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Ergonomic Optimization of Airship Passenger Cabin Design Using RULA and Fuzzy Logic Decision Method

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ABSTRACT

This article addresses the design gap in the field of passenger transport airships by focusing on the internal cabin design. While the external structure of airships has received extensive attention, the internal cabins, specifically for the mass passenger transport, have not been adequately considered. The existing airship cabin designs have primarily catered to luxury and tourism, lacking the capacity to transport large quantities of people. To bridge this gap, this research aims to identify the key cabin factors and develop an ergonomic passenger seat using fuzzy logic method, with the specific focus on enhancing passenger comfort. The research work starts with the conduct of focus groups and expert interviews to establish the design requirements for the passenger cabin of a mass transport airship. Based on these requirements, an ergonomic passenger seat design is proposed, which is then assessed by RULA method to ensure passenger comfort is adequately addressed. In addition, fuzzy logic method is applied to optimize the overall passenger cabin design for the mass transport airship with the use of the proposed ergonomic passenger seat. The fuzzy logic process has been tailored to ensure the compliance with essential aviation regulation for mass passenger transport airships. The final optimized passenger cabin design for the mass passenger transport airship is presented. On the whole, the main contribution of this study lies in the construction of the membership functions and fuzzy rules, which have been verified by the industry experts within the airship domain. The findings not only reflect the current practices in the industry but also provide a generalized framework for airship internal cabin. In addition, based on the analysis results, the optimized cabin design can provide an adequate travel comfort for passengers of mass transport airships.

Keywords: Ergonomic, Passenger cabin, Fuzzy logic, Airship, RULA

I. INTRODUCTION

As air travel becomes more accessible with improved aircraft performance and lower ticket prices, the focus on passenger comfort becomes crucial, particularly on longer flights. This is primarily due to the potential physiological and psychological discomfort to flying passengers. In fact, comfort today has become a competitive means among the airlines to attract more passengers to their offered services [1,2]. In general, airlines should be able to properly serve their passengers during flight such that they can have good flying experience, which will then translate into a positive perception of the overall airlines' image and branding [3]. Furthermore, passengers tend to develop service loyalty to airlines when they have a pleasant and comfortable flying experience, and this has motivated many airlines to search

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for more comfortable aircraft interior cabin design in order to positively differentiate their offered services apart from their competitors [4]. Among others, proper comfort of the aircraft passenger seat is crucial, which can be linked with several factors such legroom, quality of upholstery, angle of recline, seat pitch and seat width [5].

Recently, to address several ongoing issues with fixed wing aircraft like fuel dependency and harmful emissions, airships are expected to make a comeback in commercial air transportation [6]. Subsequently, this has increased the research interest on airships. However, it is observed that the significant majority of available researches on airships have been primarily focused on their external design such as development of unconventional hybrid airships [7] and also improved airship designs for better structures and also aerodynamics performance [8,9]. Meanwhile, there seems to be a clear lack of research on cabin design for passenger airships that is accessible to public. It should be noted that airship's operations these days are traditionally limited to advertising and tourism since the end of its "Golden Age" era that was marked by the Hindenburg incident in 1937. In some places however, such as in Japan, Europe and also the United States, there are still some local passenger flight operations using small airships like the 12-seater Zeppelin [10]. The passenger cabin of these small airships is clearly not designed to accommodate large number of passengers or serve long flight trips since it has been mainly tailored for sightseeing purposes. On the other hand, the passenger cabin designs of bigger airships, including those from the old airships in the "Golden Age" era, can be considered as too luxurious and prioritize high flying comfort rather than optimizing the onboard cabin space to accommodate more passengers as typical for mass air transportation vehicles. On the whole, inadequacy of existing airship cabin designs for mass passenger transport has been acknowledged [11].

The theoretical model shown in Figure 1 emphasizes that comfort is fundamentally dependent on the interaction between humans and products within specific contexts. In other words, this means that various cabin design factors including passenger seats, cabin features and overall cabin environment can contribute towards passenger's comfort. It is essential to ergonomically design the passenger cabin to ensure adequate level of travel comfort for passengers.

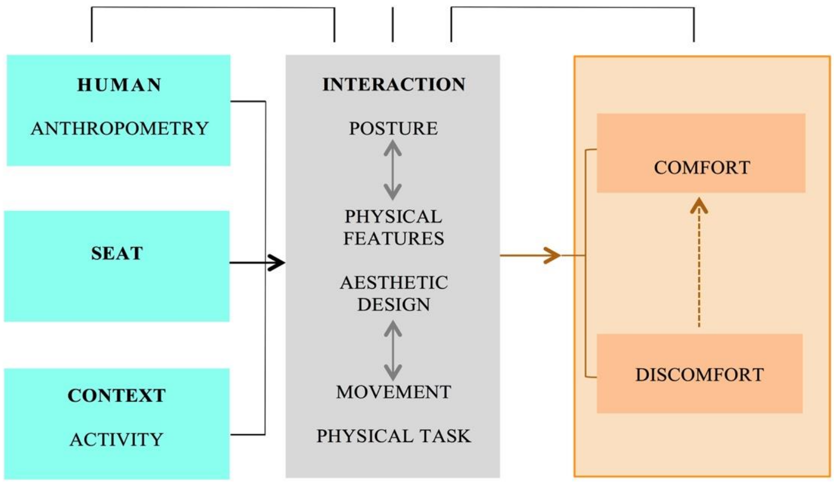


Figure 1 Theoretical model of comfort and its underlying factors [12]

In ergonomics and the related fields, various design tools and guidelines have been developed to facilitate the design and evaluation of aircraft passenger seat and cabin, including anthropometric models and recommendations of seat space dimensions [13-17]. Studies have revealed that, while the interior of the current aircraft has significantly improved, there is still improvement that should be made regarding the passenger seat design [18]. There have been many studies elaborating on passengers' sitting comfort in the cabin of air transport vehicles, especially commercial transport aircraft. Based on one of these conducted studies, the significant factors affecting passenger comfort include leg room, seat characteristics and the ability to move [19]. In addition, another study further emphasized that comfort factors in the flight context encompass environmental and physical elements including seat, legroom space, noise, air quality, temperature and visual aesthetics [20]. Moreover, human characteristics that include both psychological and physiological factors like attitudes, moods and occupation can also play a role. Time, activity, perceptions of the cabin features and their physical impact on the body are factors influencing comfort as well [20]. A strong link between the aircraft interior comfort and passengers' inclination to fly with the same airline again has also been established and this further emphasizes on the importance of comfort as a competitive factor for air transportation service providers [21].

Airships, with increased onboard cabin space, have a big potential to provide better flying comfort compared to current aircraft transport [22]. Therefore, there is a need to strike an optimal balance between comfort level and cabin capacity in the design of mass passenger transport airships. Based on this realization, there is identified design gap and also need for a new passenger cabin design that is suitable for mass passenger transport airships. Since comfort and aesthetics are highly subjective in nature, the use of fuzzy logic method in deriving the optimal cabin design is taken as highly suitable. Unlike conventional logic that classifies statements as either true or false, the fuzzy logic allows for shades of truth and falsity within the same statement [23]. In other words, this method incorporates the observer's or evaluator's perspective into the problem-solving process, making it more flexible in handling vague information that is related to aesthetic parameters like customer preferences for color, style and appearance in product design [24].

II. SETUP AND METHODOLOGY

The research methodology began with identifying the seat and cabin design requirements that can contribute to a more comfortable experience for the passengers onboard the mass public transport airship. In engineering design, it is paramount to establish the driving requirements before design process is started. The requirements are essentially the manifestation of stakeholders' needs and preferences, which later become the goals and acceptance criteria for the design output [25]. For this study, apart from literature reviews, the design requirements are also established from the conducted focus groups and expert interviews. In short, the focus group has been conducted following established guidelines as recommended by [26,27]. The targeted participants for the focus group were individuals who have frequently flown with the commercial airlines in Malaysia. This selection criterion is made because the frequent flyers have experiences in traveling aboard the current passenger aircraft, enabling them to give valuable insights and also feedback on air travel comfort. Although mass passenger transport airships are not yet operational in Malaysia, the passenger cabin section is expected to resemble that of the existing commercial aircraft, albeit with additional space dedicated to improve passenger comfort. The focus group sessions are done at the Faculty of Engineering, Universiti Putra Malaysia, Malaysia. A total of 14 people had been chosen as the voluntary participants in this study, in which there are seven participants per session. Meanwhile, expert interviews are done following recommended guidelines in [28,29]. Five experts have been interviewed in this study using the online platform Skype due to their different geographical locations. In brief, the interview process is started with preparation of interview guides or questions. This helps to ensure that answers given by interviewees can be tailored to the information of interest to be collected. The experts interviewed in this study were selected from the companies that are actively involved in airship design and development industry.

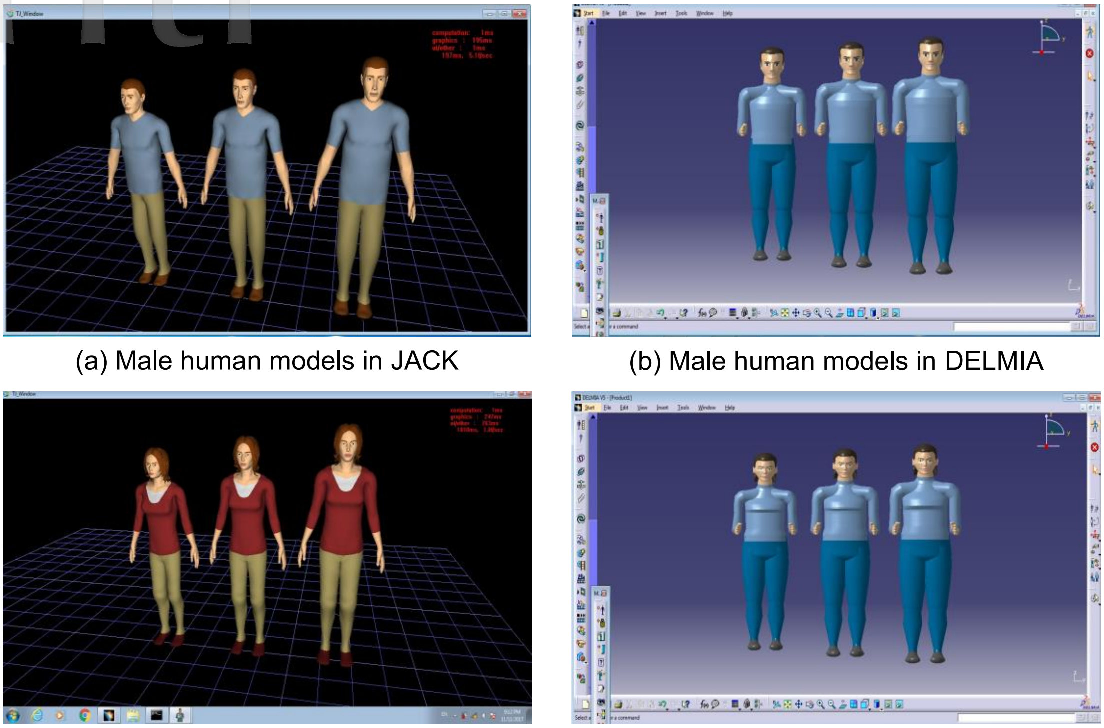
Data collected from these focus groups and interview sessions is analyzed and the findings are used to determine cabin design factors that can help to improve the comfort level of the passengers. These identified cabin factors then become reference basis in setting up design requirements for the passenger cabin of the mass transport airships. On the other hand, as identified through the literature reviews and confirmed by the findings from the focus groups and the interview sessions, the passenger seat appears to be the most consequential factor for aircraft cabin comfort [30].

In order to analyze the improvements needed to make the aircraft passenger seat better for the passengers' comfort, an ergonomic analysis that is known as Rapid Upper Limb Assessment (RULA) is used. An existing seat design that has been used for the commercial transport aircraft cabin is taken as a baseline reference seat design. This reference seat candidate is modelled using computer aided design (CAD) software tool, SolidWorks. The CAD model is then imported to JACK and DELMIA software that are applied for the simulated RULA ergonomic assessment.

For the RULA analysis, postures of passengers while they are seated on the baseline aircraft passenger seat have to be established first. To achieve this, several volunteers have been recruited as the test subjects and observation on them has been done to monitor and establish their common postures based on their sitting behaviors. This observation technique has been used in many studies to evaluate sitting postures such as for students in the classroom [31] and the aircraft passengers [32]. In this study, the test subjects have been individually observed when they were sitting on the available aircraft seat in the laboratory of Department of Mechanical Engineering, Universiti Putra Malaysia for a duration of about an hour. The observations were recorded using a Canon digital camera and the designated observer was seated at the best position to better view the subjects. The recordings were then analyzed and the common sitting postures for the passengers during flights were identified, which were modelled into JACK and DELMIA software for RULA analysis along with the passenger seat model.

Another element that is required for RULA analysis apart from the seat model and the sitting postures is the human model for the aircraft passengers, which has to be constructed using the anthropometric data of target users. Since the scope of this study is focused on the Malaysian citizen, published anthropometric data of both Malaysian males and females in the literature has been used in human modelling for the ergonomic analysis. The human models are generated for 5th, 50th and 95th percentile of both male and female anthropometric data. This is done to consider the three primary principles of ergonomic design: design for extreme individual, design for average and also design for adjustable range [33]. The developed human models, as illustrated in Figure 2, represent Malaysian population based on anthropometric data from [34,35].

Based on findings from the ergonomic analysis of the reference aircraft passenger seat design and taking account of operational aviation regulations for transport airships, a better ergonomically designed seat has been developed to improve the travel comfort experiences of the passengers. This proposed passenger seat design is subject to similar RULA analysis and the results are analyzed to highlight the ergonomic improvements made by the new seat design compared to the reference seat design. Moreover, this new aircraft passenger seat design is carried out into the overall cabin design optimization process. In this study, passenger seat and cabin design to be utilized for the mass passenger transport airship is developed using standard fuzzy logic method, which has been widely applied to derive optimum design of a product from various design alternatives [36].



(a) Male human models in JACK (b) Male human models in DELMIA

(c) Female human models in JACK (d) Female human models in DELMIA

Figure 2 The percentile human models used in this study

To ergonomically optimize a passenger cabin design for the mass passenger transport airship using fuzzy logic method, the standard primary tasks being involved include constructing the fuzzy rule base, fuzzy inference process, and also the defuzzification process. It should be noted that the Mamdani's method is the most extensively used fuzzy method and it has been also applied in this study [37]. In line with on the ergonomics optimization level of seat and cabin, a fuzzy logic model with the related fuzzy rules that reflects design ergonomics level needs to be constructed, which is often derived from knowledge and also strategic control rules expressed linguistically [38]. In the fuzzy set theory, both input and the output variables are treated as fuzzy numbers and their uncertainty is characterized by the membership function. On the whole, membership function can have a variety of shapes but commonly a triangular or trapezoid form is often used. This is because such a form can provide adequate representation of experts' knowledge and considerably simplify the computational process [39]. The membership functions in this study have been taken to be of triangular shape. The fuzzy membership functions are constructed using the linguistic categories to express the assessment of input and output variables. In this study, membership functions have been first defined through the available information from the design requirements' step and literature review. They are then circulated among the consulted experts in the airship industry for validation and subsequent amendments are made based on the gathered feedback. This process has been iterated until the settings of the memberships are agreed on and accepted by all of the experts. Using the constructed membership functions, relationships between the input and the output variables are established through the fuzzy rule base. The rules are formulated in the form of conditional if/then statements such as if <condition> then <conclusion>. For this study, Mamdani fuzzy inference method is applied because it is widely accepted for capturing the experts' knowledge. It also allows describing the expertise in a more intuitive and human-like manner [40]. Meanwhile, for defuzzification method in this study, the COA method (or also known as the centroid method) is used to convert the final combined fuzzy numbers into the single crisp number by finding the point where the vertical line would slice the aggregate set into two equal masses. It selects the output crisp value in correspondence to center of gravity of the resultant output membership function [41]. For this study, the MATLAB program is developed to execute the fuzzy inference and the defuzzification processes.

III. RESULTS AND DISCUSSION

In the literature, there have been many suggestions to determine the appropriate aircraft seat design parameters based on anthropometric data. They can also be applied to the passenger seat design for transport airships and these design parameters are presented in Table 1. It should be noted that in this study, calculated value of the dimensions depends on the anthropometric data of Malaysians as the target group. The anthropometric data for Malaysians that have been used in the development of the human models in JACK and DELMIA are shown in Table 2.

Table 1 Proposed dimensioning of seat parameters

Design Parameter	Anthropometry Sizing Suggestion	Dimension Value
Seat Height	5th percentile female popliteal height + 4.5 cm heels	40.0 cm
Seat Width	95th percentile female hip breadth + 1 cm for clothes	50.5 cm
Seat Depth / Length	5th percentile female buttock-popliteal length	38.9 cm
Armrest Height	Elbow-rest height	17.7 cm
Armrest Width	Forearm width	5.0 cm
Armrest Length / Depth	95th percentile female elbow-wrist length	24.0 cm
Distance between Armrests	95th percentile female hip breadth + 5 cm for heavy clothes	54.5 cm
Backrest Height	95th percentile male shoulder height	65.6 cm
Backrest Width	95th percentile of male shoulder breadth	52.6 cm
Backrest Lumbar	Waist height	20.0 cm
Head-Rest Height	95th of male head height	18.5 cm
Head-Rest Width	95th of male head breadth	26.5 cm
Tray Height	-	70.0 cm
Backrest Inclination	-	110 degrees
Seat Inclination	-	5 degrees
Lumbar Prominence	-	25 cm (inside radius), 20 cm (outer radius)

Table 2 Malaysian anthropometric data for the human modelling process

Body Dimensions for Male Model	Value (cm)		
	5th	50th	95th
Chest Breadth	27.07	35.46	43.85
Crotch Height	63.20	84.19	105.17
Hip Breadth	26.20	37.53	48.86
Stature	157.44	168.61	179.79
Waist Depth	18.05	25.77	33.48
Foot Length	25.37	27.05	28.69
Chest Depth	14.56	21.75	28.95
Body Dimensions for Female Model	**Value (cm)**		
	5th	**50th**	**95th**
Chest Breadth	23.40	31.78	40.16
Crotch Height	61.60	78.93	96.25
Hip Breadth	26.12	37.83	49.54
Stature	146.66	156.50	166.33
Waist Depth	17.19	23.91	30.63
Foot Length	20.11	22.45	25.00
Chest Depth	13.54	21.50	29.47

The findings from the conducted focus group indicate that, among seat design characteristics that are mentioned in the literature, the important parameters being identified in the categories include seat height, seat width, seat pitch, seat depth, backrest inclination, aisle width. In addition, in the focus group, several factors that were not established from the literature review like seat color (chromatic and achromatic) and cabin color (chromatic and achromatic) are also identified as key factors in the cabin design. Some selected quotes from the focus group participants when voicing their views on current aircraft cabin with regards to their perception of comfort are as follow:

".... I think the seat should have a wide gap with the seat in front because certain people have longer legs, so it will be more comfortable."

".... If you are going to ask me about comfort, I think my answer would be a space that is not too cramped.... one more thing is about the seat, I am not sure if aircraft seat has lumbar support because I usually just take an hour flight and it would be such a bother (sitting)....my friend had to be admitted to hospital because of back pain."

"... to me, it (color) is very important because if you put yellow color to the seat, it will be too striking, and you will get tired of looking at it. In terms of psychology, it is important."

"I think they should widen the gap between the legs and the seat..."

To verify or validate the findings from literature and focus group, the expert interview has been conducted. The results indicate that the parameters mentioned in literature and focus group sessions are agreed by experts. They also validate that seat and cabin color is one of the most crucial factors to be considered in the cabin. What follow are some of selected quotes from the interviewed experts when they were queried on the essential considerations needed to be taken in order to make the passengers' cabin of the airships more comfortable:

"... Greater legroom surrounding the seating and wider aisles are possible and very desirable. The room available for an airship cabin would allow them to feel more like a hotel lobby with ample seating rather than the cramped theatre seating as on an airplane."

"Passenger seat. Since the loads are very small, so when designing the seat or other things in the passengers' compartment, no need to go for thorough regular testing because the load is 3 to 4 times less than the airplane load. So that is a good consideration for the design."

"Comfortable seating such as more leg rooms, open aisles, two people can walk at the same time..."

Furthermore, the experts have all agreed that current regulations for the airships do not specifically cover the ergonomics factor in cabin design. Thus, it is evident that most of airship cabin designs have not been ergonomically and optimally designed for passengers' comfort.

The findings from conducted focus group and expert interview sessions imply that passenger seat design plays the pivotal role in dictating the passenger's comfort level. The main reason for this is the fact that passengers spend most of the flight time in a seat position on the seat. Hence, before optimizing the overall cabin design, it is crucial that the seat design is suitable and comfortable for passengers. An existing aircraft seat design that has been used in cabin of commercial transport aircraft is utilized in observation method to identify common sitting postures of passengers while they are seated during flight. The identified postures are then used in the RULA simulation analysis, along with constructed human models from the anthropometric data of Malaysians. In this study, 10 common sitting postures have been identified for RULA analysis and they are listed in Table 3.

Table 3 Identified common sitting postures of passengers during flight

Posture Label	**Description**
A	The passenger looks forward and sits straight.
B	The passenger's head tilts to the right and the left leg are placed on the right leg.
C	The passenger sits in similar fashion as in Posture B but the left elbow is placed on the left armrest of the seat.
D	Both of the passenger's legs are stretched through the legroom under the front seat and both hands are on the tray.
E	The passenger's trunk is bent forward to place the head on the tray.
F	The passenger's trunk and head are bent near the ground with the right hand stretched to reach something on the ground.
G	The passenger's left elbow is placed on the tray and the right elbow is on the right armrest of the seat.
H	The passenger sits straight and relaxed while the head is tilted to the left.
I	The passenger sits straight with both hands in the mobile or tablet working position (on the tray)
J	The passenger sits straight with the hand on the tray and both legs are stretched through the legroom under the front seat.

Figure 3 show an example of observed posture during the posture observation process.

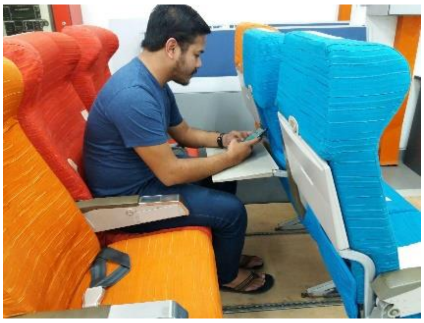


Figure 3 Example posture observation

In the meantime, RULA simulation analysis results are shown in Table 4.

Table 4 Highest risk rating for the sitting postures using baseline reference passenger seat

Posture Position	Highest Risk Rating		
	5th	50th	95th
A	3	3	3
B	3	3	3
C	6	6	6
D	6	6	6
E	7	7	7
F	7	7	7
G	7	7	7
H	4	4	4
I	4	4	6
J	5	5	5

It presents a summary of the highest recorded risk rating for each sitting posture. As observed from the results, it is concluded that there is some room for improvement to be made to the reference passenger seat design to improve the seat comfort level for the passengers. The baseline seat design scored the highest risk level in the RULA analysis for postures E, F and G, which are marked by red-colored boxes. Furthermore, the results from JACK and DELMIA can be claimed to be essentially in a good agreement with each other. Overall, this existing aircraft seat design needs to be redesigned or modified to improve its provision of comfort to the passengers of the intended mass passenger transport airship. By using the information that has been obtained so far, a new passenger seat design has been proposed and it is analyzed using the same human model and sitting postures in RULA simulation analysis. Figure 4 shows the baseline reference passenger seat and the proposed new seat design. Moreover, the comparison of RULA analysis results between these two seat designs is presented in Table 5.

Table 5 Comparison of highest risk rating for the sitting postures between baseline reference passenger seat and new proposed passenger seat

Postures	Highest Risk Level					
	Baseline Reference Seat Design			Proposed Seat Design		
	5th	50th	95th	5th	50th	95th
A	3	3	3	2	2	2
B	3	3	3	3	3	3
C	6	6	6	3	3	4
D	6	6	6	5	5	5
E	7	7	7	5	5	5
F	7	7	7	5	5	6
G	7	7	7	4	4	4
H	4	4	4	4	4	4
I	4	4	6	3	3	3
J	5	5	5	4	4	4

(a) Baseline passenger seat design (b) Improved passenger seat design

Figure 4 Baseline passenger seat design and new proposed seat design

It is observed that the risk rating for the proposed new passenger seat design is consistently lower than that of the baseline reference seat design for every sitting posture. This highlights the improvement of the newly proposed passenger seat design, particularly in its ergonomics aspect, which can also help to improve the provision of comfort to passengers. Most importantly, the proposed passenger seat design does not obtain any high-risk rating of 7. While the proposed new seat design is not fully perfect and could be further improved, particularly to accommodate sitting postures D, E and F, it is nonetheless a marked improvement from the reference seat design.

In the meantime, by analyzing the information that is gathered from conducted focus group and expert interview sessions, to optimize by fuzzy logic, the primary seat and cabin design variables that contribute toward improvement of the passengers' comfort level during flight have been identified. To implement the fuzzy system, all membership functions for the output variables need to be established. This study has employed a fuzzy system with three output variables: seat comfort, cabin ergonomics and also cabin aesthetics. To define the membership functions for these output variables, a scoring range from 0 to 100 was utilized, representing the level of achievement or satisfaction for each element. Specific scoring ranges for each category of these linguistic variables can be found in Table 6 while the linguistic descriptions for the input variables are provided in Table 7.

The resultant output crisp value from the MATLAB fuzzy program for seat comfort variable is 67.2218. The input variables for this output variable include seat height, seat width, seat pitch, seat depth and backrest inclination. In Figure 5, this value of the seat comfort variable has been mapped to its membership value. The membership value is found as 0 for the linguistic variable "very dissatisfied", 0 for the linguistic variable "dissatisfied", 0.01805 for the linguistic variable "satisfied" and 0.36109 for linguistic variable "very satisfied". Therefore, it can be claimed that the resultant satisfaction level for seat comfort is highly acceptable.

Table 6 Range of linguistic variables for output variables

Linguistic Variables	Range of the Crisp Output
Very Dissatisfied	$0 < a(\mu) \leq 30$
Dissatisfied	$20 < a(\mu) \leq 50$
Satisfied	$40 < a(\mu) \leq 70$
Very Satisfied	$60 < a(\mu) \leq 100$

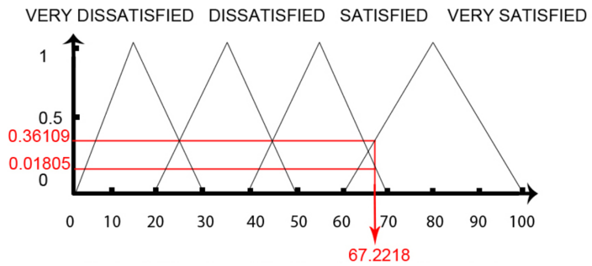


Figure 5 Fuzzy sets or membership functions for "seat comfort"

Table 7 Values of input variables

Input Variable	Linguistic Term	Fuzzy Number
Seat Pitch (cm)	Short	(74.00, 83.00, 89.00)
	Normal	(83.00, 89.00, 94.00)
	Long	(89.00, 94.00, 99.00)
Backrest Inclination (cm)	Low	(90.00, 100.00, 110.00)
	Normal	(100.00, 110.00, 20.00)
	High	(110.00, 120.00, 35.00)
Seat Width (cm)	Narrow	(38.00, 45.00, 50.50)
	Normal	(45.00, 50.50, 55.00)
	Wide	(50.50, 55.00, 63.00)
Seat Height (cm)	Low	(30.00, 35.00, 40.00)
	Normal	(35.00, 40.00, 45.00)
	High	(40.00, 45.00, 50.00)
Seat Depth (cm)	Shallow	(30.00, 33.00, 38.90)
	Normal	(33.00, 38.90, 47.00)
	Deep	(38.90, 47.00, 55.00)
Aisle Width (cm)	Bad	(38.00, 41.50, 45.00)
	Good	(41.50, 45.00, 51.00)
	Excellent	(45.00, 51.00, 60.00)
Cabin Width (m)	Narrow	(1.52, 2.50, 3.50)
	Adequate	(2.50, 3.50, 5.65)
	Wide	(3.50, 5.65, 7.80)
Cabin Length (m)	Short	(4.40, 14.95, 25.5)
	Adequate	(14.95, 25.5, 44.75)
	Long	(25.50, 44.75, 64.00)
Seat Colour (Chromatic)	The Most Unfavourable	(400, 440, 475)
	The Most Favourable	(440, 475, 510)
	Favourable	(475, 510, 550)
	Unfavourable	(510, 550, 590)
Seat Colour (Achromatic)	Favourable	(150, 175, 200)
	The Most Favourable	(175, 200, 225)
	The Most Unfavourable	(200, 225, 250)
Cabin Colour (Chromatic)	The Most Unfavourable	(400, 440, 475)
	The Most Favourable	(440, 475, 510)
	Favourable	(475, 510, 550)
	Unfavourable	(510, 550, 590)
Cabin Colour (Achromatic)	Favourable	(170, 190, 210)
	The Most Favourable	(190, 210, 230)
	The Most Unfavourable	(210, 230, 250)

On the other hand, the fuzzy output variable “cabin ergonomics” is defuzzified into crisp output with the result of 80. The input variables include aisle width, cabin length and cabin width. As indicated in Figure 6, the satisfaction level for this output variable is remarkably high. Moreover, the fuzzy output variable “cabin aesthetics” is defuzzified into the crisp output with the result of 70.7448. The input variables include seat color (chromatic and achromatic) and cabin color (chromatic and achromatic) As indicated in Figure 7, the satisfaction level for this output variable is very high.

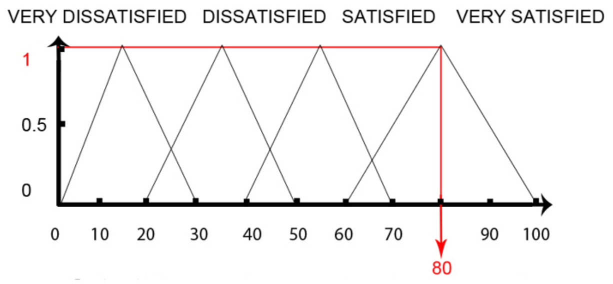


Figure 6 Fuzzy sets or membership functions for “cabin ergonomics”

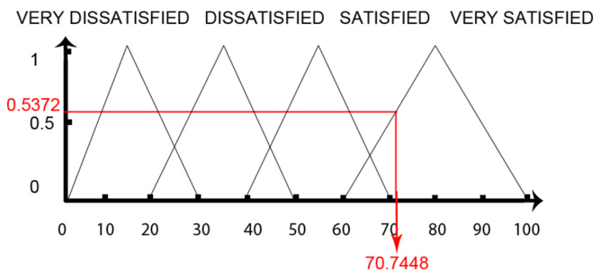


Figure 7 Fuzzy sets or membership functions for “cabin aesthetics”

It should be noted that numerous iterations have been made before these settings of membership functions for all input variables could be finally determined to ensure their correspondence to the acceptable crisp value for all output variables. Prior to the finalization, the airship experts have been once again consulted for any required modifications to the membership functions and the results. This is meant to ensure that the result is acceptable for the airship cabin design. The final values for input variables are tabulated in Table 8. On the whole, the passenger seat and cabin design has satisfied all fuzzy rules constructed with the detailed considerations of design ergonomics and regulations. It is shown to be able to provide an adequate travel comfort for passengers of a mass passenger transport airships and also satisfy governing aviation regulations by the authorities. An illustration of the optimized passenger cabin design is shown in Figure 8.

Table 8 Optimized values of the input variables for the best cabin design

Input Variable	Optimal Value	Favorable Range
Aisle Width	49.00 cm	(45.00, 60.00)
Cabin Width	4.66 m	(2.50, 5.65)
Cabin Length	34.20 m	(14.95, 44.75)
Seat Pitch	86.50 cm	(83.00, 94.00)
Backrest Inclination	113.00 cm	(100.00, 120.00)
Seat Width	50.50 cm	(45.00, 55.00)
Seat Height	40.00 cm	(35.00, 45.00)
Seat Depth	40.00 cm	(33.00, 47.00)
Chromatic Seat Colour	495	(440, 510)
Achromatic Seat Colour	200	(175, 225)
Chromatic Cabin Colour	495	(440, 510)
Achromatic Cabin Colour	210	(190, 230)

Figure 8 CAD illustration of the optimized passenger cabin design based on the fuzzy logic results

IV. CONCLUSIONS

To design the passenger cabin for the mass passenger transport airships, it is important to prioritize passengers’ comfort as a primary factor in attracting them to the flying service. The initial step in this process has been to identify cabin design factors that contribute towards improving the passengers’ comfort during flight. This has been achieved by conducting the focus group sessions involving frequent users of current commercial air transportation services. In addition, experts from major airship companies worldwide have been also consulted and interviewed to gather their feedback on cabin design considerations. Based on these inputs, several factors have been identified as significant contributors to passenger comfort, including seat height, width, pitch and depth, backrest inclination, aisle width, cabin length, cabin width, seat color and cabin color. These factors have been categorized into three main groupings: seat comfort, cabin ergonomics and cabin aesthetics. The systematic engineering design process is then employed to propose a new passenger seat design that is ergonomic and compliant with governing regulations. An existing aircraft seat design served as the initial baseline reference, which is systematically improved. The proposed passenger seat design underwent RULA assessment using two commonly used ergonomics analysis software tools: JACK and DELMIA. The analysis results indicated that the proposed design has significantly better ergonomic characteristics as compared to the baseline reference passenger seat design. This ensures a more comfortable seating experience for passengers during the flight. The proposed passenger seat design is then used in the overall design optimization of the passenger cabin. In addition to seat comfort, other cabin design factors associated with cabin ergonomics and cabin aesthetics have been considered. The output design variables need to be simultaneously satisfied to achieve an overall ergonomic passenger cabin design, even when they are conflicting. To find the optimal cabin design that best compromises all these variables, fuzzy method is chosen as the most appropriate design optimization method. The fuzzy system is set up with the assistance of the industry experts to establish membership functions for each input and output variable and construct fuzzy rules mapping the relationships between them. This ensures that the resultant cabin design is aligned with the industry standards and met passengers' demands for increased comfort. The fuzzy design method successfully satisfied all three considered output design variables concurrently, leading to optimum cabin design. This implies that the input variables have been properly set at adequate satisfaction level, resulting in an ergonomically optimized passenger cabin design that provides adequate travel comfort for passengers of mass transport airships while complies with all relevant aviation regulations set by the authorities.

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