

Design Analysis of Ergonomic Accelerator Pedal: A Case Study on Proton Persona SV

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Abstract. Ergonomic design is essential in producing an excellent human-machine interface. For a vehicle, accelerator pedal is one of the most important human-machine interfaces that is always engaged during driving. Thus, in the design process, the shape and position of the pedal must be in reference to the driver and compared with the existing anthropometric data of the user. This case study chose a Malaysian car, Proton Persona as a reference design to be analyzed. First, product design specification of the pedal is established by measuring the reference accelerator pedal design positioning and dimension. Then, the comfort angles provided by the existing design is measured and calculated. Finally, five new redesign concepts are proposed, and the improved design is analyzed. The mathematical findings show that the configuration of the existing accelerator pedal may cause discomfort during driving compared to the improved design which extends the pedal contact point by 20mm for a better ergonomic value. Whereas finite element analysis (FEA) shows reduction in stress and displacement of the weakest point of the new pedal to less than 1% of the original. The final finding shows an improved design that will be more ergonomic to 90% of Malaysian population.

Keywords: Malaysian Anthropometry, ergonomics, accelerator pedal, finite element analysis.

1 Introduction

The design of a driver's cockpit or workstation is an essential part of automotive as it includes the seat, steering, and pedals that a driver uses to operate the vehicle. It should

consider performance, comfort, and optimization in relation to anthropometry, the study of human body dimensions and their relation to physical activity. The body proportions of different populations can vary significantly and using anthropometric data specific to a particular population can ensure that the cockpit or workstation is comfortable and easy to use for drivers [1-3]. Therefore, the use of anthropometric data specific to the Malaysian population [4] is crucial in the design of the automobile parts, such as accelerator pedals.

There is a lack of research on adapting available anthropometric data of the Malaysian population into accelerator pedal design [5], which potentially leading to non-optimal driving performance. To address this issue, this research focuses on redesigning the accelerator pedal of a 2013 Proton Persona, a national sedan car, by using available anthropometric data on the Malaysian population and applying ergonomic principles.

The aim is to create an ergonomically designed pedal that is better suited to the body proportions of the Malaysian population and minimizes vibration transmissibility. The final design is tested and evaluated using finite element analysis (FEA) to determine its performance in stress analysis. By considering performance, comfort, and optimization of the accelerator pedal in relation to anthropometry, this research aims to improve the driving experience.

2 Methodology

This study is limited to using the anthropometry data was adapted from previous study based on NIOSH 2020 anthropometry data [4]. The impact force applied for simulation analysis is based on generic car accident parameters based on Chabra et al. [5]. Meanwhile, the vibration values on the foot at the pedal based on study by Yusoff et al. [6].

2.1 Product Design Specification

A “new” accelerator pedal requires a thorough Product Design Specification (PDS) that outlines key requirements for it to meet its objectives i.e., to fit the Malaysian drivers’ leg and foot anthropometry. One of the main factors to be considered is the material for the design. Accelerator pedal must be durable and comfortable for the users. Most importantly, the pedal's design should be ergonomic to provide comfort and accommodate the needs of 90% of the population. To achieve this, new pedal arm and position parameters should be developed as well. Table 1 listed all the specifications that is thought to be important for a car’s accelerator pedal.

Table 1 Specifications and expected value of the PDS.

1 Specification	2 Description	3 Expected Value
4 Ergonomic	5 The length of the pedal arm matches the calculated comfort angle value in the comfort angle analysis	6 Calculated in the results section based on the NIOSH 2020 data [4]. Calculation procedure is included in the following section.

7	Vibration Transmissibility	8	The design must follow previous research guidelines/parameters for vibration transmissibility from the car to the drivers.	9	Two different design options based on the previous research by Yusoff et al. [6]
				10	Small pedal pad
				11	35mm x 80mm
				12	2800mm ²
				13	Large pedal pad
				14	65mm x 120mm 7800mm ²
14	Comfort	15	The design of the accelerator pedal includes considerations for drivers' comfort while using the accelerator pedal.	16	Elements of design that provide drivers comfort such as rubber pedal pad and kinked design for more
				17	foot space.
18	Safety	19	The design able to withstand a set amount of force and deflect a certain amount	20	40N amount of force on the pedal pad and maximum deflection of 10mm based on previous research [6]

2.2 Accelerator Pedal Design Parameters

The dataset used for this study is from Malaysian NIOSH database tool [4]. It allows us to select the Malaysian population age groups that falls into the driving age in Malaysia. The database is sourced from nation-wide anthropometry survey of Malaysian population. For the 2020 data collection, NIOSH surveyed a total of 1025 number of male participants and total of 885 number of female participants from 9 sites across the country. The total number of participants in this multi-site survey satisfies the requirements made by Bridger [7] which is 200 individuals for an anthropometry study. As this study focused on analyzing the comfort angles of the driving position based on the accelerator pedal positioning and arm length, the extracted anthropometry data only involved the lower body section. Table 2 presented the definition of the lower body section anthropometry.

Table 2 Definition of the lower body section anthropometry values.

21	Dimension	22	23	Definition
		Symbol		
24	Thigh length (Buttock-Popliteal Length)	25L1	26	The distance between the buttock and the popliteal.
27	Lower leg length (Popliteal Height)	29L2	30	The distance between the popliteal and the heel.
31	Pedal Foot Length	32L3	33	The length of the right foot between heel point and the arc where the bodyweight rest. A reference ratio is used to calculate pedal foot length from the normal foot length which is 0.663 based on parameters used in Garg et al. [7] and SAE J826.

The pedal position in relation to the H-30 Point will ultimately dictate the drivers seating angle and this may result in seating angles less or over the comfortable range. Thus, for this study, Fig. 1a and Fig. 1b illustrated extra graphical representations on the measured points in the seating position and its reference to the H-Point and Accelerator Pedal Point (APP). All the measurements were taken manually using

measuring tape and vernier calipers.

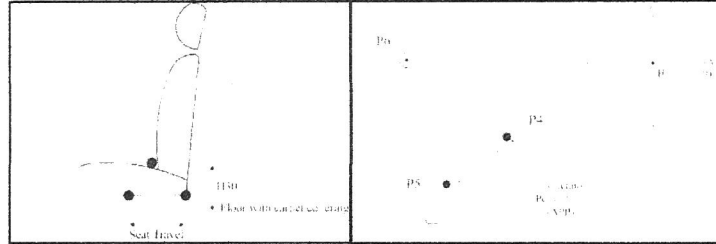


Fig. 1 Extra graphical representations of the measured dimensions.

Mathematical modeling for the comfort angle analysis method is also from Garg et al. [7]. The model established a few critical assumptions due to the complexity to analyze a 3D version of the human models. Therefore, it uses 2-dimensional plane as shown in Fig. 2. Thus, it is a 2-dimensional analysis using the measured value in X and Z axis of H-point and pedal position in relation to H-point which is P4 for unpressed state and P5 for pressed state according to Table 3.

Table 3 Finalized Min and Max Values the analyzed comfort angles with no adjustments (based on [8])

34 Comfort Angles and Corresponding Angle Symbol	35 Unacceptable Limit	36 Min Values	37 Max Values	38 Unacceptable Limit
39 Hip Angle AA	40 \angle 41 <-20	42 -10	43 15	44 >20
45 Torso Angle BB	46 \angle 47 <95	48 100	49 135	50 >140
51 Thigh Angle CC	52 \angle 53 <85	54 90	55 110	56 >115

The next assumption is the point measured in the accelerator shoe plane angle is defined as an angle between the floor and an imaginary line formed between the AHP and the Accelerator Pedal Point (APP) using the same dimension as the target percentile population pedal foot length. The last assumption is that the 95th percentile of the population will be using the rearward position of the H-point which is the most backward seat position and for the 5th percentile population the most forward seating position will be used.

The position of P5 is the depressed pedal position and will be calculated by replacing P4 in the following equations.

The first relation between P3 and P4 can be defined as:

$$X3 = X4 + L3 \cos(\angle D) \quad (1)$$

$$Z3 = Z4 - L3 \sin(\angle D) \quad (2)$$

Value of $\angle DD$ will be different for differing percentile population due to varying foot length. As the BOF of accelerator foot is coinciding with the accelerator pedal in every condition. The value of $\angle DD$ can be calculated by,

$$\angle D = \tan^{-1} ((H30 - |Z4|) / L3) \quad (3)$$

With known value of $\angle DD$, $Z3$ and $X3$ can be calculated as

$$-L1 \cos \angle A - L2 \sin(\angle A + \angle B - 90^\circ) = X3 \quad (4)$$

$$L1 \sin \angle A - L2 \cos(\angle A + \angle B - 90^\circ) = Z3 \quad (5)$$

Modifying Eq. (4) and Eq. (5)

$$-L1 \sin \angle A - Z3 = L2 \cos(\angle A + \angle B - 90^\circ) \quad (7)$$

Squaring and addition of Eq. (6) and Eq. (7) further solving the equations results in:

$$A^2 + Z3^2 * \sin^2 \angle A - 2 * A * Z3 * \sin \angle A = X3^2 * (1 - \sin^2 \angle A) \quad (8)$$

$$(Z3^2 + X3^2) * \sin^2 \angle A - 2 * A * Z3 * \sin \angle A + A^2 - X3^2 = 0 \quad (9)$$

$$(L1^2 + X3^2 - L2^2 + Z3^2) / (2 * L1) = A \quad (10)$$

two values of $\sin \angle AA$, two values of $\cos(\angle AA + \angle BB - 90^\circ)$ can be derived out. One values will be out of range and will be rejected. However, the in-range value can be used to calculate the value of $\angle BB$ and the value of $\angle CC$ can be calculated from this relation.

$$\angle A + \angle B = \angle C + \angle D \quad (11)$$

As stated in the previous process, the parameters that will be modified in the existing pedal design is related to accelerator pedal positioning. To modify the parameters, two important design elements will be changed, the maximum pedal angle when being depressed and the length of the arm or the geometry of the arm.

For the modification of the pedal pivot point, this will affect the reachability of the pedal. To keep the design practical, the pedal pivot point is fixed and only length of the pedal arm will be modified. Table 4 listed out all the modified pedal length and the new pedal point value in the X and Z axis. The best performing pedal length in the comfort angle analysis will be chosen as the new pedal length.

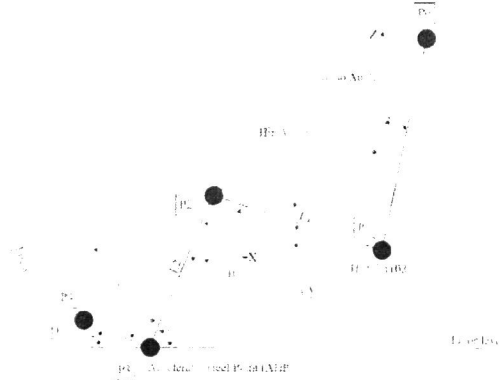


Fig. 2 Illustration of the comfort angles at A, B, C, D, the measured pedal position, and human position at P1, P2, P3, and P4 and L1, L2, L3 anthropometry position

Table 4 Modified pedal length value and its coordinate value

57	Pedal Length Value (mm)	58	Pedal Point	59 Value of Vertical & Horizontal X(mm)	60	Pedal Length Value	61	Z (mm)
62	148	63	P4	64	99	65	110	
66		67	P5	68	141	69	46	
70	168	71	P4	72	112	73	125	
74		75	P5	76	160	77	52	
78	188 (Existing Length)	79	P4	80	126		81	140
82		83	P5	84	179		85	58
86	208	87	P4	88	139		89	154
90		91	P5	92	198		93	64
94	228	95	P4	96	152		97	169
98	<85	99	P5	100	217		101	70

2.3 Design Concept Generation and Concepts Evaluation

This process starts with the creation of several sketches, to produce a variety of design ideas that can be used to meet all the objectives outlined in the Project Design Specification (PDS). In this process, a total of 5 sketches were produced and each one was analyzed to determine its advantages and disadvantages. This initial analysis helps in understanding the strengths and weaknesses of each concept, making it easier to choose the best design for the project.



Fig. 3(a) Showing Concept 1 generation sketches (Left) **(b)** Showing Concept 2,3,4 and 5 generation sketches (Right)

Then, 3D model based on the selected two best sketches based in the previous process are generated using SOLIDWORKS. The 3D model is a more refined version of the accelerator pedal concepts, and this is needed in the final evaluation using stress and displacement analysis to complete the requirements of the PDS. The material of the model was also assigned to the model with its specific properties so that the simulation results is more accurate. Two of the conceptual designs 3D model underwent 2 simulations in Solidworks. The simulation used is based on the static simulation. The model is treated as one solid body to reduce the complexity of the analysis as it is a static simulation. The displacements must not be more than 10mm [6].

3 Results and Discussion

3.1 Anthropometry data from the NIOSH 2020 database tool

The anthropometric dataset extracted from the NIOSH database is for male and female in the 20-69 age groups. It provided the detailed information in developing the dimension of the 5th, 50th and the 95th percentile lower body model for the Malaysian population of both genders. Satisfactory human factor design fulfills the need of the 5th percentile human and the 95th percentile human thus serving a 90% of the population range except the outlier in the human population. Thus, achieving its purpose as a comfortable and ergonomic pedal design. Table 5 shows the extracted data from NIOSH database.

Table 5 Extracted data from NIOSH 2020 database.

102 Population	103 Anthropometry Dimensions	104 Standard deviation	105 5 th Percentile (cm)	106 50 th Percentile (cm)	107 95 th Percentile (cm)
108 Male, 20-69, Sitting	109 Buttock Popliteal Length	110 2.89	111 40.38	112 46.71	113 51.46
114	115 Popliteal Height	116 2.21	117 37.54	118 41.18	119 44.82
120	121 Foot Length (Right)	122 1.26	123 22.85	124 24.92	125 27.00

126	Female, 1 2 7 20-69,	129 Buttock Popliteal Length	130 2.89	131 38.91	132 44.93	133 49.68
128	Sitting	134 Popliteal Height	135 2.24	136 34.27	137 37.97	138 41.66
139		140 Foot Length (Right)	141 1.14	142 21.1	143 22.97	144 24.84

The comfort angles are calculated using the mathematical modelling elaborated in the methodology. The results for the best pedal length and existing pedal length are tabulated in Table 6 and Table 7. Table 6 shows the male data results and Table 7 presents the female data results. The color coding represents the state of the angle in respect of the driver's comfort. Green is within the ideal range, yellow indicates the value is outside the ideal range but still within the acceptable limits and red is outside the acceptable limit. The data analysis showed that a 20mm extension of the pedal length enhances the ergonomic comfort for both genders. The male comfort angles increase and avoid the yellow zone of discomfort. The female comfort angles also improve and reach the green zone of comfort in all 3 locations.

Table 6 Male Population comfort angles for each pedal length.

145 Pedal length (mm)	146 Male, 20-69, Sitting	147 5 th percentile	148 95 th percentile
149 188	151 Un-Pressed State (P4)	152	153
150 Existing length	154 Thigh angle	155 2.40	156 17.96
157	158 Knee angle	159 125.89	160 116.70
161	162 Ankle angle	163 97.18	164 85.86
165	166 Depressed State (P5)	167	168
169	170 Thigh angle	171 -12.87	172 14.53
173	174 Knee angle	175 134.13	176 138.27
177	178 Ankle angle	179 101.26	180 101.27
181 208	182 Un-Pressed State (P4)	183	184
185	186 Thigh angle	187 2.32	188 14.58
189	190 Knee angle	191 120.39	192 119.14
193	194 Ankle angle	195 106.61	196 93.00
197	198 Depressed State (P5)	199	200
201	202 Thigh angle	203 -9.52	204 12.52
205	206 Knee angle	207 133.66	208 126.19
209	210 Ankle angle	211 115.03	212 105.53

Table 7 Female Population comfort angles for each pedal length

Pedal length (mm)	Female, 20-69, Sitting	5 th percentile	95 th percentile
188 Existing Length	Un-Pressed State (P4)		
	Thigh angle	2.23	18.61
	Knee angle	103.35	124.49
	Ankle angle		
	Depressed State (P5)		
	Thigh angle	-12.14	13.23
	Knee angle		
	Ankle angle		107.36
	208	Un-Pressed State (P4)	
Thigh angle		2.18	15.54
Knee angle		106.22	120.30
Ankle angle		106.61	85.34
Depressed State (P5)			
Thigh angle		-2.86	9.79
Knee angle		119.48	142.36
Ankle angle		115.03	102.09

3.2 Concept and Detail Design Generation

The concept generation of the accelerator pedal produced several innovative designs aimed at addressing the issues outlined in the Project Design Specification (PDS). Fig. 3a shows Concept 1 generation sketches. While Fig.3b shows the other concepts sketches. Through matrix evaluation analysis based on the PDS, the selected concept among 5 generated concepts is Concept 1. Concept 1 design blends premium racing car features with material efficiency, utilizing stainless steel for the pedal arm and pad. Stainless steel offers durability, resistance to rust and oxidation, and requires no paint or external coatings. However, this design is more complex than the existing design due to material optimization elements and requires a finishing phase during manufacturing due to fillet edges. The detailed designs are based on the concepts presented previously and the existing design is also modelled in the Solidworks as shown in Fig. 4.

3.3 Finite Element Simulation Analysis

The 5 designs produced in the previous section incorporated the material optimization strategy by using triangular matrix and hollowed section for reduce material usage. All designs utilized the pedal pad design based on vibration transmissibility by Yusoff et al. [6] in previous research. This reduced the effect of low frequency vibration from the vehicle to the driver's foot thus reducing the possibility of muscle fatigue. The pedal pad

position for both designs also is in the optimized position based on the calculation from the NIOSH database [4] thus presenting better comfort angles for Malaysian drivers.



Fig. 4 (From Right to Left) Existing Design, Concept 1 Concept 2, Concept 3, Concept 4, Concept 5.

The static stress and displacement analysis were conducted to compare the behaviour of these designs under usage. The 40N load parameter is based on the previous research by Chabra et al. [5], which is the minimum load that will provide variation on the results analysis to detect weaker areas of the pedal. The displacement is also limited to 10mm based on the parameters used in the research.

In the following Table 8, a summary of maximum stress, maximum displacement and its percentage compared to the original design based on similar test parameters is listed. This is to provide based inference in the final weighted matrix analysis. The stress and displacement factor must be less than the original design to be considered an improvement.

Table 8 Comparative maximum displacement and maximum stress of all concepts and existing design.

Concept	Max Displacement (mm)	Difference to Original (Lower is better)	Max Stress (MPa)	Difference to Original (Lower is better)
Existing Design	3.044	0	290.9	0
1	0.002366	-100%	0.2555	-100%
2	14.65	381%	19.85	-93%
3	0.3421	-89%	16.68	-94%
4	0.3675	-88%	21.97	-92%
5	2.527	-17%	85.33	-71%

4 Conclusion

This summary of results reflects the material choice as the deciding factor of the displacement analysis and the stress analysis. The original design uses carbon steel as its material while ABS used in Concept 2 produced the less resistance to the 40N force exerted on the pedal pad. Concept 3,4 and 5 fared better due to its aluminum alloy strength compared to ABS. Lastly, Concept 1 produced the best result due to its stainless-steel material. In summary all Concepts except Concept 2, passed the required maximum displacements of 10mm.

Additionally, Concept 1 was not only more visually appealing, but it also addressed the ergonomic needs of a larger portion of the Malaysian population. The design was improved by taking into consideration the findings from previous research that proposed a pedal pad area to reduce the transmission of vibrations from the vehicle to the driver's foot. The new pedal pad in Concept 1 also allowed for hinged movement, resulting in a more comfortable driving experience. Overall, Concept 1 stood out as the best option due to its improved performance, aesthetic appeal, and ergonomic design.

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