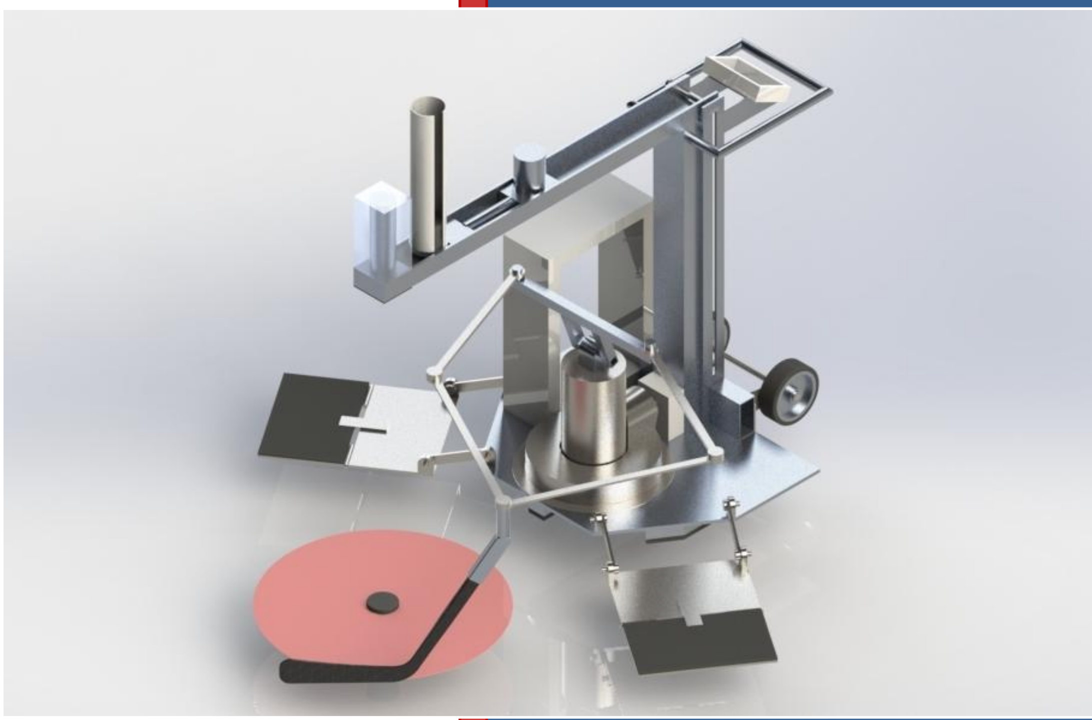
Design of a Hockey Face-off Simulator

Final Design Report



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MECH 4860 – Team 26 Hockey Simulations

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Executive Summary

The team designed a hockey face-off simulator, a project proposed by client Zeljko Djuric, which allows a user to individually practice and improve their face-off skills. The design realistically replicates the referee and the opposing player in a hockey face-off. While meeting the majority of the needs and adhering to the constraints and limitations, the team has chosen concepts that satisfy the design objectives of portability, stability, and a variety of face-off strategies. The team is providing the client with a SolidWorks model of the design in addition to this report which discusses the details of the design, an initial bill of materials with associated costs, and future recommendations.

The face-off simulator has two overarching design features: the puck dropping mechanism and the face-off motion. The puck dropping mechanism consists of a bridge and a supporting column connected via a spring-loaded pin. On the bridge, a puck storage cylinder feeds a puck so that an electric actuator can push it to the puck drop location where a pneumatic piston forces the puck down towards the face-off surface. The face-off motion has four degrees of freedom (identified in parentheses) via a five bar linkage that is supported by an upper body structure, which is connected to a motor (rotation about the x-axis) that is mounted on top of a column. The column is fixed to a bevel gear (rotation about the y-axis) on top of the base. Four of the five links of the linkage act as arms and forearms with pins as elbows (translation in the x- and z-directions). The forearms meet at a common shaft which holds a hockey stick.

When in use, the machine stands at 53.15 inches tall, 64.17 inches wide with the footings fully extended, and 83.46 inches long with the arms fully extended. The machine can be collapsed into a smaller configuration for transportation that will be 49.61 inches tall, 30 inches wide, and 32.28 inches long. A face-off can be performed every 24 seconds, based on the assimilated speeds of components of the puck dropping mechanism. The pneumatic system and all electrical components are to be run off of a rechargeable lithium-ion battery to make the design portable, in addition to its collapsible features. With these features, the machine weighs a minimum of 186 pounds. The total cost of the design is estimated to be a minimum of $6639.66, which is based on limited component selection and decisions made by the team.

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1.0 Introduction

A hockey face-off is an event that takes place in a hockey game at the beginning of each period and after every stoppage in play. A face-off takes place at one of the nine face-off dots located around the rink, as seen in Figure 1.

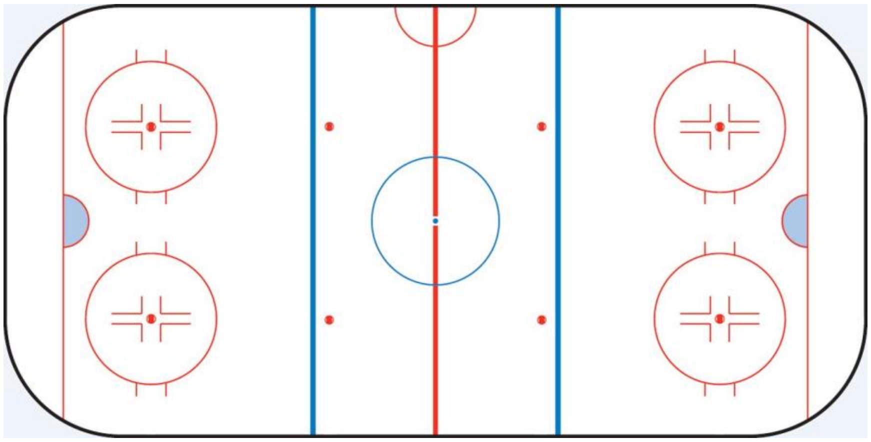


Figure 1: Face-off dot locations on a hockey rink [1].

To win a face-off, a player has to successfully retrieve the puck out of the face-off zone, away from the opposing team. This event involves three parties: one player from each of the two participating teams, and a referee who drops the puck between them. In order to practice a face-off, all three parties need to be present. However, it is not always feasible to spend time rehearsing face-offs on the ice during team practice because it takes time away from the practice and not every player needs to practice face-offs. Typically, there are only four players that play the center position, out of a roster of roughly 20 players, who take all of the face-offs during a game. In addition, puck possession is a key part of winning hockey games. If a player wins a high percentage of face-offs, he provides an advantage to the team at the beginning of every play through puck possession. Thus, a hockey face-off simulation machine would help the team in obtaining puck possession whilst optimizing practice time.

This project was acquired by the University of Manitoba from the client, Zeljko Djuric, a mechanical engineer who conceived the idea of a hockey face-off simulation machine. The client tasked the team with designing the simulator.

1.1 Background

This project does not have a role within a particular company; the idea originated when the client became frustrated after watching professional hockey teams struggle in the face-off circle during their hockey games. He wanted to find a way to help teams be more successful in this particular aspect of the game. He has been in contact with an equipment manager to see if this type of simulation machine would be valuable to a hockey team. The equipment manager expressed that teams are interested in finding tools that give them an advantage over their competition. Therefore, if a suitable machine were to be developed to provide that advantage, the team would be interested in purchasing it.

To date, there is only one pre-existing machine that is similar to this idea: the puck-dropping machine, the RoboRef "Face-off Trainer" by Boni Goalie Trainers, Inc. [2]. However, this machine only provides the simulated experience of the referee dropping the puck for two practicing players. This machine lacks the ability for one player to practice face-offs alone, which is contained within the scope of the project. Furthermore, it was found that there was a patent made for the RoboRef's face-off trainer [3]. This patent has since expired, so there is potential to expand upon the idea contained within the patent.

The client tasked the team with designing a functional model that can be brought to the next phase: prototyping. With the success of this project, there is an opportunity for this design to be manufactured into a quality product, which could be the basis for a new company that sells and distributes hockey face-off simulators.

1.2 Problem Statement

An individual cannot practice hockey face-offs alone because a face-off involves three parties, and there are currently no devices on the market that replicate the face-off experience. The sport of hockey requires players to perform over 50 face-offs in a professional game, indicating that this skill needs to be practiced [4].

1.3 Project Objectives

The purpose of this project is to design and analyze a machine that will be able to drop a puck and perform a hockey face-off against an elite hockey player. This machine will allow an individual to practice face-offs without the aid of other people. This machine should help players practice face-offs whenever and wherever they want, whether it is on the ice, in the gym, or at home on the driveway. The machine must be able to perform a face-off at a skill level that challenges the user's skills in order to develop face-off prowess. The design of this machine is intended for training high-caliber hockey players to give them an advantage when entering the face-off circle in game situations.

Due to the nature in which a face-off can be performed, various strategies can be employed to win a face-off. These strategies can include using the hockey stick to win a face-off, contacting the opposing player to prevent a win, or moving the puck back using skates. For this project, the machine will be designed to perform a 'clean draw', which will be defined as winning the face-off solely using the hockey stick without contacting the opposing player's body. The purpose of this machine will be to allow the user to improve in the art of clean draws.

Final project deliverables include a SolidWorks model of the simulator and a brief cost analysis of the simulator's components. The SolidWorks model encompasses all of the design concepts selected by the team and the cost analysis provides an initial cost for producing the simulator. The design includes all mechanical components and highlights appropriate spaces for power sources. Since the ultimate goal of this machine, as outlined by the client, is to be sold to hockey teams of various leagues, the machine cannot infringe upon any existing patents.

1.4 Target Specifications

This section establishes the customer needs, and lists specifications and quantifiable values with appropriate units to give a framework of the design.

The design needs of the simulation machine are presented in TABLE I. The importance column refers to the priority of the customer need ranging from 1 to 5, 5 being the most important. Needs from the problem description are assigned an importance of 5 whereas needs added by the team to better define the project are assigned lower importance ratings.

TABLE I: CUSTOMER NEEDS

#	Need	Importance
1	The machine simulates the face-off experience.	5
2	The machine simulates the puck drop.	5
3	The machine simulates a variety of face-off techniques.	5
4	The machine simulates left- and right-handed opponents.	5
5	The machine challenges the user.	5
6	The machine has motion sensors.	4
7	The machine has a reasonable manufacturing cost.	5
8	The machine is compact.	3
9	The simulator is safe.	4
10	The simulator has padding.	1
11	Simulator components last a long time.	5
12	The simulator withstands repeated physical forces.	5
13	The machine remains stable during the simulation.	5
14	The machine is easy to setup and use.	4
15	The simulator is easily programmable.	5
16	The simulator can be operated and used by an individual.	5
17	The simulator operates normally on different surfaces.	5
18	The simulator is easy to maintain.	3
19	Simulator components are easy to replace.	1
20	Machine components are easily accessible.	1
21	The simulator is battery powered.	5
22	The simulator can be used while recharging.	3
23	The simulator recharges quickly.	4

Next, the customer needs are quantified by establishing specifications. The following table lists specifications that are relevant to the needs in TABLE I. Accompanying the specifications are units and target values. If the team reaches these proposed target values, the goals of our design will be accomplished.

TABLE II: TARGET SPECIFICATIONS

#	Need #	Metric	Importance	Unit	Target
1	1	Records simulation	2	binary (yes/no)	Yes
2	1	Projects a face-off image	1	binary (yes/no)	Yes
3	1,2	Initial height of puck	4	feet	2 to 4
4	1,2	Freefall puck velocity	1	feet per second	12 to 15
5	3,4	Left Straight Draw	5	binary (yes/no)	Yes
6	3,4	Right Straight Draw	5	binary (yes/no)	Yes
7	3,4	Left Curved Draw	5	binary (yes/no)	Yes
8	3,4	Right Curved Draw	5	binary (yes/no)	Yes
9	3,4	Draw Back	5	binary (yes/no)	Yes
10	5,14	Reaction time (Novice)	5	seconds	0.50 to 1.00
11	5,14	Reaction time (Intermediate)	5	seconds	0.25 to 0.49
12	5,14	Reaction time (Expert)	5	seconds	0.05 to 0.24
13	6	Detects puck movements	4	binary (yes/no)	Yes
14	7	Manufacturing cost	5	$	<8000
15	8	Machine height	1	feet	<5
16	8	Machine width	1	feet	<3
17	8	Machine depth	1	feet	<3
18	9	Smooth edges: fillet radius	1	inches	0.12
19	9,10	Padding thickness	1	inches	>0.75
20	11	Simulator longevity	5	years	5 to 10
21	12	Hockey stick stiffness	1	ft-lb	6638 to 8851[5]
22	12	Force to break a hockey stick	2	lbf	>2203[6]

#	Need #	Metric	Importance	Unit	Target
23	12	Machine components withstand force to break a hockey stick	5	binary (yes/no)	Yes
24	13	Restricting the machine from moving	5	list	bracing, pins, rubber
25	13	Machine weight	4	pounds	175 to 300
26	14	Setup/shutdown time	4	minutes	2 to 5
27	15,16	User friendly interface	5	subjective	simple to use
28	15,16	Display monitor	5	inches	~7
29	17	Types of surfaces	5	list	grass, gym floor, ice, street, concrete, carpet
30	18,19	Component replacement time	3	minutes	10 to 15
31	20	Component access time	1	minutes	2 to 5
32	21	Accessible charging port	3	binary (yes/no)	Yes
33	22	Battery bypass line	3	binary (yes/no)	Yes
34	23	Time to recharge	4	hours	1 to 2

The same importance rating is used in this table to prioritize the specifications. This importance rating is based on the metric's relation to the customer needs.

Regarding metric 1 and 2, the client requested that the simulator records the user performing the simulation and projects an image of the face-off dot. However, since these features are not crucial for the machine to perform its main functions of dropping the puck and performing a face-off, the importance ratings are low.

Regarding metric 3, the height range of 2 to 4 feet was determined by visually observing professional hockey footage and from playing experience. Regarding metrics 10 to 12, the reaction times were determined arbitrarily. Using these reaction times and the target heights, the minimum and maximum freefall puck velocities were calculated for the target range in metric 4.

Metrics 5 to 9 highlight face-off motions. These motions were determined by observing professionals and from playing experience. However, these motions are not all of the possible face-off strategies used in hockey. For the purpose of this simulator, only the hockey stick strategies will be used. The target is to achieve all of the stick motions for the machine to have the utmost versatility.

Regarding metric 13 and 14, the targets of detecting puck movements and a cost of less than $8,000, respectively, were determined by the client.

Regarding metrics 15 to 17, the target dimensions were determined by the portability of the machine. Through discussions with the client, the machine would need to be transported through a normal size door, restricting the width to be less than 3 feet. Additionally, the team hopes a two-wheeled dolly could be used to move the machine. The maximum target height of 5 feet and depth of 3 feet are to accommodate the use of a two-wheeled dolly for transport. These values were determined from a team member's work experience.

Regarding the safety metrics, 18 and 19, the team decided to apply a small fillet radius for the smooth edges and have padding on components that are exerted to physical forces. The machine may not even need fillets and/or padding, which is why the importance ratings for these metrics are low.

The target of 5 to 10 years of longevity was chosen for metric 20 because the machine is expected to have a high manufacturing cost. For the average consumer, it would be unreasonable to buy a machine that lasts less than five years, especially with that kind of price.

For metrics 21 to 23, the simulator should be able to withstand typical forces exerted by a player during a face-off. Target values for metrics 21 and 22 will be used to design a hockey stick for the simulator. The client expressed that he would rather have a stick made for the machine rather than using the user's hockey sticks.

Regarding metrics 24 and 25, the machine needs to be stable during the simulation. Current ideas for stabilizing the simulator are bracing, pins, and/or rubber. Additionally, a machine weight of 175 to 300 lbs would be sufficient to keep the machine static during simulations.

Regarding the setup/shutdown time, metric 26, the target was based on the team's experience with playing the game. A setup/shutdown time of less than 5 minutes will ensure the machine's simplicity and ease of use.

The user friendly interface and the display monitor, respectively metrics 27 and 28, involve the programmability of the machine. The user friendly interface should be simple to use so that the user can easily program the machine settings. The display monitor target value of 7 inches was provided by the client.

Regarding metric 29 of various surface types, the machine needs to operate normally on various surfaces. Through discussions with the client, the team made a short list of the operating surfaces: ice, gym floor, grass, street, concrete, and carpet.

For metrics 30 and 31, respectively the component replacement time and component access time, the client and the team would like the machine to be easily maintainable. That is, the component replacement time should not be demanding which is why the target time is in the range of 10 to 15 minutes. This time excludes the component access time, where a target of 2 to 5 minutes was determined by the team. These values were chosen based on previous maintenance experience that certain team members have experienced.

The remaining metrics of charging port accessibility, battery bypass line, and recharging time, respectively 32, 33, and 34, deal with the battery power. The client stated that the simulator needs to be operated via a battery as this will enhance its portability. To make the battery convenient, the rechargeable port needs to be easily accessible and the machine should be able to run while the battery is recharging. The battery recharging target time of 1 to 2 hours was based on the recharging time of a cell phone or laptop battery.

1.5 Constraints and Limitations

To further define the project, this section outlines and elaborates on constraints and limitations the team will experience throughout the project. Firstly, project limitations unrelated to the specific design of the project are discussed. Subsequently, constraints directly affecting the specific design are acknowledged: portability, replicating real face-off motions, and final design cost.

The team's project limitations are time and cost, which are 13 weeks and $400, respectively. This budget is supplied by the course, mainly for printing expenses, but does not include costs for building prototypes or testing competing designs. Moreover, the team's background and experience limits the design to mechanical components. Thus, electrical motors and features cannot be fully developed.

The team's design limitations for this project are portability, realistic face-off motion, and manufacturing cost. Portability requires the machine to fit through a standard size doorway for entrance into a gym, a training room, or a hockey rink. The target dimensions (height of five feet, width and depth of three feet) are based on the ability to transport the machine as well as fitting it through a doorway.

A variety of strategies are utilized by players during a face-off. The player's dexterity (left-handed or right-handed) and the motion of the player (moving the puck back-right, back-left, straight-back, etc.) affect the strategy. One commonality among all of the face-off strategies is the space in which the participant's sticks are active. Through personal experience, the team has determined the space to be approximately six feet by 3 feet. Thus, the realistic face-off motion cannot exceed these dimensions.

A challenging constraint is the projected cost of the design. Ideally, the design should cost no more than $8,000, which includes materials and labour. This may limit the team in selecting parts to build the machine. However, the client stated that if a feature adds value to the design, the budget can be altered to accept that feature [7].

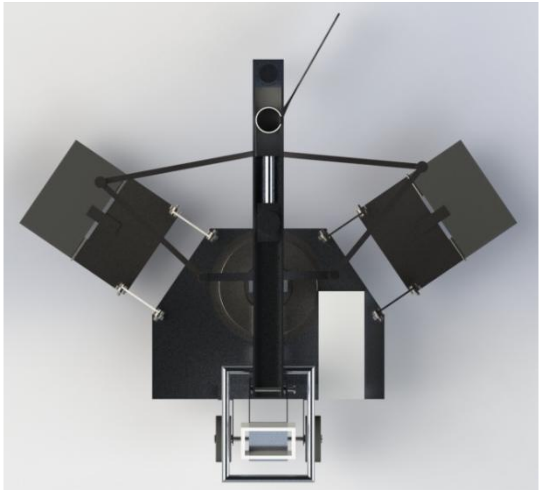
2.0 Details of the Design

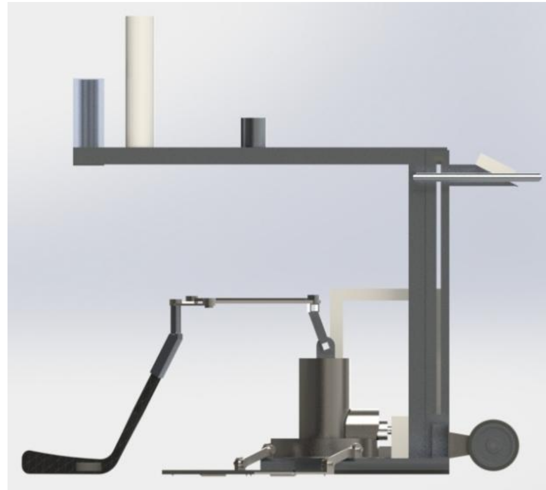
Through brainstorming sessions, concept analysis, and concept scoring, the team was able to design a machine that allows an individual to practice face-offs alone. Figure 2 shows left (a) and right (b) views of the simulator.

(a) (b)

Figure 2: Left (a) and right (b) angled views of the whole simulator [8].

The puck dropping mechanism is centered at the back of the machine and extends over the face-off motion to replicate a referee. The face-off motion is centered at the front of the machine to replicate an opposing player. Figure 3 shows top (a) and side (b) views of the simulator.





(a) (b)

Figure 3: Top (a) and side (b) views of the whole simulator [9].

The following sections outline the components of the design, including their physical forms and functions.

2.1 Puck Dropping Mechanism

The structure seen in Figure 4 simulates the action of the referee dropping the puck.

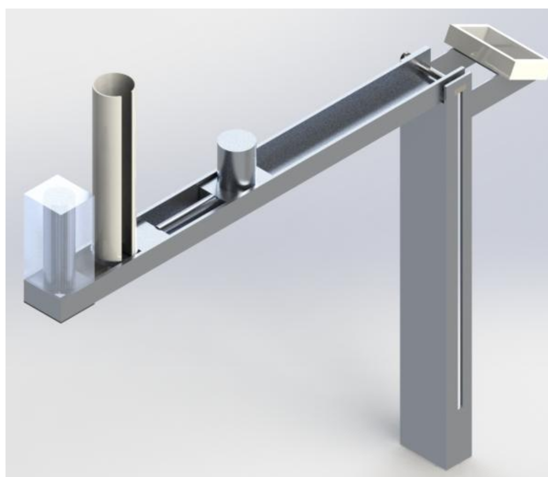
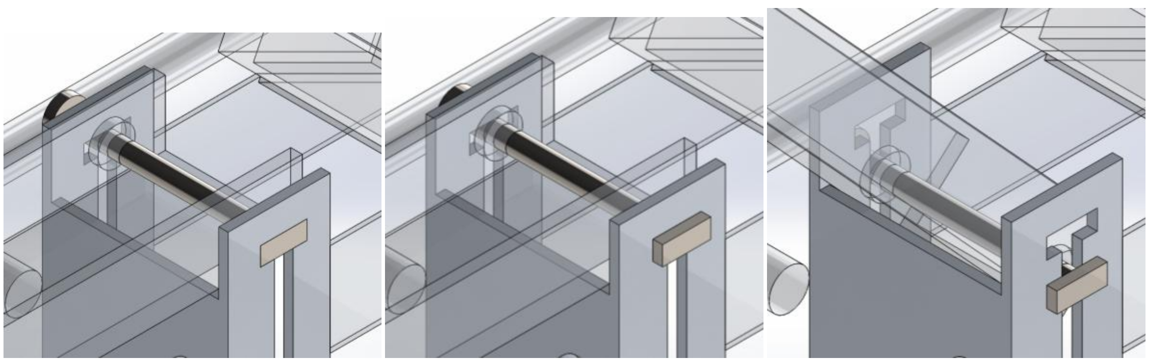


Figure 4: Image of the entire puck dropping mechanism [10].

This mechanism consists of purchased and manufactured parts. The puck dropper functions by storing pucks vertically in a cylinder. Pucks are dispensed from the cylinder via gravity and brought to the puck drop location by means of an electric actuator, mounted horizontally. Once the puck reaches the drop location, the puck is held by a rubber sheet prior to being ejected towards the surface by the pneumatic piston. The following subsections describe components of the puck dropping mechanism in greater detail. Details regarding the selection of concepts presented in this section and associated manufacturing principles can be found in the Appendix.

2.1.1 Bridge

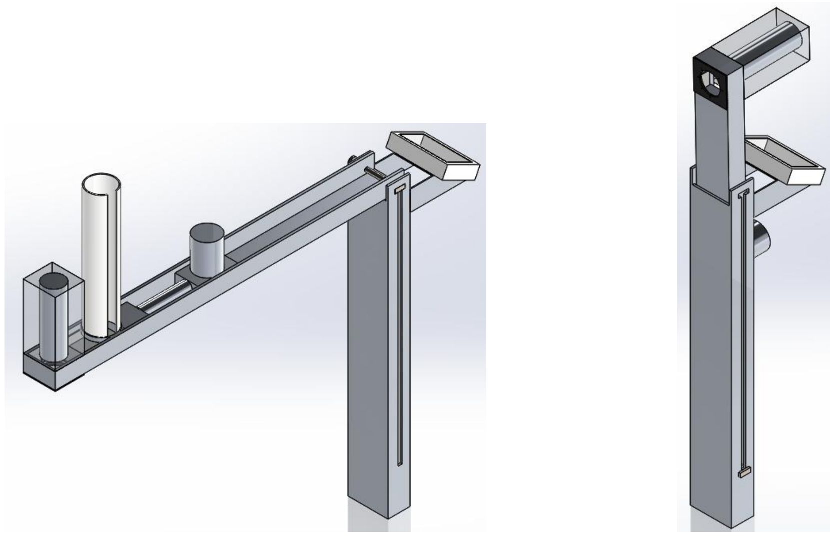
The bridge acts as the support for the puck dropping mechanism and extends over the face-off motion components. Attached to the bridge is the puck storage cylinder, puck holder, pneumatic piston for dropping the puck, and horizontal actuator for loading the puck. The bridge is connected to a supporting column by a spring-loaded pin. A close-up of the pin positions can be seen in Figure 5.



(a) (b) (c)

Figure 5: Pin positions from the bridge in operation (a) to the bridge in transportation (c) [11].

When the bridge is in operation, the pin is locked in a slot at the top of the column as seen in Figure 5a. For transporting the machine, the pin is pushed inwards, as seen in Figure 5b, and slides down vertically along the track, as seen in Figure 5c. This effectively eliminates the overhanging part of the bridge for transport. Retracted and non-retracted configurations of the bridge can be seen in Figure 6.



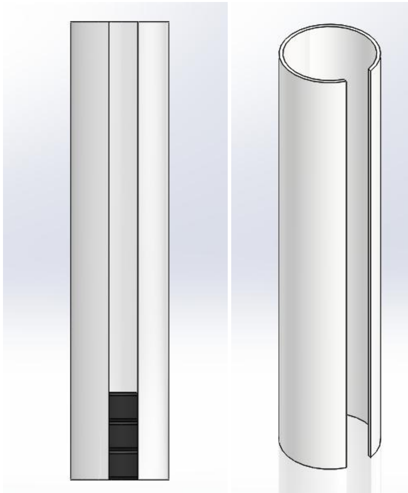
(a) (b)

Figure 6: Extended bridge (a) and collapsed bridge (b) [12].

For compact reasons, the bridge collapses vertically for easier storage and transportation. Note that the sleeve containing the pucks is removed when the bridge is collapsed. The bridge is cut from a 6061 aluminum U-channel and fits within the support column, which is also cut from a 6061 aluminum U-channel. However, the dimensions of the support column are slightly larger to allow the bridge to slide within. At the end of the bridge where the puck is being moved from the cylinder to the puck holder, a low-friction polymer lining is installed for easier puck travel. The inside width of the polymer lining is 3.125 inches to allow the 3-inch diameter puck to slide within. A tolerance of .125 inches is needed to further reduce the friction between the puck and the bridge as to minimize the force required from the electric actuator.

2.1.2 Puck Storage

Pucks are stored vertically in a cylinder that is capable of holding 15 pucks. The cylinder connects to the bridge by mechanically locking into a slot. Specifically, the cylinder is placed into the slot then twisted to lock into place. The cylinder is placed at a height that allows a puck to move freely underneath it. The storage cylinder is shown in Figure 7 with (a) and without pucks (b).



(a) (b)

Figure 7: Puck storage cylinder containing pucks (a) and empty (b) [13].

The storage cylinder is made of polyvinyl chloride (PVC) piping with a slit machined along its length. The slit is needed in the event that a puck is not oriented properly within the cylinder. Figure 8 shows the location of the storage cylinder on top of the bridge when it is extended.

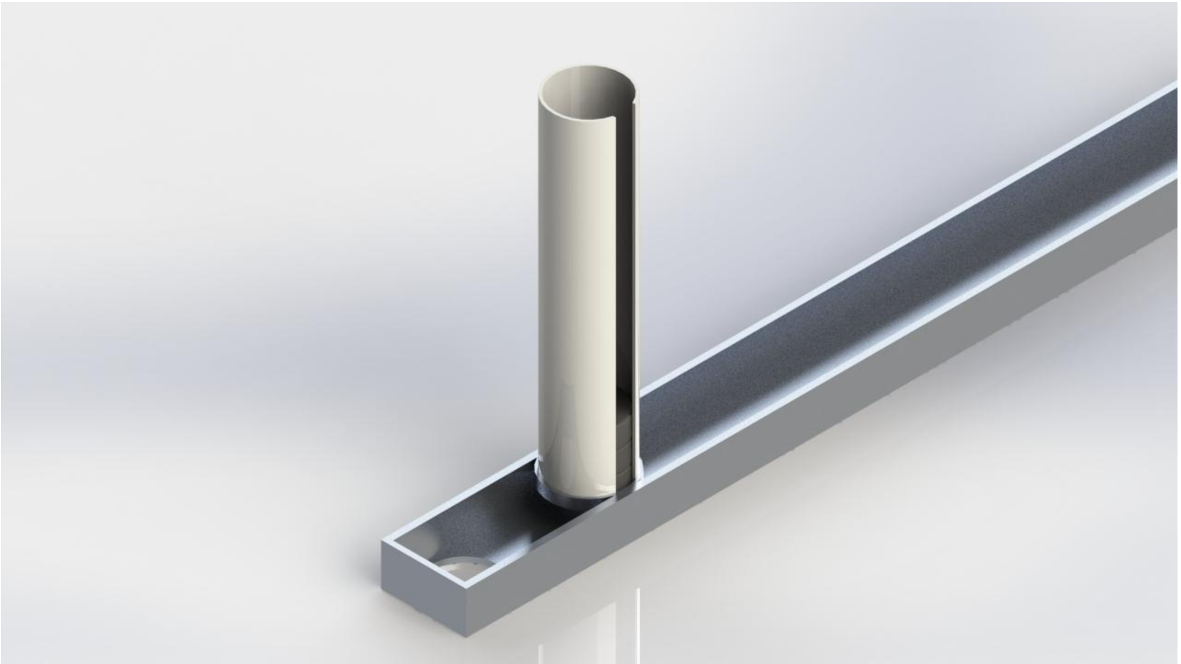


Figure 8: Storage cylinder in its slot on the bridge [14].

2.1.3 Electric Actuator

An electric actuator is chosen to push the puck from the storage cylinder to the puck drop location. As the actuator pushes a puck along the bridge, the shaft of the actuator prevents the next puck from leaving the cylinder. When the actuator shaft returns to its original position, a new puck falls into place. The actuator is mounted on the bridge on the base of the U-channel.

2.1.4 Puck Holder

The puck holder is made of rubber and is fixed under an opening at the end of the bridge, directly above the face-off circle. The opening is larger than the dimensions of a puck for easy ejection. This allows the puck to be held above the face-off circle prior to dropping the puck. The rubber will deform when the force from the pneumatic piston is applied, which allows the puck to fall to the ground. Figure 9 illustrates the puck holder.

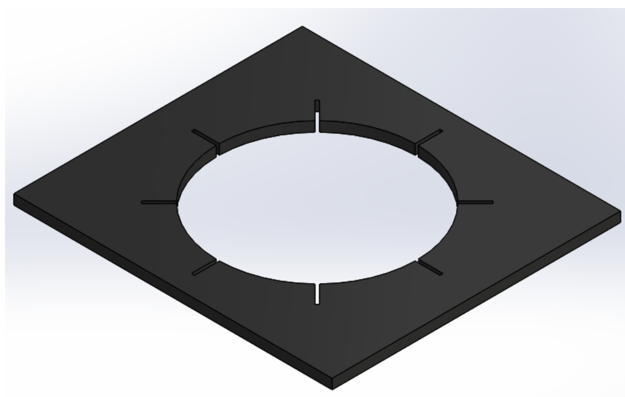


Figure 9: Rubber puck holder supporting the puck prior to the face-off [15].

The puck holder is manufactured from a rubber sheet with eight slits cut along the circumference of a hole. The diameter of the hole is smaller than the diameter of a puck so that it prevents the puck from falling. The slits allow the rubber to easily deform when force is applied to puck.

2.1.5 Pneumatic Piston

A pneumatic piston is chosen to push the puck through the rubber puck holder and onto the face-off circle. The piston is mounted at the end of the bridge, above the puck holder, as seen in Figure 10.

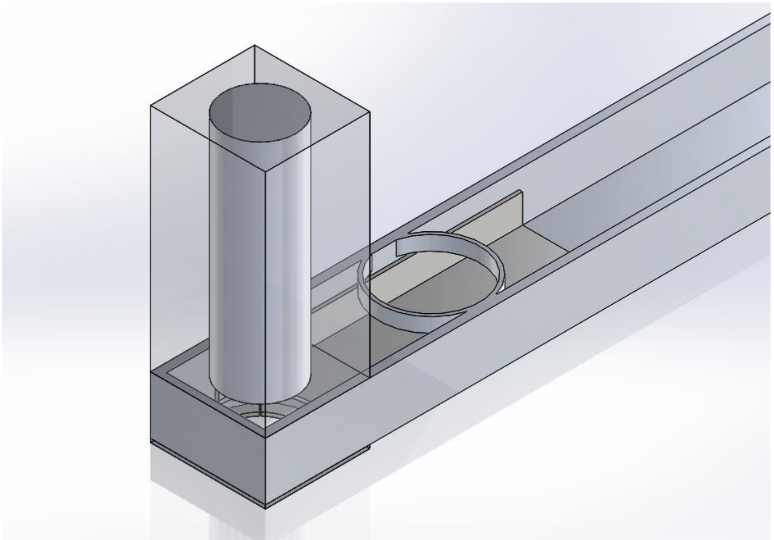


Figure 10: Piston providing an impact force to the puck mounted at the end of the bridge [16].

The piston is calibrated to lengthen at 25 ft/s and continues to extend through the puck holder. This allows the puck to fall at 25 ft/s thereby simulating the puck drop. An air hose is routed along the bridge to the piston, which is powered by an air compressor located on the base of the machine.

2.2 Face-Off Motion

The structure in Figure 11 replicates an accurate face-off motion of a hockey player and Figure 12 shows the face-off motion relative to the face-off dot.

Figure 11: Image of the simplified face-off motion [17].

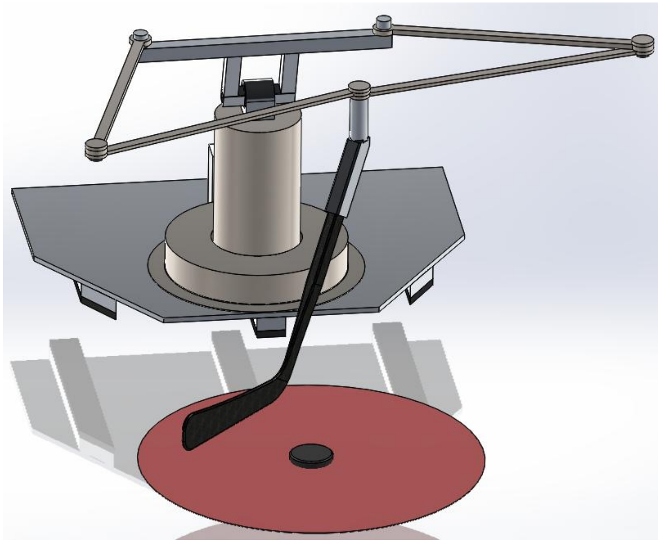


Figure 12: Face-off motion showing the location of the hockey stick relative to the puck and the face-off dot [18].

The components of the face-off motion include five servo motors, a bevel gear and pinion, thrust bearings, arms, and a body. These components provide a realistic face-off motion by incorporating numerous motion elements into the machine. The first motion element is from the body of the machine, which is a column mounted on a bevel gear. The bevel gear allows the body to rotate 180 degrees. On top of the body column, a hinge is mounted that allows forward and backward tilt. Connected to the hinge is an upper body skeleton that holds two servo motors which act as shoulders. The shoulders support two members each consisting of an arm, a pin acting as an elbow, and a forearm. The forearms meet at a common point where a shaft connects to a hockey stick. The following sections explain all the components of the face-off motion in greater detail. Details regarding the selection of concepts presented in this section and associated manufacturing principles can be found in the Appendix.

2.2.1 Rotating Body

The body column of the face-off motion is fixed to the top surface of a bevel gear, as seen in Figure 13. The gear allows the machine to rotate a total of 180 degrees.

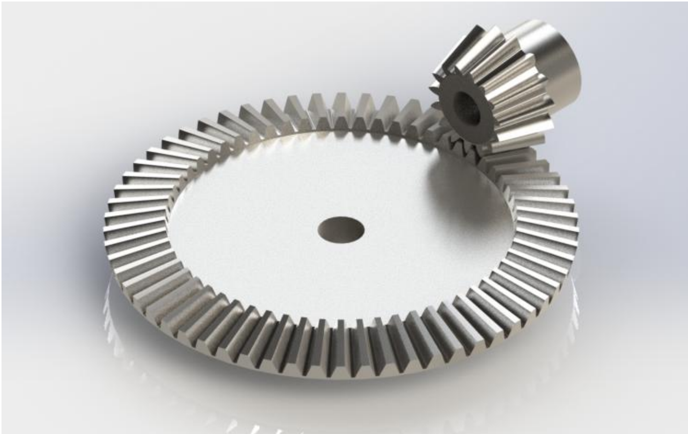


Figure 13: Bevel gears that provide body rotation [19].

Underneath the gear, a thrust bearing is fixed to the base to allow rotation of the gear. The gear is driven by a mated pinion which is powered by a continuous servo motor. This motor is mounted to the base located behind the gear.

2.2.2 Body Structure

The body structure consists of a column, a hinge, and an upper body structure. On top of the body column, a servo motor is mounted and used as the hinge that provides forward and backward tilt. Connected to the hinge is an upper body skeleton that holds two servo motors which act as shoulders. Figure 14 shows the body that supports the arms, which performs the face-off motion.

Figure 14: Body supporting the face-off motion [20].

The upper body structure is connected to both output shafts of the hinge motor. Figure 15 shows the upper body with the hip hinge isolated from the rest of the body.

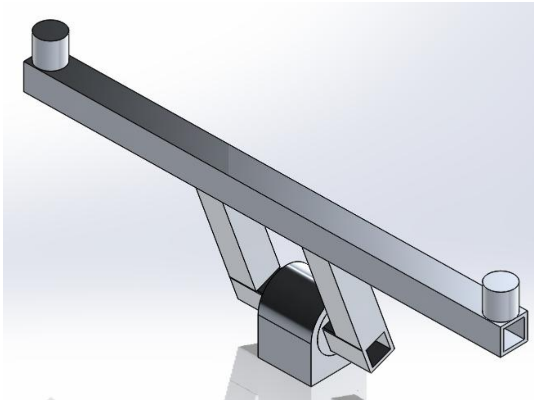


Figure 15: Upper body skeleton with the hinge [21].

The hinge is initially tilted forward at 20 degrees so that the body does not contact the bridge behind when tilting backwards. Figure 16 shows a side view of the body.

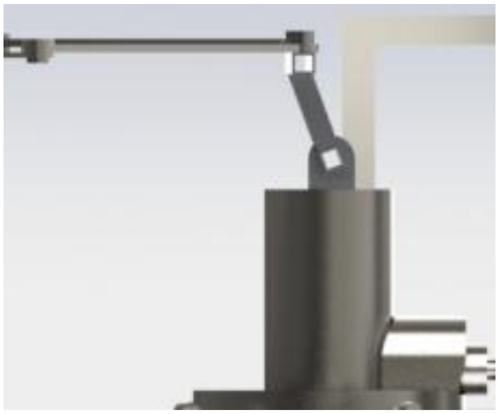


Figure 16: Side view of the body showing the initial angle of 20° when the arms are horizontal [22].

2.2.3 Arms

The design of the arms is crucial for performing the face-off motion. A five bar linkage is chosen to allow the hockey stick to have suitable 2D coverage of the face-off surface. Each arm consists of a member connected to a pin, which connects to a forearm. At the end of one forearm, a servo motor is fixed which holds a shaft. The other forearm is connected to this shaft, but does not affect the shaft’s rotation, to ensure joint movement with the other arm. Additionally, the shaft has a collar that holds the hockey stick. This design allows the shaft to move forward, backward, side-to-side, or in any combinations of those movements. Figure 17 illustrates this concept.

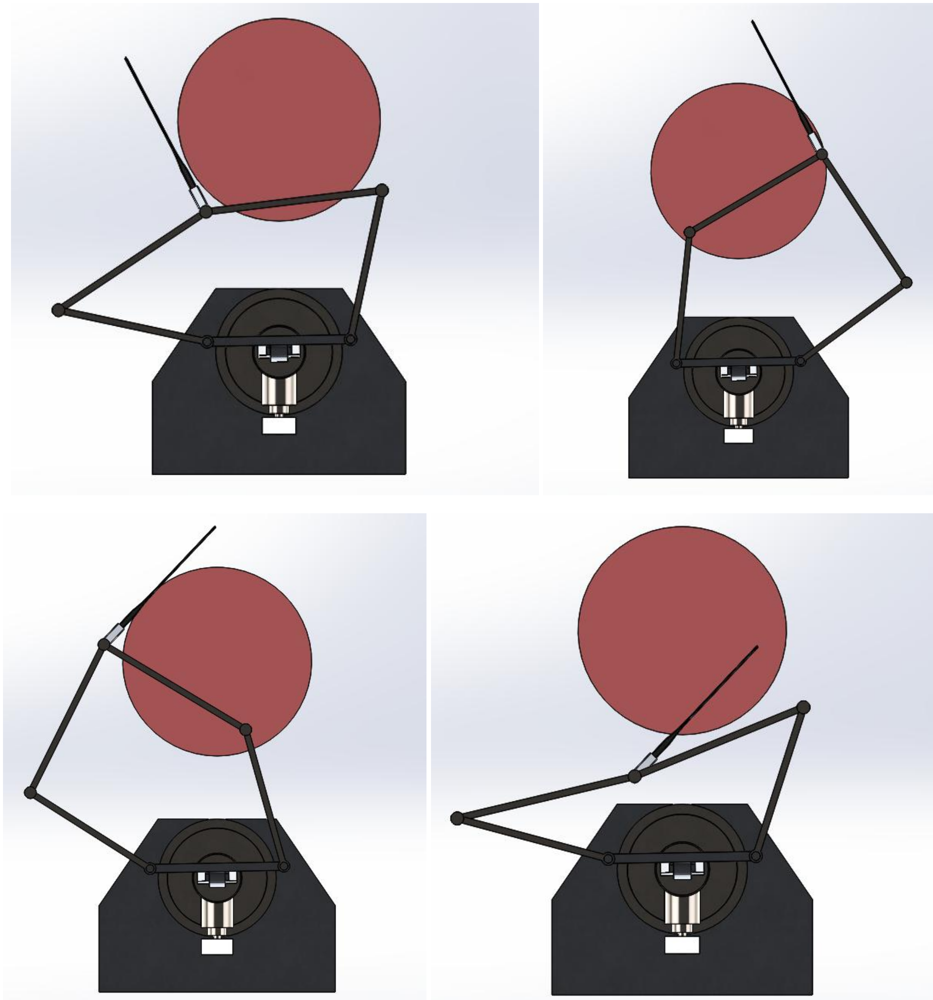


Figure 17: Top views of various arm positions relative to the face-off dot [23].

Figure 18 shows a simplified image of the connection at the hands, which holds the hockey stick.

Figure 18: Simplified image of the hands connecting the shaft that holds the hockey stick [24].

Each arm is powered by a servo motor mounted at the shoulders. The motors can also move the arms completely into the machine so as to minimize volume when transporting.

The hockey stick is expected to be subjected to the largest force exerted in a face-off, which is taken to be about 5000 Newtons (1124 pounds). Figure 19 presents a finite element analysis (FEA) on a forearm of the five bar linkage.

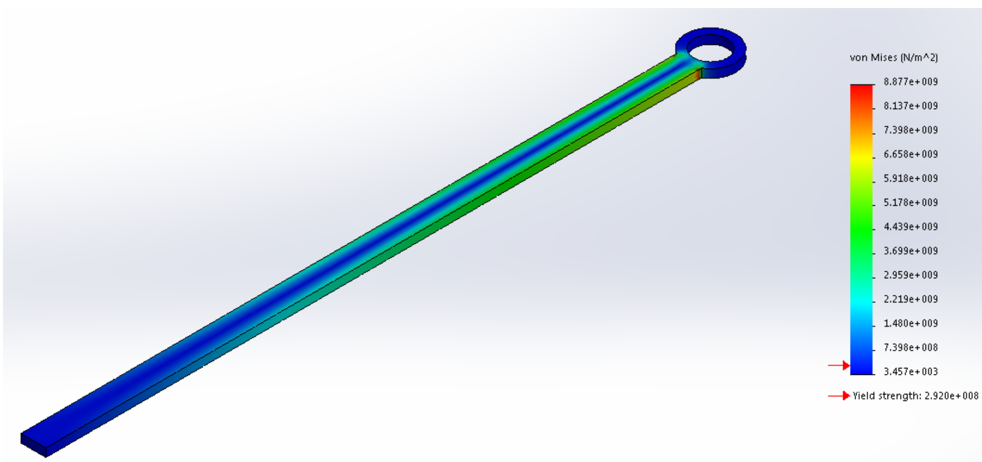
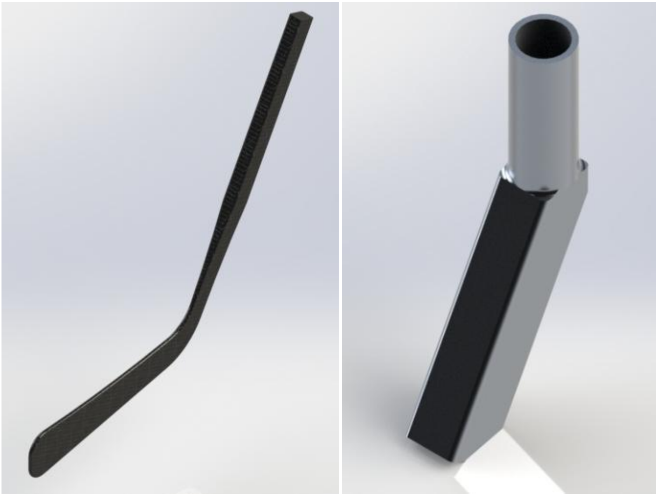


Figure 19: FEA of the forearm with an applied torque at the shaft location.

This analysis was performed with the forearm constrained at the elbow pin connection. An 1835.6 ft-lb torque was derived from the 1124 lbf and the height of the hockey stick of 19.6 inches when the blade is flat on the surface. Since there are two forearms, the torque was divided by two so the actual applied torque was 917.8 ft-lb. As seen in Figure 19, portion that encircles the shaft is cut off. This is due to complications within SolidWorks thus it was cut off in order to solve the FEA. It is assumed that the forearm portion at the shaft reacts the same way as the portion at the elbow joint based on symmetry. The FEA results show that the location of highest stress occurs at the portion of the forearm that encircles the shaft and elbow pin. This is expected since there are stress concentrations at these locations. These results can be extrapolated to the arms that are connected to the shoulder motors due to similar geometry. Again, the likely locations of failure would be at the arm portions connecting to the elbow pins and the shoulder motors due to high stress.

2.2.4 Hockey Stick

The hockey stick is held by a collar which is connected to the lower portion of the shaft at the end of the forearms via a key and a pin. The collar is connected at 60 degrees from the vertical axis to accommodate the 120 degree lie angle of the hockey stick. The lie angle of a hockey stick blade is the angle from the shaft to the top of the blade when the blade is flat on the surface. The chosen lie angle of 120 degrees covers the necessary area of the face-off zone while keeping the face-off arms high enough so as not to interfere with the human player. The hockey stick is identical to a regular, composite hockey stick available on today's market, except the blade is straight, has a lie angle of 120 degrees instead of the normal 135, and the shaft is significantly shorter, as seen in Figure 20a. The collar is shown in Figure 20b.



(a) (b)

Figure 20: Hockey stick (a) and its collar (b) [25].

Figure 21 shows the hockey stick fixed into the collar.

Figure 21: Collar holding the hockey stick [26].

Having the stick attached to the motor allows a complete 360-degree rotation, thereby increasing the skill level and versatility of the face-off simulation motion. Since the hockey stick is the main point of contact with the user, it experiences the largest magnitude of force. Figure 22 presents a FEA on the hockey stick.

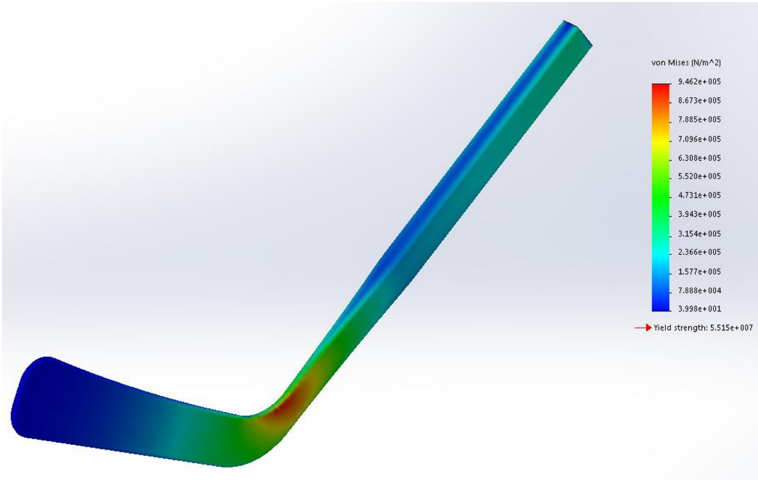


Figure 22: FEA of the hockey stick where an 1124 lbf is applied to the blade.

This analysis was performed with the shaft constrained at the end where it connects with the collar. An 1124 pound-force was taken as a typical force exerted on the stick in a face-off situation. The FEA results show that the location of highest stress occurs at the connection between the blade and the shaft. This confirms that the hockey stick is properly designed since professional hockey video shows that all hockey sticks break at this location.

2.3 Base

The base of the machine, seen in Figure 23 and Figure 24, serves as a means of support, stability, and transport.

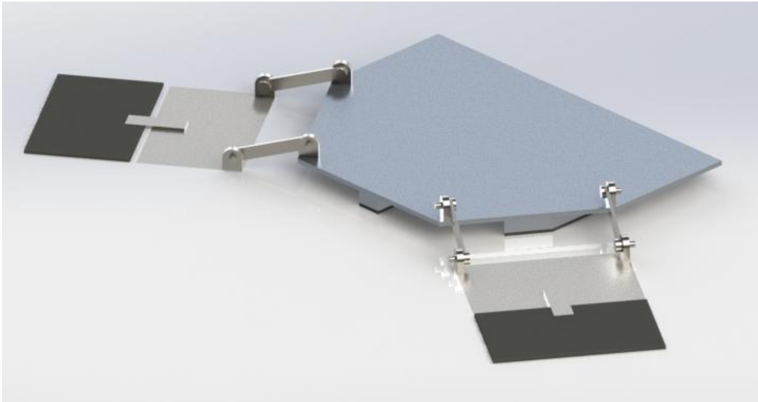


Figure 23: Angled view of the top of the base [27].

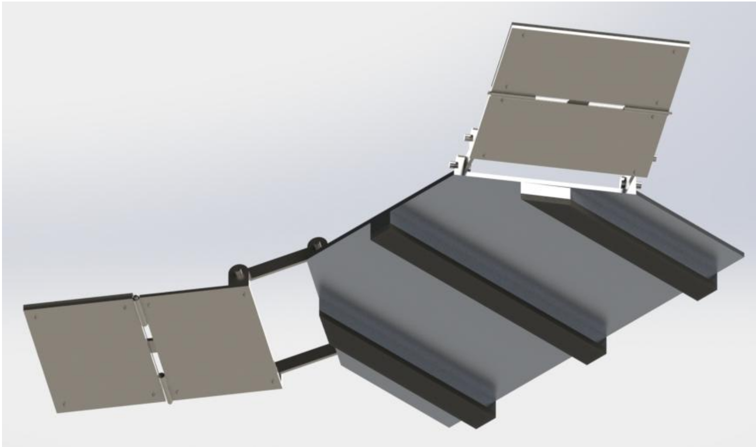


Figure 24: Angled view of the bottom of the base [28].

The base consists of a platform on which the puck dropping mechanism, face-off motion, and other components rest. Folding components with specialized grip add stability to the platform, as seen in Figure 24. Regarding transportation, wheels are fixed to the back of the platform, along with a handlebar, that allows the entire machine to be easily moved. The following sections describe the three main components of the base in greater detail. Details regarding the selection of concepts presented in this section and associated manufacturing principles can be found in the Appendix.

2.3.1 Platform

The platform geometry resembles half of an octagon to allow simple deployment of the stabilizing footings. The platform has three supports which raise it 1.5 inches off the ground. Each support has a rubber strip beneath for added friction with the surface. The 1.5 inch space allows pucks to slide under the machine and keep the face-off area clear during face-off practice. The maximum dimensions of the platform are 30 inches in width and 32.28 inches in length, which allows the machine to pass through a doorway. The platform is cut out of .375 inch 6061 aluminum sheet.

2.3.2 Stability Footings

Attached to each angled side of the platform are double-hinged stability footings, which provide stability on all surfaces. The footings are folded in on themselves and pinned into place on the platform for transportation. Each footing is comprised of two pads: the pad that can extend the furthest from the platform has a rubber sheet on one side and spikes on the other, whereas the pad closest to the platform only has spikes. Figure 25 shows the footings with the rubber sheet engaged with the surface.

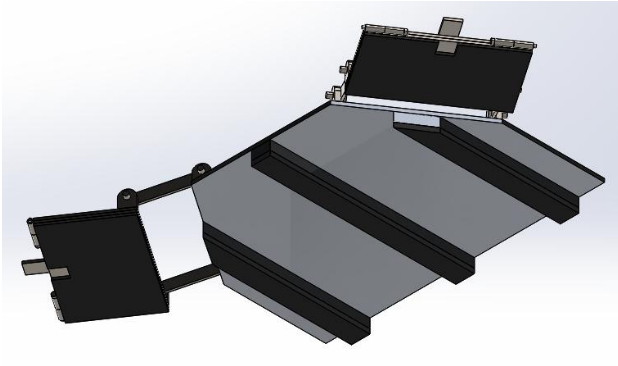


Figure 25: Bottom view of the base with the rubber footings flat on the surface [29].

For low-friction surfaces such as ice, the footings are unfolded to expose the spikes which increase friction and inhibit motion. Figure 26 shows the footings with the spikes engaged with the surface.

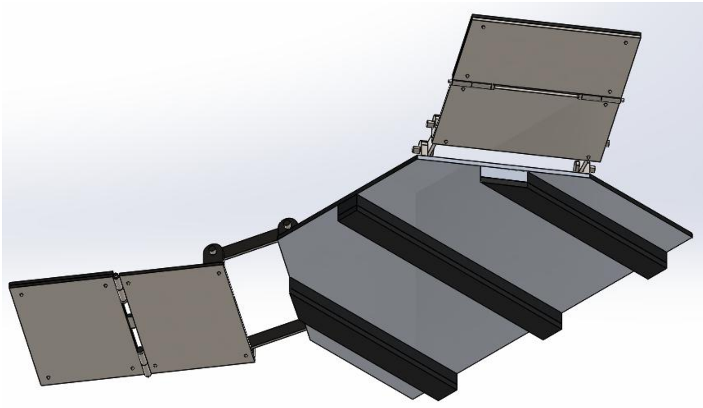


Figure 26: Bottom view of the base with the spike footings flat on the surface [30].

It is advised that the spikes are not engaged on finished surfaces to avoid damage. Figure 27 shows a close-up view of the spikes on the footings.

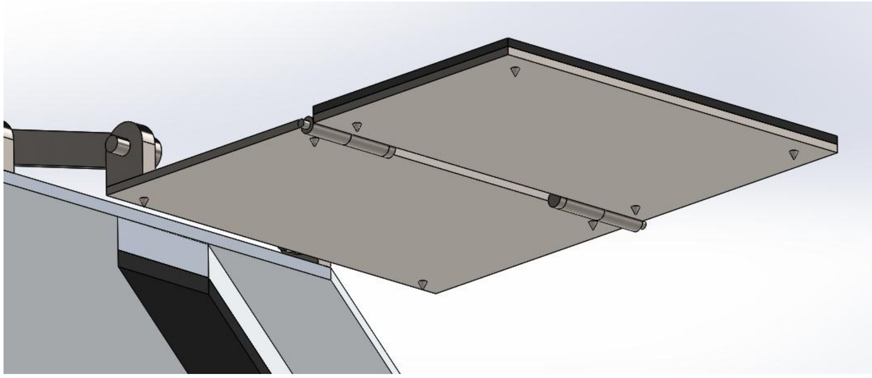


Figure 27: Close-up of the spike footings engaged with the surface [31].

2.3.3 Transportation

The machine uses two wheels and a handlebar for transportation. The wheels are fixed to the back of the platform and the handlebar is situated near the top of the puck dropping mechanism structure. Figure 28 shows the transportation components of the machine.

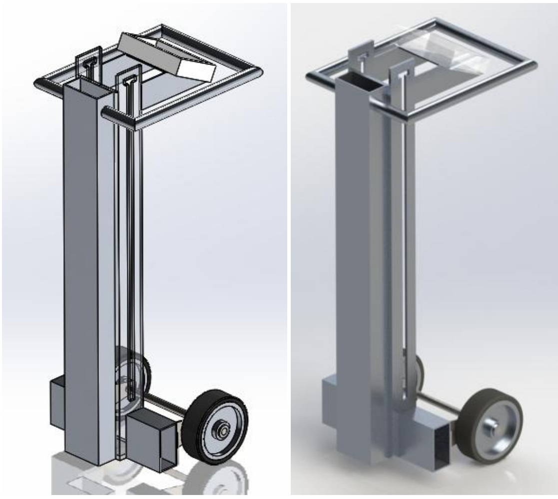


Figure 28: Transportation component of the simulator [32].

For transportation, the machine is pivoted about the axle until it is balanced and the wheels are engaged. With all of the weight on the wheels, the machine can be easily moved.

2.4 Other Components

Additional components are needed to power and operate the face-off simulation machine. Some directly affect the face-off motion while others provide power to the various components. All components are purchased parts and discussed in this section.

2.4.1 Compressor

A two gallon compressor is chosen to power the pneumatic piston. It is powered by a lithium-ion battery and located at the back of the platform, to the right of the puck dropping mechanism, as seen in Figure 29.

2.4.2 Display Monitor

An LCD touch screen display is chosen as a user interface for the machine. The touch screen can be used to select skill level, face-off type, and player replication. The screen is mounted to the back of the bridge, as seen in Figure 29.

Figure 29: Location of the monitor and the compressor on the simulator [33].

2.4.3 Face-Off Projector

The face-off projector projects an image of a face-off circle onto the surface. This allows the player to correctly position their stick prior to the puck drop. The projector is mounted at the end of the bridge. Figure 30 shows the simulator with a projected face-off dot.

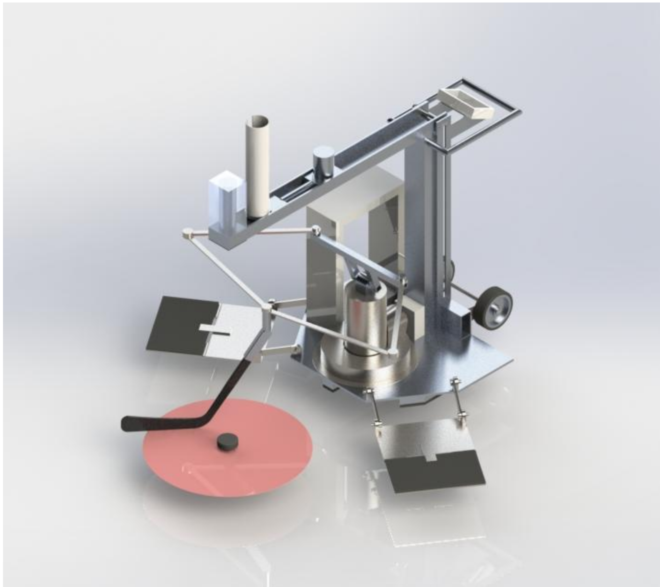


Figure 30: Simulator with the projected face-off dot image on the surface [34].

2.4.4 Motion Sensor

A motion sensor is used to sense the presence of a puck in the face-off area. It is common for the puck to remain in the face-off area after the first attempt at the draw. The motion sensor allows the machine to sense the puck until the face-off is won.

2.4.5 Battery

A lithium-ion battery is chosen to power all components of the simulator. This battery should be rechargeable and provide sufficient time for a practice session. It is to be located at the back of the platform to the left of the puck dropping mechanism.

2.5 Cost Analysis

The analysis consists all of the components selected for the function of the machine. At the onset of the project the client outlined a budget of $8,000 as an estimate for what he would like the face-off simulation machine to cost, including all necessary components, materials and manufacturing. This $8,000 was provided as a rough estimate that was subject to change under the circumstances that a feature would enhance the user's skill and experience with the machine.

All of the electrical wiring and circuitry components are considered to be out of the scope of the project so their costs are not included in the bill of materials. However, these components are a necessary part of the machines function and will have to be included in the cost analysis for further stages of the machines development.

The machine is divided into four main components: the puck dropping mechanism, the face-off motion, the base, and other components that provide power and added user experience. TABLE III presents a summary of the costs for the face-off motion.

TABLE III: BILL OF MATERIALS FOR THE FACE-OFF MOTION

Face-Off Motion				
Item	**Description**	**Price/Unit**	**Quantity**	**Total**
Servo motors with gearbox	For the shoulders, hand, and hinge	$270.00 [35]	4	$1,080.00
Servo motor with gearbox	For the gears	$1,126.00[35]	1	$1,126.00
Bevel gear		$650.26 [36]	1	$650.26
Pinion gear		$106.63 [36]	1	$106.63
Hockey stick	Modified composite hockey stick, ~18 inches long, straight blade	$99.00 [37]	1	$99.00
				$3,061.89

The servomotors chosen for the simulation machine were not specifically defined due to the variety of servos that are available. Prototype building and testing of the machine will reveal the actual speeds and strengths needed to provide the machine with a real life simulation. Based on calculations from the team's own video of a real hockey face-off, approximate stick speeds were found. The chosen servomotors reflect the approximations made from the team's data and provide an estimated cost for the design. The servomotor for the gear was identified to be different from the remaining servomotors.

The cost of the design's hockey stick is assumed to be similar to that of an ordinary composite hockey stick that can be purchased at retail stores. This assumption is based on the way hockey sticks are manufactured, where the shaft is made first then connected to a straight blade. In the midst of the curing process, the blade is given a curve. The team's hockey stick design introduces differences in the manufacturing process such that the blade is not given a curve and that the shaft is cut to length after curing. Even though the time to manufacture the stick may be less due to the differences and for the convenience of a manufacturer to modify their process to accommodate the new design, the cost is assumed to be the same. TABLE IV presents a summary of the puck dropping mechanism.

TABLE IV: BILL OF MATERIALS OF THE PUCK DROPPING MECHANISM

Puck Dropping Mechanism				
Item	**Description**	**Price/Unit**	**Quantity**	**Total**
Pneumatic Cylinder	C(D)S1, air cylinder, double acting, single rod, lube type 5" bore, 8" stroke	$804.00 [38]	1	$804.00
Electric Actuator	MX12-B8M20P0MAXJAC, 12V, ball screw, analog F/B, 6" stroke, ½ inch per second	$166.65[39]	1	$166.65
Compressor	200 PSI High-Flow Air Source Kit	$329.95[40]	1	$329.95
Regulator	8803GH-CS 3/8"	$80.55[41]	1	$80.55
Hose	NITRA® Reinforced Polyurethane Hose 3/8" 25 feet	$23.00[42]	1	$23.00
Solenoid		$471.75[43]	1	$471.75
Bridge	¼" thick, 2"X4" 6061 Al U-channel 5' long	$50.71[45]	1	$50.71
Bridge Column	¼" thick, 2.75"X5" 6061 Al U-channel, 3' long	$60.57 [45]	1	$60.57
Feeding Sleeve	PVC Cylinder with Slit For Easy Puck Grabbing, 2' long	$31.07 [45]	1	$31.07
Structural Column	Rectangular cross section 6061 Al, 1/8" thick, 2" height, 4" width, 3' long	$44.24 [45]	1	$44.24
				$2,062.50

The air system was priced out by researching off-the-shelf parts and components that fit the needs of the puck dropping mechanism. TABLE V presents a summary of the base.

TABLE V: BILL OF MATERIALS FOR THE BASE

Base				
Item	**Description**	**Price/Unit**	**Quantity**	**Total**
Wheels	6" Diameter, 2” wide polyurethane-tread Wheels with polypropylene core, 600 lbs capacity/wheel	$24.52[45]	2	$49.04
Base Supports	1”X2”, 6061 Al, rectangular member 2’ long	$32.03 [45]	3	$96.09
Base	6061 Al, 3/8” thick sheet, 2’X3’	$47.14 [45]	1	$47.14
				$192.27

Not included in TABLE V are the costs for the stability footings because the manufactured parts have yet to be designed. TABLE VI

TABLE VI: BILL OF MATERIALS FOR OTHER COMPONENTS

Other Components				
Item	**Description**	**Price/Unit**	**Quantity**	**Total**
CAREL Display Monitor	LCD Touch Screen Control of Operations	$700.00[46]	1	$700.00
GoPro Hero Session 4	Compact 1080p, Slow Motion Capabilities, Wireless	$299.00[47]	2	$598.00
HC-B405 Projector	Programmable Image Outdoor Projector Lights	$25.00[48]	1	$25.00
				$1,323.00

Not included in TABLE VI is the cost of the rechargeable lithium-ion battery. The team was unable to get an adequate quote due to the lack of specifications of all electrical components of the simulator. At the onset of the project, the client suggested a CAREL touch screen be used as the display monitor. The cost provided in TABLE VI is estimated based on the desired 7 inch screen. Additionally, video playback of the simulation was requested by the client so the team chose to add two GoPro Hero 4 Session cameras to the cost. The cameras may be used wirelessly or connected to a power source and have high resolution and slow-motion capabilities, which are attractive to increasing the user experience for feedback [47]. However, support structures for these cameras have not been designed but are compact and lightweight enough as to not influence the overall performance of the simulator.

Moreover, the face-off dot projector helps the user properly line up relative to the face-off dot. The chosen HC-B405 outdoor projection light is a relatively small and inexpensive feature that will enhance the user's simulated experience [48]. TABLE VII presents a cost summary of the bill of materials from TABLE III, TABLE IV, TABLE V, and TABLE VI.

TABLE VII: COST SUMMARY OF THE BILL OF MATERIALS

Bill of Materials	Cost
Face-Off Motion	$3,061.89
Puck Dropping Mechanism	$2,062.50
Base	$192.27
Other Components	$1,323.00
Total	**$6,639.66**

3.0 Recommendations

Due to limited time constraints and the large scope of the project, some components of the machine were not fully developed. This section contains explanations outlining tasks that have yet to be undertaken in the design of the machine as well as recommendations based on the researched materials.

Puck Dropping Mechanism

- The bridge requires the selection of a spring-loaded pin for use in transport and operation configurations.
- The polymer lining requires a fixation method to the bridge.
- Testing is required on the puck holder to determine if the puck travels through the rubber as expected. Minor tweaks to size of the hole and length of the slits may be necessary to ensure the puck holder allows ejection of the puck at the desired speed of 25 ft/s. The material of the puck holder could also be changed to accommodate puck drop speed.

Face-Off Motion

- All five servo motors require selection based on specifications. To acquire necessary specifications, testing is needed. Additionally, selection of any controllers, cables, and other electrical components necessary to power and control the motor is required. An approximate speed of 127 RPM of the stick was determined using the team's slow motion video of face-off performance. Kinematic and dynamic analysis should be employed to determine motor specifications based on the required speed and torque of the hockey stick. Testing and further in-depth analysis is likely required to determine motor specifications.
- The method of fixing the motor shafts to its corresponding components has not been determined. Keys, couplers, welded joints, and other methods should be considered.
- The thrust bearing for the gears has yet to be selected. The bearing must adhere to the specified bevel gear dimensions.
- Body rotation may not be needed for the design. It was necessary in the preliminary design, where the arms only moved back and forth, powered by pistons. Along with the circular motion of the arms, there is no doubt that body rotation would add speed and versatility to the motion however, testing is required to determine if the

added value is worth the added cost. It is recommended that the initial prototype is manufactured without body rotation and tested as such. From testing, body rotation can be deemed necessary or omitted.

- The arms require specification of the elbow joints. Components required for this joint to work include pin selection, possible bearing selection, and fastener selection.
- A hockey stick manufacturer needs to be consulted regarding the specifications of the team's hockey stick design.
- The collar that holds the hockey stick needs to be custom-manufactured. Related fastening methods for connecting the stick to the collar and the collar to the shaft have yet to be determined.

Base

- The links and pads that make up the footings should have specific dimensions that support stability specifications such as required surface friction. Related hardware such as pins and fasteners need to be selected.
- Further design is required for the spikes that will be fixed to the bottom of the footings. Mainly, the joint that allows the pads to fold needs to be looked at because of the way the spikes contact the surface. If the pads were to be folded with the spikes exposed, it is recommended that covers are designed for safety purposes.
- Testing will be necessary to confirm the need for the stabilizing wings. The machine may be heavy enough that the wings are unnecessary, or can be simplified if less grip and stability is needed.

Other Components

- Selection of the battery is required. Battery specifications are not possible without a specific selection of the motors and other electrical components. In the event that a battery is too expensive, power could be provided by an electrical outlet.
- It is recommended that the motion tracking system uses markerless tracking to track puck motion. A markerless system allows the use of ordinary pucks, without alterations, which reduces cost for both the manufacturer and the user. This system requires a slow-motion camera and a high-resolution camera sensor.

- The machine can have a guard protecting its components from the user and the environment. This enclosure would require a structure to support it and could be made of polymer or metal sheets. The air intake of the compressor and the cooling of the battery should be taken into consideration when designing the guard. The guard would add tremendous aesthetic and safety value to the design.
- Regarding the simulator as a whole, a finite element analysis could be performed if all of the components are properly chosen and if all of the forces are properly defined. This analysis can be used to confirm the robustness and durability of various components.

4.0 Summary

In conclusion, the team designed a hockey face-off simulator that allows a user to individually practice and improve their face-off skills. The design replicates the referee and the opposing player in a hockey face-off in a realistic manner as to mimic professional performances. While meeting the majority of the needs and adhering to the constraints and limitations, the team has chosen concepts that satisfy the design objectives of portability, stability, and variety of face-off strategies.

The simulator has two overarching design features: the puck dropping mechanism and the face-off motion. The puck dropping mechanism consists of a bridge and a supporting column connected via a spring-loaded pin. On the bridge, there is a puck storage cylinder mechanically locked into a slot which feeds pucks via gravity, an electric actuator that pushes the puck along a section of the bridge lined with a low-friction polymer to the puck drop location, and a pneumatic piston that forces the puck to eject from a rubber puck holder down towards the face-off surface. The bridge column has a track that the pin follows to allow the bridge to collapse for transportation needs, where the puck storage cylinder also needs to be removed. The face-off motion has four degrees of freedom via a five bar linkage. The linkage is supported by an upper body structure, which is connected to a motor that tilts back and forth. The motor is mounted on top of a column, which is fixed to a bevel gear constrained by thrust bearings that are fixed to the base. The bevel gear is allowed to rotate via a pinion and a servomotor. Four of the five links of the linkage act as arms and forearms with pins as elbows. The forearms meet at a common shaft where one forearm has a servomotor fixed at its end which holds a shaft while the other forearm connects to that shaft without inhibiting shaft rotation. Also connected to the shaft is a collar that holds the hockey stick, which has a straight blade. For transportation needs, the arms can be collapsed and folded, and the hockey stick can be easily removed via its pin connections with the collar.

The simulator has additional features such as stability footings, motion tracking, video recording, and image projection. The stability footings can be utilized on various surfaces because of its rubber pads and spikes. For added stability on finished surfaces, the rubber pads can be engaged while on slippery surfaces, the spikes can be engaged for added traction. For the face-off motion to perform a face-off, a markerless motion tracking system is employed which also allows the use of ordinary pucks. Furthermore, the user can study their techniques via the use of high-speed video cameras that record the simulation experience. In conjunction with video recording, a projector projects an image of the face-off dot which allows the user to identify faults and improve their overall techniques.

The design met several customer needs. The puck dropping mechanism successfully simulates the puck drop where the mechanism propels the puck towards the face-off surface at the correct location, accurately replicating a referee's motions. The five bar linkage face-off motion has enough versatility in the required range of motion to perform a variety of face-off techniques. Additionally, the straight blade of the hockey allows replication of left- and right-handed opponents. Since the face-off motion does not depend on the surface and the base stability can be adjusted to suit the surface, the machine can operate normally on different surfaces. The machine satisfies the portability and compact requirements due to the collapsible features of the puck dropping mechanism and the face-off motion. Moreover, the simplicity of the simulator's concepts and its ability to effectively replicate a referee and an opponent allow a single user to operate the machine. Figure 31 shows a rendering of the final design.

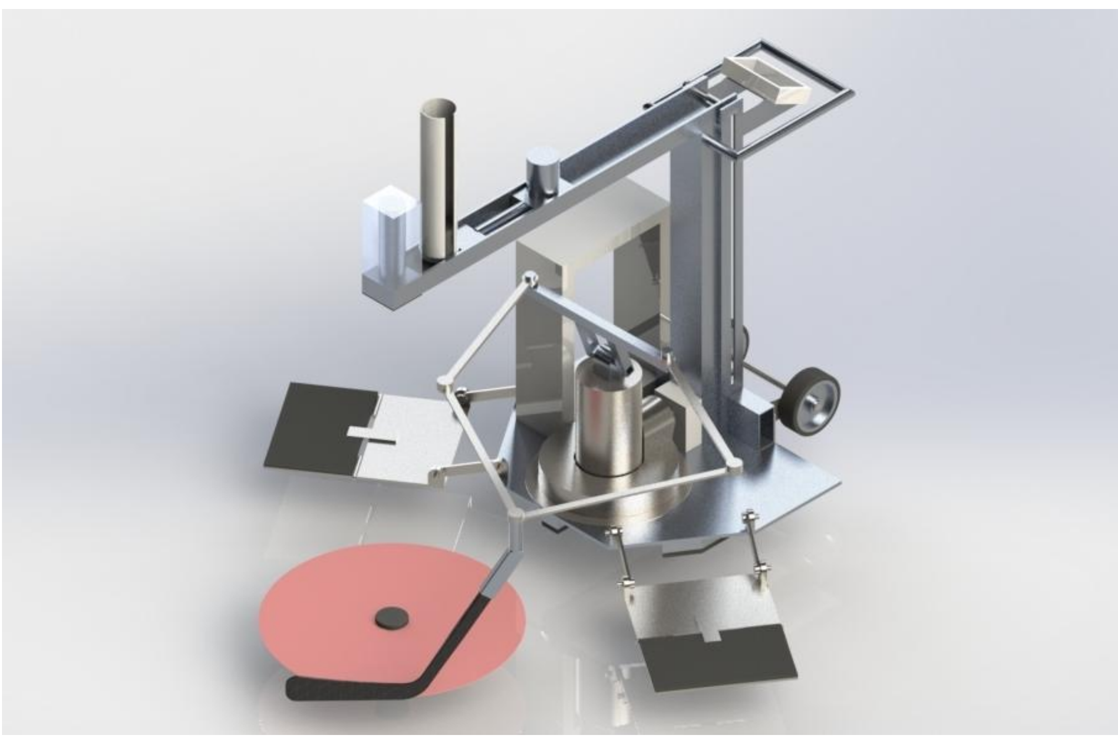


Figure 31: Image of the hockey face-off simulator [34].

Motion requirements such as stick speed (25 ft/s) and puck drop speed (25 ft/s) were determined through the team's video analysis however, it is recommended that a prototype is built and tested to better define these parameters. Using more accurate data from test results, an FEA can be performed on the simulator to determine possible areas of component failure.

When in use, the machine stands at 53.15 inches tall, 64.17 inches wide with the footings fully extended, and 83.46 inches long with the arms fully extended. The machine can be collapsed into a smaller configuration for transportation that will be 49.61 inches tall, 30 inches wide, and 32.28 inches long. A face-off can be performed every 24 seconds, based on the assimilated speeds of components of the puck dropping mechanism. The pneumatic system and all electrical components are to be run off of a rechargeable lithium-ion battery to make the design portable, in addition to its collapsible features. With these features, the machine weighs a minimum of 186 pounds. The total cost of the design is estimated to be a minimum of $6,639.66, which is based on limited component selection and decisions made by the team.

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Appendix

Relevant information pertaining to the final design of the hockey face-off simulator is contained within, and is divided into three main sections: manufacturing principles, concept development, and physical model. Firstly, the manufacturing principles section discusses how the team considered manufacturing principles when generating concepts for the final design. Concept development follows with the detailed approach the team took to generate and select concepts for the final design. Lastly, the physical model section discusses the use of a small prototype for visualizing the face-off motion.

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1.0 Manufacturing Principles

While manufacturing was not a major concern throughout the design process, it was considered in terms of simplicity and cost. The team recognized that complicated milling operations would increase the cost thus avoiding such operations was attempted. The team predominantly designed the machine so that the majority of the parts could be either cut from a sheet, or cut from circular/rectangular stock. Pieces that only require cutting from a sheet include the base, four arms, and the footings for stability. These parts would have their edges rounded off for aesthetic and safety purposes. The shafts needed for the upper body of the face-off motion require a simple cut from rectangular tubing aluminum stock then need to be welded together. The supports under the base would require a cut from rectangular bar aluminum stock. The puck storage cylinder would be cut from polyvinyl chloride (PVC) piping and require a small amount of machining to produce the mechanical locking mechanism for the bridge and the slit for manipulating pucks. The bridge and its supporting column would require simple cuts from off-the-shelf aluminum U-channels. Machining would be needed on the bridge column to make the track for collapsing the bridge. In addition, a hole for the puck to drop through would need to be cut in the bridge. The puck holder could be cut from rubber using a variety of methods. The handle for transport would be cut from aluminum stock rod and bent to the required dimensions.

Regarding the composite hockey stick, it would need to be custom-manufactured due to its unique design, likely by an existing hockey stick manufacturer for reduced cost. The main difference from a normal hockey stick is the lie angle of the blade. The lie angle is the angle the blade has relative to the shaft. Normal lie angles for hockey sticks range from 132° to 137°. The designed hockey stick has a lie angle 120°.

Hinges, pins, and fasteners have not been incorporated in the design but would most likely be purchased off-the-shelf parts and be used for removable components for easier replacement. Methods of fixing manufactured components together, such as the handle to the structural column, shafts of the upper body skeleton, and the bridge column to the base, have not been considered but would most likely involve welding. Mainly, components that are expected to last the duration of the anticipated service life will have welded connections.

2.0 Concept Development

This section shows the design approach the team used to develop concepts for the final design. Firstly, concept generation discusses the results from research and brainstorming sessions. Secondly, concept analysis discusses the processes used to select the generated concepts. Lastly, concept selection provides a brief summary of the selected concepts and discusses recommended actions for the final design.

2.1 Concept Generation

This design project is unique in that there are no current existing products that can simulate the act of a hockey face-off. This section presents external research materials found by the team and discusses methodologies employed for internal concept development.

2.1.1 External Search Results

The machine is being designed from scratch which presents several hurdles the team must overcome to design a quality product. Two unique challenges of the project are that there is practically nothing to benchmark the design against, and there are almost no existing products that can be improved upon.

The only commercial product that is remotely comparable is the Boni RoboRef [1]. The RoboRef is attached to the boards of a hockey rink and only simulates the puck drop in a face-off, not the opposing player. The patent for the RoboRef has expired, allowing the opportunity to improve upon this idea [2]. Figure 32 shows the RoboRef connected to the boards of a hockey rink.

Figure 32: The RoboRef puck dropping machine mounted to hockey rink boards [1].

Basically, the RoboRef feeds a puck to the drop location and propels it downwards in order for players to perform a face-off.

A search for other patents, using Google Patent, led us to a few ideas concerning the puck drop apparatus. The structure in Figure 33 was discovered and presented as a possible idea for a puck dropper. Note that the numbers can be disregarded.

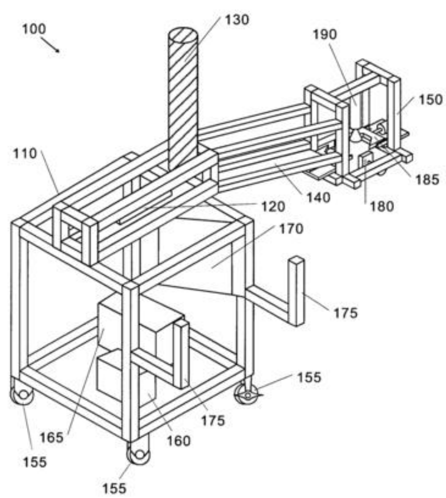

Figure 33: Image of the hockey puck face-off method and apparatus from Patent US 7121964 B1 [3].

The pucks are stored in a cylindrical sleeve for dispensing to later be pushed downward by the use of a piston. It can be seen that the apparatus is on wheels for easy transportation.

Another patent was found that could have been used to dispense pucks before dropping. It holds the pucks side by side and uses gravity to dispense them, as seen in Figure 34. Note that the numbers can be disregarded.

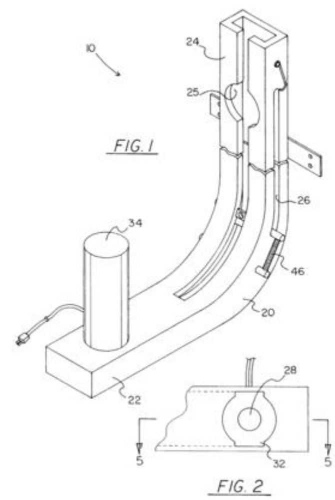

Figure 34: Image of the hockey puck storage and delivery device from Patent US 5841644 A [4].

Figure 34 also shows a variation of the puck dispensing ability: pucks are dispensed through the use of a spring. The spring is located on the side of the vertical column. The spring provides enough force to move the pucks to the drop location.

Originally, the team questioned if a curved blade would affect a player's face-off performance, mainly to avoid the need of swapping sticks for different simulations on the machine. The team was able to contact a professional ice hockey player regarding the use of a curved blade in a face-off. When asked if a straight or curved blade would be better for taking face-offs the player responded: "To be honest a straighter blade would probably be better for a face-off... Lots of the best face-off guys use a taller blade." [5]. With this knowledge, the team decided to pursue the design of a hockey stick with a straight blade.

Videos on the internet provided a visual method of comparing different ideas. The videos were helpful because tests for comparing concepts require time and money, resources the team could not invest. YouTube videos on high speed pneumatic pistons [6], hydraulic cylinders [7], and electric actuators [8] allowed the speeds to be evaluated. The search for machines that involved high speeds, accuracy, and intermediate control led to a single 6-degree of freedom armed robot [9]. Also found was the Adept Quattro that had four arms that were only moved via “shoulder” motors [10]. Figure 35 is of the Adept Quattro robot.

Figure 35: Adept Quattro robot mounted in the horizontal plane [10].

This machine was extremely fast and accurate in moving ball bearings. The Quattro had a motion sensor that allowed it to pick up and place objects that were moving along an assembly line [10].

The Mini Delta was found to be similar to the Quattro except it uses three arms [11]. The Mini Delta promoted discussion on a two arm design that used similar arms with pin at the “elbow”.

Internet searches on codes and regulations pertaining to the machine led to ISO 9409, ISO 9787, ISO 9946, and ISO 10218, which are codes concerning mechanical interfaces, coordinate systems and motion nomenclatures, presentation of characteristics, and robot safety requirements, respectively [12].

2.1.2 Internal Search Results

The main methodology used to develop concepts was brainstorming. Each member of the group is familiar with playing and watching hockey so the team understands the requirements for a realistic face-off simulation. Since the design of the simulator is complex, the team needed a point of reference. Figure 36 is a SolidWorks rendered image of the team’s rudimentary original concept.

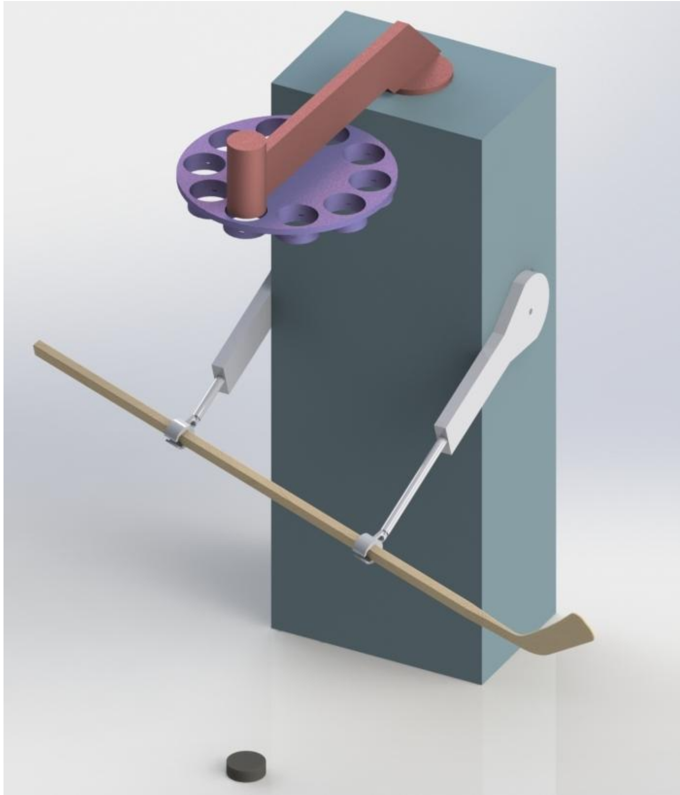

Figure 36: Rudimentary SolidWorks rendered image of the original concept [13].

This design has a rotatable base with two extendable arms that could move independently at the shoulder. With a capability of four degrees of freedom, this machine appears to simulate human-like stick movements. Additionally, a rotating disc that holds and moves pucks to the drop location is placed about the face-off motion and replicates a referee by using a piston to propel the puck onto the surface below. The components in Figure 36 were generated simultaneously in order to present the client with a general idea of the appearance, size, and functions of the machine. This concept was used as the reference concept when evaluating other ideas.

After conceiving the above design, the team decided to take a step back and focus on brainstorming ideas on a component-by-component basis rather than designing the entire machine at once, allowing individual components to be compared and evaluated in a detailed objective manner. Figure 37 shows the order of the design process.

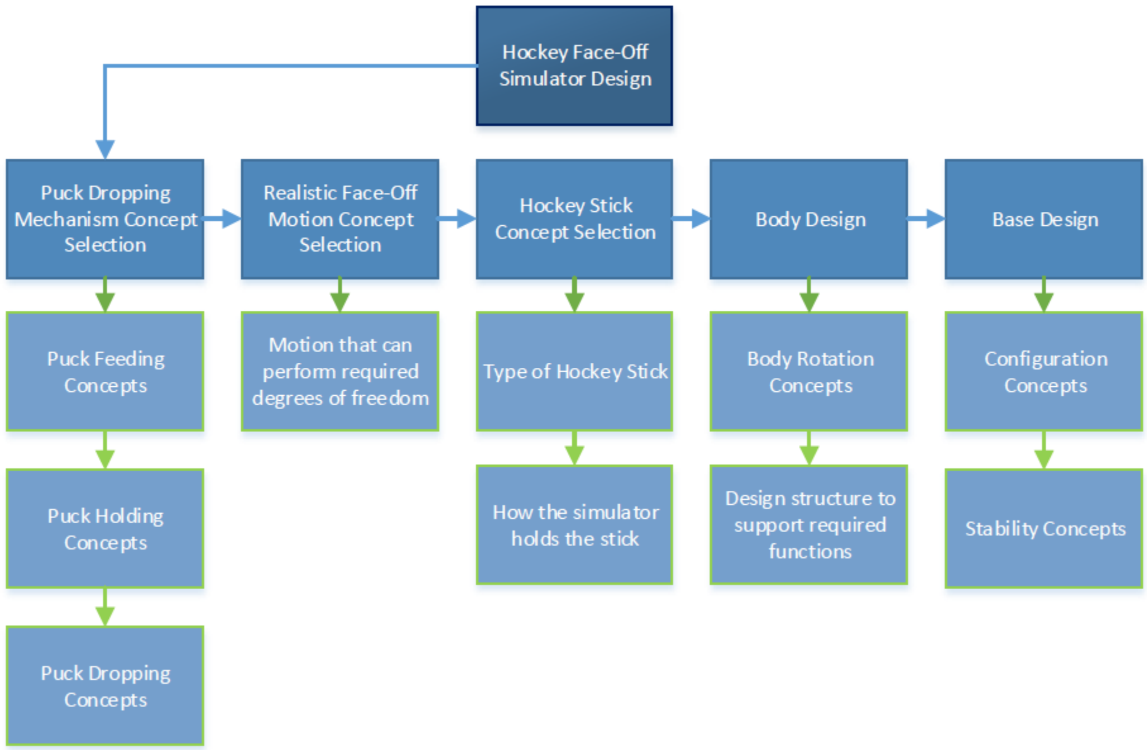

Figure 37: Design order for the face-off simulator.

The team made the moving components the top priority in the design process. The puck dropping mechanism and realistic face-off motion concepts were the top priority because there was enough information to properly evaluate these concepts. In addition, these concepts are the interactive portions of the simulator, meaning they are of high importance. Following the generation and selection of these concepts, the hockey stick will be designed for the realistic face-off motion to hold. Next, the structural aspects of the body and the base can be designed to accommodate these concepts.

Once several concepts for each component of the design were generated via brainstorming, the team used screening and scoring techniques to determine which concepts were best. The Theory of Inventive Problem Solving (TRIZ) was applied to improve upon each concept.

In order to screen and score the concepts, selection criteria needed to be determined. Using a simple rating system, concepts were screened as to filter out the poor ideas. For the scoring process, the selection criteria were evaluated relative to each other to determine the weights. Using the weighted criteria along with a more sophisticated rating system, the concepts were scored in order to select the best design. The concepts with the highest weighted score were selected. In the event that the scores between concepts were close, sensitivity analyses were performed to re-evaluate the screening and scoring processes. This entailed re-discussing the selection criteria and being more critical and assertive with the assigned ratings.

2.1.3 Generated Concepts

Based on the search results, concepts pertaining to specific components of the simulator were generated. The following subsections describe generated concepts for the two major components of the machine: the puck dropping component, and the face-off component.

2.1.3.1 Puck Dropping Component

The puck dropping mechanism consists of three main subcomponents: puck feeding, puck holding, and puck dropping. The following list presents the team's generated concepts for each of the puck dropping mechanism components:

2.1.3.1.1 Puck Feeding Concepts

The puck feeding component deals with providing a puck from the storage location to the drop location. The following concepts were generated by the team.

Revolver

Pucks are placed along a rotating disk. The disk rotates a puck to the drop location for it to get propelled downwards.

Dispenser without a spring 1

A sloped track feeds the pucks to the puck dropping location by use of gravity. As one puck ejects from the puck holder, a new one slides into place. Figure 38 illustrates this concept.

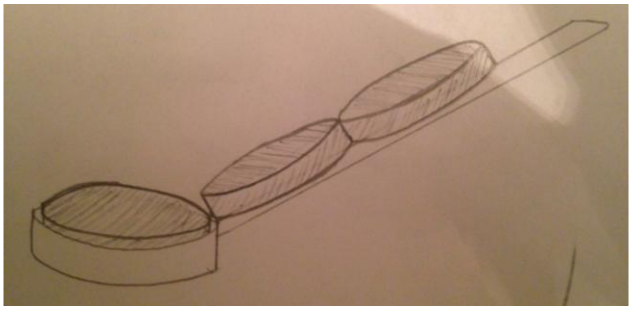

Figure 38: Side view of the gravity-fed puck feeder [14].

Dispenser without a spring 2

Pucks are placed inside a column that directs the pucks to the drop location via gravity. This concept is similar to the patent shown Figure 34.

Dispenser with a spring

Pucks are placed inside a column that directs the pucks to the drop location via a spring. This concept is similar to the patent shown Figure 34.

Vertical cylinder with a horizontal actuator

Pucks are stored within a cylindrical column that is positioned above the machine. The vertically stacked pucks are fed downwards by gravity. An actuator pushes the puck out of the cylinder from the bottom. When the actuator retracts beyond the cylinder, a new puck falls down into place.

Vertical cylinder with a spring

Pucks are stored within a cylindrical column that is located within the machine. The vertically stacked pucks are fed upwards by a spring. An actuator pushes the puck out of the cylinder from the top. When the actuator retracts beyond the cylinder, a new puck is pushed up into place.

2.1.3.1.2 Puck Holding Concepts

The puck holder component holds the puck until it is ready to be propelled downwards to the face-off circle. The following concepts were generated by the team.

Spring doors

Two to four doors are used to hold the puck at the drop location. The springs are mounted on the bottom edge of a shallow cylinder. The doors open when sufficient force is applied to the puck. Figure 39 illustrates this concept.

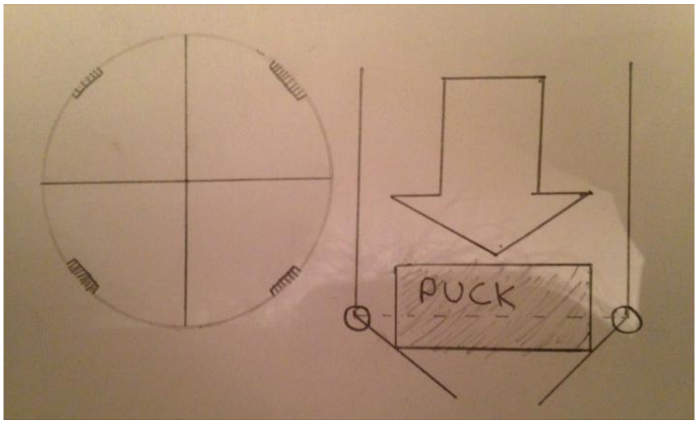

Figure 39: Top and side view of the spring door puck holder [15].

Rubber gasket

A piece of rubber, with four to eight slits cut within, is centred in the middle for the gasket. The rubber is fixed to the bottom edge of a shallow cylinder. When enough force is applied to the puck, the slits of the gasket separate and allow the puck to fall through. Figure 40 illustrates this concept.

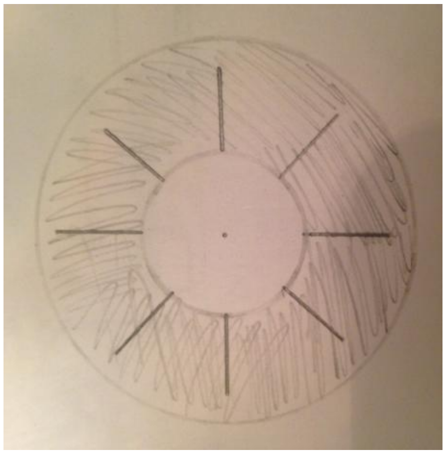

Figure 40: Top view of the rubber gasket as the puck holder [16].

Friction fit rubber piece

A conical piece of rubber has a centred hole slightly smaller than the puck's diameter. The rubber is fixed to the bottom edge of a shallow cylinder. When enough force is applied to the puck, the puck is forced through the hole.

Rubber tabs

The puck sits on four to eight rubber tabs fixed to the bottom edge of a shallow cylinder. When enough force is applied to the puck, the tabs deform to allow the puck to fall through. Figure 41 illustrates this concept.

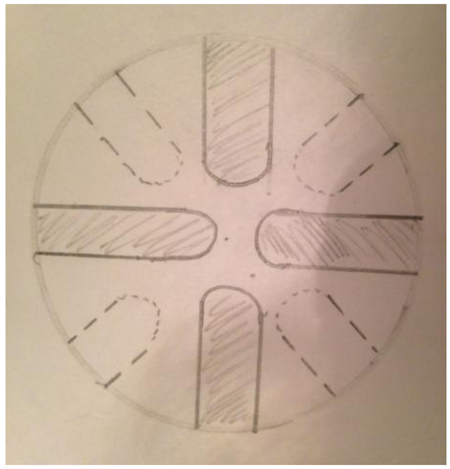

Figure 41: Top view of the rubber tabs as the puck holder [17].

Sliding door

A door that slides horizontally that allows the puck to fall. The puck sits on the door prior to getting propelled downwards.

2.1.3.1.3 Puck Dropping Concepts

The puck dropping component deals with propelling the puck downwards to the face-off circle. The following concepts were generated by the team.

Air cannon

A sealed cylinder above the drop location builds up with air. When the puck is ready to drop, the air pressure is released to propel the puck downwards.

Pneumatic piston (impact force)

A piston mounted vertically above the drop location that punches the puck onto the face-off surface.

Piston with spring (gradual force)

A piston mounted vertically above the drop location that slowly descends onto the puck. A spring is attached to the piston and gradually compresses between the puck and the piston as the piston lowers. The puck holder is remotely triggered to open to release the spring. The puck is then propelled down onto the face-off surface.

Freefall

The puck is propelled downwards by means of gravity. The puck holder is remotely triggered to release the puck.

2.1.3.2 Face-Off Component

The face-off component deals the mechanism that will mimic a player in a face-off situation. To satisfy the mimicry, the design needs a certain amount of degrees of freedom. The following presents the team's generated concepts for the realistic face-off mechanism.

Pneumatic Cylinders, Simple Motors

This is the original concept where pneumatic cylinders are used as arms, which are connected to motors with one degree of freedom. These motors are like shoulders and are fixed to a point of rotation on the machine body. The pneumatic arms move independently via the shoulder motors. Attached to the arms are hands that hold the hockey stick.

4 Hinged Arms

This concept is similar to the Adept Quattro except the hinges are all on the vertical plane. This concept is accurate and fast but infringes the use of the patent.

2 Hinged Arms

A brainstorming session lead to a two arm idea which is similar to the Adept Quattro, producing the same required motions in a 3D space. This concept has two arms, with pinned joints as elbows, and two motors that act as shoulders. The shoulder motors have one degree of freedom. Because there are only two arms, additional degrees of freedom are added by introducing a hinge on the body to provide up and down motion.

6 Degree of Freedom Arm

This concept uses one arm to perform all of the motion [9]. The arm holds the hockey stick at the end to perform a face-off.

Two paddle arms

Two hockey blades are used to swat at the puck. These blades act like the paddles of a pinball machine.

No arms

The puck is attached to a string/wire and is pulled away quickly as the puck drops onto the face-off surface.

2.2 Concept Analysis

After several concepts were generated for each component of the simulator, the team analyzed the concepts to determine the optimal concept. The first analysis was a screening process which begins filtering concepts by comparing the various designs to a reference concept, where a simple rating of 0+- was used. If the results of this analysis were close, by 1 to 2 points, a second analysis was performed. This analysis consisted of a scoring matrix to determine the most desirable characteristics of the component. The selection criteria were weighted and an importance rating of 1 to 5 was assigned to each concept independently. Oftentimes these analyses resulted in further discussion of modifying current concepts or developing entirely new concepts. In the event that the scoring process yielded similar results, a sensitivity analysis was performed to critically re-assess the values assigned to the concepts. The following sections outline the results from the screening and scoring processes undertaken to analyze and ultimately decide upon the concepts for further development.

2.2.1 Puck Dropping Component

TABLE VIII depicts the screening for the puck feeding concepts where a 0+- analysis was used.

TABLE VIII: PUCK FEEDING CONCEPT SCREENING USING A RATING OF 0+-

Selection Criterion	Dispenser w/o spring	Dispenser w/ spring	Column w/o spring	Column w/ spring	Revolver (ref)
Ease of use	0	-	+	-	0
Reliability	-	-	0	0	0
Size	0	0	+	+	0
Capacity	-	-	+	0	0
Simplicity	+	+	0	-	0
Aesthetics	-	-	0	+	0
TOTAL	**-2**	**-3**	**+3**	**0**	**0**

The selection criteria considered for this screening includes the ease of use, reliability, size, capacity, simplicity, and aesthetics. The ease of use refers to the ease of putting pucks within the feeder. The reliability refers to how well the puck is fed to the drop location. The size refers to the volume. The capacity refers to the amount of pucks the feeder can hold. Simplicity refers to the mechanism of feeding the puck, and aesthetics is subjective on how the concept appears. It was clear from this screening that the column without a spring was the best concept. Because of its dominance over the other concepts, a scoring process was not needed.

Next, the team analyzed the puck dropping concepts that propel the puck onto the face-off surface. TABLE IX depicts the screening for the puck dropping concepts where a 0+- analysis was used.

TABLE IX: PUCK DROPPING CONCEPT SCREENING RESULTS USING A RATING OF 0+-

Selection Criterion	**Piston (impact)**	**Piston/Spring (gradual)**	**Freefall**	**Air Cannon (ref)**
Consistency	+	0	-	0
Size	0	0	+	0
Maintenance	+	+	+	0
Simplicity	+	+	+	0
Aesthetics	-	-	-	0
TOTAL	**2**	**1**	**1**	**0**

The selection criteria considered for this screening includes the consistency, size, maintenance, simplicity, and aesthetics. Consistency refers to the ability the concept has to consistently propel the puck downwards. Size refers to the volume. Maintenance refers to the ease of component verification and replacement. Simplicity refers to the mechanism of feeding the puck, and aesthetics is subjective on how the concept appears.

As seen in TABLE IX, the screening process did not produce a clear winner. The team decided to eliminate the air cannon option as it was screened to be the lowest. Moreover, the freefall option was also eliminated because it does not propel the puck fast enough. In other words, it does not accurately replicate the puck motions imposed by a referee. With both piston concepts remaining, a scoring matrix was done for assistance in choosing a concept. TABLE X below shows the selection criteria being weighted relative to each other.

TABLE X: PUCK DROPPING CONCEPT SELECTION CRITERIA WEIGHTING MATRIX

	A	B	C	D	E
Consistency (A)		A	A	A	A
Size (B)			B	D	E
Aesthetics (C)				D	E
Simplicity (D)					D
Maintenance (E)					
TOTAL	**4**	**1**	**0**	**3**	**2**
Weight	**40%**	**10%**	**0**	**30%**	**20%**

As seen in TABLE X, consistency and simplicity are the most important criteria for choosing a puck dropping concept. These weights were then used for the scoring process between the chosen concepts: piston (impact), and piston/spring (gradual). TABLE XI below depicts the results from the scoring process using an importance rating of 1 to 5, where 5 is the highest value.

TABLE XI: PUCK DROPPING CONCEPT WEIGHTED SCORING RESULTS

Criteria	**Weight**	**Piston (impact)**		**Piston/Spring (gradual)**	
		Imp.	**Weight**	**Imp.**	**Weight**
Consistency	40%	5	2	5	2
Size	10%	4	0.4	4	0.4
Aesthetics	0%	2	0	2	0
Simplicity	30%	4	1.2	3	0.9
Maintenance	20%	4	0.8	3	0.6
TOTAL		**4.4**		**3.9**	

As seen in TABLE XI, the piston (impact) had the highest weighted score hence it was the chosen concept for puck dropping.

Lastly, regarding the puck dropping mechanism, the team analyzed the puck holding concepts. TABLE XII below depicts the screening for the puck holding concepts where a 0+- analysis was used.

TABLE XII: PUCK HOLDING CONCEPT SCREENING RESULTS USING A RATING OF 0+-

Selection Criterion	**Tabs**	**Gasket**	**Spring Door**	**Sliding Door**	**Friction Fit (ref)**
Loading	+	+	+	+	0
Releasing	0	0	+	-	0
Size	0	0	0	-	0
Aesthetics	0	0	0	-	0
Simplicity	0	0	-	-	0
Maintenance	+	0	-	-	0
TOTAL	**+2**	**+1**	**0**	**-4**	**0**

The selection criteria considered for this screening includes loading, releasing, size, maintenance, simplicity, and aesthetics. Loading refers to the ease of the puck falling into the holder. Releasing refers to the ability the puck leaves the holder to consistently propel the puck downwards. Size refers to the volume of the concept. Maintenance refers to the ease of component verification and replacement. Simplicity refers to the mechanism of feeding the puck, and aesthetics is subjective on how the concept appears.

As seen in the total row in TABLE XII, the screening results did not produce a clear winner. For the purpose of a scoring process, the tabs, gasket and spring door concepts were chosen. The friction fit concept was eliminated because of its difficulty with releasing the puck. TABLE XIII below shows the selection criteria being weighted relative to each other.

TABLE XIII: PUCK HOLDING CONCEPT SELECTION CRITERIA WEIGHTING MATRIX

	Loading	**Releasing**	**Size**	**Aesthetics**	**Simplicity**	**Maintenance**
Loading		Releasing	Loading	Loading	Loading	Loading
Releasing			Releasing	Releasing	Releasing	Releasing
Size				Aesthetics	Simplicity	Size
Aesthetics					Simplicity	Maintenance
Simplicity						Simplicity
Maintenance						
TOTAL	**4**	**5**	**1**	**1**	**3**	**1**
Weight (%)	**0.27**	**0.33**	**0.07**	**0.07**	**0.20**	**0.07**

As seen in TABLE XIII, releasing, loading, and simplicity are the most important criteria for choosing a puck holding concept. These weights were then used for the scoring process between the chosen concepts: tabs, gasket, and spring door. TABLE XIV below depicts the results from the scoring process using an importance rating of 1 to 5, where 5 is the highest value.

TABLE XIV: PUCK HOLDING CONCEPT WEIGHTED SCORING RESULTS

Criteria	**Weight**	**Tabs**		**Gasket**		**Spring Door**	
		Imp.	**Weight**	**Imp.**	**Weight**	**Imp.**	**Weight**
Loading	27%	3	0.81	4	1.08	4	1.08
Releasing	33%	5	1.65	5	1.65	5	1.65
Size	7%	3	0.21	3	0.21	3	0.21
Aesthetics	7%	1	0.07	2	0.14	1	0.07
Simplicity	20%	4	0.80	5	1.00	3	0.60
Maintenance	7%	4	0.28	3	0.21	2	0.14
TOTAL		**3.82**		**4.29**		**3.75**	

As seen in TABLE XIV, the gasket had the highest weighted score. This scoring process indicated that the gasket was the best option for the puck holding concept. Discussing these results and consulting the client, it was decided that the solid gasket concept should have a hole cut in the center for easier release of the puck and less strain on the gasket.

2.2.2 Face-Off Component

Generated concepts from section 2.1.3 were for the realistic face-off motion mechanism. TABLE XV depicts the screening for the face-off motion concepts where a 0+- analysis was used.

TABLE XV: FIRST FACE-OFF MOTION CONCEPT SCREENING RESULTS USING A RATING OF 0+-

Selection Criterion	**Piston Arms (ref)**	**4 Hinged Arms**	**2 Hinged Arms**	**6DOF Arm**	**Paddles**	**No arm**
Speed	0	+	+	-	+	+
Accuracy	0	+	+	+	-	-
Robust	0	0	0	-	+	+
Simplicity	0	0	0	-	+	+
Aesthetics	0	+	+	+	-	-
Maintenance	0	0	0	-	+	+
Size	0	-	0	+	+	+
Realism	0	0	0	+	-	-
TOTAL	**0**	**+2**	**+3**	**0**	**+2**	**+2**

The selection criteria considered for this screening includes speed, accuracy, robust, size, maintenance, simplicity, aesthetics, and realism. Speed refers to how fast the motion is performed. Accuracy refers to how accurate the motions are in performing the motions. Robust refers to the concept's ability to resist forces. Size refers to the volume of the concept. Maintenance refers to the ease of component verification and replacement. Simplicity refers to the mechanism of feeding the puck, and aesthetics is subjective on how the concept appears. Realism refers to the appearance of the concept's motions.

As seen in the total row in TABLE XV, the screening results did not produce a clear winner. For the purpose of a scoring process, the pneumatic arms, the 4 hinged arms, and the 2 hinged arms concepts were chosen. The paddles and the no arm concepts were eliminated because of they do not provide any realism to the design. TABLE XVI below shows the selection criteria being weighted relative to each other.

TABLE XVI: FIRST FACE-OFF MOTION CONCEPT SELECTION CRITERIA WEIGHTING MATRIX

	1	2	3	4	5	6	7	8
Speed (1)		1	1	1	1	1	1	8
Accuracy (2)			3	2	2	2	2	8
Robust (3)				3	3	3	3	8
Simplicity (4)					4	4	4	8
Aesthetics (5)						5	5	8
Maintenance (6)							7	8
Size (7)								8
Realism (8)								
TOTAL	**6**	**4**	**5**	**3**	**2**	**0**	**1**	**7**
Weight	**0.21**	**0.14**	**0.18**	**0.11**	**0.07**	**0.00**	**0.04**	**0.25**

As seen in TABLE XVI, realism and speed are the most important criteria for choosing a realistic face-off motion concept. These weights were then used for the scoring process between the chosen concepts: pneumatic arms, 4 hinged arms, and 2 hinged arms. TABLE XVII below depicts the results from the scoring process using an importance rating of 1 to 5, where 5 is the highest value.

TABLE XVII: FIRST FACE-OFF MOTION CONCEPT WEIGHTED CONCEPT SCORING

Criteria	**Weight**	**Pneumatic Arms**		**4 Hinged Arms**		**2 Hinged Arms**	
		Imp.	**Weight**	**Imp.**	**Weight**	**Imp.**	**Weight**
Speed	21%	3	0.64	5	1.07	4	0.86
Accuracy	14%	4	0.57	4	0.57	4	0.57
Robust	18%	4	0.71	3	0.54	3	0.54
Simplicity	11%	3	0.32	2	0.21	2	0.21
Aesthetics	7%	3	0.21	3	0.21	4	0.29
Maintenance	0%	3	0	4	0	4	0
Size	4%	4	0.14	3	0.11	4	0.14
Realism	25%	4	1.00	5	1.25	5	1.25
TOTAL		**3.59**		**3.96**		**3.86**	

As seen in TABLE XVII, the weighted scores are close. A sensitivity analysis was performed after discussing the results with the client. TABLE XVIII below depicts the second screening for the face-off motion concepts where a 0+- analysis was used.

TABLE XVIII: SECOND FACE-OFF MOTION CONCEPT SCREENING RESULTS USING A RATING OF 0+-

Selection Criterion	**Original (ref)**	**4 Hinged Arms**	**2 Hinged Arms**	**6DOF Arm**	**Paddles**	**No arm**
Speed	0	0	0	-	+	+
Accuracy	0	+	+	+	-	-
Repeatability	0	+	+	+	-	-
Robust	0	0	0	-	+	+
Simplicity	0	-	0	-	+	+
Aesthetics	0	+	+	+	-	-
Maintenance	0	0	+	-	+	+
Size	0	-	0	+	+	+
Realism	0	+	+	+	-	-
TOTAL	**0**	**+2**	**+5**	**+1**	**+1**	**+1**

The new selection criterion of repeatability was added and it refers to the concept's ability to repeat its motion consistently. As seen in TABLE XVIII, the 2 hinged arms was the chosen concept using the added selection criterion.

2.2.3 Other Components

Possible methods for rotating the base are listed below.

- Rack and pinion – the use of gears
- Motor at the center axis of the body
- Motor connected to the outside of the body which acts like a pivot point

The team discussed these concepts with the client and he expressed the advantage of using a rack and pinion over other forms of rotation. It can transmit forces at higher speeds than simple motors. With the input provided by the client, the team chose the rack and pinion concept for body rotation.

In an attempt to reduce the manufacturing cost of the simulator, the team looked at different off-the-shelf components. Electrical actuators, pneumatic pistons, hydraulic cylinders, and electric motors were all potential options at the beginning of the research. Through further research and discussion, the team decided that hydraulic cylinders would introduce too much complexity, and most pneumatic cylinders were found to only fully extend and/or retract, which does not provide the needed variability. Moreover, electrical actuators, while simple and inexpensive, could not move fast enough to challenge the user in a face-off. Finally, electric motors, while sufficiently fast, were complicated to implement and utilize, especially motors with a back-and-forth motion. Considering these devices, the team decided to use electric motors for the face-off motion, an electrical actuator to load the puck, and a pneumatic piston to drop the puck onto the face-off surface.

2.3 Concept Selection

Considering all of concepts mentioned in the previous section, the concepts are evaluated for the final design. This section provides recommendations for further concept development, a summary of the selected concepts, and discusses the concept integration.

2.3.1 Recommendations of Concepts for Further Development

Considering everything that was brainstormed and discussed, the team was able to decide upon the concepts. The following subsections outline the chosen concepts for the further design and analysis.

2.3.1.1 Puck Dropping Component

All of the concepts have been determined for the puck dropping mechanism. Firstly, the puck feeder will be a vertical cylinder located above the machine whilst feeding pucks downwards via gravity. Once a puck is loaded, an electric actuator will push the puck, in the horizontal plane, to the drop location. The actuator cannot have any steps on its top surface because it cannot get caught on the underside of a puck as it is moving. Figure 42 illustrates the column.

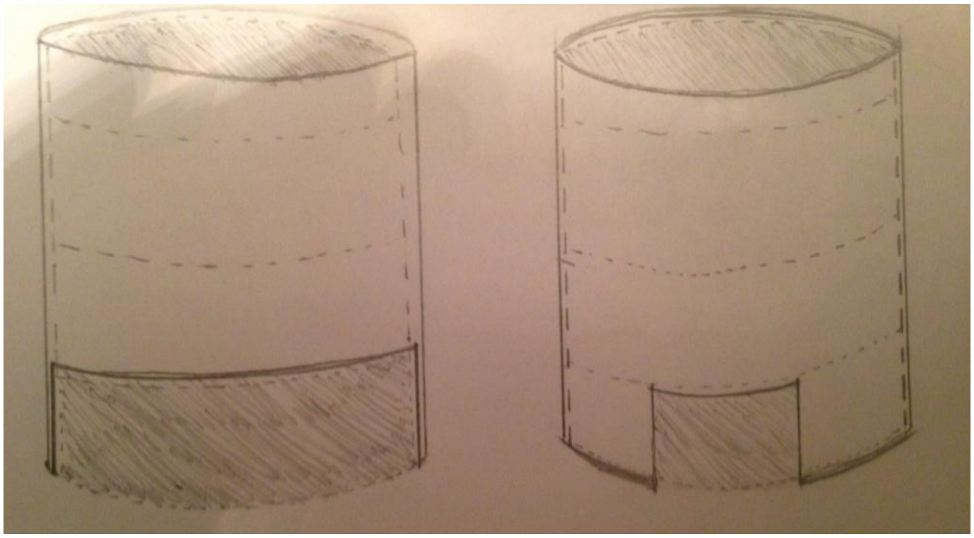

Figure 42: Front and back view of the puck feeder cylinder [18].

The pucks will be stored vertically in the cylinder and will be able to contain a minimum of 10 pucks. The cylinder will be attached to the structure by a mechanical slot, in which the cylinder is simply twisted into place. The specific details of this slot and the cylinder material have yet to be determined. This cylinder will also have cut-outs on the bottom to allow the actuator to move into the cylinder and push a puck out. On the other end of the cylinder, a cut-out will be made to allow one puck to slide out to the drop location. Further development is required for the actuator, such as the fixation method to the structure and technical specifications on desired speeds and forces to move a puck. Furthermore, the actuator will have to be chosen from available actuators on the market based on the needed specifications. Lastly, regarding the puck dropping mechanism, depending on the profile of the moving portion of the actuator, a special piece may need to be designed to ensure the top of the moving portion is flat in order to keep pucks from getting stuck in the feeder.

After a puck has been pushed out from the cylinder by the actuator, it will fall into the puck holder. The structure of the holder will simply be a shallow cylinder, much like the puck feeder. To prevent the puck from falling through to the ground, a rubber gasket will be fixed to the bottom edge of the cylinder. The gasket will have a hole in the centre and slits at four to eight locations around the hole, as seen in Figure 43.

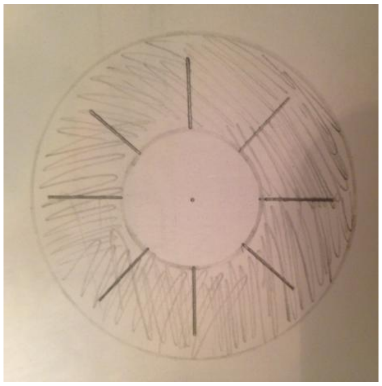

Figure 43: Top view of the rubber gasket as the chosen puck holder [16].

This will allow the puck to be held prior to being subjected to a sufficient force for propulsion. Variables that have yet to be determined are the gasket material and dimensions (purchasing a pre-existing gasket that will suit the needs is preferred), and the method of fixing the gasket to the cylinder.

Lastly, the puck will be pushed through the gasket using a pneumatic piston. The piston will be powered by a small compressor and propel the puck downwards at a high speed. The piston will be mounted to the side of the puck storage cylinder as illustrated in Figure 44.

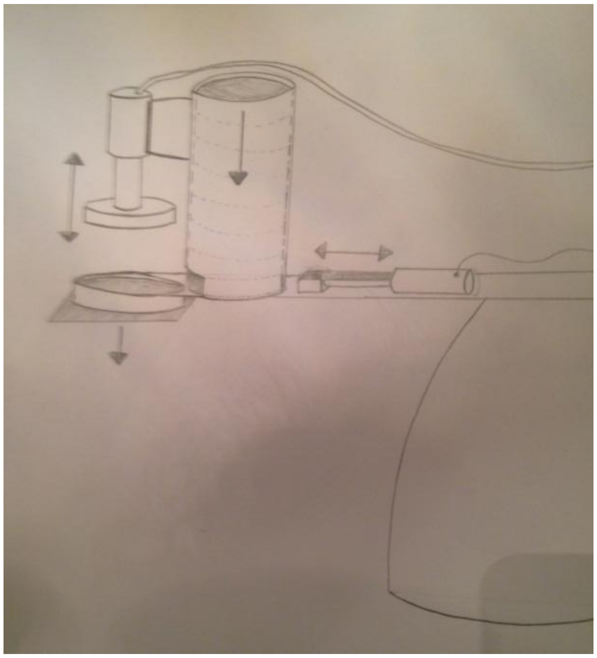

Figure 44: Possible puck dropping mechanism assembly [19].

The end of the piston will have a piece attached to its moving end that has the approximate shape of a puck. This will ensure the puck is ejected from the puck holder at an even stress distribution. This piece has yet to be designed. Further development is required in how the piston will be fixed to the cylinder as well as how the air line will be connected and routed. Additionally, the piston will have to be chosen from existing products on the market.

All of these subcomponents will come together to form the puck dropping mechanism. One component that was not vigorously analyzed was the structure that holds the entire mechanism. The bridge will be designed as the team sees fit once the other concepts have been finalized and assembled.

2.3.1.2 Face-Off Component

The team decided to use the 2 hinged arms concept, where pinned joints are used as elbows and the shoulder motors govern the motion. The shoulders are powered by servo motors, providing simple rotation. The arms will be connected to the shoulders and the hands where the stick will be held. This concept needs further development in which the design of the arms, hinges, and hands is required as well as selecting the motors for the shoulders. Additionally, there has been discussion of including a motor in the hand design that could rotate the stick independently from the shoulders. Lastly, to better replicate the realistic face-off motion, the body of the machine will be hinged along a horizontal axis to allow the arms to tilt forward. The location and the structure have yet to be determined. The hinged arms and the body will form the realistic hockey face-off motion. Not mentioned or analyzed is the body of the machine.

2.3.1.3 Other Components

The body of the machine will rotate by use of a rack and pinion. A motor will power the pinion gear and a spherical rack will be fixed to the bottom of the machine body. This will allow the body, and thus the arms, to rotate. The rack and pinion has yet to be designed and a motor has yet to be selected, although there is the possibility of purchasing an existing premade setup, if it suits the needs.

The body will be designed to support the shoulder motors, contain a hinge along a horizontal axis, and be attached to a spherical rack for its rotation. Depending on the size of the body, it may also house the air compressor and/or battery, but this has yet to be determined.

The remaining components of the machine depend on the selection, orientation, and function of the previously discussed components. Because of this dependence, it would be inefficient to brainstorm and analyze ideas that will likely become obsolete once the puck dropping and face-off components have been determined. When the puck dropping and face-off component designs have been finalized, the design of the remaining components can be done. These components include the puck dropping structure, the body of the machine, and the base, which will contain gripping and stabilizing components as well as a method for transporting the machine.

Lastly, there are some additional components that will be included in the machine that do not require any design. This includes a motion sensor, a display monitor, and an image projection device. These components will be selected based on comparisons made with the target specifications. All motors, actuators, pistons, batteries and compressors have not been selected. The power sources and components will be chosen according to what is readily available to purchase, machine specifications, and cost.

2.3.2 Summary of Selected Concepts

The hockey face-off simulation machine will be comprised of two main components: the puck dropping mechanism and the realistic face-off motion. The puck dropping mechanism will consist of a tall cylinder that can store a minimum of 10 pucks, an actuator to push a puck from the cylinder to the drop location, a rubber gasket to hold the puck at the drop location until the desired force is applied, and a pneumatic piston to propel the puck through the gasket onto the ice.

The realistic face-off motion will be comprised of two hinged arms powered by rotating shoulder motors secured to the body of the machine. The arms are pinned as to mimic a player's elbows, and will be attached to the shoulder motors and to a hand that holds the hockey stick. The body will be hinged along a horizontal axis to allow the arms to tilt up and down. Moreover, the body will rotate about a vertical axis and will be powered by a rack and pinion setup, allowing the entire body of the machine to rotate.

2.3.3 Concept Integration

The current chosen concepts, the puck dropping mechanism and the face-off motion, solve the problem outlined in the problem statement while fulfilling the client's most important needs: simulating the puck drop and performing a face-off. The chosen concepts also provide a variety of left-handed and right-handed face-off techniques to challenge the user. All of these mentioned needs of the client, while accounting for less than half of the total needs, represent the most important aspects necessary of the machine and are met by the concepts presented. The remaining needs, while not specifically met by the confirmed concepts, will be fulfilled as the remaining concepts and features are decided upon. For example, the materials selected for each component (i.e. the puck holder or puck dropper) will be selected to ensure the machine can last a long time, have a reasonable cost to build, and can withstand physical forces. Also, the design of the base will ensure the machine is stable and can operate normally on a variety of surfaces. Furthermore, the power sources selected will be convenient, and allow operation of the machine while recharging, and recharge quickly. Finally, additional components such as the motion sensor and touch screen display will satisfy the needs of having a motion sensor, being easily programmable, and ease of setup and use.

The team ensured that the chosen concepts were within the constraints and limitations set forward by the client and the group. The first constraint, that the machine cost under $8,000 has yet to be evaluated as the team only started researching existing purchasable products. This constraint is of lesser concern because the $8,000 limit is a "soft" limit and the client has clearly stated that any feature that would add significant value can be accounted for in the budget. The second constraint, which is the machine's size, will not be an issue as our concepts are relatively compact and could fit through a doorway.

The machine will allow a professional hockey player to individually practice face-offs based on the common-sense approach used to choose the concepts. Furthermore, the concepts will meet all of the client's needs while staying within the determined constraints and limitations.

3.0 Physical Model

Prior to the Concept Design Report, the team had determined that the chosen design would accurately simulate the hockey face-off motion. Mainly, the design consisted of a rotating base, a hinged body, two hinged arms controlled by servo motors, and a rotatable stick at the connection of the two hinged arms. While the team felt that the chosen concepts would work, but we still needed reassurance because of uncertainties in simply imagining the machine's motion. Therefore, the team decided that a physical/visual model was needed to confirm that the design could simulate the imagined face-off motion. Initially, the team thought a SolidWorks model would work. However, due to numerous unknowns of the design and the lack of SolidWorks experience, this model proved to be a poor option, thereby needing another approach to confirm the team's uncertainties. Using the aforementioned concepts in section 2.3.2, a team member was able to produce a rudimentary physical model of the face-off motion out of LEGO pieces. Even if the model was not exactly like the machine, as long as the key components of the face-off motion were present, the team could gain some confidence in the design in order to move forward. Key components included into the model were the rotating base, the hinged body, the two hinged arms, and the rotating stick. Figure 45 shows an angled view of the model.

Figure 45: Angled view of the physical model made with LEGO [20].

Figure 45 shows the face-off motion rotated to the right. If the model was a more accurate depiction of the chosen concepts, the puck dropping mechanism would be centered above the face-off motion and reach to the puck drop location. Additionally, the column supporting the puck dropping mechanism would be located behind the face-off motion. Figure 46 shows a side view of the model.

Figure 46: Side view of the physical model made with LEGO [21].

From Figure 46, it can be seen that the hockey stick is oriented straight forward. Figure 47 shows a top view of the model and shows a better view of the stick's orientation.

Figure 47: Top view of the physical model made with LEGO [22].

The manipulation of this model provided confirmation regarding the chosen face-off motion concept. With a more accurate visual representation of the concept, the team was able to confidently move forward with the two hinged arm design.

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