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Conceptual Design Exploration of A New Aircraft Passenger Seat's Tray Table with Adjustable Height

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ABSTRACT

Flight comfort has become an essential consideration among the aircraft passengers. One of the aspects that can contribute towards better passengers' comfort during flight is the ease for them to conduct their in-flight activities. Since most of passengers' in-flight activities involve the use of the seat tray table and each passenger has different body anthropometry, it is believed that the height of the seat tray table has a significant influence to the provision of ease and comfort for the passengers to conduct these activities. This notion is first demonstrated through conducted comfort experiment in an aircraft cabin mock-up. Based on the experimental results, it has been shown that different passengers will need different height of seat tray table to comfortably do their common in-flight activities. It is taken that these results support the need for a new seat tray table design that comes with an adjustable height feature. With this in mind, few alternative designs for a new seat tray table that is equipped with adjustable height feature have been developed and evaluated. Out of the three shortlisted design concepts, Design Concept 1 has been finally selected and it has been shown to be able to satisfy all outlined design requirements.

Keywords: Flight comfort, Seat tray table design, In-flight activities, Aircraft passengers, Anthropometry

I. INTRODUCTION

Over the years, market competition between airlines has been progressively increased along with increase in the demands of air transportation. Subsequently, the increased competition has also driven the improvement in quality of flight services offered by airlines [1]. High service quality has become a competitive means among airlines as many aircraft passengers today consider a good quality of flight service, which includes flight comfort, as one of their main factors when choosing their air travel options [2]. Several studies have already indicated the significant influence of experienced flight comfort toward passengers' perception of airlines' service quality [3-5]. It is therefore crucial for airlines to ensure that they can provide an adequate flight comfort experience for their passengers to be competitive against their market competitors. A good flying experience will translate into a positive perception of overall airlines' image and branding [6].

By definition, comfort is not just simply the absence of discomfort and it is associated with several other factors [7]. These factors also include physical, social, situational, physiological, psychological, as well as environmental [8]. For aircraft passengers, this means that their flight comfort experience can be notably dictated by their own self-state, cabin design and environment, and in-flight activities that they performed. Thus far, not many studies have been done with regard to activity-based assessment of the passengers' comfort during flight. It has been indicated in a conducted study that different in-flight activities could have different influence on the aircraft passengers' comfort [9]. This is in line with the findings from another study, which also show different comfort ratings for several in-flight activities [10]. All in all, it is crucial for passengers to be able to perform their in-flight activities with ease and comfort since this is affecting their perception of the overall flight comfort.

During flight, there are several typical activities that the aircraft passengers often perform while they are seated.

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Among others, these include activities like sleeping, eating, reading, writing, using electronic devices such as laptop or smartphone and enjoying the in-flight entertainment. It can also be noted that most of these activities involve the usage of the seat tray table as depicted in Figure 1. In this respect, having the tray table at proper height is essential to ensure that the passengers are comfortable while performing their activities. A study has demonstrated that height of the tray table can affect the sitting posture of aircraft passengers, especially neck posture, and an improper height could lead to pain and discomfort [11]. Meanwhile, another study has shown that different tray table's height might be needed by different aircraft passengers to perform the same activities comfortably, which indicates possible effect of passengers' anthropometry on required comfortable tray table's height [12]. Based on these findings, it can be said that seat tray table with adjustable height might be a good solution to be explored to provide an adequate comfort to the passengers, especially during their in-flight activities.

Figure 1 Example in-flight activities using the seat tray table [13]

To design a seat tray table with adjustable height for use in aircraft cabin, the required range of the tray table's height has to be established first. Once the range is set, the appropriate mechanism to adjust the tray table's height can be designed. This study is aimed to explore and propose a new seat tray table design with adjustable height feature to be used in the aircraft cabin. Note that for this study, design of the tray table is tailored to the Malaysian population of aircraft passengers, whereby their anthropometry database is applied.

II. METHODOLOGY

To determine the required range of height for the seat tray table, an activity-based experiment is conducted using an aircraft cabin mock-up that is available at the Aerospace Design Laboratory, Department of Aerospace Engineering, Universiti Putra Malaysia, Malaysia. For this experiment, a total of 132 volunteers have participated. All participants have declared that they did not have ongoing health issues or body pains, which ensures that any discomfort that they felt during the experiment is due to mainly the cabin setup. Three common in-flight activities that involve the usage of seat tray table are considered during the experiment: eating, writing and using laptop. The seat pitch in the cabin mock-up is set to 28 inches, which is a common setting for many economy class seating arrangements [4].

During the experiment, each participant is asked to sit at the designated aircraft seat inside the cabin mock-up and perform the three considered in-flight activities. For each of the activities, the height of the seat tray table is adjusted until the participants indicated that they were at their best comfort level to perform the activity. Figure 2 is depicting the conduct of the experiment, which in this case is during eating activity. The data on the required comfortable tray table's height for each participant in all three common in-flight activities are recorded. Based on findings from this activity-based experiment, the maximum height of the seat tray table that improve the passengers' ease and comfort to perform their in-flight activities can be roughly estimated.

A few alternative designs of the mechanism to adjust the seat tray table's height are developed and they are then evaluated to select the best among them. In this study, the selection process of the best design alternative is done with public involvement through a conducted online survey. A total of 111 respondents have participated, whereby they rated the three down-selected design concepts according to several evaluation criteria.

Figure 2 Conducting the activity-based sitting comfort experiment (eating)

Table 1 presents descriptive statistics of the survey respondents. It can be observed that most of the respondents have previously experienced air travelling using airlines and more than 40% of them can be classified as frequent flyers. The majority of them also have experiences in using both types of airlines, either low cost or full service airlines. All things considered, it can be taken that this pool of survey respondents appropriately matches the target population, which helps to ensure good reflection of the assessment on alternative design concepts by the actual aircraft passengers.

Table 1 Descriptive statistics of respondents

Respondents’ Background		**Percentage (%)**
Gender	Male	55.9
	Female	44.1
Flying Frequency	Highly Frequent	9.9
	Frequent	31.5
	Occasionally	38.7
	Seldom	19.8
Types of Airlines Frequently Used	Full Service	25.2
	Low Cost	20.7
	Both	54.1

In addition to conducted online survey, finite element analysis (FEA) on all considered design alternatives is also done. FEA is widely used to analyze engineering problems, especially those involving the study of structural behavior. For instances, FEA simulation has been utilized to study structural strength of new standing aircraft passenger seat [14] and aeroelastic effects of the aircraft’s wing structural design [15]. In this study, FEA is used to evaluate whether the design alternative concepts have the proper strength to support the in-flight activities without any failure. For this initial analysis, aluminum alloys have been defined as the material for the structural parts of the seat tray table based on their strength, durability and lightweight characteristics. Specifically, Aluminum 2024 T6 material is chosen in this study, which is in fact the common material applied for the structures of many existing aircraft’s seat tray tables. In the meantime, plastic ABS (Acrylonitrile Butadiene Styrene) is a thermoplastic material that is chosen to be applied for the tray table. ABS is the practical choice for seat tray table surface in aircraft cabin due to its strength and lightweight. Table 2 tabulates all the essential properties of these two materials, which are then used in the FEA simulation.

Table 2 Standard material properties used in the FEA simulation analysis

Material Property	**Aluminum 2024 T6**	**Plastic ABS**
Ultimate Tensile Strength	313.10 MPa	36.26 MPa
Yield Tensile Strength	259.20 MPa	27.44 MPa
Density	2.71 g/cm^3	1.03 g/ cm^3
Young Modulus	69040 MPa	1628 MPa
Poisson Ratio	0.33	0.4089
Shear Modulus	25955 MPa	577.76 MPa

In the analysis of the tray table mechanism, ANSYS static structural analysis is used due to the primarily static nature of the load. Maximum height position of the seat tray table, as selected based on the results of the conducted experiment in the previous stage of this study, is applied in the simulation analysis as the tray table will experience the most deflection and stress at this height. A load is applied to the upper surface of the tray table while the frame of the seat tray table is fixed in place as the reference point. This approach allows for evaluation of the deflection and stress distribution within the tray table mechanism. Meanwhile, boundary conditions are applied in the FEA simulation to the tray table to simulate real world operating conditions. During the analysis, these conditions define the constraints and forces acting on the seat tray table. Fixed supports are applied for the frame to prevent any movement, simulating the attachment of the tray table to the structure of aircraft’s seat. Force is also applied to simulate the weight of objects placed on the table's surface as well as other external loads encountered during use. These boundary conditions enable thorough examination for the structural behavior of tray table under realistic conditions. Another main step before conducting the FEA simulation is the mesh independence study. For this mesh study, the initial material used for the tray table structure is titanium, which is chosen to ensure that the simulation can accurately represents the behavior of the tray table without any potential material failure that could result in incorrect readings or values. Additionally, the applied load on the tray table surface is initially set to 150 N. The mesh study is done for all alternative design concepts and the obtained number of elements required to achieve reliable results with minimal variation is tabulated in Table 3. These values become the reference for meshing when conducting FEA simulation analysis on actual case study of the seat tray table.

Table 3 Summary of reference mesh settings

Design Concept	Optimal Settings	
	Element Size (mm)	Number of Elements
Design Concept 1	2.00	233999
Design Concept 2	3.00	110685
Design Concept 3	2.00	255404

Both survey responses and FEA simulation results are used to select the best design concept from the considered three down-selected alternatives. The Technique for Order of Preference by Similarity to Ideal Solution, or known as TOPSIS, is used as the method to aid the decision-making process. In general, TOPSIS is a well-known method that has been applied in various multi-criteria decision making problems for numerous fields. Among the examples of its application include for selecting the best design concept of a new in-flight food delivery and waste collection system [16] and conducting comparison analysis between several available options of public transportation [17]. Once the best design concept is selected, a more detailed computer-aided design (CAD) model of the new aircraft's seat tray table is constructed. Required adjustment or improvement on the concept is also considered and made at this stage. Ultimately, the final drawing of the proposed new design is developed to be utilized for further analysis in following stage of the design process.

III. RESULTS AND DISCUSSION

In the activity-based sitting comfort experiment, each of the participant is instructed to individually sit inside the aircraft cabin mock-up for three different sessions. At each session, participants are tasked to perform one of the three common in-flight activities and the height of seat tray table is adjusted accordingly to their best comfort requirement. There is no imposed instruction on the participants' sitting posture during the experiment and they are free to change their body posture according to their comfortable position for each in-flight activity. Table 4 tabulates the recorded comfortable height of the seat tray table for eating, using laptop and writing activities. Note that in the experiment, the seat pitch is maintained at 28 inches based on typical seat pitch used in economy class seating of many airlines.

Based on Table 4, it can be taken that seat tray table height can affect the passengers' comfort while conducting their in-flight activities.

Table 4 Overall comfortable seat tray table height for three common in-flight activities

Data	Comfortable Seat Tray Table Height (in cm)		
	Eating	Writing	Using Laptop
Minimum	70.000	71.000	67.500
Maximum	80.000	79.000	79.000
Average	73.485	73.492	73.337

This can be contributed to the fact that passengers' body anthropometry is typically different to each other and this can influence the right setting of seat tray table height in providing adequate comfort for them while doing their in-flight activities. It should be noted that the current fixed seat tray table's height in typical aircraft cabin is about 68 cm [11], which is clearly not comfortable for most passengers as indicated by findings in Table 4. In this respect, since the range between the minimum and the maximum comfortable tray table height can be taken to be substantially significant, new design of seat tray table that has a feature for adjustable height might be better solution. Such tray table feature will ensure that majority of aircraft passengers could comfortably and easily perform in-flight activities as they are able to adjust the tray table's height according to their own comfort and preference. Under this notion, a new design of seat tray table that is equipped with the height adjustment feature is explored in the next stage of this study. Referring to Table 4, it has been decided that the new design should be able to be adjusted in height from the current 68 cm to a maximum height of 82 cm.

In reference to Federal Aviation Regulations and also results of conducted brainstorming session, several design requirements for the new aircraft seat tray table have been identified apart from the range of height adjustment. These requirements have become the reference guidelines to be considered while developing design concepts for the new seat tray table design. The characteristics are as tabulated in Table 5.

Based on the established design requirements, several alternative design concepts for a new seat tray table design are generated through brainstorming session. Based on the initial assessment, three design alternative concepts have been down-selected for further consideration. The CATIA software tool is utilized to construct their respective CAD model for better visualization and for use in the evaluation process in later stage. The generated Design Concept 1 for the new seat tray table is shown in Figure 3 and Figure 4 for stowed and in-use positions, respectively. This design essentially features two hands connected to a tube that is joined to the frame. In this concept, the seat tray table's height adjustment is achieved by moving the hands up or down and securing them in place using a spring-based lock mechanism. The tube is equipped with a series of holes, enabling the hands to be fixed at different height positions and preventing any unintended movement. One of the main advantages of this Design Concept 1 is that it is closely similar to the current existing design, which means great compatibility with the current seat design. In addition, mechanism for adjustable height is supported by two hands, which provides a better stability. On the other hand, due to the added components for the adjustable height mechanism, its overall weight is expected to be slightly higher than current design and the added components also can cause higher failure rate and maintenance.

Table 5 Several main considerations for the new seat tray table design

Characteristics	Brief Description
Strength and Stability	The tray table must be strong enough to withstand various types of loads such as static loads and dynamic loads at certain conditions such as turbulence. It should not deflect too much under standard loading, otherwise it will lack functionality. The maximum allocated design loads to be supported by the tray table is set as 230 N, which is under a safety factor of 3. This maximum load is set according to estimated loading of common items used with the tray table as listed in Table 6.
Scratch and Flame Resistance	According to FAR 25.853, the design materials used should be resistant to flames. The material should also be resistant to scratches to avoid wear and tear over time.
Dimensions and Space Consumption	The design should not consume much of the space allocated to the passengers as it will reduce their sitting comfort. Since no change will be made to the aircraft seat design, the tray table is constrained to occupy a certain amount of available space.
Compatibility and Maintainability	The design should be removable or detachable from the main seat or armrest in case there is need of replacement of the tray table. Not only that, the redesigned tray tables should be simple to install in the present seats. Consequently, the tray table's legs or arm must be compatible with the present seat hinges.
Cost and Materials	The design should take account the cost of fabrication and installment together with the materials used. The materials and design should also consider the weight constraint. Materials with high elastic modulus to density ratios are considered to minimize part weight while optimizing stiffness, hence reducing deflection. Lastly, in case of failure, the material should first exhibit yield before it fractures, thus the material should be ductile.
User-friendliness	The adjustable height tray table's intuitive and simple design allows passengers to easily alter the table's height, offering an effortless and convenient experience for all users.

Table 6 Estimated weight of common items to be supported by the tray table

Items	Estimated Weight
Electronics	47 N
Book	10 N
Game	10 N
Food and drink	10 N
Total	**77 N**

In the meantime, the generated Design Concept 2 for the seat tray table is depicted in Figure 5 and Figure 6 for stowed and in-use positions, respectively. Design Concept 2 employs a tube that is connected to the frame with a hand, which is similar to Design Concept 1. However, instead of two hands, this concept utilizes a single hand positioned at the center of the tray for enhanced stability. To ensure the stability, the hand is also joined at the center of the tray, distributing the load evenly. The table's height adjustment mechanism is similar to Design Concept 1, allowing the hand to be adjusted vertically along the tube and locked into position at the desired table height. This design offers a streamlined and simplified approach, utilizing a single supporting hand for stability while maintaining flexibility of height adjustment. An obvious advantage of this Design Concept 2 is its weight, which is expected to be lower than Design Concept 1 as it has only a single hand, hence fewer number of components. In addition, due to its single hand, this design consumes less space that could lead to a better comfort for the passengers. Nevertheless, stability of the tray table support is also less due to only its single hand support. Moreover, the tray table is also supported at the center and to prevent unwanted rotation or being toppled over, a lock or stopper mechanism is required.

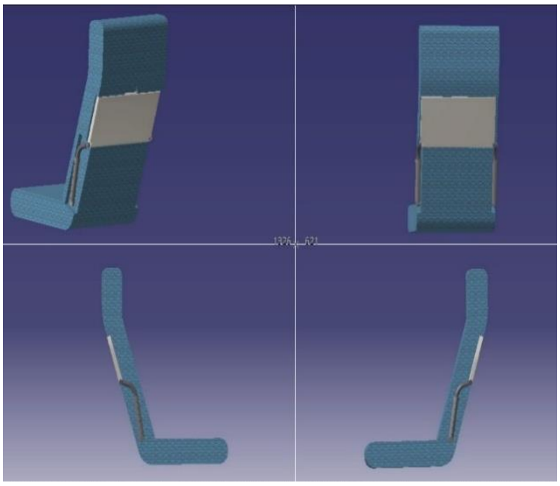


Figure 3 Illustration of Design Concept 1 in its stowed position

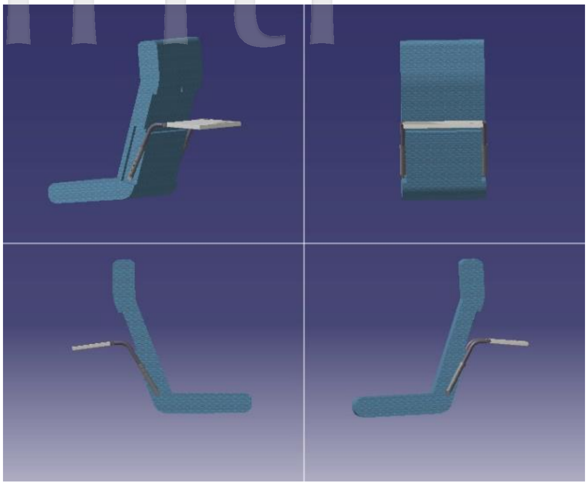


Figure 4 Illustration of Design Concept 1 in its in-use position

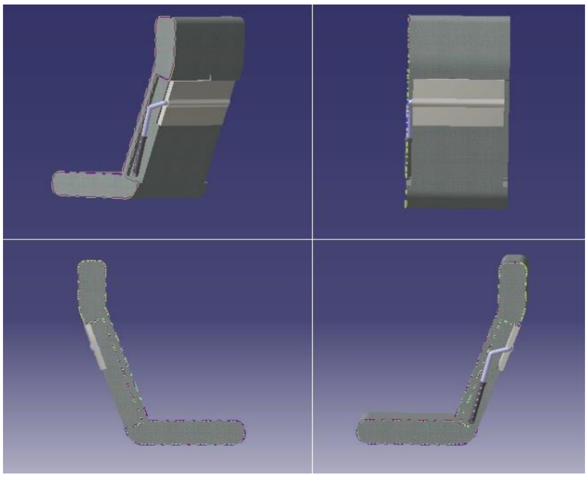


Figure 5 Illustration of Design Concept 2 in its stowed position

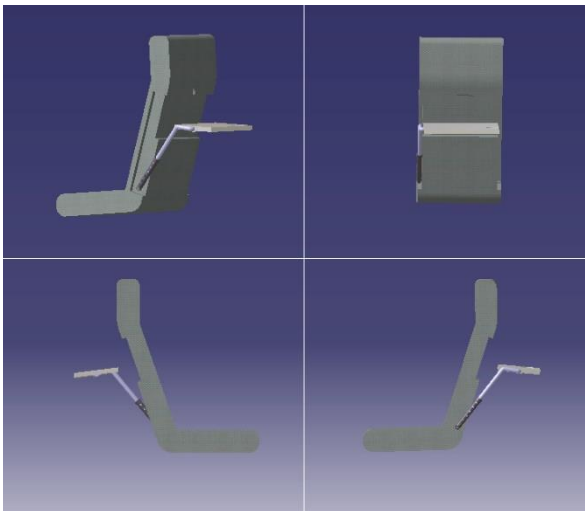


Figure 6 Illustration of Design Concept 2 in its in-use position

Lastly, for Design Concept 3, a similar hand and tube system is employed but with a different configuration. The tube is positioned at the back of the seat instead of the side, requiring a small modification to current type of tray table attachment to the seat to accommodate this design. Similar to Design Concept 2, this Design Concept 3 uses a single hand for support. The tray table is extended in the middle and connected to the hand. This configuration allows for the height adjustment by moving the hand along the tube, which provides stability in the positioning of the tray table. Illustration of Design Concept 3 is presented in Figure 7 and Figure 8 for stowed and in-use positions, respectively. Without any side hand, this Design Concept 3 can be taken as the least invasive design to the passengers among the three considered design concepts. Furthermore, this design concept uses the least amount of components and joints. However, since it only has a single hand to support the tray table, a comparatively thick support might be needed to reduce the tray table's deflection. Additionally, the support mechanism may need to be located inside the seat and this can pose extra challenges for its maintenance.

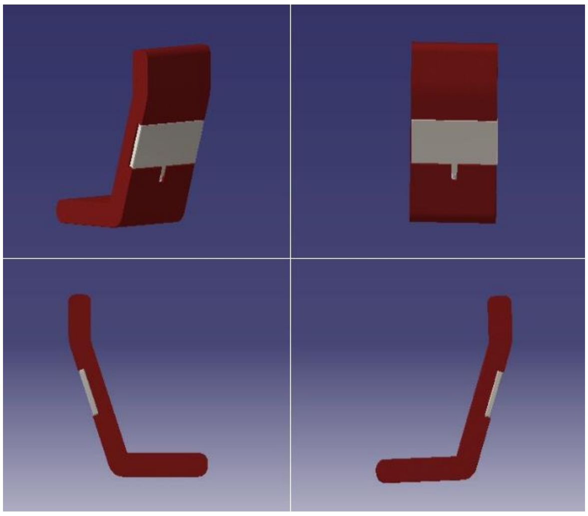


Figure 7 Illustration of Design Concept 3 in its stowed position

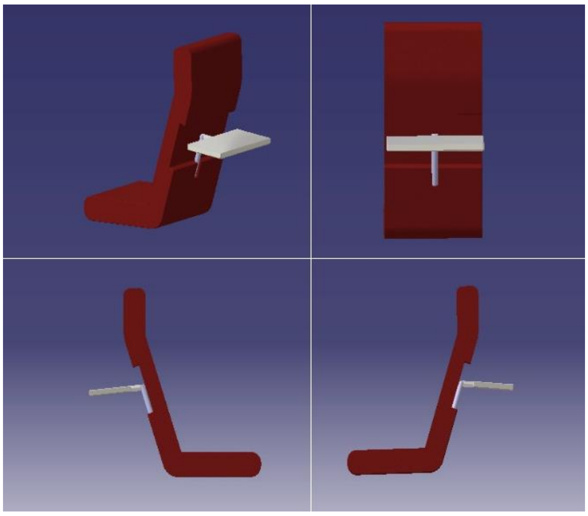


Figure 8 Illustration of Design Concept 3 in its in-use position

To gather perception of potential aircraft passengers who will be using this new seat tray table design, an online public survey has been conducted. In the conducted survey, respondents are asked to rate the importance of few design criteria for the aircraft seat tray table based on their own opinion. Five evaluation design criteria are outlined in the survey assessment: safety, ease of use, least invasiveness, appearance and stability. The ratings are assigned using a Likert scale, which is often used for assessment that needs responses ranging between one extreme to another [18]. In this study, the 5-point Likert scale is used, where 5 implies that the criterion is very important while 1 corresponds to the least important criterion. The results of this importance rating assessment are shown in Table 7, which are used as the criteria's weightage in TOPSIS evaluation.

Moreover, survey respondents have been also asked to rate all three alternative design concepts in terms of the design evaluation criteria. The average ratings as assigned by the respondents for each alternative design concept for each evaluation criterion are listed in Table 8, which are then applied for the TOPSIS evaluation. The results from the TOPSIS evaluation is shown in Table 9. As can be seen in Table 9, Design Concept 1 has evidently emerged as the best design concept according to the closeness rating score since it has the perfect score of 1.

Table 7 Assessment rating on the importance of the design evaluation criteria

Design Evaluation Criteria	Importance Rating Score	Weightage for TOPSIS
Safety	464	0.206
Ease of Use	450	0.200
Least Invasiveness	467	0.207
Appearance	394	0.175
Stability	476	0.211
Total	**2251**	**1.000**

Table 8 Average rating score for alternative design concepts

Design Evaluation Criteria	Design Concept 1	Design Concept 2	Design Concept 3
Safety	4.02	3.10	3.00
Ease of Use	4.12	3.35	3.41
Least Invasiveness	3.84	3.34	3.46
Appearance	3.69	3.36	3.49
Stability	3.92	3.03	3.02

Table 9 Separation distance and closeness rating for alternative design concepts in TOPSIS

Measure	Design Concept 1	Design Concept 2	Design Concept 3
Separation Distance from Positive Ideal	0.000	0.055	0.055
Separation Distance from Positive Ideal	0.058	0.003	0.006
Closeness Rating	1.000	0.058	0.095
Ranking	**1**	**3**	**2**

Nevertheless, it can be noted that the TOPSIS results are totally based on a subjective assessment of respondents in the conducted survey. There is a need to also ensure that the design alternatives can actually be operationally used. In this respect, FEA simulations are conducted on the three design alternatives. To conduct FEA simulation, detailed CAD model of their components has been constructed in CATIA. It should be noted that the initial dimensioning for each of these components is determined in accordance to reference aircraft passenger seat design that is available in the aircraft cabin mock-up as shown in previous Figure 2.

The CAD models are tabulated in Table 10. Furthermore, for all design concepts, material for their tube and tray is assigned as Aluminum 2024 T6. The material for the tray table, on the other hand, is assigned as plastic ABS. These material assignments ensure the appropriate properties for each component, contributing to the overall functionality and performance of the tray table. Table 11 summarizes the assignment of materials for components of the alternative design concepts that is then applied to the FEA simulation analysis.

Figure 9 depicts the applied boundary conditions to the seat tray table models for the FEA simulation analysis. These applied boundary conditions include the fixed frame and an acting static load of 230 N on the tray table's upper surface. In the meantime, based on the obtained results of conducted mesh independence study for each alternative design concept, the meshing process is performed on the CAD models for the FEA simulation analysis. Figure 10 shows the meshed model for each design concept, which clearly illustrate the structure of the mesh. These images highlight the mesh arrangement and also showcase how the elements are distributed within each design concept.

Table 10 CAD models for main components of each alternative design concept

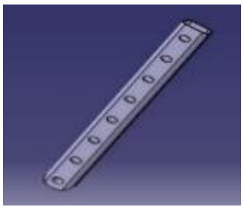
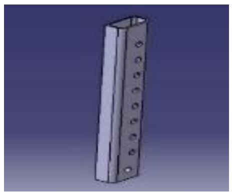
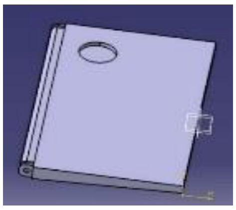
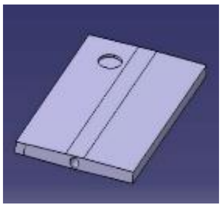
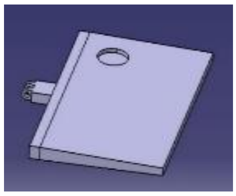
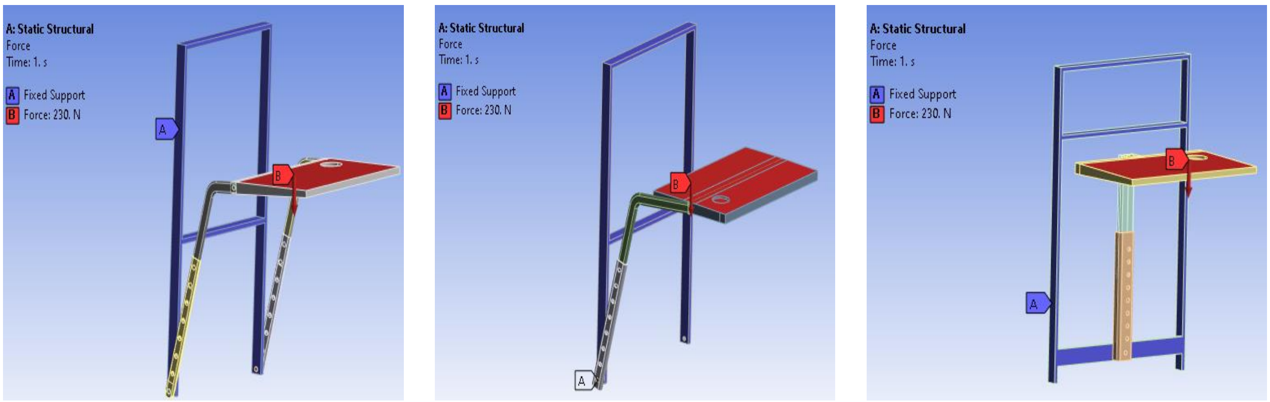
COMPONENT	DESIGN CONCEPT 1	DESIGN CONCEPT 2	DESIGN CONCEPT 3
Height Adjustment Tube			
Support Arm / Hand			
Tray Table			

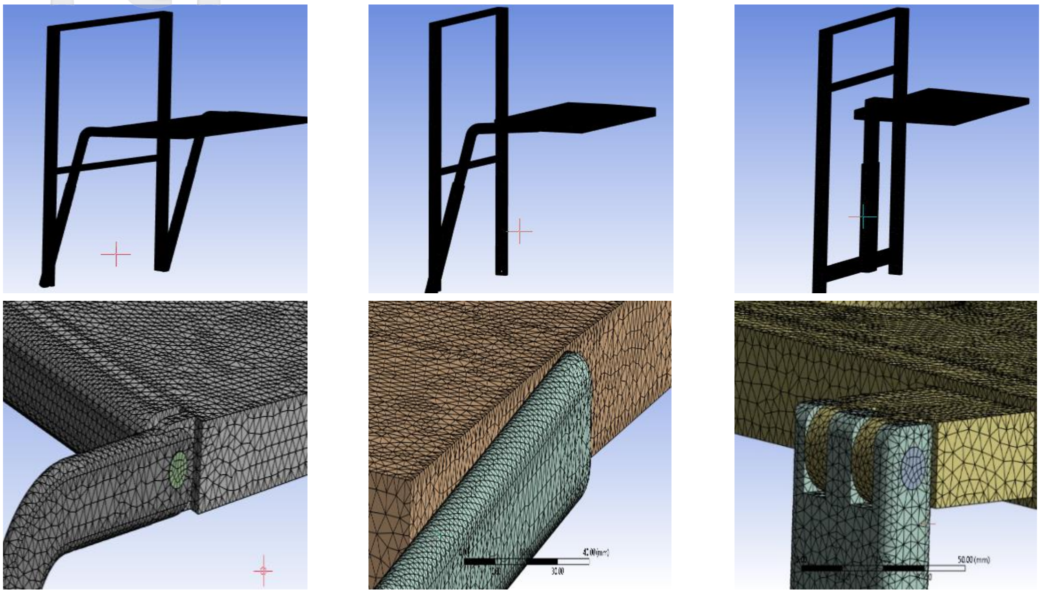
Table 11 Materials assignment for each alternative design concept

Component	Design Concept 1		Design Concept 1		Design Concept 1	
	Material	Quantity	Material	Quantity	Material	Quantity
Height Adjustment Tube	Aluminum 2024 T6	2	Aluminum 2024 T6	1	Aluminum 2024 T6	1
Support Arm / Hand	Aluminum 2024 T6	2	Aluminum 2024 T6	1	Aluminum 2024 T6	1
Tray Table	ABS Plastic	1	ABS Plastic	1	ABS Plastic	1
Total Components		**5**		**3**		**3**



(a) Design Concept 1 (b) Design Concept 2 (c) Design Concept 3

Figure 9 Applied boundary conditions in the FEA analysis



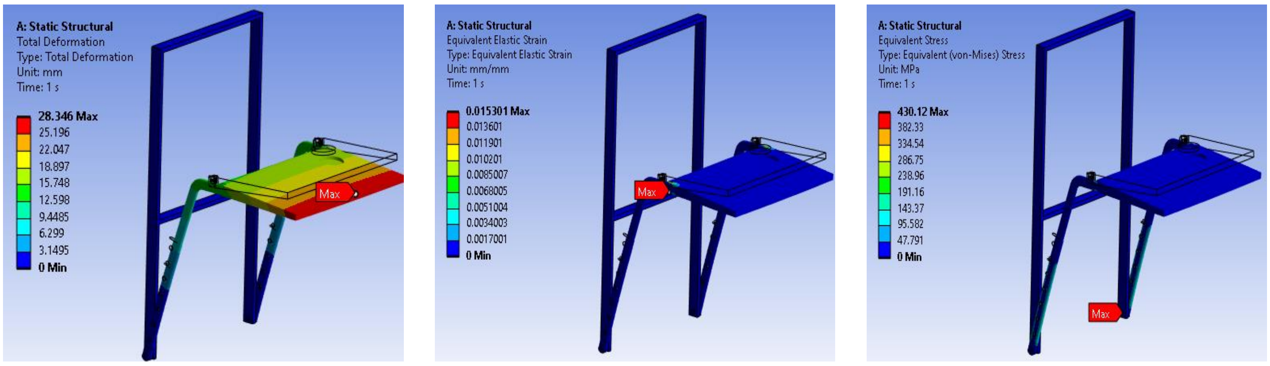
(a) Design Concept 1 (b) Design Concept 2 (c) Design Concept 3

Figure 10 Final meshing for the FEA simulation analysis

The FEA simulation results for Design Concept 1 are shown in Figure 11. It can be observed that the maximum deflection of the tray table occurs at the farthest end, which aligns with the expectation as this point is experiencing the applied load and is farthest from the supporting hand joint. The maximum deflection value is measured as 28 mm, still falling within the acceptable operational limit. Given that the daily use of the tray table involves lighter weights than the assigned load, it is expected that deflection for Design Concept 1 will be significantly lower. Meanwhile, Figure 11 also shows that the maximum elastic strain occurs at the joint between the tray table and hand, specifically at the tray surface. The value of this maximum elastic strain is measured as 1.5301×10^{-2} mm/mm, which falls within the elastic deformation range. Considering that the goal is for the structure to remain in the elastic deformation range and maintain its functionality without undergoing a permanent deformation, the observed elastic strain can be considered as acceptable. This indicates that the tray table is capable to withstand the applied load and exhibit the desired elastic behavior without compromising the structural integrity or operational performance. Lastly, Figure 11 also depicts the stress distribution in Design Concept 1, which is depicted to be concentrated at the hands, tube and also joints of the structure. The maximum stress is experienced at the joint connecting the frame and the tube, with value of 430 MPa. It should be noted that this stress value has exceeded the ultimate tensile strength of the initial material used for the joint, which means that the structure has failed in this area. To remedy this issue, design adjustments like reinforcing the joint or considering alternative materials with higher yield and ultimate strength become necessary to address this stress concentration and ensure the tray table meets the required strength and safety criteria.

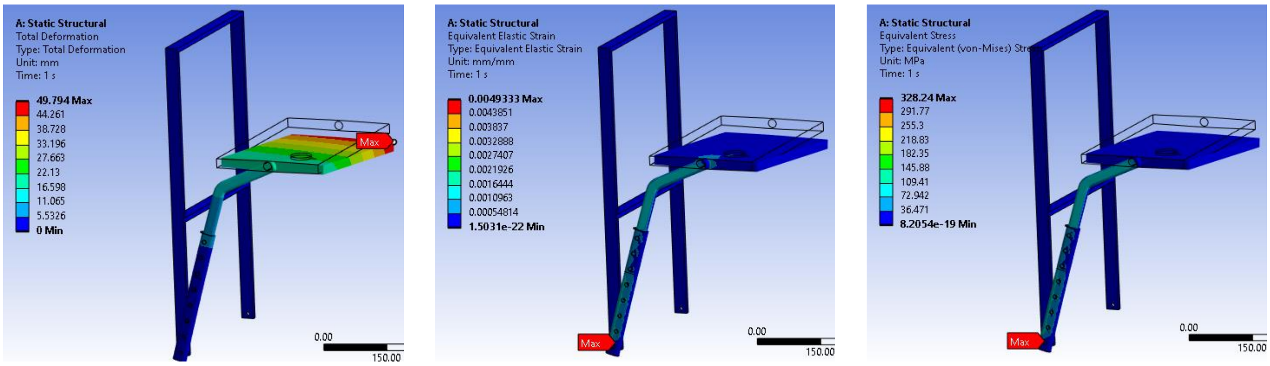
Meanwhile, Figure 12 shows FEA simulation results for Design Concept 2. It could be seen that the maximum deflection of the tray table occurs at the farthest end, which is farthest from the supporting hand joint. The maximum deflection value is measured as 49.8 mm, which is actually the highest among the considered design concepts but can still be considered reasonable given that daily usage of the tray table involves lighter weights than the assigned load. A lower deflection is also expected for Design Concept 2 in normal usage. In addition, Figure 12 also shows that the maximum elastic strain occurs at the joint between the tray and hand, specifically at the tray surface. The value of this maximum elastic strain is found as 4.933×10^{-3} mm/mm, which falls in the elastic deformation range. Considering the goal is for the structure to remain in elastic deformation range and maintain its functionality without undergoing a permanent deformation, the observed elastic strain is taken as acceptable. This indicates that the tray table is able to withstand the applied load and exhibit the desired elastic behavior without compromising its structural integrity or operational performance. Moreover, Figure 12 also shows the stress distribution in Design Concept 2. The stress is seen to be concentrated at the hands, tube and joint of the structure. The maximum stress is experienced at lower part of the tube where the joint is situated with a value of 328 MPa. It is crucial to note that this stress value exceeds the ultimate yield strength and just above the ultimate tensile strength of the material, which suggests that the structure is experiencing failure at the area. In this case, adjustments such as increasing tube thickness or considering different materials with much higher yield strength might be needed to address this stress concentration and ensure that the tray table meets the required strength and safety criteria.

Finally, FEA simulation results for Design Concept 3 are presented in Figure 13. It is observed that maximum deflection of the tray table occurs at the farthest end, which is farthest from the supporting hand joint. The maximum deflection value is measured as 17 mm, which is actually the lowest among the three considered design concepts and is well within the acceptable range. Meanwhile, Figure 13 also depicts the maximum elastic strain occurs at the joint between the tray and hand, specifically at the tray surface. The value of maximum elastic strain is found to be 1.16×10^{-2} mm/mm, which falls within elastic deformation range. Considering the aim for the structure to remain within the elastic deformation range and uphold functionality without undergoing a permanent deformation, this elastic strain is considered as acceptable. This indicates that the tray table is able to withstand the expected loading and exhibit the desired elastic behavior without compromising structural integrity or operational performance. Figure 13 also shows stress distribution in Design Concept 3, which seems to be concentrated at the hands, tube and joints of the structure. The maximum stress occurs at the joint that is connecting the frame and the tube, with value of 461 MPa. It is crucial to note that this value exceeds the ultimate yield strength of the initial chosen material, which suggests the structure is experiencing plastic deformation. This indicates that the joint might be under significant stress and potentially lead to a permanent deformation or failure over time. Therefore, further analysis and consideration are required to ensure structural integrity and safety of the tray table design.



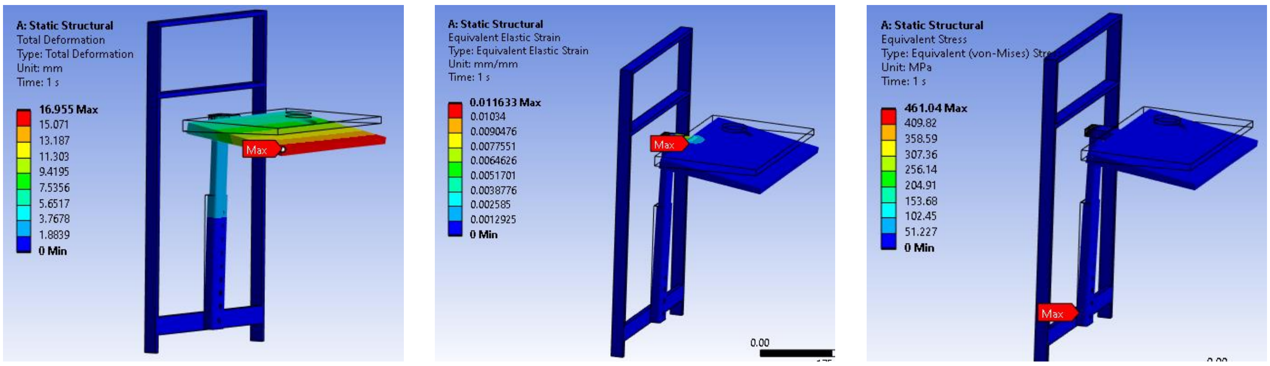
(a) Total deformation mapping (b) Equivalent strain mapping (c) Equivalent stress mapping

Figure 11 FEA simulation results for Design Concept 1



(a) Total deformation mapping (b) Equivalent strain mapping (c) Equivalent stress mapping

Figure 12 FEA simulation results for Design Concept 2



(a) Total deformation mapping (b) Equivalent strain mapping (c) Equivalent stress mapping

Figure 13 FEA simulation results for Design Concept 3

Overall, based on FEA simulation results, it has been identified that a main component of Design Concept 2 will require changes to reduce the stress concentration, which is the height adjustment tube. In addition, the joints for all three considered design concepts also need to be changed or reinforced to ensure they could withstand the maximum loading conditions. The modifications are vital to improve the structural integrity and longevity of the tray table. On the whole, it has been indicated that maximum deflection values for all three considered design concepts of the seat tray table are within acceptable range for a load of 230 N. Therefore, it can be concluded that these mechanisms for adjustable height of the tray table meet the required criteria. The deflection within the acceptable range suggests that the tray table design is structurally stable and is able to withstand specified load without a significant deformation or compromise in functionality.

The overwhelmingly strong TOPSIS results, coupled with acceptable FEA simulation results, Design Concept 1 is selected as the best possible new design of the seat tray table among the three considered design alternatives. This decision is also supported by its lowest estimated weight compared to the other two design alternatives as presented in Table 12. Note that this weight estimation is obtained by the CATIA software and based on the materials chosen for each main component of the design alternatives. It is also good to note that significant portion of the total weight is attributed to the tray itself, implying the importance of the material selection for this component. Though tray table experiences relatively lower level of stress as compared to the other parts, its weight is the highest. Therefore, careful consideration should be given in selecting a material for the tray that offers a balance between strength and weight efficiency.

As determined from previous FEA simulation results, the selected Design Concept 1 requires further refinement and finalization to incorporate the necessary details for its operational implementation. In this final stage, additional components and features are added to ensure functionality and usability of the design. Firstly, attention is given to the locking mechanism and adjustability control. By finalizing these details, the adjustable height tray table will be ready for practical application, providing enhanced comfort and convenience for passengers during their flying experience. For Design Concept 1, the mechanism for adjusting height of the tray table involves the use of a spring and a series of holes in the tube. The hand, which supports the tray table, is connected to the tube. To adjust the height, the hand can be moved up or down along the tube. The tube contains multiple holes at different heights. When desired height is reached, the hand is aligned with the corresponding hole and the spring mechanism engages, locking the hand into a fixed position. This will allow passengers to securely set the tray table at their preferred height, providing flexibility and comfort during their in-flight activities. Illustration of this locking mechanism is depicted in Figure 14.

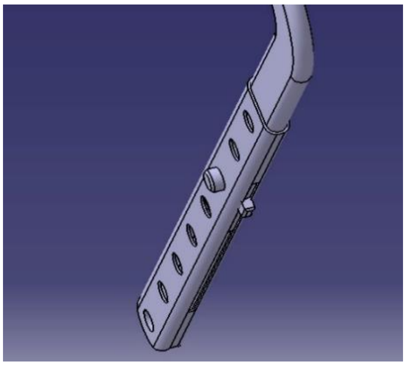


Figure 14 Lock mechanism of the finalized Design Concept 1

Table 12 Estimated mass for alternative design concepts

Design Concept	Frame Mass (kg)	Hand Mass (kg)	Tube Mass (kg)	Tray Mass (kg)	Total Mass (kg)
Design Concept 1	1.86	0.16 (x 2)	0.07 (x 2)	2.30	4.62
Design Concept 2	1.82	0.68	0.18	2.58	5.27
Design Concept 3	2.42	0.68	0.37	4.15	5.86

Since the joint for Design Concept 1 has experienced failure, a new joint is used to ensure that the whole design concept is feasible. The material chosen for this revised design is Steel AlSl, which offers a higher ultimate yield strength (440 MPa) compared to aluminum 2024 T6. This material selection aims to enhance the structural integrity of the tray table, ensuring it could withstand the required loads and stresses without compromising its performance or safety.

IV. CONCLUSIONS

Passengers' flight comfort has become an important criterion in the selection among available flying services. In view of this, all airlines are actively looking on ways to better improve provision of flight cabin comfort onboard their aircraft fleet. It has been shown that the comfort level of passengers is also affected by their in-flight activities, which means that they must be able to perform their usual activities such as eating, writing and using laptop at their seat area with ease and comfort. Since all these activities involve the use of seat tray table, the height of the table is crucial to enable the passengers to perform the activities in their most comfortable sitting posture. This assertion has been demonstrated in the conducted activity-based sitting comfort experiment inside the aircraft cabin mock-up that shows different passengers might require different height of the seat tray table for different type of in-flight activities. Therefore, it is deduced from this finding that a new seat tray table design that can be adjusted in terms of its height is required. By this notion, conceptual design exploration for a new seat tray table design is conducted. On the whole, based on the TOPSIS results using responses from public survey and the FEA simulation results, Design Concept 1 has been selected and proposed as the new seat tray table design with an adjustable height feature. It has been shown that this design concept has a good stability and is able to withstand the maximum estimated loads with acceptable deflection during use. It is highly hoped that this study will further spur more attention and researches on improving the design of the seat tray table inside the aircraft cabin for the comfort of the passengers.

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REFERENCES

[1] Gil R, Kim M, “Does competition increase quality? Evidence from the US airline industry,” *International Journal of Industrial Organization*, Vol. 77, 2021. https://doi.org/10.1016/j.ijindorg.2021.102742

[2] Prentice C, Hsiao A, Wang X, Loureiro SMC, “Mind, service quality, relationship with airlines,” *Journal of Strategic Marketing*, Vol. 31, No. 1, 2023, pp. 212-234. https://doi.org/10.1080/0965254X.2021.1894216

[3] Archana R, Subha MV, “A study on service quality and passenger satisfaction on Indian airlines,” *International Journal of Multidisciplinary Research*, Vol. 2, No. 2, 2012, pp. 50-63.

[4] Habibillah NHA, Ismail NH, Romli FI, “Influence of seat pitch and body anthropometry parameters on aircraft passengers' seating comfort,” *Journal of Aeronautics, Astronautics and Aviation*, Vol. 54, No. 3, 2022, pp. 241-250. https://doi.org/10.6125/JoAAA.202209_54(3).01

[5] Jiang H, Zhang Y, “An investigation of service quality, customer satisfaction and loyalty in China's airline market,” *Journal of Air Transport Management*, Vol. 57, 2016, pp. 80-88. https://doi.org/10.1016/j.jairtraman.2016.07.008

[6] Aminian NO, Romli FI, “Ergonomic optimization of airship passenger cabin design using RULA and fuzzy logic decision method,” *Journal of Aeronautics, Astronautics and Aviation*, Vol. 56, No. 1S, 2024, pp. 393-403. https://doi.org/10.6125/JoAAA.202403_56(1S).28

[7] Aminian NO, Romli F, “Ergonomics assessment of current aircraft passenger seat design against Malaysian anthropometry data,” *International Journal of Engineering & Technology*, Vol. 7, No. 4.13, 2018, pp. 18-21. https://doi.org/10.14419/ijet.v7i4.13.21322

[8] Hamil MHF, Romli FI, Shafiq Reincastle MSR, “Effects of seat tray table height and body anthropometry dimensions on passengers' in-flight comfort,” *International Journal on Engineering Applications*, Vol. 11, No. 3, 2023. https://doi.org/10.15866/irea.v11i3.22685

[9] Hiemstra-van Mastrigt S, Meyenborg I, Hoogenhout M, “The influence of activities and duration on comfort and discomfort development in time of aircraft passengers,” *Work*, Vol. 54, No. 4, 2016, pp. 955-961. https://doi.org/10.3233/WOR-162349

[10] Bouwens J, Tsay WJJ, Vink P, “The high and low comfort peaks in passengers’ flight,” *Work*, Vol. 58, No. 4, 2017, pp. 579-584. https://doi.org/10.3233/WOR-172637

[11] Wang L, Yu S, Chen D, Li W, Chu J, Fan H, “Effects of aircraft tray table height and neck posture on passenger comfort: A study of the economy class cabin,” *Work*, Vol. 75, No. 1, 2023, pp. 287-302. https://doi.org/10.3233/WOR-220043

[12] Hamil MHF, Romli FI, “Effects of passengers' anthropometry on their required comfortable seat tray table height for in-flight activities,” *Journal of Aeronautics, Astronautics and Aviation*, Vol. 56, No. 1S, 2024, pp. 385-392. https://doi.org/10.6125/JoAAA.202403_56(1S).27

[13] Schumm J, Setz C, Bächlin M, Bächler M, Arnrich B, Tröster G, “Unobtrusive physiological monitoring in an airplane seat,” *Personal and Ubiquitous Computing*, Vol. 14, 2010, pp. 541-550. https://doi.org/10.1007/s00779-009-0272-1

[14] Redzman A, Nor M, Romli FI, “Analysis of a new standing passenger seat design for commercial transport aircraft,” *ARPN Journal of Engineering and Applied Sciences*, Vol. 18, No. 6, 2023, pp. 640-647. https://doi.org/10.59018/032389

[15] Othman MS, Chun OT, Harmin MY, Romli FI, “Aeroelastic effects of a simple rectangular wing-box model with varying rib orientations,” *IOP Conference Series: Materials Science and Engineering*, Vol. 152, No. 1, 2016. https://doi.org/10.1088/1757-899X/152/1/012009

[16] Ishak FD, Romli FI, “Design selection for new in-flight food delivery and waste collection system of commercial passenger transport aircraft using TOPSIS,” *Journal of Mechanical Engineering*, Vol. 18, No. 3, 2021, pp. 233-245. https://doi.org/10.24191/jmeche.v18i3.15429

[17] Negin OA, Romli FI, “Study on the potential of airships as urban mass public transport in Malaysia,” *Journal of Mechanical Engineering*, Vol. SI4, No. 2, 2017, pp. 221-232.

[18] Ibrahim MQ, Romli FI, Alli H, “An investigation on aesthetic acknowledgment and adaptation in product design process among engineering students in Malaysian universities,” *International Journal of Innovative Technology and Exploring Engineering*, Vol. 8, No. 9, 2019, pp. 1561-1565.