Adaptability of Braking System of MPV-1

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EXAMINATION COMMITTEE

We hereby recommend that the dissertation prepared under our supervision by Saad Munir, Syed Usama Mutahir and Mowiz Cheema with Registration Numbers: NUST2012-01922, NUST2012-00674 and NUST2012-00284 respectively. Titled: “Adaptability of Braking System of MPV-1” be accepted in partial fulfillment of the requirements for the award of BE Mechanical Engineering degree with (___ grade).

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DECLARATION

We certify that this research work titled "*Adaptability of Braking System of MPV-1"* is our work. The work has not been presented elsewhere for assessment. The material that has been used from other sources has been properly acknowledged/referred.

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Abstract

A new vehicle named as “MPV-1 (Multi-Purpose Vehicle-1)” is to be made and launched in the automobile market of Pakistan. MPV-1 is a two seater passenger car targeted for the middle class people of Pakistan and therefore, needs to be cost-effective. Our project is to adapt to an appropriate working braking system for MPV-1 that meets its requirements, easily available in the market and is of lower costs.

In order to accomplish this, first of all, we established the requirements of the braking system for MPV-1 that were braking distance and braking deceleration. We then performed out the necessary calculations of braking forces, dynamic weight transfer, skidding forces, pedal force, braking torque, hydraulic pressure, master cylinder bore size and wheel cylinder bore size. We then selected appropriate parts from the market like master cylinder, disc rotors, brake drums etc. that fulfilled our requirements and gave the desired calculated values of the braking forces and hydraulic pressure. While selecting these parts, we ensured that they were easily available in the market and of reasonable price.

After that, we integrated our selected parts and assembled them to make the prototype for the braking system of MPV-1. We experimentally tested our prototype in two ways. Firstly, we practically achieved hydraulic pressure of 35 bars in our model whereas the theoretical hydraulic pressure was 42.4 bars. Secondly, we stopped a rotating shaft by applying the brakes of our prototype.

Keywords: MPV-1, braking system, adaptability, cost-effective, braking distance, hydraulic pressure

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ABBREVIATIONS USED

MPV-1	Multi-Purpose Vehicle-1
μ	Coefficient of Friction between road and tyre / brake shoe and brake drum
m	Mass of Vehicle
g	Gravitational Acceleration of $9.81ms^{-2}$
d	Braking Distance
V	Top Speed of MPV-1 which is 70km/h
η	Braking Efficiency
$\mathbf{F_b}$	Braking Force
$\mathbf{W_{dynamic,front}}$	Dynamic Weight on Front Tyre
$\mathbf{C_{f,tyre}}$	Coefficient of Friction between tyre and road
$\mathbf{r_{wheel}}$	Radius of wheel of MPV-1
$\mathbf{F_{braking}}$	Braking Force
a	Braking Deceleration
$\mathbf{W_{front}}$	Dynamic Weight on Front Axle
$\mathbf{W_{rear}}$	Dynamic Weight on Rear Axle
$\mathbf{C_{f,pad}}$	Coefficient of Friction between brake pad and disc rotor
$\mathbf{F_e}$	Hydraulic force on Wheel Cylinder Piston
$\mathbf{r_{drum}}$	Radius of Brake Drum

CHAPTER 1

1. INTRODUCTION

1.1 What is MPV-1

MPV-1 (Multi-Purpose Vehicle-1) is a new vehicle that is to be made and launched in the automobile market of Pakistan. MPV-1 will be a two-seater passenger car targeted for the middle class people of Pakistan and therefore, it needs to be cost-effective. The whole project of MPV-1 is divided into smaller sub-projects like adaptability of braking system of MPV-1, steering system of MPV-1, engine of MPV-1 etc. These sub-projects are assigned to final year undergraduate students from various Pakistani universities like NUST and NED etc. In the year 2015-2016, NUST SMME has been assigned the responsibility of making the chassis, steering, suspension and braking system of MPV-1 and these projects were allocated as Final Year Projects to several final year undergraduate students. In the end, all of these various sub-projects will be integrated with each other to make one final product that is MPV-1

1.2 Project Description

We have been given a task i.e. adapting an appropriate working braking system for MPV-1 whose parts are easily accessible from the market with lower costs. Two design parameters were given to us which were MPV-1's gross mass of 750 kg and braking distance of 5m. When we cross-checked the second parameter (braking distance of 5m), a parameter known as braking efficiency came out to be 550% which is impossible because braking efficiency cannot be greater than 100%. Therefore, we had to establish the other design parameters except gross mass of 750 kg ourselves and the established design parameters were braking efficiency of 80%, braking deceleration of 7.848 ms^{-2} and braking distance of 34.41m.

1.3 Project Approach

- After establishing the design parameters as discussed before, we studied the types of braking systems available and analyzed them for MPV-1.
- We then selected hydraulic brake system for MPV-1 with disc brakes on the front and drum brakes on the rear. The reason for this selection has been explained later.

- Then, we performed out the design calculations of dynamic weight transfer, braking forces, skidding forces, pedal force, braking torque, hydraulic pressure, master cylinder bore size, pedal ratio and wheel cylinder bore size.
- Next, we selected appropriate parts from the market with the required dimensions that produce the desired values of hydraulic pressure, braking forces, braking distance and deceleration.
- We ensured that the parts selected can easily be fitted onto the chassis of MPV-1 and are easily accessible from the market at reasonable price.
- Finally, we integrated the parts with each other and assembled them to make a prototype of the braking system for MPV-1.

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CHAPTER 2

2. LITERATURE REVIEW

To make an efficient braking system for MPV-1, we needed to have a strong background and pre-requisite knowledge about brakes, the types of brakes, certain mathematical and physical concepts. Therefore, an extensive literature review was carried out, and various books and articles were consulted.

2.1 Brake

A brake is a mechanical device that inhibits motion by absorbing energy from a moving system. It is used for slowing or stopping a moving vehicle, wheel, axle, or to prevent its motion, most often accomplished by means of friction.

2.2 Background of Brakes

Most brakes commonly use friction between two surfaces pressed together to convert the kinetic energy of the moving object into heat, though other methods of energy conversion may be employed. For example, regenerative braking converts much of the energy to electrical energy, which may be stored for later use. Other methods convert kinetic energy into potential energy in such stored forms as pressurized air or pressurized oil. Eddy current brakes use magnetic fields to convert kinetic energy into electric current in the brake disc, fin, or rail, which is converted into heat. Still other braking methods even transform kinetic energy into different forms, for example by transferring the energy to a rotating flywheel.

2.3 Types of Braking Systems for Automobile

There are two major types of braking systems such as:

- Air Brake System that is primarily used in large heavy vehicles, particularly those having multiple trailers which must be linked into the brake system, such as trucks, buses, trailers, and semi-trailers in addition to their use in railroad trains.
- Hydraulic Brake System that is primarily used in passenger vehicles.

2.4 Air Brakes

Air brakes are the most common brakes in heavy duty vehicles like trucks and buses. Air is everywhere but hydraulic fluid isn't. Trains, buses and tractor trailers use air brakes so that they don't have to rely on the hydraulic fluid in car braking system which can run out in the event of a leak. The most common is triple valve system which includes charging air into air tank ready to be used, applying the brakes and releasing them.

2.5 Components of an Air Brake System

Components of an air brake system are:

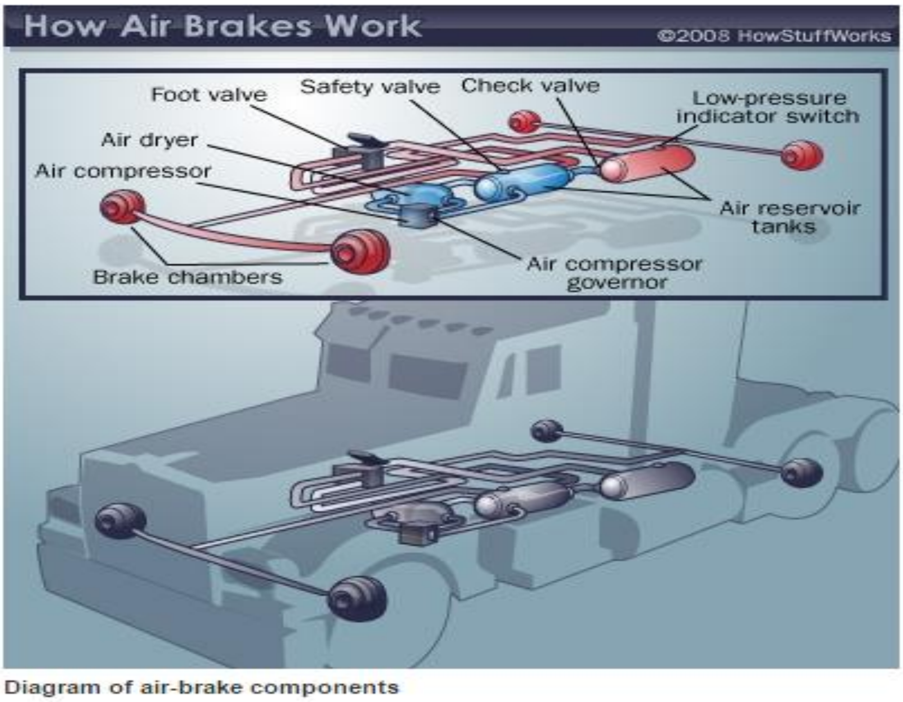

Figure 2.1: Components of an Air Brake System

- **Air compressor:** Pumps the air into storage tanks to be used in the brake system.
- **Air compressor governor:** Controls the cut in and cut out point of the air compressor to maintain a set amount of air in the tanks.
- **Drain valves:** Release valves in the air tanks used to drain the air when the vehicle isn't in use.
- **Foot valve (brake pedal):** When depressed, air is released from the reservoir tanks.
- **Brake chambers:** Cylindrical container that houses a slack adjuster that moves a cam mechanism.

- **Push rod:** A steel rod similar to a piston that connects the brake chamber to the slack adjuster. When depressed, the brakes are released. If extended, the brakes are applied.
- **Slack adjusters:** An arm that connects the push rod to the brake s-cam to adjust the distance between the brake shoes.
- **Brake s-cam:** An s shaped cam that pushes brake shoes apart and against the brake drum.
- **Brake shoe:** Steel mechanism with a lining that causes friction against the brake drum.

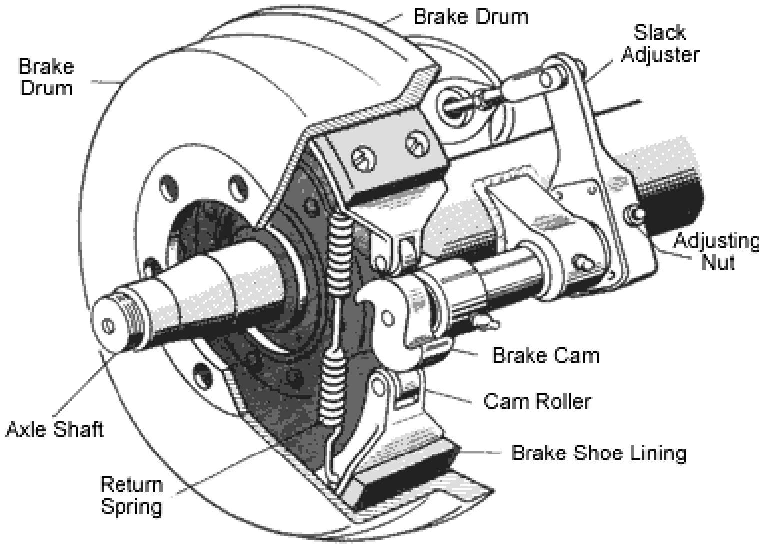

Figure 2.2: Brake Drum of an Air Brake System

2.6 Hydraulic Brakes

The principle behind hydraulic braking system is simple: braking force that is applied at one point i.e. at the brake pedal is transmitted to other point i.e. at brake pads by means of an incompressible fluid. The initial force is multiplied during the process and the amount of multiplication can be found by comparing the sizes of the pistons. For example the size of the piston driving the fluid is smaller than the pistons operating the brake pads therefore the force is multiplied helping you to brake easily and more efficiently. The hydraulic brake uses brake fluid, typically containing ethylene glycol, to transfer pressure from the controlling mechanism to the braking mechanism

2.7 Components of Hydraulic Brake System

The main components in a hydraulic brake system are:

2.7.1 Brake Pedal

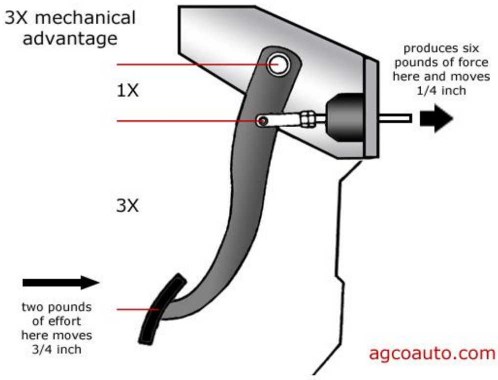

Figure 2.3: Brake Pedal and Pedal Ratio

A driver applies his leg force through the brake pedal. A brake pedal has pedal ratio which is defined as the ratio of the length from the pivot point (3X as shown in the diagram) to the length from the pivot point to the master cylinder pushrod (1X as shown in the diagram). The pedal ratio provides mechanical advantage and amplifies the driver's leg force. For example, if the driver's leg force is 2 pounds and the pedal ratio is 3, the force at the master cylinder will be 6 pounds.

2.7.2 Master Cylinder

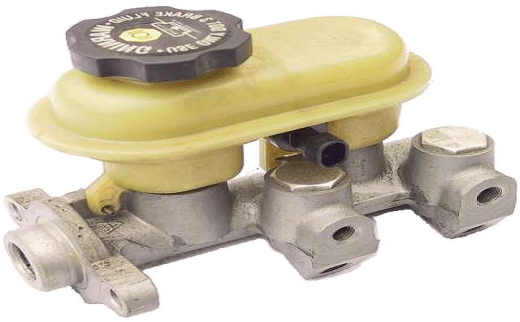

Figure 2.4: Master Cylinder

The master cylinder converts the mechanical force exerted by driver into hydraulic force. There are pistons inside the master cylinder that moves along the bore of the master cylinder when the driver applies force. This forces the hydraulic fluid to flow from the fluid reservoir towards the brake rotors or drums.

2.7.3 Dual Chamber Master Cylinder

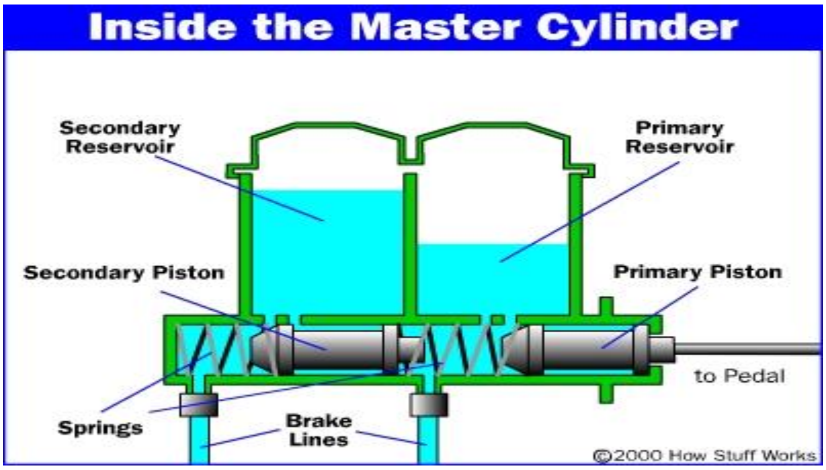

Figure 2.5: Dual Chamber Master Cylinder

A dual chamber master cylinder has two separate hydraulic fluid reservoirs called primary and secondary reservoirs with their corresponding primary and secondary pistons. The primary reservoir is for the front brakes and the secondary reservoir is for the rear brakes. These two circuits are independent of each other. In case, if the front brakes fail, the rear brakes will still function from the secondary circuit and in case, if the rear brakes fail, the front brakes will still function from the primary circuit. Therefore, there is greater safety in using a dual chamber master cylinder.

2.7.4 Hydraulic Brake Lines

Figure 2.6: Hydraulic Brake Lines

Hydraulic Brake lines carry the hydraulic fluid from master cylinder to the front brakes and rear brakes that maybe either disc or drum brakes.

2.7.5 Drum Brakes

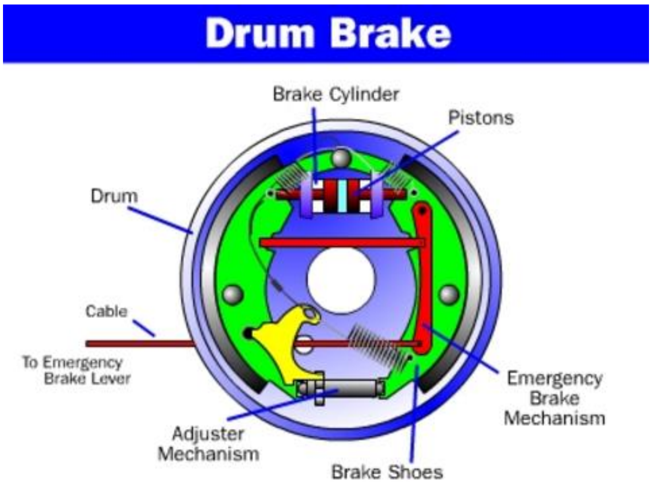

Figure 2.7: Drum Brakes

A drum brake is a brake that uses friction caused by a set of shoes that press outwards against a rotating cylinder-shaped part called a brake drum. Early automotive brake systems after the era of hand levers used a drum design at all four wheels. The basic design provided capable under most circumstances but had one major flaw. Under high braking conditions, drum brakes would often fade and lose effectiveness. Usually, this fading was often the result of too much heat buildup within the drum. For this reason, drum brakes can only operate as long as they can absorb the heat by slowing a vehicle's wheels. Once the brake components become themselves saturated with heat, they lose the ability to halt a vehicle.

2.7.6 Disc Brakes

Figure 2.8: Disc Brakes

A disc brake is a type of brake that uses calipers to squeeze pairs of pads against a disc in order to create friction that retards the rotation of a shaft, such as a vehicle axle, either to reduce its rotational speed or to hold it stationary. The energy of motion is converted into waste heat which must be dispersed.

2.7.7 Comparison of Disc and Drum Brakes

Unlike drum brakes, which allow heat to build up inside the drum during heavy braking, the rotor in disc brake is fully exposed to the outside air. This exposure constantly works to cool the rotor, greatly reducing its tendency to overheat or cause fading. Disc brakes also recover more quickly from immersion (wet brakes are less effective than dry ones).Since the majority of a vehicle’s stopping power is contained in the front wheels between 60 and 90 percent, most of the medium priced vehicles use disc brakes only on the front wheels and combined with this fact, it is clear that a well-designed, modern drum brake is all that’s required for most rear wheel brake duty.

2.7.8 Brake Calipers

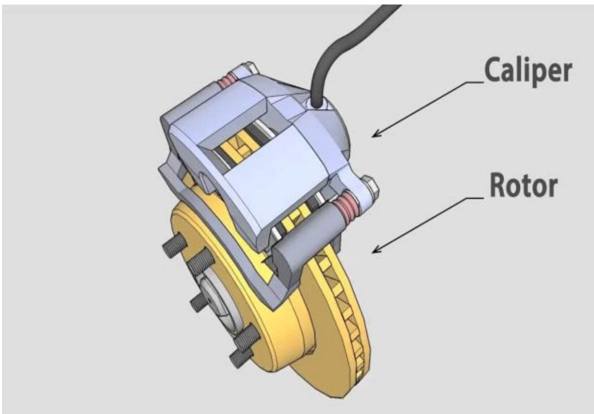

Figure 2.9: Brake Caliper

The brake caliper fits over the rotor in a disc rotor like a clamp as shown in the diagram. Inside each caliper is a pair of metal plates bonded with friction material-these are called brake pads. The outboard brake pads are on the outside of the rotors (toward the curb) and the inboard brake pads on the inside (toward the vehicle). When you step on the brake, brake fluid from the master cylinder creates hydraulic pressure on one or more pistons in the brake caliper, forcing the pads against the rotor. The brake pads have high-friction surfaces and serve to slow the rotor down or even bring it to a complete halt. When the rotor slows or stops, so does the wheel, because they're attached to one another.

2.7.9 Types of Brake Calipers

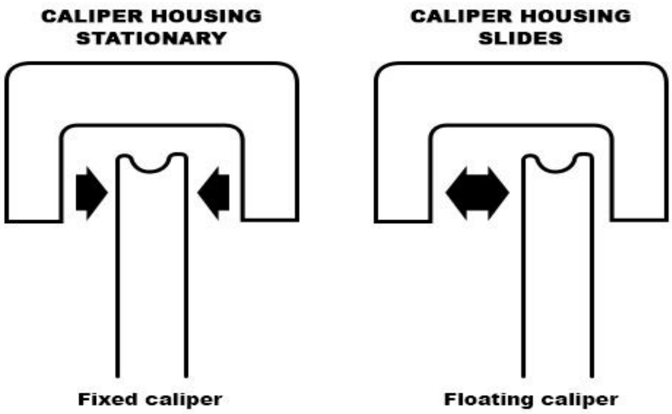

Figure 2.10: Fixed and Floating Brake Caliper

There are two main types of calipers: floating (or sliding) calipers and fixed calipers. Floating calipers move in and out relative to the rotor and have one or two pistons only on the inboard side of the rotor. This piston pushes the entire caliper when the brakes are applied, creating friction from the brake pads on both sides of the rotor. Fixed calipers, as the name implies, don't move, but rather have pistons arranged on opposing sides of the rotor. Fixed calipers are generally preferred for their performance, but are more expensive than the floating kind. Some high-performance fixed calipers have two or more pairs of pistons (or "pots") arranged on each side of the rotor -- some have as many as six pairs total.

2.7.10 Brake Pads

Figure 2.11: Brake Pads

Brake pads are a component of disc brakes used in automotive and other applications. Brake pads are steel backing plates with friction material bound to the surface that faces the disc brake rotor. Brake pads convert the kinetic energy of the car to thermal energy by friction. Two brake pads are contained in the brake caliper with their friction surfaces facing the rotor. When the brakes are hydraulically applied, the caliper clamps or squeezes the two pads together into the spinning rotor to slow/stop the vehicle. When a brake pad is heated by contact with a rotor, it transfers small amounts of friction material to the disc, turning it dull gray. The brake pad and disc (both now with friction material), then "stick" to each other, providing the friction that stops the vehicle.

2.7.11 Types of Brake Pads

1. Semi metallic brake pads: They have coefficient of friction 0.28-0.38. They have 30% to 65% metal like copper or silver.
2. Non-asbestos organic (NAO) pads: They have coefficient of friction 0.33-0.40.They are less noisy, softer pedal but creates lots of dust. On the contrary, they have less cooling effect.
3. Low metallic non-asbestos organic pads: Organic mixture with small amounts of copper or steel to increase heat transfer and braking. Coefficient of friction 0.38-0.50
4. Ceramic Brake Pads: Coefficient of friction 0.45-0.55

2.8 Pros and Cons of Ceramic Brake Pads

Pros:

- Quieter
- Cleaner
- Durable (not to be replaced frequently)

Cons:

- Do not perform well in cold weather.
- More wear on brake rotor.
- Less cooling of brake rotor than metallic.
- More expensive
- Not function well on in town trips where frequents stops and starts are required.

2.9 Pros and Cons of Metallic Brake Pads

Pros:

- Cheap
- Work well in cold weather.
- Best for in town trips where frequents starts and stops are required.
- Lesser wear on rotor.
- More cooling effect of rotor.

Cons:

- Not durable (need to be replaced frequently)
- Create noise
- Create dust

2.10 Vacuum Booster

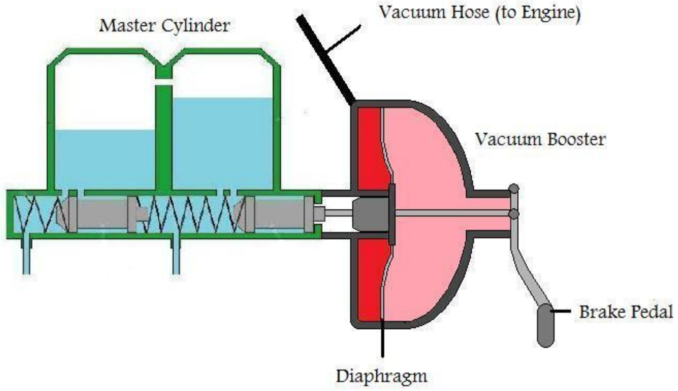

Figure 2.12: Vacuum Booster

A Vacuum Booster also known as a power booster or power brake unit uses a vacuum to multiply the drivers pedal effort and apply that effort to the master cylinder.

The vacuum can be generated in two distinct methods, dependent on the type of internal combustion engine, or other motive force (as in electric vehicles). In naturally-aspirated petrol engines, the manifold vacuum is used, whereas in turbo charged, diesel engines, and electric/hybrid vehicles a separate vacuum pump is used (or in certain high altitude places, naturally-aspirated vehicles are not capable of producing enough vacuum for the booster. The vacuum pump can be driven mechanically (from the engine) or by means of an electric motor. The vacuum is transferred to the servo along non-collapsible vacuum lines, and is stored in the servo by using a non-return valve.

2.11 Braking Efficiency

Braking efficiency is defined as "The deceleration as a percentage of gravity". The maximum braking deceleration that a car can achieve is g (9.81 ms^{-2}).Braking efficiency of 100% is not desirable because it will make the stopping distance and stopping time too short that it can be dangerous for the passengers because the chances of collisions would be too high.

Brake Efficiency	Braking Quality
30%	Very poor
50%	Fair
70%	Good
80% to 100%	Excellent

Table 2.1: Typical Ranges of Braking Efficiency

CHAPTER 3

3. BASIC CALCULATIONS

3.1 Given Design Parameters

The following design parameters were given to us:

Gross Mass	750 kg
Braking Distance	5m
Top Speed	70 km/h

Table 3-1: Given Design Parameters for MPV-1

3.2 Cross Checking Given Braking Distance

We performed a series of calculations shown below to verify the given braking distance of 5m.

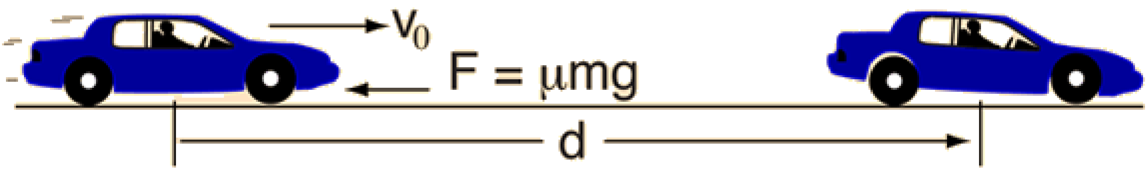

Figure 3.1: Braking Force and Stopping Distance

- Work Done by Frictional Force = Loss in Kinetic energy of the car
- Work of Friction = $\mu mgd = (1/2)mv^2$
- So the ideal stopping distance is:
- $d = V^2/(2\mu g)$
- Taking into account the brake efficiency the actual stopping distance is:
- $d = V^2/(2\mu g\eta)$ where η is brake efficiency
- Or, the brake efficiency η is $2\mu gd/V^2$

The values of every parameter and the calculated braking efficiency are shown in the table below:

Velocity (V)	70 km/h
Coefficient of friction (μ)	0.7
Gravitational field strength (g)	9.81 N/kg
Braking Distance	5m
Braking Efficiency	550%

Table 3-2: Calculated Braking Efficiency for the Given Design Parameters

We get braking efficiency of 550% which is impossible for a car to have since the maximum theoretical value of braking efficiency is 100%. Therefore, we had to re-establish the braking distance.

3.3 Modifying the Braking Distance

Consulting this table from Brake Design and Safety 3rd Edition Book

Brake Efficiency	Braking Quality
30%	Very poor
50%	Fair
70%	Good
80% to 100%	Excellent

Table 3-3: Typical Ranges of Braking Efficiency

We selected braking efficiency of 80% which shows excellent braking performance and we did not choose braking efficiency close to 100% because it would reduce the stopping distance and stopping time so much that it would be dangerous for the driver to apply the brakes because the chances of collisions would be too high.

Repeating the calculations, we got the final results:

Velocity (V)	70 km/h
Coefficient of friction (µ)	0.7
Gravitational field strength (g)	9.81 N/kg
Brake Efficiency	80%
Ideal Stopping Distance	27.53m
Actual Stopping Distance	34.41m

Table 3.4: Calculation of the New Braking Distance

Hence, our braking distance was modified to 34.41m.

3.4 Dynamic Weight Transfer

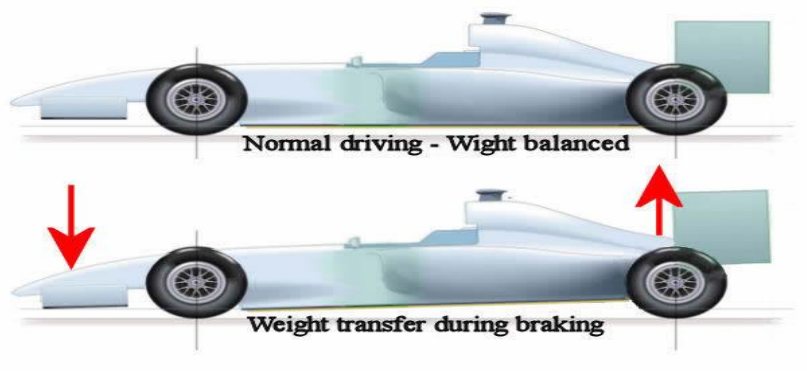

Figure 3.2: Dynamic Weight Transfer

- During braking, the weight of a vehicle is shifted from front side to rear side due to inertia
- The dynamic weight transfer is given by Dynamic Weight transfer = (Weight of Vehicle * Deceleration* Height of CG)/Wheelbase
- Hence, Dynamic Weight on Front Axle= Static Weight on Front Axle+ Dynamic Weight Transfer
- And, Dynamic Weight on Rear Axle= Static Weight on Rear Axle - Dynamic Weight Transfer

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The numerical value of each parameter in the equations stated above and the final results are shown in the table below:

Weight of Vehicle	7357.5 N
Deceleration	7.848 ms^{-2}
Height of Center of Gravity	0.4m
Wheelbase	1.6m
Static Weight on Front Axle	4414.5 N
Static Weight on Rear Axle	2943 N
Dynamic Weight Transfer	1471.5 N
Dynamic Weight on Front Axle	5886 N
Dynamic Weight on Rear Axle	1471.5 N

Table 3.5: Calculated Dynamic Weights on Front and Rear Axles

3.5 Braking Forces

- Work done by braking force = Loss in Kinetic energy of the car
- $F_b\, d = (1/2)mv^2$

Dynamic Mass on Front Tyre	300 kg
Dynamic Mass on Rear Tyre	75 kg
Braking Force on Front Tyre	1648.2 N
Braking Force on Rear Tyre	412 N

Table 3.6: Calculated Braking Forces on Front and Rear Tyres

3.6 Car Skidding Forces

Figure 3.3: Skidding in car

- A car will skid when the braking force is greater than the skidding force.
- The skidding force is defined as Skidding Force = μN.
- In this equation, μ is the dry road adhesion factor defined by the European Council and N is the reaction force on the tyre which is equal to the weight of the tyre i.e. N=mg.
- Substituting the values gives the following results:

Dry Road Adhesion Factor by European Council (μ)	1
Skidding Force on Front Tyre (μN where N=mg)	2943 N
Skidding Force on Rear Tyre (μN where N=mg)	736 N

Table 3.7: Calculated Skidding Forces on Front and Rear Tyres

- The skidding force on front tyre is greater than the skidding force on rear tyre because the dynamic mass on front tyre is 300 kg while the dynamic mass on rear tyre is 75 kg only.
- The braking force on front tyre is 1648.2 N and its skidding force is 2943 N, therefore the front tyre will not skid.
- The braking force on rear tyre is 412 N and its skidding force is 736 N, therefore the rear tyre will also not skid.
- Since both the calculated braking forces are less than the skidding forces, **the car will not skid.**

CHAPTER 4

4. ADAPTABILITTY OF BRAKING SYSTEM OF MPV-1

4.1 Types of Braking Systems Available for MPV-1

There were two types of braking systems available for MPV-1

- Pneumatic (Air) Brakes
- Hydraulic Brakes

4.2 Selected Braking System for MPV-1

The selected braking system for MPV-1 is Hydraulic Brake System because of the following reasons:

- Firstly, MPV-1 is a two seater passenger car. Air brakes are used on heavyweight vehicles such as trucks, buses and trailers. It is inappropriate to use air brakes on lightweight vehicles because excessive use of the brakes in an air brake system will deplete the air pressure reserve causing the brakes to completely lock up (which is the safety feature incase the air pressure drops too low) . A driver of MPV-1 will need to apply frequent brakes because of the usual busy traffic in Pakistan; therefore, air brakes are not suitable for MPV-1. In contrast, hydraulic brakes are specifically used for lightweight vehicles and there is no issue in using frequent braking in hydraulic system.

- MPV-1 is a low cost vehicle targeted for middle class people of Pakistan. The air brake system costs approximately $2500 more than hydraulic brakes because of the extra components needed to operate the system. Such an expensive braking system is not justified for MPV-1 because it will make it uneconomical and unsuitable for its target audience.

- Air brake system takes substantially more space than hydraulic brakes because of additional components. As already stated MPV-1 is a two seater passenger car and hence, has limited space. Therefore, air brakes will be difficult to install in it, whereas, hydraulic brakes can be easily installed.

4.3 Types of Hydraulic Brake Systems Available for MPV-1

There were three possibilities for the hydraulic brake system of MPV-1

- All four disc brakes
- Front disc brakes and rear drum brakes
- All four drum brakes

4.4 Selected Hydraulic Brake System for MPV-1

The selected combination is front disc brakes and rear drum brakes because:

We have calculated that 80% of braking effort of MPV-1 lies on front wheels. Therefore, MPV-1 needs to have superior brake performance on front wheels. Disc brakes dissipate heat faster than drum brakes and under severe usage, such as repeated hard stops or riding the brakes down a long incline, disc brakes take longer than drum brakes to lose effectiveness. Disc brakes also perform better than drum brakes in wet weather, because centrifugal force tends to fling water off the brake disc and keep it dry, whereas drum brakes will collect some water on the inside surface where the brake shoes contact the drums. Therefore, we selected disc brakes for the front wheels and drum brakes for the rear wheels to ensure high braking performance for MPV-1 by enjoying most of the benefits of disc brakes, while at the same time, lowering costs.

4.5 Adaptability of Appropriate Disk Brake Assembly for MPV-1

4.5.1 Disc Rotor

We have selected disc rotors of Suzuki Mehran of diameter 21.4 cm for MPV-1 because of the following factors:

- MPV-1 has adopted the axle of Suzuki Ravi, the axle being selected by the Chassis Group.
- Suzuki Ravi has wheel size of 12 inches.
- Suzuki Mehran also has wheel size of 12 inches.
- This means the disc rotor of Suzuki Mehran can be easily fitted onto the axle of MPV-1.
- The disc rotors of Suzuki Mehran are easily available in the market since Mehran is widely used by the people of Pakistan.
- The disc rotors of Suzuki Mehran are also cheap, PKR 1200 per piece.

- Therefore, the disc rotors of Mehran are the best candidates for MPV-1 because they can be easily fitted onto MPV-1 chassis and are easily available in the market with lower costs.

4.5.2 Brake Caliper

We have chosen brake caliper of Suzuki Mehran for MPV-1 because of the following reasons:

- Brake calipers are mounted onto the suspension rod of a car.
- The Suspension Group of MPV-1 has selected the suspension system of Suzuki Mehran for MPV-1.
- So, the only brake calipers that can be easily mounted onto the chosen suspension system of MPV-1 are of Suzuki Mehran.
- If we select brake calipers of any other car, we will have to do extra machining on both the calipers and the suspension rod which will increase the costs and add complexity.

4.5.3 Brake Caliper Piston Diameter

We have selected brake caliper piston diameter of 51.18mm for MPV-1 because of the following aspects:

- Three caliper piston diameters that are 45.26mm, 51.18mm and 60.31mm are available from the market survey.
- Bigger piston diameter is desirable because it will enhance the braking force.
- There was spacing issue with 60.31mm caliper piston. It is too large to be fitted inside the selected brake caliper of Suzuki Mehran for MPV-1.
- The 45.26mm caliper piston does not provide as much braking force as 51.18mm caliper piston does.
- Hence, 51.18mm caliper piston is chosen because it can be easily fitted inside the selected brake caliper, provides enough braking force and is readily available in the market with cheap price.

4.5.4 Types of Brake Pads Available for MPV-1

There are four general types of brake pads that are non-asbestos organic (NAO), low metallic non-asbestos organic, ceramic and semi-metallic. But only two of them are commonly used and available in Pakistan and that are semi-metallic and ceramic. The non-asbestos organic (NAO) and low metallic non-asbestos organic brake pads are therefore inconvenient for MPV-1 because users would find them difficult to search and purchase in Pakistan. So, we are only left with two options for MPV-1 and they are:

- Semi-Metallic Brake Pads
- Ceramic Brake Pads

4.5.5 Selected Brake Pads for MPV-1

We have preferred ceramic brake pads over semi metallic pads for MPV-1 because of the following recommendations:

- Ceramic brake pads have higher coefficient of friction (0.45-0.55) than semi-metallic brake pads (0.28-0.38). Higher coefficient of friction means higher braking force, therefore, greater stopping power of MPV-1. Therefore, ceramic brake pads produce greater braking force and stopping power than semi-metallic brake pads.
- Ceramic brake pads are strong enough to stop even the fastest cars without damaging the rotors. However, semi-metallic brake pads does more damage to the rotor than one might think.
- Semi metallic brake pads produce a considerable amount of brake dust. However, ceramic brake pads produce finer, lighter-colored brake dust which does not stick to the wheels.
- Semi metallic brake pads tend to be noisier than ceramic brake pads. Ceramic brake pads emit noises that are above the range of human hearing.
- Ceramic brake pads have longer lifespan than semi-metallic brake pads. Therefore, ceramic brake pads are changed less frequently than semi-metallic in the vehicle.
- Ceramic brake pads are stable under a wide range of temperatures for consistent performance, while, semi-metallic brake pads require careful and proper bedding-in for best performance.

4.5.6 Adaptability of Master Cylinder and Pedal for MPV-1

We need to do certain calculations for finding out the right master cylinder bore size for MPV-1 and then, the matching pedal.

4.5.6.1 Pedal Force

Type of Brake	Pedal Force
Power Assisted Brakes	279 N/g
Manual or Standard Brakes	445 N/g

Table 4.1: Pedal Forces in Power and Manual Brakes

- The data in the above table has been taken from the book "Brake Design and Safety 3rd Edition" by Rudolf Limpert Pages 17-18.
- The engine size of MPV-1 is 250 CC, so it cannot create enough vacuum for vacuum booster.
- Hence, the brakes of MPV-1 will be standard or manual brakes without the vacuum booster.
- From the above table, the pedal force for manual brakes is 445 N/g.
- Deceleration of a vehicle = Braking Efficiency X Gravitational Deceleration
- Deceleration of MPV-1 is -0.8g (braking efficiency of 80% as shown previously)
- *So, the pedal force for MPV-1 is 445 N/g X 0.8g = 356 N.*

4.5.6.2 Braking Torque

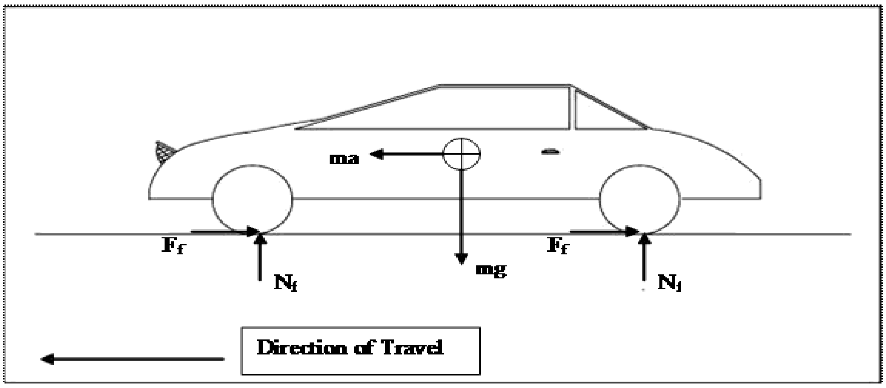


Figure 4.1: Free Body Diagram of Car

- Braking Torque on Front wheel = ($W_{dynamic,front}$ $*C_{f,tyre}$)* r_{wheel}
- Total Braking Force= Braking Force on Front Axle + Braking Force on Rear Axle
- Also, from Newton's Second Law of Motion, $F_{braking}$ = ma
- This implies ($\frac{Wtotal}{g}$)a= (W_{front}) ($C_{f,tyre}$) + (W_{rear}) ($C_{f,tyre}$)
- (W_{total}) ($\frac{a}{g}$)=(W_{front} + W_{rear})($C_{f,tyre}$)
- Hence, $C_{f,tyre}$ = ($\frac{a}{g}$)

- The value of each parameter in the equations shown and the braking torque are shown below in the table:

Deceleration	7.848 ms^{-2}
Gravitational field strength (g)	9.81 N/kg
Coefficient of friction	0.8
Radius of Wheel	10.68 inches
Dynamic Weight on Front Tyre	2943 N
Front Braking Torque	638.7 Nm

Table 4.2: Calculated Braking Torque on Front Tyre

4.5.6.3 Hydraulic Pressure

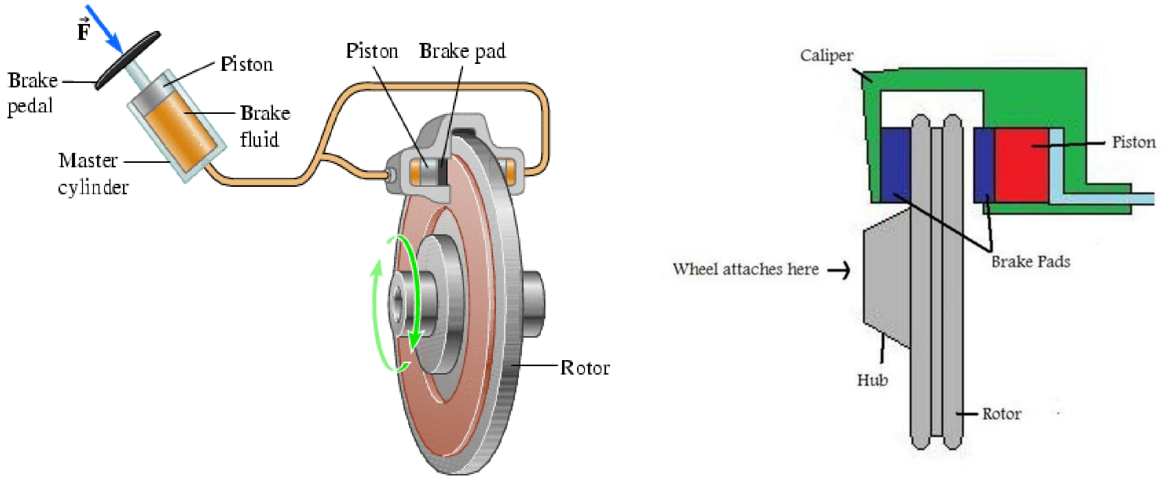


Figure 4.2: Hydraulic Pressure

- Braking Torque = 2* Hydraulic Pressure* Piston Area* $C_{f,pad}$ * effective radius
- Effective radius = $\frac{\text{Rotor diameter} - \text{Slave Diameter}}{2}$
- This implies, Hydraulic Pressure = $\frac{\text{Braking Torque}}{2 \times \text{Piston Area} \times \text{Cf,pad} \times \text{effective radius}}$
- The table below shows the numerical value of each parameter in the above equations and the final value of hydraulic pressure:

Braking Torque	638.7 Nm
Caliper Piston Diameter	51.18mm
Caliper Piston Area	$2.0573 \text{ X } 10^{-3}\ m^2$
Coefficient of Friction	0.45
Rotor diameter	21.4cm
Effective Radius	0.08141m
Hydraulic Pressure	42.4 bars

Table 4.3: Calculated Hydraulic Pressure

4.5.6.4 Selection of Master Cylinder and the Matching Pedal for MPV-1

- ❖ We have five different master cylinders that are easily available from the market.
- ❖ Their bore sizes are: 3/8’’, 3/4’’, 5/8’’, 13/16’’ and 15/16’’ inches respectively.
- ❖ We calculated the required length of pedal (called the pedal ratio) for each master cylinder available and saw which master cylinder-pedal combination was easily available from the market.
- ❖ The calculations are shown below:

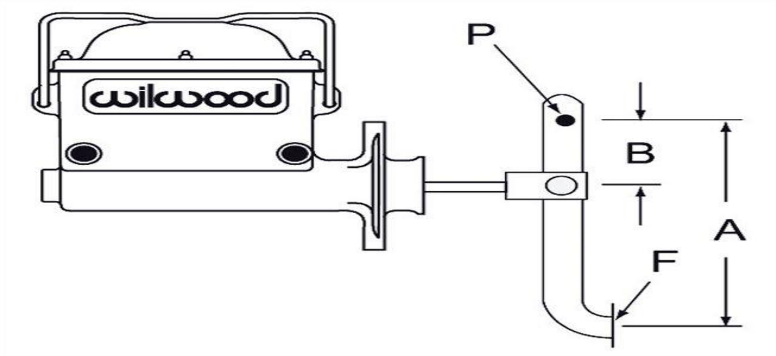


Figure 4.3: Brake Pedal and Master Cylinder Assembly

- ➢ Hydraulic Pressure = (Force on Pedal)(Pedal Ratio)/(Area of Master Cylinder)
- ➢ Pedal Ratio= (pi*Hydraulic Pressure*Master Cylinder Dia^2)/(4*Force on Pedal)

Master Cylinder Bore Size (inches)	Pedal Ratio
5/8	2.356
13/16	4
15/16	5.3
¾	3.4
3/8	0.848

Table 4.4: Various Possible Combinations of Pedal Ratio and Master Cylinder

From the market survey, the combination of *13/16 inches master cylinder bore size and pedal ratio of 4* was the most readily available and therefore, we selected this combination for MPV-1.

4.5.7 Adaptability of Appropriate Rear Drum Brakes for MPV-1

We have selected the drum brakes of Suzuki Ravi because:

- The axle of Suzuki Ravi has been adopted as the axle of MPV-1 by the Chassis Group.
- The drum brakes are mounted onto the hub of the axle.
- Hence, the drum brakes of Suzuki Ravi can be easily mounted onto the axle of MPV-1 without any machining or manufacturing required because both the brake drums and the axle will be of Suzuki Ravi in that case.
- Using drum brakes of any other car will require machining additional holes for assembling and will increase the costs.
- The drum brakes of Suzuki Ravi are readily available in Pakistani market.
- The drum brakes of Suzuki Ravi are of low cost as well, PKR 1400 per piece.
-

4.5.7.1 Re Engineering in Drum Brakes

- The selected drum brakes have to be re-engineered to achieve the minimum braking force.
- The wheel cylinder bore diameter of the selected drum brakes is 1.145cm.
- The braking force exerted by this wheel cylinder is 120 N whereas the minimum braking force required is 412 N.
- Therefore, the existing wheel cylinder in the selected drum brakes has to be replaced by a larger wheel cylinder.
- The existing wheel cylinder is replaced by a larger wheel cylinder of bore size 2.14 cm to provide the minimum braking force.
- The new wheel cylinder in the brake drums provides braking force of 470 N which fulfills the requirement of minimum braking force of 412 N for MPV-1.
- The calculations for the wheel cylinder bore size are shown as:

4.5.7.2 Calculations for Wheel Cylinder Bore Size

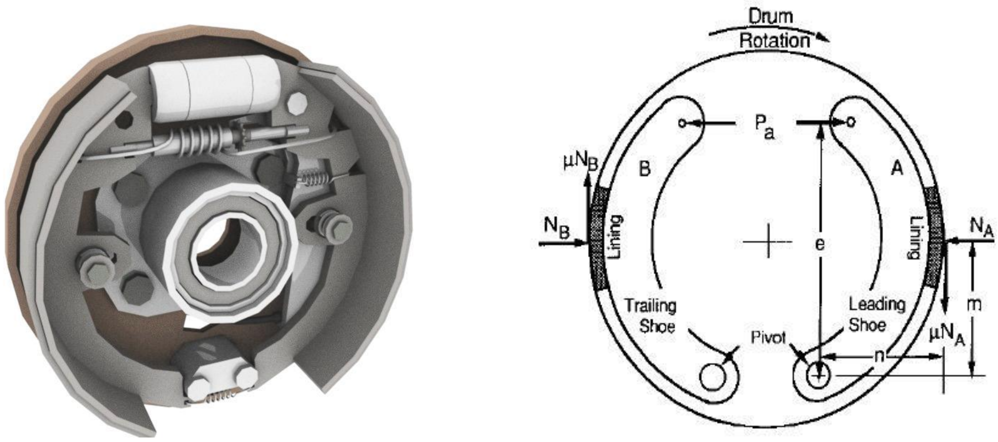


Figure 4.4: Forces in Drum Brake

- Braking Torque in Drum Brake = $2*F_e*\mu*r_{drum}$
- F_e = Hydraulic force on wheel cylinder piston= Piston Area * Hydraulic Pressure
- Braking Torque in Drum Brake = Braking Torque on tyre
- $2*F_e*\mu* r_{drum} = F_{braking} * r_{wheel}$

Wheel Cylinder Original Piston Diameter	1.145cm
Coefficient of friction between brake lining and drum	0.38
Hydraulic Pressure	42.4 bars
Radius of Drum	11cm
New Wheel Cylinder Piston Diameter	2.14cm
Original Braking Force	120 N
New Braking Force	470 N

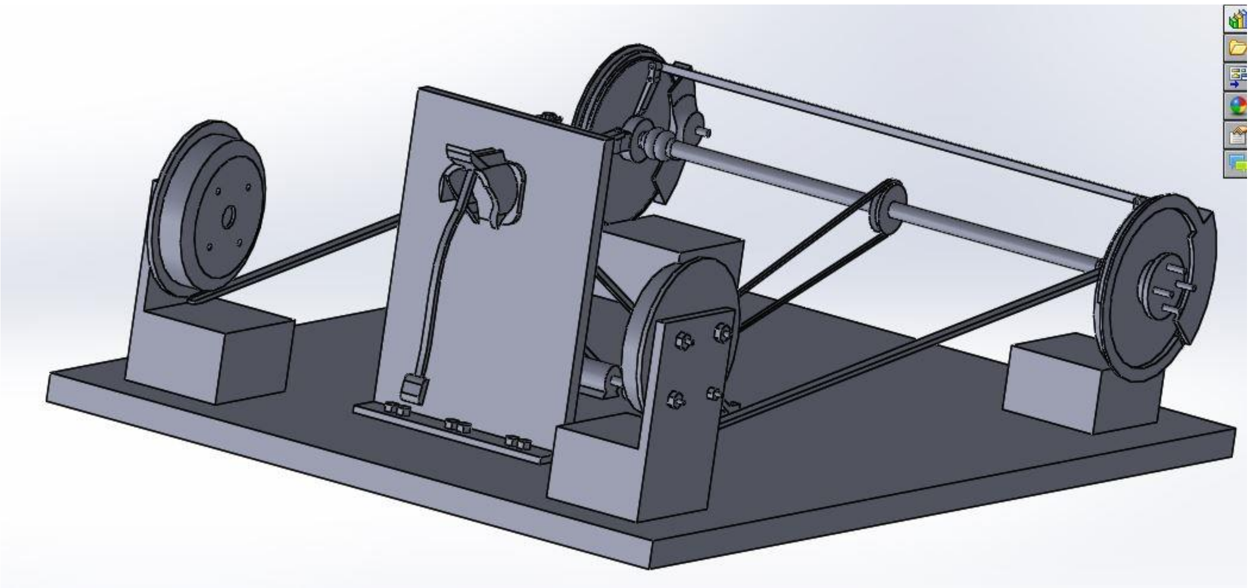
Table 4.5: Calculation of New Wheel Cylinder Piston Diameter and Braking Force

CHAPTER 5

5. RESULTS

5.1 CAD Model

We prepared a CAD Model first according to which we prepared our assembly.



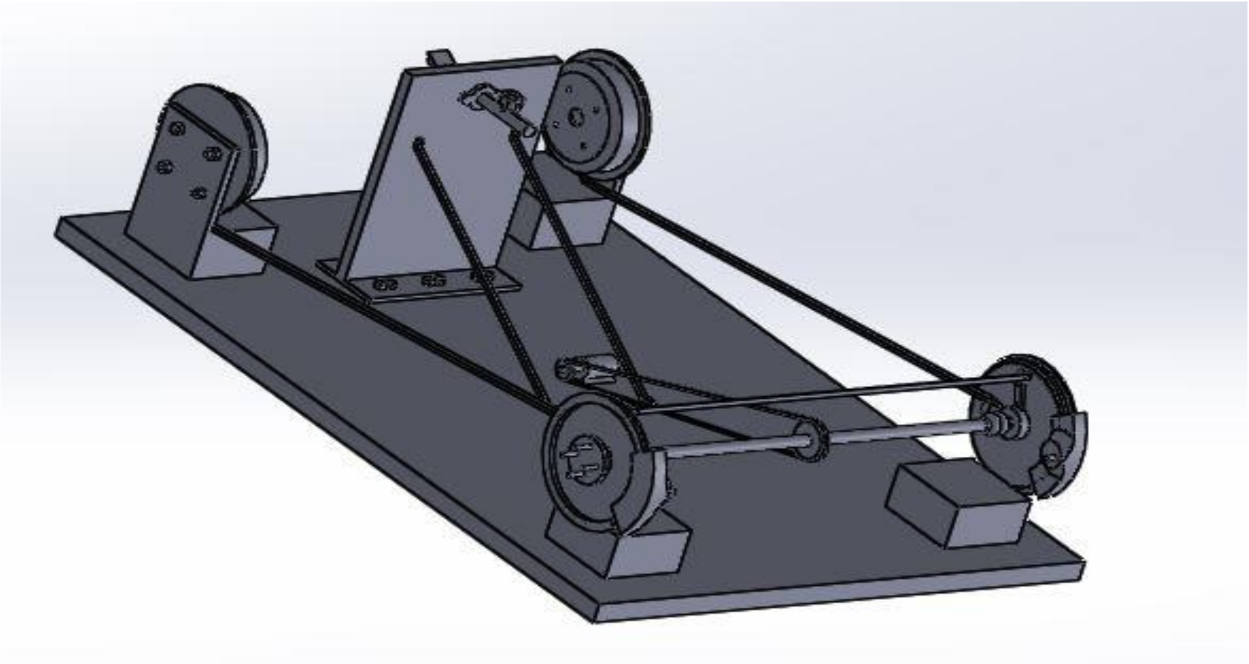


Figure 5.1: CAD Model Prepared on SolidWorks

5.2 Final Prototype Made According to the CAD Model

We assembled all the parts and made a prototype of the braking system of MPV-1.

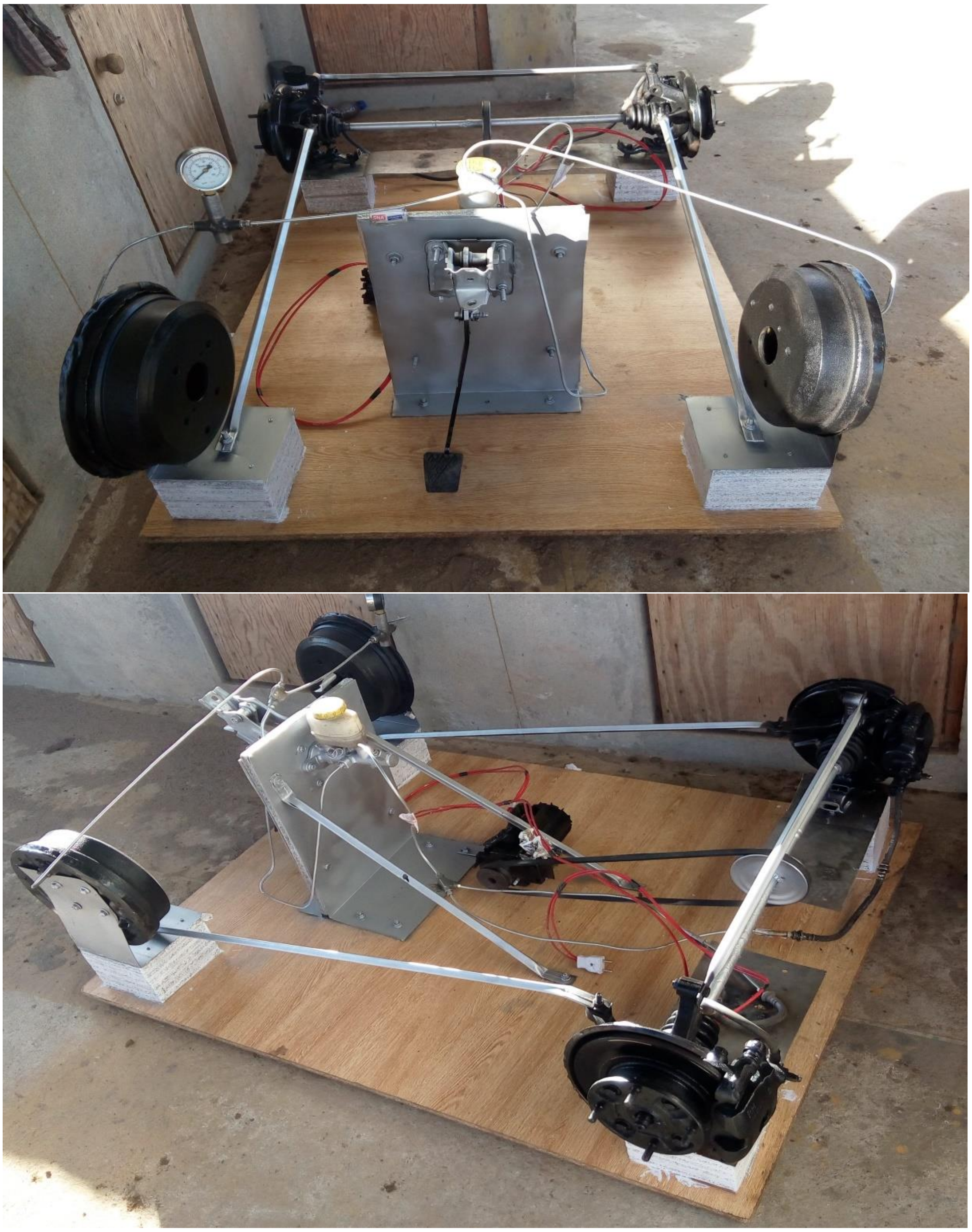


Figure 5.2: Actual Prototype Made

5.3 Use of Pressure Gauge

A pressure gauge is used in the assembly to indicate the actual hydraulic pressure achieved. The actual maximum hydraulic pressure achieved is 35 bars whereas the theoretical maximum hydraulic pressure calculated is 42 bars.

5.4 Use of External Motor and Shaft

An external motor of 233 rpm is used to drive a rotating shaft mounted between the two disc brakes as shown in the assembly. When the brakes are applied through the pedal, the rotating shaft is stopped. The external motor and rotating shaft are used for demonstration purpose only, to show that our brakes are in a working condition.

5.5 Actual Stopping Distance Achieved

- We know that Front Tyre Braking Torque = 2* Hydraulic Pressure* Piston Area* $C_{f,pad}$ * effective radius
- From hydraulic pressure of 35 bars, piston diameter of 51.18mm, coefficient of friction of 0.45 and effective radius of 0.08141m, we obtain the braking torque of 527.6 Nm.
- Also, Braking Torque = Braking Force × Radius of Wheel and hence, Braking Force = $\frac{\text{Braking Torque}}{\text{Radius of Wheel}}$
- With front tyre braking torque of 527.6 Nm and 0.2713m radius of wheel, we obtain front tyre braking force of 1944.8 N.
- We also know, Work done by Braking Force = Loss in Kinetic Energy of the car
- Therefore, Braking Force × Braking Distance = $\frac{1}{2}$×Mass ×Velocity^2
- Taking into account the Braking Efficiency, Braking Distance = $\frac{\text{Mass } \times \text{Velocity}^2}{2\times\text{Braking Force}\times\text{Braking Efficiency}}$
- With front tyre braking force of 1944.8 N, front tyre mass of 300 kg, velocity of 70 km/h and braking efficiency of 80%, we obtain the actual braking distance to be 36.45m.
- The theoretical braking distance is 34.41m and actual braking distance is 36.45m, and the percentage difference between the two values is 5.93%.

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