SAE Baja - Drivetrain

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Team 11

Engineering Analysis

Document

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1.0 Introduction

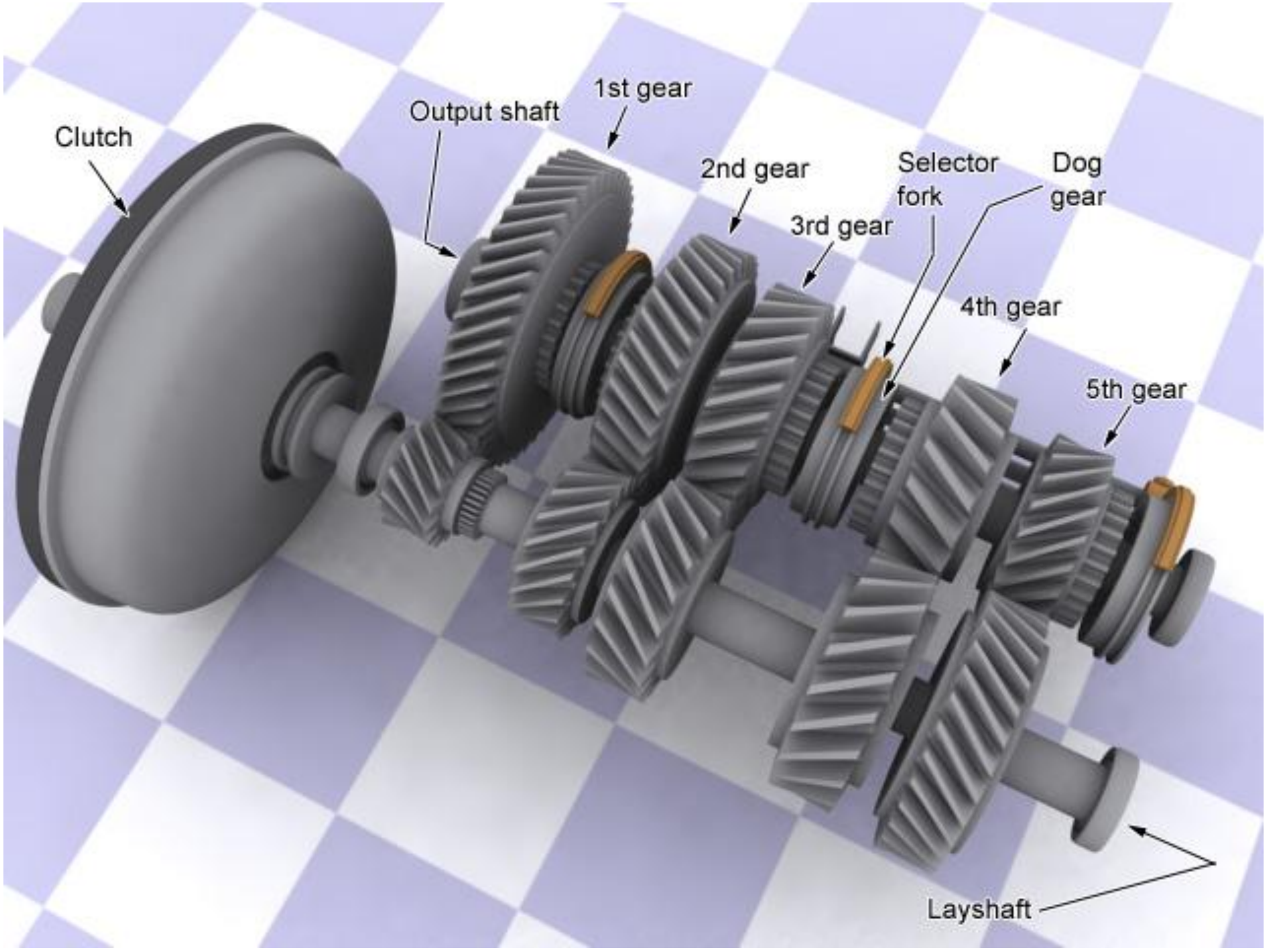
The Northern Arizona University Chapter of the Society of Automotive Engineers (SAE) has instructed our team to design and build a vehicle for the Baja SAE Series. This entails designing a single seat off road vehicle capable of performing in the top 10 in the collegiate competition at Portland, Oregon from May 27-30, 2015. This competition is a challenge for colleges to design an off road vehicle capable of exceptional performance and customer appeal. The performance aspect of the vehicle is measured from the accomplishments of the vehicle in 5 dynamic events: the Acceleration, Hill Climb, Maneuverability, Rock Crawl, and Endurance challenges.

The drive train team is responsible for the design of the engine through to the wheels. This will include the engine, transmission, differential, and any power transmitting shafts. The engine is a constraint in our design, as SAE requires the use of a Briggs & Stratton Model 20 engine. This specific model of engine proposes a challenge due to its maximum power output being 10 horsepower. Our particular engine is only 8.5 horsepower, which was discovered through the use of a dynamometer.

This year's drive train team has set a goal of placing in the top ten in two specific events: Acceleration, and Hill Climb. These events were chosen because the Baja's overall performance in these individual events depends greatly on the design and execution of the transmission design. The set performance goals to achieve this objective are to complete a 100 foot distance in 4 seconds from a complete stop, and for the vehicle to be able to drive up a hill of about 60 degrees. The contents below describe the analysis on the two chosen designs - a sequential transmission and a manual transmission - to prove both logically and mathematically which transmission will be used in the NAU Baja during the May 2015 competition.

2.0 Manual Transmission

One of the two designs the team chose to continue with is the manual transmission. The design of a manual transmission is fairly complex, but the team has chosen this as a possible design because it meets all of the requirements as requested by the client. A physical representation is shown below in Figure 2.1.



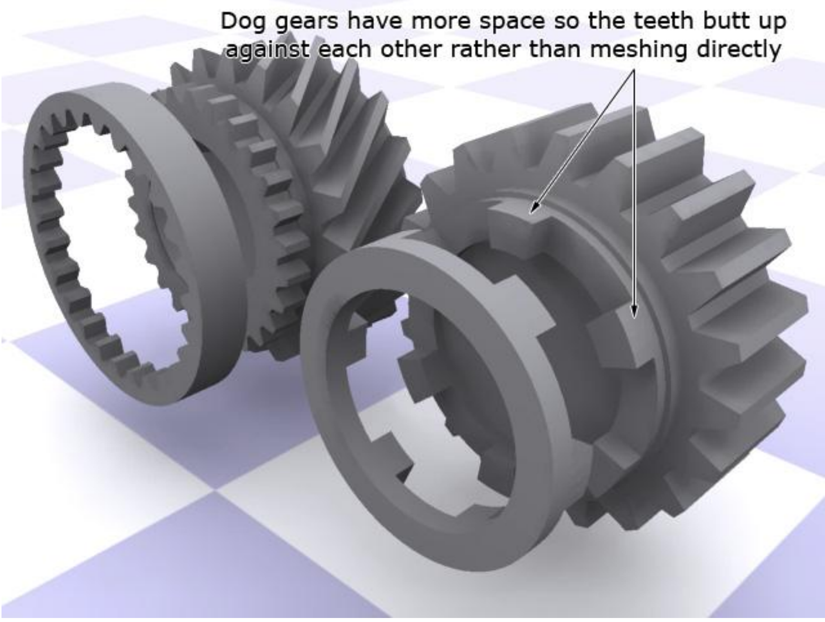
(Manual Gearbox, Figure 2.1)

The gear sets are driven by an input shaft that is connected to a clutch. The clutch acts as a means of transmitting power by engaging a spring or hydraulic lever that will connect or disengage the input shaft to the set of gears. In order to shift from one ratio to the next, a shift fork is used to choose each gear. The shift fork is connected to a lever that the operator may use to select any gear he wishes. The gears are engaged by the use of a dog ring that is connected to one of the shift forks. In a manual transmission, the dog ring and gear must match up in a 1:1 ratio in order to shift into each gear. In order to do this, the clutch must be engaged each time the operator wants to shift into another gear.

There is a drawback to the manual transmission, however, as there is a loss of power that will occur in between each shift. On average, it takes around 1-2 seconds to shift between each gear, depending on which gear is being selected. The clutch must also be used when engaging and disengaging each gear ratio. Between each shift, there is a brief period where there is no power being transmitted to the wheels. This can negatively impact the teams overall performance in both the Hill Climb and Acceleration tests, since there will be wasted time engaging and disengaging the clutch between each shift.

3.0 Sequential Transmission

The sequential transmission is nearly identical in every aspect to the manual transmission, except for the way in which the gears are selected. The sequential dog ring has a square geometry, as shown in Figure 3.1, and thus more room to engage to the gear. This allows the gear and ring to engage at different speeds, as opposed to a manual gearbox which requires both the gear and ring to be spinning at the same 1:1 ratio in order to engage the two. This means the clutch does not have to be engaged each time the operator wants to shift from one gear ratio to the next.



(Manual (left) versus Sequential (right) Dog Ring, Figure 3.1)

There are many advantages when using a sequential transmission. First, there is little loss of power because the clutch does not need to be engaged in between each shift. On average, it takes around two-tenths of a second to shift into each gear. This means there will be a minimal amount of time power will not be transmitting to the wheels, which causes an increase in performance during acceleration.

4.0 Final Design Selection and Analysis

This section will introduce the final decision matrix of the drive train, the analysis of the Hill Climb and Acceleration Challenges, and detail the team's final assembly.

4.1 Selection

This is the Decision Matrix the Drive Train Team came up with in order to determine which of the transmissions, manual or sequential, to begin analyzing and testing:

(Decision Matrix, Table 4.1)

Scale 1-5 5 = Best, 1 = Worst	Cost	Gear Ratio Range	Efficiency (Loss of Power)	Weight	Simplicity of Design	Reliability	Size/Volume	Reverse Gear Capable	Total
Sequential	3	5	5	4	3	4	4	3	3.95
Manual	3	5	4	3	4	4	3	4	3.85
Customer Weighting	15%	15%	20%	10%	5%	10%	5%	20%	

From the data that the Decision Matrix provides, it becomes clear that the team should pursue evaluation of the sequential transmission, as it will be more efficient, lighter, and overall smaller than a manual gearbox.

4.2 Gearing Analysis

4.2.1 Hill Climb

To begin the engineering analysis for the Hill Climb Challenge, the team used Google, the transmissions text, and equations stated in texts from previous classes in order to find the static, friction, and drag forces on the Baja. Any equations not shown in this section have been stated in the References/Equations section at the end of this report. Based on last year's Hill Climb in El Paso, Texas, last year's average wind speed in May in Portland, Oregon, as well as the altitude of Portland, the team assumed a hill angle of 60 degrees, a coefficient of drag of 0.62, a wind speed of five miles per hour, and an air density of 0.00228 slugs per cubic foot. Then, the team assumed a coefficient of friction of 0.16, based off a table in the transmissions textbook for driving over dirt, the maximum surface area of the Baja to be 9.98 square feet, the power of the supplied Briggs & Stratton engine to be 8.5 horsepower, or 4675 pound-feet per second, and the weight of the Baja to be six hundred pounds.

With these assumptions in mind, the team generated that the static force pulling down on the Baja to be 519.615 pounds, the friction force to be 48 pounds, and the drag force to be 0.379 pounds, leading to a total resisting force of 567.994 pounds. To calculate the velocity of the Baja travelling up the hill, we divided the power of the engine from the total resisting force, giving us a velocity of 5.616 miles per hour. From this, Team Drive Train decided to be conservative, and assume an overall resisting force of 600 pounds and a vehicle velocity of 6 miles per hour.

Assuming this 600 pound force resisting the vehicle's upward momentum, an upward angle of 60 degrees, and the engine's production of 8.5 horsepower, the team can achieve a velocity of 6 miles per hour up the hill, as stated previously. The maximum torque the engine can output is 14.5 foot-pounds in the range of 1800-2800 rpms.

With this in mind, the team used a gear ratio formula in order to find the optimum ratio that would keep the engine between 1800-2800 rpm at a 60 degree incline. First the angular velocity of the wheels were found to know exactly how fast the engine speed is, in relation to how fast the wheels would need to be turning using this formula:

$$\omega = \frac{v_{Baja}}{R_{Wheel}} = 91.67 \text{ rpm}$$

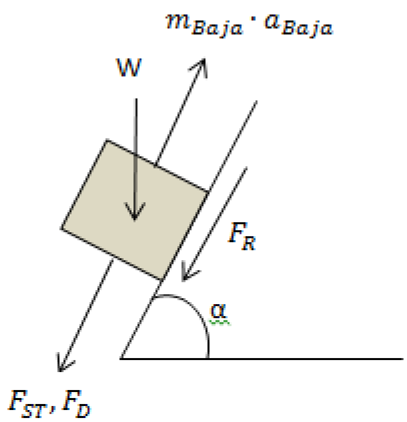
Relating the angular momentum to the engine speed to find the gear ratio needed using these formulas:

$$Gear\ Ratio_{min} = \frac{N_{min}}{\omega} = 19.63{:}1$$

$$Gear\ Ratio_{max} = \frac{N_{max}}{\omega} = 30.54{:}1$$

$$Gear\ Ratio_{avg} = \frac{N_{max} - N_{min}}{2\omega} = 25.089{:}1$$

We found that the minimum gear ratio that is needed at 1800 rpm is 19.63:1, and the ratio needed at 2800 rpm is around 30.54:1. The team decided to take the average of these two ratios at 25.089:1 so that the engine would stay in the range of 1800-2800rpm.



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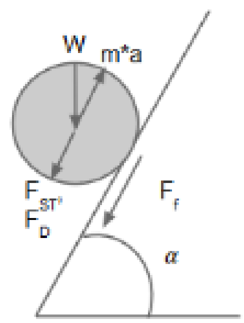


(Hill Climb Free Body Diagram, Figure 4.1)

4.2.2 Acceleration

The Drivetrain team has set the goal of achieving a 100 ft distance in 4 seconds from a dead stop on pavement. To start our calculations the team used the basic dynamics formula to find the required constant acceleration to achieve the desired goal

: $Distance = x = 100\ ft$ Time = t = 4 seconds Initial Velocity = V_0 = 0 ft/s

$$x = V_0 * x * t + 0.5 * a * t^2$$

$$a = {}^{2*x}/_{t^2} = 12.5\ ft/s^2 \qquad V_{Final} = a * t^2 = 33.733\ \text{ft/s}$$

Then using the forces of resistance on the vehicle: air resistance, and rolling resistance, the team calculated what the total resistance force on the vehicle would be as follows for Low Gear when V = 0 ft/s and High Gear when V = 33.733 ft/s.

Mass (m) = 18.65lbm Cross Sectional Area (c_a) = 9.92 ft^2 Resistance Coefficient (c_w) = 0.62

$$F_{Accel} = m * a \quad F_{Roll} = f_r * m * g \;\; F_{Air} = 0.5 * p_l * c_w * c_a * V^2$$

$$F_{Total\ Low\ Gear} = 241 \text{ lbf} \quad F_{Total\ High\ Gear} = 250 \text{ lbf}$$

Using this information and the engine torques at the idle (1800) and top (3900) rpm the team than calculated what the needed overall gear ratios were for Low and High Gear for the acceleration challenge.

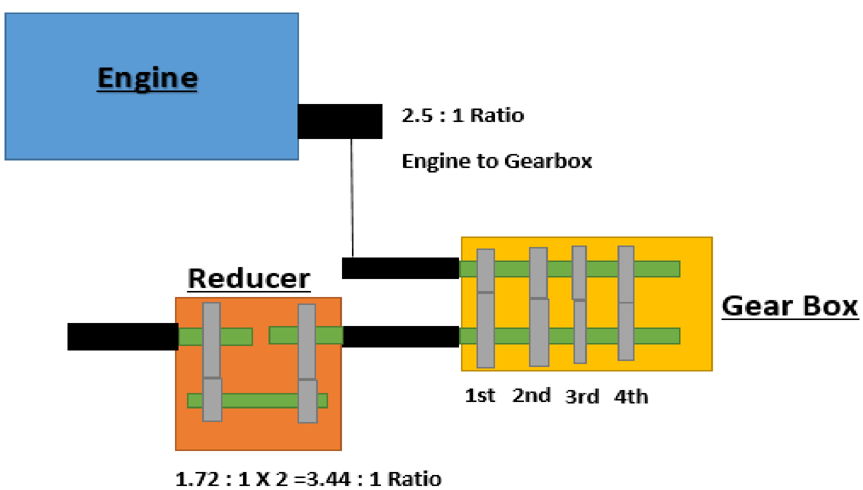
$$R_{Tire} = 11\text{in} = 0.9166 \text{ ft} \;\; \tau_{Low} = 10\, ft * lbf \qquad \tau_{High} = 13\, ft * lbf$$

$$Ratio = \frac{F_{Total}}{2} * R_{Tire}\,(ft)\,/\tau$$

From this we got that the Low Ratio needed to be 11.05: 1 and the High Ratio needed to be 8.8: 1. From the power curve calculations we calculated that the middle gear should be around 9: 1

4.2.3 Gear Ratio Selection

In Figure 4.2 is a basic concept representation of our drive train layout.



1st Gear: 2.5 x 2.4 x 3.44 = 24.16:1

2nd Gear: 2.5 x 1.25 x 3.44 = 10.75:1

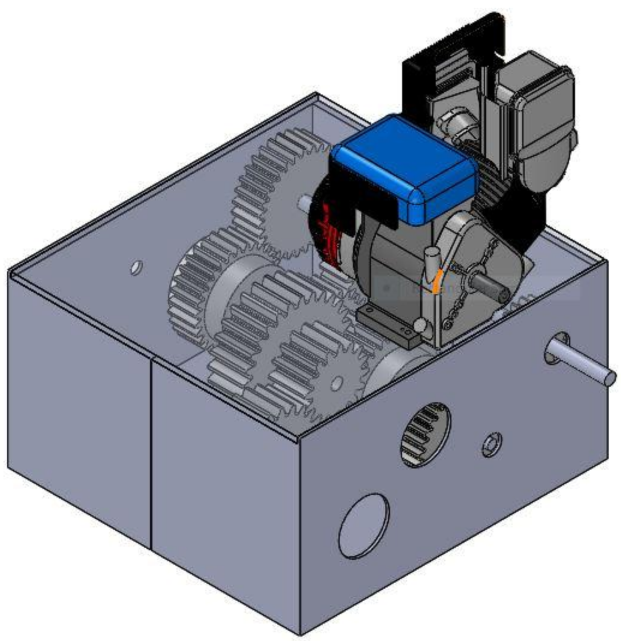
3rd Gear: 2.5 x 1.033 x 3.44 = 8.88:1

4th Gear: 2.5 x 0.967 x 3.44 = 8.31

(Gear Selection, Figure 4.2)

4.2.4 Final Assembly

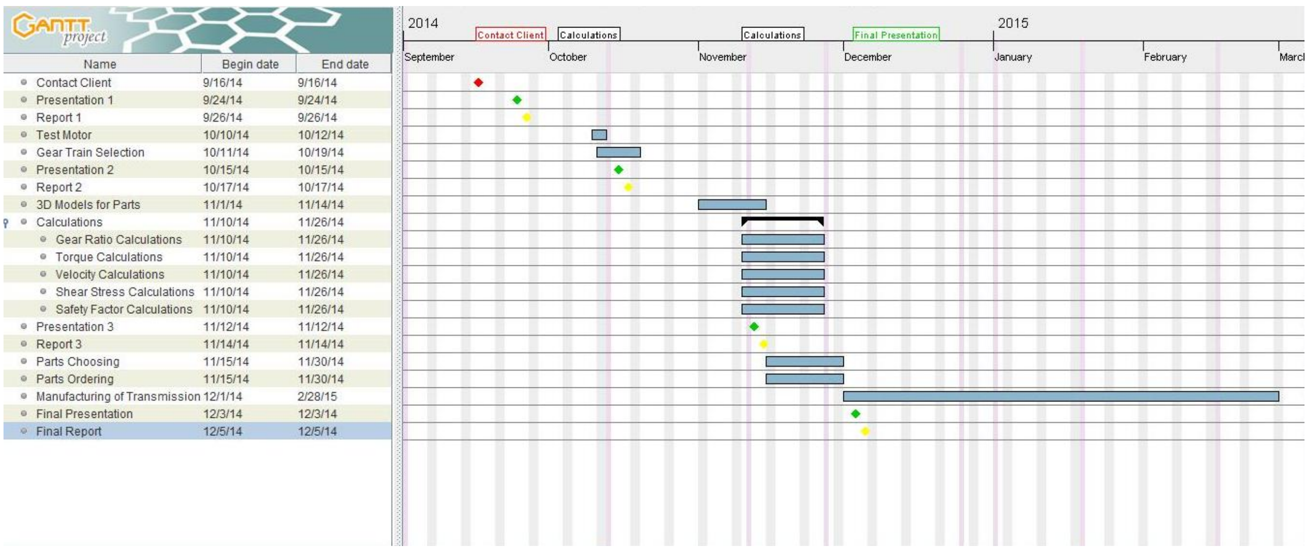
In figure 4.3 is a preliminary cad assembly of the drivetrain transmission and engine combination. It is currently sitting at 2 in x 2 in x 13 in and weights 130 lbs. This is still larger than our desired dimensions and weight. The will be further optimization of layout and materials to reduce weight and size.



(Preliminary CAD Assembly, Figure 4.3)

5.0 Project Plan

The drive train team has been progressing through the project's plan, as displayed in the team's Gantt Chart, shown in Figure 4.1. However, the "Calculations" and "Parts Choosing" sections were pushed back a couple of weeks, due to illnesses throughout the team and because two of the drive train team members were away between November 4-6, 2014 at SEMA, an automotive convention, attempting to find sponsors for the entire Baja team. Luckily, a couple companies seemed interested in sponsoring the group, which will immensely help the team.



(Gantt Chart, Figure 5.1)

6.0 Conclusion

In conclusion, the Drive Train Team chose to use and analyze the design of the sequential transmission for the Baja vehicle, due to its superiority over the manual transmission, for the Baja Team's purposes. After selecting which transmission to implement into the vehicle, the team calculated the forces against the vehicle in the Hill Climb Challenge. Using this data, the Drive Train Team then calculated the gear ratios needed to climb up the hill in a reasonable amount of time. From there, the team assumed moving 100 feet in around 4 seconds for the Acceleration Test, letting the vehicle's top speed hit around 35 miles per hour; gear ratios again were calculated to take these values into account. Afterwards, Team Drive Train compared the gear ratios needed for the Hill Climb and Acceleration Tests, respectfully, which led to the final gearbox assembly.

7.0 References/Equations

7.1 References

1. The Transmission Bible: Transmission, or Gearbox?, Manual vs. Sequential Dog Ring Picture
    a. http://www.carbibles.com/transmission_bible.html
2. Transmissions Textbook: Lechner, G., Harald Naunheimer. Automotive Transmissions: Fundamentals, Selection, Design and Application. Berlin: Springer, 1999.
3. Direct Drive Picture
    a. http://alooroea.blogspot.com/2011/05/manuel-transmission.html

7.2 Equations

1. $W = 600\ lb$
2. $f_R = 0.16$
3. $c_D = 0.62$
4. $P = 8.5\ hp = 4675\ \frac{lb \cdot ft}{s}$
5. $\alpha = 60°$
6. $A = 9.98\ ft^2$
7. $\rho_{air} = 0.002278233594351\ \frac{slug}{ft^3}$
8. $v_{wind} = 5\ mph = \frac{22}{3}\frac{ft}{s}$
9. $F_{ST} = W \cdot \sin(\alpha) = 519.615\ lb$
10. $F_R = f_R \cdot W \cdot \cos(\alpha) = 48\ lb$
11. $F_D = \frac{1}{2} \cdot \rho_{air} \cdot c_D \cdot A \cdot v_{wind} = 0.379\ lb$
12. $F_{total} = F_{ST} + F_R + F_D = 567.994\ lb \sim 600\ lb$
13. $v_{Baja} = \frac{P}{F_{total}} = 8.236\ \frac{ft}{s} = 5.616\ mph$
14. $R_{Wheel} = 11\ in = 0.916\ ft$
15. $N_{min} = 1800\ rpm$
16. $N_{max} = 2800\ rpm$
17. $T_{Wheel} = R_{Wheel} \cdot F_{Total} = 550\ lb \cdot ft$
18. $x = V_0 * x * t + 0.5 * a * t^2$
19. $a = {2 * x}/{t^2}$
20. $V_{Final} = a * t^2$
21. $F_{Accel} = m * a$
22. $F_{Roll} = f_r * m * g$
23. $F_{Air} = 0.5 * p_l * c_w * c_a * V^2$
24. $Ratio = \frac{F_{Total}}{2} * R_{Tire}\ (ft)\ /\tau$