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Renewable Energy Vehicle Project: Pedal Box Design for Formula SAE

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Abstract

The purpose of the design project was to research and design a pedal box for the Formula SAE competition. The pedal box was constructed as a part of a zero-emission vehicle project for the Renewable Energy Vehicle team, striving to demonstrate the feasibility of sustainable transportation by building road ready electric vehicles. The pedal box entity was carefully researched by viewing previous designs, patents, past research, and current manufactured products. The knowledge was then applied and combined in order to design a pedal box to fit the necessary requirements for the vehicle, which the requirements of function, design, and rules were met in the final design.

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1. Introduction

Today's society is increasingly dependent on cars and public transportation, and therefore increasingly dependent on the fuel required for transport. The words of Henry Ford, "I am going to democratize the automobile. When I am through everyone will be able to afford one, and about everyone will have one," (Couclelis 2000) have become a reality today. This, however, has caused a large demand for the fossil fuels that provide the energy to make cars go. The fossil fuel resource has been diminishing at a rapid rate, and the carbon dioxide emissions from use of this resource are also polluting the world environment. For these reasons and the fact that there has been an increase in the price of fuel for cars in the past years there has been an increased effort to find alternative fuel sources allowing for lower emission transportation services.

1.1 Background

The Renewable Energy Vehicle project (REV) at The University of Western Australia was re-started under the leadership of Professor Dr. Thomas Bräunl and Dr. Kamy Cheng in order to demonstrate the feasibility of sustainable transportation as well as promote developed research into the renewable energy field (REV 2011). Currently the REV team works on making improvements to past year projects, including a converted electrically powered Lotus vehicle, as well as designing and constructing another competitive electric car to contend once again in the yearly Formula SAE (Society of Automotive Engineers).

The Formula SAE competition is a student design competition to develop a Formula-style race car which will be judged based on design, cost, presentation, and a variety of testing runs. Undergraduate and graduate students from universities around the world compete in the Formula SAE, which purpose is to give engineering students the opportunity to work in real work experiences across multiple engineering fields and work in all aspects of the automotive industry. From the Formula SAE, there is the opportunity to enter in an electrical or hybrid-electric vehicle. In any case, in

order to be competitive, it would be necessary to enter a car which has low weight, low cost, and high performance quality, which is the goal of the REV team by entering in the competition with an electrical vehicle. The motivation for competing and excelling in the Formula-SAE would help the REV team work towards the goal of demonstrating the capability of electric vehicles on the racing circuit.

1.2 Project Aim

The overall scope of the project is to research, design, and construct a competitive electric motorsport vehicle to compete in the Formula SAE competition. However, individual projects were developed in order to break up the car entity into more manageable pieces, which could be researched and developed in detail to improve performance and design components for the individual portions.

1.2.1 *Individual Scope*

Every car is necessarily equipped with a system to convert a small form of energy exerted by the driver into braking and accelerating the motor vehicle at high speeds. In the case of the Formula SAE car, it was required to construct such a system, similar to the case of most vehicles, in which the mechanical force from the driver's foot on a lever caused the car to accelerate or decelerate. The levers and the construct housing the levers are what consist of the pedal box, which is the focus of this project. The purpose of the individual project was to research and design the working mechanics of the pedal box that was a reliable, safe, and cost effective system for the Formula SAE competition

In preparation to design the pedal box, it was essential to review the necessary requirements for the construct, as well as performing a literature review on past similar projects for a basis. Once the research was completed, initial design ideas were experimented with until the final design was chosen for the pedal box based on the requirements.

2. Requirements Analysis

As with all engineering problems, there are constraints and requirements that must be met when solving the problem. Before starting the design stages of the project, examination of the design and functional constraints as well as the rules for the competition were listed and used as the guidelines for the design of the pedal box.

2.1 Functional Requirements

An important aspect when designing the pedal box is that it would meet the necessary function requirements of a pedal box, in that it converts the mechanical force from the driver to the brake and accelerator systems. In other words, the pedal box must contain a working brake and throttle. If the pedal box contains the clutch, it must also provide the function necessary for shifting gears. With the brake, the pedal box must contain the required housing for the master cylinders, which must be able to take the force transmitted from the brake pedal. The entire pedal box must be adjustable to be able to accommodate heights of different drivers without compromising the strength and stability of the pedal box. Also it should be considered that the pedal box be comfortable to the driver and adjustable to different drivers' needs, with the pedal ratio and angle with the floor of the car. As well, the driver's trust in the pedal box functional ability must be considered as a driver feeling tentative on the brake or accelerator would decrease performance results.

2.2 SAE Rule Requirements

The SAE Formula competition requires certain standards in the competing cars in order to help ensure safety for the students and to set a measurable state of uniformity across the entered cars. The rules that apply to the pedal box and braking system and throttle are as follows: (SAE 2011)

B7.1 Brake System – General

The car must be equipped with a braking system that acts on all four wheels and is operated by a single control.

B7.1.1 It must have two independent hydraulic circuits such that in the case of a leak or failure at any point in the system, effective braking power is maintained on at least two wheels. Each hydraulic circuit must have its own fluid reserve, either by the use of separate reservoirs or by the use of a dammed, OEMstyle reservoir.

B7.1.2 A single brake acting on a limited-slip differential is acceptable.

B7.1.3 The brake system must be capable of locking all four (4) wheels during the test specified below.

B7.1.4 “Brake-by-wire” systems are prohibited.

B7.1.5 Unarmored plastic brake lines are prohibited.

B7.1.6 The braking systems must be protected with scatter shields from failure of the drive train (see B.8.13) or from minor collisions.

B7.1.7 In side view no portion of the brake system that is mounted on the sprung part of the car can project below the lower surface of the frame or the monocoque, whichever is applicable.

B7.1.8 The brake pedal shall be designed to withstand a force of 2000 N without any failure of the brake system or pedal box. This may be tested by pressing the pedal with the maximum force that can be exerted by any official when seated normally.

B7.1.9 The brake pedal must be fabricated from steel or aluminium or machined from steel, aluminium or titanium.

B8.5.6 A positive pedal stop must be incorporated on the throttle pedal to prevent over stressing the throttle cable or actuation system.

The rules require the pedal box to house two master cylinders, the brake to be able to withstand a force of 2000 N and be machined from steel, aluminium or titanium, and the throttle to contain a positive pedal stop.

During the competition, the judges score the vehicle based on static and dynamic events. The static events contain the points earned for design, cost, and presentation and total 350 points. The dynamic events include the performance of the car during acceleration, skid-pad, autocross, fuel economy, and endurance events and total 650 points. The pedal box necessarily is a contributor to both the static and dynamic events in that it is a factor in the design and cost of the car as well as a factor in any dynamic event. The design portion is worth 200 points and the cost section is worth 100 points. Due to the point system, the performance of the pedal box should be the top priority followed by the design or weight, then followed by the cost of the pedal box.

2.3 Interdependencies with other systems

The pedal box holds relations with multiple systems in the entire car including the car frame, braking system, and accelerator system. Any beneficial design to the pedal box entity must be outweighed with the relative cost to the other systems. A large increase in efficiency in one area of the pedal box could affect greatly the efficiency or workability of another interdependent system, which must be kept in mind in designing the pedal box. In this effect, joining the group and initializing the project at the beginning of the semester forced the requirement to design the box to the constraints of the already designed portions of the car.

2.3.1 *Frame*

The frame or chassis provides the main size constraint of the pedal box and the total length of adjustability. The pedal box must fit in between the railing of the chassis and adjust along the length as well as stay in the main frame. The figure below shows the designed and built chassis for the REV team's car.



Figure 1: Chassis constraint for pedal box (Photo by: Brendan Waterman)

In adjusting the pedal box along the frame, the box must be able to be supported by the frame and be attached to the frame at different locations without compromising the structural component of the frame. The frame must be able to take the force applied to the pedals on the pedal box dependent on the location of the pedal box

and force angle. Also there must be space between the pedal box and the seat in the frame, so the driver may fit in the car and use the brake and accelerator. The pedals must also be positioned so that the driver's body and feet fit within the mainframe of the car.

2.3.2 *Brake System*

The brake system has an imperative relation with the pedal box. The two required master cylinders for the brakes have to be housed in the pedal box and maintain the required connections with the brake system. The master cylinders are necessary to determine the amount of pressure on the brake lines connecting all four wheels. The connection between the master cylinders and the rest of the brake system must also be feasible and reliable.

2.3.3 *Accelerator*

The throttle system also affects the construction of the pedal box. The accelerator pedal has connections to the throttle system, which must be mounted on the pedal box. The throttle should be adjustable to the driver's needs based on angle and distance travelled. Also, the pedal should be able to return to the original position when there is no pressure on the pedal from the driver's foot.

2.4 Design Constraints

The main design constraints imposed on the pedal box are the weight and cost limitations provided by the budget of the REV group. A theoretical design is not always plausible to make due to budget constraints and the benefits of the design should be weighted with the cost of constructing the design. Due to a limited budget, the cost of the parts required to make the pedal box must not be exceedingly high. This restricts buying the pedal box configuration from a supplier as any sturdy pedal box with the necessary requirements tends to call for a high price. The cost budget also points to the fact that machining the parts individual would be

the best price option. The weight budget is required to gain points in the design competition. A lower weight car would also allow for increased acceleration and speed of the vehicle and increased manoeuvrability, which would all be beneficial in the dynamic events of the SAE Competition.

3. Literature Review

Design of a pedal box is not a new project; go-karts have been built since the first in 1956 by Art Ingles (Grist, Gidley 2006) with better and more dynamic karts being designed every year. Therefore, when starting this project, it was not necessary to start from scratch but to reference previous designs for a starting basis to build off of. Similar past projects, manufactured pedal boxes, and research papers were all referenced in order to develop a general understanding of the dynamics and individual parts of a pedal box as well as any important aspects to keep in mind during the design stage.

3.1 Overview

The entity of the pedal box consists of a brake pedal on the left side, throttle pedal on the right, and hydraulic cylinders. The current designed pedal boxes on the market work to be competitive in price, weight, and strength as well as be aesthetically pleasing. Examples of some of these pedal boxes are shown in figures 2 and 3.

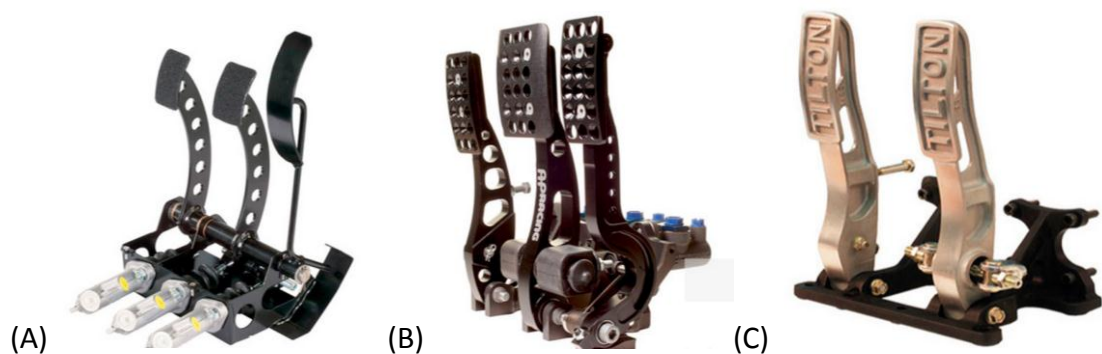


Figure 2: Pedal Box Marketed Examples A (DemonTweeks 2011)

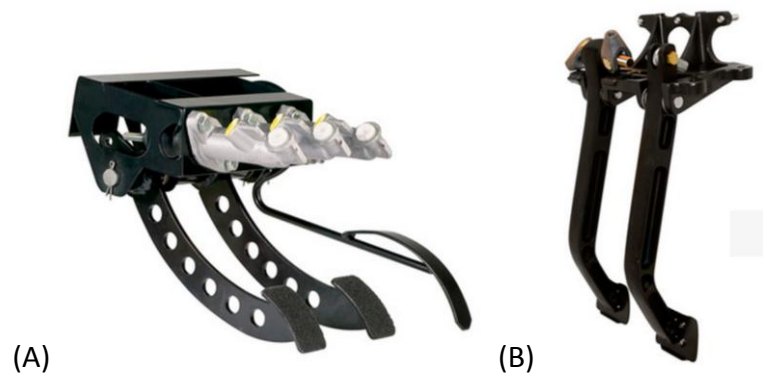


Figure 3: Pedal Box Marketed Examples B (DemonTweeks 2011)

Figure 2, displays pedal boxes which are floor mounted in comparison to those in figure 3, displaying pedal boxes which are top mounted, both which require different connections to the hydraulic cylinders and mounting to the vehicle.

The pedal boxes on the market are made of materials ranging from metal to polymers. There is much research in the area of creating pedals and other automobile components made of composites in order to increase the strength of the pedal and at the same time decreasing the weight. Composites also tend to provide material benefits as high stiffness and corrosion resistance (Sapuan 2011). The decreased weight of the components can help save in the area of fuel consumption for vehicles. A sample polymeric-based composite clutch pedal is shown in figure 4.



Figure 4: Polymeric-based Composite Clutch (Sapuan 2011)

3.2 Master Cylinders

In race cars, it is characteristic that there are two master cylinders, or a dual master cylinder. Advantages to using this type of system includes that the output pressure can be increased and the use of a balance bar between the two cylinders can affect the amount of pressure applied to the front and rear brakes of the vehicle (Oshiro 2010). Typically each master cylinder output applies to two wheels, either the front or the rear wheels of the vehicle. Adjustment of the balance bar as shown in figure 5 causes larger amount of pressure to be put on each master cylinder and therefore harder braking on either the front or rear wheels, depending on the angle of the balance bar.

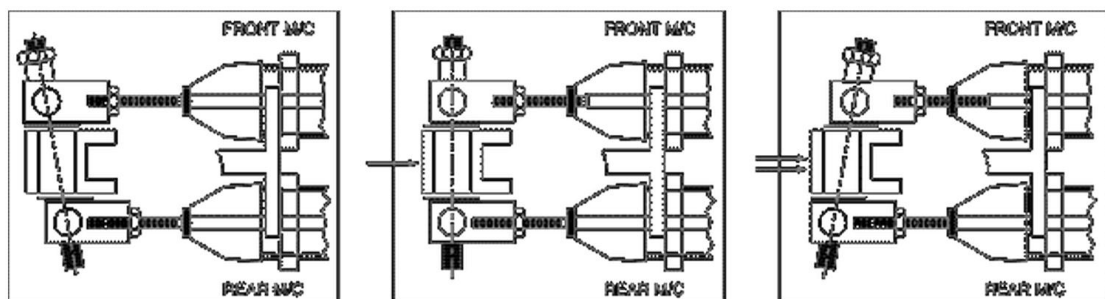


Figure 5: Balance bar Adjustment (Carl's Racing Products 2011)

Placing the balance bar equally between the two cylinders gives equal amount of pressure on both the front and rear wheels.

3.3 Pedal Ratio

The pedal ratio is the most important design factor on the “feel” of the brake pedal. Depending on the set up of the cylinders with respect to the rotation of the pedal, the pedal ratio can be calculated differently. However, for forward mounted horizontal hydraulic cylinders the calculations for the pedal ratio and resulting force is based on simple geometry.

3.3.1 Pedal Ratio Calculations

The pedal ratio for forward mounted cylinders is the distance of the centre of the pedal pad to the pivot point in relation to the distance of the pivot point to the point of push on the master cylinders or x:y (figure 6).

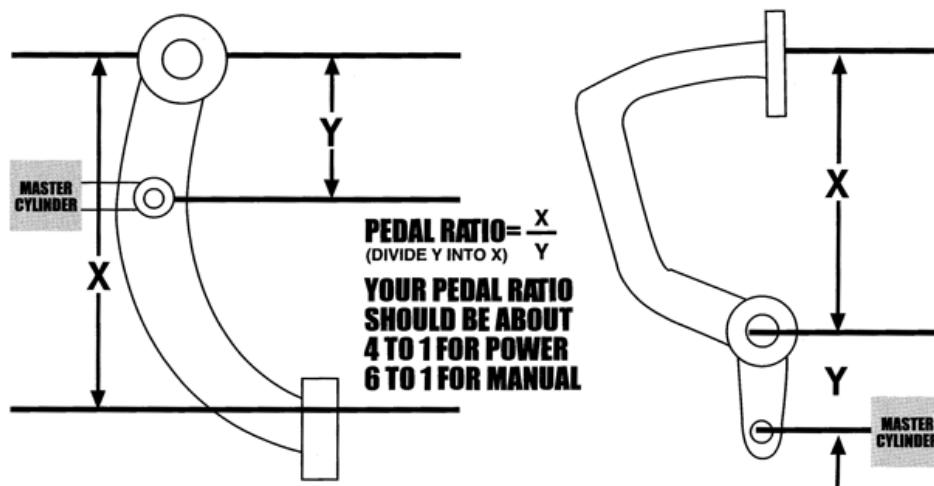


Figure 6: Calculation of the Pedal Ratio (Brake Basics 2011)

Having a higher pedal ratio would increase the effectiveness of the applied force, but would also require a higher pedal travel and poor brake feel (Yabusaki 2011).

3.3.2 Force Calculations

The effectiveness of the force applied is dependent on the pedal ratio of the brake. The effective force can be calculated using the following equation (Oshiro 2010):

$$\text{Force Applied} * \text{Pedal Ratio} = \text{Effective Force} \quad (1)$$

Therefore by increasing the pedal ratio, the actual force applied to the cylinders and therefore the braking system would increase. For typical manual brake systems, the pedal ratio is between 5:1 and 6.5:1, but for power systems a typical ratio of 4:1 to 5:1 is more likely to be seen due to the force conversion relationship (Oshiro 2010).

4. Initial Design Concepts

Before delving into the final design, initial designs were constructed and the benefits of each were weighed with the costs and fall backs of each before determining the final design for the pedal box entity.

4.1 Platform

The platform design needed to be adjustable for different driver heights and needed to be able to take the force applied to the pedals by the driver as well as be able to absorb any exterior forces that may be applied due to an uneven track during driving.

Mounting the platform on the top of the chassis was originally not considered due to the ease of design for a floor based platform as well as the ease of mounting the accessories to the pedal box. The force of gravity on each component would be a major design factor for keeping the components attached firmly to the pedal box. The platform was also chosen to be a floor based platform due to the choice of hydraulic cylinders already provided and it is what the interdependent systems were designed to fit.

Many ideas for the adjustability of the floor based platform were thought of for the pedal box with all the requirements kept in mind. It was initially planned to only have hatched positions for ease of changing the pedal box and no tools required. However, the stability of the pedal box would be compromised in some instances and this was not an option. The stability of the pedal box and the safety of the driver go hand in hand and would not be acceptable for any design to compromise this. Instead, minimal amount of effort to change the position of the pedal box was instead explored. A few design sketches were made for these instances with the pedal box moving along the front of the chassis as seen in figure 7.

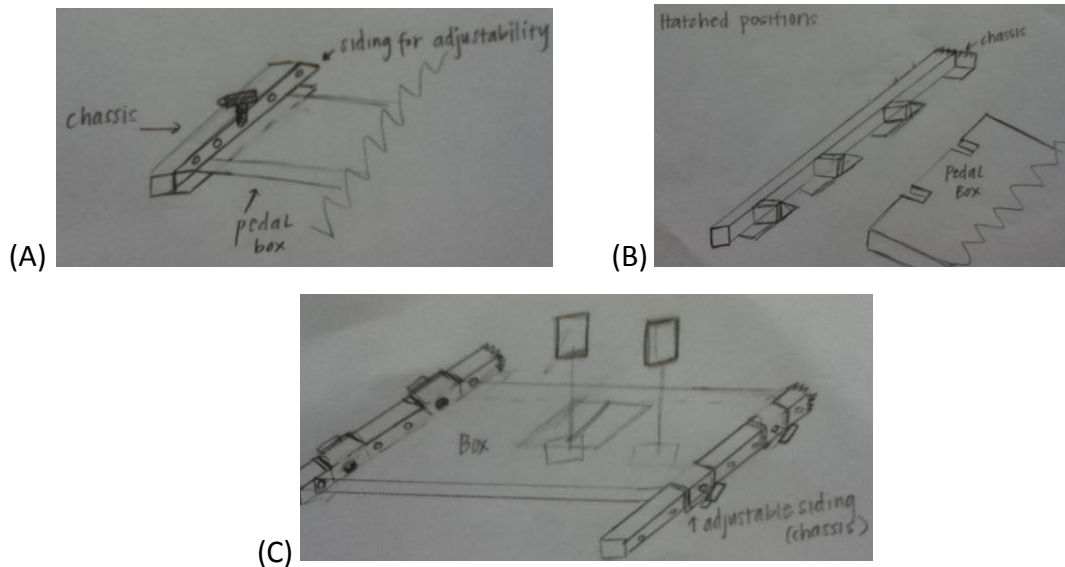


Figure 7: Platform Adjustable Design Examples

With each of the designs, the benefits and costs were analysed along with the problem of drilling holes into the chassis. It was determined through moment analysis that the spacing of the holes at a reasonable distance would not greatly affect the strength or moment inertia of the frame. The cost of added weight of material was not much difference between the designs, but the ease of adjustment between the designs was the biggest factor when choosing the final design.

4.2 Brake

In designing the brake, the pedal itself requires important analysis due to the requirement of stability under a large impact load. Because of the high strength requirement, the design of the whole pedal box then must revolve around the design of the brake pedal and its accessories. In addition to the high structural strength, there is the necessity to be able to function under normal braking loads, which plays into the pedal ratio of the brake, which should also be adjustable to meet the needs of the driver. With the requirements in mind, the brake can be positioned relative to the hydraulic cylinders in a couple of orientations to decrease the weight and size of the pedal box. However, the requirement of interdependence of other systems would also need to be considered.

4.2.1 *Position of Master Cylinders*

Due to the restriction of using the master cylinders that were already provided, the positioning of the cylinders were restricted to how they could be mounted to the frame and the force angle that was needed to apply pressure to the cylinders. This eliminates the possibility of using an angled position to the master cylinders because these cylinders require a spherical bearing mount joint attached to the cylinders, a beneficial design to reduce the length of the pedal box and therefore weight of the box. The master cylinder system used in this design was the MCBTA Twin Master Cylinders with Bias Adjustment as shown in figure 8 and in Appendix A.



Figure 8: Master Cylinders (Dent Engineering 2011)

However, the benefits of a forward mounted master cylinder are that is relatively easy to design and manufacture. Also, the pedal ratio is easily calculated in this assembly and therefore easy to manipulate and adjust for the comfort of different drivers.

4.2.2 *Pedal*

The pedal design is important, especially at the contact point from the foot of the driver, because that is where the most force would be applied. In general, the brake

pedal needed to take a 2000 N force, but needed to also be lightweight for design points. Also, the height of the pedal pad should be about the average height of the length of a male's foot from heel to sole, about 190 cm, but be able to accommodate smaller and larger sized feet. Due to the forward position of the hydraulic cylinders, the connection between the brake and the cylinders was set, except for the adjustability of the pedal ratio. The easiest way to make the ratio adjustable was to add drilled holes within the pedal and have the connection from the pedal to the hydraulic cylinders to be able to vary. However, another option was to make an adjustable balance bar on the cylinders to change the angle of the initial pedal position. An initial design sketch is shown in figure 9.

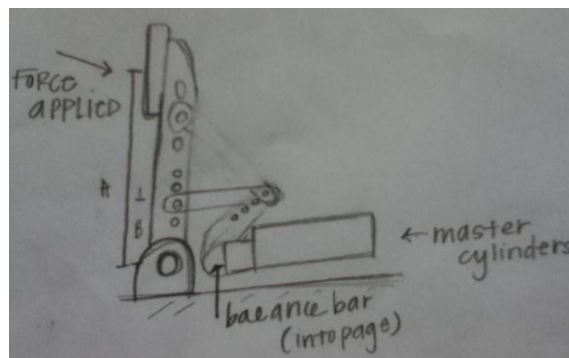


Figure 9: Brake Pedal Initial Design Sketch

4.2.3 Pedal Ratio and Geometry

The ratio and geometry was designed for the comfort of the drivers. The pedal ratio could be calculated using equation ratio of $x:y$. The adjustability of the pedal needed to be in the range of a 6:1 to 4:1 pedal ratio in order for the applied force calculations to be within a reasonable range for the driver to lock all four wheels with the brake pressure. For this to be the case, the adjustability mechanism needed to allow the pedal to rotate between angles to change the height distance from the midpoint of the pedal pad to the pivot point.

4.3 Throttle

The throttle did not have as many restrictions in the requirements as the brake pedal did, and therefore had more options in the type of design. The only requirements were that there would be a forward pedal stop to prevent overstressing the throttle system and that the pedal would return to the initial position with no force being applied to it. The initial design sketches are shown in figure 10, and the final design choice was determined by the amount of weight and stability in the design.

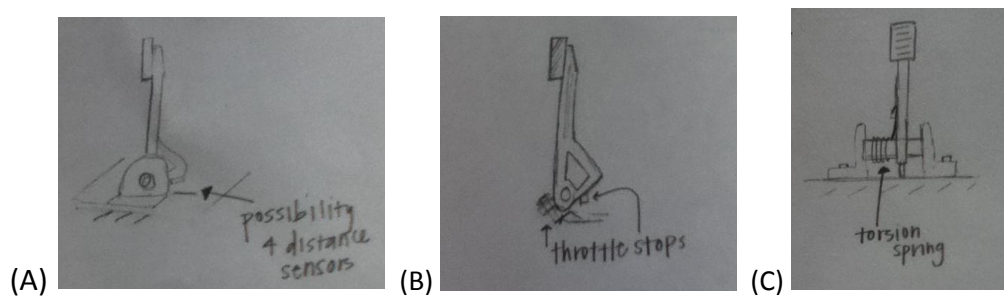


Figure 10: Throttle Pedal Initial Design Sketches

4.3.1 Adjustability

There is no pedal ratio requirement for the throttle, as much less force is expected to be exerted on this portion of the pedal box. Therefore, the adjustment of the throttle was designed to be set at the same angles the brake pedal was in order for there to be symmetry between the two pedals. These angles were determined by basic geometric calculations.

5. Final Design

The final design was created using the 3D CAD modelling system SolidWorks and analysed to determine the weight and force requirements.

5.1 Brake Pedal Final Design

Designed in SolidWorks to take a large amount of applied force as well as applying the pedal ratio requirements, the brake pedal is shown in figure 11.

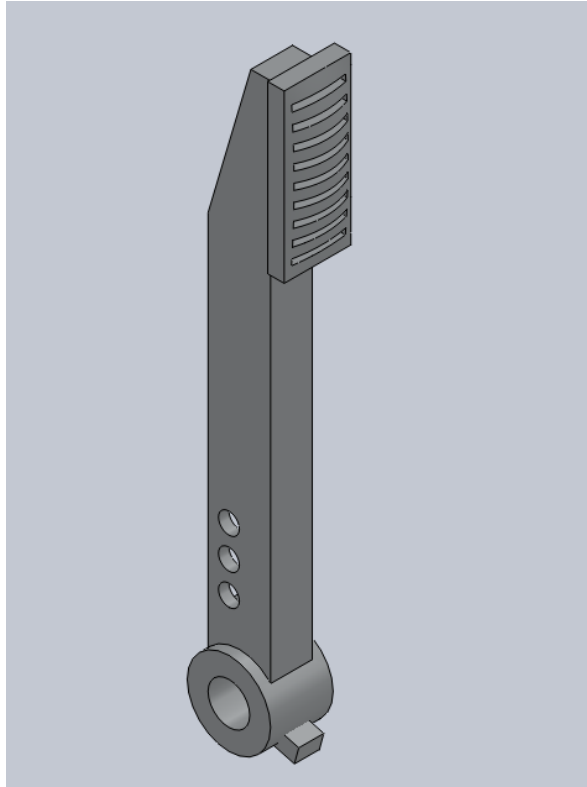


Figure 11: Final Brake Design Isometric View

The master cylinder connection was changed in order to provide greater stability to the system as well as an easier calculated pedal ratio. Based on the final design, the pedal ratios for the brake pedal range from about 6:1 to 4:1, which was what was required.

5.2 Throttle Final Design

Initially, the throttle final design was created on SolidWorks and was as seen in figure 12. However, the manufacturing of this part, and the amount of material for this part seemed excessive for the minimal amount of requirements placed on the throttle pedal.

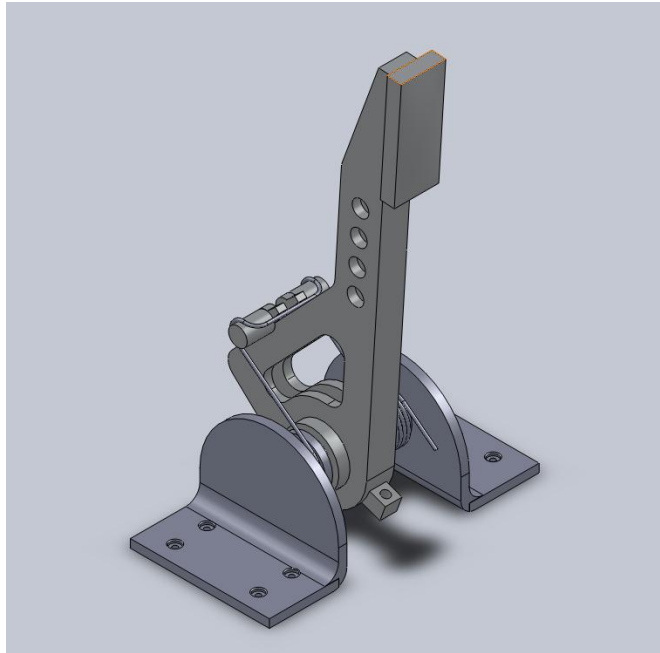


Figure 12: Initial Throttle Design Isometric View

Instead a simpler design approach was taken, with the same general idea, just with less material and a few different connections with the return spring and pedal. This simpler design is shown in figure 13 and holds the same pedal angle requirements as the initial design and the brake pedal. The support connects the throttle pedal to the front of the pedal box along which the brake pedal will also be positioned.

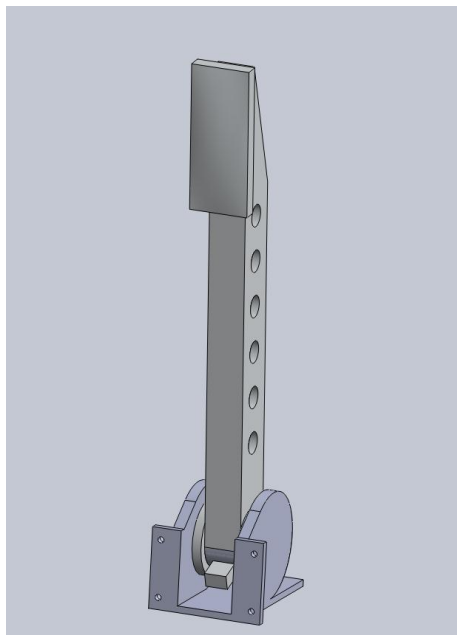


Figure 13: Throttle Design Isometric View

5.3 Pedal Box Final Design

The adjustable design from figure 7 (c) was implemented for the ease of transfer with not much added weight to the chassis or pedal box unit. The pedal box unit design is shown in figure 14 without the master cylinders.

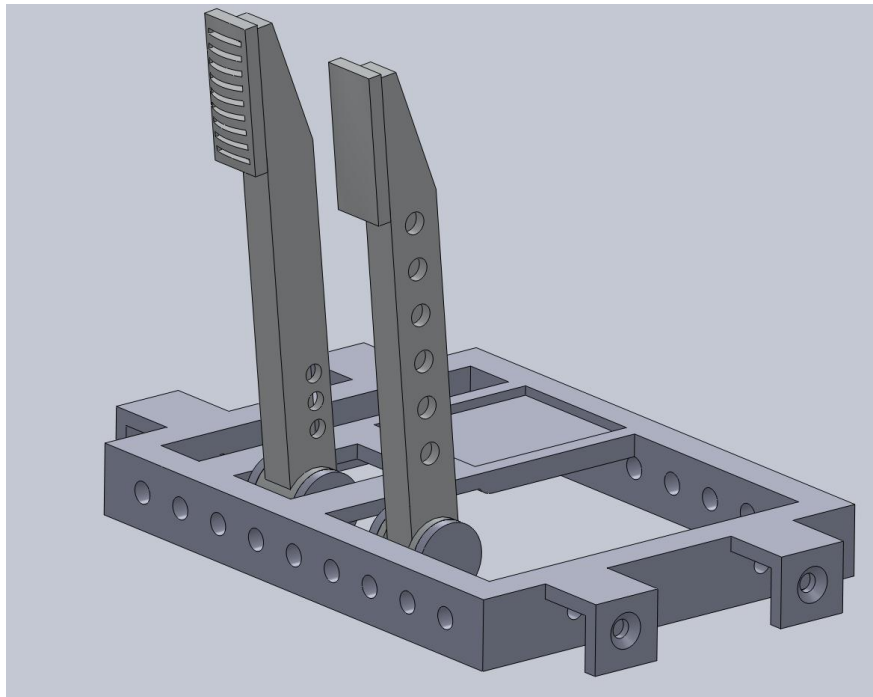


Figure 14: Final Pedal Box Design

6. Discussion

The final design of the pedal box was able to in the end meet the desired functional, size, design, and rule requirements of the system. Since the REV team decided to not compete in the competition this year, the pedal box was not constructed.

Implementing the design into construction could yield a different result, depending on which method was used to manufacture. The built system might encounter more problems with clearance or connections between the brackets and the pedals might cause more instability than which was assumed to be stable in SolidWorks, and this concern is likely applied to the return spring connections. In order to decrease the amount of instability that could be present in the construction of the actual parts, it would be necessary to have accurate manufacturing of the parts.

As with any design, there were obstacles to overcome when implementing the design. Initially, without any basic knowledge of pedal boxes or much about manufacturing and design process, it can seem daunting to design an entire pedal box. Much tedious research was required in order to reach a required level of understanding of the requirements and design of the pedal box. However, during the design process, one problem encountered when designing the pedal box included determining how to make each pedal adjustable, yet stable. It would be interesting to decide whether this adjustable bonus is worth the added instability of the mechanism for a little increased comfort of the driver. Instead one could review the angle of the pedal mechanism which fits the team the best and design to the team's needs. The added weight and more opportunities for failure of the mechanism may not be balanced with the small increased comfort of the driver in the car.

Another point of interest to look into is the interdependence of the pedal box with the other systems as outlined in the requirements chapter. As the other designs are built, the pedal box design should be compatible to these designs and may require slight adjustments in order for connections of the throttle sensors or master cylinders to work. In this manner, the final design of the pedal box will probably be adjusted for next year's car design in order to comply with the systems necessary.

For future work, the pedal box can be further developed for decreased weight through further analysis of the system to determine a different material to construct the pedal box with such as the polymer-based composites or a similar low density material. Also, use of an angle-mounted master cylinder would further to decrease the size of the pedal box length allowing for decreased weight, but would require further and a more detailed analysis in order to determine the pedal ratio for the brake pedal.

7. Conclusion

In this project, the pedal box entity was carefully researched by viewing previous designs, patents, past research, and current manufactured products. The knowledge was then applied and combined in order to design a pedal box to fit the Formula SAE requirements. The set requirements of function, design, and rules were met in the final design. However, it is likely that this design may be used to base the actual design for the kart in the competition in order to shape the pedal box to fit the systems of the developing kart for next year's competition.

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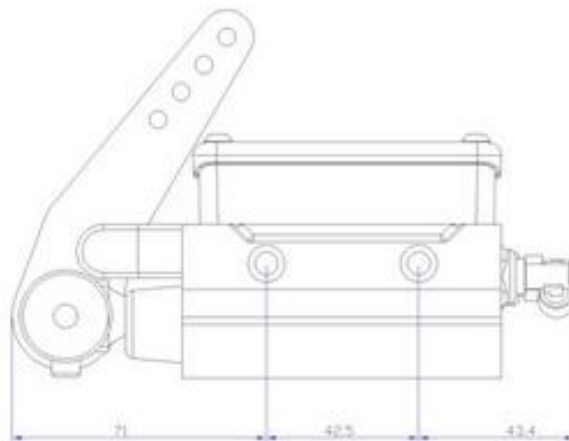
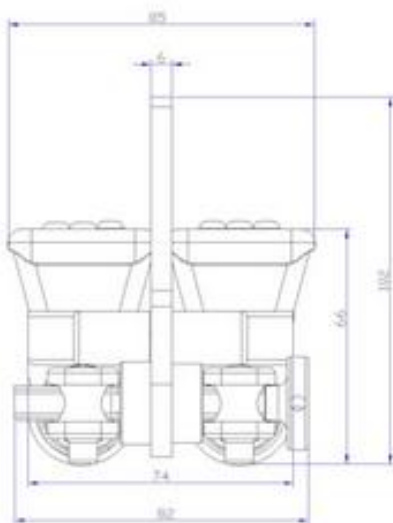
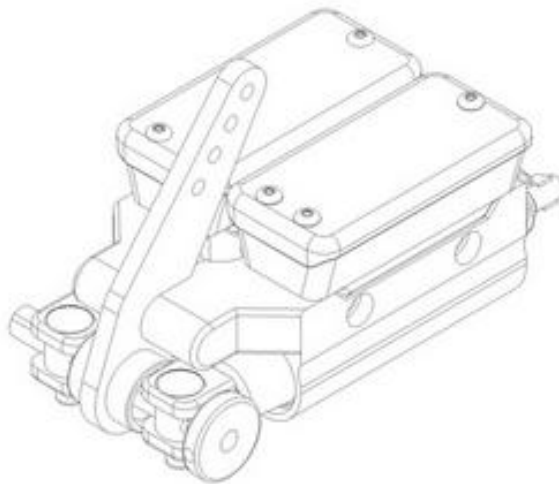
APPENDIX A

MCBTA



Twin Master Cylinder with Bias Adjust

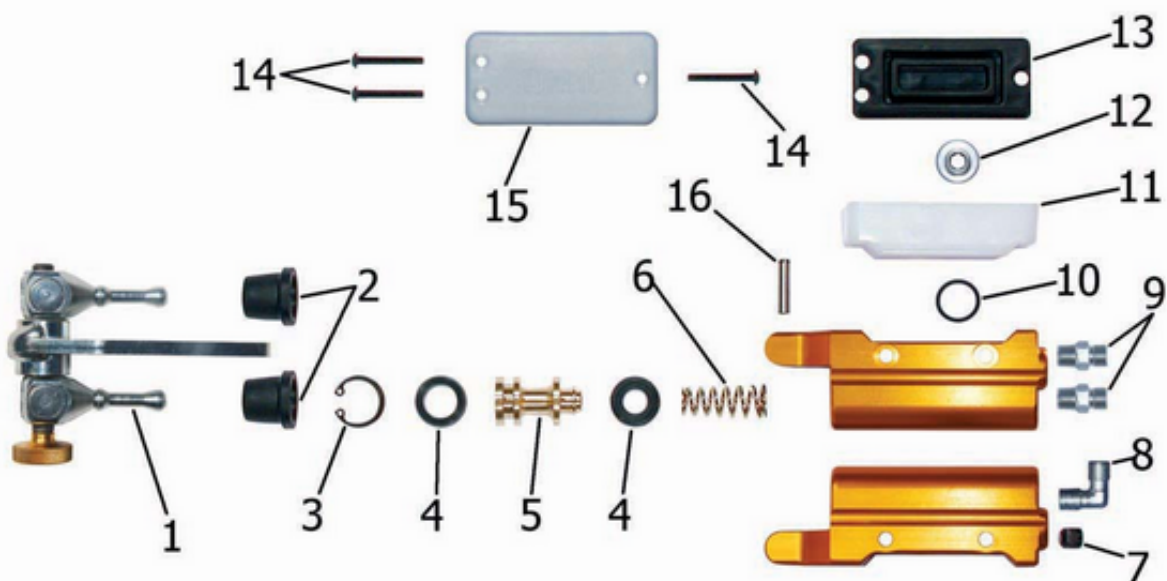
Dimensions



Master Cylinder Options - Part Numbers

Anodized Gold, with Fittings for Nylon Line.	MCBTA-GN
Anodized Gold, with Fittings for Braided Line.	MCBTA-GB
Anodized Black, with Fittings for Nylon Line.	MCBTA-BN
Anodized Black, with Fittings for Braided Line.	MCBTA-BB

Spares - Part Numbers



Ref. No.	Product Code	Description
1	MCBTA-L ASSEM	MCBTA LEVER ASSEMBLY
2	MCBA-DB	DUST BOOT FOR MCBTA
3	MCBA-C22	22MM INTERNAL CIRCLIP
4	SK07	SEAL KIT FOR MCBTA
5	MCBA-P	MASTER CYLINDER PISTON
6	SP1.6-37	MASTER CYLINDER PISTON SPRING
7	GS1/8BSPT	1/8 BSPT GRUB SCREW
8	FN-90	90 DEGREE NYLON FITTING
8	FB-90	90 DEGREE BRAIDED FITTING
9	FN-S	STRAIGHT NYLON FITTING
9	FB-S	STRAIGHT BRAIDED FITTING
10	OR16	O-RING FOR MASTER CYLINDER RESERVOIR
11	MCBA-RES	RESERVOIR FOR MCBTA
12	MCBA-RB	RESERVOIR BUNG
13	MCBA-DIA	DIAPHRAM FOR MCBTA
14	BH430	M4 X 30 BHCS
15	MCBA-CAPW	WHITE MASTER CYLINDER CAP
15	MCBA-CAPB	BLACK MASTER CYLINDER CAP
16	DL625	M6 X 25 DOWEL PIN