The Kinetic Sculpture and Factors Affecting the Sustainability of the Robotics Academy

Submitted by Jarred Sakakeeny

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School of Engineering
Tufts University
Medford, Massachusetts

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Signature of Author:
Your Name

Certified By:
Associate Professor Douglas M. Matson
Department of Mechanical Engineering
Tufts University

Committee:
Professor Chris Rogers
Department of Mechanical Engineering
Tufts University

Committee:
Assistant Professor Judith Stafford
Dept. of Computer Science
Tufts University

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Abstract:

In its second year of existence, the Robotics Academy has now branched to form two teams working on separate projects: "Team Kinetic" and "Team Spot". The purpose of this thesis is to elaborate on the challenges, successes, and pitfalls of "Team Kinetic". Throughout the year there were many successes on individual components of the sculpture, but the systemization of those components as well as the way in which we, as a team, approached that problem was a major imperfection on the whole. In addition to discussing the outcome of the design, the team dynamic and interaction of group members will also be investigated and scrutinized. Moreover, this interaction will be evaluated against the intended interaction as proposed by the original mission of the Robotics Academy [Rogers].

The design of our project is a kinetic sculpture which is to be used as an interactive learning tool for children. The sculpture incorporates many underlying engineering themes that can be subtly passed on to all who observe it. It consists of a ball which moves throughout the sculpture on a stainless steel track. Throughout the sculpture are stops which require the user to interact with the sculpture by completing a task in order to allow the ball to continue moving through the sculpture.

Two generations of Robotics Academy members agree that there is an obvious need for multidisciplinary projects. Necessary skills of leadership, project design, teamwork, scheduling, and fabrication which are ascertained throughout make this style of program essential in preparing students for the real world. As this program is so valuable, we must ensure its viability at Tufts by always seeking to improve upon the experience. The sustainability of the Robotics Academy is a main focus and concern of this year's members. In order to ensure the success and sustainability of the Robotics Academy there must be improvements to the way that group members attack problems, interact, and also how the Academy is marketed to students at Tufts.

Acknowledgements

I would like to first begin by thanking the people who have made this project the most memorable and educational experience that I will take away from my four years at Tufts University.

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History of the Robotics Academy

The Tufts Robotics Academy was started in the fall of 2002 with an initial team consisting on nine members. The intent of the Robotics Academy is to create a multi-disciplinary team to better represent the macrocosm of an engineering project. The Academy works by bringing together students from mechanical engineering, electrical engineering, computer engineering, computer science, human factors engineering and child development in order to produce a solution to a robotic design problem. By creating an environment of varied academic backgrounds, the Academy hopes to achieve optimal project results as well as overall knowledge transfer between the participants. The Academy also seeks to use the robotic design project to teach grade school children some of the fundamentals of science, math and engineering. The project is brought to classrooms as a learning tool.

In its first year in existence, the task of the Robotics Academy was to build and test a robot which could traverse rigid tubes of varying diameter and orientation. [Schrauth] The project stemmed from research that a co-founding faculty member, Caroline Cao, performed in the Ergonomics in Remote Environments Laboratory. The founding Robotics Academy team was challenged with creating a scalable design for an alternative endoscopic device.

Robotics Academy – Present

Presently, the Robotics Academy has split to form two groups working on two projects: "Team Kinetic" and "Team Spot". All participating members of the Robotics Academy are currently seniors in varying majors at Tufts University. The purpose of this thesis is to evaluate the work done by "Team Kinetic" and to propose amendments to the workings of the Robotics Academy to promote efficiency of work and knowledge transfer between participants.

The Robotics Academy is overseen by a graduate student and former member of the founding team. Matt Dombach organizes academy meetings, monitors progress, and oversees all aspects of the Robotics Academy. His prior experience in the workings of the academy is what helped our success this year and for that we are very grateful.

Though the nature of the Robotics Academy is to be mainly driven by the student members, the faculty advisors play a major role. Faculty members serve as a safety net for students. In such a diverse group of academy members, there exists a demand for an even more diverse set of faculty advisors to aid in the learning and development process. The faculty members provide help and guidance to a wide range of problems stemming from design issues to companies for possible sourcing work.

Project Goals

The overall goal of this project is to create a kinetic sculpture to be used as an interactive learning tool. We anticipate that the use of this project will subtly impart certain concepts of engineering and science onto the user. Concepts such as cause and effect, gravity, friction, and many others can be easily observed and realized. Upon further investigation and inquiry as to how the sculpture truly works, concepts such as electro magnetism, motors, torque, power, and design/construction can be taught to the user.

The sculpture is a closed loop system of chained response events all triggered by inputs from the user. The sculpture is driven with a steel ball that makes its way around the sculpture on a stainless steel track, stopping at way points until the user gives a certain input that allows the ball to continue and trigger some kind of event. By incorporating an input module, we allow people to directly interact with the sculpture by manipulating inputs to produce responses in the form of events.

An equally weighted project goal is to test the sustainability of the Robotics Academy. With this year's team consisting entirely of seniors, the foundation upon which the academy is built has been jeopardized. The Robotics Academy is a program that provides opportunities for learning in the context of multi-disciplinary problem solving. It is expected to improve the education of the student and produce engineers that are highly motivated and technically capable [Rogers]. This fact will be proven to be quite evident, but the communication between engineering disciplines, as well future marketability of the academy, brings into question the sustainability of the Robotics Academy.

The final project goal, in order to secure the sustainability of the robotics academy, is to identify fun and relevant projects for future generations of the Academy. If students do not feel that they are contributing to something relevant or worthwhile, the Academy will not be as appealing to students. This lack of interest will make it extremely hard to market the Academy to younger members and thus threaten the overall sustainability. This is why fun and relevant projects are essential to the success of the Robotics Academy.

Specifications

The specifications of our project, and therefore our design, are dependent on the goals that have previously been set. Overall, we need the sculpture to be a closed loop system which will be portable and entertaining.

To make it a closed loop system, we know there will be an end and a beginning, and that we will need something to physically chain all of the events and stops throughout the sculpture in the form of a ball on a track. The track will slope down from the beginning of the sculpture to the end in order to utilize gravity to move the ball throughout the sculpture. In order to make it continuous, we will require something to raise the ball from the bottom track to the top track within the sculpture. The design of the track will also need to incorporate the dimensions of the ball so that the ball can move on the track without ever falling off. [Kelly, Sakakeeny]

The original goal also calls for specific stops throughout the sculpture which require user interaction with the sculpture. These stops are an indication to the user that they must somehow interact with the sculpture in order for it to keep going. It is essential that the inputs which control these stops be challenging, attainable, and rewarding for the user. For entertainment, and to act as a feedback mechanism, it is required to have a way to monitor the ball throughout the sculpture as it travels along the track.

The overall weight of the sculpture is of utmost concern, because the sculpture must be portable (i.e. carried by two people of average height and weight). However, there is little that can be done to minimize the overall weight of the project by focusing on the individual components without sacrificing the integrity of each of those components. Therefore, careful attention must be paid to the material selection of the base plate and surrounding casing of the sculpture to minimize the overall weight.

Design – Successes and Failures

An overall view of the project as a whole is seen in the following sequence of events, stops and inputs. The ball starts at the bottom of the elevator and requires the user to complete the input Simon (see Appendix II) in order for the elevator to raise the ball to the elevated track. The next stop is a hanging solenoid which will not rise until the user successfully completes the second input which is a dynamic grip (see appendix III). Upon completion of the second input, the ball winds around the track and falls into a turnstile. The user must now complete a laser maze (see appendix IV) which is the third input station. Upon successful completion of this input task, the turnstile will rotate 120 degrees to deposit the ball onto the track below where it will roll until the next stop. The next stop which the ball hits is at the top of a winding coil. When the user completes a noise input (see appendix V), the ball will be allowed to pass through the coil and onto the last stop. The last stop is an accelerator which is controlled by a distance input (see appendix VI). The accelerator shoots the ball through a looped section of track and back to the start at the bottom of the elevator.

Elevator

In order to raise the ball from the bottom to the top of the sculpture, we have designed an elevator which is 42" tall. The total travel of the elevator is 33" along the Z axis. The elevator operates by rotating a lead screw while restricting the motion of a flange which is mounted to the lead screw. This produces a linear motion of the flange along the Z axis.

Frictional forces are the main concern in this concept, so it was finally decided to use a 1.500" lead, .500" nominal diameter lead screw from Kerk Motion. This lead screw has the advantage of producing 1.500" axial displacement per revolution along with a negligible amount of backlash. The lead screw needed machining on both ends to connect to the bearing on the bottom plate and to pass through the bearing in the top plate and connect to the motor. Therefore, one end of the screw has been turned down from the nominal .500" to .2508" for a press fit into the bottom bearing. The other end has been turned down in a step fashion to .2508" for a press fit into the top bearing and to .125" for the motor connection. [Kelly, Sakakeeny]

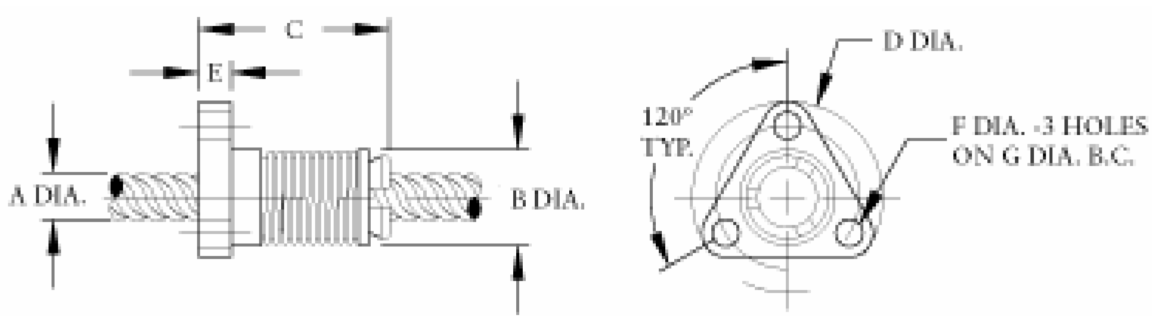


Figure 1 – A generalized drawing of the lead screw and nut from Kerk Motion.

The tradeoff between power required to raise the ball and the speed at which the ball would raise would prove to be our greatest blunder on the elevator. By adding a gear and pinion into the assembly we could achieve an excellent gear ratio to raise the ball at a steady rate while allowing for a higher torque. However, it was agreed that the lesser amount of assembly parts would be optimal. The lesser amount of moving parts decreases the likelihood of having to service the sculpture. We feel that with all the transportation of the sculpture there are many opportunities for it to get mishandled. With all the moving parts and mountings off of the elevator, it would be a prime location for failure. It is difficult to gauge if this was the right decision, but the elevator does raise the ball and has not yet broken. We consider that a success.

A great concern in the elevator design was the motor selection. We knew we wanted a motor that would operate at a relatively low RPM, and that a high torque would be needed to move the elevator car up the shaft. Coincidentally, Kerk Motion provides the following equation to determine the torque required to move a load using one of their lead screws as:

$$T_L = \left(\frac{Load \cdot Lead}{2\pi \cdot Efficiency} \right)$$

We estimated a load of just over one pound from the weight of the car and the ball, so we used three pounds in our calculations as a safety factor. Then, using the safety factor load and the specifications of the 8150 Series Lead Screw that we purchased, we have a torque of 100 N mm

We also know the distance we want our elevator car to travel, and from that we can deduce a reasonable RPM for the driving motor. A motor used in R/C cars was able to meet these specifications. [Kelly, Sakakeeny]

With the lead screw to motor connection, we felt it would be best not to drill a hole for the motor shaft into the lead screw. We felt that fitting a .125" shaft into a .250" lead screw might not give us enough space to add a set screw. We were also concerned that a wall thickness of .0625" would not accommodate the forces being applied to the lead screw. With such a small wall thickness and the high amounts of RPMs of the motor, any radial or torsional force applied to the motor shaft could result in a failure due to fatigue at that location. Finally, of utmost concern was the axial alignment of the motor and lead screw. Any misalignment could cause undue strain on the motor or cause the lead screw to bind. Therefore, we decided to fasten the two together using a .250" to .125" flexible motor coupling.

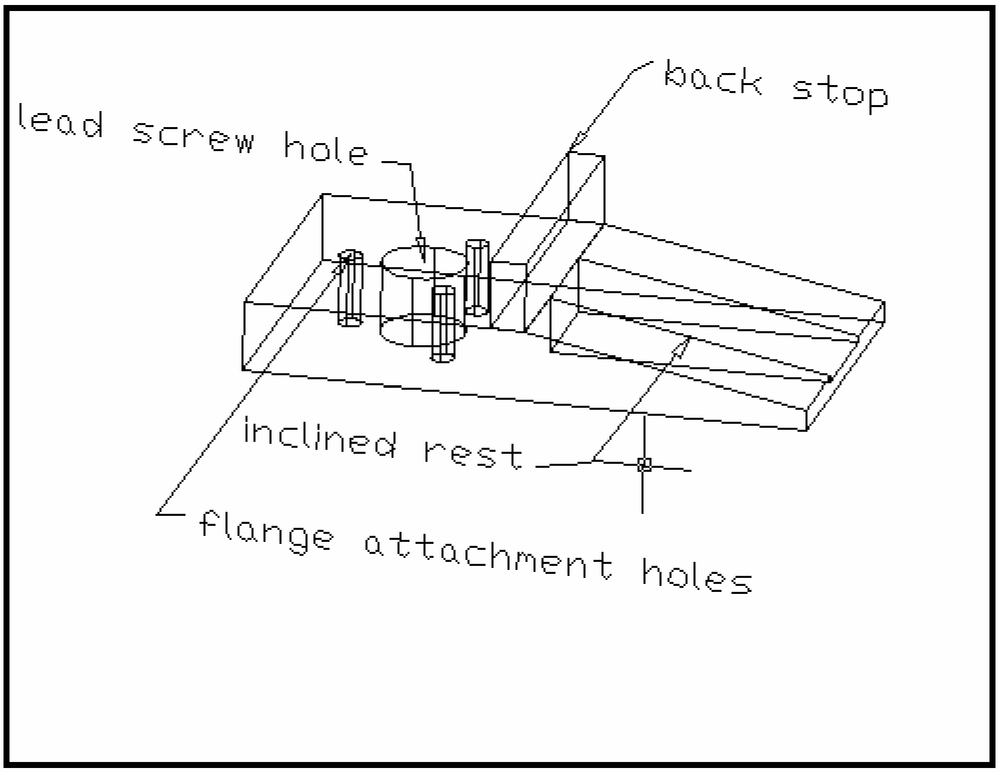


Figure 2 – A wire frame drawing of the elevator car that moves the ball in the elevator. The car is what carries the ball up the shaft of the elevator and pushes the ball onto the track.

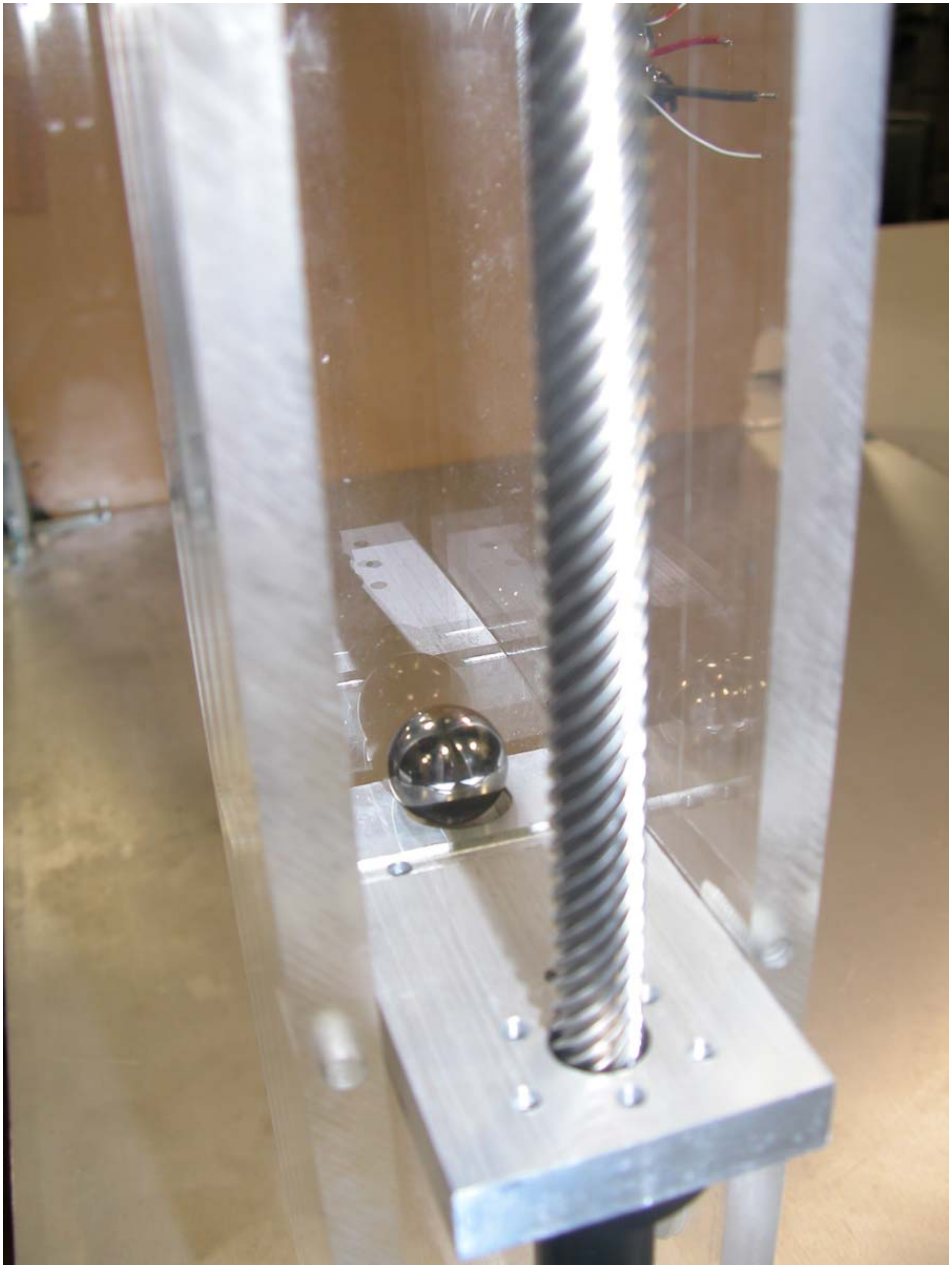


Figure 3 – A close up of the finished elevator car in the elevator shaft with the lead screw. This view shows all parts of the elevator: car, screw, shaft and ball at the front.

Turnstile

The next sequential step that would require significant interaction between mechanical engineers and electrical engineers was the turnstile. In order to solve the problem of having an event that would be able move the ball to a lower height and then reverse the direction of the ball, we designed a vertical turnstile, similar to a watermill. The ball enters the turnstile from a track slightly above the turnstile, and then is moved to a track below the turnstile where it travels in the opposite direction. We machined two side plates from Aluminum and eight fins from colored Acrylic. We decided on the acrylic to help reduce the weight of the turnstile. In order to ensure accuracy of degrees turned by the motor, we have chosen a stepper motor to rotate the turnstile. The stepper motor enables us to easily move the turnstile through a set number of degrees and then back to its original starting place without concern of turning too much or too little. The main concern with the stepper motor would be the load that we placed on it. If the motor does not have enough torque to turn through the desired rotation, it may start to skip steps. Once the motor skips steps, there is no way to correct it. In order to combat this problem, we had to keep weight as low as possible. By minimizing the size of the aluminum side plates and the use of acrylic fins, we were able to keep the weight of the system to a reasonable scale. We were able to achieve 100% success rates with the turnstile component through many rounds of testing. Presently, we have tested the turnstile more than 50 times and it has passed every time at receiving the ball, depositing the ball, then returning to its original location.

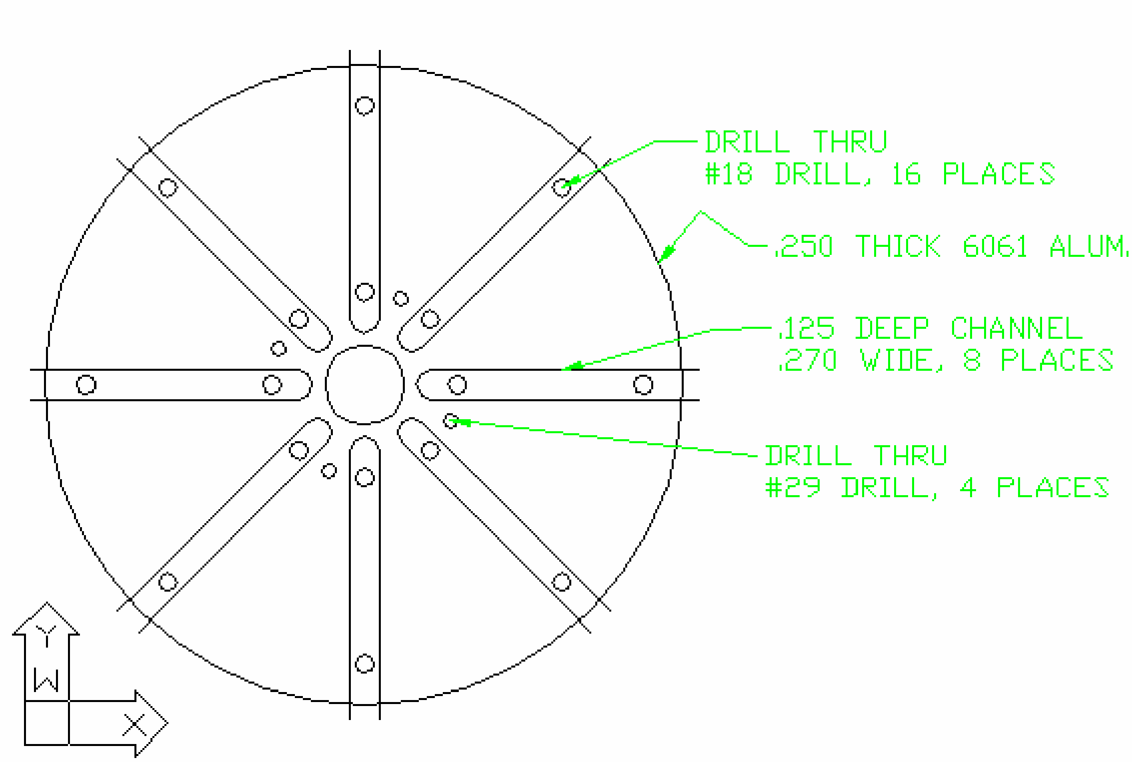


Figure 4 – Commented CNC drawing for the side plate of the turnstile

A custom Aluminum axle and flange were machined to couple the turnstile to the stepper motor on one end, and a radial ball bearing (.750"OD, .250"ID, .250" thick) on the other end.

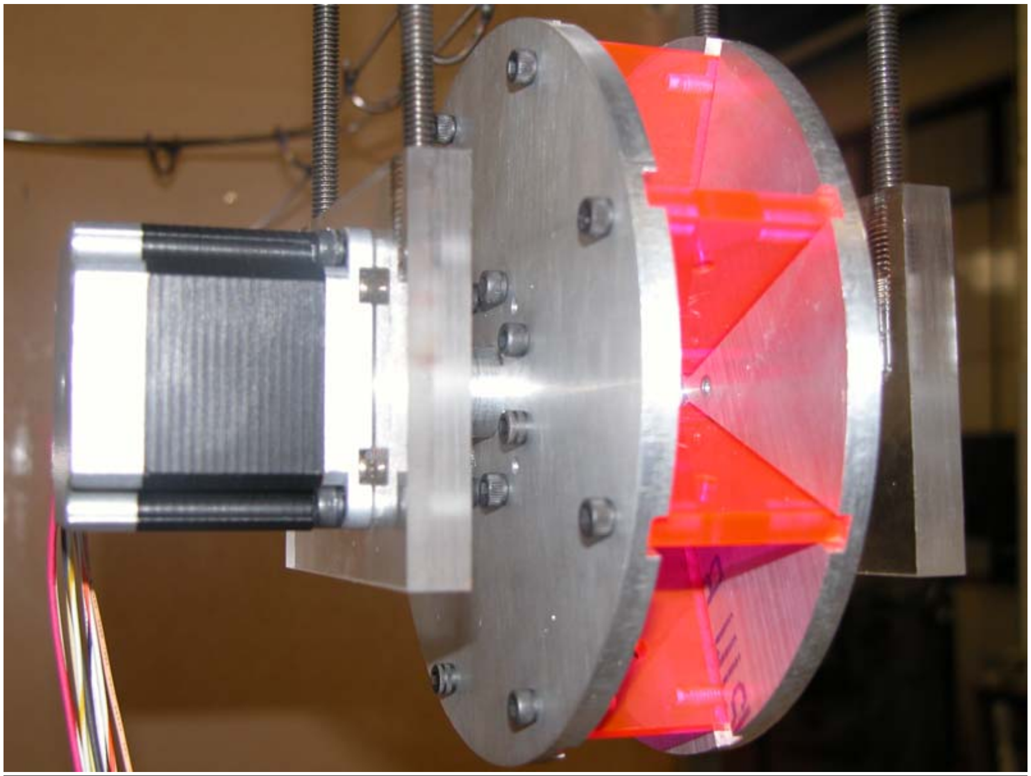


Figure 5 – The completed turnstile, including stepper motor, hanging from the support tubing in the sculpture by ¼ - 20 threaded rod.

This event is an example of improved communication and understanding between the engineering disciplines. In this case, we were more capable of dealing with the unknowns that could contribute to failure of this component. The electrical engineers selected a stepper motor and controller which could have enough power to rotate the ball through a known angle and overcome the frictional forces which we as mechanical engineers predicted. Knowing in advance the dimensions of the selected motor, we designed a system of mounting that fit in functionally as well as aesthetically into the design of the sculpture.

Vinyl Tubing

To complete the loop and to act as the rest of the track between the accelerator and the bottom of the elevator, we decided to use vinyl tubing. The use of tubing provides for a totally enclosed loop and no fear of falling off the track, however the amount of friction is greatly increased and thus slows the ball down significantly. The vinyl tubing has a 1.5" inner diameter and a 1/4" wall thickness. This allows it to be flexible while still maintaining its form around bends without kinking.

Accelerator

The accelerator serves as the last event in the sculpture before the ball is returned to the bottom of the elevator. When the input which controls the accelerator is satisfied, the accelerator turns on which starts two counter-rotating wheels which run off of one motor. The motor is mounted above the assembly and is coupled to the shaft by a flexible coupling. We chose 3" nylon gears to reduce the friction in the system. The gear assembly also allows the system to be counter-rotating while only using one motor.

Remote control car wheels were chosen to shoot the ball along its path because of their high coefficient of friction. The wheel also provides for a cushioned entrance. As the ball enters the accelerator it has to be grabbed, squeezed, and pushed through. The soft rubber of the wheel allowed us to mount the wheels so that they would be slightly less apart than the diameter of the ball. This would allow it to be grabbed, squeezed, and pushed through the system.

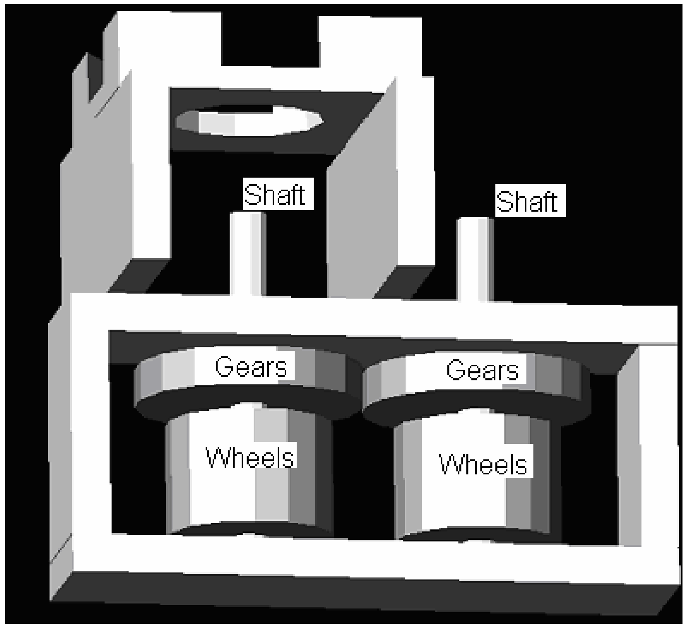


Fig 6 - 3-D close up of accelerator and motor mount

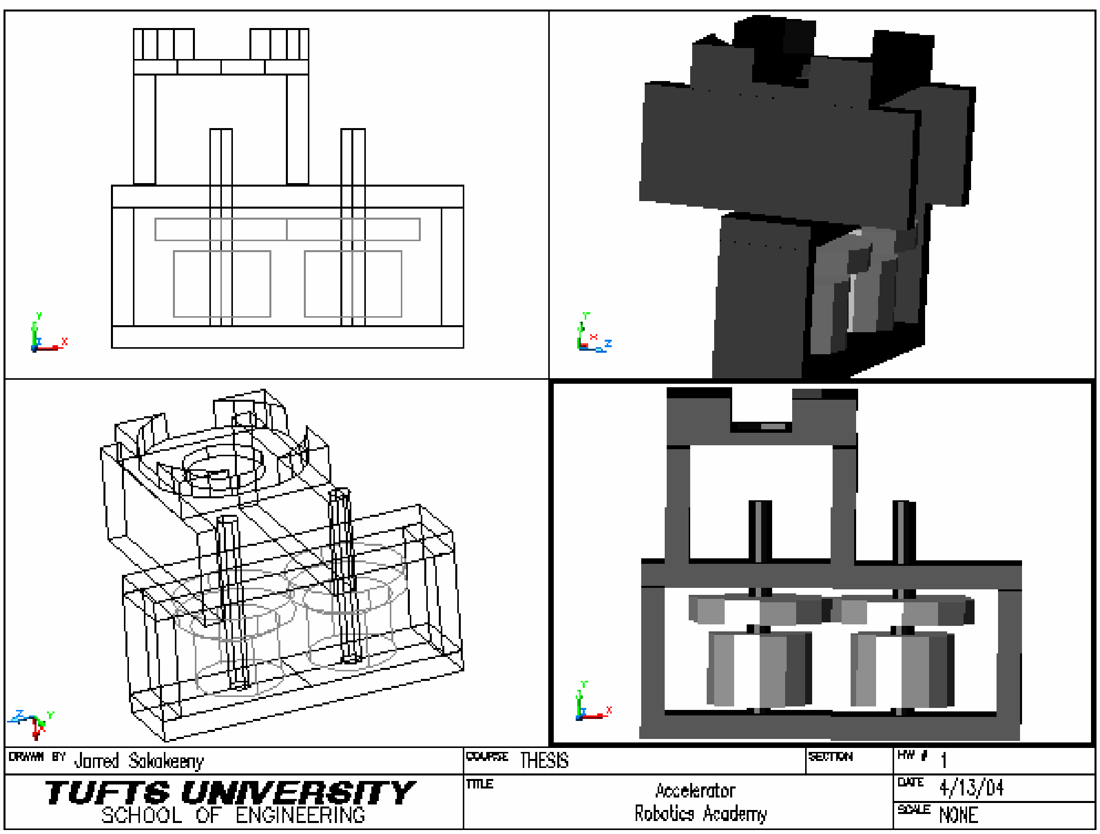


Fig 7- 3-D wire frame and Flat shaded view of the accelerator and motor mount

Above (Fig 7) are four views of the accelerator. At top left is a wire frame view as seen from the front of the accelerator. The bottom left view port shows an isometric wire frame view. Both images on the right are flat shaded to show the different components of the accelerator and how they fit together. It is apparent that where the motor is mounted (motor not shown in pictures) it will spin one shaft. This shaft has a wheel and gear rigidly mounted to it. The gear mates with another gear on the adjacent shaft which also has a wheel rigidly mounted to it. This produces the counter-rotating spin which we desire.

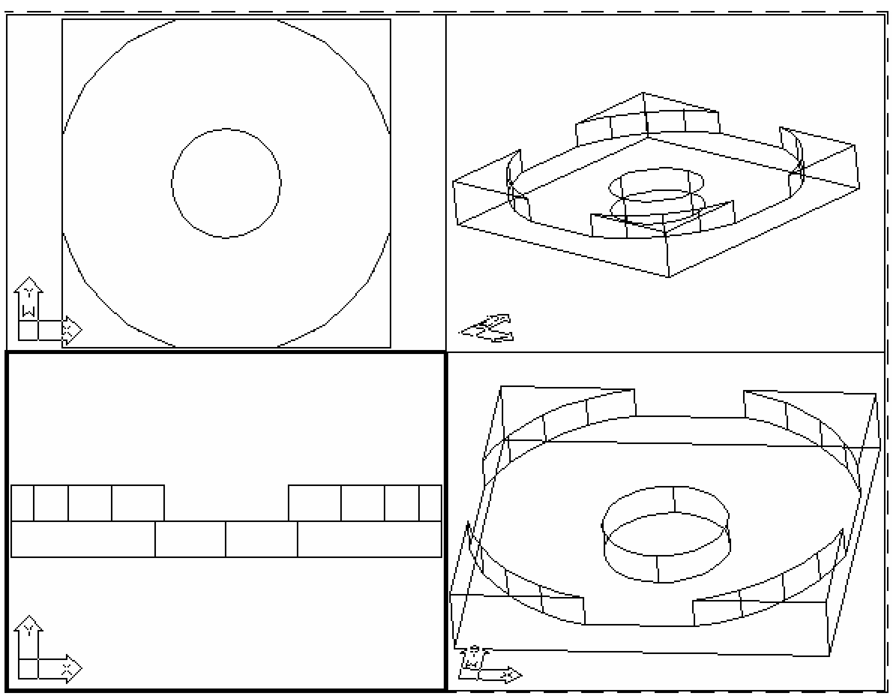


Fig 8 - Top, left and isometric views of motor mount piece to show how motor sits atop and interacts with the accelerator.

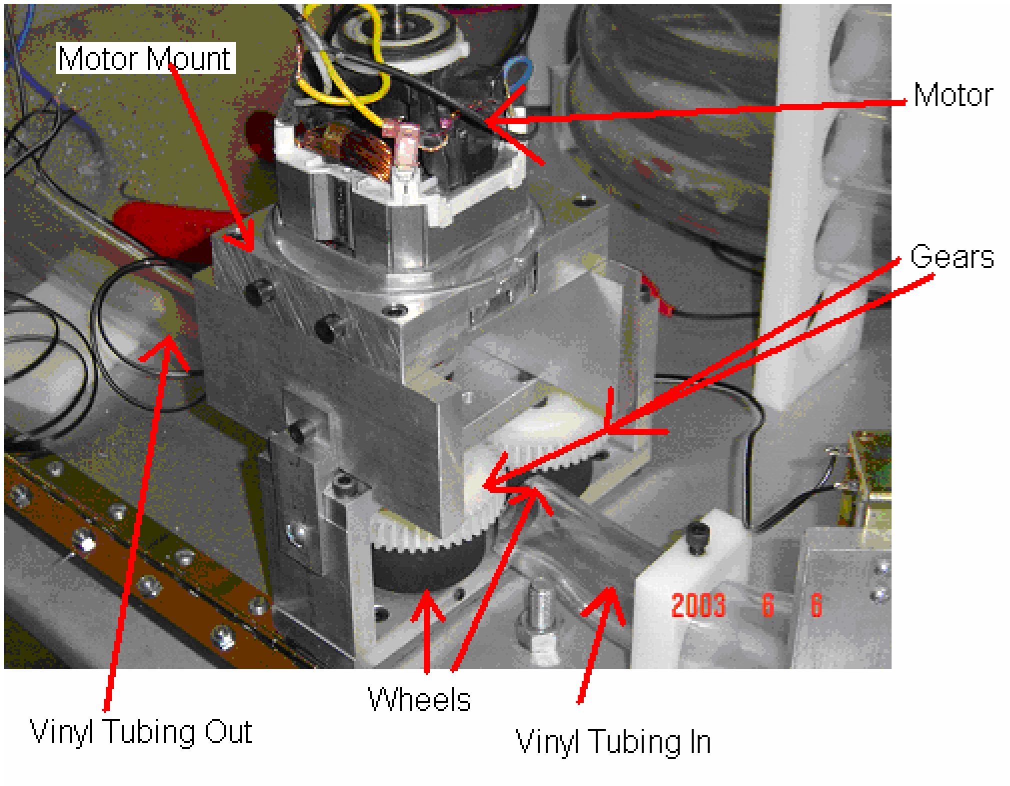
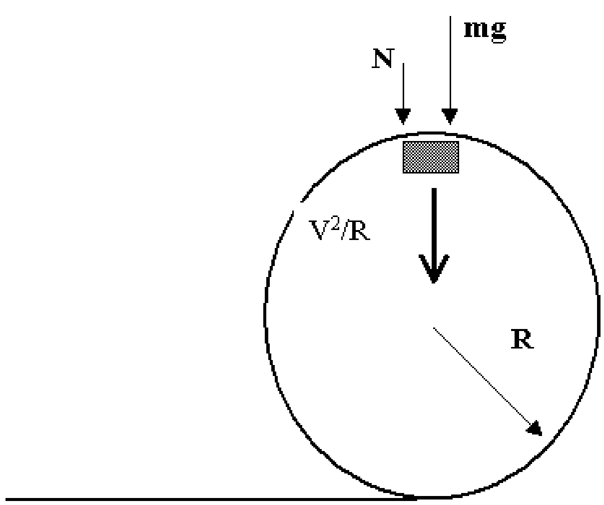


Fig 9 - View of accelerator in the system

The accelerator must be able to provide the ball with enough velocity to travel through the vinyl tube, through the loop and back to the elevator base. The height of the loop is 36 inches from the bottom of the sculpture. During the initial building process, power calculations were not performed to determine what type of motor was needed. We simply installed a motor that was taken from a vacuum cleaner because we were very short on time. This obviously added risk to the success of the project, but the motor rating seemed more than enough for our needs. I feel that this was a positive outcome for our project from an engineering standpoint. On a strict time schedule, we were able to pinpoint, eradicate, alter, test and debug a major system flaw in less than 2 days and reach our time goal. The motor was successful in its ability to deliver the ball through the loop to the base of the elevator. Despite the motor's ability to fulfill our needs, certain aspects of the motor were very troublesome and required us to find a new motor. One problem was that the motor sparked when it was turned on. In any situation with children, sparks may seem cool and get their attention, but the bottom line is that sparks are not considered child safe. Another unpleasant aspect of the motor was that it generated a noxious odor. We can only assume that in its years of use as a vacuum motor, dust and other contaminants gathered on its surfaces and when they heat up put out a very awful smell. The last problem with the motor was its loud noise. This particular motor was louder than most Harley Davidson motor cycles and was really scary when it got up to speed. For these reasons, it required us to go in search of another motor.

Motor Specs and Requirements

At the top of the loop, there are two forces acting upon the ball: gravity, pushing downwards, and the "normal" or reaction force from the track, also pushing downwards.



Fortunately, as the normal force is simply the "Newton's Third Law" reaction to the ball pushing against the frame (and we're assuming the track is infinitely rigid), the normal force can increase to any value we like - so it can never be too small.

At the top of the track (with the ball moving at speed v) we have:

$$mg+N=mv^2/R$$

In the extreme case of the ball being just about to fall off, clearly it is not pushing against the track anymore - so N can be set at zero.

$$mg=mv^2/R$$

$$v^2=gR$$

$g = 9.807\frac{m}{s^2}$ $g = 386.089\frac{in}{s^2}$ $d := 36in$ $R := \frac{d}{2}$ $R = 18in$ $m := 1lb$

$v_t := (g \cdot R)^{.5}$

required velocity to push ball through loop

$v_t = 83.364\frac{in}{s}$ $v_t = 2.117\frac{m}{s}$

$R_w := 1.1in$ $rev := 360deg$

$\omega := \frac{v_t}{R_w}$

Required angular velocity of the wheels to push ball through loop

$\omega = 2.605\times 10^5 \frac{deg}{min}$ $\omega = 12.062\frac{rev}{s}$ $\omega = 723.7\frac{rev}{min}$

This speed is required when there is a load placed on the motor, so the “no load motor speed must be higher than this. Once the steel ball passes into the grip of the wheels, there will be an instantaneous load placed on the motor.

Physically, power is defined as the rate of doing work. For linear motion, power is the product of force multiplied by the distance per unit time. In the case of rotational motion, the analogous calculation for power is the product of torque multiplied by the rotational distance per unit time.

$P_{rot} = M \times \omega$

Where:
P_{rot} = rotational mechanical power
M = torque
ω = angular velocity

The most commonly used unit for angular velocity is rev/min (RPM). In calculating rotational power, it is necessary to convert the velocity to units of rad/sec.

Ideal (frictionless) calculations

$T := 3\,\mathrm{lbf \cdot in}$ $\quad \omega = 723.7\,\frac{rev}{min}$ $\quad \omega = 75.786\,\frac{rad}{s}$

$Power := T \cdot \omega$

$Power = 25.688\,watt$ $\quad Power = 0.034\,hp$

This, however, is an extremely idealized situation in which there is no energy loss to friction. We must incorporate an energy term to show frictional losses or at least assume a safety factor to be sure that we can push the ball through to the end.

A numerical value for the coefficient of friction between stainless steel and vinyl is very hard to come by. Due to the rigidity of the vinyl tubing, there is no upper bound to the velocity at which we can push the ball through the loop (the ball is not going to pierce through the tubing if we accelerate it through the loop too quickly). So instead of calculating the energy loss due to friction between the stainless steel ball and the vinyl tube, we can simply assume a large safety factor and place that into our power calculations for the motor.

Bringing us to motor calculations for the accelerator, we must first understand what complications we may run into with certain selections. For a DC motor of relatively small size, there are several relationships which govern the behavior of the motor in various circumstances. These can be derived from the characteristics and physical laws of motors themselves. Kirchoff's Voltage Rule states that the sum of the potential increases in a circuit loop must equal the sum of the potential decreases. Applying this rule to a DC motor in series with a DC power source, the rule can be expressed as the supply voltage from the power source must be equal the sum of the voltage drop across the resistance of the armature windings and the back EMF generated by the motor.

$$V_o = (I \times R) + V_e$$

Where:
V_o = Power supply (volts)
I = Current (amps)
R = Resistance (ohms)
V_e = Back EMF (volts)

The back EMF that is generated by the motor is directly proportional to the angular velocity of the motor. The proportionality constant is the back EMF constant of the motor.

$$V_e = \omega \times k_e$$

Where:
ω = angular velocity of the motor
k_e = back EMF constant of the motor

Therfore, by substitution:

$$V_o = (I \times R) + (\omega \times k_e)$$

The back EMF constant of the motor is usually specified by the motor manufacturer in volts per RPM which is why in order to arrive at a meaningful value and understanding of these numbers, it is important to specify the motor velocity in units comparable to the specified back EMF constant.

The torque produced by the rotor is directly proportional to the current in the armature windings. The proportionality constant is the torque constant of the motor.

$$M_o = I \times \omega \times k_m$$

Where:
M_o = Torque developed at rotor
k_m = motor torque constant

Substituting this relationship we get:

$$V = \left[\frac{M \cdot R}{k_m} + \left(\omega \cdot k_e\right)\right]$$

The torque developed at the rotor is equal to the friction torque of the motor plus the resisting torque due to the external mechanical loading:

$$M_o = M_l + M_f$$

Where:
M_l = load torque
M_f = motor friction torque

Assuming that a constant voltage is applied to the motor terminals, the motor velocity will be directly proportional to the sum of the friction torque and the load torque. The constant of proportionality is the slope of the torque-speed curve and can be calculated by:

$$\frac{\Delta n}{\Delta M} = \frac{\Delta n_0}{\Delta M_H}$$

Where:
M_H = Stall Torque
N_o = no-load speed

An alternative approach to obtaining this value is to solve for velocity, n:

$$n = \frac{V_o}{k_e} - \frac{M}{(k_m \cdot k_e)}$$

Differentiation of both sides with respect to M yields:

$$\frac{\Delta n}{\Delta M} = \frac{-R}{(k_m \cdot k_e)}$$

When using dimensional analysis to check units, the result obtained shows us that a negative value describes loss of velocity as a function of increased torsional load.

To reiterate the necessary capabilities of the motor in an ideal situation (frictionless and perfect tolerances between shafts and bearings) it shows that:

Ideal (frictionless) calculations

$T := 3 lbf \cdot in$ $\quad \omega = 723.7 \frac{rev}{min}$ $\quad \omega = 75.786 \frac{rad}{s}$

$Power := T \cdot \omega$

$Power = 25.688 \, watt$ $\quad Power = 0.034 \, hp$

Assume a safety factor of 3

$\omega_{sf} := 723.7 \cdot \frac{rev}{min}$

$Power_{sf} := T \cdot \omega_{sf} \cdot 3$ $\quad Power_{sf} = 77.064 \, watt$ $\quad Power_{sf} = 0.103 \, hp$

We know that this is not the case however. As soon as the ball enters the accelerator it creates a bending moment on the shaft which in turn creates a radial load on the bearings. There are 4 of these bearings in the assembly of the accelerator. Using Petroff's equation [Juvenall, Marshek] we are able to find a simple estimate for coefficient of friction of lightly loaded bearings. This in turn allows us to see the power dissipated by the bearing. Friction of the nylon gears will be neglected here, because the majority of power loss due to friction will be at the bearings, not the gears. This will better enable us to accurately gauge the motor requirements. Certain assumptions were made using part specs and common ratio values.

Assumes bearing viscosity of 50 mPa, R/c value of 750, rotational speed of 1000rpm, Acting force of 5lbs

$D := .5\text{in} \quad R := \frac{D}{2} \qquad c := \frac{R}{750} \qquad \mu := .050 \cdot \text{Pa} \cdot \text{s} \quad P := \frac{5\text{lbf}}{.75\text{in} \cdot .25\text{in}} \qquad P = 1.839 \times 10^{5}\,\text{Pa}$

$\text{rev} := 360\text{deg} \quad n := 1000\,\frac{\text{rev}}{\text{min}} \qquad n = 16.667\,\frac{\text{rev}}{\text{s}} \qquad W := 5\text{lbf} \qquad W = 22.241\,\text{N}$

$$f := 2\pi^2 \cdot \left(\frac{\mu \cdot 16.67\,\frac{\text{rev}}{\text{s}}}{P} \right) \cdot \left(\frac{R}{c} \right) \qquad f = 0.422$$

$T_f := f \cdot W \cdot R \qquad T_f = 0.06\,\text{J}$

Power dissipated equals

$\text{Power} := 2\pi \cdot T_f \cdot n \qquad \text{Power} = 39.186\,\text{W}$

Taking into account that there will be frictional losses at the bearings, gears, and of course when the ball shoots into the tube, we have selected a motor based on these calculations. Because these calculations are based on ideal situations where friction is not accounted for, we have added a large factor of safety in our selection of motors.

Our results proved that we were very close to our predictions. As the ball enters the accelerator, the motor does exactly what we hoped it would do which is grab, squeeze, and push the ball through to the tubing on the other side. The ball loses the majority of its energy in the first inch of the tube as it rattles around; however, there is enough kinetic energy to allow it to continue along its path. The ball carries on through the loop and back down to the beginning of the elevator. In initial trials we were losing a lot of energy as the ball made its way along the vertical portion of the loop. As it turns out, the tubing was clamped too tightly and had deformed to change the inner diameter of the tube. This made it impossible for the ball to traverse the loop. Our initial design criteria were met. The ball now successfully travels the entire loop and most importantly, the results are repeatable. However, in hind sight, I would try to take more time in evaluating what is wrong with the system when it fails. By taking more time, and truly considering all possible failure points, we could have saved ourselves the aggravation of disassembling the motor many times to finally realize that it was a simple problem that was plaguing the system. However, it is these types of conclusions that can only be learned through mistakes – and it is what makes them so long lasting.

Future Sustainability of the Robotics Academy

In its second year of existence, the Robotics Academy has proven to provide a unique educational experience to all of its members. The goals which the Robotics Academy set out to achieve have been satisfied. Maintaining these conditions and assuring the self-sustainability of the Robotics Academy is now the main concern. What is needed for the Robotics Academy to be self sustaining? How can we improve upon the experiences of this year? How can we attract new and younger members to the Robotics Academy? I will attempt to answer these questions in the following discussion.

On such a highly involved machining project such as this, it was essential to have two mechanical engineers involved in the fabrication process. Our work was selectively isolated from the rest of the group due to the fact that our side of the project, similar to the electrical engineers, was so defined and specific. Without another mechanical engineer to divide the tasks, this project could not have been machined in time.

Despite being especially isolated from the rest of the group while machining, design work was always done as an entire group. This was decided upon early to maximize the diversity of ideas, rule out the electrically implausible, and to preclude the un-machinable. In this manner, we were able to work very effectively as a group. We self managed and improved our communication skills allowing for members of all disciplines to be fully informed. This manner of operation mainly served as a way to stay on top of one another's progress. In such a sequential project, where concurrent engineering is essential, constant checks of other member's work is essential to promote progression.

The main obstacle that had to be overcome by the group members was the knowledge gap. Even amongst engineers, who have had introductory coursework in these fields, the knowledge gap seemed to grow every time that we would meet to discuss progress and setbacks. In order for the Robotics Academy to be successful at Tufts, we must find a way to limit the knowledge gap between group members. Possible solutions for this could include:

Formalized weekly reports from each discipline pertaining to the choices, problems and solutions that were dealt with in the past week. In those reports would be a breakdown, or simplified description of what each problem means. For instance, "The proposed motor may not have the necessary torque to push the ball through the loop" could be broken down to elaborate on what torque and power mean to a motor and why that is so essential.

A week of seminars early in the semester or even given at the end of the summer could better prepare students of different majors to what they will have to be dealing with in the upcoming months. Students from each major could give a presentation of what they feel they will be contributing to the project. They will also address the underlying concepts behind their work. This will drill into students' minds the concept of a *system* and not just individual components.

The most important element to the future success of the Robotics Academy is addressing the need for a lab that provides students with machining capabilities and a place to do circuitry and motor controller work. The main issue that continually plagued this year's Robotics Academy project was the fact that the project had to be housed in Bray Lab's machine shop. The hours of the machine shop are 8am-4pm. With a typical 5 credit course load plus downtime for the shop when classes are in there, the window of time to work on the project was nearly impossible to work around. With most of our free time coming in the evenings, the only manner in which the two disciplines of engineering could work together was to work off of paper and computer models. There were very few occasions in which all of us could interact with each other and the sculpture. This created confusion, design flaws, and team apprehension. What is needed to remedy this situation for future generations of Robotics Academy students is a lab which is capable of accommodating a wide assortment of project needs: both machining and electrical. The basic to moderate jobs should be able to be carried out in this lab, while the more complex jobs could be outsourced to the machine shop located in Bray and assembled on location. The lab must be accessible to students when it is convenient for them. This time is presumably in the evenings to late in the night.

Need for Fun Relevant Projects

To make the Robotics Academy more desirable to students they must feel like they are working on something important. This requires that more ideas, more problems, more industry contacts be pulled in to create a sense of importance and relevance.

This year we were unable to retain two group members because they did not feel that the problem at hand was substantial. No real applications for the end product would be revolutionary. The loss of these students was a major disappointment to the other students working on the project. Moreover, it threatened the sustainability of the Robotics Academy as a whole. Despite the fact that students are being exposed to an inter-disciplinary project, if their hearts aren't in the task, then it will become extremely hard to recruit other students to join on.

Discussion:

In its second year of existence, the Robotics Academy showed that it has the potential to grow and become one of the most popular and demanded studies at Tufts. However, it also showed that there are many areas that can be focused on for future improvements.

Interdisciplinary projects motivate students to learn by allowing and encouraging them to be more involved in their learning through the selection of topics. These projects also:

- Provide opportunities for students to use their imagination and ingenuity.

- Reinforce learning in all subjects; learning that used to be taught in isolation now fits together and makes more sense.
- Use student time more efficiently by supplementing learning in other disciplines as well as the technology labs.
- Promote the use of the better communication and idea expression.

The incorporation of every discipline in all matters concerning design and planning is essential. Just as the engineers are expected to participate in the classroom teaching, so should the other majors be expected to participate in the planning and design work. Often times it is the mind that is not trained to think like an engineer that develops the best solution to the engineering problem. As we, engineers, have been trained to consider elaborate theories and circumstantial flaws, it is often times the untrained mind that delivers the most pragmatic solution. Though the other majors may feel lost in some of the technical jargon being spat about, they are an essential part of the development team and must be encouraged to become more involved in the building and designing process.

As encouragement of entire group involvement is essential, there must also exist resources to bridge the knowledge gap between disciplines. If electrical engineers and mechanical engineers are having trouble understanding one another, then it can only be assumed that the child development and human factors engineer disciplines must be having trouble understanding issues as well. Some sort of base knowledge of all relevant concepts needs to be established early off in the project. This should most likely come in the form of tutorial sessions given by each discipline. This will aid in the communication skills of every participant as well as provide a firm knowledge base for each group member. By having interdisciplinary training given by each group member, an awareness of "what people understand and what they don't understand" will be established. This sensitivity to group member's grasp on concepts will immediately remedy many of the confusions that plagued this year's project.

Pertaining to the overall sustainability of the Robotics Academy, the lack of younger students places the Robotics Academy of serious jeopardy. Younger members are part of the "Robotics Thread" which is set forth by the initial Robotics Academy proposal. [Rogers] Without younger members participating and learning as the project carries along, two major problems are created. One problem is that each year, students will come into the academy and have to learn by making their own mistakes. This is not optimal by any measure. Many of the problems stemming from fabrication, assembly, and team interaction could have been greatly reduced by having prior experience in such areas. This was one of the major drawbacks of this year's group members. Perhaps by offering a credit in independent research where the students could participate and learn the necessary skills, it could spark interest in younger students. This way both parties benefit.

The other main drawback of having only seniors working on the project is that there is hardly any ability to carry on projects after graduation. Even more importantly, however, is the lack of self-sustainability. There can be no incoming leadership roles the following year if there are no members who know what is going on. The lack of younger students severely threatens to choke the marketability of the Robotics Academy.

Younger students would be one of the most useful marketing tools for the Robotics Academy for the reason that they are walking billboards in a sense. Certainly they are getting a unique experience and the students that these younger students take classes with will recognize that and become prospect future members. Without younger students to participate, learn the ropes, create the next generation of the Robotics Academy, then pass their knowledge onto the next generation, the Robotics Academy will be always need to strain in order to survive.

In order to promote student involvement in the Robotics Academy, there must be fun, applicable projects from different sectors of industry. The more fun and more relevant these projects are, the higher the demand will be for the Robotics Academy. If these projects could in some way tie in contacts from industry, it would be more appealing to upper classmen. The chance of securing a job for after graduation by participating in a fun project would be very appealing to every student. So long as the Robotics Academy can provide a reservoir of good project ideas, there will be certain success and sustainability throughout the years.

Perhaps the most crucial element of the long term success of the Robotics Academy is addressing the need for a lab that can provide flexible hours of operation and provide the machining and electrical capabilities that these projects require. The most important issue is that this lab be accessible on the student's schedule. The minimal hours of operation of Bray Lab's Machine Shop threatened the success of this year's project. Obviously not all tasks could be expected to be machined in a new lab, but simple operations such as drilling, milling, cutting, wiring, and welding should be able to be performed in such a lab until the hour that the building closes. Assuming that this lab would be in Anderson or Robinson Hall (there already exists a room in the basement of Anderson with many of these machines) the closing time would be midnight – when the building closes. Access to such a lab would enable students to work on their schedules, not have to skip class to get parts machined, and it would also secure a future for the Robotics Academy by having their own machining and prototyping lab.

With future modifications to the way in which groups interact, where they interact, and a certain base level of knowledge by every group member, the Robotics Academy will most certainly prove to be one of the most valuable learning experiences on the Tufts Campus. It is presumed that by providing such a well balanced educational experience to students that the Robotics Academy will grow in numbers to the point where it can be self sustaining.

Conclusions:

The Robotics Academy has been successful in its mission to bring together students of different areas of study to work on a robotics project. The project enhanced communication skills, reinforced learning in all subjects, and provided an otherwise absent opportunity to network with professors and industry professionals.

To ensure future success and overall sustainability of the Academy, future modifications should be made in the way which the Academy as a whole, as well as individual groups, carry out their tasks.

- Every member from every discipline must be involved in the planning, design, and execution of the project
- There must exist resources to bridge the knowledge gap between participants – a basic knowledge of every group member's subject matter will increase lines of communication and overall knowledge transfer.
- The Academy must be marketed towards underclassmen. By offering underclassmen the opportunity to be involved with the project for credit, there will be more interest in the Robotics Academy.
- There is an overwhelming need for fun and relevant projects. Projects should tie in industry contacts and possible sponsorship to both raise funding, as well as provide students with industry contacts after graduation.
- There is a strong need for an independent lab assigned to the Robotics Academy. Academy members could perform most machining and electrical work in this lab and it would be open late in the evenings – when students are most likely to do their projects.

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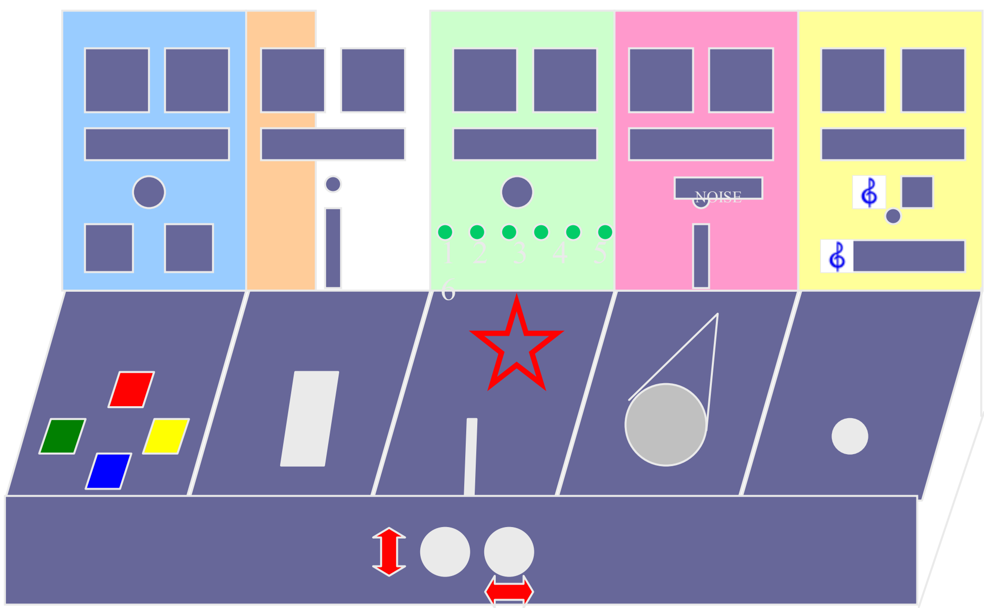
Appendix I

Inputs

To control each of these five stops, a system of challenging inputs was required. The design criteria for these inputs are that they be challenging for children ages 10-12, and that they be self explanatory.

All of the inputs will be located together on an input module. The module will have lights to notify the user when to use each input, as well as task completion lights to let the user know of their overall progress in the sculpture.



An artistic representation of the input module. From left to right, we have: SIMON, the Dynamic Grip, the Laser Maze, the Noise Input, and the Musical Distance Input.

Appendix II – SIMON

To raise the ball from the bottom to the top of the sculpture in the elevator, the user must correctly complete the first input challenge. This input is much like the child game SIMON. The user uses buttons, which correspond to colored lights, to recreate a pattern that is presented to them. By successfully repeating the given pattern three times, the ball will be lifted in the elevator to the top of the sculpture where it will fall onto the track and carry on to the next stop.

Appendix III – Dynamic Grip

The ball will hit a physical gate at its next stop. In order to raise this gate, a dynamic grip will be mounted on the input module. To complete this task, the user must squeeze the grip and as the grip is squeezed, the gate will rise proportionally. This will be done using a potentiometer so that as the grip closes, the gate will slowly rise and there will be immediate feedback to the user. This will be an interesting input to design and fabricate because of the close interdependencies of mechanical and electrical engineering that must occur in order to produce a functional input.

Appendix IV – Laser Maze

After passing through the gate, the ball will continue along the track, entering the turnstile. To move the turnstile, the user must complete a laser maze. The laser is mounted on the input module and allowed to pivot around two points to restrict its motion to one plane. The user must shine the laser on a sequence of sensors arranged in a pattern. One idea is to have a star, and the sensors would be mounted at the vertexes of the star. Then, the user would have to hit each sensor in a particular order which is hinted to them by instructions on the input module. By completing this task correctly, the turnstile will rotate and the ball will exit back onto the track.

Appendix V – Noise

As the ball enters the funnel, it will be faced with a stop. In order to pass through, the user will have to reach a certain decibel level by any means. This is one of the more fun inputs that were incorporated in the sculpture; it lets the children yell and scream without getting in trouble. There will be a noise meter on the input module and a goal noise level to achieve. The user must use the microphone to surpass the predetermined noise threshold in order to successfully complete this input task.

Appendix VI – Distance

The last input required will activate the accelerator. At this input, the user will be faced with a number of notes that they must successfully 'play'. In order to play a note, the user must find the note in a lookup table on the input module, find the associated distance, and then place their hand over the sensor at the correct distance in the input module. If the user has their hand at the correct distance, the correct note will play. The user then repeats this pattern until all of the assigned notes have been played and the task has been completed.

Appendix VII – Elevator Components

Number of Components	Description
2	End Plate (6061-T6 Aluminum)
2	Shaft Side (Clear Acrylic)
1	Shaft Back (Clear Acrylic)

1	Elevator Car (6061-T6 Aluminum)
1	Ball Stop (Colored Acrylic)
1	Lead Screw (303SS)
1	Nut to follow Lead Screw (polyacetate)
2	Radial Ball Bearings (.750"OD, .250"ID, .250" thick)
1 1	Axle Coupling 1/8" – 1/4" DC Motor

Appendix VIII – Bottom Plate of Elevator

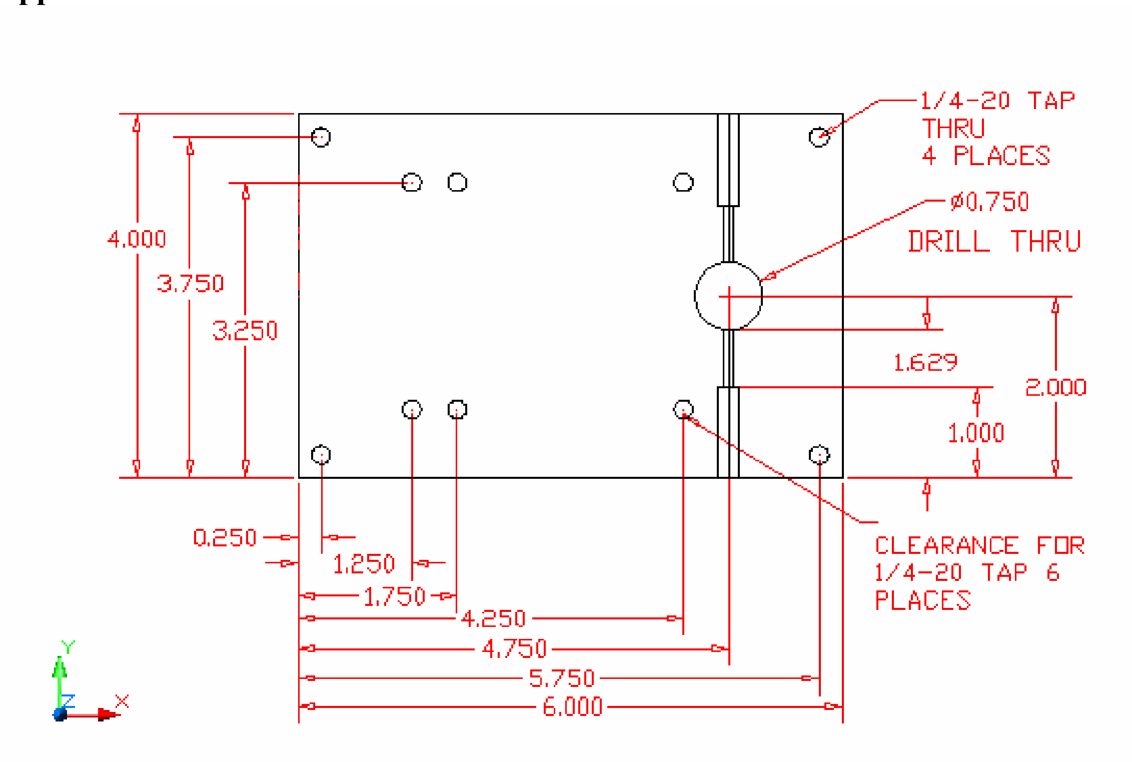


Figure 2 – Machining drawing for the top and bottom plates of the elevator.

Appendix IX – Acrylic Fin

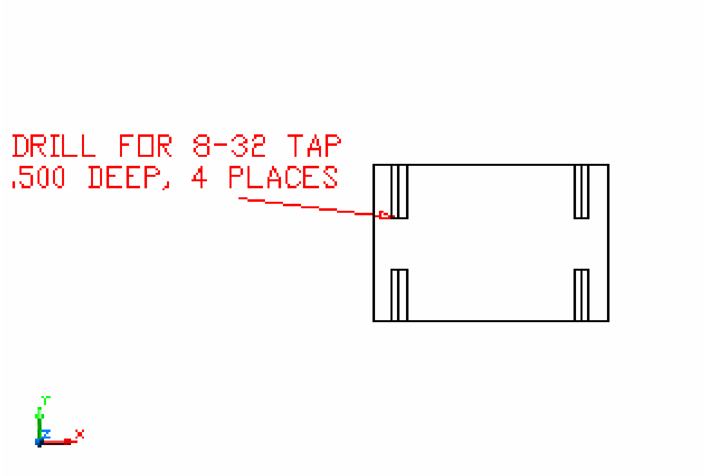


Figure 3 – Sketch of one of eight fins for the turnstile.