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EDITORIAL

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INVESTIGATION ON NOZZLE THROAT EROSION IN HYBRID ROCKET MOTOR DUE TO NOZZLE EXPANSION RATIO

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Abstract: Rocket nozzle is one of the core elements in rocket motors. Throughout the years, nozzle throat erosion in rocket motors has been heavily discussed by researchers, especially in the hybrid rocket motor due to a high amount of oxygen and unburned propellant in the combustion product. Generally, throat erosion occurs in the rocket nozzle throat where the flow experiences minimum area due to the dissipation of its material. The velocity of the hot gas in the nozzle increases throughout the converging-diverging section of the nozzle and such high speed at the throat area causes the throat erosion, which leads to enlarged nozzle throat area that consequently causes reduction in the motor performance. The purpose of studying the nozzle throat erosion is to have a closer reach to understanding of the nozzle throat erosion factors, behaviors and effects towards the efficiency of rocket propulsion. In this study, the primary focus is on the effects of the nozzle expansion ratio to the throat nozzle erosion. Based on the simulation results in ANSYS and theoretical calculations, it is found that the thrust decreases as the expansion ratio increases. Therefore, it is concluded that rate of nozzle erosion increases as expansion ratio increases, which is shown to be caused by high-speed velocity of the firing going through the small area of the nozzle throat.

Keywords: hybrid rocket motor; throat erosion; nozzle expansion ratio; rocket nozzle; ANSYS

1. Introduction

Hybrid rocket motor (HRM) is one type of chemical rocket motors that has been frequently looked at due to its advantages over other chemical rockets in terms of safety, low cost, restart capabilities and throttling abilities. These advantages and capabilities of HRM have attracted various amateur academic groups to continue its research [1]. Historically, developments of HRM can be detected as early as 1933 [2]. Recently, there have been studies related to the development of modern space transportation using HRM. This highlights that the progressive interest in HRM development, even among entities from the non-space-faring nations with various studies on untraditional combinations of hybrid propellant [3]. In general, HRM is considered as a combination of solid rocket motor (SRM) and liquid rocket engine (LRE). By comparison, HRM is designed to have both solid and liquid in its propulsion system while SRM and LRE respectively use only solid and liquid as their rocket fuel and oxidizer. In HRM, solid fuel is usually contained in a cylindrical form within the combustion chamber whereas the liquid oxidizer is separated and delivered to the combustion chamber through a single fluid system [4].

The interest over hybrid rocket engines has increased in recent years and various efforts have been aimed at researching these engines. In general, the presence of a solid component makes it possible to significantly simplify the design, making hybrid rocket engine as one of the most promising, powerful and simple rocket engine types. A hybrid rocket has fuel and oxidizer in different stages [5]. There are some main components in all HRMs. The first is the oxidizer tank. Though gaseous or liquid fuels and solid oxidizers might be utilized by HRMs, fuels are typically selected as the solid propellant as they are easily available and easier to handle than solid oxidizers. A key valve in hybrid rocket engines controls the oxidizer flow rate into the combustion chamber. Another main part is the combustion chamber of the traditional HRM. Dual functionality is provided by the combustion chamber in HRM. It houses the solid grain of fuel and also gives the propellants volume to mix and react. One end of the chamber for combustion contains the nozzle, where the combustion products are accelerated and exhausted out to produce thrust. Figure 1 shows the schematic view of a HRM.

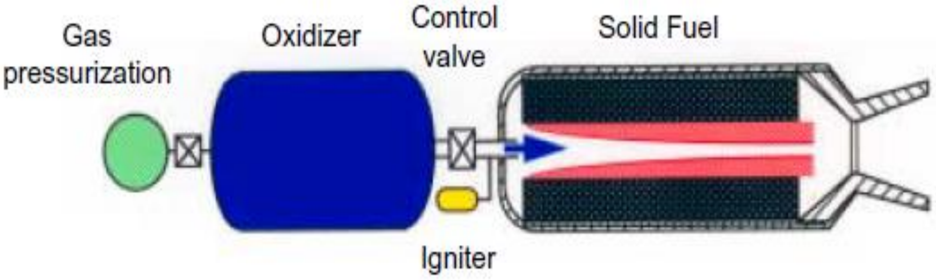


Figure 1: Illustration of a hybrid rocket system [6]

Nozzle is one of the main parts of a hybrid rocket. The propulsion and acceleration produced by a rocket happens during the firing through the nozzle. There are many types of nozzles that have been developed but the most common one is the converging-diverging (CD) nozzle. This nozzle essentially works based on the Newton's third law. In this case, the action-reaction of the rocket is produced when the hot gas leaves the combustion chamber and goes down to the smallest area of the nozzle, which is the throat. It is then expelled through the diverging section of the nozzle and, as a result, lifts the rocket upwards. Eventually, after the firing of the rocket, area around the throat section happens to experience erosion. Similarly, in the development of SRM, the nozzle throat erosion is one of the major challenges. In comparison, however, the nozzle throat erosion in HRM is significantly higher due to its distinctive feature of having greater concentration of oxygen, which affects the nozzle material behavior [7]-[8]. Subsequently, this leads to performance deterioration. Based on this realization, prediction of the throat erosion really helps in improving the development in rocket industries.

There are numerous factors that can contribute towards nozzle throat erosion. Among others, they include ratio of oxidizer to fuel (O/F), chamber pressure, fuel formulation, nozzle materials and nozzle throat parameter. Low O/F helps to reduce nozzle erosion rate since there are less free oxygen particles in the system. In addition, high chamber pressure also speeds up the nozzle erosion due to the existence of high mass flux at the nozzle throat [9]. The efficiency of rocket engine is partially dependent on the rate of nozzle material erosion caused by the flow of hot gas during the process. With the corrosion of the nozzle, the output and pressure of the rocket will decrease. For analyzing nozzle erosion, it has been demonstrated that the use of the model for classic equation of nozzle material erosion prediction has a strong agreement with experimental results [10].

This study is conducted to establish the effect of nozzle expansion ratio on throat nozzle erosion. To accomplish this, simulation modelling and analysis is performed on several CD nozzle designs with varying expansion ratio.

2. Methodology

One of the most common designs of CD nozzle is the conical nozzle. The conical nozzle has been often used in many rocket applications because of its simplicity and ease of construction [11]. Its design is not only simple but it also generates equal exit velocity to the one-dimensional value corresponding to the area ratio of nozzle throat and nozzle exit. In this study, five conical nozzle designs are considered and they are sketched and modelled in Solidworks software. It should be noted that these nozzle designs have similar length of the nozzle, inlet diameter, outlet diameter and also location of the throat to each other, which are set to 18 mm, 20 mm, 15 mm and 6 mm from the inlet of the nozzle, respectively. The only difference between these nozzle designs is their throat diameter that has been varied according to the expansion ratio. Basically, expansion ratio is the area ratio between exit area and throat area. In this study, the throat diameter is increased by 1 mm from 6 mm to 10 mm. Subsequently, the change made in the throat diameter will also change the half-angle of the nozzle design. This enables the simulation and analysis of nozzle throat erosion in optimal nozzle internal flow and abnormal conditions such as flow losses, which usually occurs when the value of half-angle exceeds 15°. All in all, the nozzle designs that are considered in this study are tabulated in Table 1.

Table 1: Expansion ratio and half-angle of the nozzle designs in this study

Throat Diameter (mm)	Half-Angle (°)	Expansion Ratio
10	11.77	2.25
9	14.04	2.78
8	16.26	3.52
7	18.43	4.59
6	20.56	6.25

For this study, the ANSYS Fluent software is utilized to simulate the flow in the nozzle and obtain resultant parameters from the analysis. In brief, the first step is to model the considered nozzle designs. The constructed drawing from Solidworks is imported into ANSYS as shown in Figure 2. If the import process is successful, the model is now ready to be meshed. In this study, the selected meshing method is the sweep method and the number of division is set to 100. Example meshed model of the nozzle is illustrated in Figure 3.

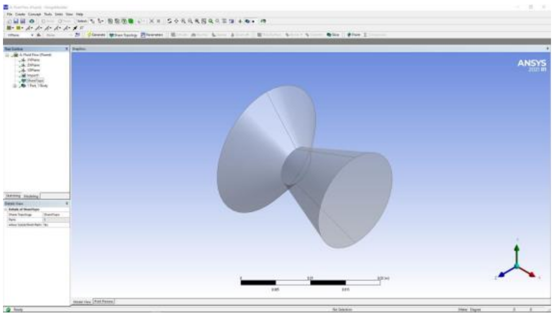


Figure 2: Imported nozzle model into ANSYS

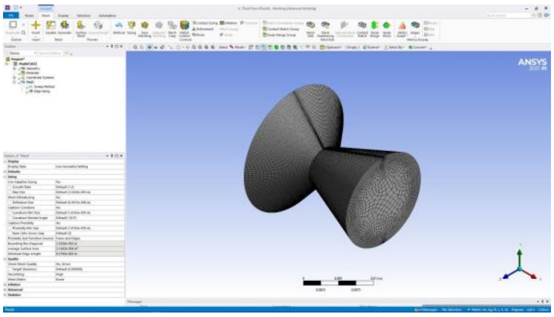


Figure 3: Meshed nozzle model in ANSYS

For the simulation analysis, density-based setup has been selected for high speed compressible flow simulation. Furthermore, the models are analyzed with energy turned on and the viscous model used is k-epsilon. In addition, the temperature, velocity and pressure of the simulated flow conditions for the analysis are set to be 500 K, 110 m/s and 3 atm (303,975 Pa), respectively. The hybrid initialization is used and the number of iterations is set to 500. For this study, the calculated primary outputs are exit pressure and velocity of the inlet. These pre-setup and post-setup are shown in Figure 4 and Figure 5, respectively. Moreover, the settings for the simulation outputs are set such that the pressure and velocity of the flow in the nozzle are presented in contour plots as illustrated in Figure 6.

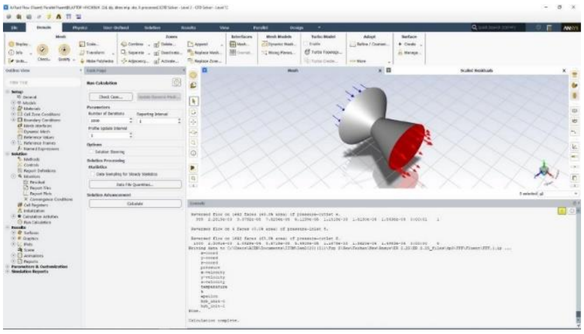


Figure 4: Pre-setup in ANSYS

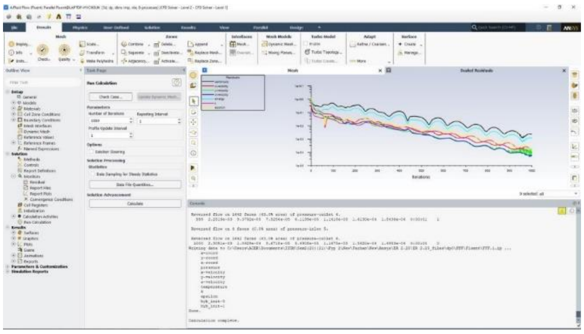
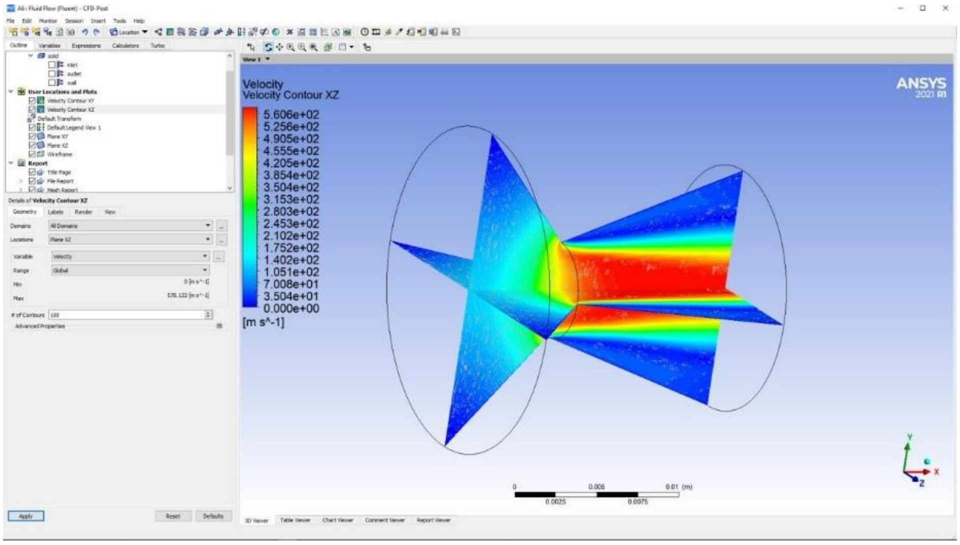


Figure 5: Post-setup in ANSYS



Details of Velocity Contour XZ
Domains: All Domains
Locations: Plane XZ
Variable: Velocity
Range: Global
Min: 0 [m s^-1]
Max: 576.122 [m s^-1]
# of Contours: 100

Figure 6: Simulation analysis output in ANSYS

After the simulation analysis has been completed in ANSYS, the investigation on throat erosion is proceeded using the calculation method. Throat erosion is studied based on comparison of initial throat nozzle diameter and final throat nozzle diameter after burning. Equation 1 is applied to determine the throat nozzle diameter, D_t where the nozzle throat area, A_t is given by Equation 2.

$$D_t = \sqrt{4A_t} \tag{1}$$

$$A_t = \frac{F}{\gamma \cdot \varsigma_F C_F \cdot P_c} \tag{2}$$

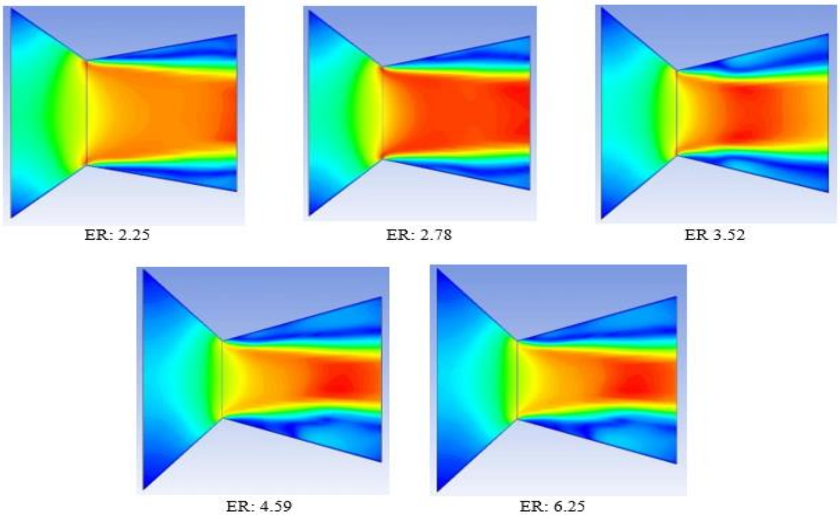
Moreover, the thrust can be derived by using the rocket thrust equation as presented by Equation 3 and the maximum mass flow rate is given by Equation 4. After the calculation is completed, the thrust versus half-angle graph is plotted for better observation and explanation on the nozzle throat erosion behavior. These results help in concluding this study of the nozzle throat erosion.

$$F = \dot{m} v_e + (p_e - p_0) A_e \tag{3}$$

$$\dot{m} = \frac{A p_t}{\sqrt{T_t}} \sqrt{\frac{\gamma}{R}} \left(\frac{\gamma + 1}{2}\right)^{-\frac{\gamma+1}{2(\gamma-1)}} \tag{4}$$

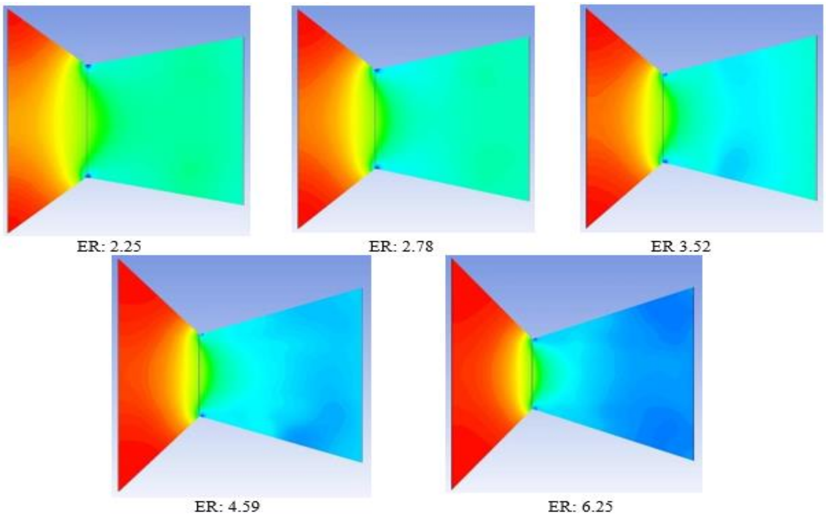
3. Results and Discussion

From Figure 7, it can be seen that the velocity near the throat area for all nozzles is in the range of 600 m/s to 700 m/s. The sturdy pattern of the thrust can also be observed in the contour velocity of the nozzles with expansion ratio 2.25 and 2.78 in Figure 8. Meanwhile, the nozzles with expansion ratio of 3.52, 4.59 and 6.25 show a little bend in the flow. Nonetheless, despite this flow behavior, the nozzles with expansion ratio of 4.59 and 6.25 have high maximum velocity of about 800 m/s, which is observed in Figure 9. Corresponding to Figure 10, the pressure of nozzles with expansion ratio of 4.59 and 6.25 is the highest among the lower expansion ratio nozzles, which explains the higher velocity of the highest expansion ratio nozzle.


ER: 2.25 ER: 2.78 ER 3.52

ER: 4.59 ER: 6.25

Figure 7: Velocity contour for nozzle designs with different expansion ratio (ER)


ER: 2.25 ER: 2.78 ER 3.52

ER: 4.59 ER: 6.25

Figure 8: Pressure contour for nozzle designs with different expansion ratio (ER)

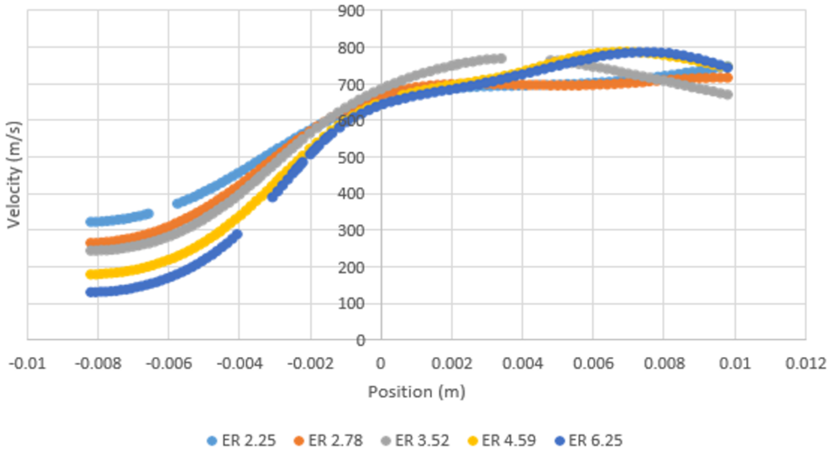


Figure 9: Velocity versus position for nozzle designs with different expansion ratio (ER)

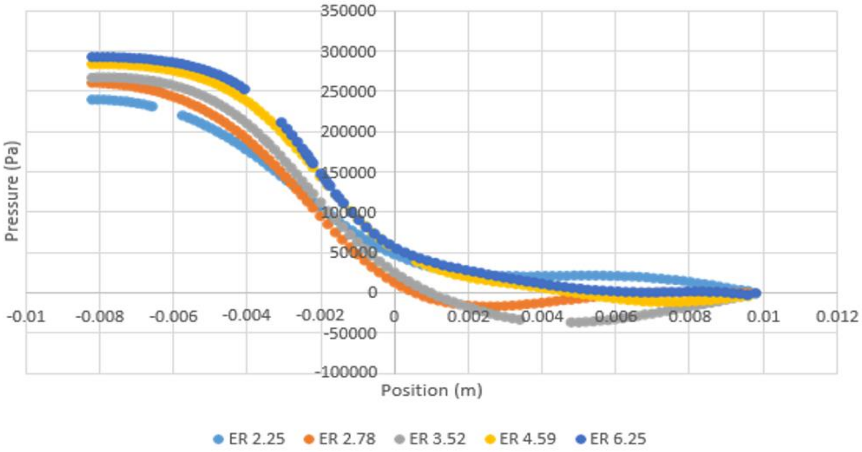


Figure 10: Pressure versus position for nozzle designs with different expansion ratio (ER)

In Figure 9, the velocity of the flow throughout the nozzle design is shown. In the converging part, velocity of the flow in all considered nozzle designs increases uniformly. As the flow reaches the nozzle throat, the flows experience linear velocity due to the constriction at the throat, which forces the flow to accelerate. Subsequently, once the flow exited the nozzle throat area, the velocity further increases. However, the loss of velocity can be seen near the end of the nozzle for flow in the nozzle designs with expansion ratio of 3.52, 4.59 and 6.25. On the other hand, the wall distribution of pressure inside the nozzles throughout the simulation is depicted by Figure 10. It can be observed that the pressure starts to decrease as the flow goes towards the rocket nozzle and the reduction is much steeper as it reaches the nozzle throat. Subsequently, pressure is low as the flow exits the nozzle throat. Pressure distribution is significantly steeper for nozzles with expansion ratio of 2.78 and 3.52. Additionally, Figure 10 also shows that the flow starts to separate for nozzle with expansion ratio of 2.25 at around 0.003 m.

From Figure 10, the flow experiences a pressure drop as the velocity increase at the nozzle throat and this phenomenon is commonly known as choked. The pressure near the nozzle exit is lower, hence resulting in a faster flow speed at the throat and it eventually reaches the speed of sound. All considered nozzle designs show sudden drop of pressure even when there is no increment of velocity. This happens due to demerit of the simulation design, which consists of a sharp turning at the throat, thus producing an oblique shock wave near the area. This behavior can be seen for the nozzles with expansion ratio of 3.52, 4.59 and 6.25. All these nozzle designs have half-angle value of more than the optimal value, which is around 11° to 15°. It can be concluded that the nozzle designs with expansion ratio of 2.25 and 2.78 have better performance.

Investigation of the nozzle throat erosion is computed using the data obtained from the simulation analysis. The mass flow rate, thrust coefficient and deduced throat area of each expansion ratio are then calculated. The final diameter values of the nozzle are obtained and differences between the initial and final diameter is tabulated in Table 2 and Table 3. It is observed that the final diameter of each nozzle design results in a percentage difference from 0.52% to 1.63% as the expansion ratio increases. This is taken to indicate that the thrust decreases as the expansion ratio increases, which further implies that the rate of nozzle erosion increases as the expansion ratio increases. One reason behind this occurrence is because of the high-speed velocity of the firing going through a small area of the nozzle throat.

Table 2: Calculated parameters

Expansion Ratio	**Mass Flow Rate (kg/s)**	**Thrust Coefficient**	**Exit Velocity (m/s)**	**Thrust (N)**	**Deduced Area (m^2)**
2.25	0.253	199.03	786.08	3165.87	7.94×10^{-5}
2.78	0.205	149.61	729.81	1928.45	6.46×10^{-5}
3.52	0.162	129.19	797.71	1315.93	5.13×10^{-5}
4.59	0.124	99.38	801.45	774.99	3.95×10^{-5}
6.25	0.091	73.88	811.04	423.33	2.92×10^{-5}

Table 3: Calculated values for throat erosion

Initial Diameter (mm)	**Final Diameter (mm)**	**Percentage Difference %**
10	10.05	0.52
9	9.07	0.76
8	8.08	1.02
7	7.09	1.31
6	6.09	1.63

4. Conclusion

Research and studies on HRM development are still blooming and garnering the attention of the educational and commercial or business sector due to its safety and also economical propulsion system. However, due to its properties, HRMs are unable to stray away from one of its major problems, which is throat nozzle erosion. This study is focusing on one of the factors of throat nozzle erosion, which is the nozzle expansion ratio. From the simulation done, it is found that the final diameter of each nozzle results in a percentage difference from 0.52% to 1.63% as the expansion ratio increases. The tabulated data of calculated values shows the decrease of thrust as expansion ratio increases. It can be concluded that the rate of erosion of the nozzle increases as the expansion ratio increases. One of the mitigations of throat erosion is to not design the throat area to be too small. Instead, a suitable dimension should be selected for the throat area. It should be noted that the results of the simulation may vary from reallife experiment, however it increases the possibilities to predict throat erosion numerically. Aside, the simulation will act as a guide for future experimental studies on throat erosion in HRMs.

Acknowledgement

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References

[1] K. Kuo and M. J. Chiaverini, Fundamentals of Hybrid Rocket Combustion and Propulsion, American Institute of Aeronautics and Astronautics, 2007.

[2] A. Karabeyoglu, 'Hybrid Rocket Propulsion for Future Space Launch', Presented at Aero/Astro 50th Year Anniversary, Stanford University, USA, 2008.

[3] A. Okninski, W. Kopacz, D. Kaniwski and K. Sobczak, 'Hybrid Rocket Propulsion Technology for Space Transportation Revisited – Propellant Solutions and Challenges', FirePhysChem, vol. 1, no. 4, pp. 260-271, 2021.

[4] E. T. Jens, B. J. Cantwell and G. S. Hubbard, 'Hybrid Rocket Propulsion Systems for Outer Planet Exploration Missions', Acta Astronautica, vol. 128, pp. 119-130, 2016.

[5] V. B. Betelin, A. G. Kushnirenko, N. Smirnov, V. F. Nikitin, V. V. Tyurenkova and L. I. Stamov, 'Numerical Investigations of Hybrid Rocket Engines', Acta Astronautica, vol. 144, pp. 363-370, 2018.

[6] B. J. Cantwell, Aircraft and Rocket Propulsion, Stanford University, 2022.

[7] D. Bianchi and F. Nasuti, 'Numerical Analysis of Nozzle Material Thermochemical Erosion in Hybrid Rocket Engines', Journal of Propulsion and Power, vol. 29, no. 3, pp. 547-558, 2013.

[8] D. Bianchi, L. T. Kamps, F. Nasuti and H. Nagata, 'Numerical and Experimental Investigation of Nozzle Thermochemical Erosion in Hybrid Rockets', Proceedings of AIAA/SAE/ASEE Joint Propulsion Conference, Atlanta, USA, July 2017.

[9] B. Kahraman, H. Karakas, B. N. Eren and A. Karabeyoglu, 'Erosion Rate Investigation of Various Nozzle Materials in Hybrid Rocket Motors', Proceedings of the AIAA Propulsion and Energy Forum (Online), August 2020.

[10] S. Chankapoe, N. Winya and N. Pittayaprasertkul, 'Performance Investigation of Solid-Rocket Motor with Nozzle Throat Erosion', International Journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering, vol. 7, no. 9, pp. 1803-1805, 2013.

[11] M. D. Khaleel, N. P. Kishore and A. S. Kumar, 'Design and CFD Analysis of Conical Nozzle for 2.75 Inch Rocket System', International Journal of Engineering Sciences and Research Technology, vol. 3, no. 9, pp. 465-470, 2014.

VISUALIZATION OF WATER INGRESS IN ALUMINIUM HONEYCOMB SANDWICH PANEL THROUGH MODE ISOLATION OF LAMB WAVEFIELD

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Abstract: Water ingress into the honeycomb cells of aerospace structures can compromise the aircraft's safety and performance. Due to this reason, detecting it as soon as possible is critical. Even though the effectiveness of guided ultrasonic wavefield propagation imaging (G-UPI) in detecting various types of damage with high resolution has already been well-demonstrated, its capability in detecting water ingress in honeycomb cells has not been investigated. In view of this, the aim of this study is to investigate the feasibility of using G-UPI to detect and visualize water ingress in the honeycomb cells by inspecting an aluminum honeycomb sandwich panel with simulated water ingress in six individual cells. Based on the results, it has been shown that isolating the A0 mode of the waves can significantly improve the visibility of the water-filled cells. Moreover, the quantitative comparison of three different visualization methods, i.e., ultrasonic energy mapping (UEM), dominant frequency amplitude mapping (DFAM), and spectral energy mapping (SEM), has revealed that SEM is the best visualization method due to its 7.2 and 1.5 times higher contrast compared to UEM and DFAM, respectively. All in all, G-UPI has been shown to be able to effectively detect water ingress. However, careful selection of a suitable wave mode and image generation algorithm is required to achieve optimal results.

Keywords: non-destructive testing; ultrasonic wave propagation; image processing; mode isolation; Lamb waves

1. Introduction

Water ingress into honeycomb cells in aerospace structures can lead to several issues. Firstly, it can cause corrosion and degradation of the structural material, leading to reduced strength and stiffness [1], [2]. Secondly, it can cause disbonding of the skin-core as well as delamination of skin, which can result in reduction or loss of load-bearing capacity [2]-[3]. Furthermore, it can cause signal blockage of radar transmission [4], which prevents external communication to the control unit. Last but not least, water accumulation in the cells can cause an increase in weight, reducing the aircraft's fuel efficiency and also possibly affecting its flight performance. All these issues are critical to the aircraft's safe operation and therefore, it is essential to detect and prevent water ingress in honeycomb cells [2][5]. Since water ingress can have severe consequences for safety and performance of aerospace structures, it is crucial to detect it in a non-destructive manner as early as possible. However, water ingress in honeycomb cells is known as a type of complex damage. It requires a very specific non-destructive testing procedure for a higher detection probability. The probability of success in detecting water ingress in a honeycomb cell depends on several factors, including the size and location of the damage, and the method applied for detection

[4]. If any water ingress is missed during the periodic inspection using common methods, then detecting the symptoms of water ingress such as moisture spots, material discoloration or microbial growth must be conducted during visual inspection. This process is time-consuming and requires laborious work to inspect the large aircraft surface. Hence, there is a need for a better inspection technique.

To date, guided ultrasonic wavefield propagation imaging (G-UPI) has shown tremendous benefits as it manages to detect a wide range of damage types with a high probability of success [6]-[7]. G-UPI offers several advantages over the traditional ultrasonic approaches such as its ability to detect damage with high-resolution imaging that leads to comparatively higher detection probability before the damage can cause significant harm. Additionally, G-UPI provides a non-destructive way of inspecting structural integrity of materials, making it an ideal choice for monitoring the critical aerospace components' health. Furthermore, G-UPI provides the capability to cover a large inspection area in a single scan, which is particularly useful for inspecting large and complex structures. High expectations have been placed on G-UPI to produce positive results in detecting water ingress due to its demonstrated ability to detect other types of damage. If G-UPI is proven capable of detecting water damage, this method will provide further evidence to support further research and development of the technique. A recent review article has pointed out that detection of water ingress in sandwiched composites has not been investigated yet using G-UPI [8]. With this knowledge, the primary objective of this study is to investigate the feasibility of using G-UPI technique for detecting water ingress in honeycomb cores. To improve the signal-to-noise ratio, a mode isolation technique that is demonstrated to successfully detect hidden corrosion [9], cracks [10], dents [11] and delamination [12] is adopted. Another objective of this study is to assess the capabilities of various image generation algorithms, i.e., ultrasonic energy mapping (UEM), dominant frequency amplitude mapping (DFAM) and spectral energy mapping (SEM), in displaying subtle water ingress with a good contrast.

2. Methodology

For the experiment, the specimen is purchased from a composites manufacturer and consisted of two pieces of flat aluminum plates and an aluminum honeycomb core, which are bonded together using epoxy glue. The thickness of the front and back plates are 1 mm and 0.5 mm thick, respectively. In the meantime, the honeycomb core has cell size of 10.4 mm and height of 15 mm. Six holes are drilled at the back side of the as-manufactured specimen using a 3 mm drill bit in a cautious manner in order to prevent any dents or over-drilling. The cell core is then fully filled with water using a syringe and covered with cellophane tape to prevent any spillage, as shown in Figure 1(a). The relative positions of the water-filled cells are shown in Figure 1(b). Only one specimen is fabricated and used for this work. Multiple water-filled cells at different positions are created to study the variation of wave interaction with the damages. The origin is located at the bottom-left corner of the scan area. Table 1 provides the locations of all water-filled cells. For easier reference, the damage will be named with 'C#' whereby 'C' represents the cell and '#' represents its cell number. The analysis for a specific cell takes the spatio-temporal data before and after it is water-filled for side-by-side comparison.

Table 1: Location of water-filled cells.

Cell No.	x-y coordinate location (mm)
1	(62.5, 40)
2	(125, 40)
3	(187.5, 40)
4	(62.5, 210)
5	(125, 210)
6	(187.5, 210)

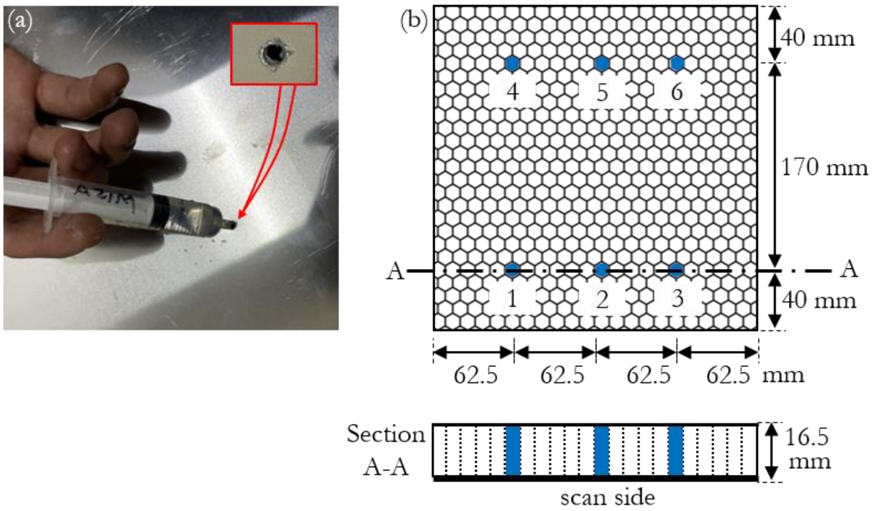


Figure 1: Infliction of damage. (a) Injection of water into a honeycomb cell through a drilled hole. (b) Relative positions of the water-filled cells. Shape and size of the internal honeycomb cells are for illustration purposes only and may differ from actual specimen.

The non-destructive inspection of the specimen is carried out using G-UPI system. Figure 2 shows the G-UPI system, which utilizes a two-dimensional (2D) laser scanning grid to generate the ultrasound and a fixed-position sensor for the measurement. The ultrasound is produced through rapid, localized thermoelastic expansion at each inspection grid point [13]. The ultrasound waves, known as the Lamb waves [14]-[15], propagated from their respective grid points, guided by the specimen boundaries, and dispersed into a mixed multimodal wave. The laser scanning is performed using a galvanometric optical scanner at a standoff distance of 1.29 m, with a pulse repetition frequency of 50 Hz. Guided waves are generated for an area of 250 by 250 mm with a uniform grid of 0.5 mm pitch in both the x (horizontal) and y (vertical) axis, resulting in a total of 250,000 grid points. Ultrasound signals are measured using a broadband, omnidirectional piezoelectric sensor that has been placed at a fixed position 125 mm above the center of the inspection area's top edge. The signals are then recorded using an oscilloscope with 500 sampling points and sampling frequency of 1.5 MHz. It should be noted that these settings of the parametric values are based on discussions in Ref. [8]. Finally, three-dimensional (3D) spatio-temporal data, v [x, y, t] is acquired from each scan.

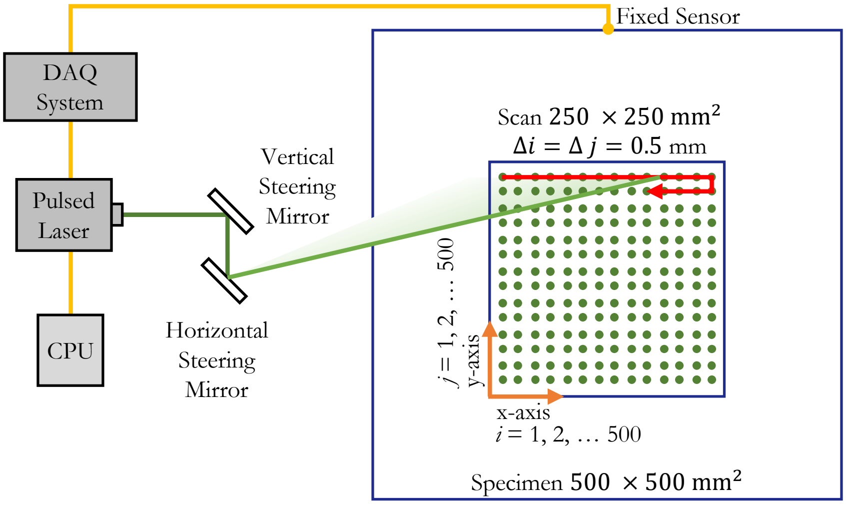


Figure 2: Schematic of the G-UPI system, specimen dimensions, inspection parameters.

As indicated earlier, the specimen used in this study has dimensions of 500 mm by 500 mm, and inspection area of 250 mm by 250 mm has been chosen at the center to reduce the effects of boundary reflections. Two repetitive scans are conducted for the specimen under eight different conditions. The repetitive scans are averaged in order to reduce noise. These eight conditions include pristine state, six holes without water, one water-filled cell, two water-filled cells and so on until all six cells are filled with water. This procedure is carried out to take a clear look at the wave behavior before and after the cells are filled with water. The captured signals are then processed using a mode-filtering algorithm to extract information about the guided ultrasonic waves, as shown in Figure 3. The processed data is later applied to generate an image to visualize internal features of the specimen, which can be interpreted to detect any damage or anomalies in the material.

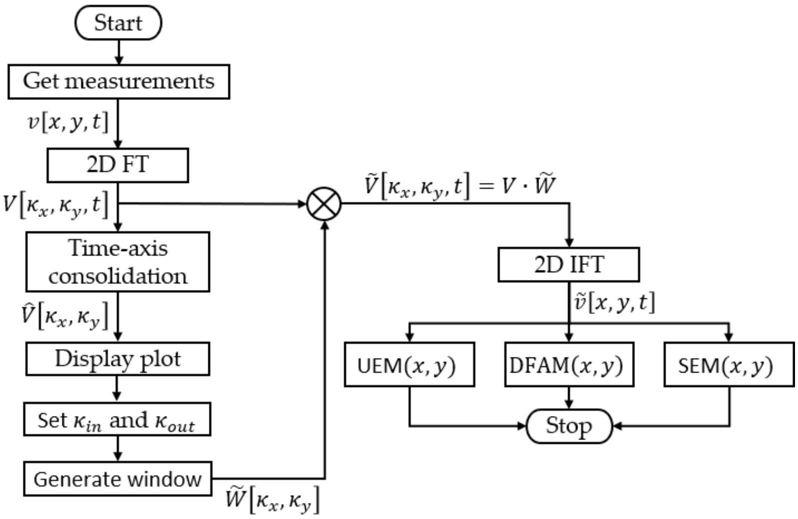


Figure 3: Flowchart of the overall result processing steps.

For mode filtering, the 3D spatio-temporal data obtained from each inspection has to undergo 2D Fourier transform (FT) in the spatial axes to convert the data into 3D wavenumber-temporal domain. A 2D FT is adopted instead of the more commonly used 3D FT [11][16] because it is found that mode filtering at similar accuracy could be obtained more efficiently using the 2D FT. After the conversion, a circular filter is generated through the function in Equation 1, where $\widetilde{W}$ represents the filter window, which is indexed by the wavenumber κ_x and κ_y along respective x or y axis, while κ_{in} and κ_{out} represent the inner and outer wavenumber values to define the circular filter, respectively, and $\kappa = \sqrt{\kappa_x{}^2 + \kappa_y{}^2}$.

$$\widetilde{W}[\kappa_x,\kappa_y] = \begin{cases} 1, & \kappa_{in} < \kappa < \kappa_{out} \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

There are several choices for the filtering, either using S0 mode, A0 mode or even anomalous mode at own discretion. The selection can be made based on the plot of the consolidated wavenumber-time domain data as shown on the left side of Figure 4. In this plot, the consolidated energy of the S0 and A0 modes can be identified over the black background as two concentric rings, i.e., S0 as the inner ring while A0 as the outer ring. Depending on the desired mode, the values of filter parameters κ_{in} and κ_{out} can be determined through visual inspection of the consolidated wavenumber-time domain data. As an illustration to aid understanding, a filter window suitable for the isolation of A0 mode is generated using Equation 1 and shown in the middle plot of Figure 4. The effect of applying the filter window is shown on the right side of Figure 4, where only the energy ring of A0 remains. The mode filtering process is important towards enhancing the ability for water ingress detection, and this is discussed further in the following next section.

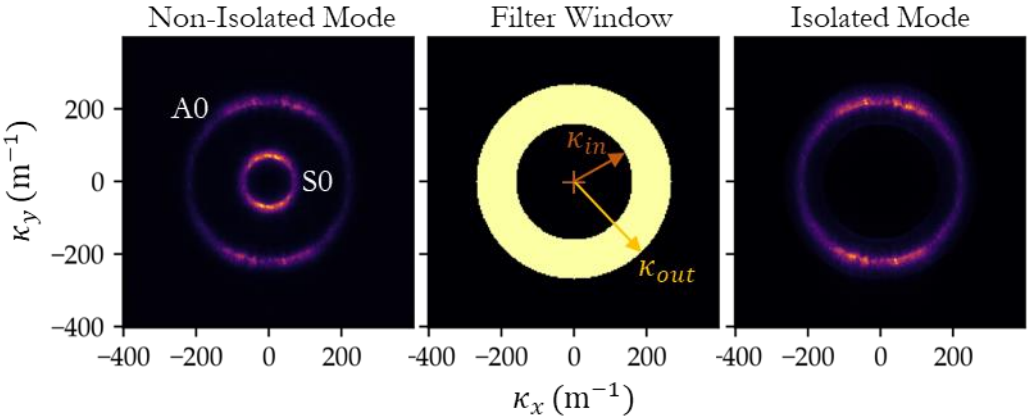


Figure 4: Mode filtering process. (a) Consolidated wavenumber-time domain data before filtering; (b) the filter window; and (c) the data after filtering.

For damage detection and visualization, the data for filtered and unfiltered modes are processed as images. Three visualization methods are used, including ultrasonic energy mapping (UEM), as reported in Ref. [17] but its wavenumber filter is replaced by the mode filter described in previous Equation 1, dominant frequency amplitude mapping (DFAM) [18], and spectral energy mapping (SEM). The UEM uses the simplified kinetic energy equation shown in Equation 2. On the other hand, the DFAM plots the highest amplitude from the frequency spectrum to show only the dominant amplitude generated to represent damage at a grid point as indicated in Equation 3. Lastly, SEM uses the amplitude from the broadband frequency and sum them all together to represent the grid position. The 3D spatio-temporal data needs to be transformed as 3D spatio-frequency data through one-dimensional FT along the time axis before being summed, which is presented in Equation 4.

$$\mathrm{UEM}(x,y) = \sum_{t=1}^{T} v(x,y,t)^2 \tag{2}$$

$$\mathrm{DFAM}(x,y) = V(x,y,f)_{max} \tag{3}$$

$$\mathrm{SEM}(x,y) = \sum_{f=1}^{F} V(x,y,f) \tag{4}$$

3. Results and Discussion

Through different methods of visualization, the results have been compared side by side in Figure 5 to help decide the best overall image visualization method suitable to detect the water ingress damage. There are three outputs for each visualization method, which are non-isolated mode, S0-isolated mode and A0-isolated mode, all of which pertain to the planar view of the specimen. It should be noted that this study focuses on the ability of mode isolation performance to visualize damage compared to a non-isolated mode based on these three outputs.

When using three different imaging methods through non-isolated mode, as represented in the left column in Figure 5, it is found that none of them is able to detect the water ingress, likely due to multiple modes causing interference that is obscuring the low-energy spots generated by the water ingress [19]. However, a wave-like pattern is observed in the images, possibly caused by the superposition of multiple modes, which contributes to the increased noise level and further obscured the water ingress damage. To counter this, isolating a singular mode before image generation can prevent mode superposition and improve imaging capability. It is also observed that superposition could lead to inaccuracies in the signal and incorrect image representation, especially in non-isolated mode, which shows a wave-like pattern. However, this issue is not present in the images of the other cases with an isolated mode, leading to the conclusion that mode isolation can help to resolve the problem of signal inaccuracies caused by mode superposition and improve visual representation. Therefore, it is taken that selecting appropriate modes and preventing superposition can greatly improve the accuracy and effectiveness of image processing algorithms for detecting damage in materials.

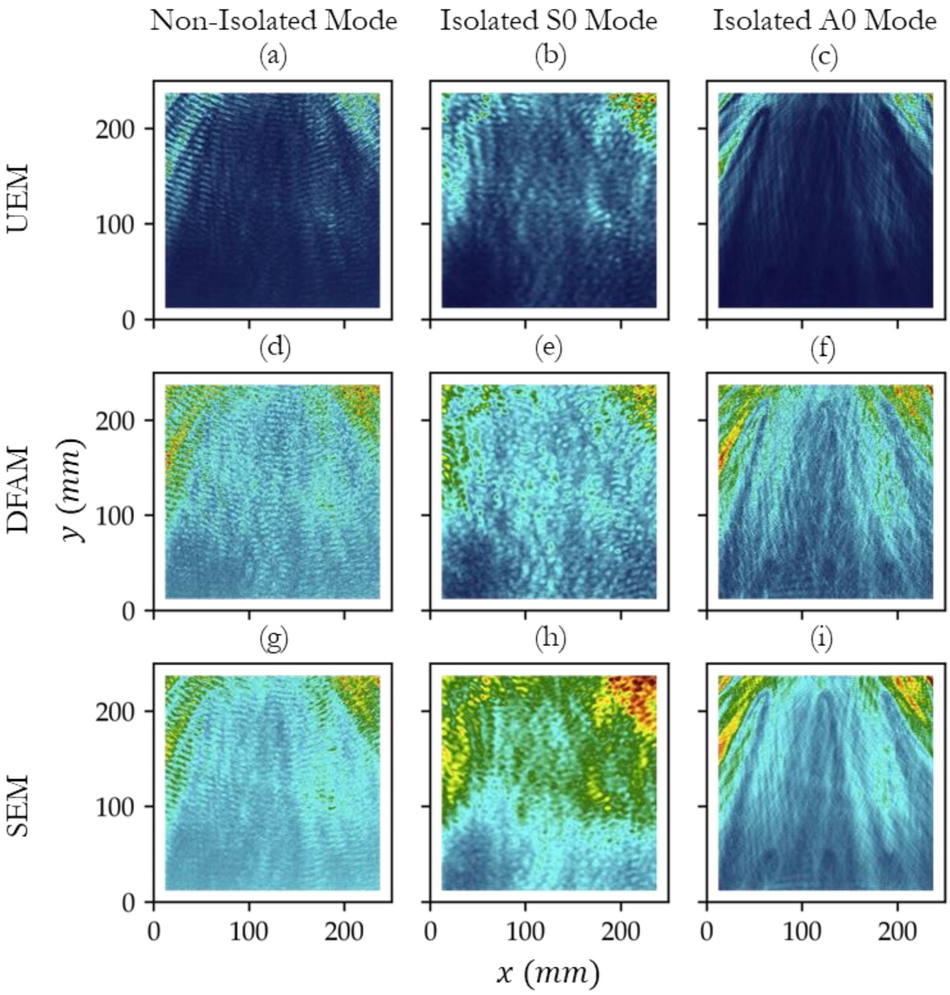


Figure 5: Comparison of damage in planar view using UEM (a to c), DFAM (d to f), and SEM (g to i). Unbalanced energy distribution was unavoidable due to directional wave propagation through honeycomb cells.

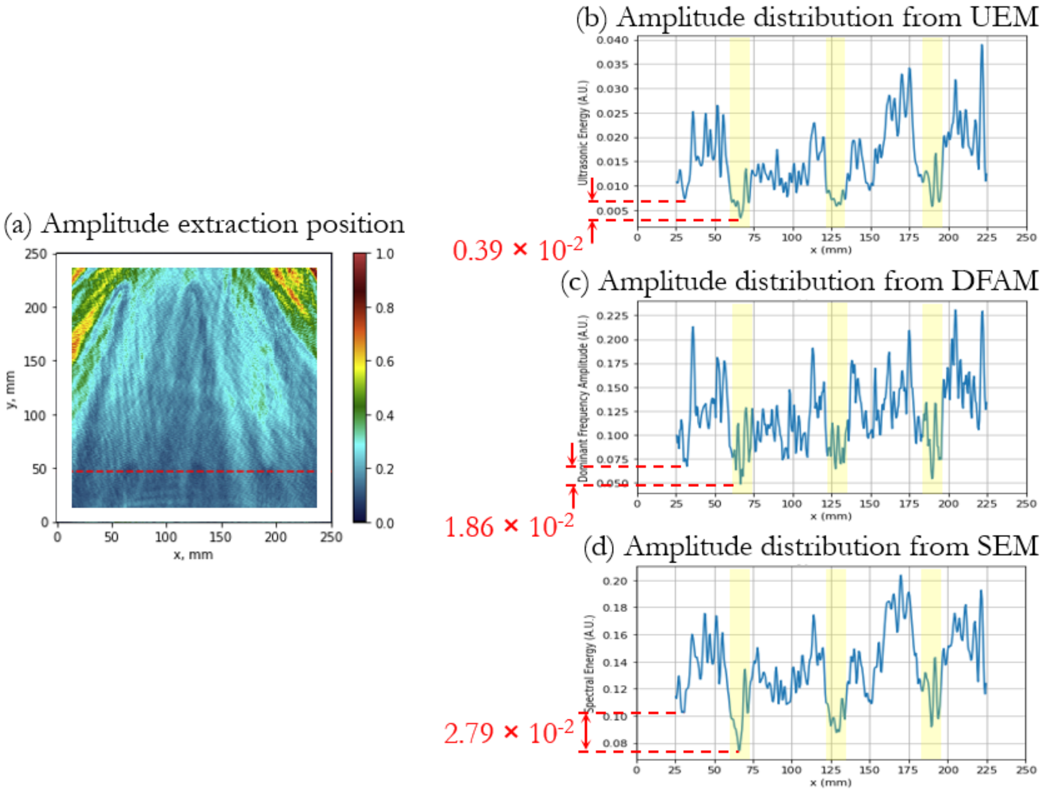
In the case of the isolated S0 mode, as represented in the middle column, none of the visualization methods has produced positive results as no information could be captured by this mode. This may be due to limitation of the S0 mode, which has a longer wavelength and penetrates through the specimen faster compared to the A0 mode, with less energy absorbed by the material. The depth of penetration of ultrasonic waves is determined by their frequency and wavenumber. However, since the S0 and A0 waves have the same frequency and the S0 wave travels at a faster velocity due to its longer wavelength, it experiences lower attenuation rates. This indicates that the S0 wave can travel further through the material without losing its energy, resulting in less energy absorption in comparison to A0 wave, which has shorter wavelength and higher attenuation rate. Though the wavelength difference is not significant, the accumulation of small differences will eventually lead to significant change. In this case, it is desired to have a significant portion of the energy to be absorbed by the damage instead of being transferred away from it since that will reduce the chances of detecting the damage.

For the isolated A0 mode, as represented in the right column, all three methods appear to provide useful results but with different visualization capabilities. With UEM, water ingress is detectable at the top section close to the sensor while DFAM and SEM detect water ingress for the entire scanning area, particularly at the bottom section farther away from the sensor. These results vary as each method uses a different approach to visualize the damage. UEM employs the simplified kinetic energy equation to represent kinetic energy within the scan area, making it suitable for simple basic structures such as flat plates with uniform structural design and microstructures that have low damping properties. However, the high damping property of the aluminum honeycomb hinders the capability of UEM to visualize the whole area properly as the wave loses its energy too fast, resulting in a large dark area in the image seen in Figure 5(a) that represents a low-energy region. This indicates that a time-derived equation is not the best option. When visualizing complex structures such as honeycomb sandwiches, a frequency-derived equation is the more viable option due to its low susceptibility to material damping. This is because the frequency property of a wave remains constant regardless of the quick decrease of energy over time due to material damping, whereas time-derived equations are more susceptible to changes in material properties over time. Furthermore, using a frequency-derived equation provides detailed information about the structure by identifying different resonances and modes of vibration, which can help identify damage or defects that may not be easily visible using other methods.

To quantitatively compare the visualization methods, amplitude distribution along a horizontal line indicated in Figure 6(a), which crosses the position of amplitude drop caused by the water ingress, is extracted for analysis. To ensure meaningful comparison, the data for each visualization method have been normalized before extraction. Figure 6(b) to (c) show amplitude distributions for UEM, DFAM, and SEM, respectively, with yellow highlights representing regions with water-filled cells. Since the detection and visualization of water ingress require a magnitude contrast between the water-filled and unfilled cells, this contrast can serve as an evaluation metric to quantify the visibility of the water ingress. Equation 5 defines the contrast, where A represents the amplitude extracted from either the normalized UEM, DFAM, or SEM, it can be observed that $\mathbb{C} = 0.39 \times 10^2$, 1.86×10^2 and 2.79×10^2 (arbitrary unit, A.U.) for UEM, DFAM, and SEM, respectively. In other words, SEM exhibits 7.2 and 1.5 times higher contrast compared to UEM and DFAM, respectively. This simple analysis clearly indicates that SEM is the best visualization method among the three.

$$\mathbb{C} = \left|\min(A_{filled}) - \min(A_{unfilled})\right| \tag{5}$$

Understanding material properties is crucial for accurate damage detection and visualization using image processing algorithms. Honeycomb structures with high damping properties pose a challenge for many visualization methods. Nevertheless, the use of a frequency-derived equation can provide more accurate and detailed information, which suits the application on complex structures with high damping properties. Although a direct explanation of this situation is not found in the literature, a few references have proven that using phase-based and frequency-based processing can improve the imaging quality compared to the amplitude-based counterpart [20]-[21]. By selecting appropriate visualization methods, the accuracy and effectiveness of the image processing algorithms can be improved. While both DFAM and SEM produce similar images based on the same frequency property, they may differ in sensitivity to different material properties or variations in the damage being detected. Therefore, it is important to carefully evaluate and select the suitable visualization methods based on specific material and type of damage to be detected. Overall, the study highlights the importance of considering material properties and selecting suitable visualization methods when developing image-processing algorithms for detecting damage in materials. By doing so, the accuracy and effectiveness of these algorithms can be improved, and the algorithms can better detect and diagnose damage in a wide range of materials and structures.


(a) Amplitude extraction position

(b) Amplitude distribution from UEM

(c) Amplitude distribution from DFAM

(d) Amplitude distribution from SEM

Figure 6: Definition of magnitude contrast ℂ. (a) Extraction of amplitude distribution along dashed red line. Getting ℂ from the amplitude distribution for (b) UEM, (c) DFAM, and (d) SEM.

4. Conclusion

Water ingress in honeycomb cells of aerospace structures leads to many issues, including corrosion, disbonding, signal blockage and also increased weight, which can compromise the aircraft's safety and performance. Early detection of water ingress in non-destructive manner in honeycomb cells is complex and requires specific testing procedure, which is time-consuming and laborious. Therefore, this study is aimed to investigate the feasibility of using G-UPI to detect and visualize water ingress in honeycomb cells. The study has found that water ingress damage can be easily hidden even by a low level of noise and eliminating this noise could improve the imaging capability and increase the likelihood of detecting water ingress. Mode isolation is found to be an effective method to resolve the problem of noises that are caused by mode superposition and improve visual representation. The isolated S0 mode is found to be unsuitable for capturing any information regarding water ingress while the isolated A0 mode could yield useful results with varying degrees of visualization clarity. Three visualization methods: UEM, DFAM and SEM, are compared to determine the most suitable one for visualization of water ingress. It is found that a frequency-derived equation is a more viable option for visualizing complex structures such as honeycomb sandwich structures since it is less susceptible to material damping and can provide more accurate and detailed information about the structure being inspected. This is supported by the quantitative analysis based on magnitude contrast ℂ, which indicates that the frequency-based SEM is the best visualization method due to its 7.2 and 1.5 times higher contrast in comparison to UEM and

DFAM, respectively. In conclusion, G-UPI can be used for the detection of water ingress in honeycomb structures. Selecting appropriate result-processing methods based on the specific material being studied and the type of damage being detected is important for improving the accuracy and effectiveness of the visualization. Specifically, for the specimen used in this study, isolating the A0 mode and presenting the result as a SEM image is the best processing option. A few potential future works have been identified, which include the automation for determination of mode filter parameters κ_{in} and κ_{out} without human subjectivity, detection of partially-filled honeycomb cells and expansion of the method for water ingress detection in non-metallic honeycomb sandwich structures.

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References

[1] H. A. Israr, T. S. Chwen, A. Abd Latif, K. J. Wong, S. S. R. Koloor, N. Yidris and M. Y. Yahya, 'Preliminary Structural Design of Coreless Spoiler by Topological Optimization', Processes, vol. 10, no. 10, 2076, 2022.

[2] G. Kim, R. Sterkenburg and W. Tsutsui, 'Investigating the Effects of Fluid Intrusion on Nomex® Honeycomb Sandwich Structures with Carbon Fiber Facesheets', Composite Structures, vol. 206, pp. 535–549, 2018.

[3] C. Ibarra-Castanedo, L. Brault, F. Marcotte, M. Genest, V. Farley and X. Maldague, 'Water Ingress Detection in Honeycomb Sandwich Panels by Passive Infrared Thermography using a High-Resolution Thermal Imaging Camera', Proceedings of SPIE, vol. 8354, pp. 20-27, 2012.

[4] X. Xu, W. Huo, F. Li and H. Zhou, 'Classification of Liquid Ingress in GFRP Honeycomb Based on One-Dimension Sequential Model Using THz-TDS', Sensors, vol. 23, no. 3, 3, 2023.

[5] V. Vavilov, A. Klimov, D. Nesteruk and V. Shiryaev, 'Detecting Water in Aviation Honeycomb Structures by Using Transient Infrared Thermographic NDT', Proceedings of AEROSENSE 2003, Orlando, USA, April 2003.

[6] C. C. Chia, J. R. Lee, J. S. Park, C. Y. Yun and J. H. Kim, 'New Design and Algorithm for an Ultrasonic Propagation Imaging System', Proceedings of Defektoskopie 2008, Brno, Czech Republic, November 2008.

[7] C. C. Chia, S. G. Jang, J. R. Lee and D. J. Yoon, 'Structural Damage Identification Based on Laser Ultrasonic Propagation Imaging Technology', Proceedings of SPIE, vol. 7389, 73891S 2009.

[8] C. C. Chia, S. Y. Lee, M. Y. Harmin, Y. Choi and J. R. Lee, 'Guided Ultrasonic Waves Propagation Imaging: A Review', Measurement Science and Technology, vol. 34, no. 5, 052001, 2023.

[9] Z. Tian, W. Xiao, Z. Ma and L. Yu, 'Dispersion Curve Regression–Assisted Wideband Local Wavenumber Analysis for Characterizing Three-Dimensional (3D) Profile of Hidden Corrosion Damage', Mechanical Systems and Signal Processing, vol. 150, 107347, 2021.

[10] P. Kudela, M. Radzieński and W. Ostachowicz, 'Identification of Cracks in Thin-Walled Structures by Means of Wavenumber Filtering', Mechanical Systems and Signal Processing, vol. 50–51, pp. 456-466, 2015.

[11] D. Girolamo, H. Y. Chang and F. G. Yuan, 'Impact Damage Visualization in a Honeycomb Composite Panel Through Laser Inspection using Zero-Lag Cross-Correlation Imaging Condition', Ultrasonics, vol. 87, pp. 152-165, 2018.

[12] F. Gao, J. Hua, L. Wang, L. Zeng and J. Lin, 'Local Wavenumber Method for Delamination Characterization in Composites with Sparse Representation of Lamb Waves', IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, vol. 68, no. 4, pp. 1305-1313, 2021.

[13] J. Monchalin, 'Laser-Ultrasonics: From the Laboratory to Industry', AIP Conference Proceedings, vol. 700, no. 1, pp. 3-31, 2004.

[14] H. Lamb, 'On Waves in an Elastic Plate', Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character, vol. 93, no. 648, 648, 1917.

[15] J. L. Rose, Ultrasonic Guided Waves in Solid Media, Cambridge University Press, 2014.

[16] E. B. Flynn, S. Y. Chong, G. J. Jarmer and J. R. Lee, 'Structural Imaging through Local Wavenumber Estimation of Guided Waves', NDT & E International, vol. 59, pp. 1-10, 2013.

[17] S. H. Abbas, T. C. Truong and J. R. Lee, 'FPGA-based Ultrasonic Energy Mapping with Source Removal Method for Damage Visualization in Composite Structures', Advanced Composite Materials, vol. 26, 2017.

[18] M. A. Shahrim, M. Y. Harmin, F. I. Romli, C. C. Chia and J. R. Lee, 'Damage Visualization based on Frequency Shift of Single-Mode Ultrasound-Guided Wavefield', Journal of Aeronautics, Astronautics and Aviation, vol. 54, no. 3, pp. 297-305, 2022.

[19] F. Ling, H. Chen, Y. Lang, Z. Yang, K. Xu and D. Ta, 'Lamb Wave Tomography for Defect Localization using Wideband Dispersion Reversal Method', Measurement, vol. 216, 112965, 2023.

[20] N. Wadhwa, M. Rubinstein, F. Durand and W. T. Freeman, 'Phase-based Video Motion Processing', ACM Trans. Graph., vol. 32, no. 4, pp. 1-10, 2013.

[21] P. Fromme, F. Bernhard and B. Masserey, 'High-Frequency Guided Ultrasonic Waves to Monitor Corrosion Thickness Loss', AIP Conference Proceedings, vol. 1806, no. 1, 1, 2017.

ENGLISH LANGUAGE PROFICIENCY AMONG AVIATION MAINTENANCE PERSONNEL IN MALAYSIA

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Abstract: The occurrence of various aviation maintenance incidents in Malaysia has been linked to the decline in English language competency among local aviation maintenance personnel. In view of this, an online survey has been conducted among 38 maintenance personnel in Malaysia to establish the level of use and importance of English language while performing their tasks. It is inferred that most essential activities involved in performing the aviation maintenance tasks substantially require the use of English language. Overall, the findings indicate that English language proficiency is highly necessary for aviation maintenance personnel to be competent in their job. English language is highly applied in the execution of local aviation maintenance tasks such as for communication, manuals reading and report writing. In essence, the findings greatly support the enforcement of the additional English language requirements by the local authority for aviation maintenance personnel in Malaysia.

Keywords: English language; language competency; aviation maintenance; survey; CAAM

1. Introduction

Safety consideration is always a paramount factor in the aviation sector, especially for the airlines industry. To date, substantial efforts are made to warrant proper safety level for aircraft operators and passengers such as through the improvement of aircraft designs that lowers potential risk of mechanical system failures and pilot errors [1]. Moreover, maintenance is also one of the primary aspects in ensuring continuous aviation safety and providing reliable services for air transportation [2]. The importance of good aviation maintenance practices to flight safety is well documented in several studies. For instances, aircraft maintenance has been indicated as one of the major causes or contributing factors in aircraft accidents [3] and positive influence of good maintenance practices on the aircraft safety has been widely acknowledged [4]. In general, aircraft maintenance tasks can be classified as scheduled or unscheduled types. Scheduled maintenance is essentially a preventive form of maintenance to maintain the aircraft's airworthiness to fly as specified by the aviation regulations. It is conducted at pre-set intervals based on total flight hours that the aircraft has been operated. On contrary, unscheduled maintenance tasks are those required when there have been any failed or damaged components that need to be immediately repaired or replaced before the aircraft can be flown again. It should be noted that maintenance tasks have also been classified as preventive, corrective and also condition-based, among others [5].

All aviation maintenance tasks can only be carried out by certified aircraft maintenance technicians (AMTs). To be qualified and licensed to work in aviation maintenance industry, AMTs are required to undertake rigorous trainings that are specified by aviation authorities [6]. These trainings are prescribed to ensure that all certified AMTs have necessary skills and competencies to perform any maintenance tasks on the aircraft. Despite this highly regulated certification process of AMTs however, it is observed that there are still occurrences of incidents related to maintenance errors. In between years 2005 and 2015, 14% to 21% of helicopter accidents among the US civil fleets are caused by flawed maintenance and inspection [7]. Moreover, almost 60% of the aircraft mishaps caused by maintenance-related issues have been linked to human errors [8]. This is supported by the findings of a research study that found AMTs regularly committed unintentional errors while performing aircraft maintenance tasks [9]. It is thus not surprising that a crucial effort towards the enhancement of safety and reliability of commercial aviation system is managing the human errors, especially among aviation maintenance personnel [10]. The cases of human errors in aircraft maintenance have shown to cause damage to the aircraft system, departure delay, urgent emergency repair, flight cancellation and/or injury to crew and passengers [11]. In worst case scenario, it could lead to loss of lives whereby it has been found that maintenance-related accidents are about 6.5 times more likely to be fatal in comparison to other types of general aviation accidents and when it does happen, the average number of fatalities is also relatively 3.6 times higher [1]. It should be noted that the issue of managing human errors is also common in the other industries such as manufacturing [12].

To ease this situation, many conducted research studies are focused on establishing the probable causes of human errors in aviation maintenance. In this respect, some of the factors that are identified include human fatigue, incorrect use of maintenance procedure, inadequate knowledge and experience to effectively carry out maintenance tasks, and also improper housekeeping and tools control [13]. Apart of the competency issues of AMTs, several studies have also highlighted possible causal factors of the human errors in the maintenance at organization level that include issues with communication [14] and implementation of the maintenance management system [15]. In the hindsight, this is parallel with the two classifications of factors for the aviation maintenance error: individual- and management- related [16]. While the causes related to skills and competencies of AMTs can be addressed through improved enforcement and delivery of the compulsory training session before they are licensed to work, the issues with miscommunication and maintenance mismanagement require a deeper analysis on the underlying root sources. Due to complexity and extensive nature of maintenance tasks, margins of communication and also coordination in performing aviation maintenance are highly critical and it is usually hard to maintain necessary levels of effective and efficient communication, and good team collaboration [17]. There have been efforts to resolve management-related contributing factors towards human errors in aviation maintenance, including development of assisting tools such as online maintenance assistance platform [18] and also framework process for aviation maintenance monitoring [19]. Despite the efforts and proposed solutions however, incidents of aviation maintenance error continue to occur.

In recent years, there are emerging interests in studying the effects of English language competency level of AMTs on their job performance. Language incompetency usually causes miscommunications and incorrect task executions, and this situation has been well-acknowledged across various industries including manufacturing [20] and construction [21]. For local aviation maintenance industry in Malaysia, emphasis on sufficient English language competency among local AMTs has garnered a high attention after local aviation authority, Civil Aviation Authority Malaysia (CAAM) formally imposed additional English language requisites for licensing purposes of aviation maintenance workers in Malaysia. This rule is enforced by CAAM as a part of their major effort to reduce the number of aviation maintenance incidents in Malaysia due to misinterpretation of Aircraft Maintenance Manual and misunderstanding of shift report, which have been subsequently linked to perceived decline in level of English language proficiency among local AMTs [22]. An overview of incidents related to the local aviation maintenance in Malaysia that can be linked to English language proficiency is presented in Ref. [23]. In line with this new policy development, there is emerging interest to establish the real need and importance of English language for local AMTs in enabling them to effectively perform their aviation maintenance tasks. This is the objective of this study that is accomplished by surveying several aviation maintenance personnel in Malaysia.

2. English Language in Aviation

Similar to the other multi-national industries, it is clear that English language is also widely used in the aviation industry. English is generally viewed as the official language for the civil aviation worldwide, particularly since many essential manuals and documents are written in this language [24]. Additionally, English is remarked as the formal language of international aviation communications [25]. With wide application throughout the industry, it is anticipated that all personnel working in aviation possess the proper level of English language proficiency to effectively perform their designated tasks. An exemplary case that is often used to highlight the necessity of English language competency in aviation is the oral communication between pilots and air traffic controllers. Since the pilots and air traffic controllers in different localities around the world have varieties of "Englishes" that differ based on their proficiency levels and local influences, this situation has caused serious and fatal accidents over the years [26]. Such variety of highly accented English could lead to problems of intelligibility and comprehensibility [27]. Due to its high consequences to the overall operational aviation safety, this situation has spawned many researches and new regulations that ensure miscommunication over use of English language between pilots and air traffic controllers can be effectively avoided. Since 2008, it is compulsory for both pilots and air traffic controllers to acquire certification of the English language proficiency as commanded by International Civil Aviation Organization (ICAO) [28]. In addition to the regulations, there have been research efforts to reduce potential effects of English language barrier in aviation operation, including the development of aviation language standards and a better language training and testing for aviation personnel. It is recommended that pilots and air traffic controllers to strictly use only standard aviation phraseology and avoid plain English while communicating [29].

Although the focus on aviation English language thus far is largely emphasized on effectiveness of radiotelephony communications between the pilots and air traffic controllers, there is also an emerging concern on English language proficiency of aviation maintenance personnel. This issue attracts a serious attention in light of the rising numbers of aviation incidents that have been associated with incorrect and improper execution of the maintenance tasks. For instances, there were 112 cases of accidents and serious incidents between years 2003 to 2017 that are contributed to aviation maintenance errors [30]. While this can still be considered as low, these maintenance-related accidents or incidents regularly incur notably high operational and repair costs due to inflicted damages to the aircraft, not to mention that they are more likely to involve fatalities than the other types of aviation accidents or incidents [31]. In view of that, reducing and preventing errors during aircraft maintenance is acknowledged as crucial to ensure the integrity of aviation safety system remains intact. According to some studies on the aviation maintenance errors, human error has been identified as one of the largest contributors for improper maintenance events, which could be linked to factors like miscommunication and misinterpretation of maintenance instructions. This means that many committed maintenance errors might not be fully due to lack of theoretical or technical skills of the personnel to perform the tasks but they could be attributed to other reasons including language barriers. It is noted that most incidences of miscommunications in aircraft maintenance organizations, which often further led to accidents, haste and misunderstanding of maintenance procedures, often involved non-native English speakers with problems to converse or fully comprehend documents in the English language [32]. Since aviation maintenance manuals are all prepared in English, though they are essentially written in simplified English to avoid misunderstanding or miscomprehension of instructions, this situation should be taken as a critical issue that negatively affects the aviation industry. After all, due to high risk of aviation operations, the execution of aviation maintenance tasks requires strict adherence to the manual instructions. In other words, the outlined procedures in the maintenance manuals should be exactly followed while performing maintenance tasks and the provided instruction comprehensively cover warnings and cautions up to actions after the task is completed [33]. On the whole, such working circumstances have prompted the impression that all maintenance personnel should have appropriate English language competency level to effectively work within the aircraft maintenance field, in addition to theoretical knowledge and practical skills that are gained from their rigorous trainings.

At present, ICAO holds primary responsibility to set the minimum necessary standard of English language ability and the related certification tests for international aviation communities [34]. However, the current enforced rule of the English language requirement is only applicable for pilots and air traffic controllers. Although there have been calls for the requirement to be also prescribed for maintenance personnel, there is still no standard regulation in place for international use. In Malaysia, amid concerns on increasing local case reports, CAAM as local aviation authority took proactive action to introduce the additional English language requirements for all maintenance personnel working in the local aviation industry. This is due to the general impression that English language competency of the local AMTs is in decline. Prior to this new rule, proficiency level in English language is also required for the issuance of basic aviation maintenance license and workplace, but no clear outline is given on specific evidence or proof that has to be provided to indicate the fulfillment of required attainment level. On contrary, under the new rule by CAAM, requirements for English proficiency level in the implementation manual of ICAO Language Doc 9835 are adopted and extended for certification of local aviation maintenance personnel. This means that, while ICAO does not impose any formal requirement of English language proficiency level, CAAM effectively requires all aircraft maintenance personnel in Malaysia to acquire proper English Language Proficiency certification for their licensing.

In general, the introduction of this additional English proficiency requirement for the local AMTs in Malaysia is justified and supported if it can be shown that English language is predominantly used and compulsory for them to effectively perform aviation maintenance tasks such that lack of English language competency can hinder their job performance. To establish this, a survey is conducted among local aviation maintenance personnel in several companies in Malaysia. The survey findings are analyzed to establish the relevancy and also necessity of this added English language requirement by CAAM.

3. Methodology

Survey method is a well-accepted means to acquire an insight or establish the perception of public or targeted groups of people with regards to specific issues of interest. Specifically, for aviation fields, some exemplary usage of the survey method can be observed for development of new aircraft design concepts [35] and evaluation of impact of aircraft subsystem functional designs and operations [36]. For this study, an online survey is conducted among the aviation maintenance personnel in Malaysia to collect the data for analysis. The survey is publicly made available on the Google Forms platform for a month, which is throughout the entire month of June 2020. Invitation to the target survey participants are sent through various social media outlets such as email, WhatsApp and also Facebook. The applied survey instrument is tailored to the objective of this study and is prepared using simple English language in order to avoid misunderstanding of the questions for non-native English speaking participants. In addition, following the standard procedure for preparing the survey instrument, an initial test run with a small group of people has been conducted to ensure that all questions are correctly worded and easy to understand. This is a very crucial step to ensure the correct answers are being extracted from survey participants. Overall, the questions are designed to establish the level of usage and importance of the English language in local aviation maintenance workplace and the difficulties in performing aviation maintenance tasks due to English language incompetency.

In general, there are three major sections of the survey questionnaire. The first section is designated to establish survey participants' background profile including gender, age, native speaking language, work experiences in local aviation maintenance industry and also qualification level of English language. Meanwhile, the second section aims to analyze the current level of English language usage among local aviation maintenance personnel in their workplace. In this section, the typical maintenance activities or tasks have been listed and the survey respondents are asked to rate their frequency of occurrence and importance of proper English language proficiency to execute them. Furthermore, in the third section of the questionnaire, possible difficulties in performing aviation maintenance task when the personnel do not have proper English language competency level are identified. In the final part before the survey is concluded, respondents are enquired to give their opinion regarding the new added English language requirements by CAAM and their general perception of English proficiency level among maintenance personnel in their workplace.

All in all, the total number of respondents in this conducted survey study is 38 and they all currently work as maintenance personnel in few local aviation companies. While the number of the respondents is rather low to represent the entire population of local aviation maintenance workers in Malaysia, it is taken to be adequate for this exploratory study. Of the total respondents, only four of them are female and this small number is consistent with the observed situation in the local aviation industry, where the aviation maintenance personnel are predominantly males. The overall average of the respondents' age is around 33 years old and their average work experience in the local aviation maintenance industry is around 6.4 years. Among the highest positions that have been held (or are currently being held) by the respondents during their career in local aviation maintenance industry ranges from junior technician up to lead engineer. It should be noted the respondents are all non-native English speakers but most of them passed the standard Malaysian University English Test (MUET) or international English language tests such as IELTS. In fact, several of them also possess the international aviation English language competency certification. All things considered, it is concluded that the pool of survey participants is greatly relevant to this study. Their diverse background and level of work experiences in local aviation maintenance industry could provide a more rounded view for the topic of interest and ensure that the collected data is accurately reflective of the actual current situation in the industry. Table 1 presents the summary of the respondents' background details.

Table 1: Background details of survey respondents

Characteristics		**Respondents %**
Gender	Male	89.5
	Female	10.5
Age	< 30 years old	31.6
	30 to 40 years old	57.9
	> 40 years old	10.5
Years in Aviation Maintenance	< 5 years	39.5
	5 to 10 years	50.0
	> 10 years	10.5
Highest English Language Certification	Professional Aviation	10.5
	International Test	15.8
	Malaysia National Test	34.2
	Lower Qualification	39.5

The respondents have also been asked to rate their own perceived level of English language ability. Based on the responses, they all rated their speaking, writing, reading and listening skills to be at average level or above. This is a good situation as it assures a very low possibility that they had difficulties or misunderstood any of survey questions while completing the questionnaire. The overall responses from survey participants regarding assessment of their own English language competency are presented in Figure 1. It is observed that the skills that have been rated as average by most of them are speaking and writing, which are the general capabilities necessary to effectively communicate instruction, report and idea for maintenance tasks. Without these skills, it could be difficult to properly communicate among colleagues or subordinates, and this increases the level of possibility for miscommunications. Moreover, the perceived English language competency of their co-workers in the local aviation industry have been rated by 87% of survey respondents to be at necessary level to effectively perform aviation maintenance task. It should nevertheless be noted that four respondents thought that the English proficiency among their work colleagues is lower than the expected or required level. This is taken to imply that there are cases of local aviation maintenance personnel who possess inadequate English language capability and this condition has hindered their job performance.

Figure 1: Respondents' rating of their own English competency

As previously mentioned, the survey instrument used in this study essentially contains two major sections that are designed to establish the level of English language usage by maintenance personnel in the local aviation companies while they perform their maintenance tasks and the importance of having good competency in English language to properly conduct their maintenance task. The responses of survey respondents for these two sections are presented and discussed in the following section.

4. Results and Discussion

Several typical activities that have been identified while performing the aviation maintenance tasks are listed in the survey questionnaire and the respondents are asked to rate their typical level of English language usage for each of these activities. Figure 2 summarizes the responses on the use of English in common communication activities in their organization. It is noted that only 50% of them implied that English is "often" or "very often" used in the oral communications with their superiors or subordinates. Meanwhile, 42% of them answered "neutral" and there are three respondents who actually "rarely" or "very rarely" use English language in their oral communications with their superiors or subordinates. A similar response situation is also found for communications with colleagues, where only 50% of the respondents stated they used English language to speak and interact with their co-workers. Close to 24% of them "rarely" or "very rarely" talked to their co-workers in English while the other remaining respondents were "neutral". However, as could be implied from the obtained responses regarding the language used in discussion and meetings, it shows that English language is very much used with the positive response from 79% of the respondents. In fact, out of all respondents, only one indicated that discussion and meetings at his organization were rarely conducted in English language, which may be an outlier case. On the whole, it is concluded that English language has been customarily used in most of formal communications in the local aviation maintenance companies, although there appears to be a notable preference to communicate in the native mother tongue language among the local non-native English speaking personnel. The latter situation is predictable and hardly surprising as it is aligned with findings from many studies on native language as the favored communication language for most people throughout the world [37].

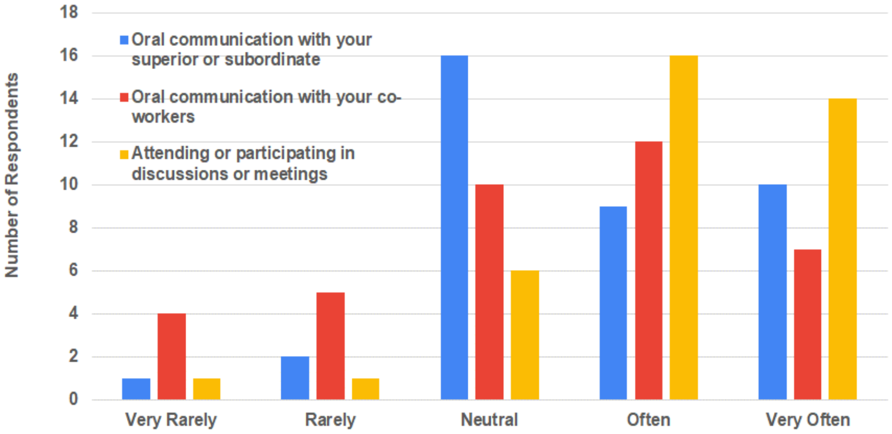

Figure 2: English language use for communication among aviation maintenance personnel

In the meantime, the respondents are also asked to rate the level of English usage in several direct activities while performing their aviation maintenance task. It can be observed in Figure 3 that English language is heavily used for these activities as the given ratings are evidently biased towards "often" and "very often". Unlike the formal (or informal) interaction and communication with their co-workers and work colleagues where they have the choice to use native mother tongue language, aviation maintenance personnel are "forced" to use English language here since almost all aviation maintenance documents such as reports and manuals are written in English. Moreover, they are also anticipated to prepare the reports or notes in English language for the maintenance work due to the global nature of the industry. In line with this notion, the skewed responses towards a high use of English language for the considered maintenance activities here is not surprising. In addition, it is observed from Figure 3 that about 95% of respondents indicated that they have to apply the English language to read aircraft manuals, memos, letters, notices and other maintenance documents for instructions in order to perform their assigned task at hand, and to prepare written maintenance reports, logbooks and other necessary documentations upon completion of their work. However, it is noted there are few "very rarely" and "rarely" responses, which indicates other languages other than English is used when they are giving and/or receiving work instructions to/from others. This can be linked to the previous inference on the preference to use native mother language in communication with other non-native English speaking co-workers and colleagues.

Moreover, there are also questions in the survey that are designed to establish the importance of English language in performing aviation maintenance tasks. In this case, the respondents were asked to answer the questions based on their perception and work experiences. Figure 4 portrays the responses regarding the importance in having appropriate English proficiency level to effectively perform aviation maintenance tasks. The respondents' perception regarding the importance of adequate English language competency level is highly consistent with their response on English language use while performing the aviation maintenance tasks. This observed agreement acts as good support for accuracy of the findings. Almost all common activities are perceived to entail proper English language proficiency to be properly conducted. Only exception is communication activities, whereby there are still notable numbers of "not important" and "neutral" responses. Again, this is very much in parallel with the previous findings on the preferred use of native mother tongue language while communicating with other non-native English speaking personnel in either personal capacity or work-related communication. When responding to the query on the imposed additional English language rules by CAAM, they unanimously agree to it with half of them marked "strongly agree". This reflects the perceived importance of having a proper English language competency among local aviation maintenance personnel to effectively perform their tasks from the viewpoint of the respondents.

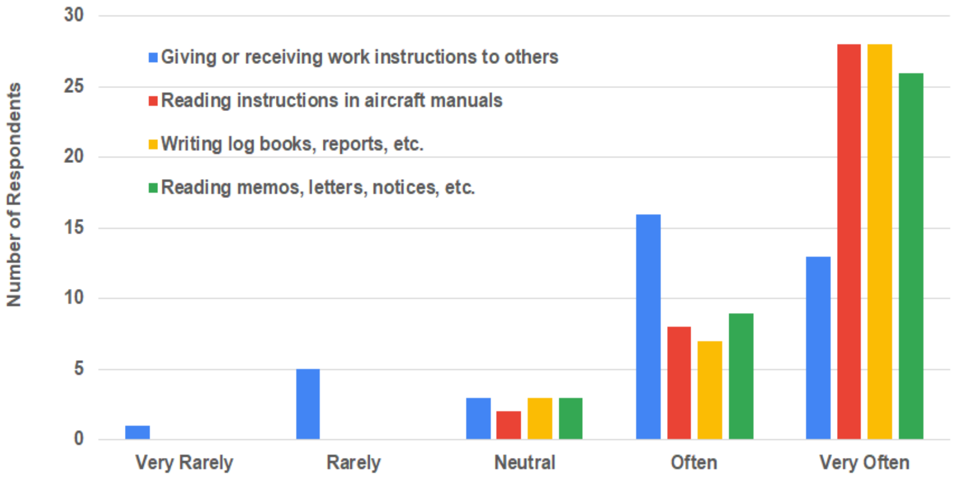

Figure 3: English language use in essential activities while performing aviation maintenance tasks

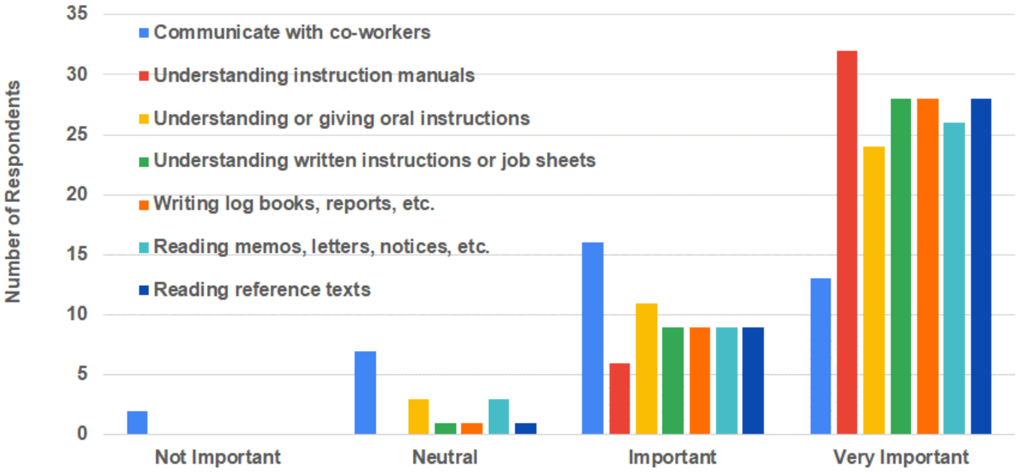

Figure 4: Importance of English language proficiency to effectively perform aviation maintenance tasks

On the other hand, the frequency of occurrence for types of typical difficulties or mistakes when performing aviation maintenance tasks due to lack of the English language proficiency as experienced or observed by the respondents throughout their working experience is depicted in Figure 5. While the occurrence of all difficulties and errors has been rated as either "rarely" or "very rarely" by almost 50% of them, it is still alarming to note that they still regularly happened as reflected by the "sometimes", "often" and "very often" responses from other 50% of the respondents. This finding corroborates the assertion of CAAM that aviation maintenance errors related to lack of appropriate English language proficiency still regularly happen among local aviation maintenance personnel in Malaysia. When asked on whether they faced similar difficulties or made similar errors as those listed in Figure 5, occurrence frequency for each of them is rated with “sometimes”, “often” and “very often” by about 30% of the respondents. Once again, this implies that such events do regularly happen in local aviation maintenance industry, which tallies with previous inference made from Figure 5.

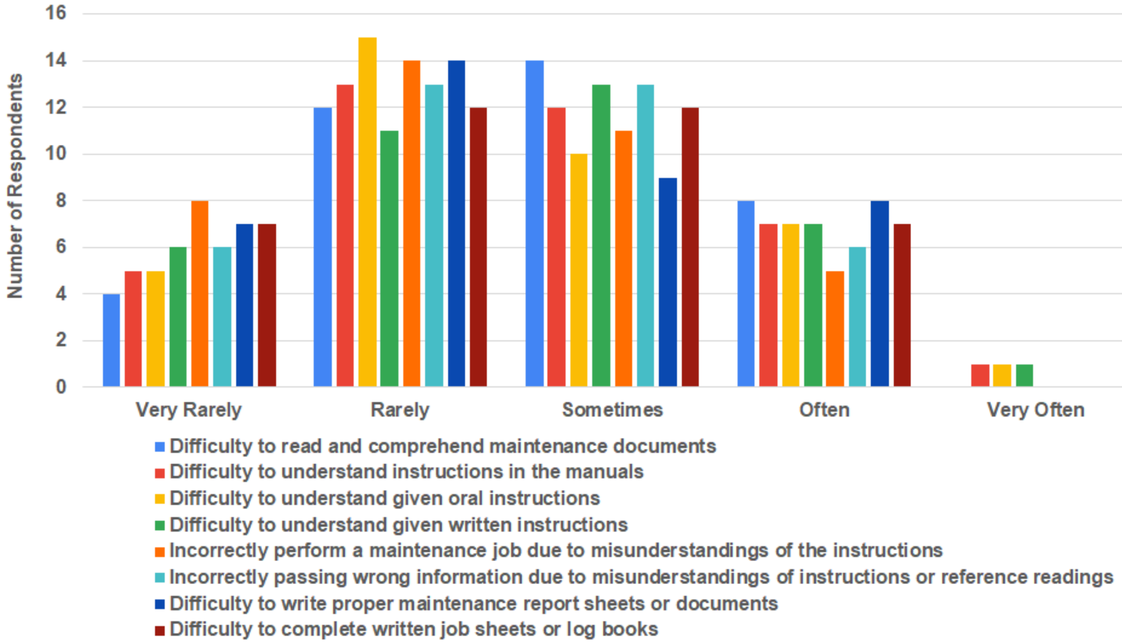

Figure 5: Frequency of observed difficulties in performing aviation maintenance tasks without English language proficiency

In hindsight, referring back to level of English language certification of the respondents in previous Table 1, it can be deduced that the percentage of the respondents who had difficulties or made errors while performing maintenance task is closely similar to percentage of them with lower English language certification. Hence, it seems that there exists connection between English language certification (which reflect on level of proficiency) and effectiveness of aviation maintenance personnel in performing their task.

5. Conclusion

An online public survey has been conducted among the local aviation maintenance personnel in Malaysia, which is aimed to establish the level of usage of English language and importance of proper English language proficiency in performing effective aviation maintenance tasks. Based on the collected responses, it is inferred that most essential activities involved in performing the aviation maintenance tasks substantially require the use of English language. However, there appears to be notable preference in using native mother tongue language for communication among the aviation maintenance personnel, either in personal or work-related communications. Meanwhile, importance of having appropriate level of English language competency to enable an effective execution of the aviation maintenance tasks has been reflected by the survey responses. Common essential tasks to perform aviation maintenance tasks have been rated with high importance of English proficiency, with only exception is for communication activities that can be linked back to the inference on the preference in using their native mother tongue language when communicating among non-native English speaking aviation maintenance personnel. Based on the responses on task difficulties and committed errors due to the lack of English language competency among local aviation maintenance personnel, it appears that their occurrences are regular and this should be seen as an alarming situation. On the whole, it is concluded that the English language is highly used in the execution of local aviation maintenance tasks and it is important for all local aviation maintenance personnel to acquire appropriate proficiency level of the English language to perform their tasks effectively. The findings of this study are evidently in good support for the action by CAAM to impose additional English language competency requirement to local aviation maintenance personnel in Malaysia.

References

[1] K. B. Marais and M. Robichaud, 'Analysis of Trend in Aviation Maintenance Risk: An Empirical Approach', Reliability Engineering and System Safety, vol. 106, pp. 104-118, 2012.
[2] A. K. Gramopadhye and C. Drury, 'Human Factors in Aviation Maintenance: How We Got to Where We Are', International Journal of Industrial Ergonomics, vol. 26, pp. 125-131, 2000.
[3] S. Dalkilic, 'Improving Aircraft Safety and Reliability by Aircraft Maintenance Technician Training', Engineering Failure Analysis, vol. 82, pp. 687-694, 2017.
[4] H. Bagan and E. Gerede, 'Use of a Nominal Group Technique in the Exploration of Safety Hazards Arising from the Outsourcing of Aircraft Maintenance', Safety Science, vol. 118, pp. 795-804, 2019.
[5] F. Aliunir, T. Zagloel and R. Ardi, 'Discrete-event Simulation and Optimization of Spare Parts Inventory and Preventive Maintenance Integration Model Considering Cooling Down and Machine Dismantling Time Factor', EVERGREEN Joint Journal of Novel Carbon Resource Sciences and Green Asia Strategy, vol. 7, pp. 79-85, 2020.
[6] D. C. Kraus and A. K. Gramopadhye, 'Effect of Team Training on Aircraft Maintenance Technicians: Computer-based Training versus Instructor-based Training', International Journal of Industrial Ergonomics, vol. 27, pp. 141-157, 2001.
[7] J. H. Saleh, A. T. Ray, K. Zhang and J. Churchwell, 'Maintenance and Inspection as Risk Factors in Helicopter Accidents: Analysis and Recommendations', PLoS ONE, vol. 14, e0211424, 2019.
[8] D. C. Krulak, 'Human Factor in Maintenance: Impact on Aircraft Mishap Frequency and Severity', Aviation, Space and Environmental Medicine, vol. 75, pp. 429-432, 2004.
[9] L. Santos and R. Melicio, 'Stress, Pressure and Fatigue on Aircraft Maintenance Personal', International Review of Aerospace Engineering, vol. 12, pp. 35-45, 2019.
[10] K. Latorella and P. Prabhu, 'A Review of Human Error in Aviation Maintenance and Inspection', International Journal of Industrial Ergonomics, vol. 26, pp. 133-161, 2000.
[11] D. Virovac, A. Domitrovic and E. Bazijanac, 'The Influence of Human Factor in Aircraft Maintenance', Promet – Traffic and Transportation, vol. 29, pp. 257-266, 2017.
[12] P. Tungjiratthitikan, 'Accidents in Thai Industry between 2001 and 2017', EVERGREEN Joint Journal of Novel Carbon Resource Sciences and Green Asia Strategy, vol. 5, pp. 86-925, 2018.
[13] I. Morag, P. Chemweno, L. Pintelon and M. Sheikalishahi, 'Identifying the Causes of Human Error in Maintenance Work in Developing Countries', International Journal of Industrial Ergonomics, vol. 68, pp. 222-230, 2018.
[14] A.V. Chatzi, W. Martin, P. Bates and P. Murray, 'The Unexplored Link between Communication and Trust in Aviation Maintenance Practice', Aerospace, vol. 6, 66, 2019.
[15] A. Shanmugam and T. P. Robert, 'Human Factors Engineering in Aircraft Maintenance', Journal of Quality in Maintenance Engineering, vol. 21, pp. 478-505, 2015.
[16] H. S. J. Rashid, C. S. Place and G. Braithwaite, 'Investigating the Investigations: A Retrospective Study in Aviation Maintenance Error Causation', Cognition, Technology and Work, vol. 15, pp. 171-188, 2013.
[17] M. Bao and S. Ding, 'Individual-related Factors and Management-related Factors in Aviation Maintenance', Procedia Engineering, vol. 80, pp. 293-302, 2014.

[18] G. Liang, J. Lin, S. Hwang, E. Wang and P. Patterson, 'Preventing Human Errors in Aviation Maintenance Using an On-line Maintenance Assistance Platform', International Journal of Industrial Ergonomics, vol. 40, pp. 356-367, 2010.

[19] H. S. J. Rashid, C. Place and G. Braithwaite, 'Eradicating Root Causes of Aviation Maintenance Errors: Introducing AMMP', Cognitive, Technology and Work, vol. 16, pp. 71-90, 2014.

[20] N. Umeokafor, K. Evaggelinos, S. Lundy, D. Isaac and S. Allan, 'The Pattern of Occupational Accidents, Injuries, Accident Causal Factor and Intervention in Nigerian Factories', Developing Country Studies, vol. 4, pp. 119-127, 2014.

[21] H. Y. Chong and T.S. Low, 'Accidents in Malaysian Construction Industry: Statistical Data and Court Cases', International Journal of Occupational Safety and Ergonomics, vol. 20, pp. 503-513, 2014.

[22] S. Ahmad Shukri, F. Romli, W.T.F. Wan Badaruddin and A. Mahmood, 'Importance of English Language Competency in Aviation Maintenance: Malaysia Case Study', Journal of Aeronautics, Astronautics and Aviation, vol. 53, pp. 113-120, 2021.

[23] S. Ahmad Shukri, R. Millar, G. Gratton and M. Garner, 'The Potential Risk of Communication Media in Conveying Critical Information in the Aircraft Maintenance Organization: A Case Study', IOP Conference Series: Materials Science and Engineering, vol. 152, 012044, 2016.

[24] J. Knezevic, 'Improving Quality of Maintenance Through Simplified Technical English', Journal of Quality in Maintenance Engineering, vol. 21, pp. 250-257, 2015.

[25] J.C. Alderson, 'Air Safety, Language Assessment Policy and Policy Implementation: The Case of Aviation English', Annual Review of Applied Linguistics, vol. 29, pp. 168-187, 2009.

[26] A. Tajima, 'Fatal Miscommunication: English in Aviation Safety', World Englishes, vol. 23, pp. 451-470, 2004.

[27] H. P. Li and H. C. Chen, 'Intelligibility and Comprehensibility of the Filipino English Accent to Hong Kong English Speakers', 3L: Language, Linguistics, Literature, vol. 25, pp. 23-42, 2019.

[28] J. C. Alderson, 'A Survey of Aviation English Tests', Language Testing, vol. 27, pp. 51-72, 2010.

[29] H. Hamzah and W. Fei, 'Miscommunication in Pilot-Controller Interaction', 3L: Language, Linguistics, Literature, vol. 24, pp. 199-213, 2018.

[30] J. Insley and C. Turkoglu, 'A Contemporary Analysis of Aircraft Maintenance-related Accidents and Serious Incidents', Aerospace, vol. 7, 81, 2020.

[31] F. Khan, A. Ayiei, J. Murray, G. Baxter and G. Wild, 'A Preliminary Investigation of Maintenance Contributions to Commercial Air Transport Accidents', Aerospace, vol. 7, 129, 2020.

[32] J. Ma, C. G. Drury and C. Marin, 'Language Error in Aviation Maintenance: Quantifying the Issues and Interventions in Four World Regions', International Journal of Aviation Psychology, vol. 20, pp. 25-47, 2010.

[33] H. Zafiharimalala, D. Robin and A. Tricot, 'Why Aircraft Maintenance Technicians Sometimes Do Not Use Their Maintenance Documents: Towards New Qualitative Perspective', International Journal of Aviation Psychology, vol. 34, pp. 190-209, 2014.

[34] D. Shin and H. Kim, 'English for Aviation Specific Purposes: Needs Analysis for English Proficiency Requirements', Korean Journal of Applied Linguistics, vol. 21, pp. 193-217, 2005.

[35] F. Ishak, F. Romli and K. Rahman, 'Public Survey on New In-flight Food Delivery and Waste Collection System', Journal of Mechanical Engineering, vol. 5, pp. 142-152, 2018.

[36] N. O. Aminian, F. I. Romli and S. Wiriadidjaja, 'Usability Evaluation Survey for Identifying Design Issues in Civil Flight Deck', IOP Conference Series: Earth and Environmental Science, vol. 30, 012013, 2016.

[37] J. Melitz and F. Toubal, 'Native Language, Spoken Language, Translation and Trade', Journal of International Economics, vol. 93, pp. 351-363, 2014.

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