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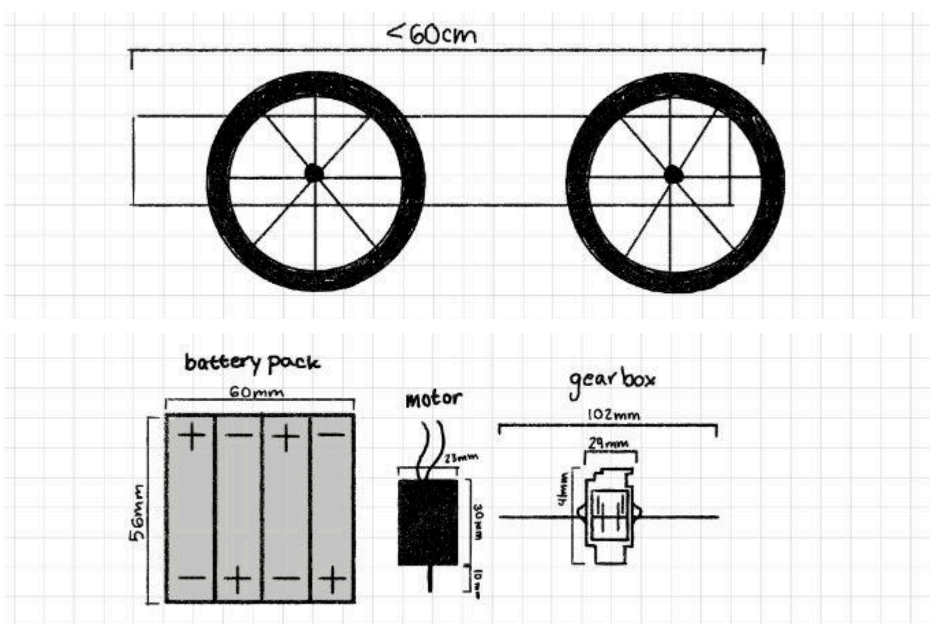
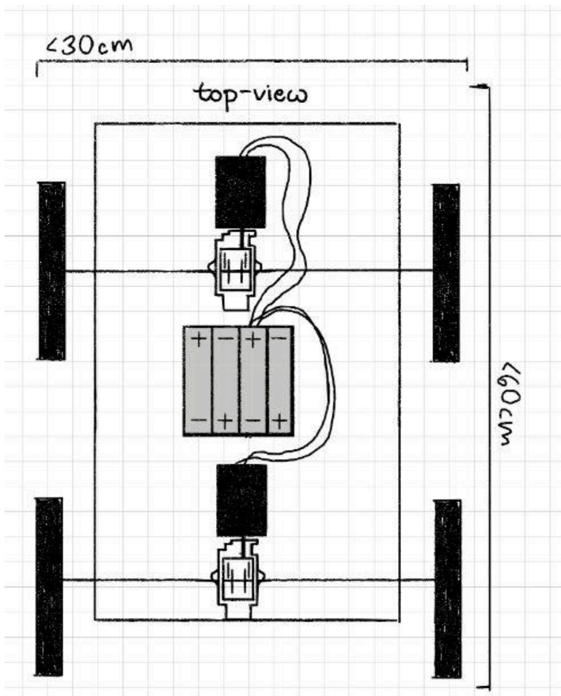
PESto: Final Design Report

Introduction
Our team was given the task of designing, manufacturing, and testing a car based on certain specifications, such as weight, torque, speed, and size. We were given a month to successfully construct this car with these certain guidelines in order to cater to the many competition elements.

Design Development
Our design evolved from an initial goal of creating a well rounded vehicle which could perform well in the speed test, tug of war, and the pull test. To achieve this, we decided earlier in the process that we wanted to use two motors and two gearboxes. This configuration allowed us to have a dual drive system, where power is delivered to the axles directly from the motors through the gearboxes. To achieve this all roundedness goal we had for the car, we planned to use two different sets of wheels. One set of wheels was created with a large radius to maximize the distance traveled per rotation and improve velocity. The second set was more torque focused, allowing for more force output. We also experimented with how the edge of the chassis can be changed to allow for less air resistance. However, through testing, we determined that a rounded edge wasn't going to allow for much more of a difference in aerodynamics. Therefore, we removed it with the purpose of making the car lighter. Through iterative prototyping and testing, our final design compromised on theoretical performance and real world constraints, such as weight limits and manufacturing feasibility.

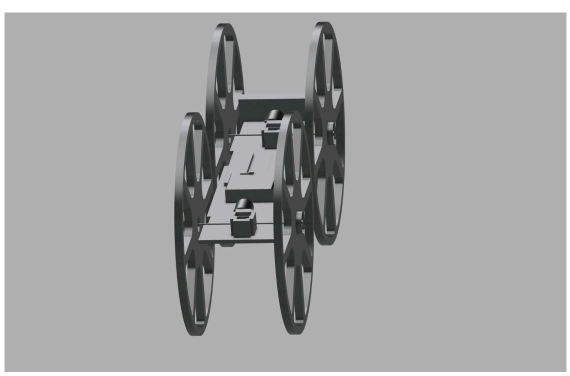
Original Sketch of PESto Car:

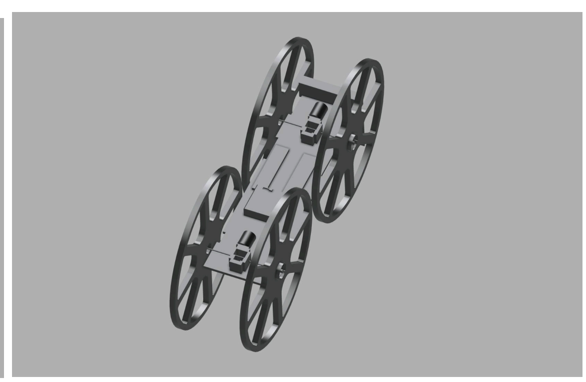


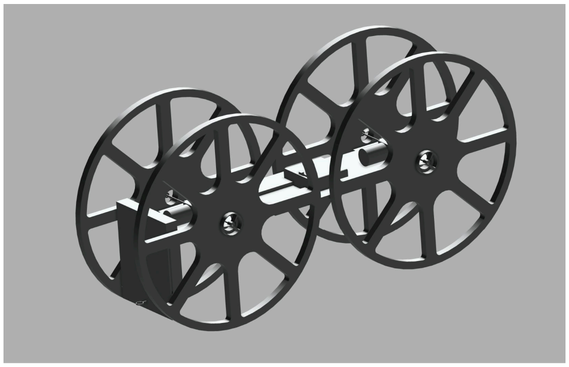
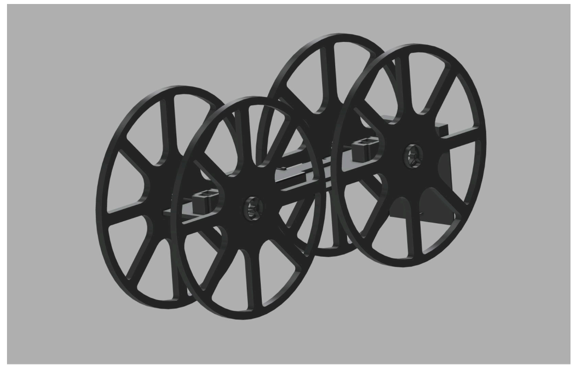


CAD Model of our Final Design:

Two Motors, Two Gearboxes, 4 Wood Wheels





Meetings
Our original plan was to meet as a group every Tuesday and to also use scheduled lab hours to discuss the progress of our car and complete manufacturing tasks. These meetings were made with the purpose of keeping us on track and to regularly evaluate our progress. Overall, we adhered to the schedule fairly well, as we consistently used lab time and worked outside of our Tuesday meetings as well. However, there were some occasional discrepancies which were primarily caused by prelims, coursework, and other scheduled events that limited everyone's availability. When conflicts did occur, we adjusted by communicating through group chats and rescheduling meetings. By doing this, we were able to stay organized and complete key milestones without compromising the quality of our car.

Manufacturing Process
One of the most successful aspects of our car manufacturing process was the creation of our wheels. Our wheels were specifically designed for our car, as they were created, modified, and laser-cut by our group. This gave us the ability to have consistent dimensions, smooth edges, and a precise fit on the axles, despite being custom made. We were also able to successfully manufacture our chassis to a target length of 60 cm, which allowed us to maintain a 30 cm distance between the front and rear axles, allowing for our wheels to turn and run efficiently. While we had some successful components, some design changes were made during the manufacturing process in response to competition requirements and performance constraints. One action we had to take was the removal of fenders. We had originally included fenders in our design to hold the axles, but since they were adding additional weight over the weight limit, we had to remove them as the performance with and without fenders was the same. We also ended up adding a rear board to the car. This addition allowed us to add a hook for the push-pull test. Since our wheels ended up making the car sit relatively high off the ground and the requirement was for the hook to be 1.5-3 cm off the ground, we added this board to keep the hook at the required height while being able to keep our wheels attached. Another addition we had to do was adding brackets to accommodate for the wood pieces not being long enough for the entirety of the chassis we wanted to build. These changes allowed us to meet the dimensional and functional requirements without compromising the structural integrity. Our manufacturing plan changed as we had to stay within the weight limit. Originally, we planned to have two sets of wheels for the car: one set for the speed test and one optimized for torque. However, since the car must carry all the wheels, the total mass of the car was approximately 828 grams, which

was nearly 100 grams over the 725 gram weight limit. To reduce weight, we drilled holes in the wheels, removed the fenders, and removed the front part of the car, since it was structurally unessential. These adjustments brought our car within the weight limit while maintaining functionality. Ultimately, our car weighed 717 grams and was 58 centimeters long and 15 centimeters wide.

Bill of Materials (BOM)

Item	Quantity	Price
3mm Hex Shaft Set	x1	$4.30

Initial Calculations
Coefficient of friction:
Started slipping at 7 degrees
tan(7) = 0.123
Coefficient of friction = 0.123
To get the coefficient of friction we took the tangent of the angle at which it began slipping since that's when the gravity pulling it down is equal to the max static friction force.

Type B Gearbox:
Rotations (Rw) ~ 14,000 RPM
Gear Ratio (GR) = 38.2:1
Radius (R) = 0.14m
Stall Torque (T) = 0.5oz-in = 0.00353Nm
Efficiency (n) = 0.85
Angle 7°
Mu static =.123

Wheel speed (RPM):
Vw = Rw / GR
Vw = (14,000) / (38.2) = 366.49 RPM

Wheel angular speed (rad/s):
ωw = Vw * (2pi / 60)
ωw = 366.49 * (2pi / 60) = 38.37 rad/s

Linear rim speed (m/s):
V = ωw * R
V = (38.37) * (0.14) = 5.37 m/s

Wheel torque with gearbox (Nm):
Tw = T * GR * n

Tw = 0.00353 * 38.2 * 0.85
Tw = 0.1146191 Nm

Max pull force at rim (N):
F = Tw / R
F = 0.01234 / 0.14 = 0.82 N

To find the max velocity and max pull force we took the rpm and gear ratio given for our chosen gear type B. We found the motor stall torque from the given motor characterization charts for the old motor and measured the radius of the wheel in cm. To find the wheel rotational speed we divided the rpm by the gear ratio. Then we multiplied that by 2pi/60 to get the angular speed of the wheel and then multiplied that by the radius to get the linear speed. To find the wheel torque with the gearbox we took the stall torque from the plots given with the old motor and multiplied that by the gear ratio and our predicted efficiency of 0.85. Finally, to get the max pull force at the rim we divided the wheel torque with the gearbox by the radius.

Competition Data

Measured Mu static	Measured Pull Force	Measured Time (Speed Test)
0.123	1.068N	5.25 sec

Performance Analysis

Pull:
Measured Mu static =.123
Measured Pull Force = 1.068N
Theoretical Pull Force = 0.82 N
Error = 30.24%

We expected rather poor results in the pull portion of the competition, however, we were pleasantly surprised when our car beat one of our opponents in Tug o' War and by the results of the pull force test where the car exerted more force than expected. We are unsure why the car was able to exert more force than thought possible. It's possible that the surface texture or measurement uncertainties such as wheel alignment caused us to underestimate the effective friction between the wheels and surface- this would cause the traction to increase. There is a chance the unaccounted for internal friction is another reason for the extra force. We will discuss these unaccounted factors in the speed performance analysis below.

Speed:
t = 5.25 sec
d = 12 m
v = d / t
v = 12 / 5.25

$v = 2.29$ m/s

Error:
$v_{obs} = 2.29$ m/s
$v_{true} = 5.37$ m/s
Error = $(v_{obs} - v_{true}) / (v_{true}) * 100$
Error = (2.29 - 5.37) / 5.37 * 100
Error = 57.35%

Due to the rather extreme design choices for our car, there are a variety of real life forces that we chose to not account for in our simple calculations. We were still highly impressed by the performance of our car, completing the speed test with an average time of 5.25 seconds to travel 12 m. When ignoring acceleration, the average speed of our car was 2.29 m/s. This speed is approximately 60% slower than expected, however, this is understandable as many unaccounted for factors were at play, along with a variety of other errors. Neither calculations account for acceleration, rather just top speed, along with this, internal sources of friction were not accounted for in our initial calculations. Another source of error that occurred was that, during both tests the car hit and drove along the guard rail producing large amounts of friction between the rubberband tires and wooden guard rails. It is clear that this produced significant friction and is likely the main source of error when compared to theoretical calculations. On a smaller note, one of the wheels also came loose from its axle which did not improve the cars capabilities in speed or pull.

Improvements
If we did this project again, we would have spent less time making theoretical designs, and would have started construction sooner. This would have allowed us to do more testing and make necessary changes. Additionally, we could've spent more time ensuring our dimensions were completely accurate as we had to rush towards the end with drilling holes for the axle and attaching the gear boxes which caused it to be slightly angled. We also could have constructed our car out of balsa instead of plywood, so the body would be lighter, allowing for use of the torque tires. When it came time to attach the rubber bands to the large wheels, we went too quickly and did not allow proper time for the rubber cement to dry with pressure. Also it would have been smart to have a print out of the requirements present at every manufacturing day so we could have easily ensured our car met all specs.