Calipers and Wiring Component Analysis

1. **Background**

Calipers, and the wiring that connects them to the manual braking mechanism within the car, are the main way to force a car to stop. Specifically, the calipers house brake pads and are attached to the rotor of a wheel. Once force is transferred to the calipers, the brake pads clamp onto the rotor and thus brakes the car. Figure 1 below how calipers are attached to a rotor.

Figure 1: How Calipers and Brake Pads are Attached (3.C)

Our task is to design an emergency brake that can stop a kart moving at 20-40 mph within 10m of the brake system activating. Specifically, we need to fit a set of calipers and brake pads onto the rear rotor (diameter of 7.5 inches, thickness of 0.5 inches). Given that our task is to employ an emergency brake for a kart, understanding how brake systems in commercial vehicles like cars will be instrumental in designing and implementing our own brake that will be functional. By implementing a calipers and brake pad system similar to those already well developed for commercial usage, we can then design our specific brake system to fit our needs, which is to brake as fast as possible.

2. **Summary of Information Learned**

There are two main types of calipers: mechanical and hydraulic. Mechanical calipers use a cable system to transfer energy, like those found in bikes, while hydraulic calipers use brake fluid to transfer the force (3.H). Generally speaking, hydraulic calipers are superior to mechanical calipers due to their efficiency and performance. Mechanical calipers use a cable system to transfer energy, but because of continuous contact, mechanical calipers will suffer from longevity issues. Not only that, hydraulic calipers transfer the force better compared to mechanical calipers. In other words, less force is required for hydraulic calipers to generate the same amount of braking force as that in mechanical calipers. Finally, because hydraulic calipers use fluid rather than a mechanical system, they are lighter than mechanical calipers. However, because of these positives, hydraulic calipers are more expensive than mechanical calipers, as

mechanical calipers range from $35-150, while hydraulic calipers range from $100-400, which is more than double mechanical calipers (3.I). Another negative is the possible leakage and pressurization of hydraulic calipers, since one of our emergency brake solutions requires the calipers to always be pressurized, which is a safety concern. If the pressure cannot be controlled, the caliper system will fail, or possibly explode and harm the passenger.

Therefore, because of these two distinct disadvantages, mechanical calipers will be our focus. The longevity of mechanical calipers are not relevant for an emergency brake, and the extra required force for mechanical calipers can be adjusted by adding more sources of force, like extra springs or magnets.

For brake pads, there are three materials that are commonly used for commercial use: organic, semi-metallic, and ceramic (3.F). Organic brake pads are made of an organic material like rubber, kevlar, or carbon, and are bound by a resin agent like epoxy. It's important to note that asbestos, while a good material for brake pads, introduces health risks from prolonged exposure, such as cancer or lung diseases, which is an important material to look out for. Organic brake pads tend to be on the cheaper side and don't generate much noise, but are not the best at fast braking, produce a lot of residue, and do not last for long. They also work best in a small range of temperatures. Semi-metallic brake pads consist of more than 30% metal, such as iron, steel, copper, or graphite. Therefore, because of their metallic component, they provide strong braking force while also generating a lot of noise. They are a little more expensive than organic brake pads, but last longer and don't produce as much residue. The last type, ceramic brake pads, tend to be the most expensive type. In exchange, they produce the least amount of noise and residue, as well as having the longest life expectancy. However, they do not produce as good of a braking performance as semi-metallic, but are still better than organic brake pads.

An important caveat before choosing brake pads would be the prices. While specific types and models are more expensive due to their material, such as carbon fiber, the general difference in prices is negligible. Specifically, they are all within the same order of magnitude, ie. within a range of $30-70 for lower quality brake pads. It's also important to remember the usage of these brake pads, which is for an emergency brake. Therefore, the only factors we really care about are how fast they can brake, and the price. Since the prices are all relatively the same, the best brake-performing brake pad would be a semi-metallic one, which is the type of brake pad material we will buy.

3. Information Gathering

Keywords:

"Brake calipers", "brake calipers wiring", "pads included", "mounting hub", "mounting bracket", "cast iron", "aluminum", "thermoplastic", "organic", "metallic", "semi-metallic", "ceramic", "friction", "hydraulic", "mechanical", "lever"

Sources:

3.A.https://www.team-bhp.com/forum/technical-stuff/188088-brake-caliper-location-how-do-engineers-decide-its-placement.html

3.B.https://www.powerstop.com/resources/helpful-tips-installing-new-brake-caliper/

3.C. https://www.lesschwab.com/article/complete-guide-to-disc-brakes-and-drum-brakes.html

3.D. https://www.goodyearbrakes.com/calipers/material-calipers/brake-caliper-material-types/

3.E.https://shop.advanceautoparts.com/p/carquest-premium-brake-caliper-18-4194-front-right-remanufactured-anti-corrosion-coated-18-4194/5620805-p?product_channel=local&store=9882&a

dtype=pla&product_channel=local&store_code=9882&gclid=CjwKCAiA3pugBhAwEiwAWFzwda6iUQ2aozBkSIgcotd1DIBp3vKWssDITA4f8011E2sacULLLveJAhoCj1kQAvD_BwE&gclsrc=aw.ds

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3.H. https://biketestreviews.com/mechanical-vs-hydraulic/

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Phone Calls/Emails:

Email to Customer Service to Power Stop:

I gave a brief introduction concerning the project, ie. the emergency brake system that needs to be assembled, as well as dimensions of the rotor. I then asked them if they could give me a recommendation for brake pads that could stop the vehicle as fast as possible within a budget of $100. They replied with one of their products (3.J) and said this would be the best fit for our needs. They were unable to give me a good estimate for the friction of coefficient, so I guessed it to be roughly μ=0.30.

Email to Customer Service to ACDelco:

I gave a brief introduction concerning the project, ie. the emergency brake system that needs to be assembled. I specifically pointed to one of their products (3.G) as one that I thought would work for the vehicle, and asked for some further information on the brake pads, specifically their friction of coefficient. I also asked them if they had any other suggestions besides the one I listed for brake pads with strong braking performance. I have not yet received an email.

Other Questions/Issues:

The caliper and brake pads system is mostly addressed, since the various materials and components are well documented and explored, and choosing one for our situation was not too difficult. Still, issues may rise up in terms of compatibility if we buy brake pads from one seller and calipers from another, as well as whether or not the brake pads themselves will be able to stop the kart fast enough with a given amount of force. These will be easy to discover as we assemble and test our emergency brake, but solving it will require either stronger brake pads, more pedal force, or worst case scenario, a different solution.

4. **Detailed Findings**

Pros and Cons of Mechanical and Hydraulic Calipers:

Calipers	**Pros**	**Cons**
Mechanical Calipers	1. Inexpensive ($30-150) 2. Easy to set up	1. Heavy 2. Continuous contact 3. More force required to transfer less energy

		4. Requires more continuous maintenance
Hydraulic Calipers	1. Light 2. Long life expectancy 3. Efficient at transferring energy 4. Maintenance is necessary only once in a while	1. Expensive ($100-400) 2. Leakage issue 3. Constant pressurization

Pros and Cons of Organic, Semi-Metallic, and Ceramic Brake Pads:

Brake Pads	**Pros**	**Cons**
Organic Brake Pads	1. Inexpensive ($30-50) 2. Low noise	1. Lowest braking performance 2. Generates a lot of residue 3. Small range of temperatures 4. Low life duration
Semi-Metallic Brake Pads	1. Inexpensive ($40-60) 2. Best braking performance 3. Works in extreme temperatures	1. Lots of noise 2. Generates residue 3. Low life expectancy
Ceramic Brake Pads	1. Quiet 2. Longest life 3. Little residue	1. Most expensive ($70) 2. Weak braking performance

All these different brake pads and calipers are easily accessible and purchasable online, either from retailers like ACDelco or Power Stop, or warehouses such as Amazon.

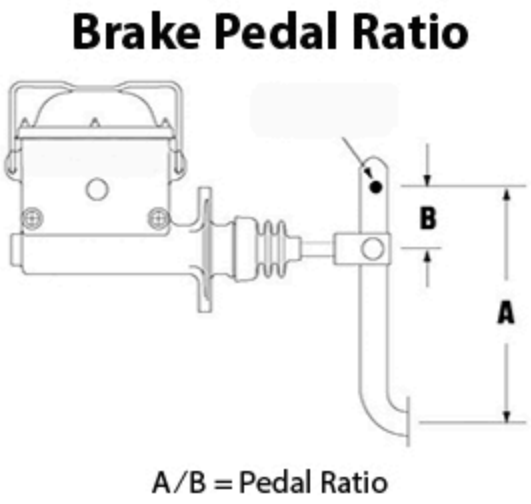
Physics of Calipers and Wiring:

Our gokart is roughly 150 lb, 350 lb (158.8 kg) with a passenger inside. If we allow the kart to move at a maximum speed of 30 mph (13.4 m/s), and using the braking formula:

$$F = \frac{0.5mv^2}{d} \qquad (1)$$

Where m is the total mass, v is the velocity, and d is the distance, which is 10m in this case, we can find that the required force to stop the kart is 1426N. Allowing a factor of safety of 1.5 means that a minimum required force of 2139N is needed to stop the kart within 10m.

There are many different factors that affect the total braking force of a vehicle, but the ones we are primarily interested in are those we can affect, namely the friction coefficient between the brake pads and rotor, the pedal force, and possibly the pedal ratio (3.J). Specifically, we want to increase all three of these factors to increase our total braking force. The pedal ratio is described as below:



1. Measure the distance from the pedal's pivot point to the center of the pedal pad.
    a. This is measurement "A" in the diagram.
2. Measure the distance from the pedal's pivot point to the center of the master cylinder pushrod.
    a. This is measurement "B" in the diagram.
3. "A" divided by "B" equals the pedal ratio.

Figure 2: Calculating the Pedal Ratio (3.L)

Therefore, the most feasible way to increase the pedal ratio would be to increase the distance of A, or the distance between the pedal's pivot and the center of the pedal pad. Most cars use a pedal ratio of 4:1, which is a 4x increase in our braking force. We can add an attachment to the end of the brake pedal to elongate the pedal ratio, but constructing our own pedal set from scratch is difficult, as it would require custom building it, since most vehicles already have a predetermined pedal ratio. Additionally, increasing the length would mean even less room on the car, especially if the brake pedal is vertical, meaning less clearance with the ground. This would force us to orient it sideways, which could be impossible due to the limited space.

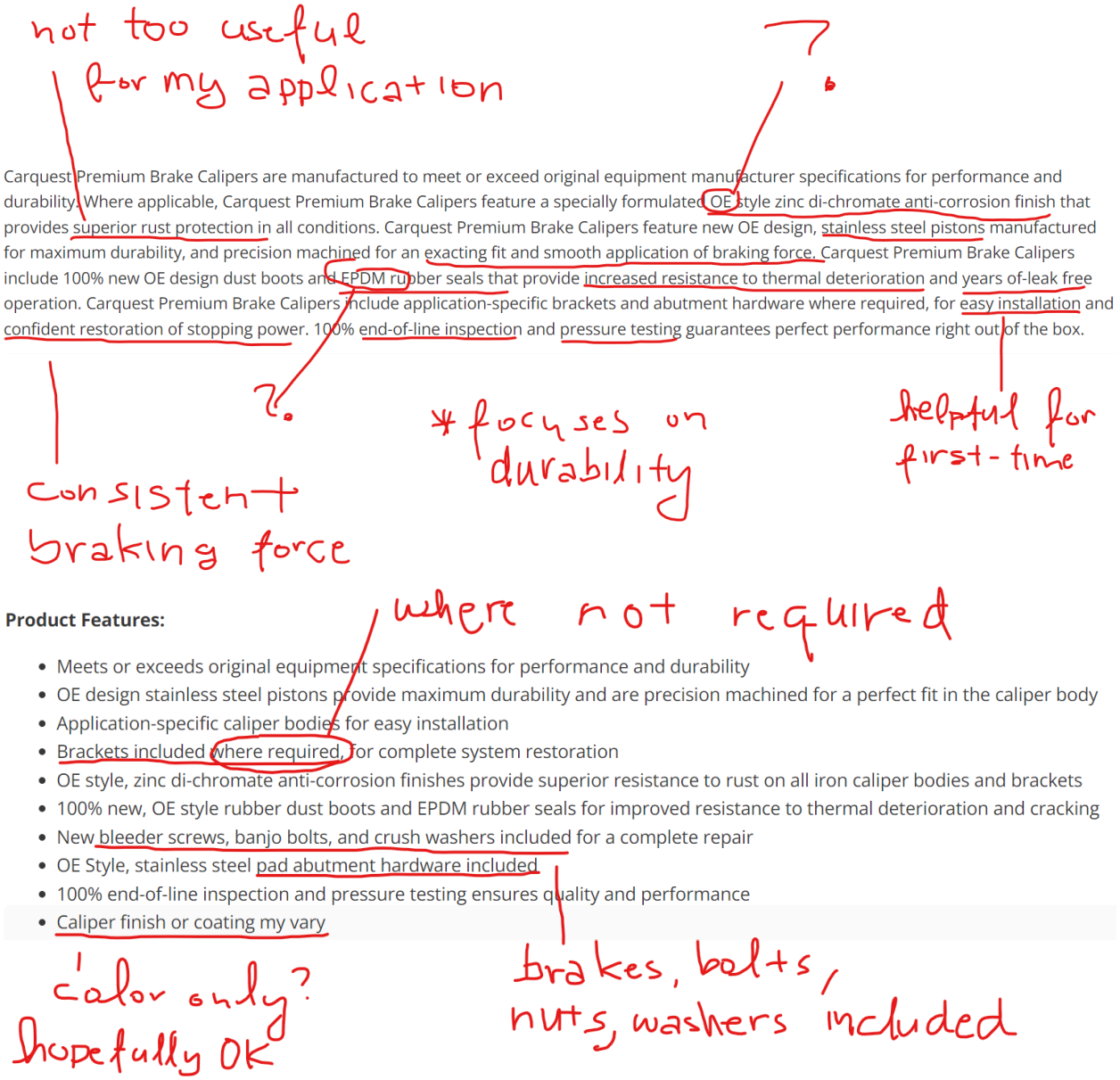
The two other factors however, friction coefficient and pedal force, are easily adjustable for our case. The friction coefficient is based mainly on the material of the brake pads. A semi-metallic brake pad would likely be the best for stopping power, since metal tends to have a higher coefficient of friction, but a high-quality ceramic brake pad made of various materials could also have a high coefficient of friction. This essentially boils down to finding the right material or compound for our purposes, but can be adjusted by buying different types of brake pads. In terms of pedal force, because the brake system needs to be activated mechanically, we can adjust the amount of pedal force that is given, meaning this is our main method of increasing braking force. Our current solution uses springs and magnets, so adding more springs will increase the pedal force and thus increase the braking force. Space is still an issue however, as well as safety, since too many springs could lead to injuries when setting up the system.

Industry trends relating to brake pads are not extremely relevant for our case, mainly because we are developing an emergency brake. The majority of research and testing of brake

pads is done for commercial vehicles, and thus focus on the life expectancy of brake pads, with braking performance being an important secondary concern. This means that brake pads are generally built to last for years with relatively good braking performance, rather than the converse of having extremely good braking performance but breaks after only a few attempts. Unfortunately, we are not concerned with how long brake pads can last, but more so how fast brake pads can force a car to stop moving, so industry trends are not that useful.

5. **Appendix**

Mark up of 3.E:



Mark up of 3.G:

what material?

Manufacturer	ACDelco
Brand	ACDelco
Model	ACDelco - Semi-Metallic F (Slp-1) (17D784MH)
Item Weight	7.1 pounds
Product Dimensions	11 x 6.25 x 3.88 inches
Country of Origin	Mexico
Item model number	17D784MH
Exterior	Painted
Manufacturer Part Number	17D784MH
OEM Part Number	88927919
Position	Front

light

can still be put on rear

measurements of what dimension?

might not fit

- Fit type: Vehicle Specific
- Tested to D3EA and SAE J2784 for braking effectiveness, along with Noise/Vibration/Harshness (NVH) and durability/wear testing for assurance of quality
- Tested to D3EA and SAE J2784 for braking effectiveness, along with Noise/Vibration/Harshness (NVH) and durability/wear testing for assurance of quality
- Ceramic, semi-metallic, and organic formulas provide safety and reliability for a range of vehicle applications
- Integrally molded friction material molded to backing plate for bond integrity
- Premium shims, slots, and chamfers help to diminish noise, vibration, and braking harshness
- Stamped backing plate allows for proper pad movement within the caliper assembly, reducing noise, brake pulsation, and helping to protect against premature wear

not useful for fast brake

no friction coefficient

Phone Calls/Emails notes:
Power Stop Email:

Hello! I'm working on developing an emergency brake for a client and was wondering what would be the best option? The main goal is to have the kart brake as fast as possible once, so noise/residue/durability is not a factor. The only two things I worry about would be the friction coefficient, which I want to be as high as possible to brake as fast as possible, and budget, which I would like to be under $100. We plan on attaching calipers to a 0.5 inch thickness and 7.5 inch diameter rotor, and the brake pads would fit inside those calipers. A 2006 Toyota Prius would fit our needs. Any suggestions would be greatly appreciated. Thanks!

Best,

Alex

ACDelco Email:

Hello! I'm working on developing an emergency brake and saw one of your products, "ACDelco Gold 17D784MH Semi-Metallic Front Disc Brake Pad Set," to be a good fit for my project. However, I still have some questions regarding this specific product that were not listed in the specifications, in particular the friction coefficient of these brake pads? Any other suggestions for brake pads for a rotor of diameter 7.5 inches and thickness 0.5 inches would be greatly appreciated! A 2006 Toyota Prius would also be a good match for my current project, so brake pads that give the best braking performance on that vehicle would be helpful for me. Thanks!

Best,

Alex