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Effects of Passengers' Anthropometry on Their Required Comfortable Seat Tray Table Height for In-flight Activities

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ABSTRACT

In-flight sitting comfort is often associated with the ease of passengers in performing their in-flight activities. Subsequently, having the appropriate height of seat tray table that matches the passengers' body anthropometry is vital in enabling them to adopt comfortable sitting posture while performing their activities. In this study, an activity-based sitting comfort experiment is conducted in an aircraft cabin mock-up where the participants were asked to rate their comfort level while using the seat tray table for eating, writing and typing activities at seven different settings of the tray table's height. A total of 64 volunteers have participated in the experiment and the collected sitting comfort data is statistically analyzed using MINITAB software. Regression analysis is used to derive mathematical metamodel for the effects relationship between passengers' anthropometry parameters and the required comfortable height of the seat tray table for each considered activity. The metamodel is tested for goodness-of-fit through standard testing. Overall, the metamodels for all three activities have shown good predictability with R^2 value of higher than 99%. The fitted models indicate that different activities correspond to a different comfortable seat tray table height, and this also varies for different passengers due to their different body anthropometry measurements.

Keywords: Flight comfort, In-flight activity, Regression analysis, Passenger comfort, Tray table height

I. INTRODUCTION

In a conceptual design stage of engineering products, including aircraft systems, there are many design decisions that need to be quickly made under lots of uncertainties as not much is known about the products at this development stage. Because of this situation, several engineering design researches have been pursued to develop new methods that aid in bringing more knowledge of the product to the early design stages for designers. These methods or approaches enable designers to make sound judgement and estimation that will eventually aid them in making better decisions [1]. Subsystem Change Ranking Methodology [2,3] and also Integrated Product/Process Development [4] are examples of methods that assist in bringing more product knowledge forward to early stages of design and development process.

In general, most of these methods use historical data of previous design iterations or similar available products to increase designers' understanding and knowledge about the expected design behaviors of the product. Meanwhile, an approach that has also been increasingly used in design engineering methods is metamodeling. By definition, this metamodeling approach refers to the process of creating a mathematical metamodel that can effectively describe the underlying relationship between the measure(s) of interest and the input variable(s) into the model [5]. In engineering design process, the metamodel is often seen as "black box" model that can estimate complicated, time-consuming and costly experimental or simulation analyses. For instance, to explore the effects of sweep angle on the aerodynamic lift-to-drag ratio of the aircraft's wing, wind tunnel tests or computational fluid dynamics (CFD) simulations need to

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be performed every single time the sweep angle is changed. This can take a lot of efforts, especially when decisions are to be made in a short timeframe during conceptual design stage. It has been shown that by having a metamodel of the relationship between the sweep angle and the lift-to-drag ratio beforehand, exploration of the design space could be done faster and easier as the designer only needs to change the value of the wing sweep angle in the metamodel and it instantly updates the corresponding predicted value for the lift-to-drag ratio [6]. Other studies that have demonstrated potential benefits of metamodeling in engineering design include its applications for assessing the flight comfort due to seat pitch and passengers' body anthropometry [7] and the performance of anti-icing system of an aircraft [8].

These days, the level of market competition between airlines is very high as they try to win potential passengers for their offered services against their competitors. One of the primary considerations for passengers in selecting their travel options is found to be flight comfort. In view of this, many large airlines have been focusing on enhancing their passengers' in-flight comfort in order to capture and retain their loyalty [9]. Based on various research studies, several different factors have been identified to contribute towards passengers' in-flight comfort. Among others, they include cabin design features such as legroom and passengers seat design [10], along with cabin's environmental settings like temperature, humidity and noise levels [11]. Furthermore, it is suggested that flight comfort level is also affected by the passengers' body size and changes in body proportions [12,13]. Overall, it has been concluded that flight comfort is influenced by physical, physiological and psychological factors, plus their interactions with each other. It is crucial for airlines to consider these factors to improve the flying experience of passengers, particularly since flight comfort has now become a key competitive market advantage.

It has been suggested that one of the effective means to evaluate flight comfort is by considering the passengers' activity and posture simultaneously [14]. Since passengers are conducting different activities at their seat during flight, their sitting posture changes accordingly to their activities. Some activities might cause improper sitting postures and this is reflected by the discomfort feeling of the passengers. For instance, a conducted study to assess several factors of flight comfort considers the context of two flight activities: sleeping and watching in-flight entertainment [15]. In the meantime, a different study evaluates passengers' comfort during in-flight activities such as eating, drinking, reading, relaxing and sleeping [16]. It should be noted that most of these in-flight activities involves the use of seat tray table and depending on their body anthropometry, the passenger may need different heights of the tray table to comfortably do their activities [17,18]. Hence, because flight comfort is linked to the ability for aircraft passengers to do their in-flight activities with adequate ease and comfort, having a suitable setting of the seat tray table's height is important.

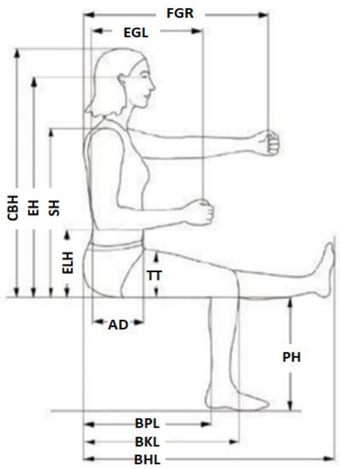
In order to design aircraft seat tray table with a proper height for passengers' comfort, the underlying relationship between tray table height, passengers' anthropometry and flight comfort level needs to be considered by the designer. In conjunction to this, having an appropriate metamodel of this relationship is of great help in facilitating the designer to aptly make such design decisions. Based on this notion, the main objective of this study is to construct appropriate metamodel that is able to capture the effects of passengers' anthropometry on the required seat tray table height that is adequately comfortable for them while performing several common in-flight activities. To achieve this, an experiment is done using mock-up aircraft cabin to assess the comfort of participants during writing, eating and typing-on-laptop activities. The height of the seat tray table is varied during the experiment and the participants are asked to rate their perceived comfort at each different height for each activity. In addition, the body anthropometry measurements of the participants are also collected. The data is then statistically analyzed for the metamodeling process.

II. SETUP AND METHODOLOGY

In total, 64 people have participated in the conducted experiment. 20 of them are females and the remaining are males, and all of them are between 20 to 30 years old. It is believed that many aircraft passengers today are in this age group. The participants have declared to be free from any musculoskeletal injuries or health issues at the time of the experiment. This declaration is crucial to confirm that any discomfort felt by the participants during the experiment is not due to their health issues, and is influenced by the experimental setup as intended. In addition to the health criterion, another big consideration is that the participants should have previous flying experiences. The study is also only focused on adult aircraft passengers as they are more susceptible to the discomfort in the activity-based context. At the start of the session, anthropometry dimensions' data of each participant are first measured and recorded. It should be noted that, since this study prominently focuses on flight activities of aircraft passenger while seated, only anthropometric measures that are used to describe human sitting position are taken. Table 1 lists the standard sitting anthropometry parameters that are taken from participants of the experiment. The anthropometric measurements are based on the definition in MS ISO 7250-1:2008 standard.

The experiment is conducted using available aircraft passenger cabin mock-up at Aerospace Design Laboratory, Universiti Putra Malaysia. This cabin mock-up is made up of passenger seats that were previously used in the cabin of commercial Boeing 737 aircraft. Before the experiment is started, participants are briefed on procedures and also expectations of the experiment. In short, participants have been instructed to sit in the aircraft cabin mock-up. They are tasked to perform several typical flight activities while seated using the tray table: eating the food served, writing short paragraph on a paper and typing short paragraph on a laptop as depicted in Figure 1. They are allocated about five minutes to perform each task before the height of the tray table is increased and they are supposed to do the task at the new height. At the end of the task at each tray table's height, they are asked to rate their perceived comfort level during the task. A simple five-point Likert scale between 1 to 5 is applied in the comfort rating, whereby a score of 1 indicates highly uncomfortable and a score of 5 signifies highly comfortable. It should be noted that seven settings of tray table's height are considered for this study: 66 cm, 69 cm, 72 cm, 75 cm, 78 cm, 81 cm and 84 cm, measured from the cabin floor. Note that the seat pitch is maintained as 71.12 cm, which is the usual seat pitch used in economy class cabin of a commercial transport aircraft.

Table 1 Considered human anthropometry measurements at sitting position

Parameter		**Illustration**
Thigh Thickness	TT	
Abdominal Depth	AD	
Crown Buttock Height	CBH	
Eye Height	EH	
Shoulder Height	SH	
Elbow Height	ELH	
Elbow Grip Length	EGL	
Forward Grip Reach	FGR	
Buttock Popliteal Length	BPL	
Buttock Knee Length	BKL	
Buttock Heel Length	BHL	
Popliteal Height	PH	

(a) Eating (b) Writing (c) Typing

Figure 1 Activities using the seat tray table [19]

The collected data are then imported to the MINITAB software for statistical analysis. For this study, polynomial regression is used to construct the metamodel based on the data. This regression analysis has been widely applied for modelling relationships between interested variables that might be adequately captured by simple linear regression. Several example applications of polynomial regression in engineering studies include the modelling of relationships between runway occupancy and flight departure delays at an airport [20], and between the resultant average surface roughness and several machining process parameters like revolution speed, federate and depth of cut [21]. After the metamodel for the effects of passengers' anthropometry on their comfortable tray table height has been constructed for each considered in-flight activity, it is subject to goodness-of-fit assessments. This is done to ensure the metamodel is a good fit for the collected data.

III. RESULTS AND DISCUSSION

Basic descriptive statistics for collected participants' anthropometry data are tabulated in Table 2. Based on the measurements, body dimensions of male participants seem comparatively larger than those of the females. In general, this is essentially consistent with anthropometry databases of Malaysian population that have been published in other research works such as [13,22].

Moreover, Table 3 shows the resultant comfort rating as assigned by the participants for the in-flight activities at different tray table heights. It can be observed that there is a similar trend of the assigned rating for each flight activity. As the tray table height is increased, the assigned rating is also increasing.

Table 2 Descriptive statistics of collected anthropometry measurements (in cm)

Parameter	Statistics	Female	Male
Thigh Thickness (TT)	Mean	14.37	15.37
	Standard Deviation	3.25	2.60
	5th Percentile	9.32	11.43
	95th Percentile	22.05	20.53
Abdominal Depth (AD)	Mean	21.70	23.42
	Standard Deviation	5.49	5.68
	5th Percentile	15.70	15.83
	95th Percentile	35.15	37.15
Crown Buttock Height (CBH)	Mean	81.19	85.74
	Standard Deviation	4.06	4.72
	5th Percentile	75.27	78.08
	95th Percentile	89.42	95.95
Eye Height (EH)	Mean	70.02	74.76
	Standard Deviation	3.72	4.00
	5th Percentile	62.64	69.40
	95th Percentile	76.69	84.10
Shoulder Height (SH)	Mean	53.96	55.43
	Standard Deviation	4.78	4.59
	5th Percentile	45.47	47.73
	95th Percentile	65.09	66.13
Elbow Height (ELH)	Mean	21.76	20.12
	Standard Deviation	3.03	3.81
	5th Percentile	15.55	13.98
	95th Percentile	27.51	26.40
Elbow Grip Length (EGL)	Mean	34.73	40.07
	Standard Deviation	2.99	4.62
	5th Percentile	30.13	34.50
	95th Percentile	39.96	53.75
Forward Grip Reach (FGR)	Mean	68.14	75.24
	Standard Deviation	5.09	5.30
	5th Percentile	58.31	64.70
	95th Percentile	79.45	83.60
Buttock Popliteal Length (BPL)	Mean	44.46	47.10
	Standard Deviation	2.61	2.82
	5th Percentile	39.30	43.00
	95th Percentile	49.38	52.15
Buttock Knee Length (BKL)	Mean	55.30	58.97
	Standard Deviation	3.00	3.26
	5th Percentile	50.25	53.28
	95th Percentile	62.08	64.63
Buttock Heel Length (BHL)	Mean	96.81	105.32
	Standard Deviation	5.14	5.83
	5th Percentile	88.59	96.63
	95th Percentile	111.27	116.85
Popliteal Height (PH)	Mean	44.29	46.54
	Standard Deviation	3.61	3.33
	5th Percentile	36.59	41.23
	95th Percentile	49.77	53.28

Table 3 Average comfort rating for in-flight activities at different tray table heights

In-Flight Activity	Tray Table Height (in cm)						
	66	69	72	75	78	81	84
Eating	2.19	2.92	3.72	4.14	3.69	2.80	1.83
Writing	2.33	3.14	3.81	3.86	3.22	2.42	1.45
Typing	2.84	3.44	4.05	4.34	3.84	2.94	2.06

However, the assigned rating for all of the considered activities appear to averagely peak at tray table height of 75 cm, after which the rating seems to reduce as the tray table height is increased. Based on this observation, it can be taken that there is an optimal height that suits the passengers for these activities. Having the tray table height as too low or too high will cause discomfort to passengers. It should also be noted that standard deviation for comfort rating at each tray table height is mostly less than one. This means that most of the participants' assigned ratings are in a similar category of comfort level as the average rating. All things considered, based on these findings, it is evident that the height of the tray table has an effect on the comfort level of aircraft passengers while they perform the in-flight activities.

On the other hand, based on the Likert scale used for comfort assessment by the participants in the experiment, a comfort score of 3 and above implies an acceptable level for the participants while performing respective activities. In other words, it is taken that is the required comfortable tray table height that they need to comfortably perform the assigned activities. By this notion, Table 4 shows average required tray table height for each activity based on given comfort assessment by the participants.

Table 4 Average required comfortable tray table heights for different in-flight activities

Statistical Parameters	In-Flight Activities		
	Eating	Writing	Typing
Mean of Table Height	74.344 cm	72.422 cm	72.750 cm
Standard Deviation	3.183 cm	4.031 cm	4.036 cm
Minimum Table Height	66.000 cm	66.000 cm	66.000 cm
Maximum Table Height	81.000 cm	81.000 cm	81.000 cm

It should be noted that the comfortable tray table height of each participant in each of the three in-flight activities is taken based on first tray table height that they gave their highest comfort score during the experiment. In Table 4, it can be observed that minimum and maximum tray table heights for all activities are the same to each other. This can be taken as a good sign that, if height of the tray table is to be made as adjustable for better comfort of the passengers, this can be viewed as the required range of heights to be considered. Moreover, it is seen that the average required tray table height for the participants to comfortably perform the typing and writing activities is very close to each other. However, the required tray table height for the eating activity is clearly bit higher than for other activities. Due to this observed difference, it appears that constructing just a single mathematical model to concurrently capture the comfort for all these activities may not be suitable. On the other hand, since the seat pitch is kept constant and the environmental conditions are also controlled to be similar as possible throughout the conduct of the experiment, it is taken that these observed variations in required comfortable tray table height for the different activities are due to body anthropometry measurements of the participants and their different adopted body postures while they are performing the activities.

The collected data from the conducted experiment is then analyzed and used for constructing the mathematical metamodel that relates the comfortable tray table height to passengers' body anthropometry parameters in each of the considered in-flight activities. In this study, the MINITAB software tool is applied for the statistical analysis. For the construction of the model, the stepwise regression method is used. By definition, stepwise regression is the regression modelling method that eliminates the predictor variables to only those that are significant to be kept inside the final model without causing its goodness-of-fit to be reduced. For this study, the main predictor variables are the twelve anthropometry measurements while the output variable is the comfortable tray table height. Moreover, the stepwise regression modelling feature in MINITAB is applied and the standard default value of 0.15 is used here for the level of significance.

Equation (1) shows the constructed metamodel for the in-flight eating activity. From the model, only a handful of anthropometry parameters can be seen to have statistically significant influence on the required comfortable tray table height (CTTH). These parameters are buttock knee length (BKL), thigh thickness (TT) and buttock popliteal length (BPL). It should be noted that each term in Equation (1) has a p-value lower than 0.015, which indicates their influence is substantially important.

$$CTTH_{eating} = 1.8374 * BKL - 0.000193 * BKL^3 + 0.000182 * TT * BPL^2 \quad (1)$$

The polynomial regression model in Equation (1) has a coefficient of determination, R^2 of 99.85%, which can be taken as very good. In general, a high R^2 value implies that the regression model appropriately captures the variability of the data very well, which in turn implies its goodness-of-fit and predictability [23]. Furthermore, the goodness-of-fit tests for the model can also be done by looking at the histogram and normal probability plots of the residuals as depicted in Figure 2 and Figure 3, respectively. These plots indicate whether the residuals are normally distributed. If the residuals are normally distributed with zero mean, this implies that the regression model captures the main pattern and source of variation of the fitted data, and that the errors are random and independent. As can be observed in Figure 2, the histogram of the model's residuals resembles normal distribution with a zero mean although it is not perfectly symmetry around the mean. Additionally, in Figure 3, the normal probability plot of residuals indicates that most of the data points are closely aligned to the straight line and this signifies a good level of normality of the residuals.

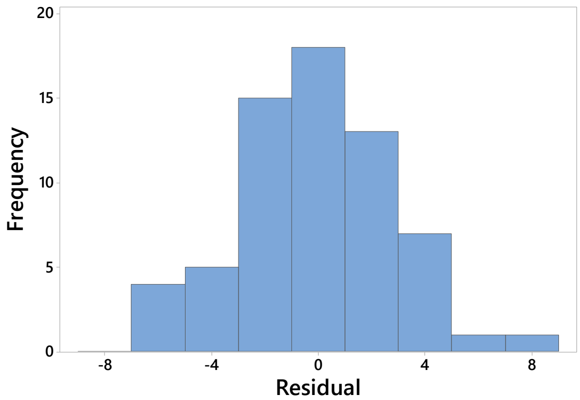


Figure 2 Histogram of residuals for the fitted model of required seat tray table height for eating activity

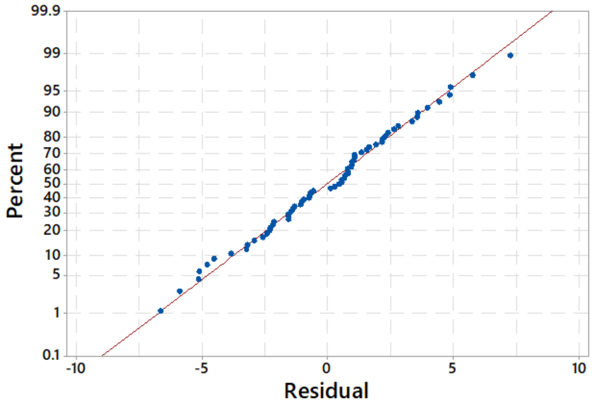


Figure 3 Normal probability plot of residuals for the fitted model of required seat tray table height for eating activity

In the meantime, Equation (2) presents the metamodel to predict the required seat tray table height for the flight passengers to comfortably perform any writing activities. This fitted regression model corresponds to the

R^2 value of 99.79%, which signifies good agreement with the data. In similar fashion to the previous fitted model for the in-flight eating activity, only some of anthropometry measurements have significant influence on determining the required seat tray table height for this writing activity. They include eye height (EH), shoulder height (SH), crown buttock height (CBH), elbow grip length (EGL), buttock popliteal length (BPL), forward grip reach (FGR) and buttock heel length (BHL). Each term inside the final fitted metamodel has a p-value of less than 0.05, which implies their significance level of effects. R^2 value for this fitted model is 99.79%.

$$CTTH_{writing} = 4.69 * EH + 0.548 * SH - 0.0521 * EH^2 - 0.028 * CB * BHL + 0.000334 * CBH * EH * BHL + 0.000065 * EGL * FGR * BPL \quad (2)$$

To indicate goodness-of-fit for this regression model, Figure 4 and Figure 5 show the histogram and the normal probability plots of the residuals.

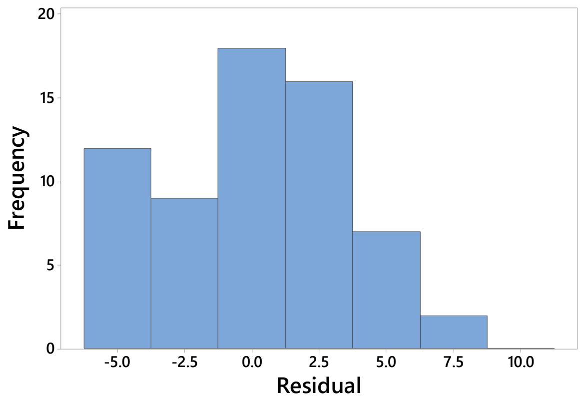


Figure 4 Histogram of residuals for the fitted model of required seat tray table height for writing activity

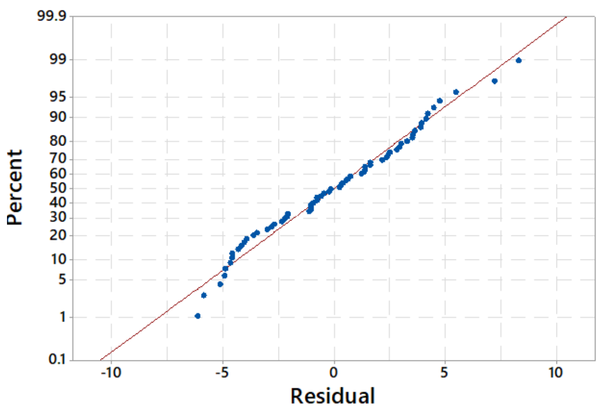


Figure 5 Normal probability plot of residuals for the fitted model of required seat tray table height for writing activity

As can be observed, the distribution of the residuals resembles normal distribution with mean zero, although not perfectly and a bit skewed to the left. On the other hand, the normal probability plot of the residuals shows that most of the data points are closely aligned in the straight line, which can be taken to imply a good level of normality of the residuals.

Last but not least, the fitted metamodel for the typing activity is presented by Equation (3). From the equation, the significant anthropometry parameters that are influencing comfortable height of the seat tray table for the passengers to perform the writing activity are eye height (EH), crown buttock height (CBH) and popliteal height (PH). All these parameters have p-value of less than 0.06, which indicates their high significance level of effects on the seat tray table height. Moreover, the R^2 value for this model is also high, which is 99.7%. This can be seen as a sign for its goodness of fit and also predictability.

$$CTTH_{typing} = 1.738 * CBH - 0.0087 * CBH^2 - 0.00349 * EH * PH \quad (3)$$

Furthermore, looking at Figure 6, the residuals for the model seems to be normally distributed with mean of zero. On the other hand, Figure 7 shows the normal probability plot of the residuals, in which the data points appear to be adequately aligned in a straight line.

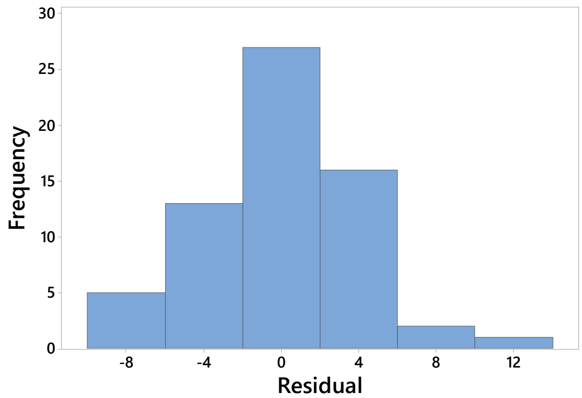


Figure 6 Histogram of residuals for the fitted model of required seat tray table height for typing activity

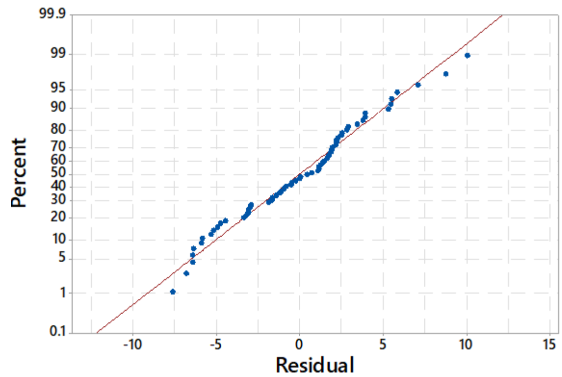


Figure 7 Normal probability plot of residuals for the fitted model of required seat tray table height for typing activity

Both of these figures can be taken to indicate acceptable goodness-of-fit for the fitted metamodel of the comfortable seat tray table height due to the anthropometry measurements of the passengers.

Summary of all fitted polynomial regression models in this study is presented in Table 5. For the eating activity, it seems that the significant anthropometry parameters are all related to lower human body parts. In this case, as also observed during the experimental session, the height of the tray table should be at proper comfortable height distance from the thigh of the participants when they were eating. This will help to reduce the distance or amount of leaning forward motion that they have to do to pick the food and put it in their mouth. However, if the tray table is too high, they might feel a little constricted and uncomfortable since the food is now close to their upper chest area though they do not have to lean forward as much anymore. On the other hand, as can be expected, the writing and typing activities share most of their influential anthropometry parameters, which also includes some parts of the upper human body. This might be due to a close similarity in motion and body position of the passengers while performing the activities. The writing activity has a higher number of the significant anthropometry parameters as its nature is more manually-driven (i.e. involves more parts of the body and posture) than the typing activity on a laptop.

Table 5 Summary of fitted metamodels for comfortable seat tray table height in different in-flight activities

Activity	Model's R^2	Significant Anthropometry Parameter
Eating	99.85%	Buttock Knee Length Thigh Thickness Buttock Popliteal Height
Writing	99.79%	Eye Height Shoulder Height Crown Buttock Height Buttock Heel Length Forward Grip Reach Elbow Grip Length
Typing	99.70%	Crown Buttock Height Eye Height Popliteal Height

All in all, based on the findings, it can be said that the comfortable seat tray table height for aircraft passengers is essentially different for different in-flight activities and for different passengers' body anthropometry. In this sense, it is hard to find a single height of the seat tray table that can satisfy the need of comfort for all passengers. Therefore, it is proposed based on this finding that it might be better for the seat tray table to have an adjustable height feature that can cater the requirements for different activities and also different passengers' body anthropometry measurements.

IV. CONCLUSIONS

Aircraft passengers' comfort has become an essential consideration for many people in selecting their air travel options. In general, in-flight comfort is affected by several different factors and one of them is the comfortability level of the passengers in performing their in-flight activities. It is noted that most of the in-flight activities involve the use of the seat tray table and its height is an important feature that can influence the ease and also comfort of passengers while they using it. In line with this notion, an experiment is conducted to study the relationship between comfortable seat tray table's height that is required by the passengers for some in-flight activities and their body anthropometry. For this study, three common in-flight activities using the seat tray table are considered: eating, writing and typing. Based on the obtained results, it has been shown that the height of the seat tray table affects the comfort level of the passengers while doing the considered in-flight activities. Furthermore, the different activities seem to correspond to different comfortable seat tray table's height, which varies between passengers based on their body anthropometry. In order to capture the effects of body anthropometry on the required comfortable height of the seat tray table for each considered in-flight activity, the corresponding metamodel has been constructed. All of the derived metamodels have been shown to be a good fit to the collected data, with R^2 value of more than 99% for each of them. Based on these models, they highlight that different in-flight activity will be affected by different body anthropometry parameters in accordance to the body posture and nature of the activity. All things considered, it can be concluded that it is hard to find a single height of the seat tray table that could satisfy simultaneously the comfort for all in-flight activities and also all passengers. Therefore, a new seat tray table design with an adjustable height might be considered as a solution to improve the passengers' comfort during flight. In future, posture analysis of the passengers while they are doing the in-flight activities can be done to supplement the findings in this study.

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