Susan Zhao

MEAM 248: The Book

5/5/2017

Overall Performance Review

A particular trend that I observed over the course of this class was the hope of creating simple but reliable mechanisms oftentimes resulted in complexities being discovered over time, the rush to change aspects of the mechanism in order to fulfill forgotten requirements, and as always, the misjudgment of time available. Now this trend is unfortunately the result of poor planning, and the lack of urgency that comes with multiple weeklong projects. The greatest difficulty I faced when working on projects was the false sense of security when being allotted around 3 -4 weeks to complete a project. Each project would seem to be easily doable with the help of rapid prototyping or quick Solidworks modeling, and despite the weekly briefs, it would always come down to working on the project in the last few days before presenting. If anything else, a lesson that I have learned the hard way through all MEAM labs is that a mechanical design -although seemingly-perfect in theory and in design -will never perform as planned. For the derby project, there was not enough friction force between the wheels and the tube, causing it to slip. In the case of the heat engine, the Solidworks model seemed to achieve the purpose, but when the physical components were fitted together, friction brought its own challenges. While these are common sense issues, they are hard problems to fix. I hope for future projects that success will come through expecting the best, preparing for the worst, and through it all working efficiently.

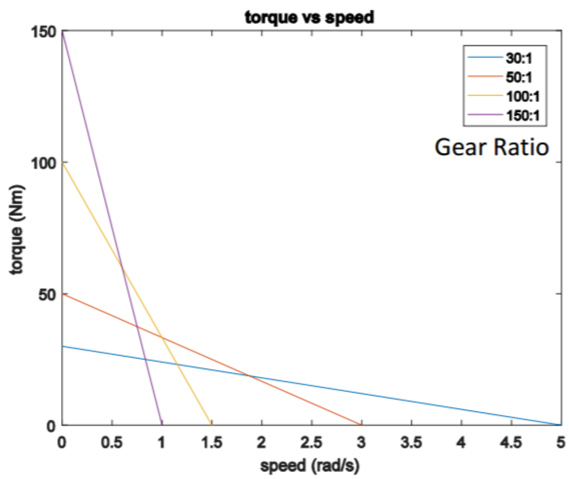
Major Lessons Learned/Skills achieved

- Working with multiple MEAM classmates, oftentimes with people that I haven't worked with previously or had even communicated with
- Delegating and dividing up work, while still maintaining a cohesive understanding about the project and project goals
- Meeting weekly deadlines and slowly researching/collecting data for final execution of the design
- Engineering skills: Using Matlab and Arduino alongside physical machined/lasercut/3D printed components, Solidworks for modeling and component analysis, circuits and microcontrollers, using oscilloscopes/force sensors/motors (Servos and cylindrical motors)

Project 1: Drag Race

Summary of Project

This main purpose of this project was to understand the relation existing between torque and RPM, and apply that new knowledge into designing and creating the fastest car that can go through a tube either on flat ground or more ideally, up an inclined tube.

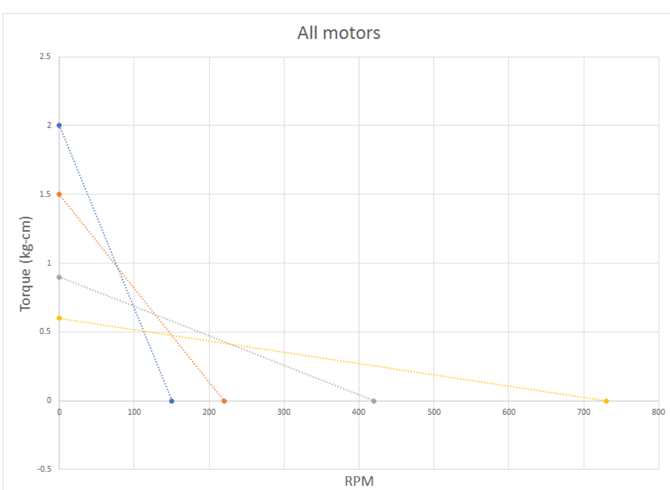


Gear Ratio	Stall Torque (Nm)	No Load Speed (rad/s)
30:1	30	5
50:1	50	3
100:1	100	1.5
150:1	150	1

The graph to the left allowed for easy visualization of the inverse relationship between torque and speed. The table above gives information about how the graph was created, connected the points where the max torque and the max speed are achieved.

Comparatively, our group's data:

30:1			50:1			100:1			150:1	
Theoretical			Theoretical			Theoretical			Theoretical	
RPM	Torque (kg-cm)		RPM	Torque (kg-cm)		RPM	Torque (kg-cm)		RPM	Torque (kg-cm)
730	0		420	0		220	0		150	0
0	0.6		0	0.9		0	1.5		0	2
Experimental			Experimental			Experimental			Experimental	
46.38	0.4158		109.348	0.4158		79.3355	0.4158		0.4158	106.536
92.296	0.3024		202.65	0.3024		93.6878	0.3024		0.3024	116.524
						115.442	0.147		0.147	126.829
8.04s (made this up)	198g		3.41s	198g		4.7s	198g		3.5s	198g
4.04s	144g		1.84s	144g		3.98s	144g		3.2s	144g
n/a	70g		n/a	70g		3.23s	70g		2.94s	70g



Yellow: 30:1

Grey: 50:1

Blue: 100:1

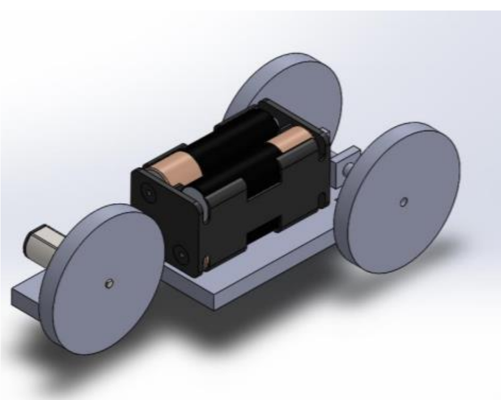
Orange: 150:1

Key steps

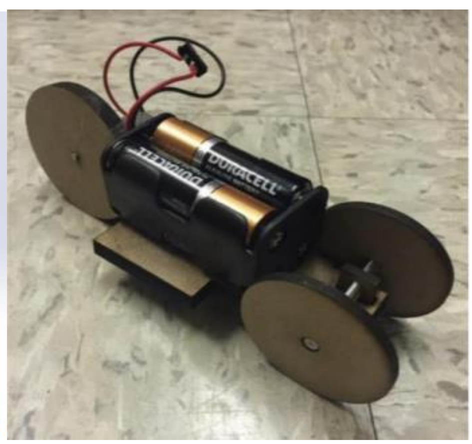
- Formulating and then implementing an experimental setup to measure the torque and RPM of each motor
- Designing a small vehicle that will be powered by a motor (chosen prior to testing) and can fit inside the tube and optimized for speed
- Constructing the vehicle with lasercut, pressfit pieces
- Testing the vehicle in the tube provided

Issues realized

A major issue realized at the end of the performance of the vehicle concerned sloppy construction of the wheels. Not only where the wheels liable to slip on the inner surface of the tube, but they were designed to be pressfit to the outside of the axles without any spaces. Unfortunately, this resulted in the wheels not being parallel to one another. I was very discouraged by the time it took for my vehicle to reach the end of the tube. If I were to redo this project, I would attached rubber bands or a material with a rougher surface that will allow for grip, and increase the size of the front wheel and decrease the size of the back wheels so the vehicle would traverse the curved edge of the tube with more ease.



Final CAD



Main Lessons Learned

- Torque vs. Speed relationship, and selecting the motor with the best gear ratio for a certain goal
- Test on the actual test platform, not just the floor/desk

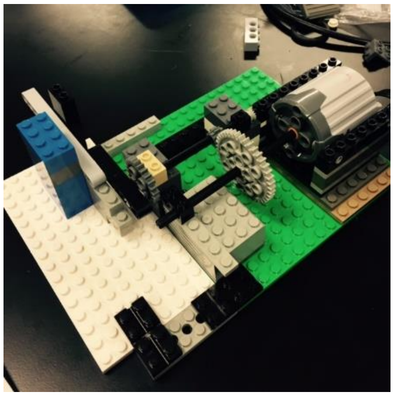
Project 2: Accelerometers, in Space!

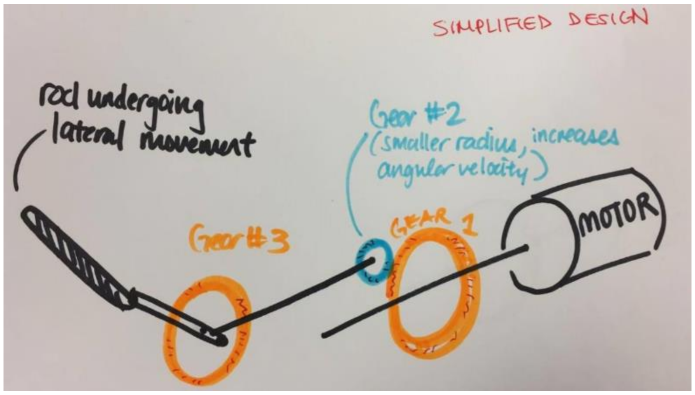
Summary of Project

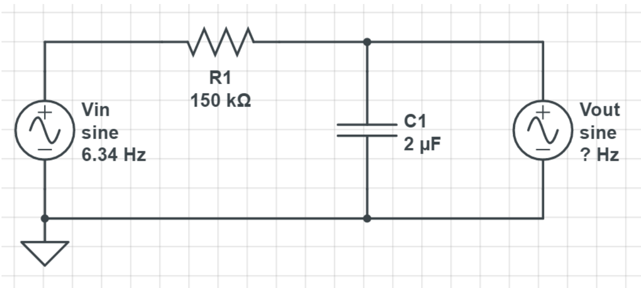
This project was to be completed using Lego technics (including a Lego motor). The goal was to create a device that will measure the angle of the landing craft with respect to gravity whilst filtering out the vibration created by the "landing craft". This inertial measurement tool required both an accelerometer and a potentiometer to determine the angle of tilt. A digital and analog filter was constructed to complete this project.

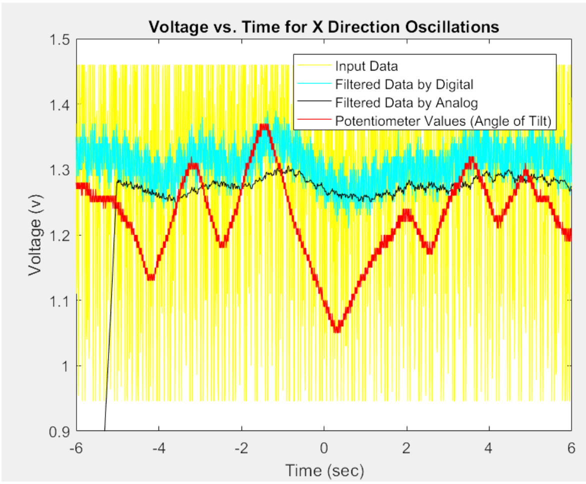
Key steps

- Understanding the basic goals of this project.
  - The tilt plate was to be provided, and our goal was to initially construct, out of Legos, a mechanism that generated peak linear accelerations of ~1G in a single axis.
  - Another requirement included the digital and analog filter to calculate the degree of tilt from the accelerometer signals. This was to be completed using Matlab and an electrical circuit.
- Designing and building the Lego mechanism
- Constructing a physical low-pass filter, and then comparing the filtered signal to the digital, Matlab-coded filter
  - Choosing the capacitor and resistor value to attain the best cutoff frequency
- Using the oscilloscope to collect accelerometer data, both filtered and unfiltered

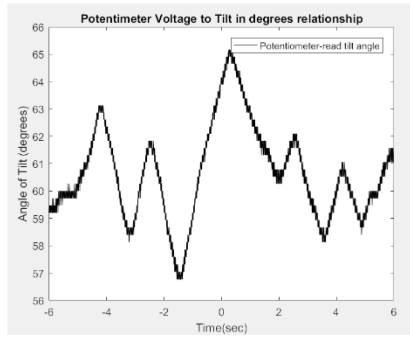








$$g's = \frac{(V_{measured} - ZeroGBiasLevel)}{Sensitivity}$$



Issues Realized

Attaining the best cutoff frequency is a very tricky process. For this project, we chose a cutoff frequency of 0.5Hz. Unfortunately, the concept of choosing a cutoff frequency is still unclear. I hope to understand this better in future projects. On the other hand, a better filter would have produced different results. In this project we used a first-order low pass filter, but there are several other filters such as Butterworth, Sallen-Key, and filters of higher orders that would result in a steeper slope after the cutoff frequency, attenuating the frequencies outside of the passband quicker.

Relevant equations for filters: $F_c = \frac{1}{2\pi RC}$ $\qquad RC = \frac{1}{\pi}$

Main Lessons Learned

- Performing kinematic analysis to determine the acceleration

Relevant equations: $f = \frac{1}{T} = \omega/2\pi$ $\qquad x = r\cos A + \sqrt{l^2 - r^2 \sin^2 A}$ (derive for acceleration)

$$a = x'' * \omega^2$$

- Nyquist-Shannon Sampling Theorem: Data collection should be at least twice the frequency of the fastest frequency in the signal (this was useful in Matlab codes in Dynamics)
- As I had already taken an ESE circuits class, this was a refresher on low-pass filters (filters in general), capacitors/resistors/inductors/Kirchoff's Law
- Use of Matlab's filter() function
- Using accelerometers and analyzing filtered signals

Project 3: Rockets

Summary of Project

A water-bottle rocket was created with the intention of launching it to land on a target. This rocket was composed of an airtight nozzle to allow for the rocket to be pressurized, and a nose piece and fins on the outside for a more aerodynamic body. The rocket was launched at an angle determined by the members of the group, and the members each specialized in either propulsion, navigation, or aerodynamics.

Key Steps

- Devising experiments that will allow for good data collection to understand how the numerous variables affect flight (amount of water, weight of the rocket body and distribution of that weight, level of pressure, angle of release)
- Using this information, design a rocket and its launch characteristics
- Adjust this to reach the landing destination

Initial design and Data Collection Table (2 trials)

Trial No.	1	2
% of Volume, Water	40	60
Pressure of Rocket	60psi	80psi
Distance Traveled (horizontally)	35m	45m

Issues Realized

At first, the calculations for this project seemed extremely complicated and convoluted with the presence of multiple variables. There was also the concern regarding drag, wind resistance, and certain material properties for the water bottle and the fins. The best way to tackle this problem was to have several idealizations, such as disregarding drag and air resistance, and focusing on the measurable aspects of this project which in cluded the volume of water and pressure of the rocket.

Related equations: Thrust profile $T = u\frac{dm_e}{dt} + A_e(P_e - P_a)$

$$u^2\rho A - mg - \frac{1}{2}C_d\rho A_c v^2 = m\frac{dv}{dt}$$

solve above ODE for v and then for maximum height y(t) when $v_v=0$

Main Lessons Learned

- Having members be specialists on certain topics, but requiring that all the knowledge comes together to create a successful rocket
- Center of Pressure dependence for aerodynamics

- Thrust profile of the water-filled, pressurized rocket: stages include the initial launch phase, the water-impulse phase, the burn rate of the water as it's expelled from the rocket body, then the sharp decrease of thrust once the all the water is expelled from within the rocket


Final thoughts: Water-bottle rocket launch paths are difficult to predict! It proved to be a good idea to weigh down the nose of the rocket, as this resulted in a more straight-directed, parabolic path-flying rocket. Larger fins also proved to be more effective for longer flights, and high pressures led to a greater impulse of the rocket when launched, but a good water/pressure ratio was required to get the distance needed.

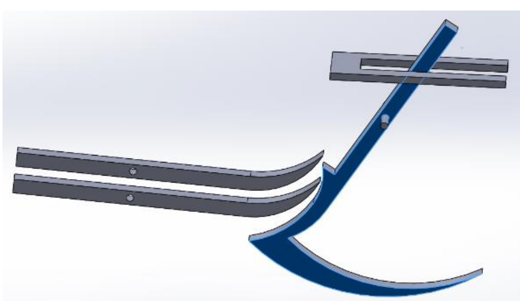
Project 4: Heat Engine

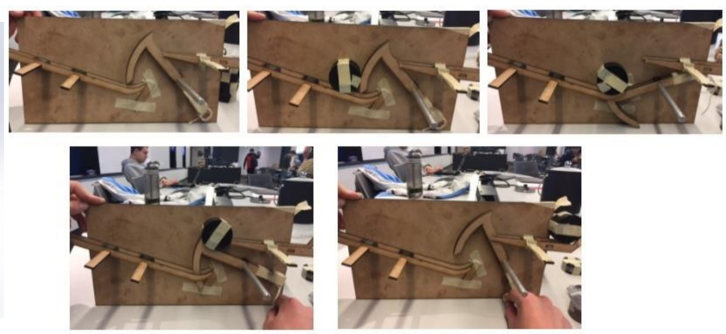
Summary of Project

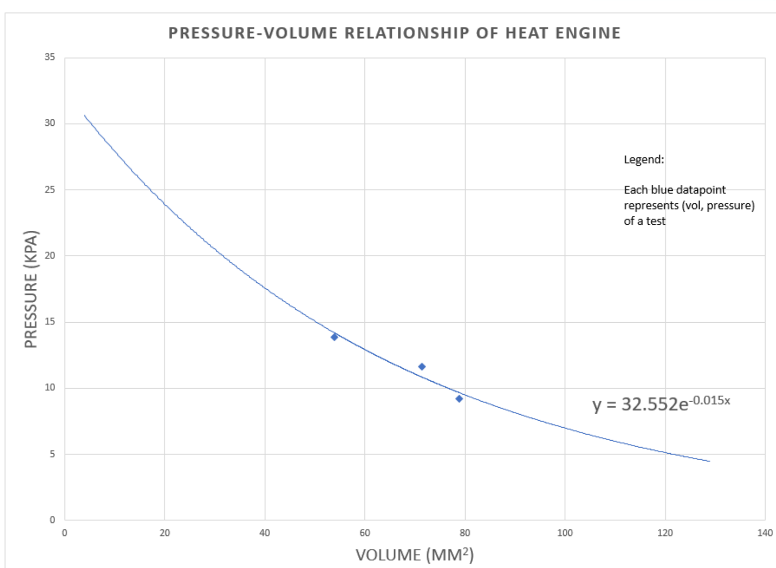
The purpose of this project was to create a fixed-working-fluid heat engine that would store gravitational potential energy. This included a fixed amount of air in a canister, and the canister would be heated then cooled, giving a rise in pressure in volume with the rise in temperature, and the decrease of volume and pressure with the sharp decrease in temperature. The challenge was to create a method or mechanism to make use of this work and storing it as gravitational potential energy.

Key steps

- Understanding and analyzing the amount of work that could be done when transferring the canister of air from boiling water to the ice bath, and then the reverse process
- Designing a mechanism to use the work done to store gravitational energy, namely lifting weights from a lower height to a greater height, increasing gravitational energy
- Testing thoroughly in order to optimize the amount of mass lifted (gravitational potential energy stored)







Images (clockwise from top left):
-Solidworks design
-Physical, lasercut mechanism
-PV diagram of heat engine (4 trials)

Issues realized

There were several sources of error that caused our heat engine to perform below our expectations. First, we discovered that there were many areas where friction negatively affected our mechanism. In theory and ideally (using our hands), the mechanism was able to transfer weights from a loading ramp onto a higher shelf. However, despite the use of spacers and tape to eliminate some of the friction, the weight would sometimes get stuck as it was levered up. Likewise, the syringe used for this experiment had friction due to the walls of the syringe that was not easily eliminated with oil. Otherwise, the experiment actually worked fairly well, and exceeded some of our expectations.

Main Lessons Learned

- Pressure-Volume relationship in heat engines
- The amount of work that can be done by a small canister of air (the amount of pressure created was surprising)
- Understanding and correctly using kerf will eliminate a lot of wasted laser-cutting time