MSE 312 - Mechatronics Design II

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Conceptual Design

Development of the Conceptual Design of a Vertical Ball Launcher

Lab 2 Group #4

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Solution Neutral Problem Statement

Mechanism for launching spheres at various distances and trajectories using one DC Servo Gearmotor as the actuation mechanism, AC function generator as the power source, ATMEGA16U2 + USB Cable with connection to Simulink for motor controls interface and L298N H-bridge PWM drive board and standard LCR components as as electrical interface.

Clarified Task and Requirements list

Objectives:

1. Hit a ball into a vessel placed at a given distance
2. Given two different distances randomly within the pre-given range, the ball will be hit into the vessels at those distances
3. Propel your ball to the minimum and maximum distances of the pre-given range.

Requirements:

- Ceder balls for launching are 2cm diameter and 2 g.
- Target vessel is 31mm diameter and 55cm high with ball capture areas at 112mm and 258mm diameters.
- Ranges Accuracy trial (75 cm), Robustness trial (200cm)
- Geared motor with encoder used GM8224S009 DC Gearmotor
- Software and Control: Arduino programmed through Matlab
- Mounting arrangement: Pillow block bearings
  Shaft height freely adjusted between 15cm and 55cm
- Setup of apparatus: position of loading the ball freely chosen, Ball holder stationary when being loaded.

- Design and build the power drive circuitry for the DC motor by using available power MOSFETs and/or Bipolar Junction Transistors, H-bridge Integrated Circuit, and other components such as resistors, capacitors, logic gates, etc.
- Practice electronic test procedures to evaluate circuit operation in the lab using regular measurement and test equipment such as breadboards, function generators, oscilloscopes, power supplies, and multi-meters.
- Build a working power electronic driver on a pre-drilled copper prototyping board (proto-boards).
- As a part of the control system connect the circuit to an Arduino MCU and Matlab/Simulink in the Windows Real-time Target environment and perform tests for the feedback control system.

Fig.2 DC servo Gearmotor

“Is the maximum torque enough to launch a ball with the given motor?”

Verify the maximum speed of the motor and the maximum torque at that speed.

Workaround for prototyping the hypothetical system

Perform the position, velocity and acceleration control with PID controller and map the trajectory using matlab. A lightweight rod can be added for verification and eccentric loading within the motors loading specifications.

Because the use case of this motor has been to control the frame swinging side to side, the speed and load of the motor. For the vertical gravity swinging action of this use case, the maximum speed of the motor and the maximum torque at that speed is verified.

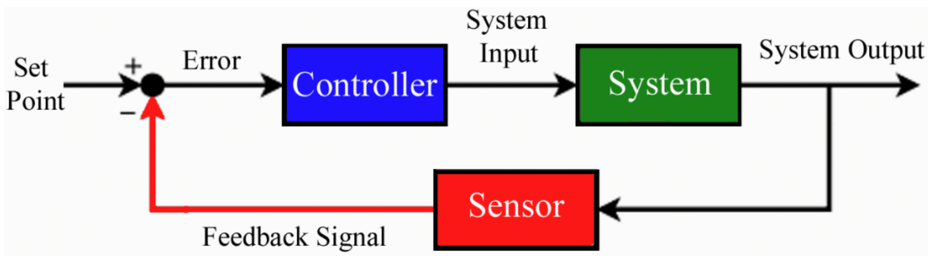

Fig.3 Controller diagram

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<table>
<tr><td colspan="3">Requirements List for Ball laucher</td><td>Issued on
2022-07-02</td></tr>
<tr><td>Changes</td><td>D/W</td><td>Requirements</td><td>Responsible</td></tr>
<tr><td></td><td></td><td rowspan="10">Motor:
Given the available DC servo gearmotor GM8724S009,operate the input voltage and current within the suggested limits from the datasheet to control speed and position for the intended use.
Motor specs:
No-Load speed (before Gear reduction): 720 rpm
Peak Torque: 42 oz-in (0.3 N-m)
Max Allowable gearbox torque: 0.71 N-m

Functional:
Launch a 2 cm diameter 2 gram wooden ball into a 31mm diameter cylinders at varying distances. (Suggested Distances for Evaluation ranging from 75cm- 200cm) Is this possible from the torque speed curves of the motor?

Mechanical:</td><td>C</td></tr>
<tr><td>04-07-22</td><td>D</td><td></td></tr>
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<tr><td>08-07-22</td><td>D</td><td></td></tr>
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<tr><td>16-07-22</td><td></td><td></td></tr>
<tr><td></td><td>D</td><td></td></tr>
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22-07-22	D	From the constraint of the motor Torque-Speed curves, the design requirements of the truss space frame: Total Mass: Center of mass: Moment of inertia: Maximum torque condition: 90 Degrees upswing Assuming the maximum length arm allowed being 30cm, massless arm and with point mass at the end, what is the maximum mass that can be lifted by the motor? Torque = Mass* distance 0.3 N-m = Mass * 0.3 m Mass of less than 1 N needed for the arm to lift. 1N = 102 grams Entire truss arm must be less than 102 grams. Taking into account the added torque from moment of inertia to rotate. (Torque due to acceleration = Mass * Moment of inertia *angular acceleration) Maximum speed condition: 90 degrees downswing Throwing distance calculation: Shown in the hand calculation on next page.	

		Electronics Design Heat Sink Design Controller Design PWM Generation 1D lookup table Direction Control State Machine	

Identify the Functions

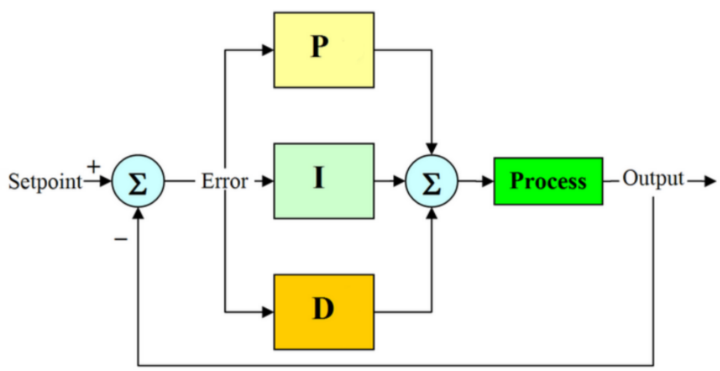


Fig.3 PID Controller diagram

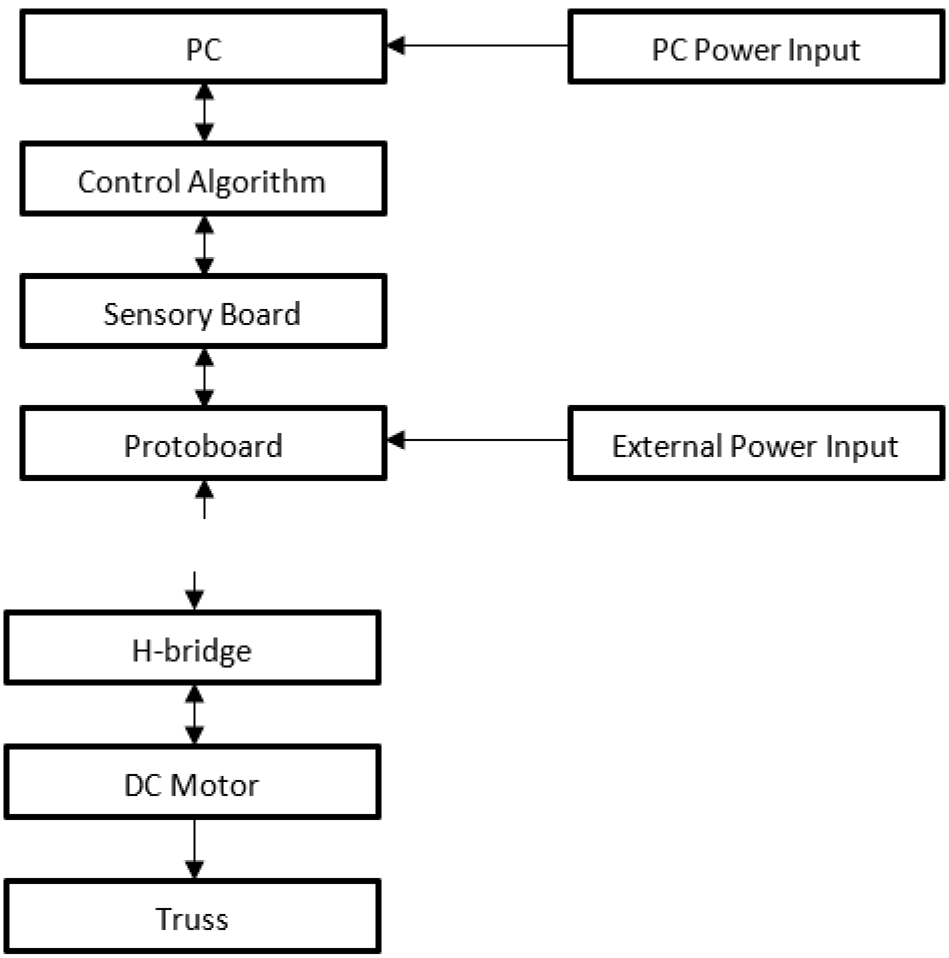
The process block or the system block is a gain that depends on the physical parameters of the system including motor parameters, moment of inertia, and resting load.

Position control System Gain:

$$\frac{\eta n K_m}{s[(L_s+R)(J_s+B)+\eta n^2 K_m{}^2]}$$

Speed control System Gain:

$$\frac{\eta n K_m}{(L_s+R)(J_s+B)+\eta n^2 K_m{}^2}$$



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Broadening the options and Synthesis

200 cm distance
45° launch angle

$$x - x_0 = \Delta x = V_{0x} t$$

$$V_x = V_{0x} = V_0 \cos\theta$$
$$= V_0 \cos(45°)$$

$$y - y_0 = \Delta y = V_{0y} t = V_{0y} t - \tfrac{1}{2} g t^2$$

$$V_y = V_{0y} - gt$$

$$\text{Range} = \frac{2 V_0^2 \sin\theta \cos\theta}{g}$$

$$V_0^2 = \frac{2(9.81)}{2 \cdot \sin\theta \cos\theta}$$

$$V_0 = 4.43 \text{ m/s}$$

$V_0 = \omega r$ where r = arm length
ω = angular velocity

$$4.43 \text{ m/s} = \omega \cdot (0.20\text{m})$$

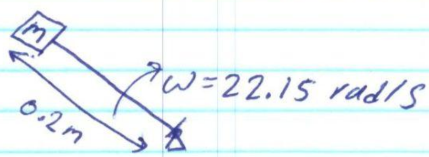
$$\omega = 22.15 \text{ rad/s} = 211 \text{ rpm}$$

≈211 rpm to launch a ball 200 cm with a 45° launch angle using a 20 cm length arm.

Refer to GM8724S009 datasheet.

@ 211 rpm, max torque = 30 oz·in
current = 2 Amps
max torque = 0.212 N·m

Torque = mass x g x armlength
0.212 = mass x 9.81 x (0.2 m)
mass = 0.212 / (9.81 x 0.2)
= 0.108 kg
mass = 108.05 grams = m



Mass of arm truss must be ≤106.05 grams

Mechanical Requirements:

Total mass = 108.05 grams
Total length = 20 cm
withstand torque of 0.21 N·m
axial load of 1 N = 102 grams
minimal deflection ≤ 10%

Suggested material is 3/32" brass rod

Brass density = 8.73 g/cm³

$$\text{mass} = \pi\left(\frac{0.238\text{ cm}}{2}\right)^2 \cdot \text{length} \cdot \left(8.73\ \frac{g}{cm^3}\right)$$

mass ↑ grams, length ↑ cm

For 106 grams, 273 cm length of brass rod can be used.

Total mass = cross sectional area x length x Density

Cross sectional area $= \pi \left(\frac{0.238}{2}\right)^2$

$= 0.0444 \text{ cm}^2$

Density $= 8.73 \text{ g/cm}^3$

length = ~~20 cm~~ Total length of Brass used

Total mass should be ≤ 106 grams assuming the center of mass is at the end of the rod.

$$106 \text{ grams} = \pi \left(\frac{0.238\text{cm}}{2}\right)^2 \cdot \text{length} \times \text{Density}$$

$$\text{length} = \frac{106}{0.0444 \times 8.73} = 273 \text{ cm}$$

Refer to mechanical design brief submitted by this group.

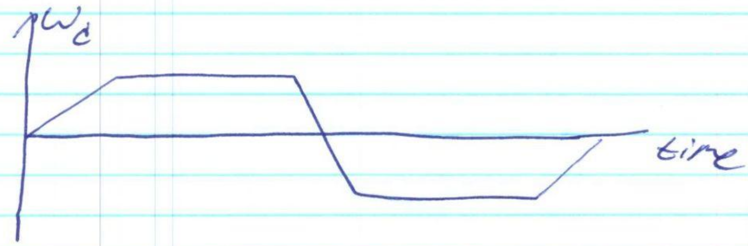
Total length of brass $= 129$ cm

total mass of truss $= 131$ grams

$131 > 106$ but center of mass is at < 15 cm

Thus, it is proven that the mechanical design of the truss structure meets the requirements.

Trapezoidal speed profile



Condition for ball to lose contact with surface of ball holder.

$$l\ddot{\theta} \le -g\sin\theta \rightarrow \ddot{\theta} \le -\frac{g}{l}\sin\theta$$

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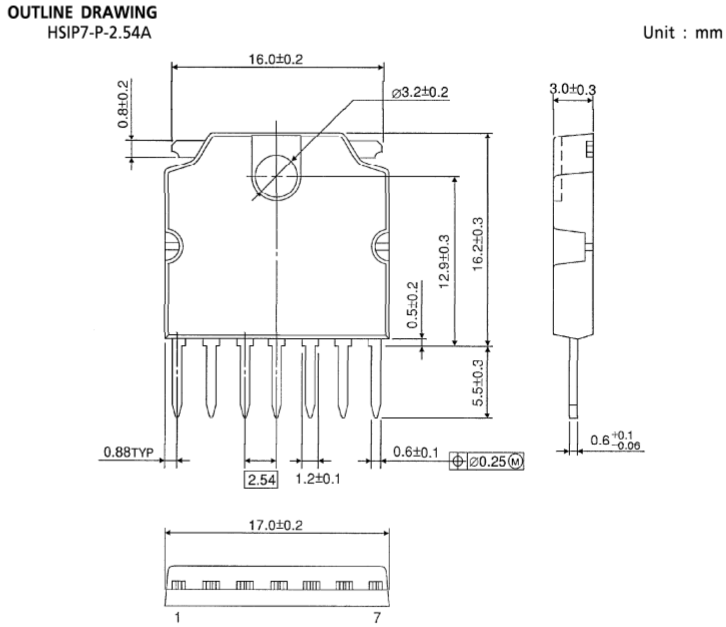
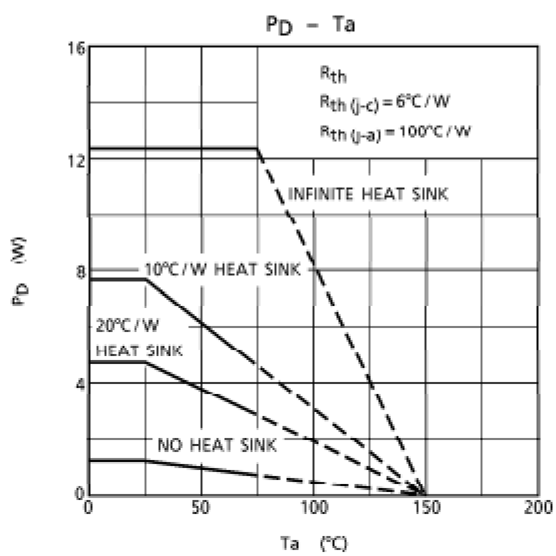
Heatsink Design for H-Bridge





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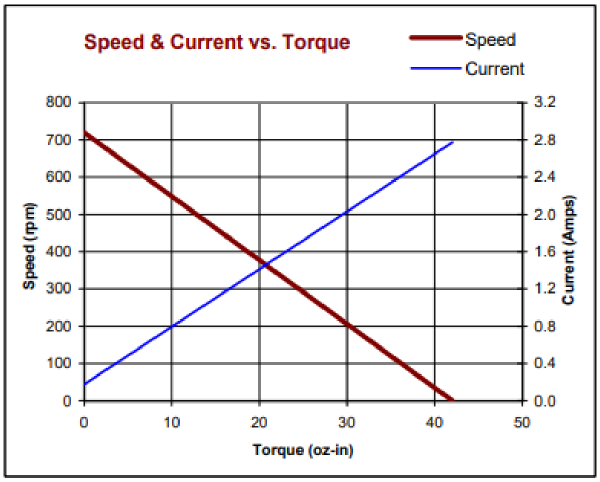
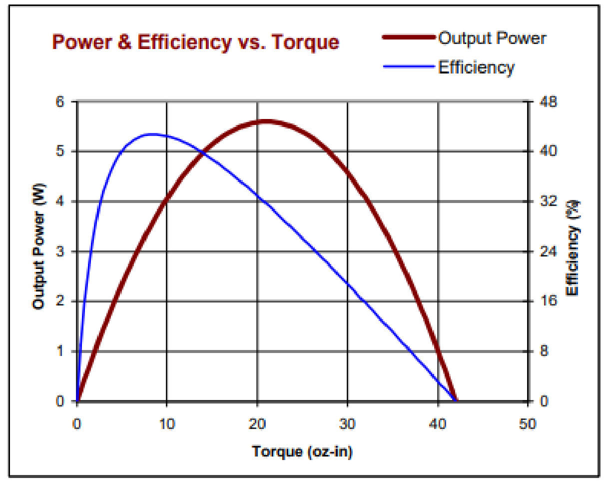
Torque-speed curves for the DC Servo Gearmotor model

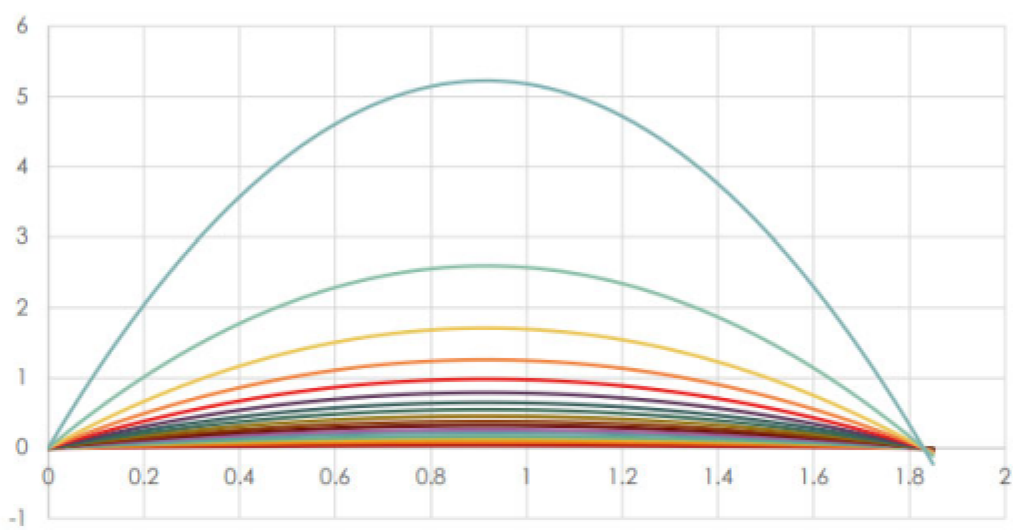
GM8724S009





All values are nominal. Specifications subject to change without notice. Graphs are shown for reference only.

Trajectories for projectile motion



• Hold a ball of dimensions 2cm diameter and 2 grams

• Built using the limitations of materials and methods of manufacturing specified (6ft brass rod, 2 51mmX51mm plates, 35g 3D printed parts, Solder, nuts, bolts, toolbox, etc.)

• Sustain a 5 N vertical load and keep within a deflection of 10mm when held horizontally by a square shaft

• moment of inertia, deflection under load Output for space frame design

• Truss structure torque on the motor while stationary and while in motion

Maintaining the transfer of torque to the space frame by using square shaft to space frame adapter mechanism.

• Room for adjustments Input (Identification of Requirements):

• Frame connection to motor

• Release mechanism (overhand or underhand throw)

• Release mechanism (natural release from deceleration of arm) • Length of arm (affects moment of inertia, speed, and angle of the throw)

• Range of motion (ball needs to stay in holder until the release point) • Speed and position control of the motor (depends on the moment of inertia of the arm, current control of the motor, Max torque, PWM, PID, etc.

Stages of throwing ball: 1. Acceleration from rest 2. Motion to the desired angle of release 3. Deceleration to facilitate release from holder at the correct angle and the correct speed.

Design Evaluation

Evaluation Chart															
				A		B		C		D		E		F	
	No.	Evaluation Criterion	W	P	(P)	P	(P)	P	(P)	P	(P)	P	(P)	P	(P)
Func.	1	Motor operating within the safe range for electrical and mechanical loading	1	2		3		4		1					
Work Princ.	2	Arm position control using PID	1	3		2		2		1					
Embod	3	Arm speed control	1	4		4		1		2					

.															
Assy.	4	Mechanical testing of arm	1	1		1		1		2					
Operation.	5	Electronics protoboard operation	1	4		3		3		1					
Maint.	6	Heatsink	1	3		4		3		2					
Physical	7	Max truss weight	1	2		2		4		1					
		Ranking	4			1		3		2					

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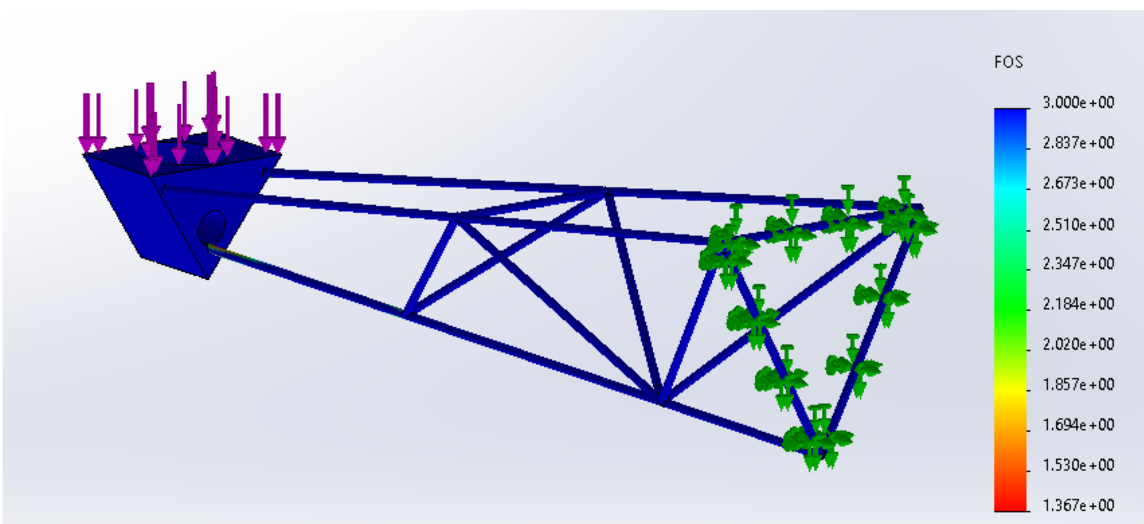
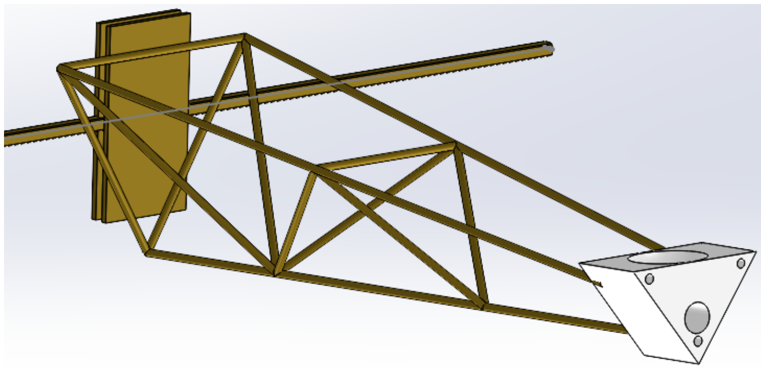
Identified Conceptual design choice

The truss space frame which meets the requirements for using the motor in the ranges of torque and speed required to launch the 2g ball a distance of 200cm was calculated to be the frame shown in the figure. The electrical system of the H-bridge circuit for controlling the motor is tested using breadboard, verified and transferred to protoboard along with a heatsink designed for the current and voltage loading specifications.





For the launching mechanism, we considered using various ball holders and different launch angles. The launch angle that was chosen is the 45 degrees angle because it has the best range and trajectory for landing. With a 45 degree trajectory the options for launching are at the clockwise upswing while the frame is 45 degrees above the horizontal or on the counterclockwise upswing while the frame is 45 degrees below the horizontal. We decided to first test the case for the 45 degrees above horizontal because loading the ball and keeping it in the holder for the duration of the swing is more feasible. However to reach the full revolutions per minute accounting for the moment of inertia, a release using the counterclockwise 45 below may be calculated for and tested with the requirement that the ball stays in the ball holder for the duration of the downswing. The condition for the ball to stay in contact as shown in the hand calculation