sometimes disadvantages fresh graduates, as employers might prioritize skilled workers to minimize training and transition time. On the other hand, it could also be a blessing and an opportunity for aviation graduates if those furloughed show a reluctance to return to service for personal reasons. Universities offering aviation are also affected as they need to provide means for graduates to cope with the career shock that comes with it. The graduate employability study is thus vital for the industry and university in adapting the program accordingly to provide good service in facing the challenges in the industry. This study will investigate the trend in aviation graduate employability during the COVID-19 pandemic and its recovery phase. Using the graduate employability data that has been released by the Ministry of Higher Education Malaysia, the study will investigate the graduates' field of employability in six months after graduation. This analysis might reveal whether any specific areas within the aviation industry have experienced more significant changes in employment opportunities compared to others.

2. Methodology

The data utilized in this study has undergone analysis, drawn from the graduate tracer study survey participated by graduates from Universiti Kuala Lumpur – Malaysian Institute of Aviation Technology (UniKL MIAT). It should be noted that MOHE Graduates Tracer Study is a survey conducted by the Malaysian Ministry of Higher Education among graduates of higher learning institutions in conjunction with their convocation ceremonies for the purpose of knowing their job status and also for getting their feedback on various aspects of their institutions. The employability rate attributed to the institution’s graduates includes those engaged in work, pursuing further education, undergoing training or upskilling, and those awaiting job placement.

UniKL MIAT, Malaysia’s premiere technical aviation institute, offers a diverse range of aviation-related educational program encompassing diplomas, bachelor’s degrees and also postgraduate degrees. In terms of diploma offerings, the institute provides programs like Diploma of Engineering Technology in Aircraft, Diploma of Engineering Technology in Avionics and Diploma of Engineering Technology in Helicopter. For those pursuing bachelor’s degrees, available options include the Bachelor of Aircraft Engineering Technology (Hons.), Bachelor of Aircraft Engineering Technology (Hons.) in Avionics and Bachelor of Aviation Management (Hons.). The postgraduate realm includes Master of Engineering Technology (Aerospace) and Doctor of Philosophy (Aerospace) programs. Additionally, UniKL MIAT facilitates Professional Certificate (Aircraft Maintenance License Program – EASA Part 66), ensuring graduates are equipped for careers spanning Aircraft Maintenance and Repair, Aviation Management, and various other professions within the aviation domain.

To scrutinize the trajectory of graduate employability for UniKL MIAT students during and after the COVID-19 pandemic, data spanning from 2019 to 2022 is examined. Table 1 displays the count of respondents or graduates from UniKL MIAT who have participated in the tracer study. Only diploma and bachelor’s degree graduates’ responses are included in this study for practical purposes. On average, approximately 687 respondents participated in the survey, with 2021 and 2020 highlighting notably high numbers of participants at 730 and 721, respectively. The response rate is 99.1% for the four years (i.e. 2019 to 2022) included for this study. For each year under examination, the graduates’ employability is dissected based on their current status at time of the survey: being employed, pursuing further studies, undergoing training or awaiting job placement.

Table 1: UniKL MIAT graduate tracer study respondents

Year	Respondents	Graduating Students
2019	639	653
2020	721	725
2021	730	733
2022	656	659

In the meantime, Figure 3 shows the employability status of UniKL MIAT students from 2019 to 2022. The graph highlights that employability status within the “employed” and “furthering studies” categories are dominant trends across the four years. However, it should be noted that this study’s main focus rests on analyzing employed graduates, with plans for future research directed towards the other employability categories.

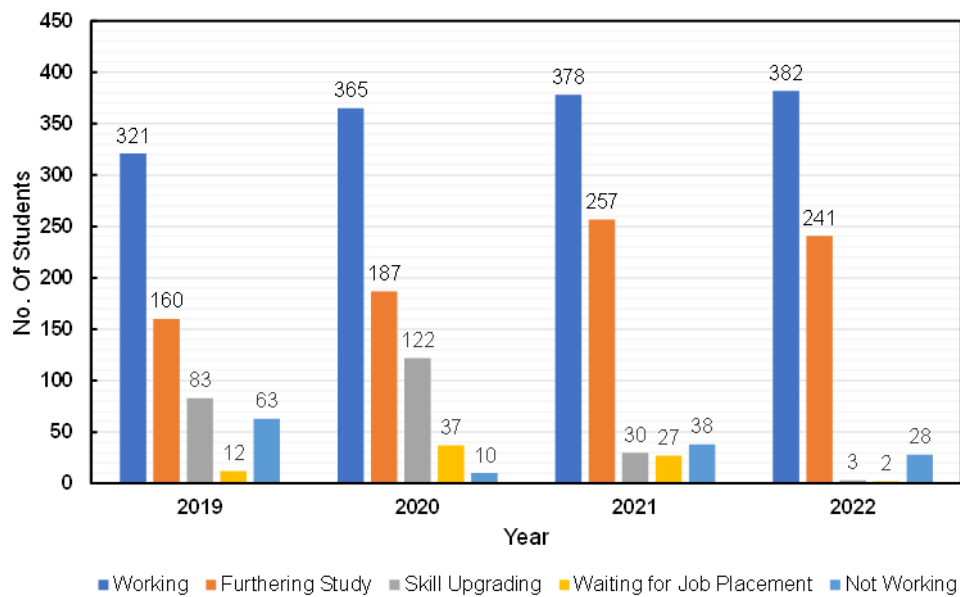


Figure 3: Students graduate employability status

3. Results and Discussion

Graduates holding employment status have consistently demonstrated an upward trend, with an average of 362 graduates securing employment in the six months' post-completion of their studies. The research additionally delves into the employment sectors of this working graduate group, categorized into three major segments: aviation, engineering-related and others. Figure 4 reveals that in year 2020, coinciding with the initial impact of COVID-19, the number of graduates employed in aviation sector has experienced substantial decline compared to the previous year, 2019, representing only 19% of the employed graduates. Amid the continued global economic strain in 2020, 40% and 41% of employed graduates managed to secure roles in engineering-related fields and other industries beyond the aviation and engineering, respectively. Meanwhile, year 2021 has shown even distribution of graduates employed across the three fields mentioned above as shown in Figure 4. While there is 12% increase in percentage of graduates employed by aviation companies in 2021, this percentage remains lower than that in 2019. The surge may be attributed to governmental initiatives in Malaysia permitting specific critical sectors, including aviation, to resume operations. Aviation companies proactively prepared their workforce with the anticipation of increased air travel demands following the easing of the movement control order (MCO) in November 2021 [14]. Nevertheless, the discovery of several new COVID-19 variants in 2021 has instilled uncertainty, leading aviation companies to tread cautiously in expanding their workforce due to concerns about managing personnel costs.

Post-COVID-19, in 2022, the employability rate for graduates seeking employment in the aviation industry has experienced a sharp increase. Notably, 56% of employed graduates secured positions with aviation-related companies. This remarkable 25% growth, compared to the previous year 2021, mirrors the trend observed in Figure 2, which indicates an upswing in the air travel demands in Malaysia. The announcement by the Malaysian government regarding the shift from pandemic to endemic measures instilled confidence, prompting companies to recruit and enhance operations to pre-pandemic levels. The concerns raised regarding the reluctance of the furloughed staff to return to service underscore the opportunity for newly graduated aviation professionals to fill the void left by staff layoffs resulting from the pandemic-related measures.

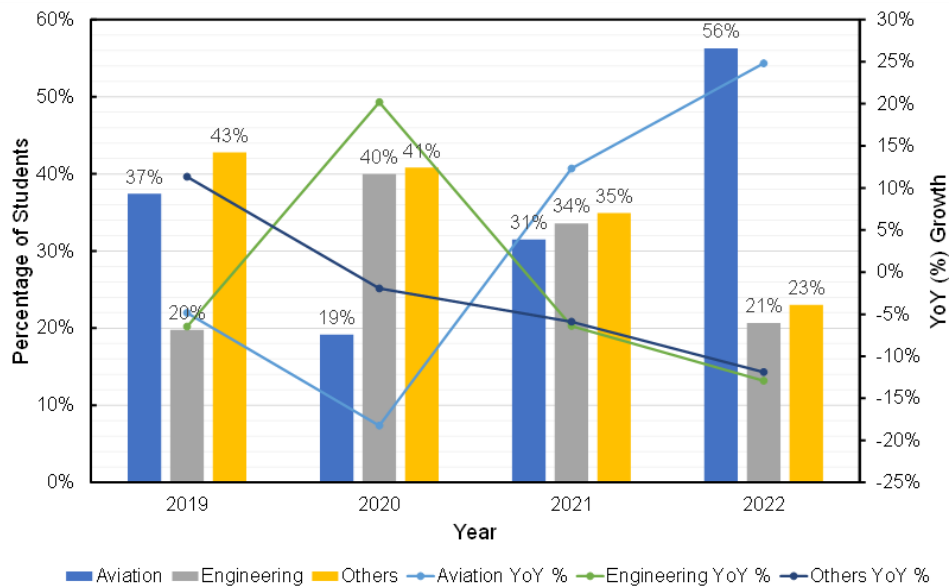


Figure 4: Graduate field of employment

UniKL MIAT has distinguished itself through its innovative Teaching Factory concept, which has been introduced in 2011. This concept is a mutually beneficial strategy that involves close collaboration with industry partners operating within UniKL MIAT’s premises. The approach fosters an environment where students and staff gain invaluable exposure to real-world aircraft industry settings and can engage in hands-on aircraft maintenance activities. Simultaneously, participating companies reap advantages such as financial benefits, reduced rental expenses and a consistent source of skilled human resources to support their operational needs. As indicated in Figure 5, particularly during the peak of the COVID-19 pandemic in 2020, UniKL MIAT’s Teaching Factory partners played a significant role in alleviating the employment crisis. Notably, 21% of the total aviation industry workforce employed that year have been sourced from the UniKL MIAT’s Teaching Factory companies. This statistic could be taken to underscore the effectiveness and also sustainability of this collaborative model, even during challenging periods that have been marked by economic uncertainty. The data demonstrates that such partnerships continue to thrive and provide valuable employment opportunities in both favorable and also adverse conditions. This signifies the resilience and adaptability of the Teaching Factory concept in maintaining a steady supply of skilled professionals and contributing positively to the aviation industry’s workforce dynamics.

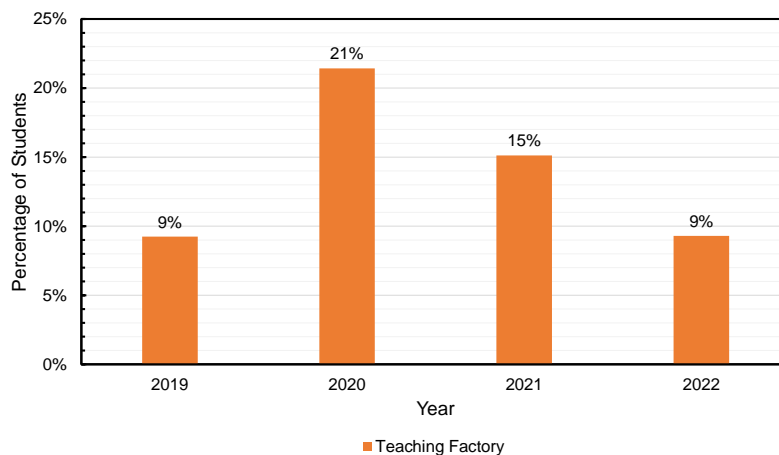


Figure 5: Job employment opportunities provided by the Teaching Factory

4. Conclusion

The aviation industry is currently experiencing an encouraging growth trajectory, accompanied by rising demand for jobs across various sectors within the industry. This positive trend bodes well for the young aviation graduates as it presents them with improved employment prospects. In order to sustain and amplify this growth in Malaysia, it is imperative to continually nurture a pool of skilled professionals to meet industry demands. Achieving this necessitates a collaborative effort between the government, universities and industry to establish a robust and sustainable framework that benefits all stakeholders involved. The Teaching Factory concept has demonstrated effectiveness, particularly during challenging times, which is emphasizing its value. This success underscores the potential for government to expand further and enhance this concept, thereby cultivating a self-sustaining ecosystem conducive to fostering industries, particularly those of high value such as aerospace. Despite the positive trajectory observed in industry growth and graduate employability within the sector, attention now shifts to critical aspect of supplying the necessary human capital to support the industry's expansion. The pandemic has cast a shadow on the industry's image, triggering big concerns about job security due to the substantial layoffs witnessed during the peak of the crisis. Such perception of instability has become the challenge for the aviation industry's human resource supply. The forthcoming future research work will delve into this very challenge, focusing on topic of human capital supply within aviation industry and the implications of the pandemic-induced shifts in job security perception.

References

- [1] A. Sharma, H. Shin, M. J. Santa-María and J. L. Nicolau, 'Hotels' COVID-19 Innovation and Performance,' *Annals of Tourism Research*, vol. 88, 103180, 2021.
- [2] M. Sengupta, A. Roy, A. Ganguly, K. Baishya, S. Chakrabarti and I. Mukhopadhyay, 'Challenges Encountered by Healthcare Providers in COVID-19 Times: An Exploratory Study,' *Journal of Health Management*, vol. 23, no. 2, pp. 339-356, 2021.
- [3] M. Shahbaz, M. Bilal, A. Moiz, S. Zubair and H. M. Iqbal, 'Food Safety and COVID-19: Precautionary Measures to Limit the Spread of Coronavirus at Food Service and Retail Sector,' *Journal of Pure and Applied Microbiology*, vol. 14, no. 1, pp. 749-756, 2020.
- [4] N. I. S. Paisan and R. Z. Wan-Chik, 'Stress Factors and the Impacts of COVID-19 Pandemic: A Review on the Aviation Industry,' in *Industrial Revolution in Knowledge Management and Technology*, pp. 51-59, 2023.
- [5] R. M. Löffert and M. Diehl, 'A Psychological Contract Perspective to Managing the Employment Relationship during the COVID-19 Pandemic in the Aviation Industry,' *The International Journal of Human Resource Management*, vol. 34, no. 15, pp. 3023-3050, 2023.
- [6] H. McLaughlin and C. Fearon, 'Labor in the Aviation Industry: Wages, Disputes and Shocks,' in *The Air Transportation Industry*, pp. 55-76, 2022.
- [7] Air Transport Bureau, *Effects of Novel Coronavirus (COVID-19) on Civil Aviation: Economic Impact Analysis*, International Civil Aviation Organization (ICAO), 2021.
- [8] *Waypoint Malaysia Aviation Industry Outlook*, Malaysian Aviation Commission, 2023.
- [9] C. Y. Yiu, K. K. Ng, C. M. Simon and C. W. Yu, 'Sustaining Aviation Workforce After the Pandemic: Evidence from Hong Kong Aviation Students Toward Skills, Specialised Training, and Career Prospects through a Mixed-method Approach,' *Transport Policy*, vol. 128, pp. 179-192, 2022.
- [10] M. A. Momen, S. H. Shahriar, N. Naher and N. Nowrin, 'Unemployment During the Recent COVID-19 Pandemic: Exploring the Perspective of Fresh Graduates from a Developing Nation,' *Economics and Business*, vol. 36, no. 1, pp. 105-119, 2022.

- [11] N. H. Abd Rahman, S. Ismail, A. R. Ridzuan and K. Abd Samad, 'The Issue of Graduate Unemployment in Malaysia: Post Covid-19,' *International Journal of Academic Research in Business and Social Sciences*, vol. 10, no. 10, pp. 834-841, 2020.
- [12] J. L. H. Nga, W. K. Ramlan and S. Naim, 'Covid-19 Pandemic and Unemployment in Malaysia: A Case Study from Sabah,' *Cosmopolitan Civil Societies: An Interdisciplinary Journal*, vol. 13, no. 2, pp. 73-90, 2021.
- [13] D. A. Spencer, M. Stuart, C. Forde and C. J. McLachlan, 'Furloughing and COVID-19: Assessing Regulatory Reform of the State,' *Cambridge Journal of Regions, Economy and Society*, vol. 16, no. 1, pp. 81-91, 2023.
- [14] R. Z. Wan-Chik, N. S. S. Zamri and S. S. Hasbullah, 'Technology Application in Airports Reopening and Operations Recovery Due to COVID-19 Pandemic,' in *Technology Application in Aviation, Tourism and Hospitality: Recent Developments and Emerging Issues*, pp. 143-166, 2022.

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