2018 University of Cincinnati SAE Baja Dynamometer

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By

Dennis Dickerson

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Thesis Advisor:

Dean Allen Arthur

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ABSTRACT

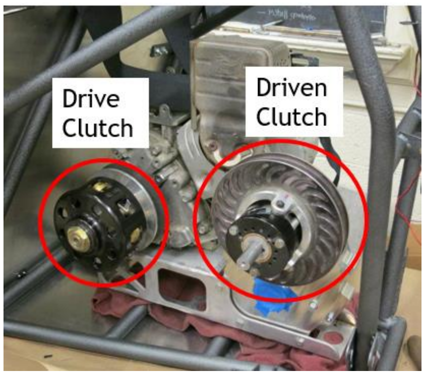
The Society of Automotive Engineers (SAE) holds Baja competitions for colleges around the world. These colleges come and compete their Baja's in competitions such as acceleration, hill climb, maneuverability and endurance. In SAE Baja, not knowing the output of different continually variable transmission (CVT) clutch configurations can mean the difference between first and last place. To measure the output at the wheel of different CVT configurations a dynamometer must be used.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

The #6 University of Cincinnati Baja currently has a continually variable transmission (CVT) as its transmission. In a CVT there are 2 clutches present: a drive clutch and a driven clutch (see figure 1). The drive clutch contains roller weights (on 4 arms) and a spring while the driven clutch contains just a spring. The team had no current (in house) way to test the outputs of different combinations of drive clutch weights/springs and driven springs to see which would be best for applications such as hill climb and acceleration tests. The design and build of a dynamometer would provide a solution to this problem.

Figure 1: CVT System



BACKGROUND

The goal in Baja SAE is to design, build and race off-road vehicles that can withstand elements of rough terrain against many different colleges around the country. These vehicles are often similar in appearance to dune buggies with large tires and a complete role cage that completely protects the driver. One main component of these cars is the suspension which allows for the cars to travel over rough terrain at high speeds by conforming to the terrain. This is made possible by combining long wheel travel, high ground clearance, strong structural frame ect.

The University of Cincinnati currently has three cars that are in various stages of their life. The most recent is the #6 car which currently sits as a completed car however it has never been certified for competition and has many design flaws. The remaining two completed cars are both still fully functional and certified, which will serve as great models for testing.

We are proposing a redesign of multiple aspects of the #6 Baja car that include but not limited to; front and rear suspension, cage design, ergonomics and a **dynamometer**. These improvements are needed for the car to be fully capable within the requirements for the 2018 SAE Baja competition. These were completed in time for the Spring 2018 competition.

RESEARCH

CURRENT STATE OF THE ART

UC's Baja team has not previously owned a dynamometer. There are currently a few designs out in the market. Three current designs in the market today are motoring/driving dynamometer, absorption/passive dynamometer and a universal/active dynamometer (5). Motoring/driving dynamometers are when the motor drives something such as a pump (5). An absorption dynamometer is one that is meant to be driven (5) and a universal/active dynamometer is one that can either drive or absorb (5).

END USER

The end user for the dyno will be the UC's current and future years Baja team. The dynamometer will be designed based off the Baja Teams requirements. This includes the need for the dyno to be above ground, as portable as possible, torque/power data must be obtained from dyno and must dissipate load safely.

CUSTOMER FEATURES AND OBJECTIVES

Weighted importance of design specifications from Baja Team:

0.25 - Safety
0.15 - Weight
0.20 - Above Ground
0.10 - Ease of Use
0.10 - Durability
0.15 - Cost
0.05 - Easy to Maintain

- Safety
  - Design will adhere to UC's require protection
  - Design will be able to operate safely
- Weight
  - Weight must be enough to not move during operation
- Above Ground
  - Apparatus must be above ground.
- Ease of Use
  - Operation from start to finish must be less than 10 steps
- Durability
  - Dynamometer must be able to withstand load from heaviest Baja
- Cost

    - Fabrication of parts will be done in house to reduce cost
    - Design must not exceed budget
- Easy to Maintain
    - Maintenance must be kept to a minimum
    - Use of universal parts, easy to replace

DESIGN

DESIGN ALTERNATIVES AND SELECTION

There were a few different design alternatives throughout this project. Figure 2 below shows the first design. This design contained 2 rollers that would be coupled to a load output such as a motor or pump. This design also contained 4 holes in the box so the Baja could be loaded down with straps. Figure 3 shows the second design I had come up with. In this design a pump was directly attached to the Baja and a pulley/v-belt or sprocket/chain system would couple to the wheel. This design was voided because the Baja contained a differential in the rear drive. This means that if one wheel got stuck the other wheel can still spin freely due to the differential. Figure 4 shows the third design concept. The idea of this design was to attach a spur gear to the wheel and have 2 rods that the wheel spur gears would sit on. This idea was voided as well due to the fact that manufacturing spur gears is difficult. Figures 5 and 6 show the chosen design for this project. This design contains 2 rollers that are attached to 3 bearings a piece. These bearings sit on risers which are attached to a base plate. One of the rollers is coupled via a love joy coupling to a hydraulic oil pump. The pump is attached to a hydraulic oil reservoir and the hydraulic system contains: a control valve, flow meter, pressure gauge and a non-contact tachometer.

Figure 2: First Design

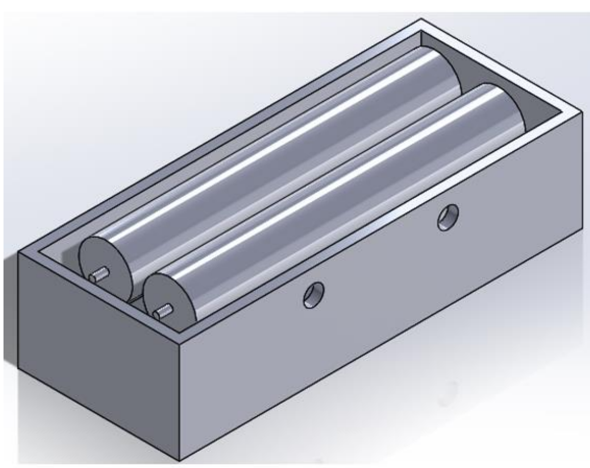


Figure 3: Second Design

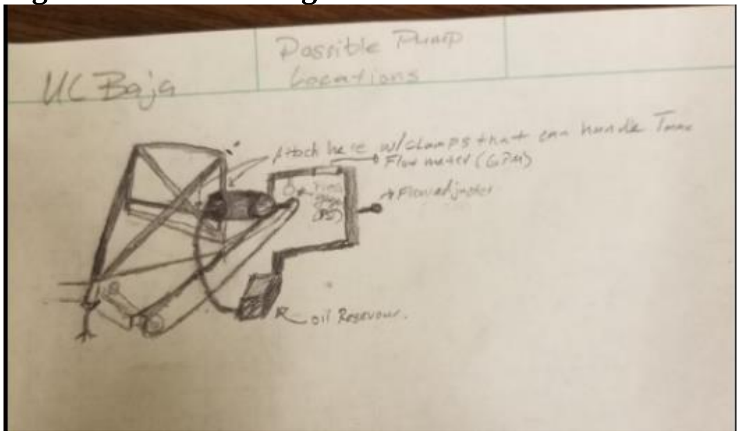


Figure 4: Third Design

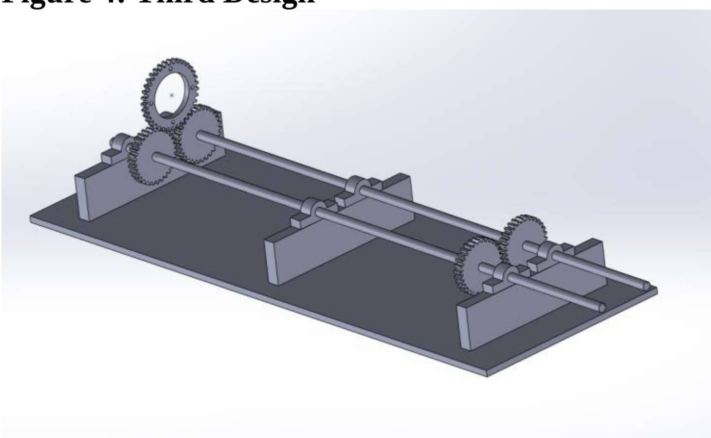


Figure 5: Fourth Design (Drawing)

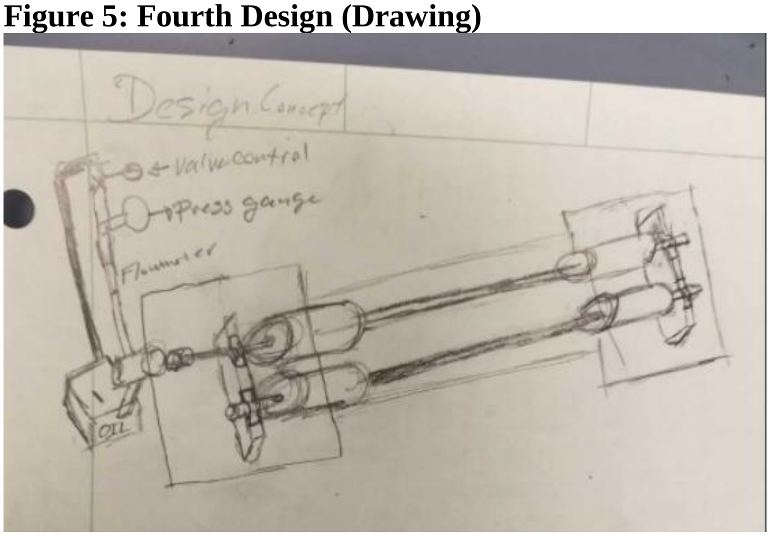


Figure 6: Fourth Design (3d Model)

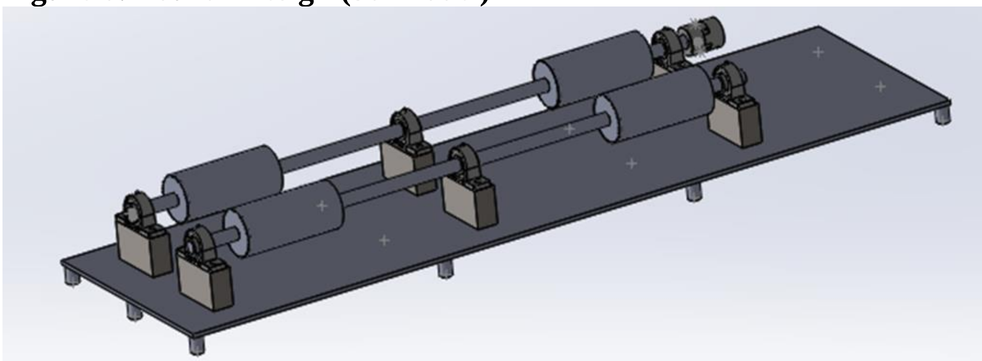


Figure 7: Fourth Design Build

LOADING CONDITIONS

There were a couple of calculations that were key for this design. These calculations included circumference of the wheel, max MPH to ft/min, max RPM of the wheel and max torque experienced at the wheel. Figure 8 shows these calculations below.

Figure 8: Loading Calculations

HP of Engine: 10hp

Maximum MPH: 31.7mph

Diameter of Wheel: 22in (1.83ft)

1. **Circumference of wheel**
   C = pi*Diameter
   C = 3.14 * 1.83ft
   C = 5.75ft
2. **MPH to ft/min**
   (31.7mph) * (5280 ft./mi) * (1hr/60mins)
   ft./min = 2789.6
3. **Max RPM of Wheel**
   (2789.6 ft/min)*(1rev/5.75ft)
   Max RPM of Wheel = 485.15 RPM
4. **Torque at Wheel**
   T = (HP * 5252)/RPM
   T = (10 * 5252)/485.15
   T = 108.25 ft-lbs

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

Cost

The initial cost for this design was aimed to be right around $1000. The total cost of this design ended out being just over $1600 (see table 1 below). One explanation for this project going over budget would be the cost of the CVT kit from Gaged Engineering. This kit was not initially thought of in the beginning of the project.

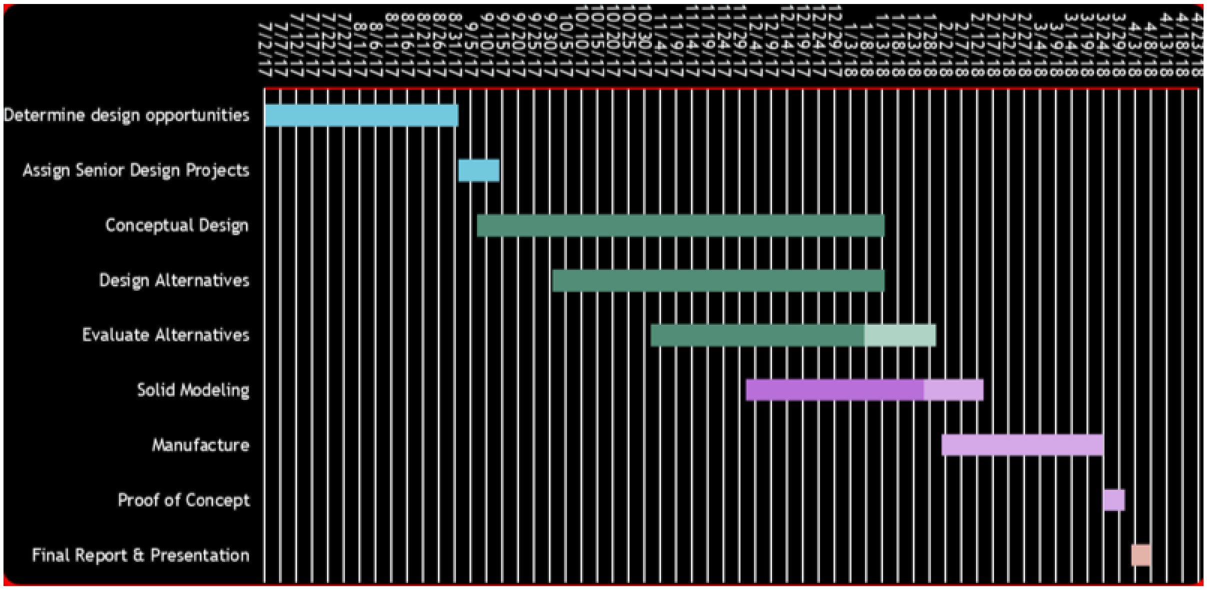
Table 1: Bill of Materials

Decription	Amount
Bearings	63.8
Tachometer/Pressure Gauge	42.46
Scrap Yard 3/27/18 (Risers, Pump Plate)	73.57
Scrap Yard 3/8/18 (Through Rod for Rollers)	149.8
Scrap Yard 2/27/18 (Base Plate, Rollers, End Caps)	267.5
Mcmaster Carr 4/3/18 (High Pressure Piping)	499.24
Gaged Engineering CVT Kit	448.5
Hydraulic oil and Straps	78.77
Total	**1623.64**

SCHEDULE, PROPOSED /ACTUAL

The schedule shown in figure 9 below was followed for the most part. The manufacturing ran over schedule by about a week which also pushed back the proof of concept by about a week.

Figure 9: Schedule



TESTING AND RESULTS

The testing procedure and after operation analysis can be seen in appendix A. As stated previously in this report, there were a total of 12 CVT combinations. These combinations can be seen in figure 12 below. The testing set-up can be seen in figure 13. The combinations that were tested to prove out this design were 4,5,6,10,11 and 12. Appendix B shows the testing results and graphs obtained from testing.

Table 2: CVT Combinations

Drive: Stiff Driven: Stiff			
	Combination 1	Combination 2	Combination 3
Drive Spring	Orange	Orange	Orange
Driven Spring	Red	Red	Red
Weight per arm (g)	118	130	140

Drive: Stiff Driven: Less Stiff			
	Combination 4	Combination 5	Combination 6
Drive Spring	Orange	Orange	Orange
Driven Spring	Yellow	Yellow	Yellow
Weight per arm (g)	118	130	140

Drive: Less Stiff Driven: Stiff			
	Combination 7	Combination 8	Combination 9
Drive Spring	Black	Black	Black
Driven Spring	Red	Red	Red
Weight per arm (g)	118	130	140

Drive: Less Stiff Driven: Less Stiff			
	Combination 10	Combination 11	Combination 12
Drive Spring	Black	Black	Black
Driven Spring	Yellow	Yellow	Yellow
Weight per arm (g)	118	130	140

Figure 10: Testing Set-up

CONCLUSION AND RECOMMENDATIONS

CONCLUSION

From the data obtained it can be said that clutch configuration 12 is the worst set up for the Baja. For the application of Baja events of hill climb and acceleration it can be said that clutch configuration 4 is the best. For hill climb it is ideal to have a higher torque at lower rpms. Clutch configuration 4 has the highest torque at lower rpms. This can be seen in appendix b “Wheel Speed vs Torque @ Wheel” graph. If clutch configuration 4’s data set was continued to lower speed, it would produce the most torque at the wheel. For acceleration it is ideal to have more HP at lower rpms since more HP equates to faster/better acceleration. The graph “Wheel Speed vs. HP at Wheel” shown in appendix b supports this claim. Clutch configuration 4 produces the most HP at lower rpms. Once again if configuration 4’s data set was continued to lower speed, it would produce the most HP at the wheel at lower rpms.

RECOMMENDATIONS

Since completing this design project, there are a few recommendations I have. First and foremost I would recommend using electronic gauges. If these were used instead of the analog gauges I used, the data would be more accurate. Another recommendation I have for this project would be to design the rollers out of a higher friction material. When testing on one of the old Baja’s with thinner tires, it seemed to slip a bit when a load was applied. This wasn’t a big problem when testing the thicker tire of the #6 Baja. One more recommendation I have for this project would be to have a rubber mat underneath the baseplate. Vibration was present when testing which caused very loud noises.

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APPENDIX A – OPERATING INSTRUCTIONS/RECORDING SHEET/AFTER OPERATION ANALYSIS

Dynamometer (Dyno) Operating Instructions

Notes: Proper PPE **MUST** be worn during operation of the dyno. This includes steel toe footwear, safety glasses and ear plugs. This procedure must be done in an approved ventilated area.

1. With the lift or help of team members place the baja onto the dyno.

2. Secure the baja to the dyno by placing stops on front 2 tires and tightening the baja with straps on the 6 eye bolts on the baseplate.

3. Once baja is secure to the dyno, one team member should be in the driver seat.

4. With the control valve fully, another team member should start the engine and the driver should apply the gas pedal about halfway down. This should happen for about 5 minutes or until the oil reaches a consistent temperature.

5. Once oil is to temperature the driver shall keep the gas pedal pressed down all the way. Another team member shall then record the wheel RPM and flow from flowmeter at pressure readings of: 150psi, 500psi, 750psi, 1000psi, 1500psi and 2000psi.

Recording Sheet

	Clutch Assembly: "X"					
PSI	150	500	750	1000	1500	2000
Actual Wheel RPM						
Wheel MPH						
Flow (GPM)						
Calculated HP						
Calculated Torque						

After Operation Analysis

After Wheel RPM, GPM are obtained at psi ranges, a graph of MPH vs HP/Torque will be constructed.

1. **Power** will be obtained from the dyno runs. This is calculated by: $\boldsymbol{HP = \frac{PSI * GPM}{1714}}$
2. **Speed** will be calculated from the dyno runs. This is calculated by $\frac{"X"\ REV}{min} * \frac{5.75ft}{1REV} * \frac{60min}{1hr} * \frac{1mi}{5280ft}$ = **“x” mph**

APPENDIX B – `

	Clutch Assembly: 4					
PSI	150	500	750	1000	1500	2000
Actual Wheel RPM	313	288	279	270	255	232
Wheel MPH	20.45	18.82	18.23	17.64	16.66	15.16
Flow (GPM)	2.25	2.00	2.00	1.88	1.75	1.50
Calculated HP	0.20	0.58	0.88	1.09	1.53	1.75
Calculated Torque	3.30	10.64	16.47	21.28	31.54	39.62

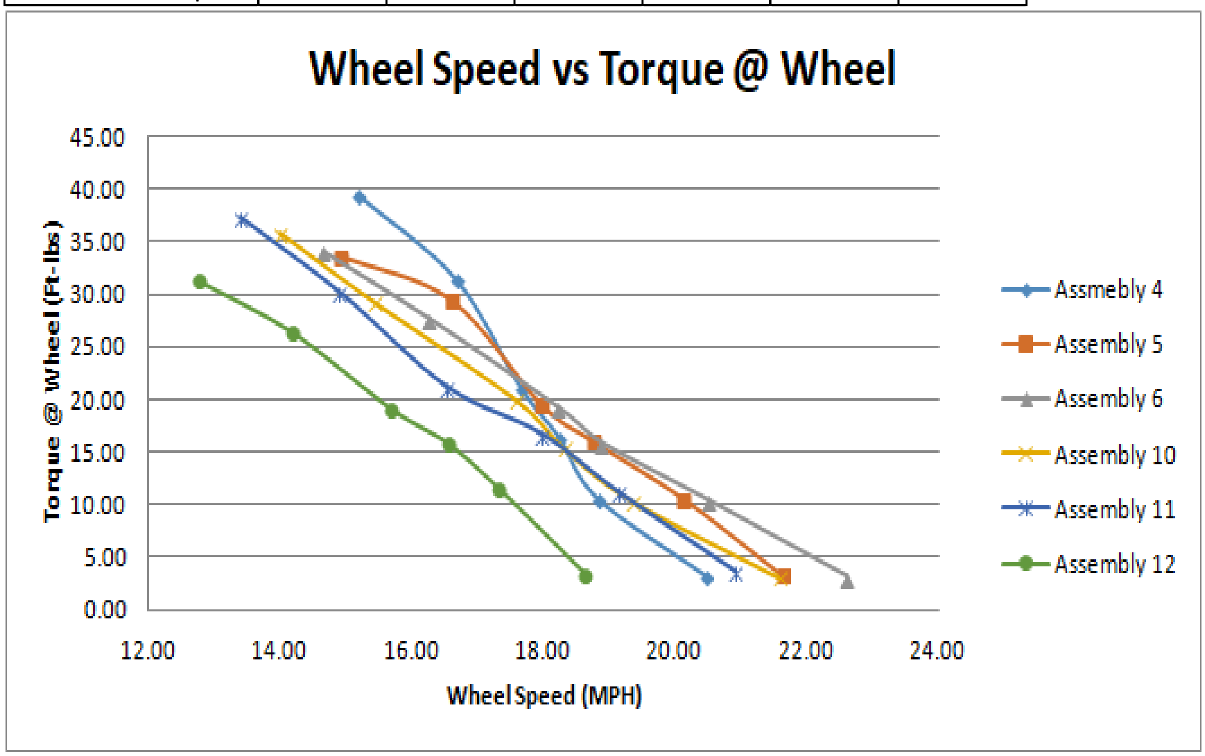
	Clutch Assembly: 5					
PSI	150	500	750	1000	1500	2000
Actual Wheel RPM	331	308	287	275	254	228
Wheel MPH	21.63	20.13	18.75	17.97	16.60	14.90
Run 1 GPM	2.38	2.13	2.00	1.75	1.63	1.25
Calculated HP	0.21	0.62	0.88	1.02	1.42	1.46
Calculated Torque	3.30	10.57	16.01	19.50	29.41	33.60

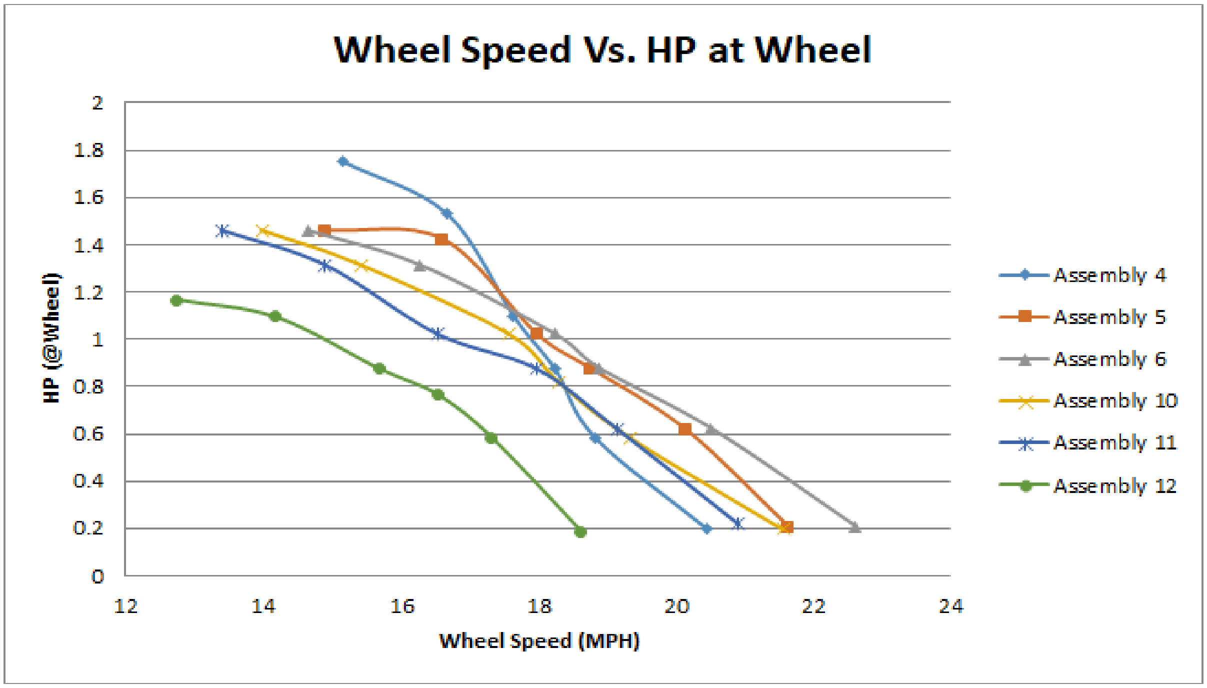
	Clutch Assembly: 6					
PSI	150	500	750	1000	1500	2000
Actual Wheel RPM	346	314	289	279	249	224
Wheel MPH	22.61	20.52	18.88	18.23	16.27	14.64
Run 1 GPM	2.38	2.13	2.00	1.75	1.50	1.25
Calculated HP	0.21	0.62	0.88	1.02	1.31	1.46
Calculated Torque	3.15	10.37	15.90	19.22	27.69	34.20

	Clutch Assembly: 10 (118g per arm)					
PSI	150	500	750	1000	1500	2000
Actual Wheel RPM	330	296	280	269	236	214
Wheel MPH	21.56	19.34	18.30	17.58	15.42	13.98
Flow (GPM)	2.25	2.00	1.88	1.75	1.50	1.25
Calculated HP	0.20	0.58	0.82	1.02	1.31	1.46
Calculated Torque	3.13	10.35	15.39	19.93	29.21	35.80

	Clutch Assembly: 11 (130g per arm)					
PSI	150	500	750	1000	1500	2000
Actual Wheel RPM	320	293	275	253	228	205
Wheel MPH	20.91	19.14	17.97	16.53	14.90	13.39
Flow (GPM)	2.50	2.13	2.00	1.75	1.50	1.25
Calculated HP	0.22	0.62	0.88	1.02	1.31	1.46
Calculated Torque	3.59	11.11	16.71	21.19	30.24	37.37

Clutch Assembly: 12 (140g per arm)						
PSI	150	500	750	1000	1500	2000
Actual Wheel RPM	285	265	253	240	217	195
Wheel MPH	18.62	17.32	16.53	15.68	14.18	12.74
Flow (GPM)	2.13	2.00	1.75	1.50	1.25	1.00
Calculated HP	0.19	0.58	0.77	0.88	1.09	1.17
Calculated Torque	3.43	11.56	15.90	19.15	26.48	31.43




Wheel Speed Vs. HP at Wheel
HP (@Wheel)
Wheel Speed (MPH)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12
14
16
18
20
22
24
Assembly 4
Assembly 5
Assembly 6
Assembly 10
Assembly 11
Assembly 12