Rochester, February 28, 2012.

TO: NFPA Education and Technology Foundation Board of Directors

FROM: Larry VILLASMIL and Robert GARRICK, **Project Organizers.**

Project Name: Fluid Powered Prototype "Green" Vehicles.

Overarching Goal: Introduce the fundamental concepts of fluid power technology by using an integrating experience approach.

Specific Goal: Apply fluid power technology to the design, construction, and testing of a fluid powered vehicle (single rider bicycle/tricycle).

Course: Pneumatics & Hydraulic Systems.

Description: The course involves the study of the basics of fluid power and hydraulic/pneumatic components such as pumps, actuators, valves, accumulators, lines, directional controls, sealing devices, servomechanisms, and fluid containers. It has a hand-on laboratory component.

STATUS REPORT

<u>Fall Quarter 2011 – September 05 to November 15</u>

Course: Pneumatics & Hydraulic Systems.

The project was given to the four sections of the fall cohort class of the course as two separate assignments.

The first assignment was a literature review focused on one hydraulic application and another one pneumatic elaborating on the use of fluid power regarding power generation, storage, transmission, and final use. We recommended searching for articles, magazines, books or the web and the students were given instructions in how to proceed to do a literature search using endnote web and library resources.

Several students submitted papers on the basic use of pneumatic and hydraulic hybrid vehicle technology and their application to delivery and large trucks in general terms. One paper focused more specifically in the BMW 530i hydraulic hybrid and a hybrid pneumatic power system that was developed to replace the electrochemical energy of the battery of an electric hybrid. Other papers focused on more conventional applications such as hydraulic hybrid excavators, plane landing gears or air pneumatic brakes. It should be mentioned that the students were asked to present their finding to the entire class in short presentations.

The second assignment was a group paper with the specific goal of getting familiar with the state of the art of fluid power technology and applications to control and automotive systems, including fluid powered propulsion mechanisms of light weight vehicles by designing the basic components of a fluid powered vehicle that would carry at least one 150 lb. person on an approximately 3 mile route along a RIT loop consuming less total energy per person than a typical electric bicycle. The suggested activities were: estimation of the energy, torque and power required; calculating the storage and accumulator size; and selecting the drive train and vehicle.

The instructions given to the students were somewhat 'loose' and open ended to expose the student to real situations where incomplete information is given to solve a particular task while promoting creativity. As an example, only the street layout for the route was given. Most students figured out that the elevation layout was missing and that such information was needed in order to estimate accurately the energy required. Some of them used smartphones with apps driving through the loop to 'measure' the elevation layout.

In terms of the fluid power technology, students chose evenly pneumatics or hydraulics citing more compatibility with the environment in the case of the former. For actuators, essentially all students chose rotary motors. In terms of the vehicle, there were a variety of two, three and four wheeled vehicles. Figure 01 presents the summary of one student group project, a "Pneumatic Powered Tricycle". The following is an excerpt from their executive summary: "In order to further simplify the design, we chose a direct drive system for ease of design and use as well as for real world testing and data analysis. Based on our calculations we achieved a design that required less horsepower (around 0.70HP vs. 1 HP) in all scenarios in relation to a comparable electric non-assisted bicycle". This group was practical in terms of the storage by suggesting the use of scuba tanks. Although their direct drive solution might not be the best, they supported their analysis by calculations performed using the software learned within the context of the course, Engineering Equation Solver (EES by F-Chart Software).

An example of a hydraulic solution is shown in Figure 02, a "Hydraulic Hybrid Bicycle". An excerpt from the student paper executive summary: "After some preliminary calculations, it was decided that a hydraulic system would be used for this design project. This design would incorporate a pump, motor, accumulator, reservoir, and the ability to actuate assisted braking". This outstanding student work included friction and air resistance in the energy losses, the initial energy provided by human power, selection of commercially available hardware, design of a reservoir to match the frame of the bicycle, and as already seen in Figure 02 a vehicle selection modeled after a successful previous design.

Approximately hundred students were involved in these two assignments as a total of 93 students completed the course.

Winter Quarter 2011-12 – November 28 to February 28

Course: Pneumatics & Hydraulic Systems.

A similar approach to the fall session is being followed in the course that is currently coming to an end.

In the first assignment, the literature review, several students described interesting past and current applications of fluid power. As an example, one student presented 'Project Azorian', a national security project, where the centerpiece was a specially designed hydraulically powered lifting rig (using sea water). A group of students presented a sophisticated hydraulic rollercoaster launcher system. And another group discussed the use of pneumatic bladders as artificial muscles that could contract or extent while being powered and operated by pressurized air.

The second assignment is also a group paper with the same specific goal of getting familiar with the state of the art of fluid power technology and its application to fluid powered propulsion mechanisms of light weight vehicles but this time by designing the basic components of a fluid powered 'dragster' vehicle that would not exceed 1000 lb. to compete in a 100 m drag race in the upcoming E-Dragster race of the RIT Imagine 2012 festival. In this case, students were required to estimate the energy, torque, and power, calculate the storage and accumulator size, do pipe sizing, calculate working and bursting pressures, motor or cylinder flow rates and torques, and selecting and drive train and vehicle (students were assigned hydraulic/pneumatic and motor/cylinder options). This second paper is due the day of the final exam and the course is still in progress with 24 students expected to complete it.

Course: Independent Studies.

Seven students enrolled in independent studies to pursue further the design and construction of the "Fluid Powered Prototype 'Green' Vehicle". Given the number of students interested in pursuing the studies (we originally planned for five), students and faculty decided to pursue the design and fabrication of two vehicles, one pneumatically powered and another hydraulically powered. Both teams are pursuing designs based on their original proposal, Figure 01 and Figure 03. On the other hand, this group of students had at their disposal all the previous work of the fall class including those of the current class. Indeed, the faculty teaching the current class and co-advisor of the independent studies made sure that this approach was followed.

As guide for the independent studies, we indicated to the student that they needed to: 1. Estimate the energy/work required including a. Acceleration, b. Aerodynamic Losses (Drag), c. Friction Losses (Tires), d. Drive Train Friction; 2. Estimate the torque/power required; 3. Estimate the Storage/Accumulator Size; 4. Estimate the Motor/Actuator Speed & Size; 5. Estimate/Select Drive train (Chain/Gears/Direct Drive); 6. Estimate Piping/Hose connections; 7. Adjust the vehicle selection (Bulk weight/maneuverability/storage) evaluating a. Construction/Style Alternatives b. Vehicle frame stress Analysis. To evaluate and grade the outcome of the independent studies we requested the following 'products': 1. Spread Sheet Calculations: a. Energy, b. Power, c. Accumulator, d. Motor/Actuator, e. Drive Train; 2. Design Specifications: a. Components sizing, manufacturer comparison, drawings etc., b. Vehicle frame part drawings, assembly and manufacturing details.

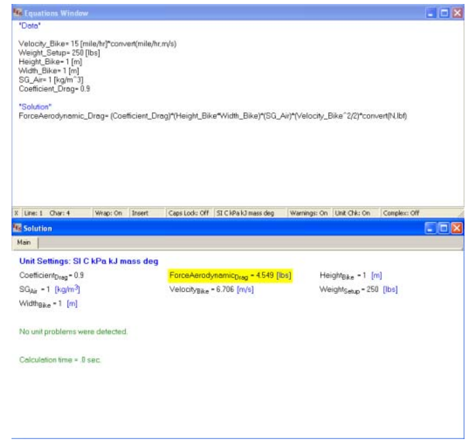
Figure 04 presents the preliminary spreadsheets with the calculations of both independent studies teams for their respective vehicles. Both teams are currently working on design and component specifications as we prepare to buy main system components shortly. It should be noted that both teams have chosen opposite design approaches. The pneumatic team has decided to work on an 'ad-hoc' drive train based on a recycled engine and part components, see Figure 05, while the hydraulic team is pursuing a more traditional approach with standard and off-the-shelf components and equipment. It shall be mentioned that the hydraulic team has received an offer of sponsorship from a local company with some parts and components for their vehicle.

Both teams will continue pursuing independent studies in the spring quarter, March 12TH to May 18TH. It is expected that a couple of student will join them as they will work in the fabrication and testing of both vehicles that will unofficially participate in the E-dragster race the first Saturday of May. In addition to the final product, two working prototypes, the students are expected to prepare a draft conference paper summarizing the design experience and comparing the performance of the fluid power vehicles and the vehicles of the E-dragster race.

Carbon Fiber Scuba Tank

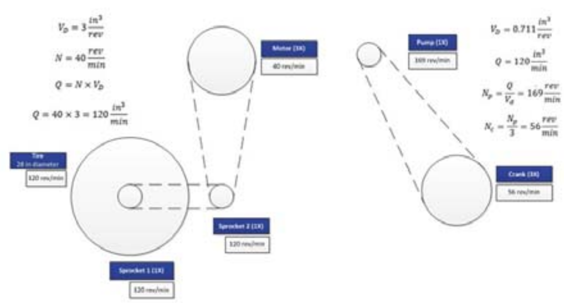
550W Air Vane Motor

26" wheels, 60" by 30" tricycle.

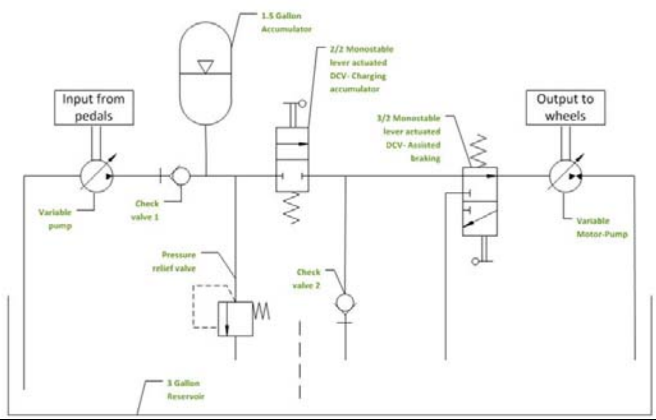


EES Spreadsheet

Figure 01. Pneumatic Powered Tricycle



Drive Train Calculations



ISO drawing Schematic

Pump #	Volume dispacement in^3/rev	Volume dispacement m^3/rev	Pressure out Pa	Pressure out psi	max psi	Q in^3/min	N rpm
1	0.065	1.06E-06	89282487	12949	3000	120	1846
2	0.129	2.11E-06	44987300	6525	3000	120	930
3	0.388	6.36E-06	14957118	2169	3000	120	309
4	0.711	1.16E-05	8162253	1184	1800	120	169
5	0.976	1.60E-05	5946067	862	4000	120	123
6	1.159	1.90E-05	5007215	726	2700	120	104
7	1.403	2.30E-05	4136395	600	4000	120	86

Q in^3/min	Vd in^3/rev	N rpm	Power thr HP	Power thr W	Pressure psi
120	3	40	0.3596	268.19	1184

$$T_{pump} = 15.13\,Nm$$

$$Q_{pump} = 120\frac{in^3}{min}$$

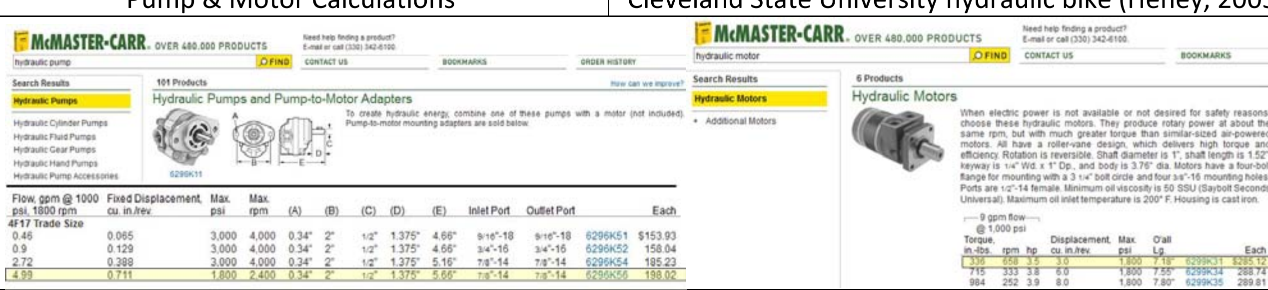
$$N_{pump} = 169\frac{rev}{min}$$

$$p_{pump} = \frac{T_{pump} \times 2\pi}{V_{D_{pump}}}$$

$$P_{motor} = \frac{V_{D_{pump}} \times p_{pump} \times N_{motor}}{2\pi}$$

Pump & Motor Calculations

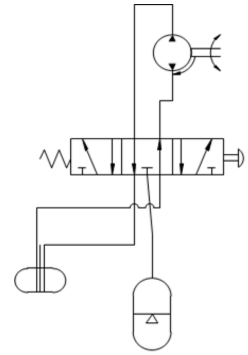
Cleveland State University hydraulic bike (Heney, 2005)



Pump & Motor Selection

Figure 02. Hydraulic Hybrid Bicycle

15gallon accumulator

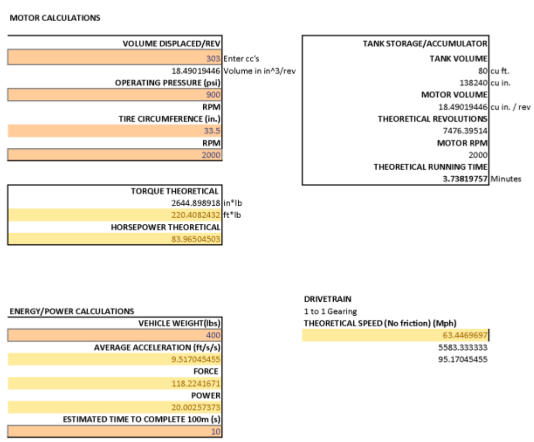


ISO drawing Schematic

Hydraulic Gear Motor

Tricycle

Figure 03. Hydraulic Powered Tricycle



MOTOR CALCULATIONS

VOLUME DISPLACED/REV	
303	Enter cc's
18.49019446	Volume in in^3/rev
OPERATING PRESSURE (psi)	
900	
RPM	
TIRE CIRCUMFERENCE (in.)	
33.5	
RPM	
2000	

TORQUE THEORETICAL	
2644.898918	in*lb
220.4082432	ft*lb
HORSEPOWER THEORETICAL	
83.96504503	

TANK STORAGE/ACCUMULATOR	
TANK VOLUME	
80	cu ft.
138240	cu in.
MOTOR VOLUME	
18.49019446	cu in. / rev
THEORETICAL REVOLUTIONS	
7476.39514	
MOTOR RPM	
2000	
THEORETICAL RUNNING TIME	
3.73819757	Minutes

ENERGY/POWER CALCULATIONS

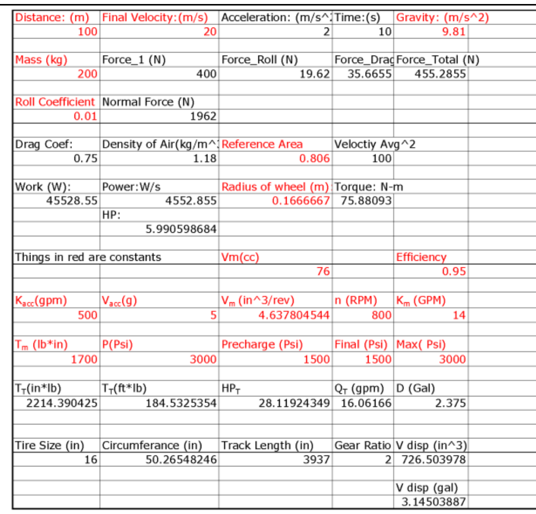
VEHICLE WEIGHT(lbs)
400
AVERAGE ACCELERATION (ft/s/s)
9.517045455
FORCE
118.2241671
POWER
20.00257373
ESTIMATED TIME TO COMPLETE 100m (s)
10

DRIVETRAIN

1 to 1 Gearing

THEORETICAL SPEED (No friction) (Mph)
63.4469697
5583.333333
95.17045455

Pneumatic Powered Vehicle



Distance: (m)	Final Velocity:(m/s)	Acceleration: (m/s^	Time:(s)	Gravity: (m/s^2)
100	20	2	10	9.81
Mass (kg)	Force_1 (N)	Force_Roll (N)	Force_Drag	Force_Total (N)
200	400	19.62	35.6655	455.2855
Roll Coefficient	Normal Force (N)			
0.01	1962			
Drag Coef:	Density of Air(kg/m^	Reference Area	Veloctiy Avg^2	
0.75	1.18	0.806	100	
Work (W):	Power:W/s	Radius of wheel (m)	Torque: N-m	
45528.55	4552.855	0.1666667	75.88093	
	HP:			
	5.990598684			
Things in red are constants		Vm(cc)		Efficiency
		76		0.95
K_{acc}(gpm)	V_{acc}(g)	V_m (in^3/rev)	n (RPM)	K_m (GPM)
500	5	4.637804544	800	14
T_m (lb*in)	P(Psi)	Precharge (Psi)	Final (Psi)	Max(Psi)
1700	3000	1500	1500	3000
T_T(in*lb)	T_T(ft*lb)	HP_T	Q_T (gpm)	D (Gal)
2214.390425	184.5325354	28.11924349	16.06166	2.375
Tire Size (in)	Circumferance (in)	Track Length (in)	Gear Ratio	V disp (in^3)
16	50.26548246	3937	2	726.503978
				V disp (gal)
				3.14503887

Hydraulic Powered Vehicle

Figure 04. Spread Sheet Calculations.

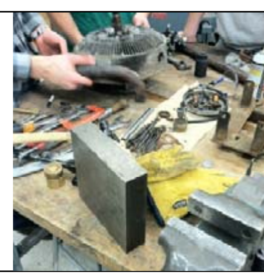


Figure 05. Wankel Rotary Engine (left). Students working on the engine (right)