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Compact Electric Personal Transport

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Senior Design/Honors Project
Compact Electric Personal Transport

Designed and Manufactured By: James Maganja

Graduation: Spring 2016
Major: Mechanical Engineering
Project Advisor: Dr. Dane Quinn
Readers: Dr. Graham Kelly, Dr. Scott Sawyer
Abstract

The goal of this project was to design a compact and powerful personal transport vehicle around the high performance electric power systems associated with large radio controlled aircraft. The relatively powerful and lightweight components associated with these models are the perfect candidate for this application. The selected electric motor for instance is rated at 3kW of continuous power with a mass of just 384 grams.

There were engineering challenges that arose from using these types of components for a vehicle application. At its designed operating voltage the motor will be spinning at around 25,000 rpm. This will require a novel reduction drive to get useful torque to the rear wheel and a reasonable top speed. Different mechanisms for transferring rotational motion including roller chains, gears, and timing belts were considered before deciding on the 2 stage belt system. The selected arrangement is capable of transmitting 3 kW of power while remaining fairly compact.

The general embodiment of the vehicle is a two wheeled scooter/skateboard hybrid with 20 cm diameter wheels. The goal was to have the simplicity of 2 wheels from a scooter but the compact lean controlled steering of a skateboard. The design of the steering required a unique kinematic 4 bar mechanism that responds reasonably well at low speeds yet still remains stable at higher speeds.

The design phase was assisted with a spreadsheet that models the performance of the finished board based on the chosen battery, gearing, motor, wheel, and rider specifications. This sheet provided everything from top speed and max climbable gradient to estimates of range.

Manufacturing was accomplished with an inexpensive and open source CNC router to keep prototyping costs down. The only other operations required were the drilling and tapping of several holes which was done in the university’s machine shop.

The finished prototype satisfies nearly all of the requirements boasting a 6.3 kg mass, 20 mph top speed, and a range of about 10 miles. And while this vehicle may not appear to solve any immediate societal problems, it does lend itself towards a future where automobiles become impractical due to fuel costs or general congestion. So, with more widespread use of public transportation, this could be a viable “last mile” vehicle to get from point A to B.
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Introduction

Proposed Design Criteria

- Mass of 5 kg or less
- Max speed 40 km/hr
- Range 10 km
- Wheel diameter 20 cm
- 3 kw motor with ~25 k rpm no load speed
- 2 wheels arranged with one in front of the other
- Lean based steering mechanism

10 milestones during 2 semesters

1. Decide if gears, chains, or timing belts are the way to go
2. Determine the arrangement of drive elements that gives the desired reduction ratio
3. Specify parts for the transmission that can be purchased from a manufacturer
4. Determine the kinematics of the lean based steering assembly
5. Decide how elements are going to be linked together and other embodiment principals
6. Choose materials for each element based on calculated stresses
7. Construct a 3D model and create detailed drawings so that each part can be manufactured
8. Purchase all parts and construct the prototype
9. Troubleshoot and test the prototype by logging data to see how it matches the design criteria
10. Organizes all data into the final technical report

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<td>March</td>
<td>9</td>
</tr>
<tr>
<td>April</td>
<td>10</td>
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</table>

Final product specifications

- **Battery**: 10S 3P soldered from Samsung INR18560 25R cells (~260 Wh)
- **ESC**: open source VESC setup in BLDC mode
- **Motor**: Xnova 4025 560 kv 24 slot 8 pole
- **Drivetrain**: 2 stage gates GT3 15 mm width belts with roughly a 16:1 overall reduction (17:60, 26:120)
- **Wheels**: MBS Rockstar Pro for easy pulley mounting, 200 mm diameter tires
- **Deck**: 2x 6mm thick carbon fiber plates roughly 150mm by 600mm
- **Frame parts**: 0.5 inch thick 7075 aluminum
- **Steering**: 4 bar linkage based positive caster system (15 degrees of rotation in each direction)
- **Mass**: 6.7 kg or 14.8 lbs
- **Top speed**: calculated at 38 km/h or 24 mi/h
- **Max gradient**: calculated at 27% with a rider mass of 70 kg
- **Minimum turning radius**: around 3.5 m
- **Range**: around 10 miles typical, but depends on a lot of variables (velocity, rider mass, gradient)
Conceptual Design

- The vehicle was designed around a motor that was on hand; this was the starting point
  - This determined gear ratios and component placement
- To reduce complexity, parts were chosen that were easy to design around
  - The most critical parts were the wheels
    - They determined the general dimensions and layout of the board
    - The specific wheels were chosen because they had 5 bolt hole circle that would be easy to mount the drive pulley to
    - With the wheel diameter and the motor known, the gear ratio could be selected for an intended top speed of 40 km/h
    - Once the gear ratio was found to be around 16:1, it was understood that 2 stages would be necessary
    - Then I started to puzzle how I would arrange the 2 stages to have the most compact orientation
  - The most critical parts were purchased without completing the CAD model
    - The wheels were needed in hand to measure the bolt hole circle to design the 120 tooth drive pulley
    - This also afforded the opportunity to lay the parts out and determine the best way to arrange them before committing to a design

(The “Dirtsurfer”, a similar 2 wheeled inline board with positive caster steering)
Concept Sketches

Early in the design process sketches were used to plan the layout of the drive components, design of the belt tension mechanism, FBD of the steering linkages, and the electrical wiring of the battery.
- lean to right
- force direct to the left through contact point
- initiates rotation about instantaneous center
- rotates wheel clockwise viewed from above

Bushings pressed into linkages

10 mm dia. shaker bolts

Battery wiring layout
- want to minimize the free length of wire
It was important to create a mathematical tool in order to assess the performance of the resulting design. This calculator, that was created in excel, requires input fields for the battery, gearing, motor, wheel, and rider (in yellow). These are used to determine things like the max battery power available, top speed, and max torque at the rear wheel (in green). For the most part these calculations were very simple arithmetic operations, but the benefit was that everything could be updated by changing a single constant or value.

Calculating the estimated range required a bit more work. Similar calculators meant for cyclists found online proved to be very useful. Based on a certain constant velocity, the gravity, rolling friction and aero drag forces can be estimated and totaled to determine the amount of mechanical power required to maintain a certain speed. This information combined with the energy stored in the battery can give an estimate of range.

This is dominated by the aero drag force at higher speeds because is based on the square of the velocity. Any amount of gradient also significantly increases the power required to maintain a certain speed. Essentially the faster the rider travels, the shorter the resulting range.

### Drivetrain Calculator

<table>
<thead>
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<th>output</th>
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<tr>
<td>battery</td>
<td>battery</td>
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<tr>
<td>cell voltage under load</td>
<td>voltage</td>
</tr>
<tr>
<td>3.4</td>
<td>34</td>
</tr>
<tr>
<td>cell capacity (Ah)</td>
<td>capacity</td>
</tr>
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<td>2.5</td>
<td>255</td>
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<td>cells in series</td>
<td>max voltage</td>
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<td>10</td>
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<tr>
<td>cells in parallel</td>
<td>max power</td>
</tr>
<tr>
<td>3</td>
<td>2040</td>
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<td>efficiency</td>
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<td>mph</td>
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<td>23.9</td>
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<td>gradient of hill (%)</td>
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<tr>
<td>0.5</td>
<td>0.26</td>
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<tr>
<td>rider</td>
<td>0-max km/h time (sec)</td>
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<td>mass of rider (kg)</td>
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<tr>
<td>70</td>
<td>0-max km/h distance (m)</td>
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<td>6.7</td>
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<tr>
<td>frontal area (m^2)</td>
<td>max angle of hill (degrees)</td>
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<td>drag coefficient</td>
<td>max gradient of hill(%)</td>
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<td>0.65</td>
<td>27.5</td>
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<tr>
<td>air density (kg/m^3)</td>
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<td>1.226</td>
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</table>
(The power required to maintain a certain speed goes up with the cube of the velocity)
**Embodiment Design**

With the required gear ratios known and timing belts chosen, the Gates literature and design manuals were utilized to select the proper belts and pulleys to handle the previously calculated speeds and torques.

- This was an iterative process to find the optimal arrangement
- Ended up going back and forth as thoughts changed and the voltage of the battery pack was lowered
- Decided to use standard 18560 lithium ion cells for the battery sandwiched between the two carbon fiber plates, so this determined the 20 mm separation distance
- Standardized on M6 threads for all of the bolts so that a single tap could be purchased

**Belt and pulley selection process**

1. Based on the rated torque and speed of the smaller pulley
2. Started with a target reduction of 16 to 1 from the spreadsheet
3. Decided to use the same pulley and belt profile and width for both stages rather than used a different profile for each
   a. That was within the design guidelines in the gates design manual
4. Started with the rated torque of the motor at its max 68 amps
5. Worked backwards from there to determine the intermediate torque and rpm
6. Had to keep at least 6 teeth in mesh on the smaller pulley as according to Gates
7. The motor speed was higher than Gates recommended so values needed to be de-rated accordingly
8. Wanted the shortest belt lengths possible to make the assembly compact
9. Smaller belt pitches are more ideal for higher speeds
   a. For example, a gt5 belt wouldn’t last as long in my application (but could handle more torque)
10. Had to work off of the readily available pulley and belt length sizes that could be purchased
11. Required multiple iteration steps to ensure all of Gates guidelines were met

A lot of time was spent determining how to make the reduction drive as compact as possible. For a given gear ratio this meant using the smallest pulleys with the fewest number of teeth that could still handle the rated torques. And because the rated torque depends on the speed of the pulley, every time the overall gear ratio was changed the values had to be updated.
(This is the intermediate shaft with lightened 60 tooth pulley and 26 tooth pulleys)

<table>
<thead>
<tr>
<th>rpm</th>
<th>velocity (km/h)</th>
<th>Data tables</th>
<th>Fully adjusted</th>
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<tr>
<td></td>
<td>16 tooth</td>
<td>17 tooth</td>
<td>18 tooth</td>
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<td>10</td>
<td>2.08</td>
<td>2.24</td>
<td>2.40</td>
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<td>100</td>
<td>0.2</td>
<td>1.58</td>
<td>1.71</td>
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<tr>
<td>500</td>
<td>1.2</td>
<td>1.23</td>
<td>1.34</td>
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<tr>
<td>1000</td>
<td>2.4</td>
<td>1.08</td>
<td>1.18</td>
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<td>2000</td>
<td>4.8</td>
<td>0.93</td>
<td>1.02</td>
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<td>4000</td>
<td>9.6</td>
<td>0.78</td>
<td>0.86</td>
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<tr>
<td>8000</td>
<td>19.1</td>
<td>0.63</td>
<td>0.70</td>
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<tr>
<td>10000</td>
<td>23.9</td>
<td>0.57</td>
<td>0.64</td>
</tr>
<tr>
<td>12000</td>
<td>28.7</td>
<td>0.53</td>
<td>0.60</td>
</tr>
<tr>
<td>14000</td>
<td>33.4</td>
<td>0.50</td>
<td>0.56</td>
</tr>
<tr>
<td>18000</td>
<td>43.0</td>
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<td></td>
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</table>

- Gates data only went to 14,000 rpm. Had to extrapolate to 18,000 rpm
- 5 teeth in mesh results in a torque reduction of 0.8
- length factor of 0.9 for 219 mm pitch length belt
- length factor of 1.15 for 489 mm pitch length belt
- 15 mm wide belt has a factor of 3.03
Factors of safety were calculated to ensure they were over 1 by some margin.

<table>
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<th>tooth</th>
<th>required</th>
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<th>FOS</th>
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<td>0.98</td>
<td>0.84</td>
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<tr>
<td>17</td>
<td>1.16</td>
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<td>18</td>
<td>1.16</td>
<td>1.54</td>
<td>1.33</td>
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<td>3.88</td>
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<td>30</td>
<td>4.36</td>
<td>6.20</td>
<td>1.42</td>
</tr>
</tbody>
</table>

Gates provided equations used to calculate the center to center distance of a resulting pulley and belt arrangement. This information was valuable within Autodesk Inventor for the modeling process.

**Speed vs. Rated Torque Characteristics**

![Graph showing speed vs. rated torque characteristics for 16, 17, and 18 tooth pulleys.]

- For 16 tooth pulley:
  - Equation: $y = -0.669\ln(x) + 8.0992$
  - $R^2 = 0.9999$

- For 17 tooth pulley:
  - Equation: $y = -0.632\ln(x) + 7.5743$
  - $R^2 = 0.9999$

- For 18 tooth pulley:
  - Equation: $y = -0.476\ln(x) + 5.6395$
  - $R^2 = 0.9999$
Battery Design Process

1. Decided on a 10 cell lithium ion arrangement because that was the max voltage my selected controller and charger could handle
   a. A higher system voltage means I will need less current to draw the same power
   b. Lower currents are easier on electronics and generate less heat
2. Ended up with 3 cells in parallel because 30 cells was the max that I could fit under the deck
3. Balancing the effective power rating of the board
   a. Motor rated for 3000 watts continuous
   b. Battery rated for 2000 watts continuous
      i. Had to account for the voltage sag under load due to the cells internal resistance
      ii. This information was provided by the INR 18650 25R datasheet
   c. Controller rated for about 50 amps continuous and 240 amp burst depending on cooling
      i. At 36 volts nominal that is about 1800 watts continuous

(Finished battery assembly soldered, wired, and tested)
Frame and Structure Design

A major goal of this project was to have a very simple and robust design with the fewest number of individual components. This resulted in certain parts performing multiple tasks such as the 4 struts connecting the carbon fiber deck to the wheel axles. The mounting of these struts was limited by the separation distance between the 2 carbon deck plates at 20 mm. This presented a challenge in designing the struts to handle the large cantilever bending forces due to the weight of the rider. With such a small board design it was important to maximize the available area on top of the deck to give the most freedom of foot placement. This meant that nothing could be mounted to the top of the deck. The final design makes use of an extra member that wraps under the lower carbon plate to offer more resistance to a bending moment.

The following FEM (finite element model) of the entire frame was subject to a 10,000 newton (2,250 lb) distributed load applied to the top carbon fiber deck surface. This magnitude of load could easily be reached with a heavy rider encountering a large bump, or some such similar shock load. The maximum displacement in the middle of the board was just 2.5 mm, but this is a worst case scenario as the riders feet are normally placed very close to the ends of the board. The weakest point appears to be in the middle of the lower carbon fiber plate near the chamfered bolt holes. This and the interface between the aluminum struts and the carbon fiber should be inspection points to check for future damage.
Max von Mises stress of 480 mPa is well below the tensile strength of the carbon.

(The outer 2 aluminum threaded standoffs are loaded in shear due to the bending moment.)

(This simulation took over an hour to run with a mesh size of 1mm.)
**Design of the Steering Geometry**

The steering concept for this project is similar to a bicycle fork in the sense that the axis of rotation is in front of the tire contact patch so that there is a natural "trail" effect. But with the 4 bar linkage, the axis of rotation is an imaginary moving point rather than a fixed one like on a bike. This allows the wheel to pivot about a point that does not require a physical hinge at that location. This has several benefits when compared with the Dirtsurfer which uses a simple pivot located in ahead of the front wheel. The 4 bar linkage approach has nothing in front of the wheel that could potential snag on an obstacle.

(LEGO model used to simulate different steering geometries)

(Simulating the steering geometry to show that the center point does not actually appear stable)
A LEGO model was used to see immediate results to small tweaks in the geometry. The final configuration worked in such a way that it could be given a good push, and it would self-right itself until it lost speed.

The rough linkage ratios from the LEGO version were transferred to the final design. The relative size of the linkages was governed by the 200 mm dia mountain board wheels that had settled on previously.

The positive 15 degree caster angle used was intended to push the contact patch further from the instantaneous center of rotation. The thought was that that would increase the trail effect and make it a little more stable. It also has the benefit of allowing the board to handle bumps and other tall obstacles better than it would without the angle.

A big challenge was to get the front wheel shaft as short as possible. Minimizing this distance increased the angular range that the front wheel could rotate with. This translates to a smaller turning radius. In the final CAD model, there is only 1 mm between the linkage and the spinning aluminum hub. This also required modifying the valve stem so that it was out of the way on the front wheel.

For the linkages bushings were chosen over ball bearings for a couple of reasons:
-a bushing for the same shaft diameter is smaller than a comparable bearing
-bushings can handle higher shock loads and are not going to be upset with a little dirt
-they are also considerably cheaper which was important because 8 were needed

Force is applied at the contact patch of the front tire due to the lateral force of leaning. Because this force is not located at the instantaneous center of rotation of the mechanism, a moment is created. This moment rotates the front wheel in the direction of the lean.
Manufacturing Strategy

- Optimize to machine parts from single square foot sheet of 0.5 inch thick aluminum
  - This was to minimize material cost and minimize the amount of required machining
- Because the carbon fiber used for the 2 deck plates was so expensive it was smart to waste as little material as possible
  - 0.25 inch material thickness was chosen based on very simple beam deflection and bending moment calculations
  - Essentially, one plate could handle the load of the rider, so 2 separated by 20 mm would be more than enough
  - A standard 24 inch by 6 inch plate would clean up nicely to 600 mm by 150 mm without much material waste
- A major goal was to manufacture the board at home without the help of a machine shop
  - This was a great learning experience and gave complete control over the process
    - I got to see firsthand what tolerances really corresponded to
    - Learned a great deal about G-code and CNC programming
    - Got to see what I did wrong in the design stage as I struggled to assemble certain parts
  - The only tools that were available during the build was an inexpensive CNC router, cordless drill, and an angle grinder
  - A drill press was the only other tool that was needed that I got access to from the UA machine shop with the help of Steve and Mike
  - I knew these limitations ahead of time and was able to optimize the design for what was on hand
  - A goal was to show that with the advent inexpensive open source tools like the Shapeoko 2 CNC router, anyone can design and manufacture their own products without having access to machines costing tens of thousands of dollars
  - This prototyping approach was also faster than traditional manufacturing methods
    - Never had to wait on a part to be delivered and could modify something instantly when something sprang up
  - The design had to adapt to the lower manufacturing tolerances that could be achieved with an inexpensive CNC router
  - Was able to build the board for just the cost of materials and tooling, saving thousands of dollars in potential manufacturing costs
  - I gained a better understanding of the strengths and limitations of my CNC setup
- Machining and Assembly observations
  - Required a total of about 18 hours machining time for all of the aluminum parts because the Shapeoko 2 doesn’t have the rigidity or power to go any faster
  - All of the aluminum parts required a great deal of filling and sanding in order to fit together properly
  - Manufacturing and assembly would probably have taken 1/3 the time if a proper CNC milling machine had been used
(Shapeoko 2 CNC router setup to machine the 2 rear struts)

(Layout of all the frame parts on the 0.5 inch thick 7075 aluminum plate)
Bill of Materials

<table>
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<th>Part</th>
<th>Details</th>
<th>Quantity</th>
<th>price per</th>
<th>total price</th>
</tr>
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<td>6.42</td>
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<td>14</td>
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<td>12 mm ID bearings</td>
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<td>INR 18650 25R</td>
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<td>4.72</td>
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<td>VESC speed controller</td>
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<td>Xnova brushless motor</td>
<td>4025 560 kv 3Y</td>
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<tr>
<td>Traxxas transmitter and receiver</td>
<td>salvaged from RC car</td>
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<td>bronze bushings</td>
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<td>M6 shoulder bolts</td>
<td>8 mm shoulder dia</td>
<td>8</td>
<td>1.23</td>
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<td>mountain board tire</td>
<td>8 inch dia, 2 inch wide</td>
<td>2</td>
<td>15</td>
<td>30</td>
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<tr>
<td>mountain board tube</td>
<td>8 inch size</td>
<td>2</td>
<td>7.5</td>
<td>15</td>
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<td>30</td>
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<tr>
<td><strong>Grand Total</strong></td>
<td></td>
<td></td>
<td><strong>1284.25</strong></td>
<td></td>
</tr>
</tbody>
</table>
*does not include consumables, tooling, multiple, or unused parts
**Some parts like the motor and the radio I had on hand
***also does not include shipping or applicable taxes

(Most of the main materials components laid out)
Testing and riding experience for best results
1. Rear foot perpendicular to the length of the board
2. Front foot at a 45 degree angle to the length of the board
3. Steer primarily with the rear foot
4. Balance center of gravity front to back to anticipate acceleration or braking
5. Board struggles at very slow speeds due to the slow steering rate
6. The faster you go the more stable the steering becomes
7. The exposed bolt heads provide a replaceable wear surface when the board comes to a stop
8. Foot placement is critical to avoid rubbing the spinning motor or front wheel

VESC (electronic speed controller) setup
1. Establish current limits
2. Establish voltage cutoffs
3. Regen braking cannot be relied on with a fully charged battery
4. Handheld radio controlled car transmitter as the throttle and brake (seen in the above picture)
What could be improved for Future Revisions?

- Add adjustability to the steering mechanism to allow fine tuning
- Safety really needs to be addressed with things like electronic and a failsafe for the wireless transmitter acting as the throttle and brake
- Better square and concentric machining on the pulleys would result in a quieter drivetrain
- Optimize the parts for waterjet cutting
  - Don’t need the lightening holes in the struts or the slots in the carbon fiber
  - I can save a great deal of time by doing just the off axis machining on the CNC router
- The deck should really be wider for more stability
- Battery should have been spot welded, not soldered (excessive heat damages lithium cells)
- The electrical connectors chosen were overkill for this application
- Pulleys and belts really need a shield or covering to prevent debris from getting in
  - The motor and front wheel also need some shielding to avoid foot contact
- The VESC needs a cooling solution to operate without thermal throttling
- Shoulder bolts are a bit overcomplicated for the 4 bar steering
  - PTFE filled Delrin bushings might be better than bronze bushings which require grease
- 6061 aluminum would be fine to use instead of 7075 to save money
- Simplify the rear wheel tension adjust mechanism
- Damping mechanism for the steering to prevent oscillation and improve low speed performance
- Further optimize part design with FEA to make lighter and cheaper
- Powder coat or anodize the aluminum parts to avoid corrosion
- Stainless steel bolts to avoid rust
- Waterproof the chassis, including the battery, radio receiver, and speed controller
- Gates specifically says that belts should not be relied on for braking forces
  - Might need to design a mechanical caliper brake instead of relying on regenerative braking
  - The two pulley stages are in series, so there is a greater statistical risk of failure
- With a motor with a lower kv value I could likely get away with a single reduction stage
- The hand held radio controller could be a lot smaller and integrate other features like showing the remaining battery level in the board
- An onboard BMS (battery management system) would simplify charging
- Address legal restrictions for this type of motorized vehicle in the United States
Conclusions

This board is a lot of fun to ride on relatively smooth and flat surfaces with gradual turns! When it starts to experience any type of rough terrain, the lack of suspension, makes it a less fun and more terrifying experience at higher speeds. Lowering the tire pressure helps, but there is a reason why skateboards and longboards have thin and flexible decks.

While this board packs more sustained power than a professional cyclist can output, it is hard to take advantage of that in such a small form factor. This, of course, is the sacrifice you make when you design to minimize size. And while the top speed is 24 mph, you have to be somewhat insane to take advantage of that when your only point of contact to the board is two precariously placed feet. Any mistake, no matter how small will result in a tumble.

Modern electric components such as batteries and motors have extremely high power densities allowing these elements to work their way into products typically powered with internal combustion engines. Combining these components with a light and strong chassis, 2 stage belt drive, and 4 bar steering mechanism results in a very compelling product.

From the FEM analysis, the weak points that identified were the central bolt hole locations on lower carbon fiber plate and the 6061 aluminum standoffs that were loaded in shear. The interface between the 7075 struts and the carbon fiber was another location where high stresses were seen. This was universal for each of our three loading conditions.

In general this analysis has shown that the frame of this electric vehicle is strong to the point of being overbuilt. For future revision there are several changes that could be made based off of the interpretation of the preceding results.

- Switch to 6061 aluminum for the struts (was 7075) to reduce the cost while not negatively impacting performance.
- Due to the high tensile strength of the carbon fiber, a plate thickness thinner than 6 mm should suffice while also reducing weight and lowering the cost.
- Remove the standoff location that is directly in the center of the board where the highest stress concentrations were seen. This should increase the strength of the board considerably.
References, Suppliers, and Data Sheets

McMaster Carr- source for all fastening hardware for this project
http://www.mcmaster.com/

Rock West Composites- source for the carbon fiber plate used for the deck
https://www.rockwestcomposites.com/

Online Metals- source of the 7075 aluminum plate and other plastics
http://www.onlinemetals.com/

Royal Supply- had all of the Gates belts and pulleys for this project

Gates corporation pulley design tools

Samsung INR 18650 25R lithium ion specification sheet

Xnova brushless motor specification sheet
http://www.xnovamotors.com/xnova-4025-560kv/

The Endless Sphere online forum dedicated to homebuilt electric skateboards and scooters
https://endless-sphere.com/forums/viewforum.php?f=35&sid=ae8638fa58c9ae8aebd80ce4440fedd4ba0

An interactive cycling power and speed calculator used as the basis of my spreadsheet
http://www.gribble.org/cycling/power_v_speed.html

Vedder’s open source VESC specifications
http://vedder.se/2015/01/vesc-open-source-esc/

General information on 2 wheeled vehicle dynamics
https://en.wikipedia.org/wiki/Bicycle_and_motorcycle_dynamics

Special thanks to Ryan Hayes for helping during the manufacturing process in the ASEC machine shop
Appendices
Miscellaneous Pictures

(Alternate rendered view of the complete design)

(Early design with the motor offset to one side as opposed to located centrally)
(The purchased 120 tooth pulley required modification to mount on the rear wheel)

(Motor mount incorporates a sliding mechanism to adjust belt tension)
(Machined copper solder bars)  (Machined acetal battery cell holders/spacers)

(Soldered group of 6 cells arranged with 2 groups of 3 cells in parallel)
(External battery balance charging setup with the Icharger 4010 duo)

(Finished steering links with bronze inserts press fit)
(The VESC, the open source speed controller designed for electric skateboards)

(Compartment where the VESC and 2.4 GHz radio receiver sit)
Deck Assembly

Motor mount 2

7075 aluminum

Global tolerance +/− 0.1 mm

DIA 01 12/20/2016

Scale 1:1

Rev. 1

Sheet 1 of 1

12.70

47.00

30.00

6.35

6.25

17.30

M6x1 - 6H
steering block
Deck Assembly

total tolerance +/- 0.1 mm
Global tolerance: +/ - 0.1 mm