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The Anthropometric Differences among Malaysian, Singaporean and Indonesian, and Their Compatibility with Boeing 737 Cockpit Layout Design

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Abstract: ***The aim of this study is to identify the anthropometric differences among Malaysian, Singaporean and Indonesian, and analyse the compatibility of the anthropometric data with the selected Boeing 737 cockpit layout. The data of 16 anthropometric dimension for Malaysian, Singaporean and Indonesian adults were analyzed, arranged according to percentiles (5th, 50th and 95th)and compared. The result of comparative analysis between anthropometric data with the selected cockpit layout dimensions showed that the 95th percentile of anthropometric dimensionsof the Indonesian adult is compatible with the Boeing 737 cockpit layout. The results of this study could be used as references by the aircraft manufacturer to increase the effectiveness of the cockpit design in the future especially in considering the anthropometric data of ASEAN population.***

Keywords: Anthropometry, Cockpit, Layout, Design

I. INTRODUCTION

Anthropometry or anthropometric measurement can be defined as the study of human body measurements that is basically used to help scientists and anthropologists understand physical variations among humans. The anthropometric measurement application is use variously in order to provide a kind of baseline for human measurement (Al Wardi, 2016).One of the applications of anthropometric measurement is commonly about ergonomics which is to increase efficiency in the workplace area (Al Wardi, 2016).

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A good anthropometric data is needed to accommodate a well-designed workspace in order to accommodate variability in the worker population.

As anthropometric changes over years and generation, thus, the updated data is needed in order to get the best design suits in the workplace of this new era.

The concern in anthropometry itself is about the differences of one generation to other generation also geographically factor that will affect human body measurement itself (Şenol, 2016). This means that different culture, occupation and nutrition will give the different result of body height, arm length and others. As an example, an army's body height is higher than the normal population. Or, the American people have a longer arm's length compared to Asian people.Anthropometry measurement always related to ergonomics efficiency. Anthropometric data will always be as a reference for a specific population to allocate the workplace design that satisfying ergonomics (Pronk, 2015). This is how anthropometric data works for the ergonomics efficiency, to ensure the workplace design that fit in ergonomic concern.

In aviation field, the most significant place is in the cockpit itself. To reduce the loss of productivity which is one of the main purposes of ergonomic in workplace, cockpit design plays the main role in the aspect to be evaluated also known as critical reaches in cockpit are pilot visual capability, synchronised use of controls and display, frequency of the use of controls and display, balance strength for controls also controls and display compatibility (Şenol, 2016).As most commercial aircraft is manufactured by the United States such as Boeing aircraft, also by the United Kingdom, for example, Airbus, the cockpit design may not suitable for Asian people. It can be seen when a study conducted related to European pilot anthropometry estimation and cockpit design (Poirson et al., 2014).

Thus, it is useful to understand the difference in anthropometric data between three distinct countries, so that the design of the products can be improved, and for this research, the focus is specifically on cockpit design itself. This study will collect the human measurements data and analysis for the three Asian countries (Malaysian, Singaporean and Indonesian) people which will be used for comparing the population and the differences will be retrieved to be adapted in the aircraft cockpit design.

II. METHODOLOGY

Aircraft Cockpit Design Identification

The existing cockpit layout has been identified before the anthropometric data being compared to the manufactured dimension of the cockpit. The cockpit layout has been taken from the general familiarization of aircraft as depicted in Figure 1 & 2,to get the actual value of important dimension such as main instrument panel to back of pilot seat (52cm), main instrument panel to front of pilot seat (26cm), floor to lower edge of Primary Flight Display height (63cm), windshield height (108cm), floor to front overhead panel height (128 cm), floor to main panel height (99.5cm), control column height (81cm), pilot seat width (54cm), depth (70cm) and height (115cm). This study used a Boeing 737 cockpit dimension to compare with anthropometry data.

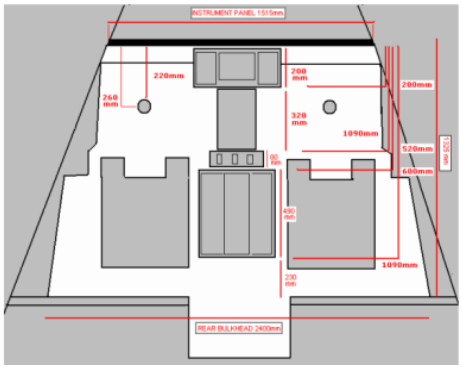

Fig. 1 The standard dimensions of Boeing 737-300, measurements from the main instrumentspanel (www.markuspilot.com)

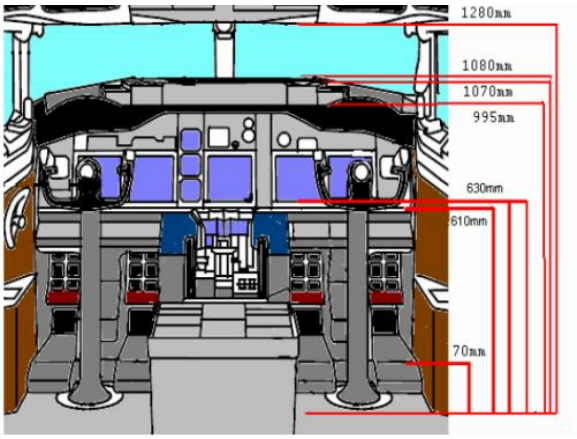

Fig. 2 The general requirement for cockpit height, measurements from the flight deck door (www.markuspilot.com)

Anthropometry Measurement Selection

Sixteenanthropometry measurementshave been selected including stature, sitting height, shoulder height, popliteal height, hip breadth, elbow rest height, buttock to popliteal height, buttock to knee length, thigh circumference, sitting eye height, shoulder to elbow length, chest depth, foot length, knee height, shoulder breadth, shoulder to fingertip length.

Subjects Determination

In total, 100 subjects comprised of 70 males and 30 female adults range of ages from 18 to 30 years old that fulfilled the criteria of the Malaysian pilot which height is not less than 163 cm and age is between 18 to 32 years old were involved in this study. During the measurement taken, due to Malaysia culture, individuals should dress properly when in public. Thus, the subjects need to be barefooted, wearing thin T-shirts and thin trousers during the measurement process to ensure the anthropometry data taken were less varied. The subjects were placed in a controlled environment and the same protocol of measurement has been applied to all subjects.

Anthropometry Data Collection

Anthropometric measurements among 100 subjects (70 males and 30 female) have been performed using anthropometry tools including steel ruler, measuring tape, stadiometer, weighing scale, anthropometerand sliding caliper. The measurement for each anthropometry dimension has been taken three times before being recorded in measurement datasheet to prevent errors and improve the accuracy. The anthropometry data for Singaporean and Indonesian has been taken from the previous study (Chuan et al., 2010).

Anthropometry Data Analysis

The value of the mean, standard deviation and the percentile (50^{th}, 75^{th}, and 95^{th}) has beencalculated. The anthropometry data among Malaysian, Indonesian and Singaporean has been analysed and compared with the selected dimension of the cockpit layout.

III. RESULTS

Anthropometry Data

The anthropometry data of 100 Malaysian adults are presented in Table 1.

Table. 1 Anthropometry Data for Malaysian Adult

	Anthropometry Dimension (cm)															
	Stature	Sitting Height	Shoulder Height	Popliteal Height	Hip Breadth	Elbow Rest Height	Buttock to Popliteal Height	Buttock to Knee Length	Thigh Cir.	Sitting Eye Height	Shoulder to Elbow Height	Chest Depth	Foot Length	Knee height	Shoulder Breadth	Shoulder to Fingertip
Mean	167.7	84.2	58.8	15.1	24.5	14.6	39.4	50.7	24.4	73.4	30.9	15.3	23.1	47.8	33.9	73.5
SD	5.3	4.6	3.6	1.3	2.8	1.7	3.0	3.0	5.3	3.7	1.8	0.9	1.6	2.8	3.9	4.4
Max.	181.6	110.0	67.0	19.0	33.2	19.0	47.0	57.0	38.0	84.0	37.0	20.0	27.0	54.0	44.0	84.0
Min.	163.0	76.0	53.0	12.0	18.5	10.0	33.0	42.0	18.0	63.0	27.0	12.0	19.0	41.0	23.5	65.0
Percentile																
5th	163.0	78.5	54.0	13.0	20.5	12.0	35.0	46.0	18.0	69.0	28.5	13.0	20.5	43.0	27.5	67.0
50th	166.0	84.0	58.0	15.0	24.0	14.5	39.0	51.0	23.0	74.0	31.0	15.0	23.0	47.5	34.5	73.0
95th	178.5	90.1	65.0	17.0	29.5	18.0	45.0	55.5	36.0	80.0	34.0	18.0	25.5	53.0	39.2	81.0

Anthropometry Differences among Malaysian, Singaporean and Indonesian

The comparison of data between Malaysia, Indonesian and Singaporean is presented in Table 2. The result showed

Table. 2 Anthropometry data for Malaysian, Singaporean and Indonesian

No	Dimension	Malaysian					Singaporean					Indonesian				
		5th	50th	95th	Mean	SD	5th	50th	95th	Mean	SD	5th	50th	95th	Mean	SD
1	Stature	163.0	166.0	178.5	167.7	5.3	165.0	174.0	182.0	174.0	5.2	162.0	172.0	183.0	172.0	6.2
2	Sitting Height	78.5	84.0	90.1	84.2	4.6	73.0	78.0	83.0	90.0	4.9	80.0	89.0	96.0	88.0	5.2
3	Shoulder Height	54.0	61.3	65.0	58.8	3.6	55.0	61.0	67.0	77.0	4.5	52.0	59.0	67.0	59.0	6.3
4	Popliteal Height	13.0	15.0	17.0	15.1	1.3	39.0	43.0	46.0	43.0	2.9	38.0	44.0	49.0	44.0	3.8
5	Hip Breadth	20.5	24.0	29.5	24.5	2.8	32.0	35.0	39.0	35.0	2.3	28.0	35.0	43.0	36.0	4.4
6	Elbow Rest Height	12.0	14.5	18.0	14.6	1.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7	Buttock to Popliteal Length	35.0	39.0	45.0	39.4	3.0	41.0	46.0	51.0	46.0	3.4	40.0	46.0	54.0	46.0	4.8
8	Buttock to Knee Length	46.0	51.0	55.5	50.7	3.0	53.0	57.0	63.0	57.0	3.3	48.0	56.0	64.0	56.0	4.9
9	Thigh Circumference	18.0	23.0	36.0	24.4	5.3	24.0	30.0	38.0	30.0	5.4	24.0	32.0	44.0	32.0	3.6
10	Sitting Eye Height	69.0	74.0	80.0	73.4	3.7	73.0	78.0	83.0	77.0	4.9	69.0	76.0	84.0	76.0	4.6
11	Shoulder to Elbow Height	28.5	31.0	34.0	30.9	1.8	33.0	37.0	43.0	38.0	6.0	NA	NA	NA	NA	NA
12	Chest Depth	13.0	15.0	18.0	15.3	0.9	18.0	21.0	25.0	21.0	2.5	16.0	21.0	27.0	21.0	3.5
13	Foot Length	20.5	23.0	25.5	23.1	1.6	23.0	26.0	28.0	26.0	1.4	22.0	25.0	29.0	25.0	2.6
14	Knee Height	43.0	47.5	53.0	47.8	2.8	49.0	54.0	58.0	54.0	2.9	46.0	54.0	62.0	54.0	5.2
15	Shoulder Breadth	27.5	34.5	39.2	33.9	3.9	31.0	37.0	43.0	37.0	3.6	31.0	37.0	43.0	37.0	3.6
16	Shoulder to Fingertip	67.0	73.0	81.0	73.5	4.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Anthropometry Comparison with Existing Cockpit Dimension

In this study, comparison of anthropometry data among Malaysian, Singaporean and Indonesian have been sorted out into three selected percentiles 5th, 75thand 95th. It can be seen that the anthropometry data that closer to the selected cockpit dimensions are 95th percentiles from Indonesian anthropometry data, as summarized in Table 3.

Table. 3 The result of a comparison between anthropometry dimensions with the Boeing 737 cockpit dimension

Cockpit Dimension	Measurement	Related Anthropometry Dimension	The Suitable Percentile	Measurement
Length (Horizontal Measurement)				
Main instrument panel to the back of pilot seat	52 cm	Shoulder to fingertip length	5th from Malaysian	67 cm
Main instrument panel to the front of pilot seat	26 cm	Knee-length	95th from Malaysian	17 cm
Height (Vertical measurement from cockpit floor)				
Floor to lower edge of Primary Flight Display	63 cm	Popliteal height	95th from Indonesian	49 cm
		Sitting eye height	50th from Singapore	78 cm
Windshield height	108 cm	Sitting height	95th from Indonesian	96 cm
		Sitting eye height	95th from Indonesian	84 cm
Floor to front overhead panel	128 cm	Shoulder to fingertip length	95th from Malaysian	81 cm
		Shoulder height	95th from Singapore	67 cm
Floor to main panel height	99 cm	Sitting eye height	95th from Indonesian	84 cm
		Sitting height	95th from Indonesian	96 cm
Control column height	81 cm	Shoulder to elbow height	50th from Singapore	37 cm
		Knee-length	95th from Indonesian	62 cm
Seat dimension				
Width	54 cm	Shoulder breadth	95th from Indonesian	43 cm
		Hip breadth	95th from Indonesian	43 cm
		Thigh circumference	95th from Indonesian	44 cm
Depth (front to back)	70 cm	Buttock to knee length	95th from Indonesian	64 cm
		Buttock to popliteal length	95th from Indonesian	54 cm
Height	115 cm	Sitting height	95th from Indonesian	96 cm

IV. DISCUSSION

In this study, the anthropometry data for 16 body dimensions have been measured. All subjectsfulfilled the pilot physical requirements including the minimum height, 163 cm with normal body mass index (BMI). There are 100 subjects involved, divided into 70 males and 30 females. Meanwhile, the anthropometry data for Indonesian and Singaporean has been extracted from the previous study data (Chuan et al., 2010).Out of 16 dimensions, 10 anthropometry dimensions were selected for comparative analysis. These dimensions are consideredaligned with the selected cockpit dimension. The dimensions including sitting height, sitting eye height, sitting shoulder height, shoulder breadth, hip breadth, buttock to knee length, buttock to popliteal length, knee height, shoulder to elbow length and shoulder to fingertip length.

The 1st cockpit dimension is the distance between the main control panel to the back seat (109 cm). As anthropometry data for shoulder to fingertip length among Singaporean and Indonesian is undefined, the Malaysian shoulder to fingertip length is used whereby the highest measurement on this anthropometry measurement is at 95th percentile (81 cm). This measurement is quite ideal because the pilot's hand is reachable to the main instrument panel.

Another cockpit dimension evaluated is the distance between the main instrument panel to the front of the pilot seat (52 cm). In this dimension, the thing that must be considered is on the space needed for the knee to stretch out during pilot works. Thus, the suitable anthropometry is the knee length. In this case, the 95th percentile from Malaysian population is selected due to the limited length of the front of the pilot seat to the main instrument panel which evaluated 43 cm. It can be seen that Indonesian and Singaporean knee length at the lowest percentile is not really suitable for being in the cockpit due to a larger value than the space of front seat to the main instrument panel. It may cause the pilot to get fatigued when in long journey flight or back pain due to the undesirable length of the front of the pilot seat to the main instrument panel. Thus, the manufacturer should refer to the Singaporean and Indonesian in order to design their own cockpit for the selected country. The length should be doubled from original as the knee length of the population is by 30% difference from Malaysian population.

The floor to lower main primary flight display's minimum requirement is 63 cm and this measurement needs to consider the knee height to ensure the pilot get enough workspace. The knee height from Singaporean at the 5th percentile (49 cm) is the best measurement suits to ensure the lower main panel is just enough for the pilot to fit in the cockpit.

However, the 95th percentile of knee height from Indonesian is not suitable for the lower main panel height. It shows that, at the 95th percentile, the Indonesian knee height is 62 cm and this is only 1 cm difference before reach the maximum measurement of the low edge Primary Flight Display. It may cause the pilot to felt uncomfortable due to excess knee height and may cause ineffective eyesight when pilot needs to bow to try to reach the PFD during flight operation.

Sitting eye height can be considered useful to be compared to the lower main panel height. This is related to the eye clearance factor either the sitting eye height is being disturbed or not when the pilot looking at the lower main panel. In order to satisfy the pilot comfort, the lower main panel height should not be too low compared to the sitting eye height. The selected sitting eye height is 78 cm contributed by Singaporean population which have the medium differences with the lower main panel. Logically, when there is less difference between sitting eye height with the lower main panel, there is less movement of the pilot head to see the lower main panel. In order to get the comfort workspace in the cockpit, it is relevant to increase the lower main panel height to 63 cm, so that the difference to the eye sitting height is lower than calculated before.

Another dimension is windshield height. Windshield height value is 108 cm. In this dimension, the concern is more on the pilot's eye clearance. With that, the related anthropometry dimension is sitting height and sitting eye height. Sitting height and sitting eye height position must be in the range of 108 cm ± 20 cm due to the wide of the windshield is 20 cm upward. Among the three populations, Indonesian sitting height at the 95th percentile suits the windshield height with a value of 96 cm. Meanwhile, for the sitting eye height, the most relevant percentile to suit in the cockpit is 95th percentile from Indonesian which the value is 84 cm. However, these sitting height and sitting eye height is not really satisfied to have the best eye clearance. It is recommended for the cockpit to have the lower windshield height in the range of 96 cm ± 20 cm. So, the lowest value of windshield is 76 cm and the highest is 116 cm. The sitting height and sitting eye height of the selected percentile can be suited perfectly to have better eye clearance when pilot sits in the cockpit.

The next dimension is floor to main panel height with value 99 cm. Based on the anthropometry data collected, the related dimension for the cockpit measurement is sitting eye height and sitting height. For the sitting eye height, the most suitable value is 84 cm which is contributed by Indonesian at 95th percentile. Same goes for sitting height, the best measurement comes from the Indonesian population at 95th percentile which the value is 96 cm. In this cockpit dimension, the maximum height is selected to ensure the pilot can easily see the main panel info preventing higher sight degree when looking at the main panel. The maximum height is selected, less difference between eyesight and the main panel so less movement needed to see info through the main panel.

The dimension where pilot hands need to reach to the front of the forward overhead panel height is 128 cm from the floor to the overhead panel. To compare the effective dimension in term of ergonomics in the workspace, the important dimension for this cockpit measurement is shoulder to fingertip length. By looking at the maximum measurement of shoulder to fingertip length, the estimation of pilot ability to reach the overhead panel has been made using percentile. The anthropometry data available is only for Malaysian population. Thus, by making assumption using the 95th percentile of shoulder to fingertip length from Malaysian population, the height from floor to overhead height should be shortened as a measurement of shoulder to fingertip length only shows approximately 81 cm.

Meanwhile, for the height of the control column, the anthropometry involved is shoulder to elbow length and also the sitting shoulder height. Based on the cockpit dimension, the control column is about 81 cm. Thus, the sitting shoulder height can be in the range of as same as the 50th percentile of Singaporean and Indonesian. The sitting shoulder height seems in medium measurement that the hands can reach the control column easier. The range value is about 61 cm. While the shoulder to elbow length, the suitable percentile is at 95th percentile from Singaporean.

The cockpit seat dimension including the width, height and depth. The width of the seat has a relationship to thigh circumference and hip breadth. By comparing the thigh circumference among Malaysian, Singaporean and Indonesian, the one which best suit to the width of the seat is the 95th percentile of thigh circumference from Indonesian. The value given is 32 cm. The 95th percentile measurement of the population is the highest one compared to Malaysian and Singaporean. Thus, there is a quite big difference between the width of the seat with thigh circumference which the value is 54 cm and 32 cm respectively. However, the smallest thigh circumference that belongs to Malaysian gives more advantages in terms of comfort to the pilot itself. The smaller thigh circumferences mean that the thigh clearance is bigger and more space left for the seat width.

Another anthropometry that has a correlation with seat width is hip breadth. The identified percentile that most suitable for the seatis at 95th percentile from Indonesian population. In terms of seat height, the anthropometry involved is sitting eye height, shoulder to elbow length, buttock to popliteal length, buttock to knee length. Sitting eye height must be higher than main instrument panel to ensure there is always eye clearance to look through the windshield, thus it must be higher than the floor to main instrument panel height (99 cm). So, the perfect measurement for sitting eye height must be higher than 99 cm. Based on percentile, the sitting eye height among Indonesian at 95th percentile is the best to be used in this cockpit dimension. The value is 83 cm and with the adjustable seat height by ± 5cm can is the nearest perfect sitting height. However, to fulfill pilot comfort, the height of main control panel from the floor can be reduced. The buttock to popliteal length and buttock to knee length are another anthropometry data that have been considered in the seat dimension to ensure that the depth (from the front seat to back seat) is suitable and not lead pilot to fatigue.

The nearest anthropometry measurement is from Indonesia, which shows the maximum measurement at percentile 95th and the calculated value is 64 cm.

Based o the results, it can be seen that anthropometry data among the different population can be varied in terms of percentile measurement, mean and standard deviation. This may due to the environmental factor, dietary consumption and genes. Thus, there are few cockpit dimensions that need modification including the distance between main instrument panel to the front of the pilot seat that should be doubled from original and for Asian population. The manufacturer can refer to the 95th percentile of the knee height from Indonesian and Singaporean. Other than that, distance from the floor to lower main primary flight display's minimum requirement must be increased in order to satisfy the anthropometry of the Indonesian population. Thus, for the existing cockpit, the suitable percentile is 5th percentile from Singaporean. However, it is recommended for the cockpit to have the lower windshield height in the range of 96 cm ± 20 cm since the highest value of percentile do not guarantee the best eye clearance from the cockpit.

Meanwhile, the other dimensions including seat dimension, control column height, floor to the overhead panel, anthropometry data from Indonesian at 95th percentile is considered suit to the existing dimension of the cockpit.

V. CONCLUSION

It can be concluded that anthropometry data varies among different population. There are quite small differences with the range of 1%- 5% for the anthropometry data of the three Asian countries. It is suggested for the modification on the existing cockpit design referring to Asian population anthropometry data to ensure the effectiveness of pilot comfort during the flight. The results of this study can be used as references and guideline by the aircraft manufacturer in designing the cockpit layoutto optimize workspace whileconsidering the comfortability and ergonomics issue of the ASEAN pilot.

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