EGR 421L – Fall 2024

DUKE DUNK TANK

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October 11, 2024

I understand and have adhered to all the tenets of the Duke Community Standard in completing every part of this assignment. I understand that a violation of any part of the Standard on any part of this assignment can result in failure of this assignment, failure of this course, and/or suspension from Duke University.

Contents

1 DUKE DUNK TANK

The Duke Dunk Tank is a hybrid carnival game that combines basketball shooting skills with a fun water-dunking experience. The goal is to make 3 successful shots to trigger a water splash onto the "victim" sitting below the hoop.

How to Play

1. Press the **Start** button to begin the 60-second countdown.
2. Shoot the balls into the hoop. The **ultrasonic sensor** detects each successful shot.
3. For each successful shot, a **basketball player figure** "jumps" up behind the backboard.
4. After 3 shots, the **solenoid valve** opens, releasing water onto the person below.

Figure 1: State Fair Game in Action

Mechanical Devices & Justifications

PVC Frame: Supports the hoop and water tank while providing a seat for the person. It is lightweight, durable, and water-resistant, making it ideal for outdoor use.
Plywood Backboard: Durable and cost-effective surface behind the hoop.
3D-Printed PLA Hoop: Customizable but brittle, intended to be replaced with metal in the final design for durability.
Ultrasonic Sensor Circuit: Non-contact sensing technology to reliably detect when a ball passes through the hoop.
Motorized 3-Arm System: Converts motor rotation to linear movement, raising the player figures behind the hoop.
Solenoid Valve: Controls the release of water from the tank through a 3D-printed shower head.
Water Tank and Shower Head: Stores water and disperses it evenly over the participant.
Cloth Ball Return: Catches and stores all balls that fall through the net and other stray balls.

Design Criteria & Concerns

Safety: The PVC frame is sturdy and has no sharp edges, ensuring it's safe for all ages.
Functionality: The design works consistently for the entire demonstration period, and the control panel is user-friendly.
Moving Parts: The basketball players behind the backboard jump up to show successful shots.
Cost and Appearance: The prototype is cost-effective and aesthetically pleasing.
Size: The entire game fit within the required 3x6 foot size constraint.

Concerns & Improvements:

- The PLA hoop is prone to fracture; switching to metal will improve durability.
- The ultrasonic sensor sometimes detects stray balls—lowering the sensor and adding a guard will prevent misdetections.
- To prevent water from splashing onto the floor and catch excess water, a shower curtain and a larger kiddy pool could be added.
- To improve the game's weatherproofing, enclosing the circuits in a watertight container and using plastic for the basketball figures ensures durability in rainy conditions.

Figure 2: Mechanical System with Solenoid Switch

2 Design

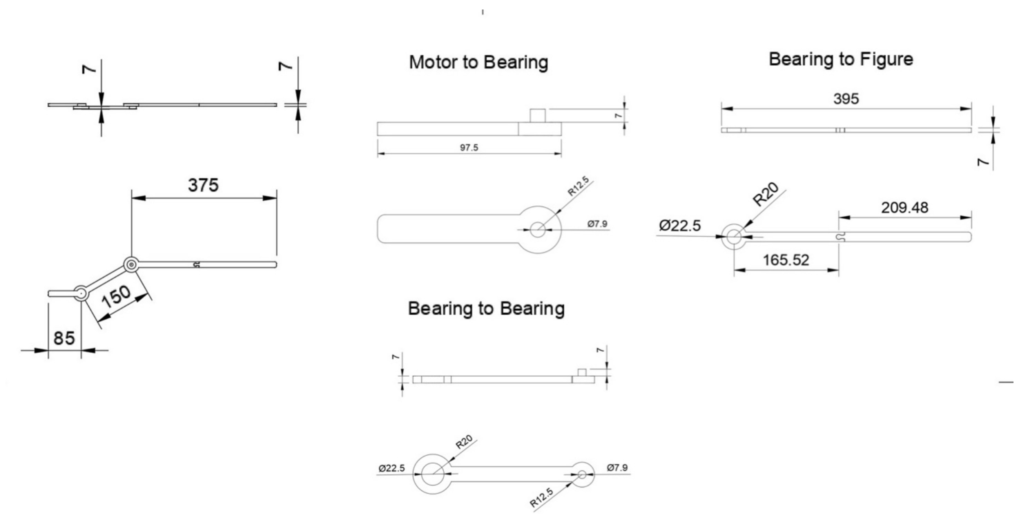

Figure 3: 3-Arm System Assembly and Component Drawings

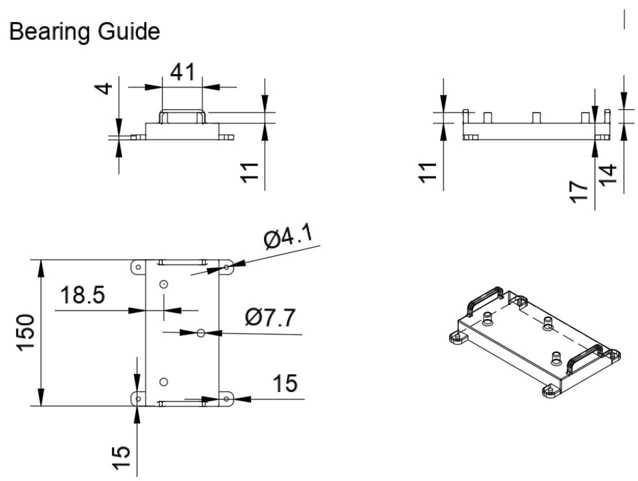

Figure 4: Bearing Guide Drawings

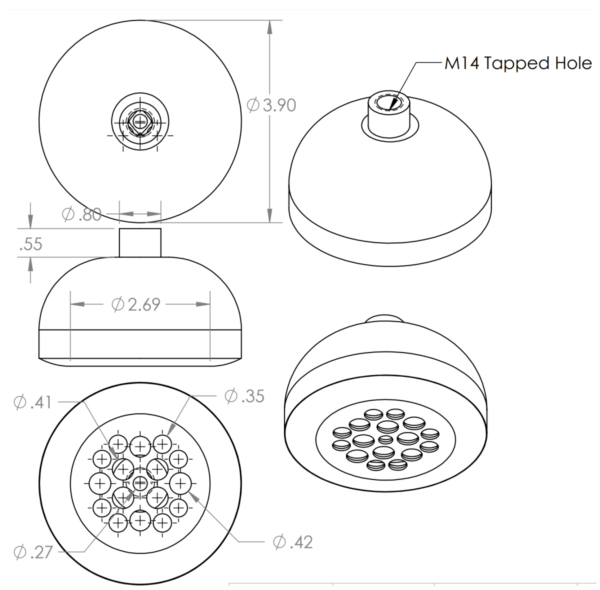

Figure 6: Shower Head Dimensions in Inches

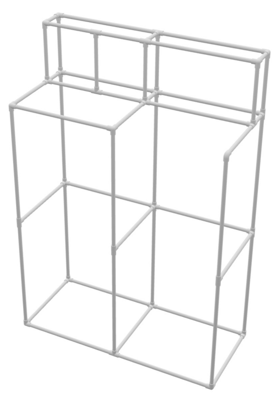

Figure 5: PVC Frame Perspective Sketch

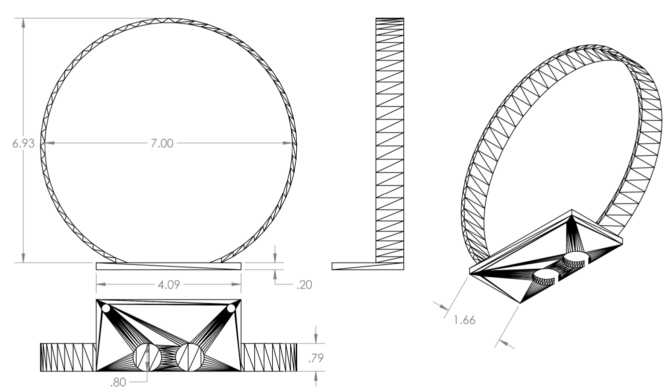

Figure 7: Basketball Hoop Solidworks Design

3 Project Budget

Bill of Materials

Project Name:	Duke Dunk Tank	Group Members	Chris Cosby, Izzy Dudlyke, Olivia Lee, Minha Kim	Date:		11 October 2024	

Item	Description	Material	Source	Quantity	Part #	Unit Price	Total Price
			Subsystem 1: Electronics				
Ultrasonic Sensor	For Sensor Circuit	Various	Digikey	1	1528-2711-ND	$3.95	$3.95
Arduino Uno	For Both Circuits	Various	Ardunio Store	2	A000066	$14.99	$29.98
Servo MG966R Motor	For Sensor Circuit	Various	Amazon	3	B07MFK266B	$4.75	$14.25
Joystick Module Button	For Sensor Circuit	Various	Digikey	1	2234-JOY-01-ND	$5.95	$5.95
LCD I2C	For Sensor Circuit	Various	Digikey	1	4411-CN0295D-ND	$8.63	$8.86
9-Volt Alkaline	For Both Circuits	Various	Amazon	4	6LR61-8PK	$1.42	$5.68
Motorized Ball Valve- 1/2" Brass Ball Valve with Full Port, 9-24V AC/DC and 2 Wire Auto Return Setup by U.S. Solid	For Water Valve Circuit	Various	US Solid	1	JFSV00015	$30.39	$30.39
Switch for Hobart - Part# 00-347717-00001	For Water Valve Circuit	Various	sharpteksupply	1	347717-00001	$13.85	$13.85
						Subtotals:	$112.91
			Subsystem 2: Frame				
1/2 inch PVC Pipe	For Frame	PVC	IPEX/ Home Depot	86	319692959	$0.47	$40.51
1/2 in. PVC Schedule. 40 90-Degree S x S Elbow Fitting	For Frame	PVC	Charlotte Pipe/ Home Depot	1	203812033	$0.67	$0.67
1/2 in. PVC Schedule 40 S x S x S Tee	For Frame	PVC	Charlotte Pipe/ Home Depot	5	203812195	$0.67	$3.35
/2 in. PVC Side Outlet 90-Degree S x S x S Elbow Fitting	For Frame	PVC	Charlotte Pipe/ Home Depot	10	PVC025100600HD	$2.58	$25.80
1/2 in. Furniture Grade PVC 5-Way Cross in White	For Frame	PVC	Charlotte Pipe/ Home Depot	3	F0125WC-WH-10	$2.70	$8.10
1/2 in. Furniture Grade PVC 4-Way Tee	For Frame	PVC	Charlotte Pipe/ Home Depot	5	F0124WT-WH-10	$1.40	$7.00
						Subtotals:	$85.42
			Subsystem 3: 3D Printed Elements				
Basketball Hoop		PLA	Co-Lab	1		$2.00	$2.00
3 Arm System	Convery roattion to linear motion	PLA	Co-Lab	3		$2.00	$6.00
						Subtotals:	$8.00
			Subsystem 4: Other Elements				
Backboard	Laser cut and engrave plywood	Acrylic	Co-Lab	1		$4.00	$4.00
Basketballs	Small enough for 6-10 to throw	PVC	Walmart	1	472930881	$12.55	$12.55
Ball Return Cloth	1 yd needed for ball return	Craft Fabric	Michaels	1	10608161	$1.79	$1.79
Kiddy Pool	To colect water from shower head	Plastic	Walmart	1	926488570	$6.98	$6.98
Mounting Backboard	3x2 Plywood	Plywood	Co-Lab	1		$4.00	$4.00
Bearings	For 3-arm motor system	Various	Digikey	15	1995-1011-ND	$0.73	$10.95
						Subtotals:	$40.27
						Total Bought with Budget	$135.34
						Total	**$246.60**

Figure 8: Final Bill of Materials

4 Iterations and Design Challenges

During the project, the team encountered several challenges with the initial plan. First, when the backboard was mounted as shown in Figure 12, the hoop was positioned too low, making it impossible for players to arc the ball properly. This issue was resolved by adding 12 inches to the frame, as seen in Figure 13, which allowed both the hoop and shower head to be raised.

Building the tank also posed a challenge, as it needed to be watertight and allow water to flow via gravity. Ultimately, the team decided to use a Sterlite shoebox that was heat-treated and fitted with a plastic connector. Marine-grade epoxy was then used to seal the tank.

Initially, the plan involved using a solenoid valve, but it produced a much lower mass flow rate than desired. To address this, the team ordered a ball valve that could fully open and close, significantly increasing the flow rate.

Perhaps the biggest challenge was integrating the electronics. The team struggled to provide enough power to activate the solenoid, and they discovered that the Arduino lacked sufficient computing power to operate an LCD, three servo motors, a relay, a solenoid valve, and a push button simultaneously. They resolved this issue by activating the solenoid valve mechanically. As shown in Figure 14, when the third player stood up, popsicle sticks would hit the push button, powering the solenoid valve. When the game reset, the solenoid valve closed, taking advantage of the capacitor inside that allows it to shut even without power.

Additionally, the team had difficulty supplying enough voltage to the solenoid, which required a minimum of 9V. As the 9V batteries drained, the solenoid struggled to open. This issue was resolved by connecting two 9V batteries in series, as shown in Figure 15, which provided a total of 18 volts.

5 Supplemental Documentation

5.1 Subcomponents

5.1.1 Ultrasonic and Solenoid Valve Circuit

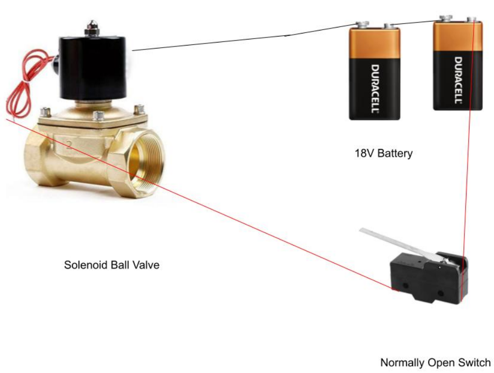

Figure 9: Solenoid Valve Circuit

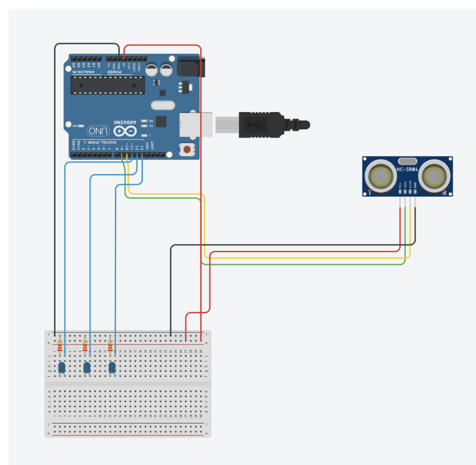

Figure 10: Ultrasonic Sensor Circuit

This circuit operates by combining an LCD display, push button, ultrasonic sensor, and servo motors to create an interactive game. When the push button is pressed, a 60-second countdown starts, displayed on the LCD. During this time, the ultrasonic sensor detects when a basketball passes through a hoop by measuring the distance. Each time the ball is detected within a set range (e.g., 10 cm), one of three motors rotates 180 degrees to cause a basketball player to pop up, indicating a successful shot. Once the timer expires, the motors reset, and the LCD returns to displaying ”Ready” for the next round.

The solenoid valve circuit will regulate the inflow and outflow of water when activated. The circuit diagram below illustrates the model; in the final design, the circuit will activate when the third servo motor is activated which will trigger the normally open switch mechanically.

5.1.2 Hoop and Shower head

The Basketball hoop was designed to have a place for the ultrasonic sensor to fit inside. The CAD design for the shower head that will release the water from the tank onto the person is pictured below. The top is designed to slide onto the solenoid valve. The cutouts at the bottom allow for a large amount of flow to pass through while dispersing the water so it travels to the outer edges instead of dropping straight through the bottom where the surface is aligned with the valve.

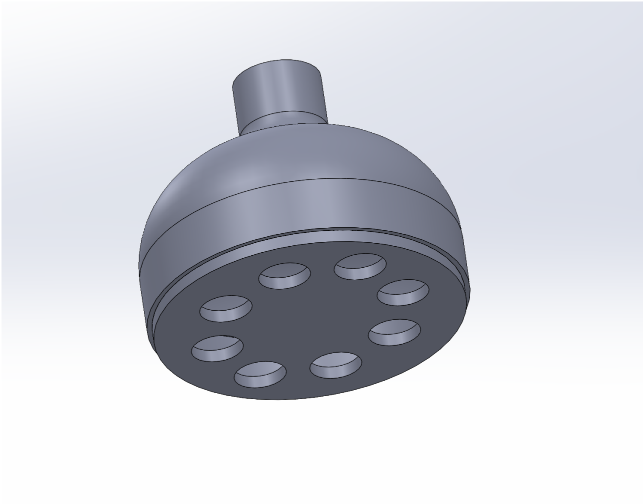

Figure 11: Shower Head CAD Design

Figure 12: Basketball Hoop CAD Design

5.2 Updated Calculation of Axial Force and Factor of Safety for PVC Members

For the updated design, the team needs to support a reduced load of 10.5 lbs of water using 1/2-inch PVC members. The design remains focused on maintaining structural integrity while optimizing costs.

Given Data

- Total load: $W = 10.5$ lbs
- Number of PVC members: $n = 4$
- Cross-sectional area of each PVC member: $A = 0.196$ square inches
- Yield strength of PVC: $\sigma_{\text{yield}} = 500$ PSI

Axial Force on Each PVC Member

The axial force on each member is:

$$F_{\text{axial}} = \frac{W}{n} \tag{1}$$

Substituting the values:

$$F_{\text{axial}} = \frac{10.5 \text{ lbs}}{4} = 2.625 \text{ lbs} \tag{2}$$

Stress in Each PVC Member

The stress σ is:

$$\sigma = \frac{F_{\text{axial}}}{A} \tag{3}$$

Substituting $F_{\text{axial}} = 2.625$ lbs and $A = 0.196$ square inches:

$$\sigma = \frac{2.625}{0.196} \approx 13.39 \text{ PSI} \tag{4}$$

Factor of Safety

The factor of safety (FoS) is:

$$\text{FoS} = \frac{\sigma_{\text{yield}}}{\sigma} \tag{5}$$

Substituting $\sigma_{\text{yield}} = 500$ PSI and $\sigma = 13.39$ PSI:

$$\text{FoS} = \frac{500}{13.39} \approx 37.4 \tag{6}$$

This updated calculation shows that the PVC members can safely support the load with a significant factor of safety.

5.3 Calculation for Derivation of Mass Flow Rate of Tank to Outlet Velocity

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \tag{7}$$

where:

- P_1 is the pressure at point 1 (surface of the water in the tank),
- v_1 is the velocity at point 1 (negligible compared to v_2),
- h_1 is the height of point 1 above some reference level (5 inches),
- P_2 is the pressure at point 2 (hole),
- v_2 is the velocity at point 2 (velocity of water flowing out),
- h_2 is the height of point 2 above the same reference level.

Choose Points

1. **Point 1:** Surface of the water in the tank. 2. **Point 2:** Hole through which water is flowing out.
   Assume:

- The velocity of water at the surface of the tank v_1 is negligible, so $v_1 \approx 0$.
- The pressure at the surface of the water is atmospheric pressure $P_1 = P_{\text{atm}}$.
- The pressure at the hole is also atmospheric pressure $P_2 = P_{\text{atm}}$.

Thus, Bernoulli's equation simplifies to:

$$P_{\text{atm}} + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_{\text{atm}} + \frac{1}{2}\rho v_2^2 + \rho g h_2 \tag{8}$$

Since v_1 is negligible and P_{atm} cancels out, we get:

$$\rho g h_1 = \frac{1}{2}\rho v_2^2 + \rho g h_2 \tag{9}$$

Rearranging the equation to solve for v_2:

$$\rho g h_1 - \rho g h_2 = \frac{1}{2}\rho v_2^2 \tag{10}$$

$$g h_1 - g h_2 = \frac{1}{2} v_2^2 \tag{11}$$

$$2g(h_1 - h_2) = v_2^2 \tag{12}$$

$$v_2 = \sqrt{2g(h_1 - h_2)} \tag{13}$$

Assuming $h = h_1 - h_2 = 5 \text{ inches} = \frac{5}{12}$ ft:

$$v_2 = \sqrt{2gh} \tag{14}$$

Where $g = 32.1522\,\text{ft/s}^2$, $h = \frac{5}{12}$ ft:

$$v_2 = \sqrt{2 \times 32.1522 \times \frac{5}{12}} \approx 10.0\,\text{ft/s} \tag{15}$$

For 4 holes, each with an area of $0.011\,\text{in}^2$:

1. Area of one hole (converted to ft^2):

$$A = 0.011\,\mathrm{in}^2 = 0.011 \times \frac{1}{144} \approx 7.64 \times 10^{-5}\,\mathrm{ft}^2$$

2. Total area:

$$A_{\mathrm{total}} = 4 \times 7.64 \times 10^{-5} \approx 3.056 \times 10^{-4}\,\mathrm{ft}^2$$

3. Volumetric flow rate:

$$Q = v_2 \times A_{\mathrm{total}} = 10.0 \times 3.056 \times 10^{-4} \approx 3.056 \times 10^{-3}\,\mathrm{ft}^3/\mathrm{s}$$

4. Mass flow rate (using density of water $\rho = 62.4\,\mathrm{lb}/\mathrm{ft}^3$):

$$\dot{m} = Q \times \rho = 3.056 \times 10^{-3} \times 62.4 \approx 0.191\,\mathrm{lb/s}$$

Given:

- Mass flow rate $\dot{m} \approx 0.191\,\mathrm{lb/s}$
- Cycle duration = 10 s
- Tank capacity = 10.5 lbs

Mass used per cycle:

$$\text{Mass per cycle} = \dot{m} \times \text{Cycle duration} = 0.191 \times 10 \approx 1.91\,\mathrm{lb}$$

Number of cycles:

$$N = \frac{10.5}{1.91} \approx 5.5$$

You can run approximately $\lfloor 5.5 \rfloor = 5$ cycles before needing to be refilled.

5.4 Original Bill of Materials

Bill of Materials

Project Name:	Duke Dunk Tank	Group Members	Chris Cosby, Izzy Dudlyke, Olivia Lee, Minha Kim	Date:	11 September 2024		
Item	**Description**	**Material**	**Source**	**Quantity**	**Part #**	**Unit Price**	**Total Price**
			Subsystem 1: Electronics				
Ultrasonic Sensor	For Sensor Circuit	Various	Digikey	1	1528-2711-ND	$3.95	$3.95
Arduino Uno	For Both Circuits	Various	Ardunio Store	2	A000066	$14.99	$29.98
Blue LED	For Sensor Circuit	Various	Digikey	3	732-5015-ND	$0.26	$0.78
Push Button	For Sensor Circuit	Various	Digikey	1	2223-TS02-66-70-BK-260-LCR-D-ND	$0.13	$0.13
Resistor 220 Ohm	For Sensor Circuit	Various	Digikey	3	CF14JT220RTR-ND	$0.10	$0.30
Resistor 10kOhm	For Sensor Circuit	Various	Digikey	1	738-CF14JA10K0CT-ND	$0.10	$0.10
7 Segment Display	For Sensor Circuit	Various	Digikey	1	1080-1182-ND	$2.51	$2.51
12-Volt Alkaline	For Water Valve Circuit	Various	Amazon	1	A23-4PK	$1.14	$1.14
9-Volt Alkaline	For Sensor Circuit	Various	Amazon	1	6LR61-8PK	$1.42	$1.42
U.S. Solid Electric Solenoid Valve- 1/8" 12V DC Solenoid Valve Brass Body Normally Closed, NBR SEAL	For Water Valve Circuit	Various	US Solid	1	JFSV00015	$13.99	$13.99
							$0.00
						Subtotals:	$54.30
			Subsystem 2: Frame				
1/2 inch PVC Pipe	For Frame	PVC	IPEX/ Home Depot	65.33	319692959	$0.47	$30.77
1/2 in. PVC Schedule. 40 90-Degree S x S Elbow Fitting	For Frame	PVC	Charlotte Pipe/ Home Depot	1	203812033	$0.67	$0.67
1/2 in. PVC Schedule 40 S x S x S Tee	For Frame	PVC	Charlotte Pipe/ Home Depot	7	203812195	$0.67	$4.69
/2 in. PVC Side Outlet 90-Degree S x S x S Elbow Fitting	For Frame	PVC	Charlotte Pipe/ Home Depot	8	PVC025100600HD	$2.58	$20.64
1/2 in. Furniture Grade PVC 5-Way Cross in White	For Frame	PVC	Charlotte Pipe/ Home Depot	1	F0125WC-WH-10	$2.70	$2.70
1/2 in. Furniture Grade PVC 4-Way Tee	For Frame	PVC	Charlotte Pipe/ Home Depot	5	F0124WT-WH-10	$1.40	$7.00
						Subtotals:	$66.47
			Subsystem 3: 3D Printed Elements				
Basketball Hoop		PLA	Co-Lab	1		$2.00	$2.00
							$0.00
						Subtotals:	$2.00
			Subsystem 4: Other Elements				
Backboard	Laser cut and engrave acrylic	Acrylic	Co-Lab	1			$0.00
Basketballs	Small enough for 6-10 to throw	PVC	Walmart	1	472930881	$12.55	$12.55
Ball Return Cloth	1 yd needed for ball return	Craft Fabric	Michaels	1	10608161	$1.79	$1.79
Stool	Dunked person sitting	Plastic/Steel	IKEA	1	101.356.59	$4.99	$4.99
Water Tank	Occasional refill	Plastic	Walmart	1	1530344	$9.70	$9.70
Kiddy Pool	To colect water from shower head	Plastic	Walmart	1	926488570	$6.98	$6.98
				1		$7.99	$7.99
							$0.00
						Subtotals:	$44.00
						Totals:	$166.77

Figure 13: Original Bill of Materials

5.5 Photos of Prototypes

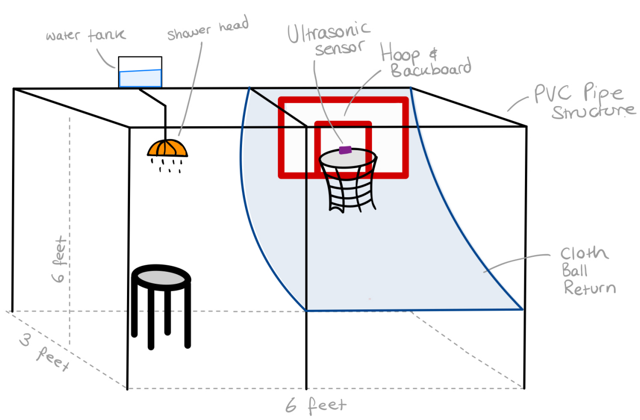

Figure 14: Initial Sketch

Figure 15: First Iteration of Frame

Figure 16: Framework of Dunk Tank

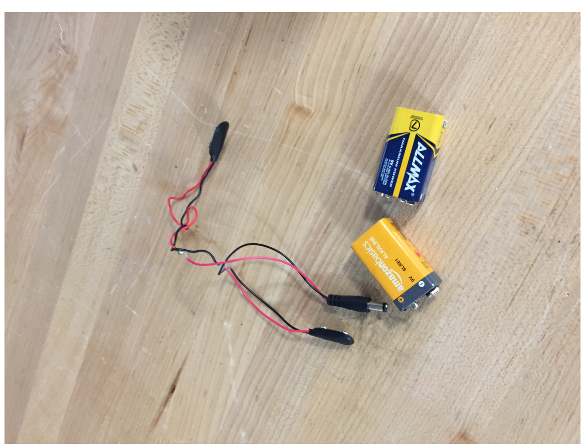

Figure 17: 18 Volt Battery

References

[1] James, Fuller "Solenoid Water Liquid Valve – Arduino Tutorial." April 1 2023