

Design of a Dental Mirror Mechanism

A Major Qualifying Project Report
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Authorship Page

The entirety of this report was written and reviewed as a joint effort by both team members. Although one team member initially wrote a section, that section was later reviewed and contributed to by the other team member. The report is considered by each team member as an equal authorship.

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Abstract

The goal of this MQP was to design and create a prototype of a device which will effectively clean the surface of the dental mirror and restore its reflective qualities. In creating such a design, the team aimed to reduce fatigue of the user's hand while streamlining any dental procedure which involves the dental mirror. This project has progressed through the engineering design process to a final design selection and working prototype of the team's design solution. Through background research and consultation with dental professionals, the team created an initial list of design concepts, out of which a wiper-based mechanism was selected. This initial wiper mechanism design concept evolved through the use of several modes of testing and analysis, until a final design was reached. The selected final design is a variation of a slider-crank which utilizes the material properties of its components to achieve the desired stroke and force to clean the mirror through deflection of one of the links. The team has constructed a working prototype that is a proof of concept: recommendations for furthering the design and implementing its production are given at the end of this report.

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Introduction

Mirrors have been used to assist in viewing inside a patient's mouth by dentists and professionals working in the oral health field for many years. The specific mirror used by such professionals, called the dental mirror, consists of a small, cylindrical, metal shaft with a metal disk attached at the end of it which holds the mirror. Typically, such mirrors are biologically inert, environmentally stable and durable, and are capable of being autoclaved and/or sterilized.

There are problems with the design of such mirrors. The small, hand-held mirrors used by dentists present considerable difficulty in that the reflective surface becomes fogged due to moisture and heat in the patient's mouth, or that the surface of the mirror becomes non-reflective due to debris from drilling operations and other dental procedures. The current method for cleaning the mirror is by use of the non-mirror holding hand or the hands of an assistant, with cloth to remove fog and debris. This current method was declared a problem by the project's liaison, Lisa Anderson, a dental assistant from the Worcester area. Ms. Anderson believes the current method is costly in terms of time and effort, and believes that there is potential for improvement through the invention of a device which would clean the mirror to achieve an operable reflection. The design team listened to Ms. Anderson's proposal for the project, and accepted it to be a challenge to streamline procedures in the dentist's office for the benefit of both the dental professional and the patient.

The main objective of this MQP is to design and create a prototype of a device which will effectively clean the surface of the dental mirror and restore its reflective qualities without requiring the removal of the mirror from the patient's mouth for either cleaning or replacement. In addition, to increase ergonomics and user-friendliness, such a device should be able to be operated by the dentist in the same hand as is used to hold the mirror during dental procedures.

This project had an emphasis on the engineering design process. The first step in the design of a mirror-cleaning device involved research of pre-existing solutions. In addition, research of medical instrumentation was conducted to understand what factors must be considered in designing such tools. This project also included extensive testing of human forces, namely forces applied by the human hand, and the ability of different materials to remove fog and debris from the mirror's surface. From this testing, preliminary designs have been developed in kinematic, dynamic, and stress analyses. Based on these analyses, a final design was selected, prototyped, tested, and reiterated.

Background

Demonstrated Need for Design

There is a clear demand for the improvement of the current use of the dental mirror. The mirror must be cleaned repeatedly throughout the duration of any given dental procedure. This cleaning operation is currently performed by removing the mirror from the patient's mouth, taking a cloth material, wiping the mirror clean, and then re-situating the mirror in the working area within the patient's mouth. Some dental procedures can take place over extended periods of time, on the order of hours. The project sponsor, Ms. Anderson, explained that some procedures will last up to three hours. Understandably, the number of instances of cleaning the mirror adds up to a considerable portion of the procedure. Herein lies the need to develop a device which would clean the dental mirror. The first valuable step in design of such a device is an examination through patent research of what solutions have been previously considered.

Patent Research: Previous Solutions

There is a variety of pre-existing solutions to the problem of designing a dental mirror cleaning device. One such device, which has several patented variations, is one that utilizes the fluid dynamic properties of water and air to remove the debris from the surface of the dental mirror. Refer to Patent numbers 3969824 and 10/677195, both titled *Self Cleaning Dental Mirror*, which both function in generally the same way, with different geometric configurations.

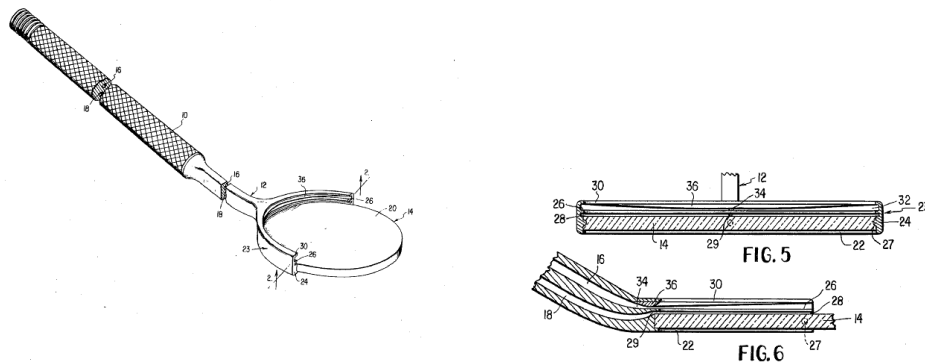


Figure 1: Self Cleaning Dental Mirror from patent 3969824

Each patented design requires an air and water line connected to the mirror hand-piece. Water and air continuously flows over the mirror surface, removing the opportunity for debris to accumulate.

Another completely different design concept is that of the rotating mirror head. This design has taken form in several variations. One such variation incorporates a simple turbine underneath the mirror surface, which has a rotating shaft attached to the mirror. The neck of the dental mirror is widened and hollowed out, allowing the passage of air across the aforementioned turbine's blades, causing the mirror to rotate. An illustration of the design was provided in its patent, patent number 6,247,924, titled *Self-Cleaning Rotating Dentist's Mirror*.

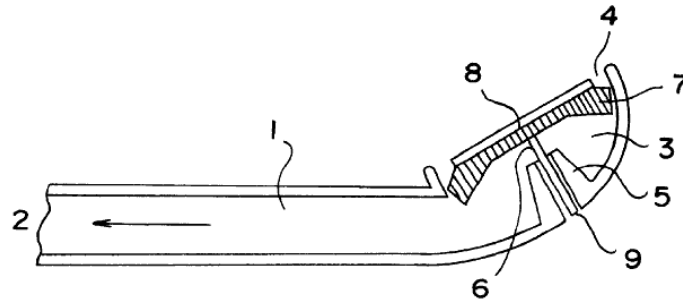


Figure 2: Self-Cleaning Rotating Dentist's Mirror from patent 6,247,924

Another design incorporating the rotation of the mirror piece of the dental mirror is that of patent 4,408,991, titled *Self Cleaning Mirror*, which incorporates vanes through the surface mirror, which extend laterally with respect to a shaft mounted perpendicular to the mirror surface. Fluid enters through the neck of the mirror hand-piece, flows circumferentially around the center shaft, and accelerates the mirror rotationally. Figure 3 below is an illustration from the design's respective patent.

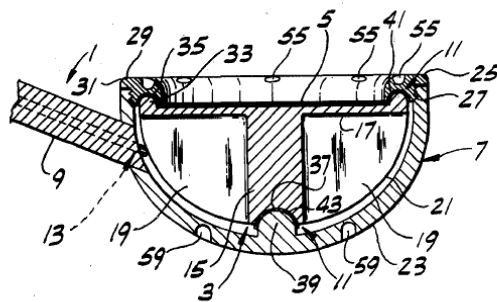


Figure 3: Self Cleaning Mirror from patent 4,408,991

A key aspect of this design, which reduces its feasibility considerably, is the fact that it requires an external line for water. Also, while the design configuration of Figure 1 is relatively uncomplicated compared to the second, neither is particularly simple. They are both highly elaborate in terms of the

size of new parts and the alteration of the current mirror geometry. This can be considered as negatives to the design of an effective new device.

Another design concept that has been considered before is one of a wiper mechanism. Not similar to the intuitive wiper mechanism one may initially have in mind, a patented wiper mechanism design involves the mirror surface itself rotating while keeping the wiper itself stationary. The patented design titled *Portable Self-Cleaning Mirror Apparatus and Method*, number 5,654,824, is the design in reference.

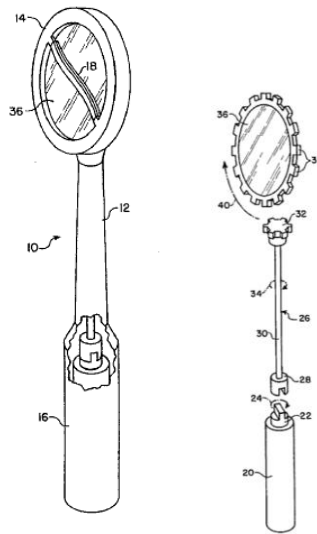


Figure 4: Portable Self-Cleaning Mirror Apparatus and Method from patent 5,654,824

As can be seen in this design, a gear assembly within the shaft of the mirror will cause the mirror to rotate. The wiper blade rests across the surface of the mirror, which obstructs the vision of the operator. Not only is this a design flaw, but the significant alteration of the current mirror geometry and the size of new parts are both hampering design considerations. Another design that has been considered previously involves the dispersal of a mirror surfactant, to reduce the bonding abilities on the surface on the mirror. This patented design, titled *Anti-Misting Attachment for Dental Mirrors*, patent no. 3,755,903, incorporates an 'exposed' carrier which holds the surfactant fluid. This carrier is external and is proposed to be detachable. The concept of its operation is as follows. When exposed to ambient water spray, the surfactant supposedly will leach out of the carrier, in small quantities, tasteless to the patient, but effective to break down surface tension of water drops (Spinello, 1973). Refer to the image below, a schematic provided by the patent author.

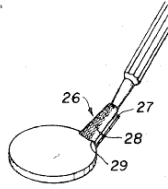


Figure 5: Anti-Misting Attachment for Dental Mirrors from patent 3,755,903

One could be skeptical of what would be used as a surfactant, given continuous dispersal into the mouth of the patient.

This section is a summary of the design team's patent research. The previously considered designs are feasible, but lacking in one aspect or another. In the next section, the design team begins its explanation of design approach.

Project Objectives

The goal of this MQP is to design and create a prototype of a device which will effectively clean the surface of the dental mirror and restore its reflective qualities without requiring the removal of the mirror from the patient's mouth for either cleaning or replacement. In addition, to increase ergonomics and user-friendliness, such a device should be able to be operated by the dentist in the same hand with which the mirror is used during dental procedures.

Prior to the process of creating design concepts, a list of factors to consider for this device was created to narrow the focus. The first of these factors is the size of the device. The device must be small enough that the mirror's intended use is not affected. Not only is the mirror used as a reflective surface, but it also allows dental professionals to retract tongues and tissues comfortably to allow for better access during exams. Effectively using the mirror allows a clear view of the working site without impinging on the nearby tissues or pinching the lip, which is painful for the patient. The size of the device must take both uses of the mirror into account.

Weight is another factor to consider. Currently the mirror is extremely lightweight and causes minimal fatigue during use. The addition of a significant amount of weight to the mirror as it is currently designed will increase fatigue on the dentist's hand. Another important factor to consider is the user-friendliness of the device. The design must not be cumbersome to use, and it should be easy for the dentist to understand how it operates. Adding air or water lines to the device are not ideal, but will be considered. Additionally, the ergonomics of the device must provide for comfort while using. One of the problems trying to be eliminated through the creation of this device is the reduction of fatigue on the hand, so the final device should allow for only minimal fatigue during both short-term and long-term use.

After being used in a dental procedure, the mirror is autoclaved, a process where pressurized steam is used to destroy any microorganisms which have built up on the surface. Any device added to the mirror must be made out of materials so that it can be autoclaved with the rest of the mirror, be removed and sterilized in some other way, or simply be disposable. This is another factor which must be taken into account when choosing the material the device will be made out of. Materials for removing debris and fog must carefully be reviewed, as they must both remove debris and fog effectively. Whatever is chosen must have a melting point higher than that of the temperature a material is autoclaved at, or be cheap enough that disposal will not be costly. Furthermore, the selected material

must not have any toxic properties, so as to be safe to both the patient and the dentist. Lastly, the device must be designed so that it is easy to manufacture and so costs of manufacturing are kept minimal. All of the above factors play a role in affecting the cost of the device, which must be kept as low as possible.

After taking all of the mentioned factors into account, a list of performance specifications that our device must meet was created.

Performance Specifications

- Device must remove all traces of debris from the dental mirror.
- Device must be able to be operated by only the mirror holding hand.
- Total cost of manufacturing must be no more than 25 dollars.
- Device must be made out of a non-hazardous material.
- Device must contain no sharp edges.
- Device must contain no pinch points.
- The size and orientation of device must not obstruct the oral cavity, or the dentist's worksite.
- Total weight of device must not exceed an extra 20% of the original mirror weight.
- Device must have weight evenly distributed throughout.
- Device must be either autoclavable or disposable.
- Device must use a minimal number of components.
- Position of device must not obstruct the mirror's image.

Initial Design Concepts

After obtaining a sufficient understanding of what designs have been considered and patented for dental mirror cleaning mechanisms, the design team brainstormed design concepts that could be used. Below is a brief description of the designs that the team had initially considered.

Design Concept 1: Water and Air Flow

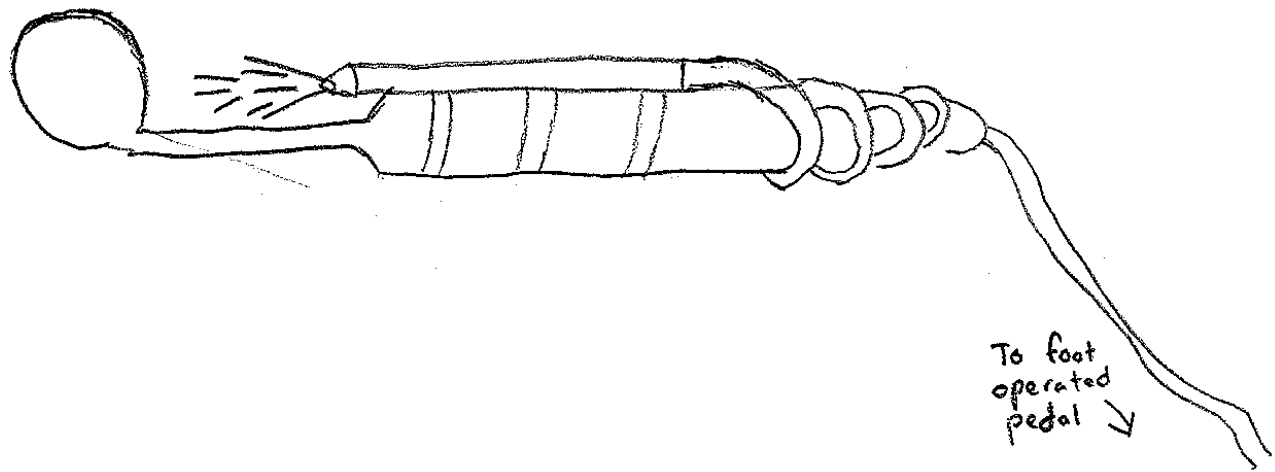


Figure 6: Water and Air Flow Design Concept

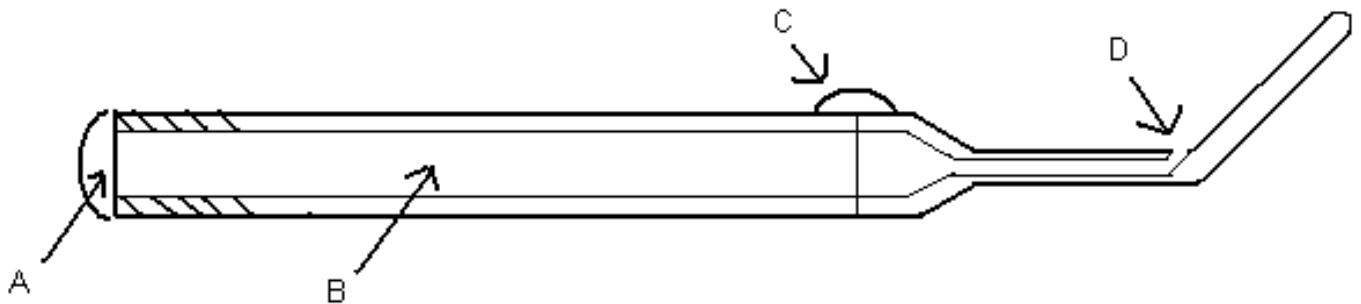
A water and air design cleans the mirror with the use of air and water flowing from a dispenser that can be clipped onto the handle of the mirror. This dispenser would utilize a second water and air line in addition to the hand piece water and air line used by the hygienist during dental procedures. The dispenser would be activated by foot pedals to keep the hands of the user free to accomplish other tasks. The head of the dispenser would be detachable and cleaned via the same procedure as a suction head, using a solution bath. Refer to figure 6 above for a schematic. This design would involve design of the dispenser geometry of the snap-on components, the fluid flow component, and the pedal activation assembly.

Design Concept 2: Disposable Thin Film

The thin film design works as follows. A stack of thin, transparent disposable films are positioned and secured over the mirror and remain there during use. Once the top layer is soiled, a hand activated linkage would then peel and remove the soiled layer, exposing a new clean surface. Design of this concept would include a design of the linkage, and a desired layering technique of the thin films. Also, design of the film stack support and securing device is required.

Design Concept 3: Surfactant Dispenser

The surfactant dispenser design works by a push-button release of surfactant solution over the mirror surface. This design is not intended for use during a procedure, but rather at the start of the procedure to ensure better image clarity for the user. Design of this concept would include the design of a reservoir within the mirror handle, and a push-button activated outlet for surfactant. Refer to figure 7 below for a schematic of the surfactant dispenser design.



- A - Reservoir Cap
- B- Surfactant Reservoir
- C- Pushbutton Activator
- D- Outlet for Surfactant

Figure 7: Surfactant Dispenser Design Concept

Design Concept 4: Pneumatic Spinning Mirror Head

In this design, the reflective surface rotates around the axis of the mirror handle at a velocity great enough to remove debris from the reflective surface. The mirror head would be held under a debris capturing reservoir during cleaning. The spinning mechanism will be pneumatically powered and operated by foot. For cleanup, the mirror will detach from the handle and the handle will detach from the air line. This design would have all autoclavable parts. Design of this mechanism would include a complete redesign of the current mirror. The new design's handle would need to house all of the gearing required for the spinning operation. This requires design of a new handle, and the gearing itself. Furthermore, the investigation into the air pressure necessary to operate the pneumatic mechanism at the desired operating speeds would be required.

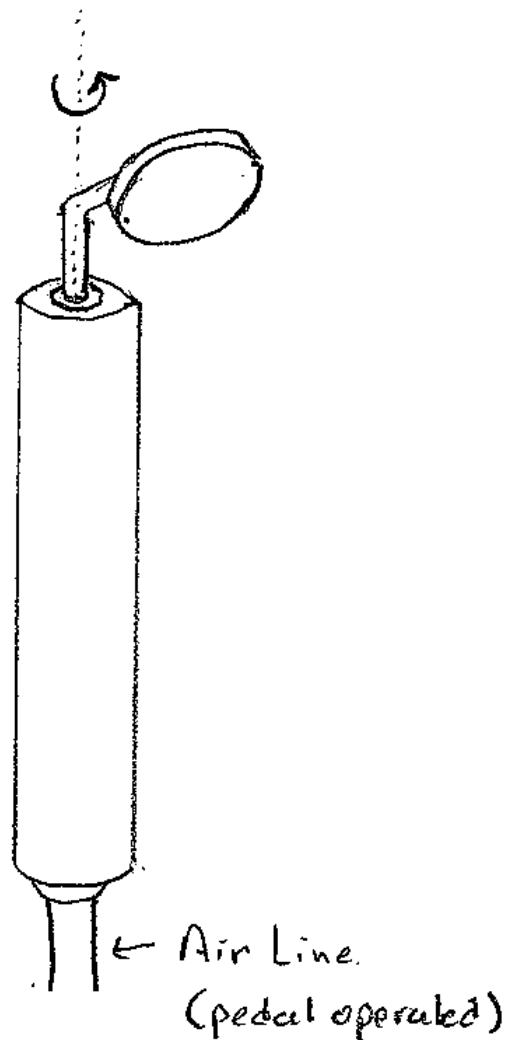


Figure 8: Pneumatic Spinning Mirror Head Design Concept

Design Concept 5: Wiper Mechanism

The wiper mechanism design would incorporate a hand or motor activated wiper that passes over the mirror's surface. This design would take form of an attachable assembly to the stock of the dental mirror. The wiper assembly has the possibility of being disposable or reusable, depending on the design.

Design Concept Review and Analysis

This section discusses the positive and negative aspects of each design. At the end of this section, a selection is made of the design concept to pursue. Each design was evaluated based on five design factors: cost, safety, ease of use, performance, and reliability. Cost includes the cost to manufacture the design, and the subsequent cost to the customer. Safety measures the design's susceptibility to cause injury to the patient and the user during use. Ease of use rates the design in terms of ergonomics, ease to control and assembly required by the user. Ease of use also includes measures of disposing and reusing the design. Performance simply rates the design in its ability to perform the task. Lastly, reliability ranks the design in its susceptibility to failure. Each of the design concepts and the rating given for each design criteria is shown below in Table 1. On a 1.0 scale, the weight of each factor is as follows: 0.10 for Cost, 0.20 for Safety, 0.225 for Ease of Use, 0.275 for Performance, and 0.20 for Reliability. The reasoning behind each of the ratings is explained in further detail below.

Table 1: Design Table of Initial Design Concepts

Design Factor	Cost (materials manufacturability)	Safety (to the patient and the user)	Ease of Use (ergonomic, easy to control, balanced, size)	Performance (ability to remove debris, reduce fog)	Reliability (does it break?)	Rank (out of a possible 10)
Weight	0.10	0.20	0.225	0.275	0.20	
Design 1: Water and Air Flow Design	2	8	4	10	5	6.45
Design 2: Disposable Thin film	4	5	7	9	5	6.45
Design 3 Surfactant Dispenser	3	4	7	4	7	5.175
Design 4 Pneumatic Spinning Head	1	3	2	7	2	3.475
Design 5: Wiper Mechanism	9	7	9	8	9	8.325

Design Concept 1: The Water and Air Flow Design

The water and air flow design has been proven to be the most effective design to date. The current method for cleaning the dental mirror during its use in a procedure involves using the hand-piece which supplies water and air, and running the two fluids over the surface of the mirror to remove fog and debris. The design would be safe to use, as there would not be any external moving parts that could harm the user or the patient, and the design could be autoclavable. However, this design would be cumbersome to use, as it requires a line for the water and air in an already cramped worksite. This line also adds weight and potential for unbalanced mass of the mirror. This design would also be costly to manufacture. The parts necessary are a water and air line, a water and air outlet, and the activating mechanism at the handle of the mirror.

Design Concept 2: The Disposable Thin Film Design

The disposable thin film concept has the potential to be effective; however, its potential for performance comes at great costs. First, the design comes at a high risk of safety to the patient. There would be a risk of the patient swallowing one of the ejected thin films. Furthermore, the ejector mechanism used to remove the top film layer would most likely be comprised of some sharp edges and could puncture the patient's mouth. Second, the cost to make the design would be relatively high. The cost of materials includes the stack of thin films, and materials. There would be anticipated high costs to manufacture the stack of thin films as this would require precision manufacturing. The ease of use would only be marginal, as user assembly has potential to be difficult, and there would have to be a hazardous waste basket nearby for disposal of the thin film. Furthermore, the design could fail in a variety of ways. The user could run out of thin film supplies or the apparatus could break due to its complexity and could be hard to reinstall on the mirror.

Design Concept 3: The Surfactant Dispenser Design

The surfactant dispenser immediately can be thought to be inferior in that it does not remove debris during a procedure: the design only reduces fog. The appeal of the design is that it wouldn't change the usability of the current mirror. The surfactant reservoir would be inside the mirror handle, thus the mirror could be held and operated as it is now. However, the design would be costly to make, as it requires a remodeling of the current geometry of the dental mirror. The cost of the surfactant is additional to the user. Also, if the design leaks surfactant during a procedure, the safety of the patient is threatened. The design is less prone to break than other designs, as it has less moving parts. The only

point of possible breakage is the surfactant door. One last concern in performance is that the pressure in the surfactant reservoir needs to be great enough to initiate flow.

Design Concept 4: The Pneumatic Spinning Head

The pneumatic spinning head is a concept that is difficult to manufacture, maintain, and is risky to the patient and the user, but offers perceived marketability in its showiness during use. In terms of performance, the design could be expected to remove large debris, but its effectiveness in removing fog is questionable. The pneumatic powered turbine used to rotate the mirror surface would be costly due to size and complexity of parts, and the entire mirror would need to be redesigned to house such a mechanism. Also, the design has the possibility of failing in such a way that the mirror head becomes a high velocity projectile. Moreover, the spinning of the mirror, similar to a drill, will cause vibration of the apparatus, which is undesirable to the dentist who already uses tools that vibrate. This is an ergonomic concern to the user. Furthermore, the design is difficult to use in that it would require an air line to operate, a similar problem to the water and air design. Sterilization of the design would be cumbersome as well. Overall, this design is less favorable than the others considered.

Design Concept 5: The Wiper Mechanism

The wiper mechanism is a design that theoretically will perform the desired task with adequate efficacy, while being easy to manufacture. The design could have several configurations, retrofitted or complete mirror redesign, different linkage types, and the design has potential to be motored or hand-activated. The hand-activated design will most likely be the desired power source, as a motor would involve a more cumbersome design and several more opportunities for failure. The hand-activated design would only involve design of a mechanism to perform the desired function and its cost would only include the cost of the parts, most likely to be made of a plastic. The failure of such a design lies only in the mechanism itself. These are relatively slow moving parts, so should the design fail, the safety of the patient would be less compromised than, for example, the use of the pneumatic spinning head design.

Design Concept Selection

In choosing a design to pursue, the team decided not to change the original geometry of the mirror, given the timeline of this project. Fourteen weeks does not provide sufficient time for appropriate prototyping and testing of a completely new mirror incorporating a cleaning mechanism. Designs requiring complete redesign of the mirror are discussed in the Recommendations section of the report.

Having established that a retrofitted design is one the team can pursue, the design team ceased to consider the pneumatic spinning head design, and the surfactant dispenser design. The evaluation of each of the remaining design concepts led the design team to select the wiper mechanism, for the reasons stated in its analysis section. Primarily, the design would theoretically perform the task adequately while keeping manufacturing costs low.

Wiper-Based Design Concepts

Based on the analysis of preliminary designs, it was decided that a wiper based design would be optimal. Therefore, as our client had requested pursuing a motor-driven design, it was decided that both motor-driven and hand-operated devices should be considered. After brainstorming and considering our design parameters, five possible design concepts were created, two which were motor-driven and three which were hand-operated. It was decided that the optimal use of the design, based off of the way that the mirror is held by the dentist during procedures, would either be a push button device, or one where it could be operated through the sliding of the thumb up the shaft or a sweeping movement of the index finger.

Wiper-based Concept #1: Fourbar and Slider Combination

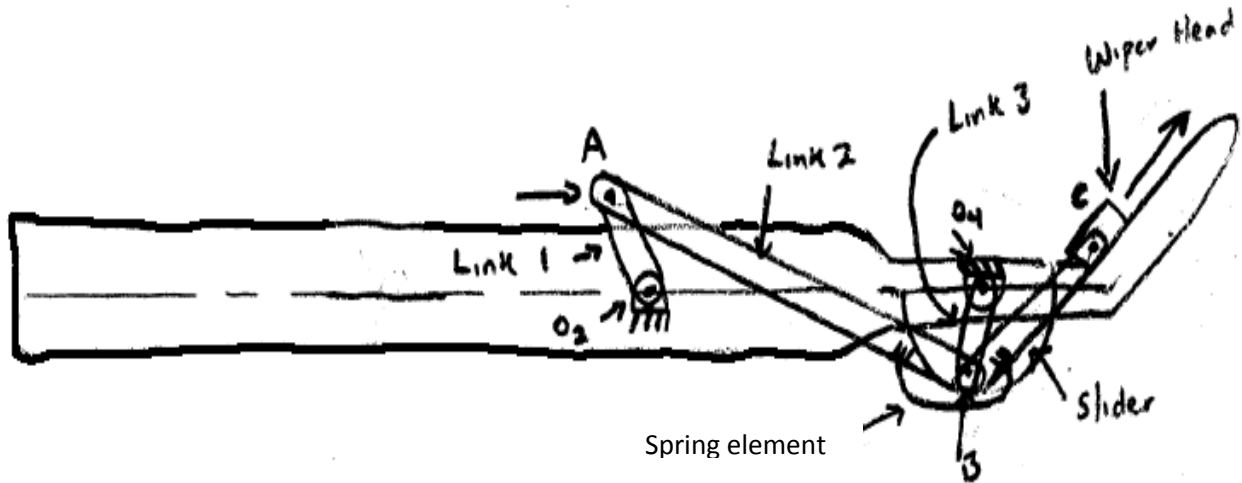


Figure 9: Fourbar and Slider Combination Concept

The first of the wiper-based design concepts created is a combination of a fourbar mechanism with a Grashof slider-crank. To obtain the coupler curve required to clean the mirror's surface, the rocker of the fourbar linkage (link 3 in figure 9), is combined with the crank of the Grashof slider-crank, so that they are effectively the same link in the design. To operate the wiper, the user pushes on point A with their thumb, which results in the slider moving upwards and pushing the wiper head up the surface of the mirror. However, to ensure the surface contact is constant (with a constantly applied force); a spring element must be implemented to apply a force on the slider link.

To attach this device to the mirror, ground points O_2 and O_4 require drilling holes into the shaft of the mirror and inserting pins. The remainder of the links require rotating full pin joints (at locations: A, B, and C). Note that the joint at point B joins links 2, 3, and the slider and is thus a second-order pin joint.

To ensure that the device as designed will be capable of cleaning the mirror, a kinematic analysis was completed using Fourbar and Slider programs, created by Robert L. Norton, a WPI professor, for the purposes of Kinematic Analysis and Synthesis of Fourbar and Slider linkages. Using these programs, all link lengths were found, as well as initial and final positions and evidence that the required coupler curve was possible. Based on the analysis, the starting position of link 1 would be a 10 degree angle relative to the mirror shaft (shown in Figure 10). To achieve a complete stroke up the surface of the mirror, link 1 must make a 160 degree clockwise rotation from that position (shown in Figure 11). To complete the process, the user would then return the link to its starting position by hand.

Figure 10: Starting Position

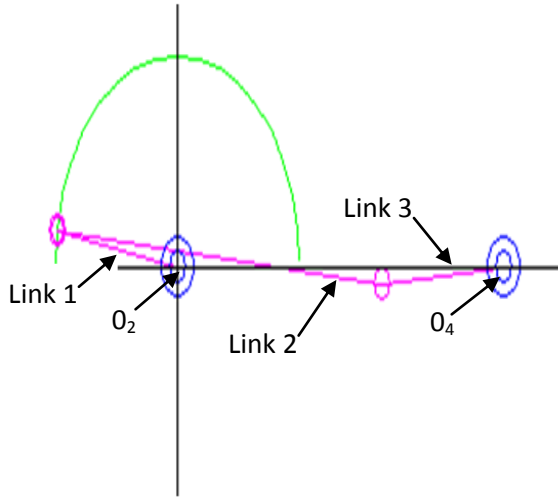
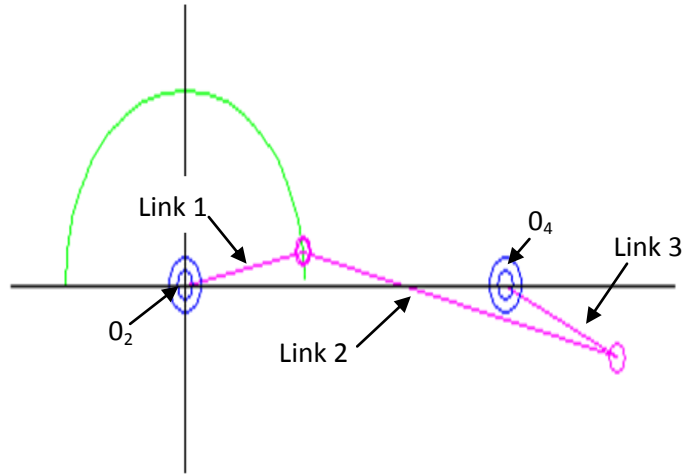


Figure 11: Final Position



To further the analysis, using the Slider program, a graph of the coupler point (in both the x and y directions) versus the crank angle was created and evaluated to ensure that the stroke length will cover the entire surface of the mirror. This graph is shown in Figure 12 below.

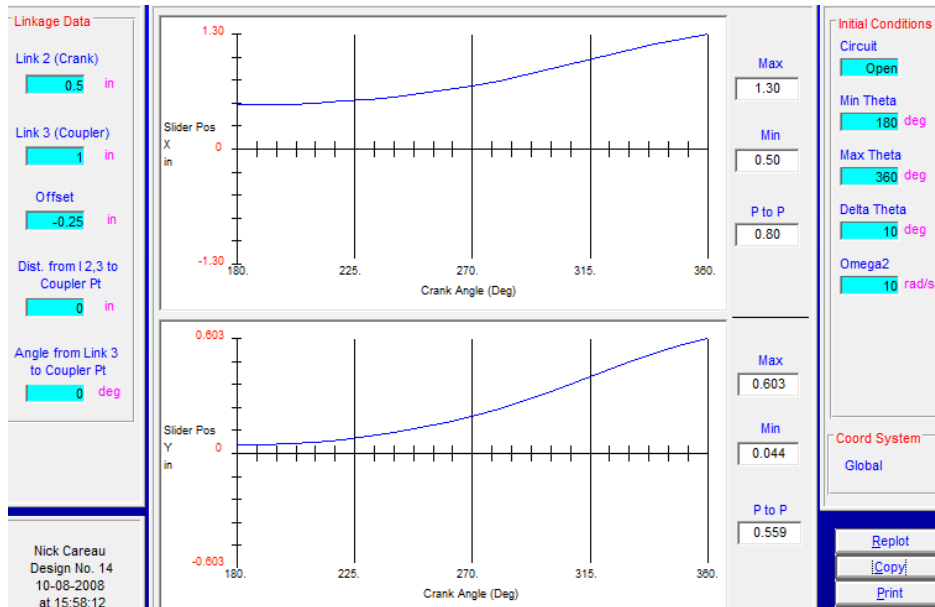


Figure 12: Graph of Crank Angle (in degrees) vs. Slider Position (both x and y coordinates, in inches) created in Slider program

From the graph, the movement of the wiper in the x-direction is found to be 0.80 inches, and 0.559 inches in the y-direction. Using the Pythagorean Theorem, the total distance traveled along the mirror surface is approximately .97 inches, which is extremely close to the 1 inch surface of the dental mirror. In order to accomplish this, link 3 must be half an inch in length and the slider link must be 1 inch in length. In regards to the other links, link 1 must be half an inch and link 2 must be 3 inches. The total distance between points O_2 and O_4 in Figure 9 is 2 inches.

Wiper-based Concept #2: Spring-loaded Wiper

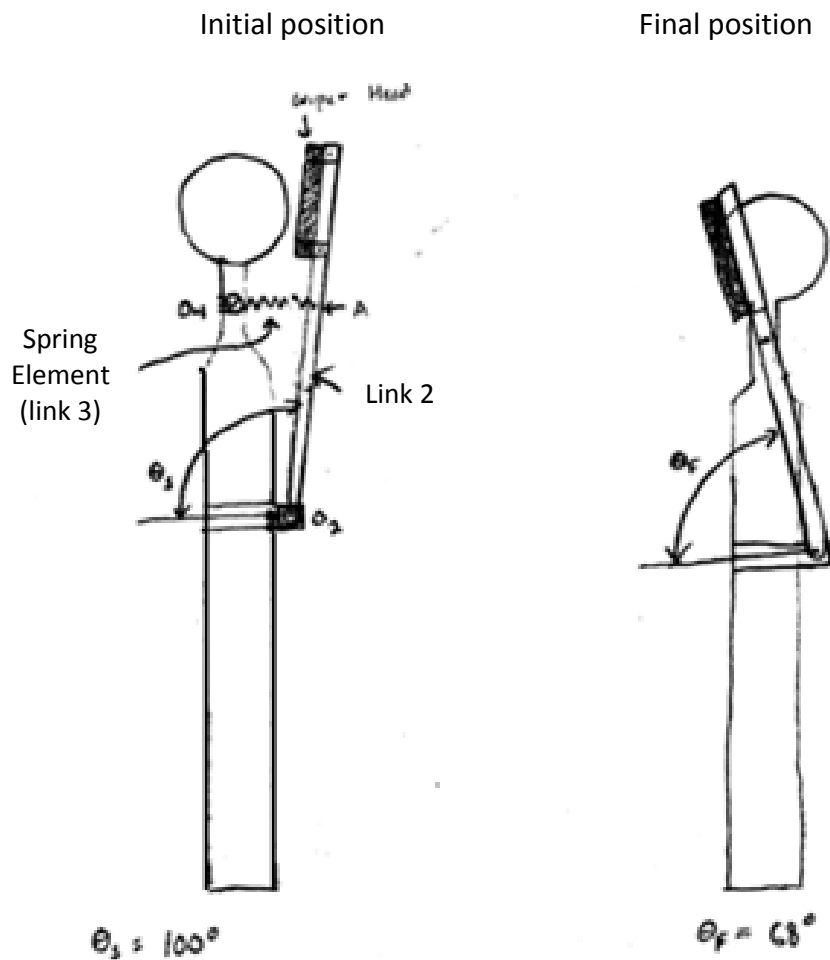


Figure 13: Initial, right, and final, left, Positions of Spring-loaded Wiper Concepts

This concept involves a simple wiper design which includes a spring element to bring the wiper link (link 2) back to its starting position after one pass over the mirror's surface. In order to operate the device, the user simply pushes on link 2 with their index finger and moves the link until the spring is completely compressed and the wiper is at the opposite side of the mirror. The starting position of link 2

is at a 100 degree angle relative to the sleeve on the mirror handle (angle θ_2 as depicted in the initial position in Figure 13). This position leaves only minimal distance between the edge of the mirror and the wiper, so as to not impact the prying function of the mirror during a dental procedure. In the final position this angle is approximately 68 degrees (as depicted in the final position of Figure 13).

In order to achieve the desired size and functionality of this concept, link lengths must be manufactured to be the following sizes. Link 2 must be 3 inches, link 3 must be .875 inches, and the distance between O_2 and O_4 must be 2 inches. It was calculated that the desired spring constant is approximately 0.75 lb-force/inch.

The assembly of this device would be relatively simple to achieve. A snap on plastic piece could be created, with a small protrusion from it, large enough in size so that a hole could be drilled and a pin fit through to connect link 2. In addition, the smaller portion of the mirror shaft would have to connect to the spring, and link 2 would also have to compensate for the connection to the spring. Link 2 would need a hole drilled through it to attach to the spring or the spring would have to connect by another means. The wiper head would have to be attached to link 2.

Wiper-based Concept #3: Deflecting Wiper

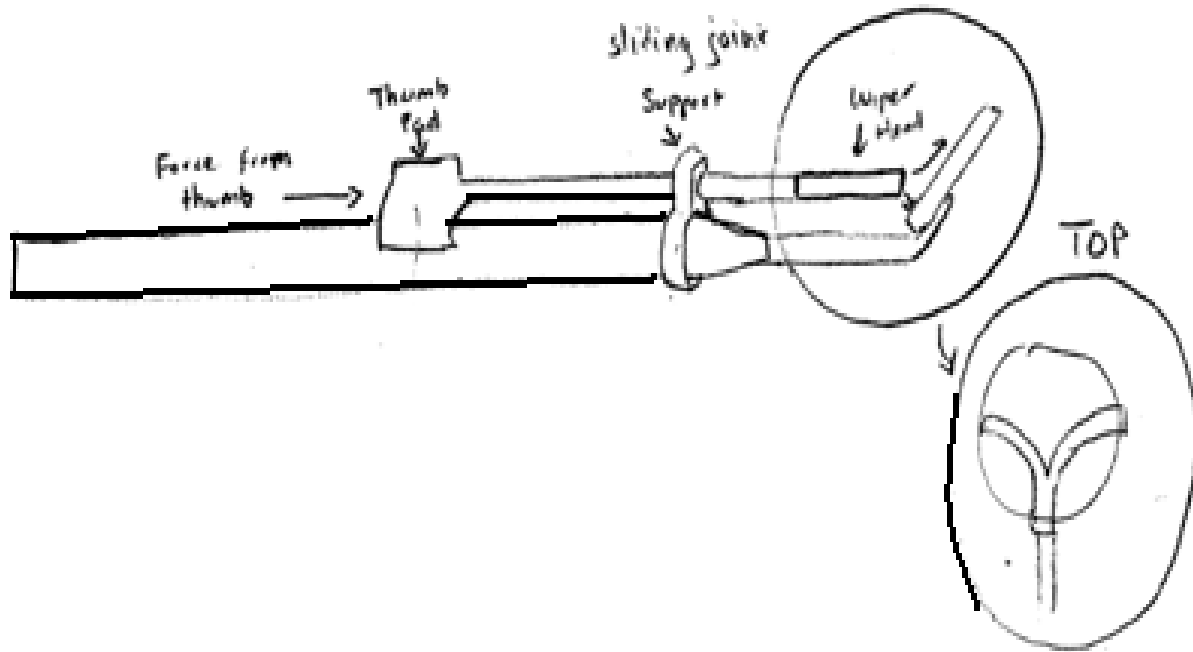


Figure 14: Deflecting Wiper Design Concept

As often is the case in design, previous design concepts can be combined to create a new design which often exceeds the performance. Such is the case with the deflecting wiper design. Originally, the desired coupler curve was achieved through a fourbar slider-crank mechanism. However, it was found that the crank component of the fourbar and slider combination design concept could be removed. This design concept simply utilizes the natural bending of the material upon contact with the mirror surface to achieve the desired movement up the surface of the mirror.

The deflecting wiper design also needs an input force from the user's finger. For this design, the user pushes on the thumb pad (depicted in Figure 14), moving the arm down the shaft and causing the wiper head and arm to deflect along the path of the mirror. Initially, the wiper head design considered would fan open upon contact with the mirror.

The assembly of this device requires the least work of any of these design concepts. All that would be required is the snapping-on of the support piece onto the mirror handle, and the attaching of the wiper head to the end of the arm.

Wiper-based Concept #4: Motor-driven Slider

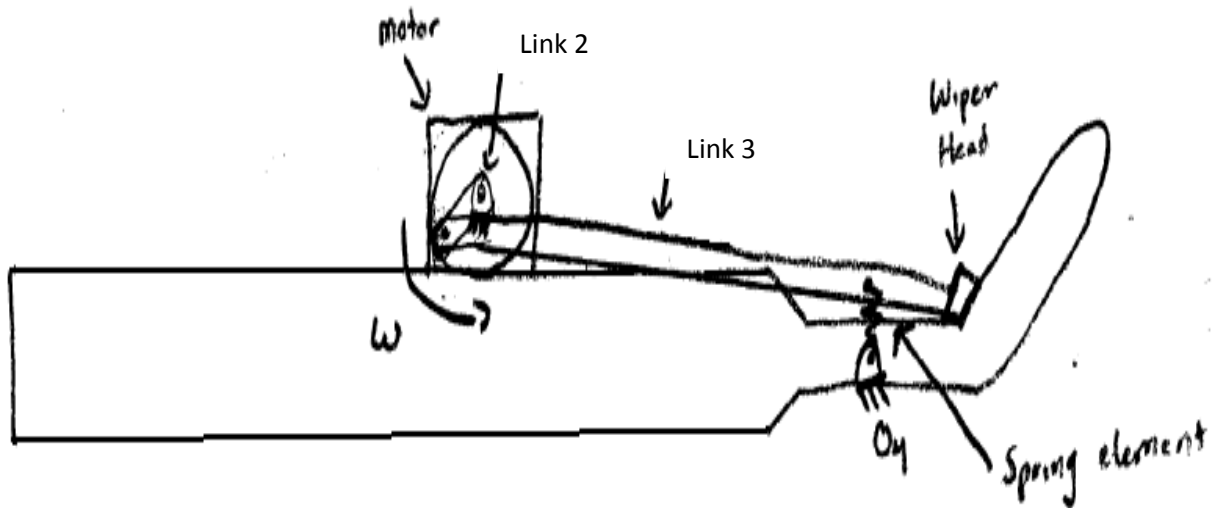


Figure 15: Motor-driven Slider Design Concept

The motor-driven design concepts are fundamentally the same as Wiper-based concepts 1 and 2; the only difference being they are adapted to use a button-operated motor as the input force rather than the user's finger. This concept involves the use of a slider mechanism which is run by a motor. The motor's drive shaft is attached to a flywheel, which is pinned to the drive link (link 3). The wiper head is attached to the end of the drive link. Additionally, a spring element is necessary to keep the wiper head in contact with the mirror surface throughout the stroke of the motor.

Ideally, this concept would utilize a button on the mirror handle which would allow the motor to complete one stroke, rotating the flywheel a full 360 degrees, resulting in the wiper head traveling up the mirror surface and then back to its starting position. A servo could be utilized instead, having the drive shaft rotate 180 degrees and then rotate back to its starting position. However, additional information regarding a button activated setup is required and needs to be sought to pursue this design concept.

In order to find the size of the motor that would be required to operate this device, calculations were made by the team to find the torque requirements to overcome static equilibrium. This value was

found to be 8.846 oz-in. This led the design time to choose a 5-gram servo motor, which, on the average yields 9-11 oz-in. of torque.

As for the assembly of this design, the motor would be mounted to a plate attached to the mirror handle. The linkage assembly involves small pins and thus would most likely be assembled during manufacturing. Also, optimal spring element selection and placement is a design and assembly concern.

Wiper-based Concept #5: Motor-driven Wiper

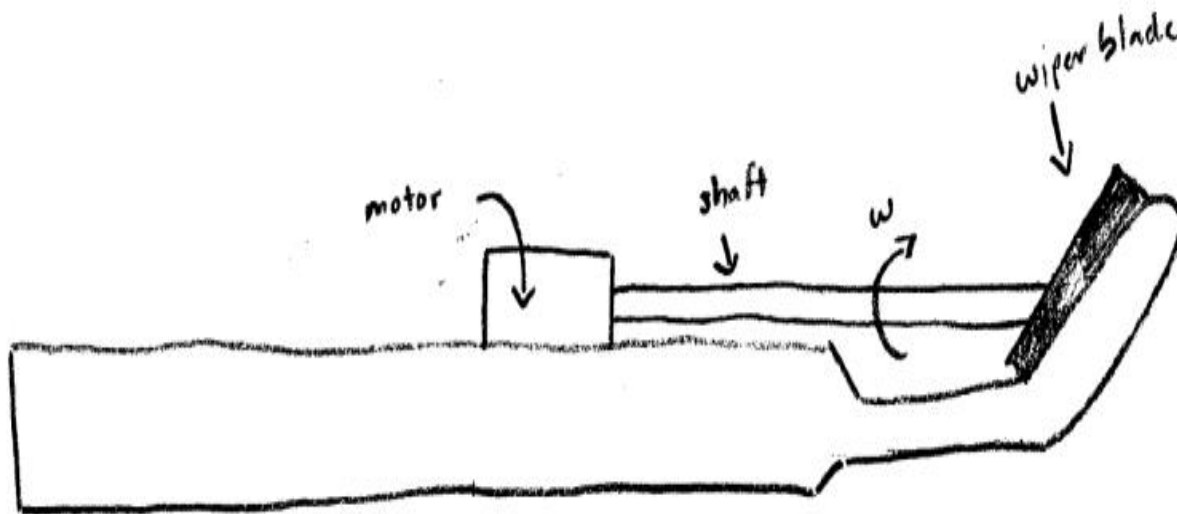


Figure 16: Motor-driven Wiper Design Concept

The motor-driven wiper design is simple in concept. Again, a button-operated motor is the input force, which causes the motor to turn the shaft a stroke of 180 degrees. To work effectively, the wiper blade would be attached to the shaft at a 35 degree angle with reference to the mirror handle. Furthermore, the assembly would have to be preloaded in order to have the wiper blade apply a force to the mirror surface during operation. This would be accomplished by the utilization of a screw to secure the motor to the mirror handle, providing the user the ability to manually achieve the preloading of the wiper arm.

Design Selection

These five design concepts were entered into a design matrix and evaluated based on the criteria of cost, safety, ease of use, performance, and reliability. It was decided that safety, ease of use, and reliability were the most important factors, each of which was rated as 22.5% of the total.

Performance came next with a rating of 17.5%, and last was cost at 15%. Again, these factors were considering the same criteria as in the previous design table. Table 2 below shows each design, the values received for each criterion, and the total values for each design.

Table 2: Design Table of Wiper-based design concepts

Design Factor	Motored	Cost (manufacturability)	Safety (to the patient and the user)	Ease of Use (ergonomics , easy to control, user assembly)	Performance (performs task without complication)	Reliability (susceptibility to failure)	Rank (out of a possible total of 10)
Weight		0.15	0.225	0.225	0.175	0.225	
Concept #1: Fourbar and Slider Combination	No	5	7	4	6	5	5.7
Concept #2: Spring-loaded Wiper	No	8	8	8	7	7	7.6
Concept #3: Deflecting Wiper	No	10	9	9	8	9	8.975
Concept #4: Motor-driven slider	Yes	1	3	5	8	2	3.8
Concept #5: Motor driven Wiper	Yes	2	3	5	7	2	3.775

The fourbar and slider combination Concept #1 had a few concerns which lowered its scores in each of the categories. For cost, the assembly of the design would require drilling holes into the shaft of the mirror. In addition, the assembly of the device would include the attachment of the wiper head to the slider linkage, and also the attachment of a spring element. The spring would be located between link 2 or 3 and the slider to ensure that the wiper head is always in contact with the mirror surface. Since this design concept relies on an effective spring element to work properly, the performance score

for this design suffered. In terms of safety, concerns arose about the geometry of the device prodding or pinching the patient's mouth during use. Design concept #1 is relatively easy to use, with the only exceptions being the aforementioned difficulties in assembly and also the cleanup, which may be resolved by the creation of a disposable wiper head, which is easily attachable and removable. Lastly, the design is reliable in all aspects as long as the problem with keeping the wiper head in contact with the mirror surface (with an applied force) is resolved by the spring element, or another solution.

The spring-loaded wiper concept received a high score for cost, because all the components should be inexpensive, and the design can be made out of plastic. In terms of safety, the concept also received a high score, as the only foreseeable problem is the breaking of the spring. This design concept should also be very easy to use, as the assembly requires the simple snapping-on of components and attachment of the wiper head and spring. In terms of performance, the only problem is that without testing, it is hard to tell whether or not there would be adequate force pushing down on the wiper head to clean the mirror surface effectively. This concept should be reliable as none of the parts undergo significant stress; the only concern is the spring breaking and needing to be replaced.

The deflecting wiper design is the best design concept. In terms of cost, all parts are inexpensive and can be disposable. The only safety issue is the wiper head detaching and falling into the patient's mouth during use. The concept is extremely user-friendly. Assembly simply requires the snap-on of components and is disposable, so it does not require any cleaning. In terms of use, it simply requires the push of the user's thumb on the thumb pad and pulling of it back to the original position. Lastly, the only concerns for safety and reliability are the wiper head detaching.

The motor-driven slider design has some complications which caused it to receive low scores. The cost of creating such a device is extremely expensive compared to the other design concepts. The primary reason for this is the cost of the motor. Most motors that would provide the torque requirements needed for this design cost between 50-70 dollars, and also require a power supply and additional materials to mount them to the mirror. A servo motor which would supply the required torque is roughly a cubic inch in size, making positioning of the motor an issue. Using electricity poses a possible safety risk to the patient and user, and motor failure is another safety concern. The assembly of the device reduces the user-friendliness of this concept, as the motor requires mounting, and the use of a power supply. This concept should perform well, as long as the power supply does not get in the user's way, or die during use. The reliability of the device is dependent on the motor and the spring element not failing.

The motor-driven wiper, for the same reasons as the motor-driven slider, is very expensive. The safety concerns for this concept are also the same as for the other motor-driven concept. The concept is not very easy to use in that it requires the mounting of the motor and connection of the power supply, as well as preloading of the device during assembly. Operation of the design also requires the changing of the wiper arm and head after use. Performance of this concept relies on the preloading working. The concept is reliable as long as the motor does not fail.

The project liaison, Ms. Anderson, originally had a motor-driven design in mind as a solution. If a motor-driven design were to be pursued, a complete redesign of the mirror would be required for optimization of size and shape of the design. This type of design could not be completed by the project team within the time period of the project, given that a prototype would take on the order of months to construct. To further substantiate that the retrofitted motor-driven designs are not optimal for balance, a model of the motor-driven slider design was completed using SolidWorks software. This model illustrated the center of gravity of the original dental mirror, and for comparison, the center of gravity of the motor-driven slider design and the deflecting wiper design. The models showed that the deflecting wiper design resulted in much less of a change in center of gravity location than the motor-driven slider design.

Based on our evaluation, design concept #3, the deflecting wiper, was rated the highest by a significant margin of 1.375 points, and was chosen as the design that would be pursued for prototyping.

Detailed Design

The first design parameter needed for the design of an effective wiper mechanism was the force required to remove debris from the mirror surface. Not knowing of any reports or previously found data for this parameter, the team constructed an experiment to determine this cleaning force. The next section explains the test conducted, title the Mirror Cleaning Test, and the conclusions made about different materials used to clean a mirror and the required cleaning force associated with each material.

Mirror Cleaning Test

Introduction

The objective of this experiment is to test the effectiveness of different materials that could be used as the wiper ‘head’ of the mirror cleaning mechanism, using realistic normal force applied by the digits of the human hand. These cleaning materials were tested in their effectiveness to remove debris material found in the dental field application, i.e. water, saliva, and a polish and water mixture. The results of this test are then used directly to select a cleaning material for the wiper mechanism, and to understand the force required to clean the mirror.

Methodology

Experiment Design

The experiment is designed to test four treatment factors and their effect on the ability to clean a 1 inch diameter round mirror specimen. These factors include: the material used to clean the mirror, the type of debris to be cleaned off of the mirror, the value of the applied load on the mirror, and the number of passes of the cleaning material over the mirror. If all possible configurations were tested, 81 individual tests would need to be conducted. Furthermore, 3 tests of each configuration would need to be conducted in order to yield conclusive results (Ross, 1988). Given the timeline of this design project, it is not feasible to conduct each individual test three times. Thus, as recommended by the project advisor, Taguchi methods of experiment design were employed to strategically select the configurations which would allow the design team to make conclusions about the configurations not tested.

Statistician Genichi Taguchi contributed time and cost efficient methods for experiments. Given several parameters of which several values needed to be tested for, Taguchi devised tables, also called *arrays*, which are specific combinations of values for each parameter which yield statistically sound results. Taguchi’s method prevents the experimenter from having to test every single value combination. The table below describes an L9 orthogonal array, which describes the different configurations to be tested given 4 test factors with 3 different values.

Table 3: Factor configurations to be tested

Trial No.	Factor			
	Load	Cleaning Material	Debris Material	# of passes
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Factor Number Designation	Factors			
	Load	Cleaning Material	Debris Material	# of passes
1	.150kg	Rubber	Water	1
2	.3kg	Foam	Water/Saliva Mix	2
3	.450kg	Cloth	Polish/Water Mix	3

As mentioned above, Taguchi has developed models for interpreting ‘multiple level’ experiments given quantitative values for each factor. A level is understood to be a different value of a treatment factor that would yield different results (Ross, 1988). This experiment does not involve quantitative figures for determining levels: rather, this experiment established ‘levels’ of each factor involved in cleaning the mirror based on direct application of the design project. For example, when selecting the ‘levels’ of debris material, the design team did not find any quantitative figures for determining the viscosity each material. Nor did the design team ensure that the values of the viscosity for debris material were linearly related. Instead, the team directly tested the materials which the designed mechanism would clean in its desired application. The other factors in the experiment, including applied load, and mirror cleaning materials, were established in the same manner.

What does this mean in regards to interpretation of the results? This means that no numerical conclusions can be made, or predictions about how effective a material would clean the mirror given values for each treatment factor (Ross, 1988). However, based on the results of this experiment, a selection of cleaning material can be made for use in the design. Also, from this experiment, an

understanding of the selected applied force can be established for use in the design of the wiper mechanism.

Experiment Design: Measurement Specification

The measurement taken in this experiment is the clarity of the reflected image from the mirror after the cleaning material has passed over the mirror. The measurement is recorded by digital photograph. The image documents were then used to qualitatively judge the cleanliness of the mirror. The measurement value recorded is a number in a 1 to 3 scale: 1 is a clean image almost as the original unsoiled mirror, 2 is an acceptable image for practical use, 3 is a reflected image of no practical use. Each configuration was tested 3 times, and the average of the three tests was used for the final measurement of the configuration trial. Each judgment of the resulting image was made unanimously by the design team.

Setup

Fabricated Parts

Several parts were fabricated to construct this experiment. The first is an aluminum base with a polished track cut down the middle. Upon this track rested a Delrin sled that was used to hold the mirror. Also, two supports for the aluminum track were fabricated to allow a clearance underneath the aluminum base through which the drive chain could pass. Lastly, a plate used to support the masses which provide the applied load needed to be fabricated. This support plate has two holes tapped with a running fit, a clearance of 0.005 inches (Reference for clearance sizes). All of these parts were fabricated in Higgins Labs on campus at Worcester Polytechnic Institute. Refer to Appendix B for parts drawings.

Setup: Robotics: Mechanical Parts

Having constructed the fundamental parts required for the experiment, a robotics system needed to be constructed to pull the mirror sled along the track, under the applied load with the cleaning material.

The first component that needed to be chosen was the servo motor which would pull the mirror sled. This was selected given the required torque to pull a Delrin piece over aluminum, with a 50N normal force applied and a friction coefficient of 0.46. The motor chosen for the application was a VEX 9.0V motor as its torque output exceedingly met the requirements of this application.

Other necessary mechanical components for constructing the robotics include two 24-tooth gears, a chain, and two axels: one axel which would be driven by the motor, the other is an idling axel on the other side of the aluminum base. This setup, as seen in Figure 20, created a linear motion of the Delrin mirror sled over the aluminum base. Refer to Appendix B for a complete list of parts of the mechanical components in the robotics system.

Setup: Robotics: Controls

The controls required for the robotics system included a control hub, a remote control, and a remote control signal receiver. All of these components were taken from a VEX robotics system package and are listed in Appendix B. The control hub needed to be programmed to have the motor drive the sled the desired distance, which was 1.25in., starting an eighth of an inch away from the 1in. mirror specimen and ending an eighth of an inch away on the other side. Given the diameter of the driving gear, an angular displacement of 255 degrees was calculated to be the required angular displacement for the desired linear displacement. The program easyC Pro was used to create the program that defines the movement of the servo. Refer to Figure 17 below for the simple program created for the intent of the experiment.

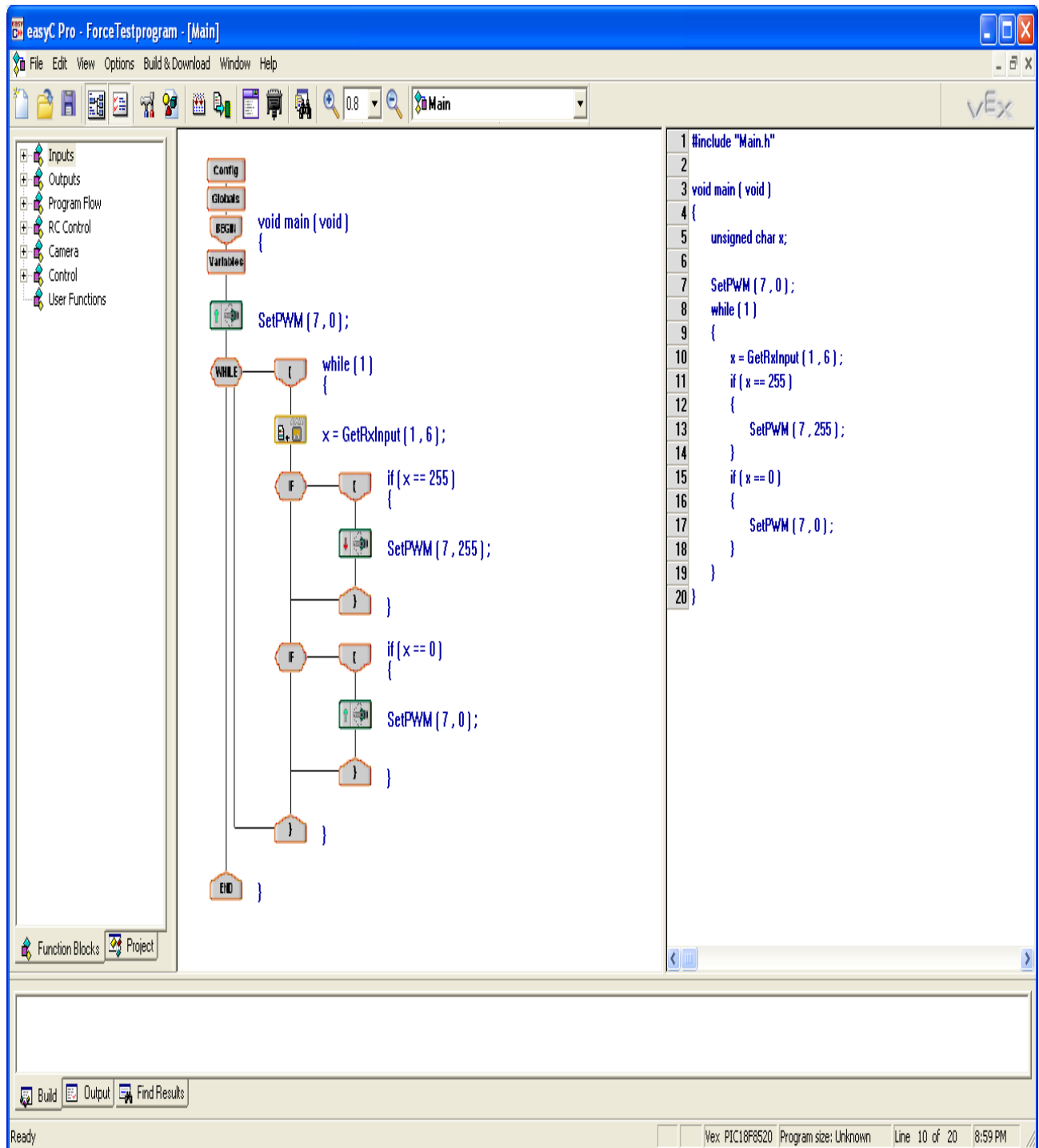


Figure 17: easyC Pro Robotics Program for the experiment

After this program was written, the physical assembly of the experiment took place. The aluminum base was fastened to the supports using screws. Two quarter inch pins were inserted into the base to act as guides for the mass support plate. The Delrin sled was placed onto the aluminum base and then all of the robotics components were mounted and configured. Figure 18 below depicts the final setup of the experiment:

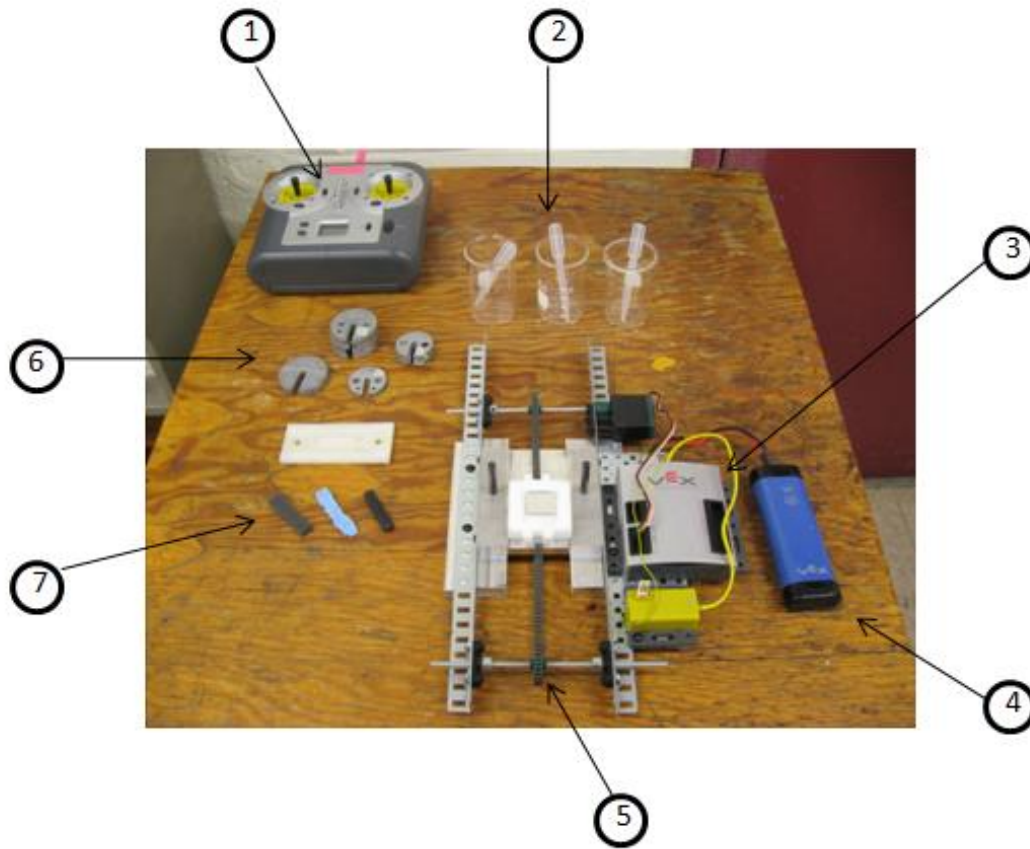


Figure 18: Complete experiment setup

Table 4: Key for Figure 18

Number	Description
1	Remote Controller
2	100ml Pyrex Beakers (debris vessels)
3	VEX Transmitter/Receiver Combination
4	VEX 7.2 Volt Robot Battery
5	VEX Chain and Gearing
6	Masses
7	Cleaning Materials

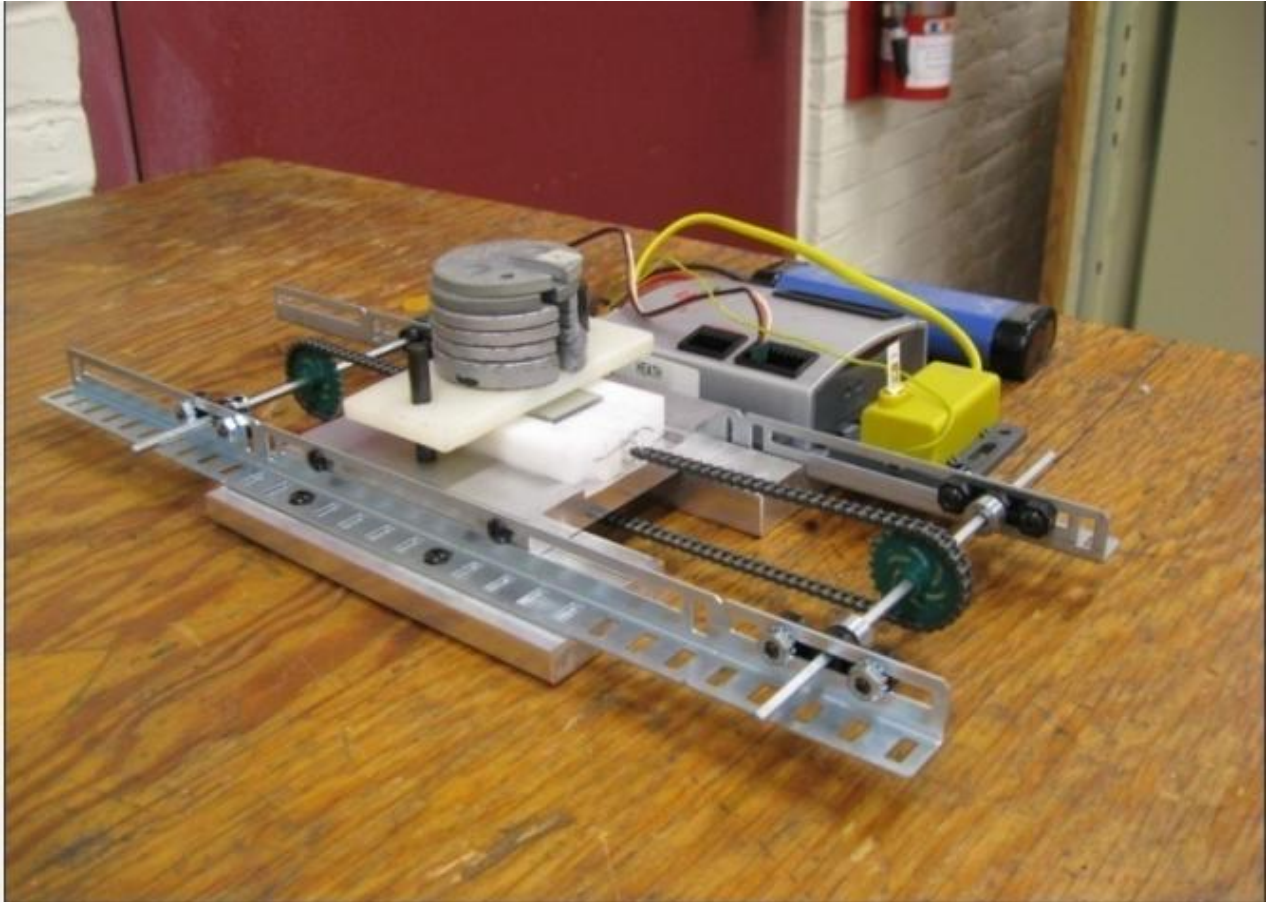


Figure 19: Experiment setup in testing configuration

Setup: The Mirror Specimen

The mirror component of a dentist's mirror is available in two types: glass and acrylic (McMaster-Carr, 2008). For the design project and this experiment, a glass mirror was chosen for study. A 2in. x 3in. mirror was purchased and a 1in. square piece was cut using glass cutters and a square. The mirror was then placed on the Delrin mirror sled, ready for testing.

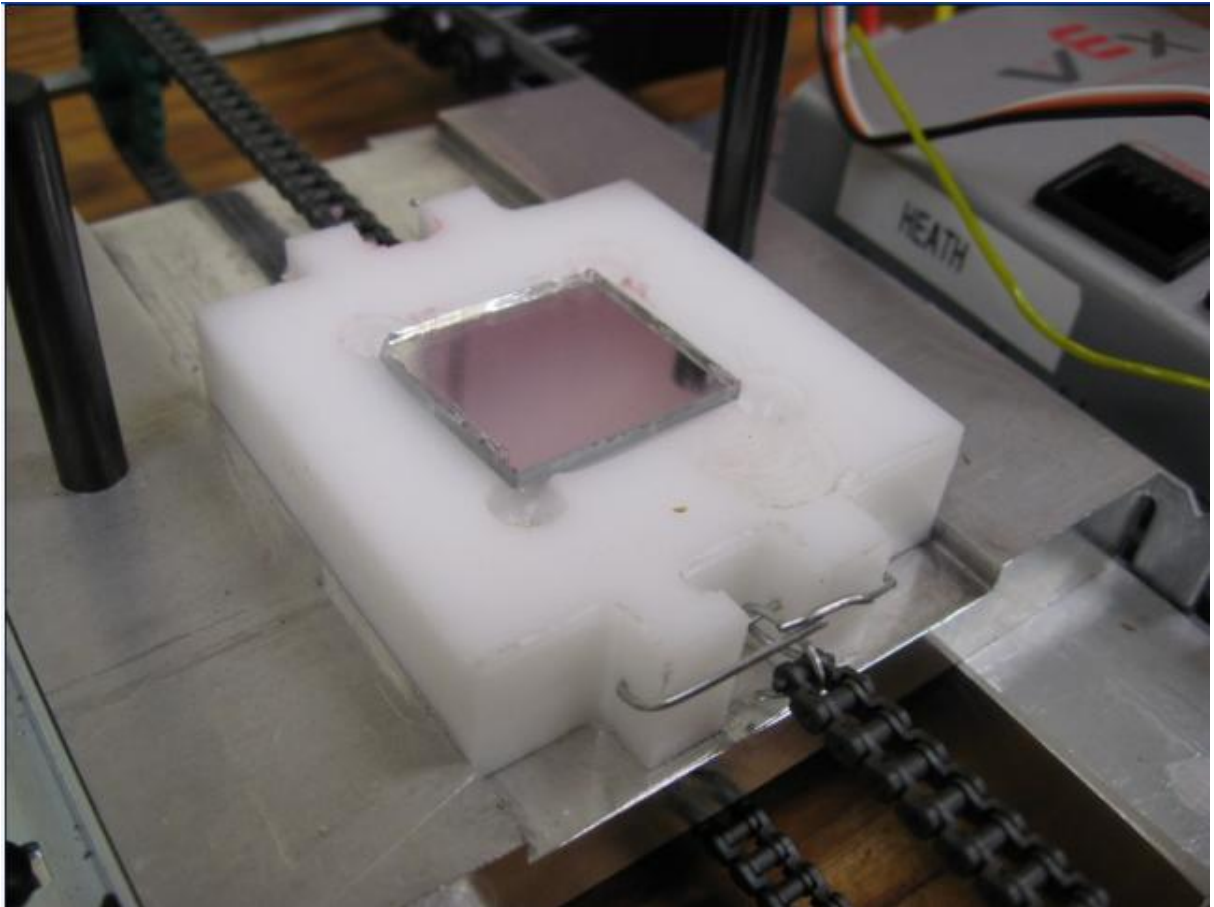


Figure 20: Mirror specimen in Delrin sled

Setup: Treatment Factors: The Cleaning Materials

The materials selected as possible for the cleaning mechanism were selected because they are fundamentally different, yet used in other cleaning applications; rubber, as is commonly used for windshield wiper blades; foam, as is used in cleaning sponges; and cloth from a towel used to remove debris from larger surfaces. Each material was cut into .25in. width, one quarter of the mirror specimen length. The cleaning material was also cut to be roughly 1.25in. long, to ensure contact over the entire width of the mirror specimen. Refer to the figure below for all of the specimens used.

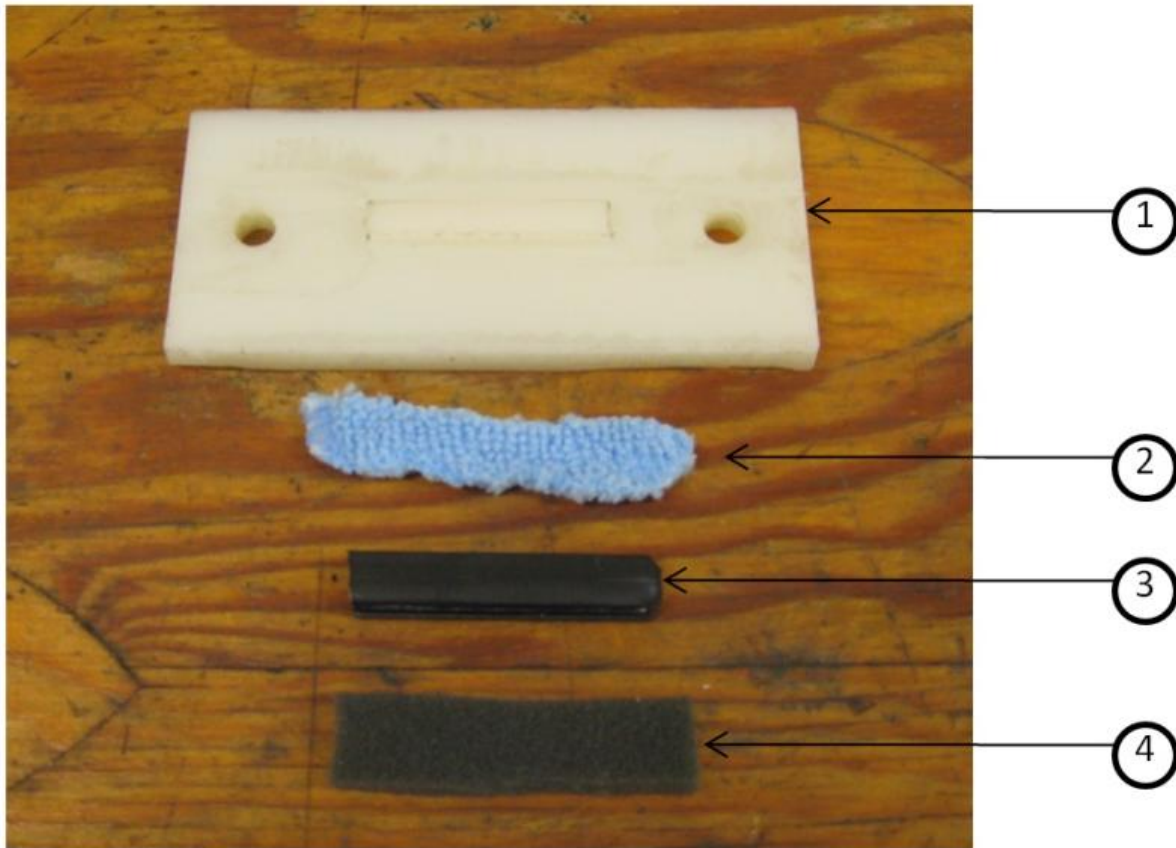


Figure 21: Mass support/Material cleaning fixture (above), and the three cleaning materials

Table 5: Key for Figure 21

Number	Description
1	Delrin Mass Support
2	Cloth Towel Cleaning Material
3	Rubber Cleaning Material
4	Foam Cleaning Material

Setup: Treatment Factors: The Debris Materials

The debris materials were chosen based on their varying viscosity and also because they are the direct application of the design project. The debris materials include water, as is provided by the 'hand piece' held by the dental assistant; a mixture of water and saliva, as is introduced by the mouth; lastly, a mixture of water and tooth polish used by dental hygienists is used to provide the highest viscosity debris material in the experiment.

Each debris material was prepared as follows. The water used in the experiment was filtered, distilled water, as is used in a dentist's office hand piece. The current convention is to use distilled water to limit the amount of biofilm in the unit (Dr. Bruce Goldman, 2008). The saliva/water mixture was made using a 1:1 volumetric ratio of saliva to water, each dispensed via volumetric pipette. The polish/water mixture was made using a 1:4 volumetric ratio.

Setup: Treatment Factors: The Range of Force

In designing the wiper mechanism, the first crucial piece of information required is the amount of force the human hand is capable of supplying for such an application. The mirror holding hand has two potential movements for operating a mechanism: the first is a sliding motion of the thumb along the handle of the mirror and the second is a flexion of the index finger, crossing over the neck of the mirror. As is discussed in a previous chapter, the maximum amount of force hand in either motion is 50N. So, to avoid fatigue, 10 percent of the maximum force was used for the operation of this mechanism, and thus a range of 1.47-4.42N was used in this experiment, provided by .150kg, .300kg, and .450kg. The mass of the support plate also needed to be considered in the normal force, as it acts on the mirror as well.

Setup: Treatment Factors: Number of Passes

The number of passes tested, 1, 2, and 3, were chosen keeping in mind the possible operation of the mechanism. Cleaning the mirror was tested with two and three passes to observe any improvements in cleanliness of the mirror with multiple passes.

Experimental Procedure

Each trial run was prepared and executed through the following steps. The trial to be conducted established the treatment factor selections. Once this was established, the appropriate cleaning material was attached to the bottom side of the mass support using double sided adhesive tape. The 1in mirror specimen was placed in the sled, and was ensured to be clean. Then, 5 drops of the selected debris material was applied via volumetric pipette to the mirror surface. The mass support plate was then aligned over the mirror and the appropriate mass was placed upon the plate to apply the cleaning

force. The cleaning material was aligned to be an eighth inch off the mirror surface. Once this configuration was obtained, the motion of the mirror was initiated via remote control, and the mirror moved completely under the cleaning material. Upon completion of the motion, the mass support plate was raised, exposing the surface of the mirror. At this point, a digital image was captured of the mirror's reflection of a square grid. Refer to the pictures in Figure 22 below for a visual of a sample reading. The mirror was then cleaned by hand using optical cleaning cloth. This procedure was repeated for every trial run.



Figure 22(left to right): A clean mirror specimen, the mirror specimen soiled with polish, and the 'cleaned' mirror after a trial run

Results

The results of the experiment are summarized in the table below:

Table 6: Trial results

Trial No.	Factor				Results (scale of 1 to 3, average of three runs)
	Load	Cleaning Material	Debris Material	# of passes	
1	1	1	1	1	1
2	1	2	2	2	1
3	1	3	3	3	3.00
4	2	1	2	3	2.33
5	2	2	3	1	1.5
6	2	3	1	2	1.66
7	3	1	3	2	2
8	3	2	1	3	1
9	3	3	2	1	2.66

Table 7: Factor Legend

Factor Number Designation	Factors			
	Load	Cleaning Material	Debris Material	# of passes
1	.150kg	Rubber	Water	1
2	.3kg	Foam	Water/Saliva Mix	2
3	.450kg	Cloth	Polish/Water Mix	3

From these results, it is clear that a cloth material used to clean a dentist mirror using only 1 to 3 passes will not yield acceptable results. In its three trials, cloth obtained image clarity of 3.00, 2.66, and 1.66. The cloth trial obtaining the clearest image is when it passed over water as the debris, earning a 1.66. This score was given based on how refracted the resulting image was. Overall, cloth was concluded to be the least useful in cleaning the mirror.

The next material, rubber, in its three trials produced image clarity of 1, 2, and 2.33. Its clearest results were from the trial using water as the debris material. The rubber produced a clear image with minimal image refraction. When used to clean polish using the maximum load and two passes, the rubber material earned an image clarity of 2, which is deemed acceptable for use. When used to clean

saliva and water off of the mirror with 3 passes and median loading, the rubber material earned an average of 2.33, which is closer to acceptable than poor.

The last material, foam, in its three trials produced image clarity of 1, 1, and 1.5. The foam removed the lower viscosity debris materials, water and saliva, producing image clarities of 1 for each trial. In the trial in which foam cleaned polish, the image clarity was rated as a 1.5, average the three test results.

In addition to the cleaning material tested in this experiment, another point of interest in the results is the values of the applied force. The values of the applied force chosen for this experiment proved to be adequate. This was concluded from trial 7, in which rubber removed polish in 2 passes and produced an image clarity of 2, which is acceptable. This trial proves that given a cleaning material and applied load of $\sim 5\text{N}$, the debris material of highest viscosity can be removed and an adequate image can be obtained.

Conclusion

From the results, it can be concluded that foam is the best material for cleaning the mirror. The trials in which foam and rubber were used produced images of greatest clarity. Having established desired material for the design, several more tests may be conducted to better understand cleaning behavior of a material. First, varying the geometry of the wiper 'head' can provide an understanding of which geometric configurations will yield the best results. It may also be desired to test rubber as well, as its trials produced images of acceptable results. Also, a more precise testing of applied force could be desired to understand required force for cleaning materials of maximum viscosity.

Detailed Design of Each Component

The inception of the wiper mechanism designed by the team incorporates an arm, a support for the arm, the wiper head which attaches to the arm, the cleaning material, and a push piece for the thumb to transmit force through the arm to the wiper head

ITEM NO.	PART NUMBER	QTY.
1	Push Piece	1
2	Arm	1
3	Support	1

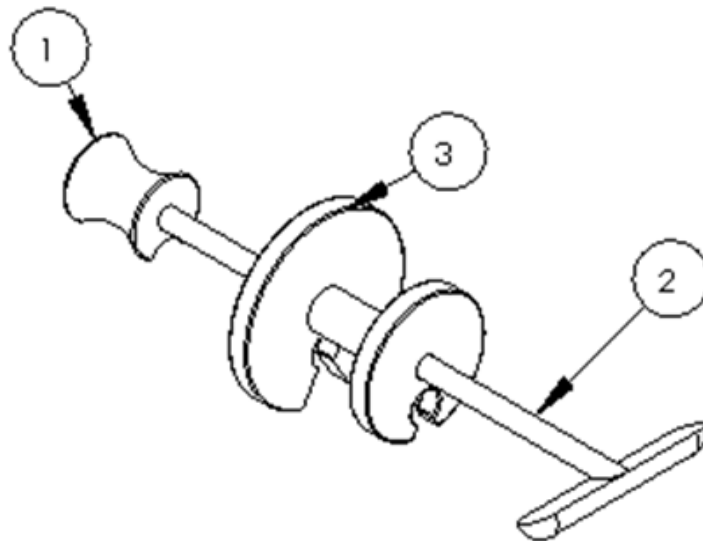


Figure 23: Isometric view of final design with bill of materials

The linkage used in some of the wiper-based concepts is a combination of a fourbar mechanism and slider-crank. The Deflecting wiper is a hybrid of the combination linkage, keeping the fourbar aspect, but removing the crank and instead utilizing the elastic properties of the Arm material to provide the cleaning force.

The Arm

The Arm is the link through which force is transmitted from the Push Piece to the Wiper Head. On one end of the Arm, the Push Piece is attached for the thumb to transmit force effectively. On the other end of the Arm, the Wiper Head is connected. In assembly, the Arm is supported and guided

along the axis of the mirror handle by the Support. The Arm translates the pushing force from the thumb, which acts parallel to the mirror handle, from the hand to the surface of the mirror by deflecting upon contact of the Wiper Head on the mirror surface. The effectiveness of this design relies heavily on the deflection performance of the Arm, and subsequently how much force is transmitted to the Wiper Material on the material surface.

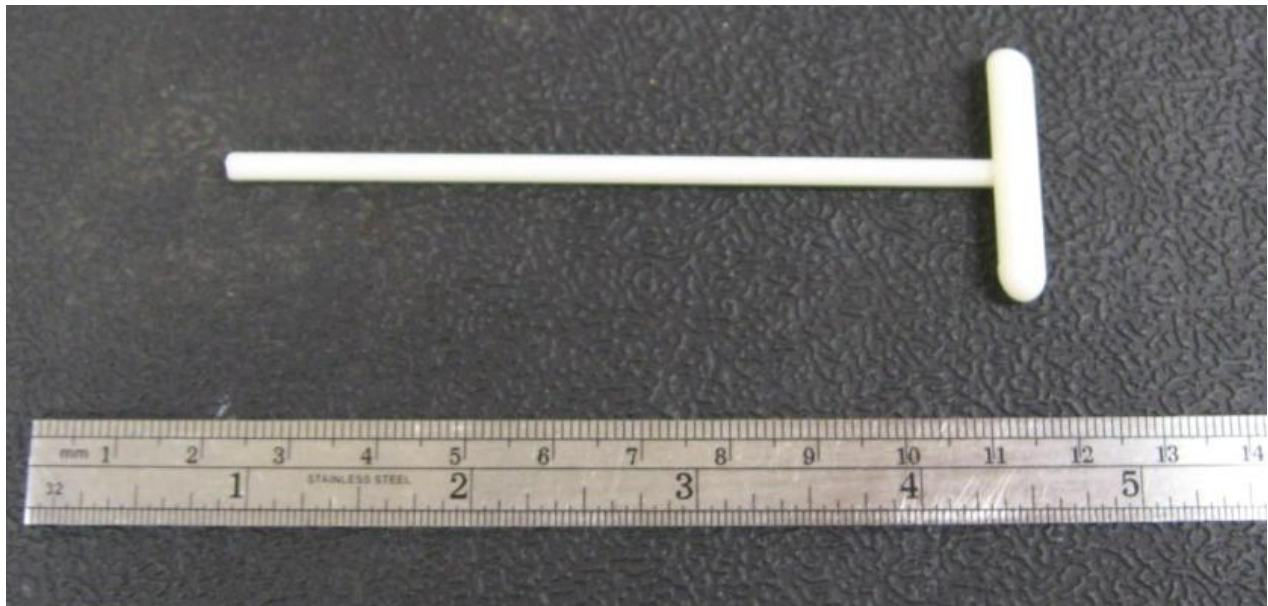


Figure 24: Arm

When first considering the cross-sectional geometry of the Arm, a circular cross-section was elected for the application. A circular cross-section eliminates sharp edges and thus any additional discomfort to the patient and the user. Using these characteristics of the Arm—how it is supported and its cross section—as well as the data from the Mirror Cleaning test, required normal force to clean the arm, the material properties of the prototyping material, supporting calculations were made to determine the required material properties of the Arm. When selecting a radius, the design team wanted a round dimension for manufacturing purposes, and thus chose a 1/16 inch radius.

The Arm was modeled as an Overhanging Beam with a point load at the end. This model is two dimensional, as all of the contributing forces are in the x-y plane according to the convention used in this project. In this situation, there are three forces, the reaction force from the Push Piece, the reaction force from the Support, and the normal force of the mirror on the Arm, also known as the cleaning force. The Arm was analyzed in maximum static deflection, which would have the Wiper Head

at the top of the mirror. This defines the location of the Push Piece's and the Support's reaction forces. The required force for cleaning the mirror surface was found to be 5N from the Mirror Cleaning test. This value was used as the normal force of the mirror on the Wiper Head, which acts at the end of the Arm in this calculation. Knowing this value and the locations of the other two forces, the unknown forces were resolved using force and moment equations, which can be referred to in the calculations in Appendix C. Once the forces were resolved, a function was derived to describe the deflection of the Arm under the loading. Manipulating this equation to solve for the required elastic modulus gave a value of 2.129×10^6 psi, which is within range of elastic moduli for ABS plastic, according to the data provided by CES EduPack material database software, a program written by Sia Najafi of Worcester Polytechnic Institute. The maximum stress, found where the Arm emerges from the Support, the maximum bending stress was found to be 6.75×10^3 psi. This value falls below the yield strength value of ABS plastic, according to CES EduPack software. These results are highly convenient as ABS plastic is the prototyping material, and thus an iteration process for the Arm radius was not required.

Push Piece

The purpose of the Push Piece is to allow the thumb of the user to transmit force effectively to the Arm and subsequently to the Wiper Head for the cleaning motion. The intent of the Push Piece is to allow the thumb to move the Arm forward to clean the mirror, and to return the Arm to the starting position. This design requirement governed the team's thought process in shaping the Push Piece. Further discussion of Push Piece shaping is in the Prototyping section of the report.

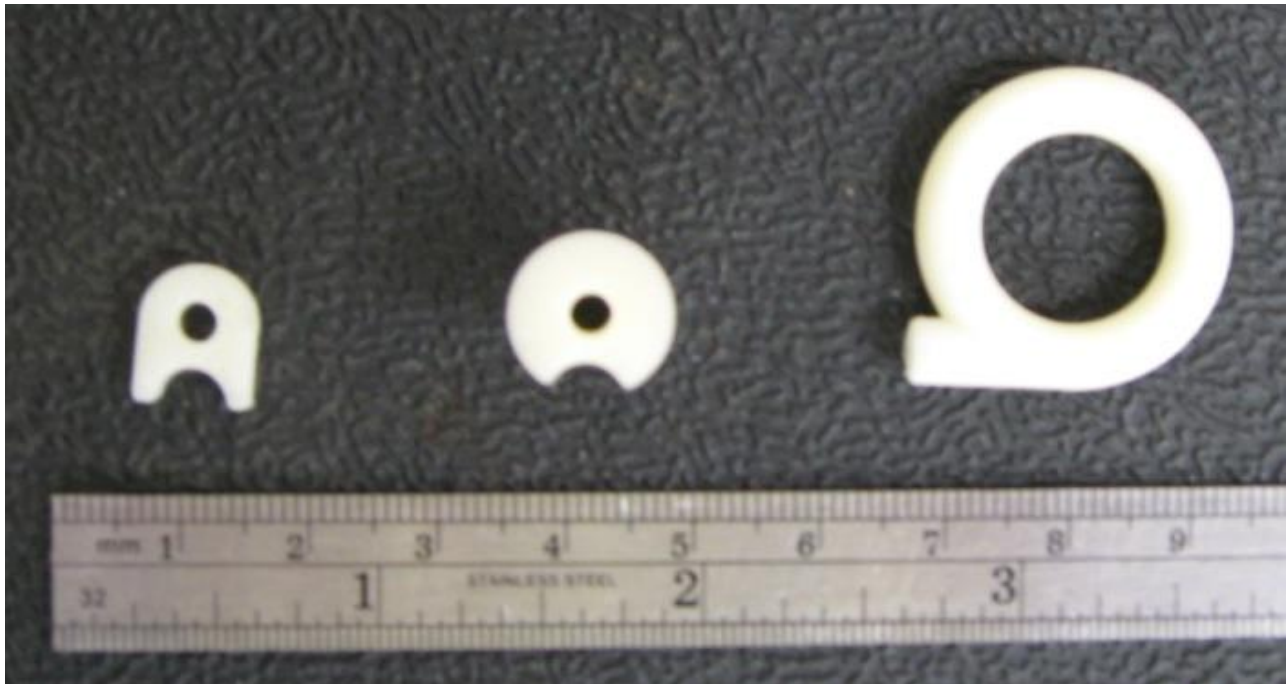


Figure 25: Front view of variations of Push Pieces; first design at left, further iterations at right

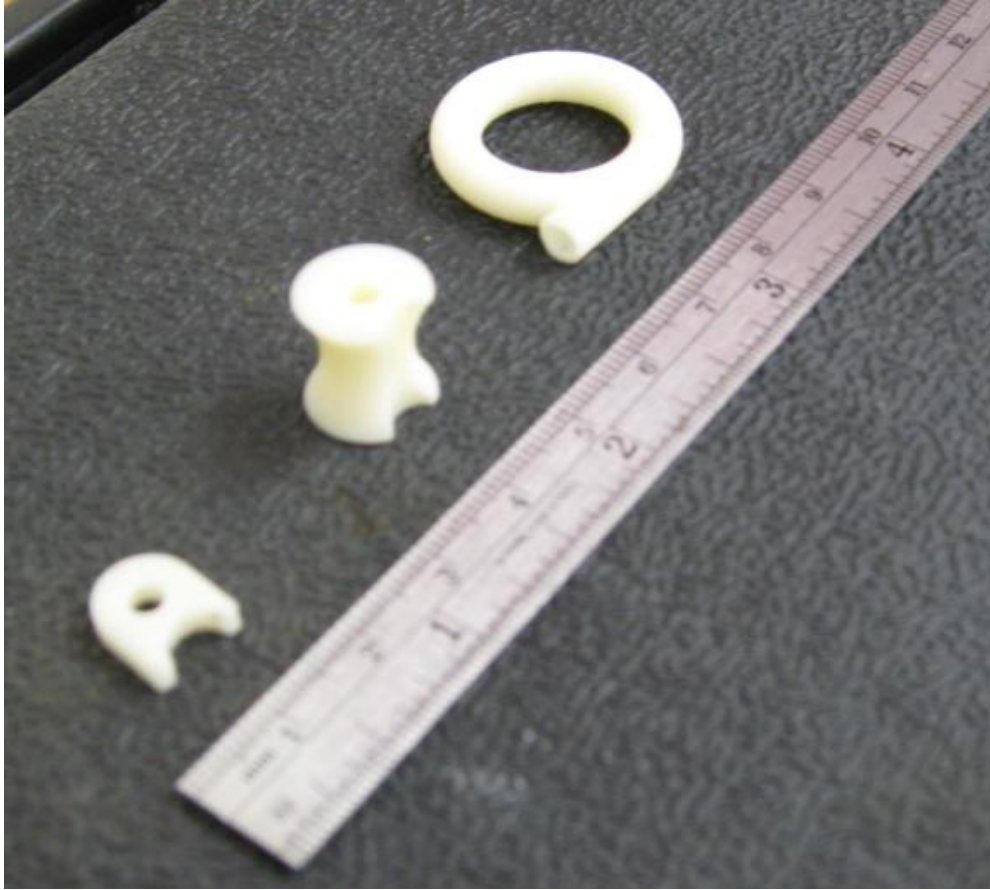


Figure 26: Side view of variations of Push Pieces; first design at left, further iterations at right

Wiper Head

The Wiper Head must perform three functions. The first is to provide a mounting surface for the wiper material. The Wiper Head also provides a constant contact point between the wiper and the mirror surface. Lastly, and most importantly, it must apply an adequate force on the Wiper Material so that the mirror surface is cleaned effectively. There are two different components to the Wiper Head which were considered during design. These components were the geometry of the Wiper Head and the material to be used for the wiper.

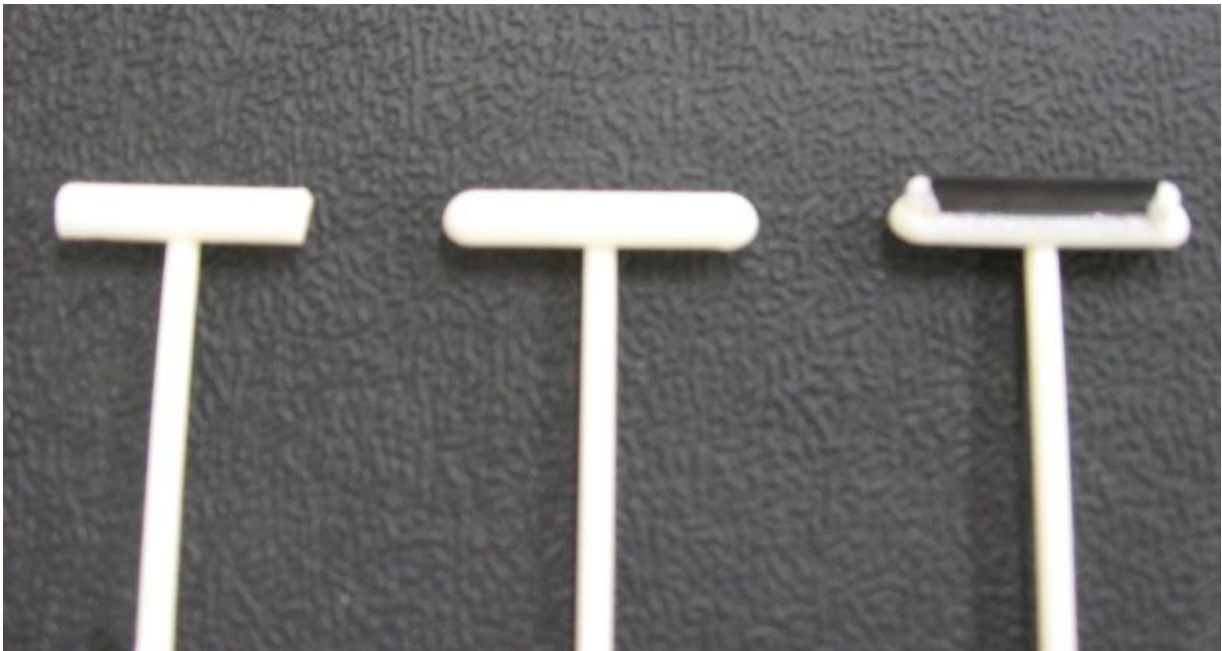


Figure 27: Variations of Wiper Head; first design at left, final design at right

During the design process, several different head geometries were investigated. During the initial design of the Deflecting Wiper concept, a wiper which would open up was thought of to reduce the impact, in terms of space, of the design on the original mirror geometry. After further review, it was determined that this design would not be possible, as the size requirement to perform such a function was too large and would impede ergonomic factors. Specifically, a Wiper Head made of rubber, which would provide adequate cleaning force, would have to be designed longer than desired for the movement of the thumb. Since these lengthened wiper blades lengthen the effective length of the Arm, a longer thumb stroke would be needed to complete a full pass over the mirror.

Other considerations were looked into, and both a wedge and hemi-cylindrical Wiper Head were considered. After designing both components, it was determined that the hemi-cylindrical design would

work better, as it helps maintain normal contact of the Wiper Head on the mirror. Based on prototype testing of this design, the hemi-cylindrical orientation was found to be successful for the application of foam as a Cleaning Material. The resulting image clarity was not optimum using foam in this design, so rubber needed to be considered. The initial design, with flat ends, was changed to rounded ends to avoid exposure of the patient's mouth to sharp corners during use. Changes were made per the prototype testing conducted, and the final design incorporates the hemi-cylindrical Wiper Head, with a groove for the placement of a rubber wiper blade as the Cleaning Material.

The choice of Wiper Material was determined during the mirror cleaning test. When materials were first considered, they included rubber, foam, brushes, and fabrics. The brush idea was discarded due to the concern that some bristles could come off during use and get into the patient's mouth. During the Mirror Cleaning Test, a sample of each of the other three materials was tested, with fabric not performing well, and foam and rubber wipers yielding similar results.

Support

The primary function of the Support is to guide the arm to the surface of the mirror, and also to prevent rotation of the device about the axis of the mirror shaft. It was decided that the only way this component could fail is by the breaking of the snap-on component, or by plastically yielding so that rotation about the axis becomes possible.

Using Alexander Blake's Practical Stress Analysis in Engineering Design, an example of the deflection and stresses induced on a snap ring was discovered, and formed the basis of our calculations. The first step in these calculations was to find the forces induced on the support by the arm, which the support would have to overcome to prevent movement. These forces are the frictional force and the force the wiper arm induces on the support during maximum deflection. The only way to prevent movement is to ensure the force between the support and the mirror shaft is greater than that of friction or deflection. To estimate the frictional force between the wiper arm and support, the coefficient of kinetic friction was assumed to be 0.33, since the two components were desired to be manufactured out of plastic. The frictional force was then calculated to be 1.244N. Based on the geometry of the support piece which contacts the mirror shaft, the required force to constrain degrees of freedom is 3.735N, with a safety factor of 2.

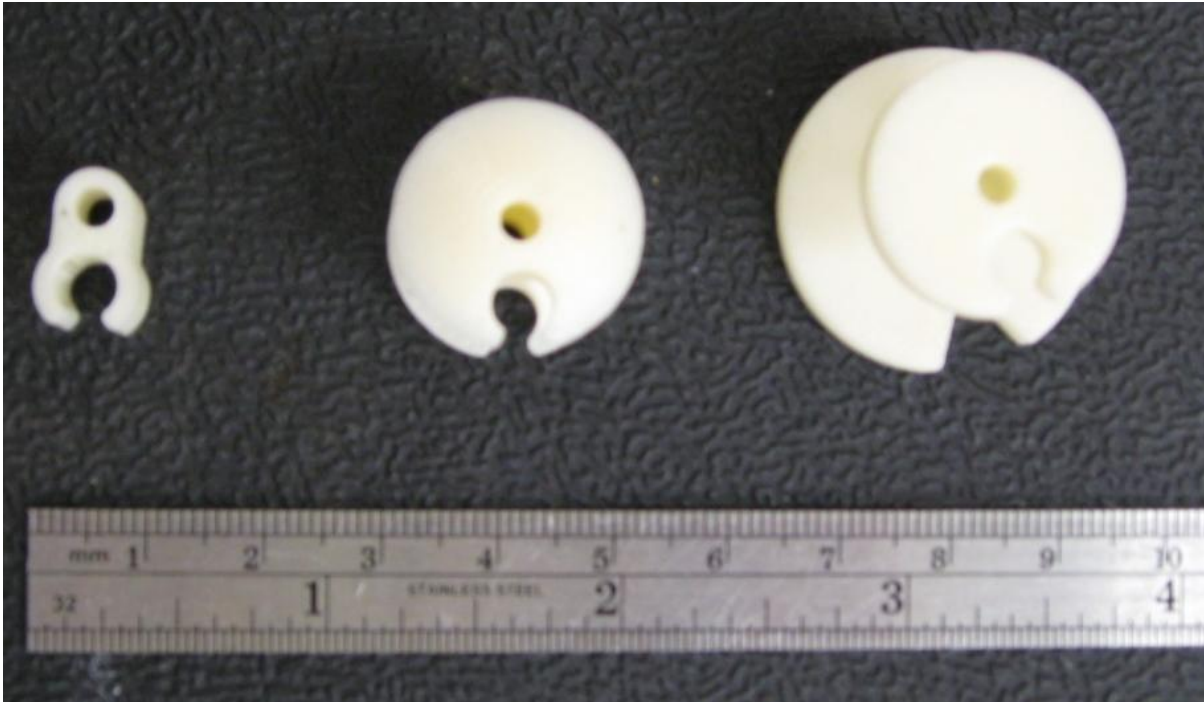


Figure 28: Front view of variations of Support; first iteration at left, further iterations to right



Figure 29: Side view of variations of Support; first iteration at left, further iterations to right

Based on the snap ring problem on pages 293-294 of Blake's book, the forces on the snap ring were resolved into two components, y and z. Using the force in the y-direction induced on the support by the arm (from the arm calculations), the load in the z-direction was calculated. Using this force, as well as the Support radius, second moment of area of the support ring about the x-axis, and the elastic modulus of the prototype material, the deflection in the z-direction was found to be 0.035 inches. This deflection is much less than the failure deflection at which the Support would snap off of the mirror handle. To further support our selection of material, the bending stress on the support was also calculated, and found to be 555.023 psi. Based on this value, a material with higher yield strength must be selected to prevent failure. For complete calculations please refer to Appendix C.

Thus, from the calculations described above, the part of the Support which connects to the Mirror Shaft was designed so it was slightly smaller in diameter than the mirror shaft. Doing this ensures that a force is constantly being applied on the mirror shaft, and safeguards against the movement of the support piece in any direction.

Prototype Construction

All of the prototypes were constructed using Dimension's 1200es Series 3D printer. A computer 3D model was drawn using SolidWorks software. The model file was saved in .stl format, a file able to be read by Dimension's software. The file is read by Dimension's software, and most of the process from this stage is automated. The material of the prototype is ABSplus plastic.

The prototype was made with the intention of creating one that proves the concept. This involved the manufacturing of an Arm, Support, and Push Piece. In the first attempt to manufacture a prototype, all three parts were sent to be made as an assembly. The Arm was manufactured already running through the Support, and the Push Piece was manufactured as part of the Arm. The tolerance limits of the rapid prototyping machine were too large to manufacture the entire assembly and achieve the fits the design team desired. Thus, the second prototype was made by manufacturing the three parts separately.



Figure 30: First iteration prototype, manufactured as one piece

The assembly of the device was initially designed to be completed in the following steps. First, the Support piece would be affixed to the mirror handle by a snap-on motion. Next, the Arm was fit through the Support. The Push Piece was then affixed to the end of the arm. Lastly, the Wiper Material was affixed to the Wiper Head with the use of one of two different adhesives: double sided tape, or Gorilla Glue. The one change that was made to this procedure was in regards to affixing the Support piece to the mirror handle. After changes in the Support design, it was found that a sliding of the Support over the mirror handle was easier than the snap-on motion.

During assembly, the design team concluded that the Arm radius calculated proved to be of sufficient size to avoid failure. The first Arm that was made had the semi-cylindrical Wiper Head geometry. Once this part was fabricated, it was apparent to the team that there existed sharp corners on the Wiper Head, at each end. To improve upon this, the team redesigned the Wiper Head to have round edges.

Upon assembly, the Support fractured at the contact with the mirror handle. This was thought to be due to the length of the Support, which is an eighth of an inch. The team decided to lengthen the support by a quarter of an inch and test the Support again. After this minor adjustment, the Support has not failed after repeated use.



Figure 31: Support fracture in first iteration of prototype

In assembly, the Push Piece was placed on the Arm and was kept on due to the size of fit. The Push Piece underwent several iterations, which are discussed in the next section of the report.

Prototype Testing

As the goal of the project was to create a functional prototype, the first testing conducted was to determine whether the device performed the task of removing debris and fog from the mirror surface adequately. To do this, the same foam and rubber wiper which had been used in the Mirror Cleaning Test were adhered to the wiper head using doubled sided tape and Gorilla glue, respectively. The prototype was then assembled and attached to the shaft of the mirror. A solution of dental polish and water was applied to the mirror surface, and each member of the design team took turns using the device. The preparation of the polish/water solution was exactly that of the procedure included in the Mirror Cleaning Test. With every application of solution to the mirror surface, the prototype was tested by making two passes over the mirror surface.



Figure 32: Final prototype assembled and attached to the mirror. Figure shows device in its initial position.

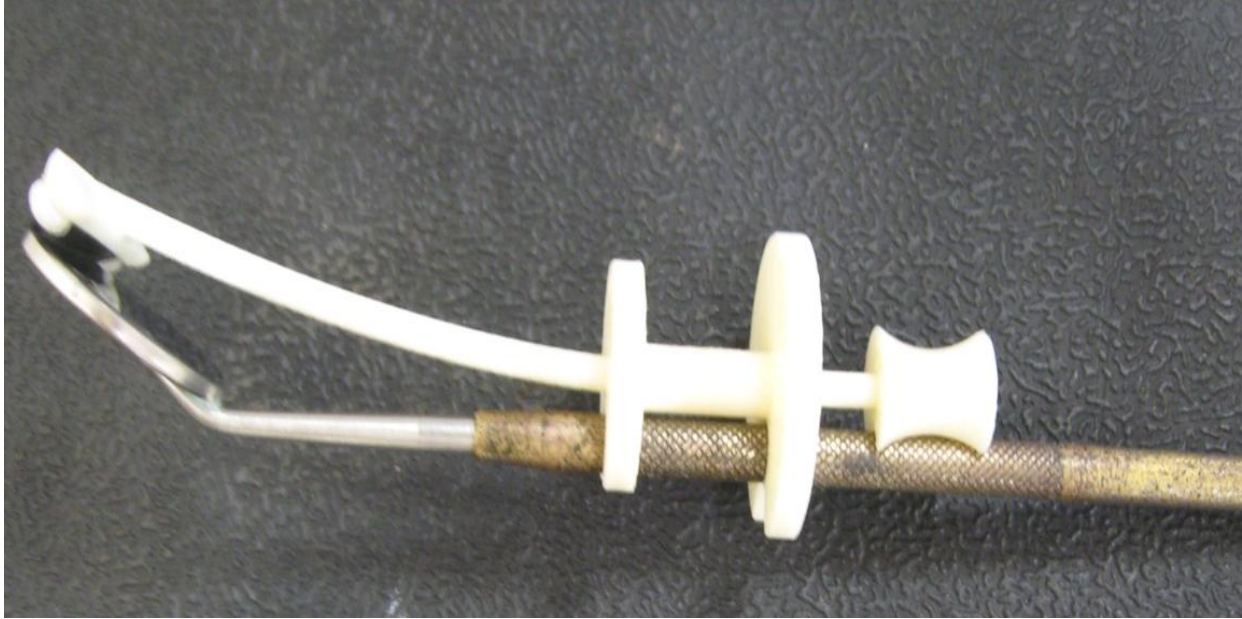


Figure 33: Final prototype assembled and attached to the mirror. Figure shows device in the position of full deflection.

The results of this testing were that the design cleans the mirror adequately so that an operable image is obtained. The results were found to be similar to that of the original Mirror Cleaning Test: a usable, but not ideal, image was obtained from the 'cleaned' mirror. Responding to this issue, the team made changes to the Wiper Head. To achieve better image clarity, the team decided that a rubber wiper blade would be best in removing debris from the mirror surface. The previous rubber wiper blade was restrained by excessive amounts of Gorilla glue such that the deflecting properties of the rubber wiper were hindered. Improving upon this, the team made a slot in the current Wiper Head geometry to enable better placement of a piece of rubber wiper. This improved the design in two ways: placing adequate amounts of adhesive and in keeping the rubber wiper secured. In summary, this geometry suited the rubber wiper material better than the purely hemi-cylindrical Wiper Head.



Figure 34: Final Wiper Head with slot. Figure shows rubber wiper attached.

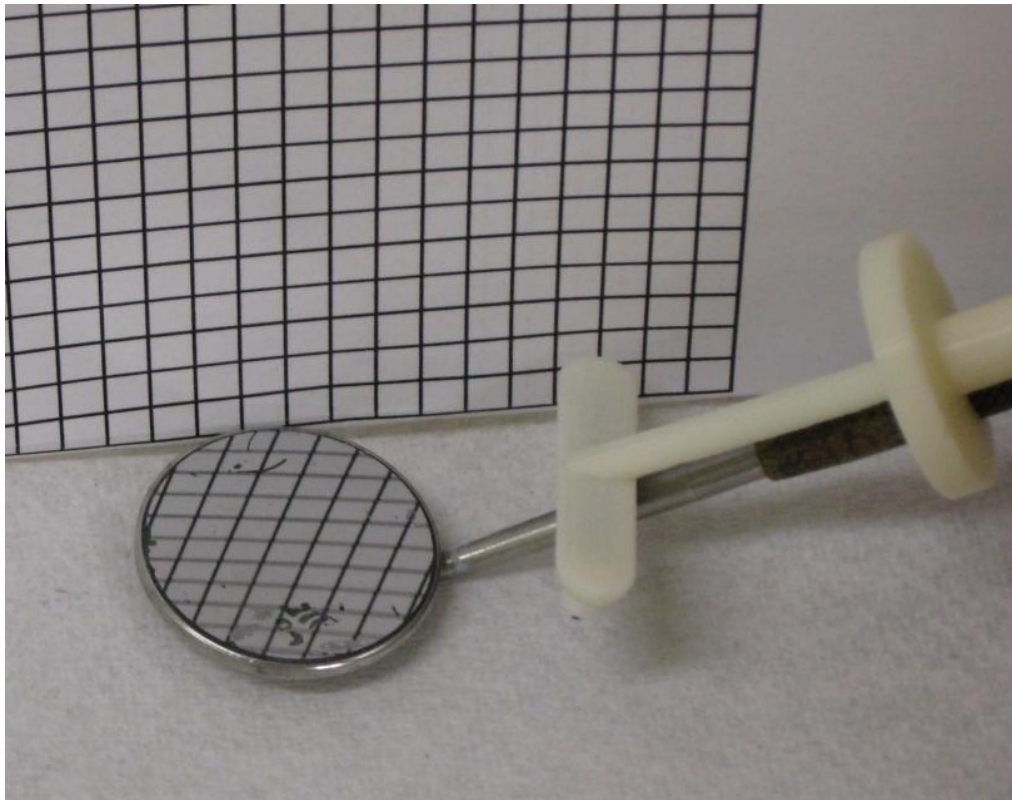


Figure 35: Condition of mirror prior to application of debris

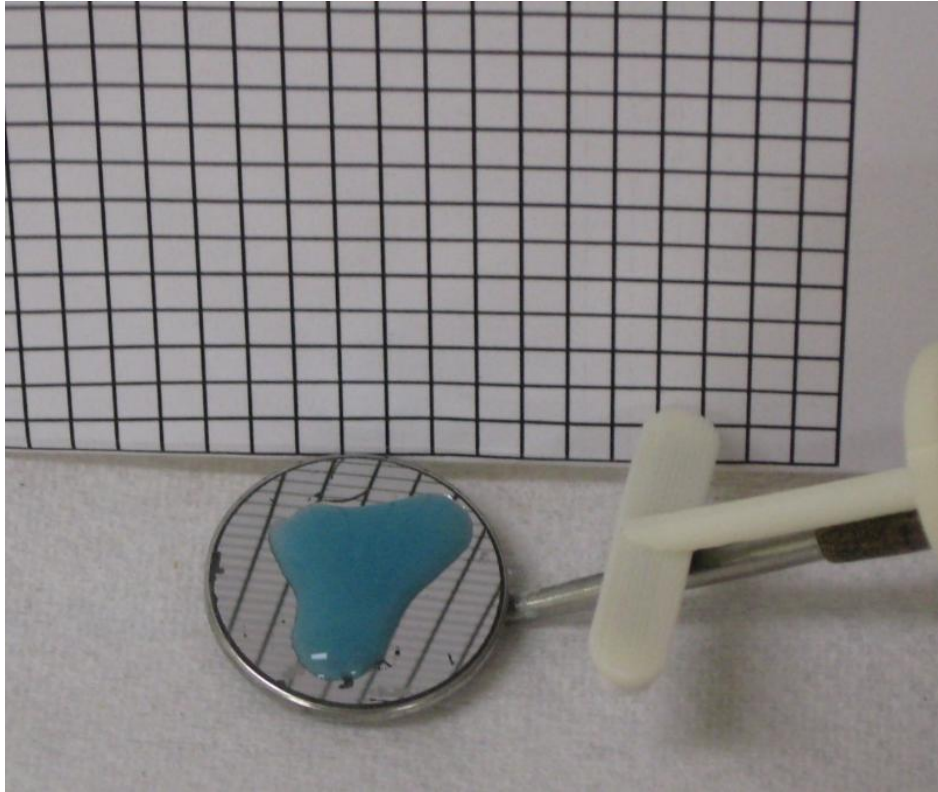


Figure 36: Condition of mirror after application of debris

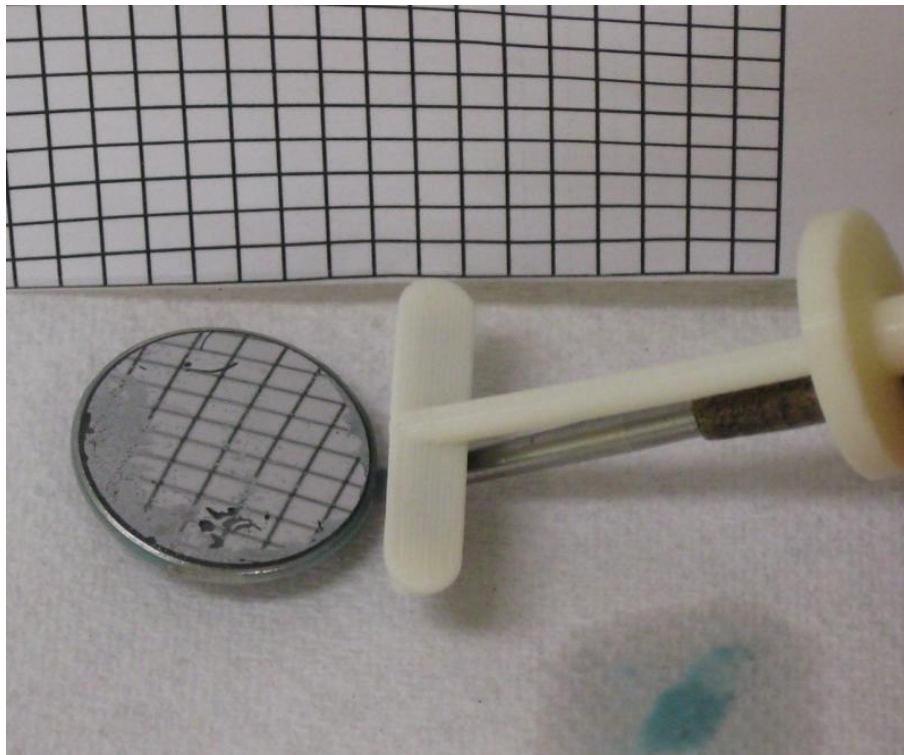


Figure 37: Condition of mirror after performing two swipes with the rubber wiper

Also, the ergonomics of the current design were not ideal. The operation of the mechanism required excessive effort which would not be practical during the application of the design. The required effort to operate the design made for a two-handed operation, which does not satisfy the one-handed performance requirement, as outlined in the Project Objectives section of the report. The part of the operation which required two hands was the movement returning the wiper head to the starting position. The current Push Piece was deemed too small for the user to achieve adequate leverage using just the thumb, thus the design team made changes to this part.

The design team investigated easier methods to achieve the desired motion, which was experimentally determined to be a combination of flexion and adduction of the thumb. This motion is similar to the movement of the hand while using a syringe. The design team created variations of the Push Piece and the Support to facilitate this effective movement. After manufacturing prototypes of these additional parts, and assembling them on the mirror in various combinations, testing of ergonomic effectiveness was conducted. Upon completion of this testing, a final Support and Push Piece combination was selected and can be viewed in Figure 40 below.

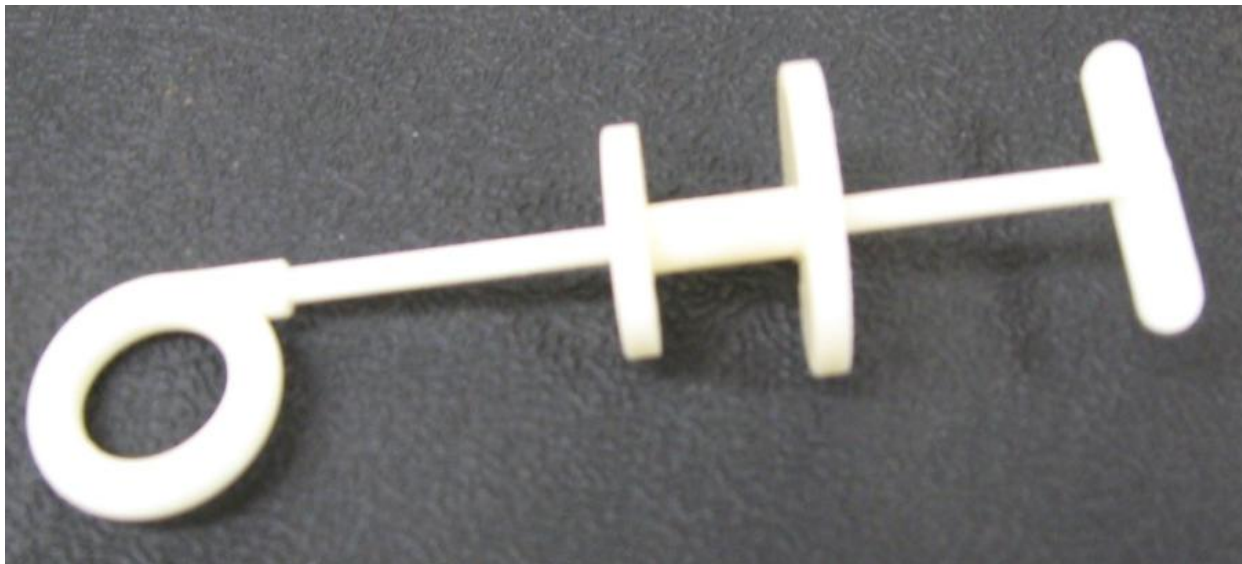


Figure 38: First tested iteration of final prototype

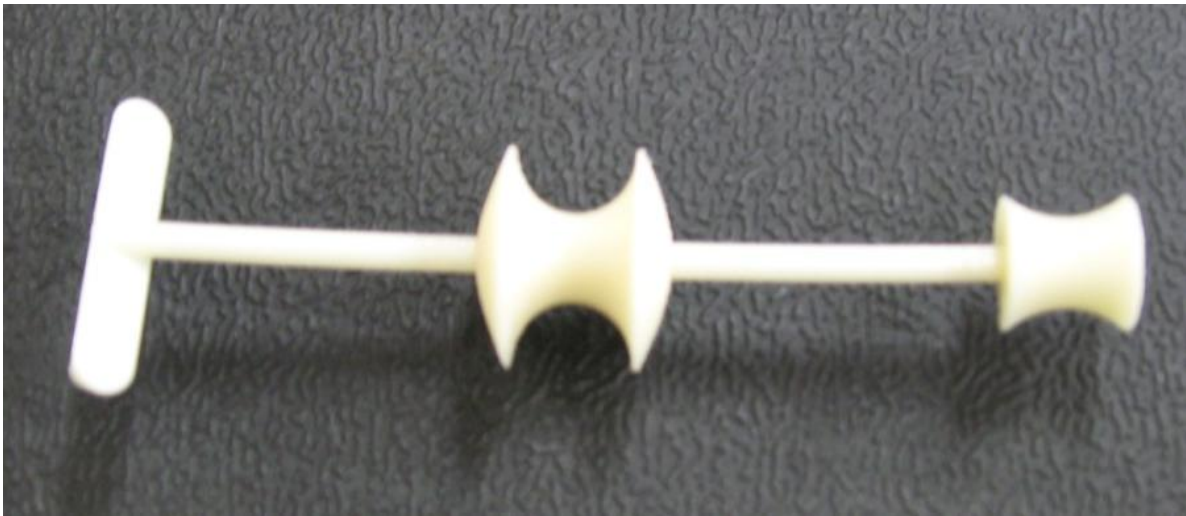


Figure 39: Second tested iteration of final prototype

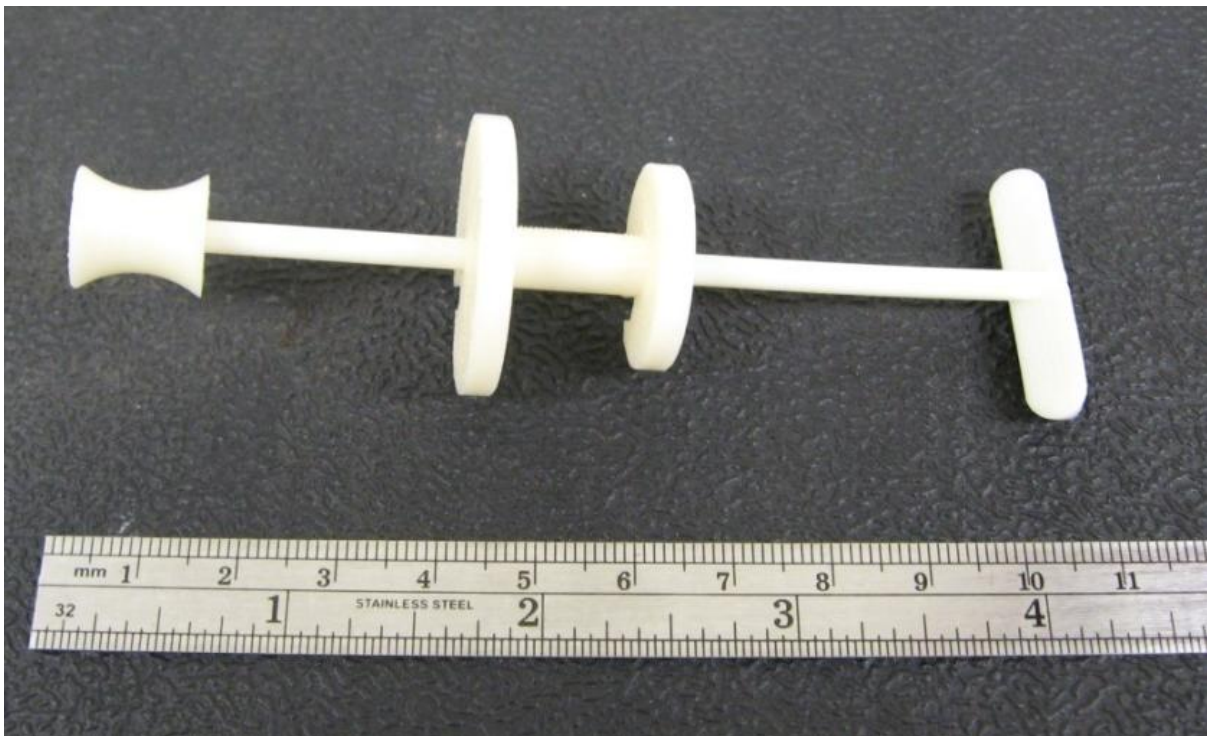


Figure 40: Final design, consisting of optimal Push Piece and Support combination

Conclusion

This Major Qualifying Project embodies an extensive design process. Through background research, interaction with dental professionals, and conceptual design development, a successful working prototype has been created which accomplishes all of the primary objectives and performance specifications of the project. Given the timeframe of the project, the team is pleased to have designed and created a prototype of a functional dental mirror cleaning mechanism.

The Mirror Cleaning Test, which was performed per ASTM standard operating procedure, (as stated in ASTM Document G115, *Standard Friction Testing Procedures*), was essential in determining the required forces and optimal selection of material to clean a dental mirror soiled with debris associated with the application. Furthermore, the Solidworks solid modeling analysis, MathCAD calculations, and kinematic analyses were all indispensable in obtaining the results of this project. These analyses were critical tools in making assumptions, identifying problems, and making changes to achieve the successful design. Lastly, the rapid prototyping machinery in Higgins Laboratories was pivotal in development of the concept up to final design.

The final design meets and, in some aspects, exceeds the performance specifications the design team set to accomplish at the start of the project. Primary to the success of the project, the final design removes all traces of debris from the dental mirror while using the mirror holding hand. The operation of the mechanism allows the user to remain situated close to, or within, the oral worksite, which streamlines the dental procedure. The design has also been optimized to reduce fatigue involved with the cleaning operation, and possibly the fatigue involved with the use of the mirror itself. The Support developed allows for a relaxed grip of the mirror, and the motion required to operate the cleaning device is similar to that of a syringe. The design does not change the balance of the mirror, nor does it present any risk of safety to the patient or the user. In effect, the team has developed an effective, functional, and safe solution to the presented problem.

Having established a foundational design for a mechanical mirror cleaning device, the team suggests expanding on and refining the current design. The first step in doing so would require extensive feedback from dental professionals. In the following section, the team has described a number of recommendations in which the current design can be improved for creation of an optimal design.

Recommendations

This section outlines recommendations for further improvements that could be made to the final design, the next steps for manufacturing the final design and the plausible designs considered in the Initial Design Concept section.

Upon completing this project, the team has several recommendations in mind for those who would continue the design of this mirror cleaning mechanism.

Improvement of Final Design

1. Feedback from dental professionals must be sought to verify the success of the design and to learn which aspects of the design could improve. The team achieved what we believe to be a successful design, however, the mechanism is intended for the dental professionals, and thus their feedback is of primary importance.
2. A finite element analysis could be conducted to aid in the material selection process. Upon selecting a material, further testing of the design, including fatigue cycle experiments, would be useful to determine the life of the assembly.
3. Should hand-fatigue be a concern for weaker-handed individuals, the addition of a spring element to aid in the return motion of the wiper could be considered. This spring element would most likely be made of non-toxic, open-cell foam, such as polyurethane foam, which could be made experimentally in the lab using the required raw materials. This spring could be attached to the support, and would come in contact with the Push Piece at end of the forward motion. The spring would then compress, absorbing energy, and then would utilize this energy to push the wiper arm back, aiding the thumb in this return motion.
4. In addition to the spring element, other ergonomic improvements could be made to the final design. The shapes of the Support and Push Piece currently are conducive for use of the mechanism given the size of the team members' hands. A study could be done of average hand sizes for men and women to dimension the support appropriately. Also, it is possible for the Support and Push Piece to be manufactured in different sizes, accommodating all sizes of hands.
5. For manufacturing the design, all of the major components are plastic, and can be made of the same material. The prototype material, *ABSplus* plastic, has suitable material properties for the

application. The wiper cleaning material should be made of a rubber wiper, as this has been found to perform the best of all materials.

Initial Design Concepts

The one initial design concept that the team did not pursue, but the team deems as worthy of consideration, is the Water and Air flow design. This design was originally met with opposition by those in the oral healthcare field. Obtaining feedback from the project sponsor, a dental assistant, and a general dentist, both of the dental professionals stated that the addition of an extra line to their worksite would be a hindrance. If this design were to be pursued, the water and air hand piece currently in use could be integrated into the mirror cleaning mechanism to avoid use of a second line. Otherwise, the designers would have to find another way to relieve the use of another water and air line.

The design team does not recommend pursuing the following initial design concepts. The surfactant dispenser requires redesign of the entire mirror, while it would only prevent fogging during a procedure and not remove debris. The team concludes that if a complete redesign of the mirror were in order, the consideration of how debris would be removed should be a design requirement. The thin film dispensing design should not be pursued because it is impractical for the user in that the user could run out of thin film materials. These thin films and the mechanism required to remove them would present significant manufacturing difficulty and, in turn, cost. The pneumatic spinning head was deemed by the design team as an unfavorable design because of its user-unfriendliness and impracticality. The vibration of the spinning mechanism is not something the dentist should have to experience in both hands, using two pneumatic tools. Not only does this provide immediate discomfort, it could result in health complications after long term use, as stated in the Design Analysis and Review section.

References

Armstrong, W. P., Nov. 16, 1961, "Self Cleaning Vibratory Dental Mirror," (3137071).

Astin, A. D., 1999, "Finger Force Capability: Measurement and Prediction using Anthropometric and Myoelectric Measures."

ASTM International, 2008, "Annual Book of ASTM Standards," ASTM International, West Conshohocken, PA, pp. 492, Chap. Section Three.

Blake, A., 1990, "Practical Stress Analysis in Engineering Design," CRC Press, New York, pp. 690.

Brown, T.H., Mischke, C.R., and Shigley, J.E., 2004, "Handbook of Machine Design," McGraw-Hill, New York, 2004.

Croop, D., and Carter, D., 2003, "Self Cleaning Dental Mirror," **10/677 195**(3755903).

Fries, R.C., 1997, "Reliable Design of Medical Devices," Marcel Dekker, Inc., New York, pp. 703.

Gunnarsson, S., Nov. 12, 1999, "Self-Cleaning Rotating Dentist's Mirror," **09/423308**(6247924).

Norton, R.L., 2008, "Design of Machinery," McGraw-Hill, New York, NY, pp. 825.

Norton, R.L., 2005, "Machine Design: An Integrated Approach," Prentice Hall, New York, pp. 984.

Ross, P.J., 1988, "Taguchi Techniques for Quality Engineering: Loss Function, Orthogonal Experiments, Parameter and Tolerance Design," McGraw-Hill Book Company, New York, NY 10020, pp. 279.

Spinello, R. P., "Anti-Misting Attachment for Dental Mirrors," **251452**(3755903).

Widen, R. M., and Simon, D., 1976, "Self Cleaning Dental Mirror," **534136**(3969824).

Young, W.C., Roark, R.J., and Budynas, R.G., 2002, "Roark's Formulas for Stress and Strain," McGraw-Hill, New York, pp. 852.

Appendices

Appendix A: The Friction Test



Figure 41: The Friction Test

INTRODUCTION

To understand the power requirements for the motor which will draw the mirror sled across the aluminum base in the mirror-cleaning testing, the team needed to understand the forces the motor will be working against. In this case, the primary force opposing the motor is friction. As is well known, planar friction force is normal force multiplied by the friction coefficient. Two types of friction force exist: static and kinetic friction forces. Static friction, as defined by ASTM, is the maximum friction force that must be overcome to initiate macroscopic motion between two bodies. Kinetic friction is defined as the friction force during relative motion between two bodies. Static friction force is the force of greatest concern for motor selection, since it is widely known that static friction force is larger than kinetic friction force. The motor must be able to overcome this static friction force, and then will operate against kinetic friction for a limited period of time (less than a second). Thus, kinetic friction is neglected in this experiment.

After thoroughly searching online and on-campus resources for the static friction coefficient of delrin on polished aluminum alloy 7075 without success, the team designed a primitive friction coefficient test for the two materials. After reviewing ASTM Document G115, *Standard Friction Testing Procedures*, the team derived an acceptable procedure, which is outlined in the following pages.

METHODOLOGY

First, the team needed to obtain a level surface on which to conduct the experiment. Thus, the team precision-leveled the precision leveled table in the Surface Metrology lab in Washburn Shops. This provided a level table to a precision of a thousandth of an inch. Refer to figure 42 for an image of the precision table.



Figure 42: Rotary vice placed atop precision-leveled table

The team the obtained a rotary vice with a vice width of 2", which was smaller than the piece of aluminum desired to fit. This required the team to augment the aluminum base so it may fixed in the rotary vice. To accomplish this, the team connected a squared, faced stock piece of aluminum onto the aluminum base in order to hold the aluminum base in the vice. Super glue was used along the two edges of aluminum pieces that were not going to be interfaced with the vice clamp. This ensured a flushed grip of the vice on the part. Refer to figure 43 for an image stock piece which was attached to the aluminum base to be used in the Mirror Cleaning Test.

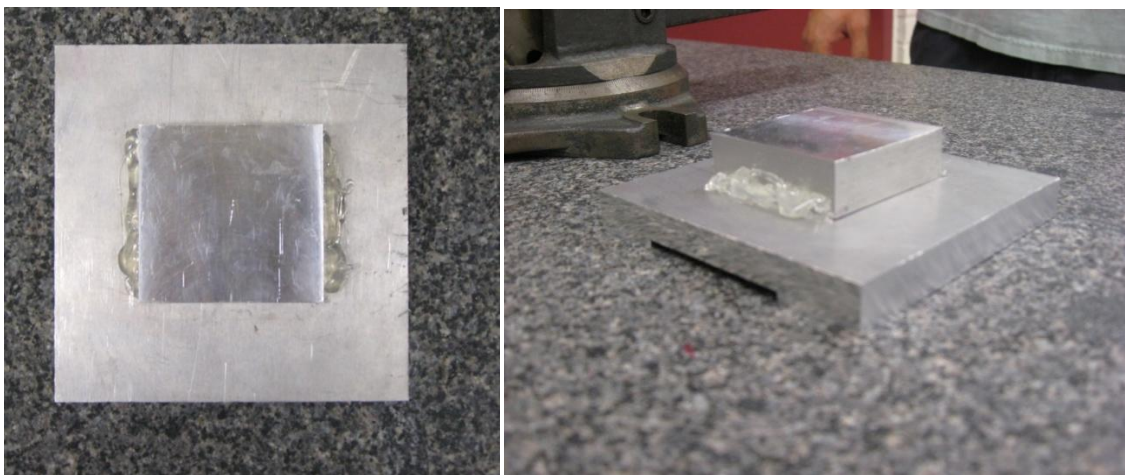


Figure 43: Squared stock piece of aluminum attached to aluminum base

After attaching this stock piece, the aluminum base was then secured to the rotary vice, which rested on the precision leveled table. The delrin sled was then placed atop the aluminum base. This is the completed physical setup of the experiment: The aluminum base of the Mirror Cleaning Test secured in the rotary vice which rests on a precision leveled table. It should be noted that the delrin-aluminum couple was not altered in any significant way, as the team wanted to retain the surface condition of each part as it would be implemented in the Mirror Cleaning Test performed afterwards.

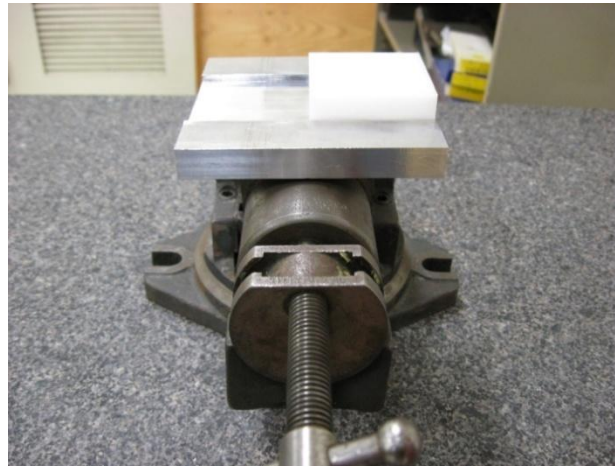


Figure 44: Fully assembled friction test

Upon completion of the setup, the team then took measurements of the angle of incline required for the delrin mirror sled to slide across the track. Angle of incline of the rotary vice was initially set to zero. The angle of inclination was increased by one degree manually using the analog readout on the rotary vice for reference. Refer to figure 45 for an image of the analog readout of the rotary vice. Given the measurement precision of the vice, the resolution of measured angles is 0.5 degrees.



Figure 45: The angle of inclination readout on rotary vice

For each degree of angle increase, it was recorded whether or not the delrin started moving along the track. The angle at which the delrin started moving down the track was recorded. This angle was then used to calculate the coefficient of friction as per the suggestion of the ASTM standard procedure. The calculation employed was the tangent of the angle of inclination.

RESULTS

The results of the static friction test are as follows. Upon adjusting the angle of inclination by one degree increments, the delrin piece moved after achieving an angle of inclination of 13 ± 0.5 degrees. This translates to a friction coefficient of 0.43. This coefficient of friction was then used to calculate the power requirements for the motor used to pull the sled holding the mirror. Using these coefficients, the maximum friction force has been found to be 5lbf for static friction. The derived force was then used for torque requirements for the motor, which can be referred to in the pages of the following calculations. It has been concluded that the VEX hobby servo module.

Appendix B: Equipment, Instrumentation, and Parts for the Mirror Cleaning Test

Equipment and Instrumentation List for the Mirror Cleaning Test

Qty	Device	Model #	Manufacturer	Serial #	Calibration Date
1	VEX Microcontroller Module	P/N: 276-2170	VEX Robotics	N/A	N/A
1	VEX Transmitter/ Receiver Combination	P/N: 276-2153	VEX Robotics	N/A	N/A
1	VEX 7.2 Volt Robot Battery	P/N: 276-2183	VEX Robotics	N/A	N/A
1	VEX 9.6 Volt Trasnmitter Battery	P/N: 276-2220	VEX Robotics	N/A	N/A
1	VEX Fast Battery Charger	P/N: 276-2221	VEX Robotics	N/A	N/A
1	VEX Servo Module	P/N: 276-2162	VEX Robotics	N/A	N/A
1	Angle 30 Holes/ Slots	ANGLE-001-4PK	VEX Robotics	N/A	N/A
1	Angle 30 Holes/ Slots Inv	ANGLE-001R-4PK	VEX Robotics	N/A	N/A
1	24x5 Hole Plate	PLATE-25-5-4PK	VEX Robotics	N/A	N/A
	8-32 Nuts		VEX Robotics	N/A	N/A
	8-32 Screws		VEX Robotics	N/A	N/A
2	Square Shaft		VEX Robotics	N/A	N/A
2	24 Tooth Gear		VEX Robotics	N/A	N/A
1	VEX Chain	P/N: 276-2182	VEX Robotics	N/A	N/A
	VEX Shaft Collar		VEX Robotics	N/A	N/A
	Delrin Bearing		VEX Robotics	N/A	N/A

Masses Used for Applied Load

Mass	Label	Actual Weight (in grams)
100	No Label	100.2
50	A	50.2
	B	50.1
	C	50.1
Nylon Mass Support	No Label	36.2

Parts List

Part	Description	Quantity
Aluminum Track	Al 7075 Aluminum. Milled track, polished. Two .25in. holes thru-tapped for support pins	2
Aluminum Supports	Al 7075. Made to support aluminum track and to allow chain linkage to pass underneath.	2
Nylon mass support plate.	Nylon plastic: Used to support masses for applied load.	1
Delrin Mirror Sled	Delrin plastic: Mirror rests in this part. Mirror sled rests on Aluminum Mirror Track. This part is pulled under the applied load with cleaning material by the chain linkage.	1
Dowel Pins	Steel: Two 2in., .25in. pins used to guide mass support over the Aluminum Track.	2
Paper Clips	Secured the VEX Chain to the Delrin Mirror Sled	2
Pyrex 100 mL Beaker	From the Chemistry Department of WPI. Used as vessel to hold various debris materials for Mirror Cleaning Test	3
Pasteur Pipet	Provided by the Chemistry Department. Used to dispense debris material over the mirror surface.	15
Rubber Wiper Blade	Volvo Dealership replacement wiper blade	
Finish Factor Foam Brush 9/16" x 2" x 6-1/2"	Model #0122 Serial 106084, Used as the foam material in the mirror test.	Finish Factor
Microfiber Towel	Generic auto care towel	

Appendix C: Supporting Calculations for the Parts of the Deflecting Wiper Mechanism

Supporting calculations for selection of diameter and material for arm

Known values

$L_{arm} := 2.875\text{-in}$	Arm length	
$a := .25\text{-in}$	Distance from midplane of push to midplane of support	
$F_{mirror_y} := 0.516\text{ lbf} = 2.295\text{ N}$	Force of mirror on arm in y direction	
$r_{arm} := \frac{.125}{2}\text{in} = 0.063\text{-in}$	Radius of arm	
$I_z := \frac{\pi}{4} \cdot r_{arm}^4 = 1.198 \times 10^{-5} \cdot \text{in}^4$	Moment of inertia	$3.4414\text{N} = 0.774\text{-lbf}$ $2.294\text{N} = 0.516\text{-lbf}$
$E := 2.568 \times 10^6 \cdot \text{psi}$	Modulus of elasticity	

Unknown values

$$\sin(35\text{deg}) \cdot 5\text{N} = 0.645\text{-lbf}$$

$$F_{support} \quad F_{hand}$$

Singularity Functions

$$S(x, z) := \text{if}(x \geq z, 1, 0)$$

$$C_1 := 0 \quad C_2 := 0 \quad C_4 := 0 \quad C_3 := -6.276\text{ lbf} \cdot \text{in}^2 \quad \text{Proven below}$$

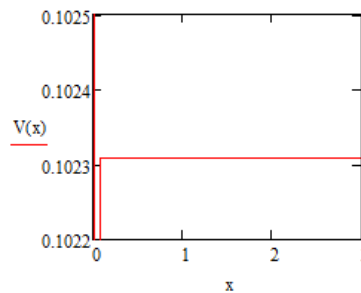
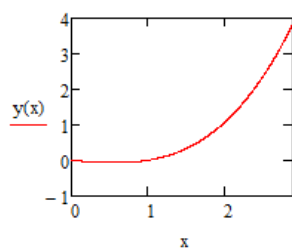
$$F_{support_y} := 5.67\text{ lbf} \quad F_{push_y} := 5.177\text{ lbf}$$

$$V(x) := F_{push_y} \cdot S(x, 0) - F_{support_y} \cdot S(x, a) + F_{mirror_y} \cdot S(x, L_{arm}) + C_1$$

$$M(x) := F_{push_y} \cdot S(x, 0) \cdot x - F_{support_y} \cdot S(x, a) \cdot (x - a) + F_{mirror_y} \cdot S(x, L_{arm}) \cdot (x - L_{arm}) + C_1 \cdot x + C_2$$

$$\theta(x) := \frac{1}{E \cdot I_z} \left[\frac{F_{push_y}}{2} \cdot S(x, 0) \cdot x^2 - \frac{F_{support_y}}{2} \cdot S(x, a) \cdot (x - a)^2 + \frac{F_{mirror_y}}{2} \cdot S(x, L_{arm}) \cdot (x - L_{arm})^2 + \frac{C_1}{2} \cdot x^2 + C_2 \cdot x + C_3 \right]$$

$$y(x) := \frac{1}{E \cdot I_z} \left[\frac{F_{push_y}}{6} \cdot S(x, 0) \cdot x^3 - \frac{F_{support_y}}{6} \cdot S(x, a) \cdot (x - a)^3 + \frac{F_{mirror_y}}{6} \cdot S(x, L_{arm}) \cdot (x - L_{arm})^3 + \frac{C_1}{6} \cdot x^3 + \frac{C_2}{2} \cdot x^2 + C_3 \cdot x + C_4 \right]$$



Boundary conditions

Since the reactions have been included in the loading function, the shear and moment diagrams both close to zero at each end of the beam, making $C_1 = C_2 = 0$

$$\text{The boundary conditions to be evaluated are: } V(L_{arm}^+) = 0 \quad M(L_{arm}^+) = 0$$

$$y = 0 @ x = 0 \quad y = 0 @ x = a$$

$$V(L_{arm}^+) = F_{push_y}(L_{arm}-0)^0 - F_{support_y}(L_{arm}-a)^0 + F_{mirror_y}(L_{arm}-L_{arm})^0 = 0$$

$$F_{push_y} - F_{support_y} + F_{mirror_y} = 0 \quad F_{push_y} = F_{support_y} - F_{mirror_y}$$

$$M(L_{arm}^+) = F_{push_y}(L_{arm}-0)^1 - F_{support_y}(L_{arm}-a)^1 + F_{mirror_y}(L_{arm}-L_{arm})^1 = 0$$

$$M(L_{arm}^+) = F_{push_y}(L_{arm}) - F_{support_y}(L_{arm}-a) = 0 \quad F_{push_y} = \frac{F_{support_y}(L_{arm} - a)}{L_{arm}}$$

Solving both equations simultaneously yields

$$F_{\text{support_yz}} := \frac{F_{\text{mirror_y}}}{.091} = 5.67 \cdot \text{lbf}$$

Now we can solve for $F_{\text{push_y}}$

$$F_{\text{push_yy}} := \frac{F_{\text{support_y}} \cdot (L_{\text{arm}} - a)}{L_{\text{arm}}} = 5.177 \cdot \text{lbf}$$

$y = 0$ @ $x = 0$

$$y(0) = 0 = 1/EI_z [F_{\text{push_y}}/6 \cdot (0)^3 - F_{\text{support_y}}/6 \cdot (0-a)^3 + F_{\text{mirror_y}}/6 \cdot (0-L_{\text{arm}})^3 + C_3(0) + C_4]$$

Therefore, $C_4 = 0$

$y = 0$ @ $x = a$

$$y(a) = 0 = 1/EI_z [F_{\text{push_y}}/6 \cdot (a-0)^3 - F_{\text{support_y}}/6 \cdot (0)^3 + F_{\text{mirror_y}}/6 \cdot (a-L_{\text{arm}})^3 + C_3(a) + C_4]$$

$$0 = \frac{1}{E \cdot I_z} \left[\frac{F_{\text{push_y}}}{6} \cdot (a-0)^3 - \frac{F_{\text{mirror_y}}}{6} \cdot (a-L_{\text{arm}})^3 + C_3 \cdot (a) \right]$$

$$C_3 := \frac{-\frac{F_{\text{push_y}}}{6} \cdot (a)^3 + \frac{F_{\text{mirror_y}}}{6} \cdot (a-L_{\text{arm}})^3}{a} = -6.276 \cdot \text{lbf} \cdot \text{in}^2$$

$$y := \frac{1}{E \cdot I_z} \left[\frac{F_{\text{push_y}}}{6} \cdot x^3 - \frac{F_{\text{support_y}}}{6} \cdot (x-a)^3 + F_{\text{mirror_y}} \cdot (x-L_{\text{arm}})^3 + C_3 \cdot x \right]$$

Since the maximum deflection occurs at $x = L_{\text{arm}}$, we substitute L_{arm} for x in the above equation

$$y_{\text{max}} := \frac{1}{E \cdot I_z} \left[\frac{F_{\text{push_y}}}{6} \cdot L_{\text{arm}}^3 - \frac{F_{\text{support_y}}}{6} \cdot (L_{\text{arm}} - a)^3 + F_{\text{mirror_y}} \cdot (L_{\text{arm}} - L_{\text{arm}})^3 + C_3 \cdot L_{\text{arm}} \right] = -0.475 \cdot \text{in}$$

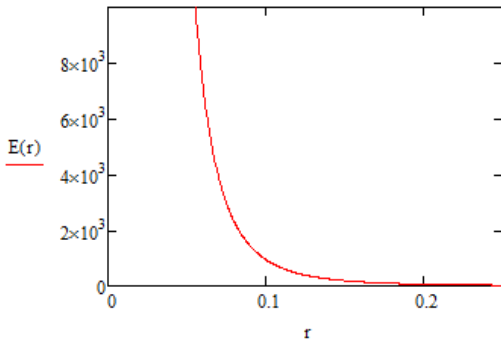
Since we know the maximum deflection, y_{max} , we can solve for a suitable Elastic Modulus, E

$$y_{\text{max}} := -0.57357 \cdot \text{in}$$

$$E(r) := \frac{1}{y_{\text{max}} \cdot \left(\frac{\pi}{4} \cdot r^4\right)} \left[\frac{F_{\text{push_y}}}{6} \cdot L_{\text{arm}}^3 - \frac{F_{\text{support_y}}}{6} \cdot (L_{\text{arm}} - a)^3 + C_3 \cdot L_{\text{arm}} \right]$$

$$E(r_{\text{arm}}) = 2.129 \times 10^6 \cdot \text{psi}$$

Plotting the equation for the Elastic Modulus over radius of the Arm



$E_{max} := .464 \cdot 10^6 \text{ psi}$ Maximum Young's Modulus of Polyamide (Nylon) PA according to CES edupack

$$r := \left[\frac{4}{\pi \cdot Y_{max} \cdot E} \left[\frac{F_{push_y}}{6} \cdot L_{arm}^3 - \frac{F_{support_y}}{6} \cdot (L_{arm} - a)^3 + C_3 \cdot L_{arm} \right] \right]^{0.25}$$

$$r = 0.09147144 \text{ in}$$

Calculations for support

Dental Mirror MQP
 Nicholas Careau
 David Nill
 November 20, 2008

Supporting Calculation for the Selection of Material for the Support

$d_{\text{mirrorhandle}} := .2\text{in}$	mirror handle diameter
$b := .25\text{in}$	base width of support ring cross section
$h := .0625\text{in}$	thickness of support ring cross section
$I := \frac{b \cdot h^3}{12} = 5.086 \times 10^{-6} \cdot \text{in}^4$	second moment of area of support ring about the x-axis
$\alpha := 30\text{deg} = 0.524\text{-rad}$	half angle of opening in support
$R_{\text{support}} := \frac{d_{\text{mirrorhandle}}}{2} + h = 0.163\text{-in}$	radius of support snap ring
$F_y := .516\text{lbf}$	Approximate force in y-direction, Refer to Arm Calculations
$Z := \frac{1}{2} \cdot d_{\text{mirrorhandle}} + \frac{1}{2} \cdot h = 0.131\text{-in}$	support displacement in z-axis
$P_z := \frac{F_y}{\sqrt{3}} = 0.298\text{-lbf}$	Load in z-direction
$E := \frac{P_z \cdot R_{\text{support}}^3}{Z \cdot I} \cdot [(\pi - \alpha) \cdot [1 + 2 \cdot (\cos(\alpha)^2)] + 1.5 \cdot \sin(2 \cdot \alpha)] = 1.502 \times 10^4 \cdot \text{psi}$	Elastic Modulus of Required Material
$E = 1.502 \times 10^4 \cdot \text{psi}$	Elastic Modulus Selected

Figure taken from Practical Stress Analysis....

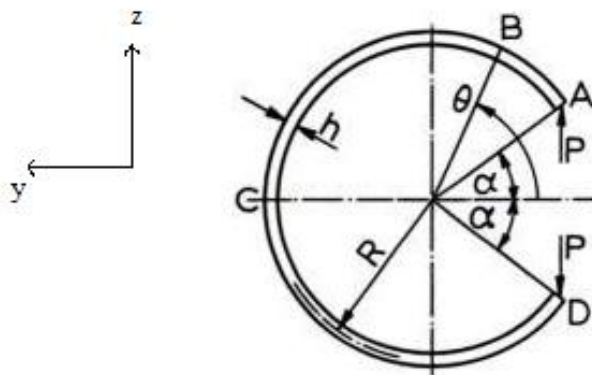


Fig. 26.2 Snap-ring spring.

Calculation for Friction Force between support and mirror handle required to overcome friction force between wiper arm and support.

During maximum deflection, Normal Force of Support on Wiper Arm is:

$$F_{\text{wiperarm}_y} := 3.769\text{N}$$

Assuming coefficient of kinetic friction between selected material of wiper arm and support is 0.33 (plastic on plastic)

$$\mu_{\text{s_arm_and_support}} := 0.33$$

The force of friction between wiper arm and support is:

$$F_{\text{friction_am_and_support}} := F_{\text{wiperarm}_y} \cdot \mu_{\text{s_arm_and_support}} = 1.244\text{N}$$

This force is experienced at the interfacing between the support and the mirror handle and must be overcome by the friction between the support and the mirror handle.

Assuming a static friction coefficient of 0.333 between the support and the mirror handle,

$$\mu_{\text{s_support_and_handle}} := 0.333$$

Also including a safety factor of 2, the normal force required for this friction would be

$$F_{\text{normal_support_handle}} := 2 \cdot \left(\frac{1}{\mu_{\text{s_support_and_handle}}} \cdot F_{\text{friction_am_and_support}} \right) = 7.47\text{N}$$

Given that the angular relation of forces is roughly a 30-60-90 triangle

As is widely known, ratio of sides of 30-60-90 triangle is 1:sqrt(3):2

Thus, required force P in the Z-axis is:

$$P_{z_axis} := \frac{F_{\text{normal_support_handle}}}{2} = 3.735\text{N}$$

This would be a constantly applied force while the mirror cleaning mechanism is in use. Perhaps a sustained-load fatigue calculation is needed.

The required deflection with theoretical selected material of ABS

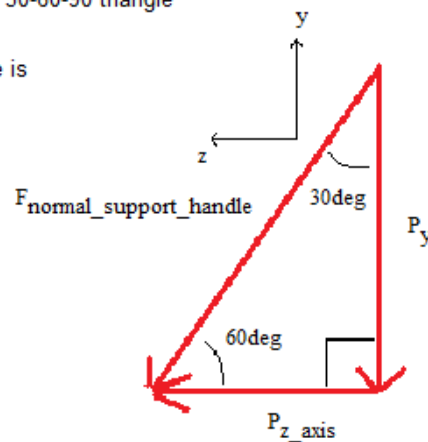
$$E_{\text{ABS}} := .16 \cdot 10^6 \text{ psi} = 1.103 \times 10^9 \text{ Pa}$$

$$x_{\text{deflect}}(P_{z_axis}) := \frac{P_{z_axis} \cdot R_{\text{support}}^3}{E \cdot I} \cdot [(\pi - \alpha) \cdot [1 + 2 \cdot (\cos(\alpha))^2]] + 1.5 \cdot \sin(2 \cdot \alpha)$$

$$x_{\text{deflect}}(P_{z_axis}) = 0.035 \cdot \text{in}$$

Bending Stress of Support

$$\sigma_{\text{bending}} := \frac{6 \cdot P_z \cdot R_{\text{support}} \cdot (1 + \cos(\alpha))}{b \cdot h^2} = 555.023 \cdot \text{psi}$$

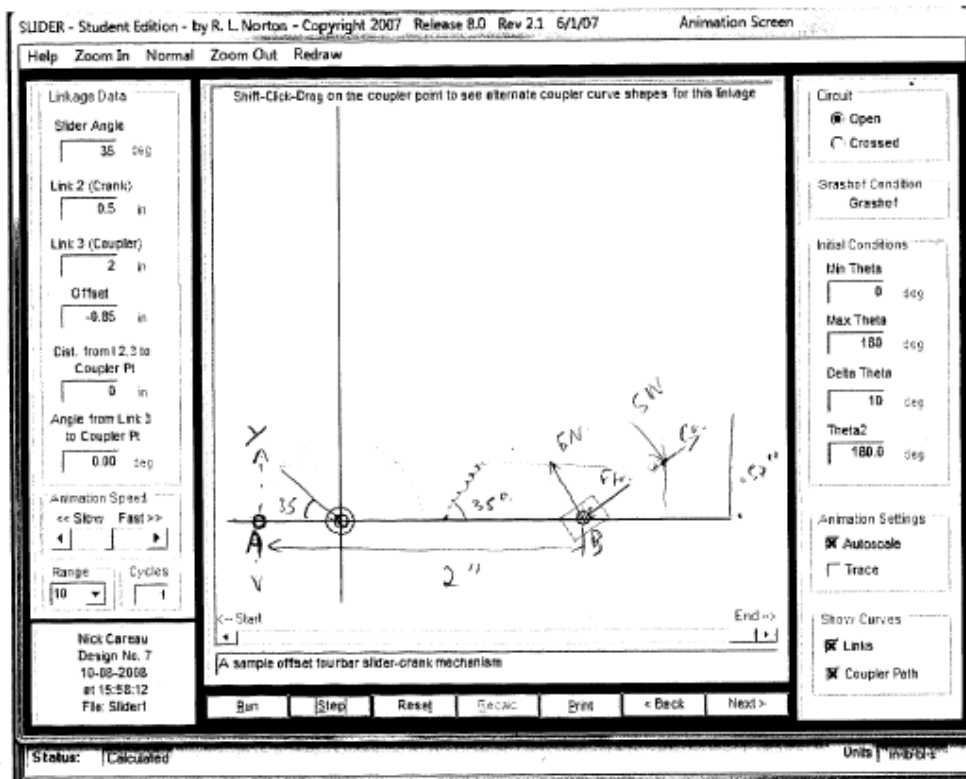


Dental Mirror MAP
 Nicholas Careau
 David Nill
 November 1, 2008

Design with motor analysis

Motion of Crank and Slider

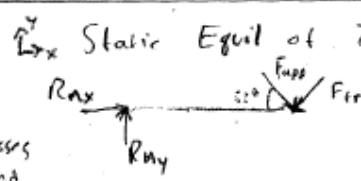
Start Position



Analysis.

Assumptions

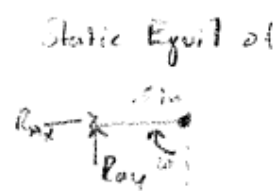
- $\mu_s = 0.30$
- rigid body
- neglects masses of links and machine.



Static Equil of 7" link at starting position.

$$\sum F_y = R_{Ay} - F_{Fup} \sin(55^\circ) - F_{Fr} \sin(35^\circ) = 0$$

$$R_{Ay} = 4.956 \text{ N} = 1.114 \text{ lbf}$$



Static Equil of Crank link at starting position.

Torque required to overcome static equil. (neglects mass)

$$T > R_{Ay} \cdot 0.5 \text{ in} = 0.557 \text{ lbf} \cdot \text{in} = 0.657 \text{ lbm} \cdot \text{in}$$

$$= 8.846 \text{ oz} \cdot \text{in}$$

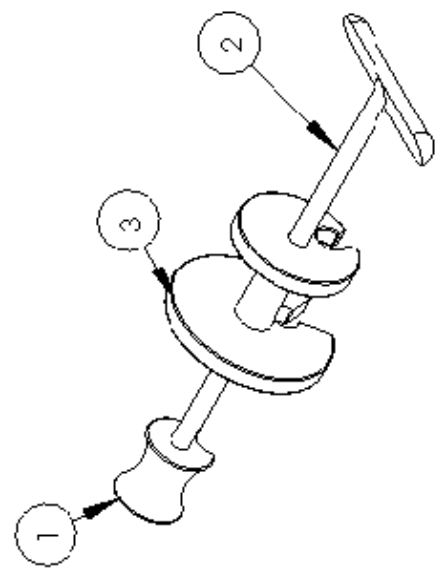
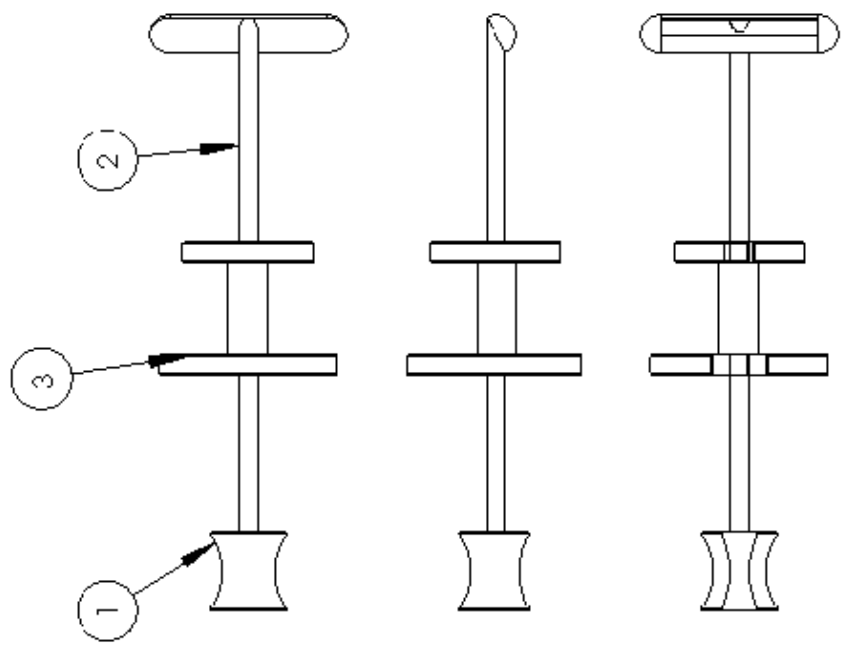
Possible servos:

S_g servos: Torque output of 9-11 oz-in., require external power and controls, programming, needs to be mounted.

NDC/DGN

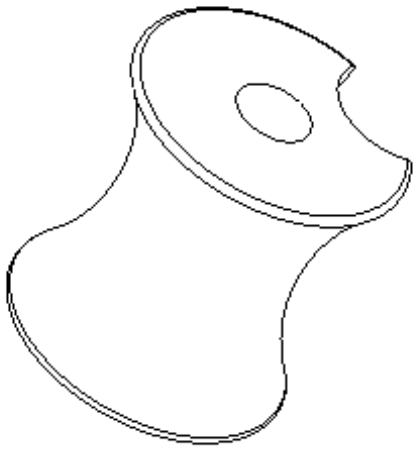
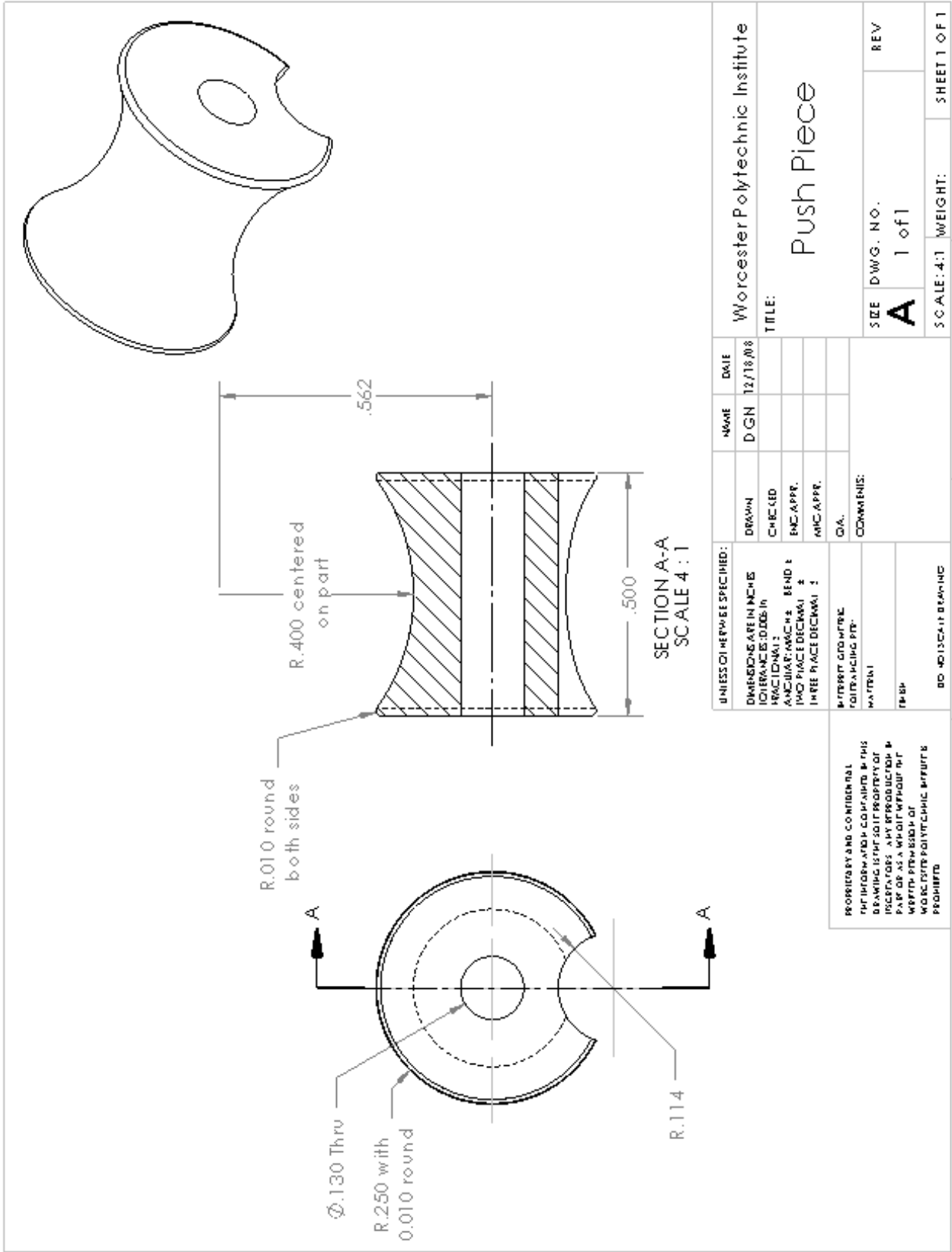
Appendix D: CAD drawings of the Final Parts of the Deflecting Wiper Mechanism

ITEM NO.	PART NUMBER	QTY.
1	Push Piece	1
2	Arm	1
3	Support	1

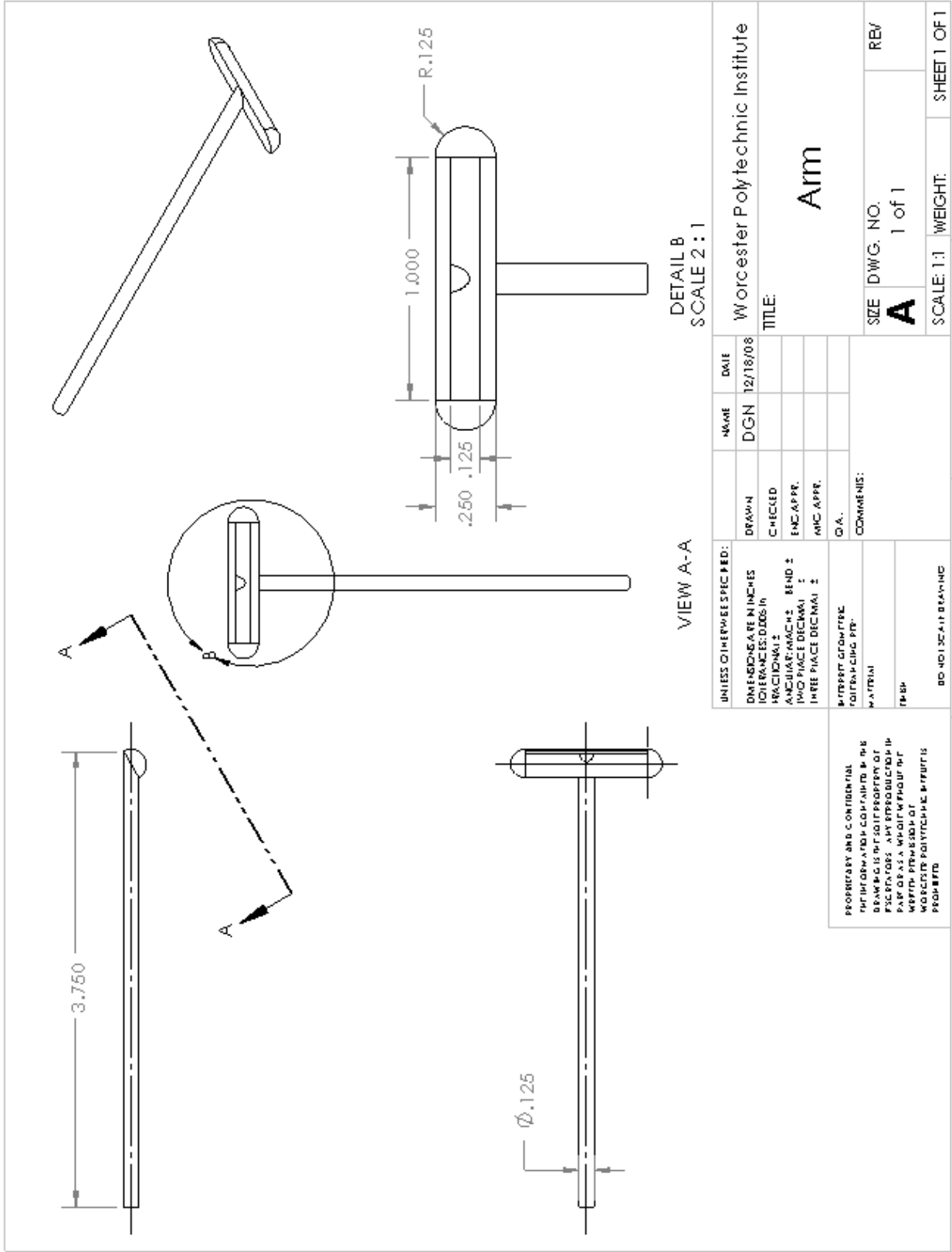


UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES		DGN	10/18/08
TOLERANCES: DECIMAL			
FRACTIONAL: 3			
ANGULAR: MINUS 2, BEND 2			
TWO PLACE DECIMAL: 2			
THREE PLACE DECIMAL: 2			
INTERPRET GEOMETRIC TOLERANCING PER ASME Y14.5			
MATERIAL			
FINISH			
DO NOT SCALE DRAWING			

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SCALE: 4:1	WEIGHT:	SHEET 1 OF 1	1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Worcester Polytechnic Institute
DIMENSIONS ARE IN INCHES	DRAWN	DGN	12/18/88	TITLE: Push Piece
FRACTIONS: 16ths In	CHECKED			
DECIMALS: 1/1000 In	END APPR.			
ANGLES: 1/16 INCHES	AMC APPR.			
TWO PLACE DECIMALS	D.A.			SIZE DWG. NO. A 1 of 1
THREE PLACE DECIMALS	COMMENTS:			SCALE: 4:1 WEIGHT: SHEET 1 OF 1
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VIEW A-A
DETAIL B
SCALE 2 : 1

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DIMENSIONS ARE IN INCHES		DGN	12/18/08
TOLERANCES: FRACTIONS			
DECIMALS			
FRACTIONS: 1/16			
DECIMALS: .0005 - .0010			
TYPED PLACE DECIMALS			
THREE PLACE DECIMALS			
DRAWN BY			
CHECKED BY			
ENGINEER			
DATE			
PROJECT			
DRAWING			
SHEET			
OF			
TITLE		Arm	
SIZE		DWG. NO.	REV
SCALE		A	1 of 1
SHEET 1 OF 1		WEIGHT:	1

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