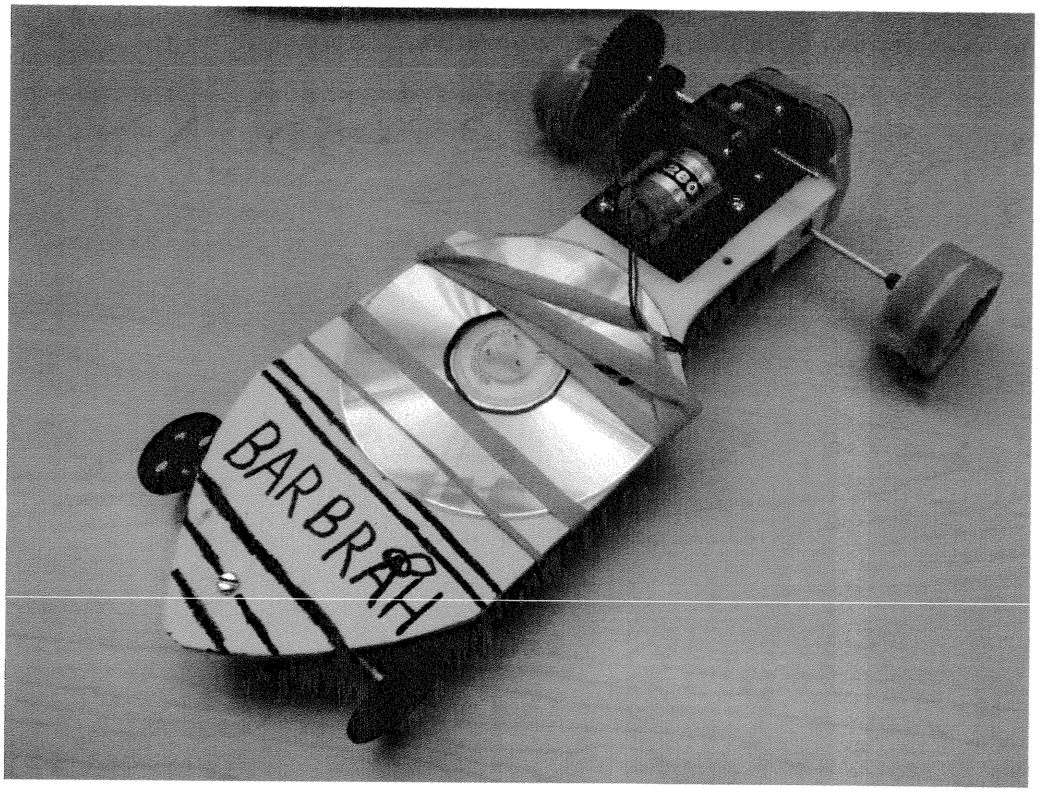


Electric Car Design and Manufacture Report

ENGRI 1170: Introduction to Mechanical Engineering

Lab: Friday
Group number: 1

December, 5th, 2009

Introduction:

For our final lab in our Introduction to Mechanical Engineering class, we performed a month-long project that involved designing and manufacturing our own electric car. The goal of this lab was to build a car that could both pull the most force and travel fifteen meters the most quickly (based on the specifications of the provided motor). The purpose of this lab was to apply what we had been learning during the semester to a real-life object, as well as gain first-hand experience building and manufacturing a product.

Development of Design:

Before beginning the building and manufacturing of our electric car, our group decided to spend some time doing research on similar car projects. We chose to do this because one of our group members had a time conflict with a Friday lab and could not be present during the first day of this project. Because of this, our group spent our first week doing research on mousetrap cars – similarly sized model cars powered by the mechanics of a household mousetrap – and coming up with possible design ideas. After we met as a team for the first time during the second week, we began brainstorming the design of our own car and sketching possible final designs.

The design of our car began as a simply shaped rectangular board with a rounded nose. In our initial design, we planned to build of a car that had adjustable parts for the two parts of the competition. For example, our early ideas included a ways of adjusting gears outside of the gear box and two sets of wheels of different diameter and width (see figure 1 in Appendix). The reason we chose to use a long, narrow rectangular base for the car instead of a square was because we wanted to minimize the cross-sectional area of the car, which we hoped would decrease air drag. We planned to use the space towards the front of the body for storing the spare set of wheels and battery pack while reserving the back for the provided gear box and motor. We knew that we wanted to be able to have different gear ratios for the two different competitions, and designed the back of the car to have room for adjusting the placement of the motor and its connected gears (see figure 2).

Much of our design process was included with our manufacturing process: we thought that it would be more efficient to begin the actual building of the car, identify flaws, and make changes to the design as we went. We began building the car as early as possible in order to allot enough time for the process to run its course.

Project plan/schedule:

1. Research past car designs showcased outside of the Taylor Design Studio and study existing knowledge about mousetrap cars.
2. Sketch the basic design of the car.
3. Choose what materials we wanted to use for the different parts of our design.
4. Order materials that we needed that were not already available (mentioned in next section)
5. Cut out and shape the platform/body of car.
6. Build the separate parts of the car.
7. Assemble the car and test out its performance
8. Make changes to fix problems. Rebuild parts.
9. Repeat steps 7 and 8 until car is perfected.

Manufacturing Process:

Because we chose to use a "build, experiment, then redesign" process for our project plan, the success of our car ended up significantly depending on the time we spent on the manufacturing process. After finishing the manufacturing of our initial car for the TA check on November 20th we realized that the car had many problems. For one, our prototype was assembled almost completely with tape. From our first few trials runs, we realized that our car would run very inefficiently if the parts were not put together very carefully and precisely. For example, we noticed that unless the motor and gearbox were very securely attached to the platform of the car, the gears outside of the gear box would mesh incorrectly between the two axles. Although tape was adjustable and non-permanent, it was ineffective at holding the different car parts securely in one place. Glue was not an ideal choice for bonding parts together because even though it is reliable in terms of sturdiness, it is permanent and not adjustable. Therefore, we chose to drills holes in our car and use screws and nuts to secure all our cars parts in to place.

Making the car go straight was a major barrier in our design process. Initially, we had glued the bearings for each of our two axles onto the car (see figure 3). This made adjusting the angle of the two axles very difficult. Since the two axles needed to be perfectly parallel to each other for the car to go straight, we devised a design in which one of the axles could be easily adjusted. We accomplished this by gluing the front axle bearings to a small board and drilling a hole through both the board and the platform of the car (see figure 4). By placing a screw and nut at that hole, the whole front axle would be able to swivel about the screw and could be set permanently in place by simply tightening the nut.

good ✓

We also encountered a problem with the axle rotating within the rear wheels (causing them not to spin with the axle). We could not bond the wheels to the axle with glue because our design depended on the ability to switch between two sets of wheels. Instead, we bonded two cranks to the axel to which both sets of wheels could attach (see figure 5). Because these cranks were bound to the axle with epoxy, and because the cranks attached to the wheels with a screw, it was impossible for the wheels to slip.

✓

Another helpful innovation was the integration of a platform with securely held the motor and gearbox as one construction. Because we needed to move both these pieces when we switched gears, and because these two essential pieces needed to be securely fastened in place so that they would not move with respect to one another, securing them both to a movable platform resulted in a less troublesome transition to switch gears between competitions.

✓

During manufacturing, we not only changed the design of the car, but also our manufacturing plan. Originally, we planned to build an entire car, test it, and the change what needed to be adjusted and fixed. However, after the TA check on the 20th, we began focusing less on the whole construction of the car at once and more on the quality of each section of the car. We began carefully building the final versions of all our separate parts, such as the adjustable front axle, rear wheel cranks, motor and gearbox platform, and so on. As a result, all the separate parts of our car were very sturdy and reliable, and when assembled well with screws and nuts, the car would run well as a whole.

✓ good

In general, our manufacturing process went very well. By going through the "redesign" process as we actually built our car, we were able to see all the flaws that our initial design had and address them when they appeared. Although the first couple of weeks our manufacturing process did not yield the results we hoped for, it became more systematic as time progressed and yielded better results. The only setback we encountered was the lack of time we had to perfect our car parts after Thanksgiving break. Our procedure relied on being meticulous during the fabrication of different sections of the car, which required us to spend the majority of our time building slowly and carefully. Fortunately, after putting in extra time at office hours, our precision and attention to detail paid off in our final design. The more reliable parts we ordered from McMaster, Pitsco, and Tower Hobbies also contributed to the reliability and simplicity in taking apart and rebuilding our car (see figure 6 for a list of parts we ordered). Overall, we were able to learn from our mistakes and our manufacturing process was a success.

good!

Analysis of Performance:

List of variables:
m = mass of car
M = the torque or moment applied by the motor
W = the angular velocity of the motor
P = the power being put out by the motor
G = the gear reduction = W / V
M_0 = the stall torque
W_f = the angular velocity when motor is applying no torque
P_p = the peak power of the motor = $M_0 * W_f / 4 = F_0 * V_f / 4$
F_{thrust} = the force at the wheels = $G * M_0$
V_f = the velocity when the force at the wheels is zero = W_f / G
F_{drag} = the drag force
A = cross sectional area
rho = density of air
c_d = the drag coefficient

Known Equations
$F_{thrust} = F_0 - c'v$, where $c' = F_0 / V_f$
$F_{drag} = ½ * A * rho * c_d * v\string^2$
$\Sigma F = m * a$

Calculation to minimize time to travel 15 meters by determining the ideal gear ratio:

$$\Sigma F = F_{thrust} - F_{drag} = (F_0 - c'v) - F_d = (G*M_o - (F_0 / V_f) * v) - F_d =$$
$$(G * M_0 - (G^2M_0 / W_f) * v) - F_d = (G*M_0 - ((G*M_0)^2 / (4*P_p))*v) - F_d$$
$$= (G*M_0 - ((G*M_0)^2 / (4*P_p))*v) - (½ * A * rho * c_d * v\string^2) = m * a$$

how does this minimize time?

$$\boxed{dv/dt = ((G*M_0 - ((G*M_0)^2 / (4*P_p))*v) - (½ * A * rho * c_d * v\string^2)) / m}$$

What?

All variables in this equation are known besides G, which is what we were trying to find.
P_p = 12watts, $m = 20*0.0283495231$, rho = 1.2 (thanks wikipedia), $c_d = 1$ (an estimation)
$A = .0028$ (this was determined by measuring the front dimensions of car, see figure 3)
W_f = 14200 rotations per minute = 14200*2*pi/60 rads per second
$M_o = 4 * P_p / W_f = (4 * 12 * 60) / (14200 * 2 * pi)$

Through Matlab (see figure 7), we found that the optimal gear ratio was 148.7879 and the theoretical time to cover 15 meters using that gear ratio was 2.5624 seconds.

Calculation to maximize pull force:

Assuming a lossless construction,
[Power In] = [Power out]
[Power In] = F * v
As a result of this equation, the generalization can be made that the force will be largest when the velocity is smallest due to power balance. Another way to view this is through the equation:

$F = F_0 - c'v$

Where the force approaches the stall force (which is the maximum force) as the velocity approaches zero. The entity that slows the velocity, G, has several components which are important to look at individually. The best way to do this is the chronological sequence of how the rotation rate is altered at different points in our construction:

1. The motor has some angular velocity W
2. At the gear box, W is reduced by some factor X, resulting in a new angular velocity W/X
3. Through an external gear combination, the angular velocity is reduced again by another factor K, resulting in an angular velocity of W / (X * K)
4. Finally, the angular velocity becomes linear velocity at the wheels, where the linear velocity is equal to the angular velocity multiplied by the radius of the wheels. Therefore, $v = (W * r) / (K * X)$, and because $v = W / G$, it can be concluded that $\boxed{G = (K * X) / r}$

good ✓

So, ideally, we would want to maximize G to some nearly infinite value by maximizing K and X and minimizing r, thus reducing v to some nearly zero value. However, in a real application the gear reduction can only be so large. In addition, the design of our car placed serious restrictions on how high our gear reduction could be. In the effort to maximize X, we were restricted by the position of the output axle. If you look closely at the different ways to set up the gear box, it can be seen that for different gear reductions the output axle switches between two possible positions. Only one of these axle positions could fit into our design, so we were restricted to using a reduction of only 138 in the gear box when a reduction of 344 would have been available otherwise. ✓

In the effort to maximize K, further restrictions existed. The greatest reduction possible with the available parts would have been to use a 60 tooth gear and a 10 tooth gear in combination. However, the ten tooth gears were notorious for breaking and the 60 tooth gear had a larger radius than our rear wheels (on the same axle). So we ended up using a 20 – 50 tooth gear combination. Finally, we used smaller wheels in order to reduce r. ✓ good

In conclusion,

- Discuss the accuracy of your predicted results against the performance. What are possible sources or error and what assumptions were made in your calculation?

Predictions vs. Performance and the Results of Competition Day

Speed Competition:

Trial:	1	2
Time:	5.28	5.185

Torque Competition:

Trial:	1	2
Force Pulled:	17.5?	24.0
Weight of Car:	20.3	20.3
Force / Weight:	0.862	1.182

} units?

In the speed competition, our car traveled 15 meters in 5.185 seconds. There are many factors which may have contributed to the disparity between this time and our predicted time, 2.56 seconds. First and foremost, the ideal gear ratio could not be perfectly manifested on our car. The closest we could get to this ideal value, 148.79, was 167.93 due to a finite number of ways to combine gears. Another factor was friction. In our calculations, we did not account for internal friction at all because it is very difficult to calculate even an estimation of friction for such a complex system. Internal friction surely played a role in slowing the car. We did include air friction in our calculation, but it was only an estimation and air friction may have been more effective than we predicted. Also, our car did not travel perfectly straight down the track, which not only resulted in the car traveling a longer path down the track, but also in the car hitting against the wall and riding along it for several meters. This was probably the greatest factor in the slowing of the car. Regardless, our car preformed well and achieved 4th place in the speed competition.

✓ very good

In the torque competition, our car performed even better, winning best torque to weight ratio. I feel like the aforementioned restrictions on our gear reduction ended up benefitting us. Because our car was light, the friction between the wheels and the ground was not very great, so it is likely that the wheels would have spun more (and our car would have performed worse) if our the gear reduction was higher. Between our first and second torque trial, we made the decision to move the battery box from the front of our car to the back. By increasing the weight at the rear of the car, the normal force on the wheels increased greatly resulting in a dramatic increase in friction, and ultimately a dramatic increase in pulling force. We did not expect this small chance to yield such a severe result

avoid "I" and "You" in professional reports

✓

In the tug of war competition, indisputably the most entertaining competition of the day, our car did fairly well despite its light weight. Our first and second matches were won and lost respectively. In the latter, we faced a much heavier car against which our car was no match. Following this, we had three or 4 races in quick succession with no time to make repairs in between. By the last one, the rubber bands around our wheels (held on by hot glue) were beginning to fall off. As the pull-off began, our car slowly started to be dragged to defeat by "The Square." After being pulled about half way across the circle, one of our rubber bands fell off at all but the very end point, so that it was loose to flap around but still attached to the wheel. What happened next I can only describe as pure luck – the rubber band began to go through a process of wrapping and unwrapping itself around the wheel. For some reason I do not understand, when the rubber band rolled up on the wheel, our car started to pull "The Square" back in the other direction. This continued until we nearly achieved victory, however, a leaf on the floor caused the miracle rubber band to fall off resulting in a stale mate. Lacking a rubber band and unable to make repairs before the rematch, we were defeated anticlimactically.

better to type "four"

increased friction coefficient

To improve our performance in the 15 meter race, we could have found a way to get our gear ratio closer to the ideal one that we calculated. Also, we could have figured out a way to make our car travel in a straighter path. In the torque competition, we could have weighed down the back of our car more and used a material with better traction than rubber bands for the tread. In the tug of war, our car probably would have benefitted greatly from simply being heavier. Its light weight made it easy for other cars to win by simply being heavier.

Conclusion:

By building this electric car, we were able to achieve the purpose of this lab: to apply what we have been learning in class to making a car that could maximize the speed and pulling force the given motor could allow. We learned first-hand what it's like to make mistakes, learn the mistakes, and reevaluate the validity of our design through a "MacGyver" (as Professor Ruina would put it), "use-what-you-have" type approach. Although this trial and error process took up some extra time, our manufacturing and designing process eventually resulted in a reliable, well-built car that was able to place 4th in the fastest time to travel 15 meters competition and 1st in the force-to-weight ratio pulling force competition.

good

Very Good.

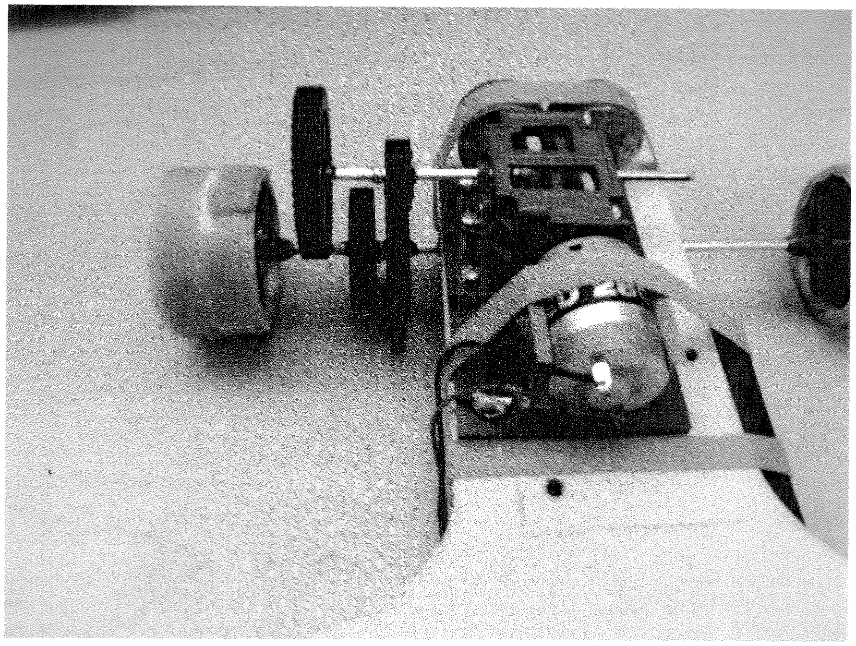
9.5/10

Appendix

Figure 1:

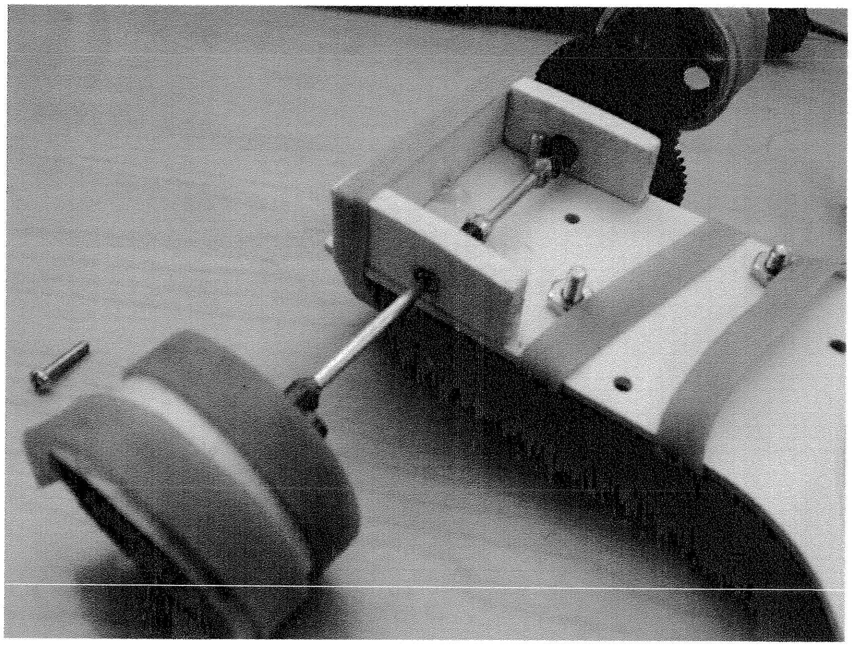
Note: Rubber band is missing on the CD wheel because it fell off

Figure 2:



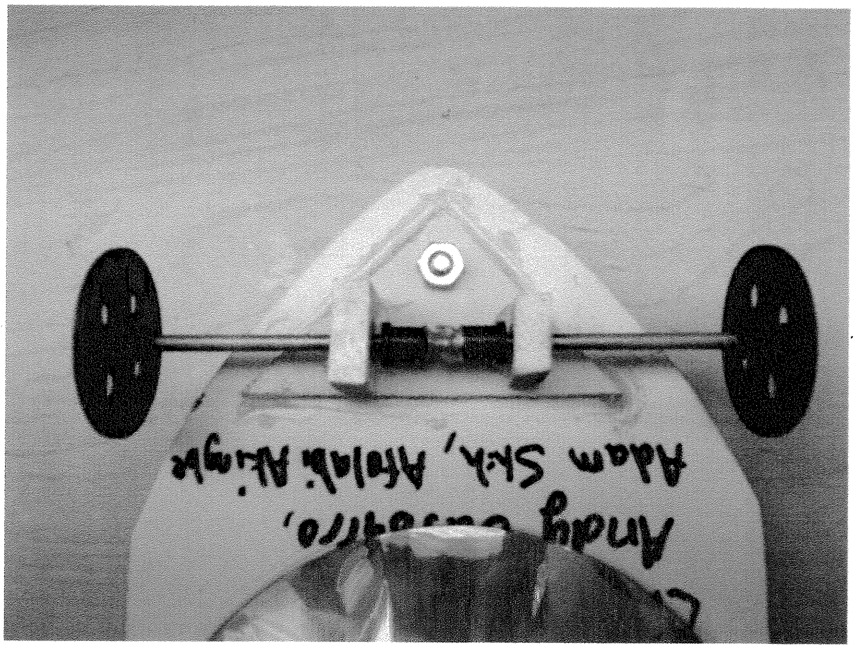
Note: Notice how two gears mesh while the other two gears spin freely. When the motor is moved to its other position (shown by the pencil drawn box and two holes where the screws from the motor's platform would fit in), the gears switch.

Figure 3:



Note: Back axle's bearing holders are permanently attached to the car's body by glue.

Figure 4:



Note: The whole front axle platform can rotate about the pin/screw when the nut is loosened.

Figure 5:

Note: Notice how there is a hole on the CD that matches up with where the screw would hold the CD in place. This ensures that the CD does not spin out when the axle rotates at a high angular velocity.

Figure 6:

Parts Ordered from Online

Part Name/Description (Order Number)	Supplier	Quantity	Unit Price (Dollars)
Stainless Steel Ball Bearings (6391K113)	McMaster	2	4.37
Bronze Sleeve Bearings (57155K347)	McMaster	2	*0.48*
CD Wheel Inserts (W24642)	Pitsco	1	2.95
Velcro Strap 24" (LXVTW1)	Tower Hobbies	1	3.49

Figure 7: (Matlab code to calculate ideal gear ratio for 15 meter race)

```
function CarODESolverfinal
clear all; home;

n = 100;

global P
P.p_p = 12;
P.m = 20 * 0.0283495231;
P.M_not = 12*4/(14200*2*pi/60);

P.rho = 1.2;
P.A = ((2.5*11/16) + (1.5*1.3)+(1/8 * 5)) * 2.54^2 /10000;
P.c_d = 1;

Gspan = linspace(130,190,n);
tresult = zeros(n);

for i = 1:n-1
    P.G = Gspan(i);
    tresult(i) = fsolve(@MyError, 1);
end

plot(Gspan, tresult);

magicIndex = 1;
for i = 2:n-1
    if (tresult(i) < tresult(magicIndex))
        magicIndex = i;
    end
end

Gspan(magicIndex)
tresult(magicIndex)

end

function y = MyError(t_t)

y = 15 - DistanceTraveled(t_t);

end

function [d] = DistanceTraveled(t_t)

x0 = 0;  v0 = 0;
zzero = [x0; v0];
tspan = [0,t_t];

[t zarray] = ode23(@myrhs,tspan,zzero);

x = zarray(:,1);
d = x(end);
```

```
end

function zdot = myrhs(t,z)
x = z(1);  v = z(2);
global P;

xdot = v;
vdot = ((P.G*P.M_not - (1/(4 * P.p_p)) * v * (P.M_not * P.G)^2) - ...
    (P.A * P.rho * P.c_d * v.^2 * .5))/P.m;

zdot = [xdot;vdot];
end
```