Semi Pro

Design Report

Semi Pro - Team 16
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Calvin College Engineering 339/340
Senior Design Project
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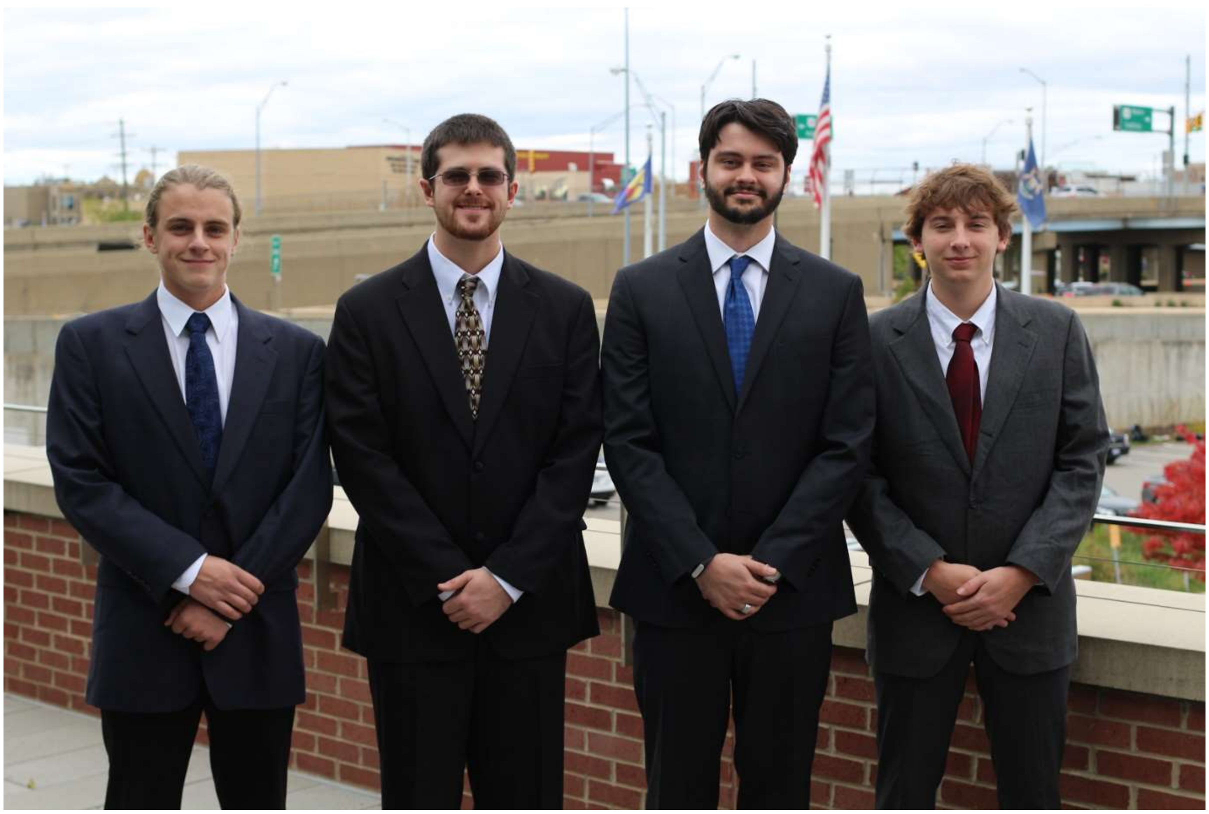

Abstract

Team 16 – Semi-Pro has tasked itself with the safety concern of blind spot visibility with semi-trucks and the fuel efficiency of trucks on the road. Implementing a camera system will replace the need for optional convex blind spot mirrors, improve vehicle fuel efficiency and increase visibility in the truck. Calvin College's senior engineering team Semi-Pro's proposed camera system would decrease semi-truck drag by nearly 0.1%. If implemented on every truck in the United States, this camera system would save an estimated 99 million gallons of fuel. Drag force from the mirrors on the truck was reduced to 4.7% of the drag induced by the mirrors by use of cameras in lieu of convex blind spot mirrors. Lastly, accident reconstruction and liability insurance will both be aided by the digital recording capabilities of the system.

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1 Introduction

This Final Report document contains information pertaining to the Calvin College senior design Team 16 - Semi-Pro. Outlined below is the tackled issue along with a proposed solution extensively backed by testing, analysis, and financial feasibility.

1.1 Problem Definition

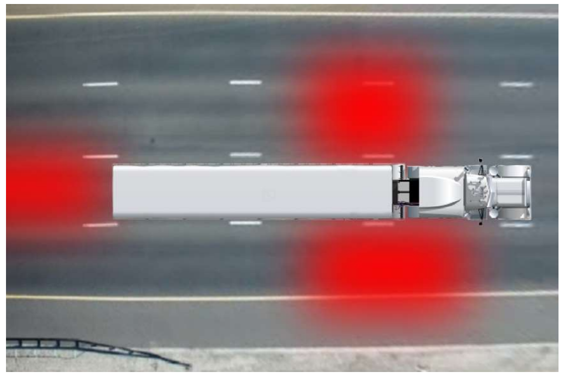


Figure 1: Semi-truck Blind Spots

Blind spots are a common safety concern for all drivers. A blind spot is any area around a vehicle of which the driver does not have vision. Blind spots typically increase with vehicle size, and as you can see in the figure above, are very large on semi-trucks. Currently, semi-trucks have the option to use additional convex mirrors for enhanced visibility, as seen in the figure below, to increase visibility in blind spots. These convex mirrors increase the wind resistance on the truck which requires more work to move the semi-truck, resulting in a lower fuel efficiency. Companies, like Inontime (a freight service based out of Zeeland, MI), have been reducing the number of convex mirrors implemented onto their fleet in order to save in fuel costs. Our team seeks to decrease the drag on the truck while increasing the blind spot visibility.

Figure 2: Semi-Truck with Convex Blind-Spot Mirror

The other problem our team seeks to solve is visibility when backing a semi-trailer into a dock. Currently semi-truck drivers rely solely on side view and rearview mirrors to back up. While it is a skill than many seasoned truck drivers have mastered, backing a semi-trailer up can still be very difficult and dangerous. There is no way to see if there is something directly behind the truck. Team Semi-Pro seeks to make a way for semi-truck drivers to have a convenient back-up system with more visibility and a way for to see if there are people or objects in the way when backing up a trailer.

If semi-truck drivers get into an accident there is not a way to tell who is at fault rather than word of mouth and after crash analysis. Based on data from the Federal Motor Carrier Safety Administration, there are on average more than 90 thousand injury accidents per year on large trucks and busses, more than 4,600 of which are fatal accidents. [1] With our design, we hope to both lower these numbers, and provide accurate data when a crash does occur. This will promote our integrity, stewardship and trust design norms mentioned later in this document. Some type of digital recording system would aid law enforcement with crash data; holding drivers, and trucking companies accountable for the problems caused by crashes in semi-trucks.

1.2 Design Considerations

To solve the problems listed in section 1.1, team Semi-Pro primarily focused on a camera system. This camera system would be introduced in replacement to the optional convex mirrors, but would not replace the standard and legally required side mirrors. In the case of camera failure, no visibility would be lost for a semi-truck which decided to omit any blind spot convex mirrors. The proposed camera system can be broken into three categories: the front camera system to replace the optional convex mirrors, the rear camera system to add visibility behind a trailer, and the central display system to allow the driver to view all camera displays and simultaneously record them. This system will be discussed in further detail later in the report.

1.3 Team

The team consists of two electrical and two mechanical engineering students. Taylor Mulder and Isaac Embertson are the electrical engineers of the team. Robert Lanser and Adam Christensen are the mechanical engineers on this project. All members of the team are in the fourth year of the engineering program at Calvin.

Adam Christensen is a mechanical engineering student pursuing a sustainability designation. Adam has interned at Masonite Corp., an internationally leading residential door manufacturer, in their codes and compliance department at their research and development center, and with Farnsworth Group, an architectural-engineering firm, as an HVAC and plumbing design engineer. After graduation, Adam has accepted a commissioning position with Farnsworth Group in Shorewood, IL.

Isaac Embertson is an electrical engineering student in his fourth year of the engineering program at Calvin. He has one year of internship experience at BorgWarner, working with the assembly systems of an automotive plant. He has accepted a position with Apex Controls as a Controls Engineer.

Taylor Mulder is an electrical engineering student in his fourth year at Calvin College. He also has a minor in Computer Science. He has two years of internship experience at Cadillac Castings, Inc working in electrical construction and controls engineering with a significant focus on computer vision. He has accepted a job with Cadillac Castings, Inc as an Electrical Engineer.

Robert Lanser is a mechanical engineering student with an international designation, and four years of internship experience at Innotec, working with the production of automotive components. Robert has accepted a job at JR Automation as a controls engineer.

1.4 Course & College Information

Calvin College is a liberal arts college with an ABET accredited engineering program. For the engineering program, seniors are required to work on a final capstone design project in the last year of the program. This capstone class is split up in two semester long classes called Engr 339, and Engr 340. ENGR 339 is a two-credit semester portion of the class. This section is focused on defining the project and determining feasibility of the project. The second section of the class, Engr 340, is a four-credit class that is focused on implementing and developing the final design project.

2 Project Management

Initial organization is key to any project's success. Understanding this, Team 16 has laid out groundwork to provide themselves with the best opportunity for success by establishing team organization, a schedule, a budget, and approach method early in the design process. These are outlined in detail below.

2.1 Team Organization

The team is split into two primary parts, mechanical and electrical. The mechanical engineering students, Adam Christensen and Robert Lanser, focus on the physical components of the system. This includes the camera case, mounting equipment supporting the cameras, drag calculations, and system assembly. The electrical engineering students, Taylor Mulder and Isaac Embertson, work primarily on the software and communication aspects of the camera system. This includes all coding, data display and networking between system components.

Team 16 has an established mandatory meeting time on Thursday of every week. In addition to the scheduled time, Team 16 meets on mornings according the availability of individual team members. Team meetings typically begin with updates and a brief informational introduction to get the group up-to-date, then work is assigned and the group carries out the assigned work. At the conclusion of the meeting, the group assigns work yet to be completed and sets a date for the next group meeting. All meeting minutes are recorded by Isaac Embertson. All documents pertaining to tasks and scheduling are kept in a central location on a Google Drive and are accessible to all members.

The following figure shows the current organization of the group, including advisors, course instructors and consultants associated with the project.

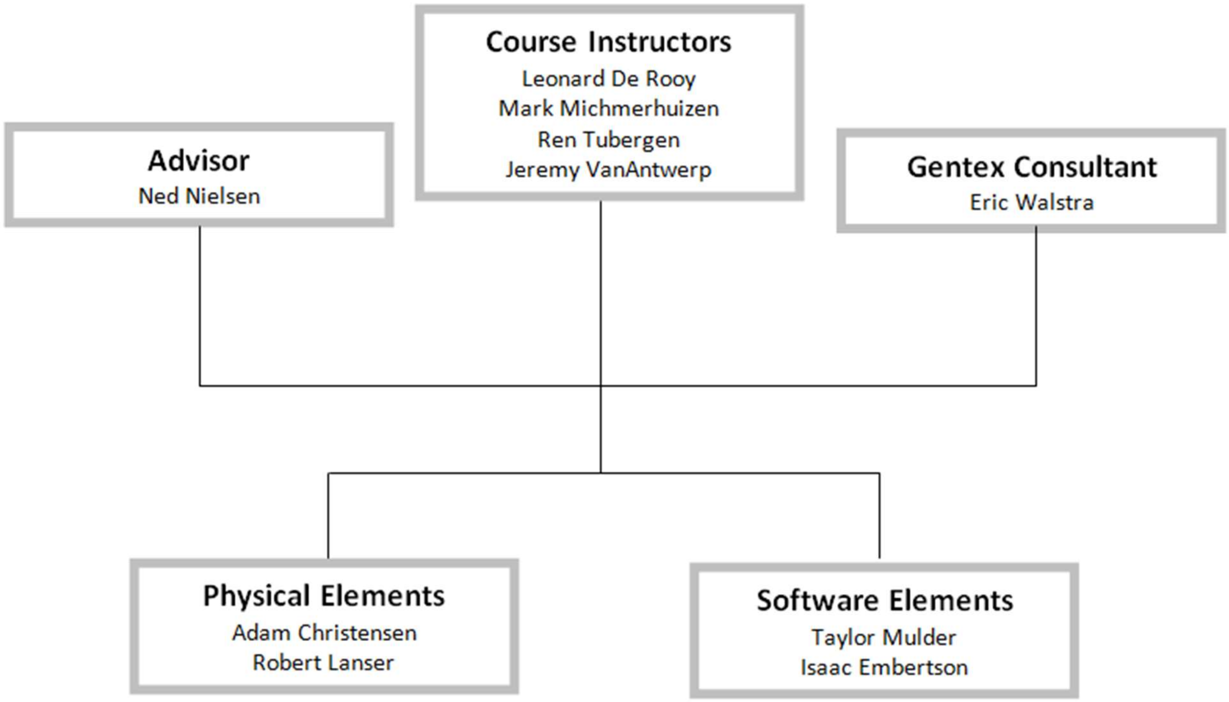


Figure 3: Team Management Diagram

2.2 Schedule

The group handles scheduling in several ways. A work breakdown structure (WBS) was created by Adam Christensen to schedule tasks for the project and set priorities and hierarchies for tasks. During the weekly meeting, Team 16 discusses the state of tasks currently scheduled, new tasks that must be scheduled and any issues that have arisen in the schedule. If any issues arise, they are discussed within the group and resolved in a way that takes each member of the group into consideration. The average number of work hours for each team member varies depending on the current tasks assigned, but this number is typically 5-7 hours per week. For further information, see Task Specifications and Schedule.

2.3 Budget

Isaac Embertson maintains the budget and all team finances and purchases. Calvin College graciously provided $500 dollars to Team 16, and any additionally needed funds would have to be fundraised. During the project feasibility stage, the team estimated the needed budget to produce working prototypes of the proposed system, and it was determined that addition funding was not needed. During the construction of the prototype, the budget is reviewed and is updated before every expenditure to ensure that the project stayed on track.

2.4 Method of Approach

After identifying the problem, Team 16's process of design was to research existing solutions, create a list of requirements for the proposed system, brainstorm solutions, implement a design and prototype it, and finally test that prototype and repeat the process for any failures. The team's initial research led to existing camera solutions which were expensive ($200+ per unit) and incomplete. This led to the requirement that the team should design a complete system and so work was divided. Each member researched with a concentration on the part of the project that corresponds the most with their engineering concentration and experience. Useful research is evaluated at the group level and either used as a tool to work on the project or set aside for possible future use.

Brainstorming sessions involved the whole group. Each member submits solutions, whether to the larger problem or some smaller issue within the project. These ideas are evaluated by the group and the best idea is used. If there is a tie in the decision, the group enters an educated discussion where all sides of the issue are presented and the group, as a whole, re-evaluates the ideas present. These decisions became the design choices and were tasked to individuals based on concentration. Prototypes were then created, evaluated by the team for failures, and the design process was restarted for final revisions.

In terms of communication methods, each member of the group has an equal voice whenever the group needs to discuss a topic. The group members maintain good communication with each other, keeping the group tight and well-informed through weekly update meetings. Outside of meetings, most communication was done primarily through social media and email.

In all approaches, Christian values are applied. Each team member is responsible for maintaining self-control and imitating Christ in their interactions with one another. Each team member is expected to act with integrity and positively represent Calvin College.

3 Requirements

Given the issues outlined early in this document, it was determined that the proposed system must have interface, functional, performance, environmental, and legal requirements. For this project to be considered a success, the system must conform to the following requirements.

3.1 Interface Requirements

The interface of the camera system must be convenient for the truck operator to use. This convenience will mean that the camera system does not require the driver to turn it on, make adjustments, or modify the camera system in any way after initial installation. The diver should be able to look at the side he wishes to change lanes in and see the camera display that corresponds to the same side.

3.2 Functional Requirements

Some functional considerations of this project include the stability of the camera mounts, which must be able to hold up against wind, 70 MPH driving speeds, and occasional impacts from small road debris. The camera system must be durable; the camera system must be able to hold up in harsh conditions including, but not limited to, freezing, muddy, or hot conditions. The cameras must withstand a temperature between -20 to 120 degrees Fahrenheit. The video must have sufficient quality; video must be wide angle of at least 120 degrees so drivers can clearly see what is behind them when driving. Finally, the system must be able to store at least 1 minute of footage and have sufficient viewing range. The wireless connection between rear camera and display must be able to easily and reliably reach from a truck cab to the back of a 53' trailer.

3.3 Performance Requirements

Some performance requirements taken into consideration that team Semi-Pro hopes to achieve through research and development include the following: A measurable increase for the miles per gallon (mpg) of a semi-truck, measurable reduction in force acting on the front of the vehicle, and a viewing angle that significantly increases visibility in all blind spots. In addition, our design must meet or exceed the requirements set by our design norms.

3.4 Legal Requirements

According to Section 393.60(e)(1) of the FMCSRs (Federal Motor Carrier Safety Regulation), vehicle safety devices must be mounted "(A) not more than 100 mm (4 inches) below the upper edge of the area swept by the windshield wipers; (B) not more than 175 mm (7 inches) above the lower edge of the area swept by the windshield wipers; and (C) outside the driver's sight lines to the road and highway signs and signals."[10] This means that any and all displays that are implemented in our design must conform to these regulations and not obstruct the view of the driver.

The system will not replace any required equipment in place on semi-trucks that are currently required by law, such as the side mirrors, which are required by Section 393.80 of the FMCSRs. The system is instead intended to be used in addition to these required systems to aid in visibility.

The system shall not infringe on any currently existing patents. Should we choose to apply for a patent for our design, some additional research must be done to absolutely ensure that a patent does not already exist for our system and demonstrate that our system is unique. As of this report, there are several patents for automotive camera systems, but none corresponding to our design.

4 Task Specifications and Schedule

These are the major tasks and subtasks for this project, as well as percentage of completion:

Assigned Project Tasks:

- PPFS Outline (100%)
- WBS (100%)
- Project Brief for Industrial Consultant (100%)
- 4 Oral Presentations (100%)
- Website (100%)
- Poster (100%)
- PPFS Draft (100%)
- PPFS (100%)
- Final Report First Draft (100%)

Project Design Tasks:

- Mirror Testing (100%)
    - Test Guideline Generation (100%)
- Side Camera Design (100%)
    - Component Research (100%)
    - Case (100%)
    - Mounting Design (100%)
- Display Design (100%)
    - Layout Design (100%)
    - Communications (100%)
    - Component Research (100%)
- Rear Camera Design (88%)
    - Component Research (100%)
    - Case (100%)
    - Communications (50%)
    - Mounting Design (100%)
- DVR (100%)
    - Research (100%)
    - Implementation (100%)

The estimated total expected design time needed to complete the design is over 1000 hours.

5 System Architecture

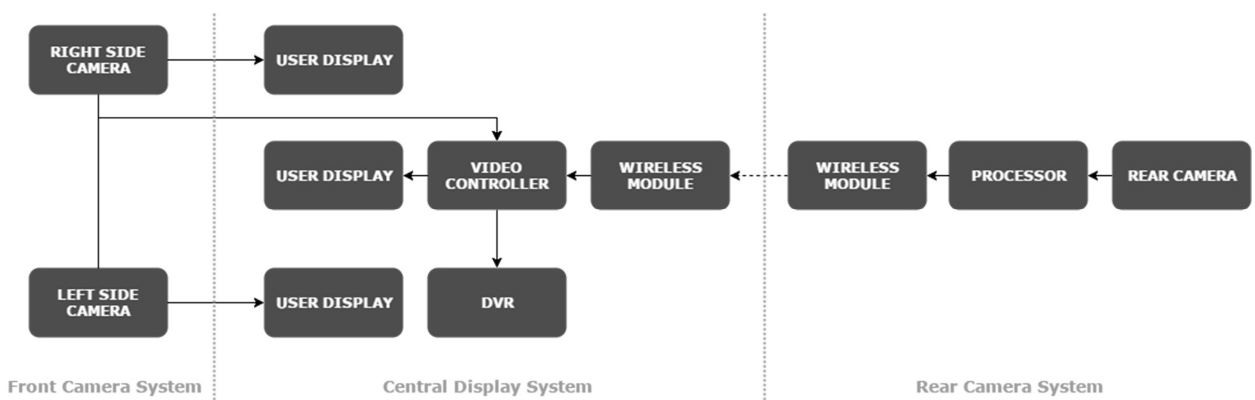


Figure 4: System Block Diagram

The figure above describes the hardware of the system. The system is divided into three main systems: the front camera system, central display system, and the rear camera systems. The front system consists of two cameras that are mounted to the front of the truck to replace the optional convex mirrors. The central system consists of three displays, a junction hub to hold all the wiring and a microcontroller acting as both the video controller and wireless module. The central system is located in the cab of the truck. The rear portion consists of a camera and a microcontroller that will act as both a video controller and an Ethernet to Wi-Fi bridge. The rear module and the central system will communicate via Wi-Fi communications while the front cameras and central system will communicate via a wired connection.

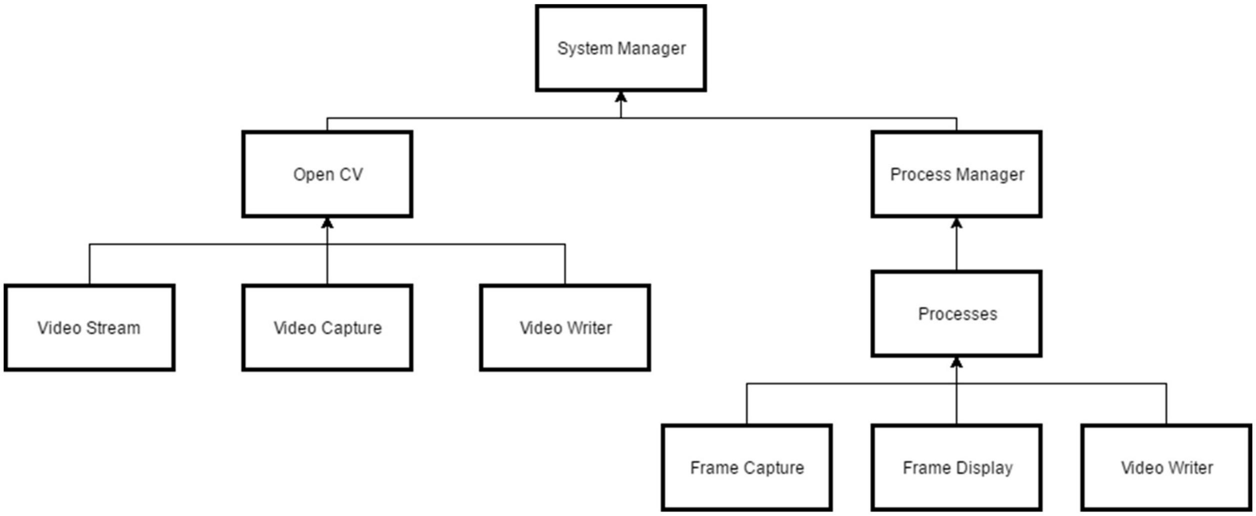


Figure 5: Software Architecture

The software of the entire system is managed by a central object called the System Manager. This object brings together the OpenCV library and the multi-process system designed by the team. "OpenCV is an open source computer vision and machine learning software library. OpenCV was built to provide a common infrastructure for computer vision applications and to accelerate the use of machine perception in the commercial products." [11]. Three main objects were used from the OpenCV library: Video Streamer, Video Capture, and Video Writer. These three provide the essential capabilities needed for the project. The multi-process system performs the tasks. A separate process is created for each camera of each process needed. These all continue in parallel as long as the system runs.

6 Front Camera System

The front camera system is a camera mounted to the fenders of the truck. The purpose of these cameras is to detect cars in the side blind spots. This camera is wired into the truck and displayed in the cab. The system consists of a case which houses all the components, a camera, a light, a lens, and the wiring.

Figure 6: Front Camera

6.1 Design Criteria

Design criteria for the camera on the front camera system included: Latency, cost, size, infrared capability, and availability. The camera needed to be low latency in order to get instant video feed to the cab. Low cost was desirable to fit within the project budget. A smaller size was desirable to make a small more aerodynamic case. We wanted to have the camera infrared capable in order to work with an infrared light. This will satisfy the Trust design norm as the camera must be reliable in a variety of situations and environments.

Design criteria for the case were: Water resistance, aerodynamics, size, mounting, access to wires, a way to house all of the components, and durability. It is important that the case is waterproof, and durable because it will be exposed wind, rain, dirt, and impact. The case needs to have an aerodynamic shape in order to decrease drag. The case needs to hook up securely to the mount. There needs to be access to wires so the camera can be wired into the truck. All the selected electrical components need to fit into the case conveniently. The case needs to be durable, and can hold up to wear and tear as well as impact from objects on the road.

The camera must give clear visibility in night-time conditions without being a distraction to other drivers on the road. For example, using an external light to illuminate other cars may impair the vision of other drivers on the road.

The mounts should be adjustable, sturdy, and able to mount to different contours of the truck. The camera needs to be adjustable so the driver can move where the camera is viewing to get good vision of the blind spot. The mounts need to be sturdy and able to take the drag force on the camera. The mounts should be able to mount up to the truck easily for a curved surface as well as on a flat surface.

6.2 Design Alternatives

Three different camera styles were considered and analyzed. The first camera style is a USB connected camera. These cameras are very cheap, mainly due to their prevalence in a desktop environment. They are very easy to connect and run. Most computers and microcontrollers have USB ports and so this camera would be useable with almost any video controller we decided on. The major difficulty with using USB cameras in our design is that the USB protocol was designed around a desktop environment and so has a specified cable length of 5 meters. This length is shorter than our upper estimates of cable lengths needed. Additionally, depending on the quality of the camera, there can be large amounts of latency. The second camera style is an analog camera, and for our considerations we looked at an NTSC camera. These cameras all provide nearly instantaneous video transmission as well as being able to transmit large distances. These cameras are prevalent in many different recreational activities and thus their prices are low. The problem with these cameras in this design is that to implement our DVR capabilities, we need to convert the analog signal transmitted by these cameras into a digital signal that can be saved. This means additional hardware will need to be designed or purchased to be properly implemented. The last camera style that was considered is an Ethernet Internet Protocol camera. These cameras are cheap as well as being able to transmit very large distances. The main advantages of this camera are the quality that it can transmit and the distance that it can transmit. A secondary advantage is that they are very easy to interface with. The only but very large disadvantage of these cameras is that they tend to have a high latency.

Some alternatives that were evaluated for the fabrication of the case. Aluminum sintering was considered, as the aluminum would be strong and impact resistant. Despite this, the aluminum sintering process would be expensive and harder to find. 3D printing was a cheap, available option with tight tolerances, but 3D printed prototype parts tend to be brittle. Injection molding would be impact resistant, with tight tolerances and cheap to produce at high volume, but have huge upfront costs.

Alternatives for the design of the overall case were: one-piece plastic case, two-part case, and a three-part case. The one-part case would be difficult to fit all the components into conveniently without wiring issues, or weatherproofing. The two-part case would not properly house the wiring in the system. The three-part case could hold all the electrical components, and have access to the wiring of the camera.

The alternatives for attaching the pieces of the case together were: screw together, push together and quarter turn, snap together, and adhesive. The screw together option would be difficult to design properly, and has a chance of threads getting broken or worn. The push together and partial turn option would be difficult to get a tight weatherproof seal. The snap together design would have potential for snaps for breaking, but would be easy to adjust if necessary. The gluing option would be a permanent fixture, and could not be undone when the parts have been adhered.

The team picked between lighting and not lighting the side camera system. Not lit, the camera would be able to see headlights on cars at night, but could not make out objects if the headlights were off. In addition, the distance from the bright lights can be deceiving in the dark. LED lights were considered, but the lights would shine on passing cars and distract the driver. Security cameras generally use infrared lights, which utilize a wavelength not visible to the human eye, but the camera picks up the light in the dark.

Mounting alternatives were: mount the case directly to the semi-truck, mount using a ball and socket joint similar to a rearview mirror in a car, fabricate mounts, or use Go-Pro mounts. Mounting directly to the truck would not give any adjustability to the system and would need to be changed to mount on different contours of the truck. The ball and socket joint would be difficult to mount to the truck and would be difficult to lock the ball into place, so the camera could easily be knocked loose. A fabricated mount would be costly and would not adjustable. The Go-Pro mount is adjustable, lockable, and able to mount onto contoured surfaces.

6.3 Design Decisions

Team Semi-Pro decided on a NTSC camera donated by The Gentex Corporation. These NTSC cameras have been used in other automotive back-up cameras and are automotive grade. This camera meets the requirement for latency, streaming video without a delay. The cost and availability requirements were hit for this camera as well as it was donated. This NTSC camera is an appropriate size for our system and an aerodynamic case can easily be built around it. This camera is also desirable because it is infrared capable.

The front camera case was 3D printed, because it was affordable for the team budget and available with the 3D printer on campus. The part was made with clips and snapped together. Our team decided on the snaps, so the part could be taken apart, tested, and put back together. The team decided on a 3-part case to cover the wires, and fit all the components.

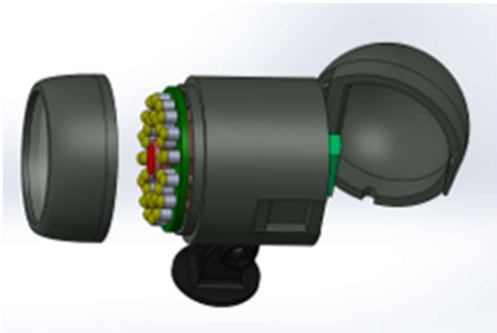


Figure 7: Front Camera CAD Model

To aid camera visibility in low-light conditions, Team Semi-Pro decided on a simple ring configuration of Infrared (IR) emitting LEDs. A light sensor was integrated with the LEDs to switch the LEDs on only when in low-light conditions, reducing the power wasted by the system.

Figure 8: Day vs. Night Infrared Display

The optimal mount was decided to be a Go-Pro mount with a ball joint that could be tightened. The base of the mount is flexible so it can be fixed to various contours on a truck. The Go-Pro mount is easy to fix to the camera and the system is easily adjustable so the driver can adjust to suit the blind spot that is shown.

7 Rear Camera System

The rear camera system is a wireless system mounted to the top-back of the trailer. It views the rear blind spot using a wide-angle lens with an Ethernet camera and microcontroller. A directional antenna is attached for communications. The components will be powered from the trailer's power and housed in a low-profile, streamline box since it will have direct wind resistance.

7.1 Design Criteria

The rear camera should be equipped with a processor and wireless communication module powerful enough to send a clear video stream to the driver with no interference from other devices. The primary limiting factors of wireless communication are the bandwidth, reliability, and range. The communication method will need to have enough bandwidth to stream a live video stream and be able to provide a smooth displaying experience while being able to work in any common conditions seen on the road. All of this needs to be packaged in a sealed and secure container that is mounted at a height high enough to give the driver a perceptive distance between the trailer and objects behind it.

7.2 Design Alternatives

The biggest decision was choosing a form of wireless communication to transfer the video stream from the rear camera. Interference was a very large problem that directed the wireless protocol choice. Analog signals were ruled out due to this and thus limited communication to digital forms. Two common methods were analyzed along with a newer less common method. These were Bluetooth, Wi-Fi, and spread spectrum respectively. Spread spectrum is unique for instead of transmitting over a few frequencies at high power, it transmits over a large spread of frequencies at low power. This means it is less likely to run into interference since devices would only interfere over a few frequencies. The major problem with method is the price of components of these capabilities. Next, Bluetooth was rejected. While being reliable and able to be used at larger ranges, it contains significant limitations with bandwidth.

There were two main options for a camera in the rear section. These were an analog camera or an ethernet IP camera. While an analog camera was ideal for our front systems, it would have to function differently in the rear section. The rear section transmits its video signal wirelessly. Because of the wireless communication method that was chosen, an analog camera would not be able to be incorporated easily into the design. The signal would first need to be digitized before the signal would be able to be sent. This could be done with a capture device but they add an additional cost to the cost spent on the camera. An ethernet camera works well with the wireless communication method chosen, as the signal is already digitized and in the correct format needed to be used in Wi-Fi communications. Also, it has a high frame rate along with a high resolution to provide excellent video quality.

Three housing options were analyzed to house our electronic components for the rear module. The first was a removable container that could be transferred between different trailers. At the beginning this was our desired outcome. The benefits of a container designed to be removable is that it can be transferred between different trailers. This would be especially useful when used by independent truckers. The second option analyzed is a container that mounted on the truck in a permanent fashion. This method of mounting has the benefit of being more secure than a removable housing along with having the option to be directly wired to the trailer, thus eliminating the need for a designed power source or energy storage system. The final analyzed housing is one that is incorporated into the trailer design. This type of a container would not be able to be prototyped or implemented in a system that we design. It would need to be built into the trailer at construction. The benefits of a housing such as this is it would be extremely durable, depending on where it placed, as well as being low in profile and not adding any additional drag, which is the primary goal of our system.

7.3 Design Decisions

Wi-Fi was the communication method that was chosen as it stood out in the categories assessed. The problem we see for the future is interference if introduced to highly residential areas (e.g. apartment complex, cities, subdivisions) since about 61% of Americans own Wi-Fi routers. [2] This problem was designed to be minimized through the implementation of directional antennas and thus limit any interference with similar systems or any Wi-Fi enable device in operational range of the system. To provide this Wi-Fi communication, a Raspberry Pi in an Ethernet to Wi-Fi bridge configuration was chosen, as the components are readily available and simple to implement. An ethernet IP camera was chosen as the camera as it is easily integrated into the system and easily communicates over Wi-Fi. The housing of the rear section was not prototyped or completely designed in this project. We determined that our rear module would need to be built into an actual trailer. This decision was made after discussion with employees of the company Inontime. They expressed concern with an external module placed at the rear of their trailers. The trailers are constantly bumping into objects, whether it be the loading dock they are backing up to or the bridge they just barely have clearance to drive under. A proposed integrated system can be seen in the figure below.

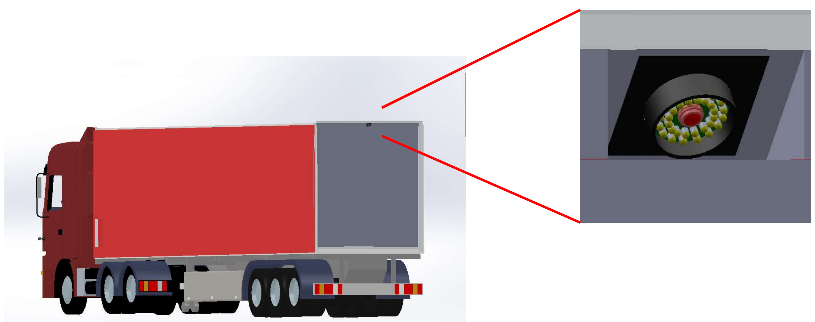


Figure 9: Integrated Rear Camera

8 Central Display System

The central display system includes all components that are installed in the cab. This includes three monitors which display the feeds of each front camera and the wireless rear camera and the microcontroller which communicates to it. In addition, the microcontroller along with analog video capture devices record all camera feeds and save them to an external storage device provided by the user for accident reconstruction and insurance liability.

Figure 10: Display

8.1 Design Criteria

The camera displays must be large enough such that no visibility is lost in comparison to the mounted convex mirrors. The displays must be positioned in a way that is natural and comfortable for the driver. The left (driver) and right (passenger) displays must display the feed from the camera as close to instantaneously as possible to give the driver live updates to the situations in the truck's blind spots. The rear camera display must have low latency in transmitting data to provide the driver with enough time to react to a changing situation when driving the truck at low speeds in reverse. In accordance with our design norms, the displays must be reliable and worthy of the customer's trust. The displays must not waste energy or space within the truck cabin, supporting the Stewardship design norm.

The software of the system should be well organized, easily expandable, and well documented. The code needs to be expandable so that if future systems were to be designed, more cameras could easily be integrated. The code needs to be documented so if an immediate change need to be made, the original coder does not need to be present. Also, all support libraries need to be well documented and supported as design choices can change anytime and all changes need to be supported. The code needs to be well organized so those that the system can be understood by those who are not the ones who wrote it. These criteria follow our chosen design norms: Trust, stewardship, and integrity. The user should be able to trust that the system is reliable as well as easily to determine that it contains nothing malicious. The requirement that the system be easily expandable also demonstrates stewardship.

8.2 Design Alternatives

Initially, the primary factors guiding the team's decision regarding displays was screen size, type of input and power consumption. The team decided early in the project that the input would be analog due to the type of cameras donated to the group by Gentex. The power consumption factor was taken under consideration when choosing a display, but all displays the team considered used similar voltage, so this factor was not used as a determining factor. In terms of design alternatives, this left the screen size as the determining factor.

The first design alternative the team considered were 4" LCD dash-mounted monitors. Although they are reasonably priced and do not take up large amounts of space in the truck cabin, the visibility of each monitor is less than what was desired. It would be required to mount the displays closer than the desired A-Frame section of the window to maintain the visibility of the cameras compared to the convex mirrors. For this reason, the team decided that this would not satisfy the criterion for the displays.

The next design alternative the team considered was the 5" range LCD dash-mounted monitors. These are more expensive to implement, but provide a significant improvement in visibility compared to the 4" monitors. Despite the larger display size, the monitors appear small enough to avoid wasting space or distracting the driver. This alternative was promising with regards to the criterion for this aspect of the design.

The next design alternative for the LCD displays considered was the 6" range of LCD dash-mounted monitors. These provide even more visibility than the 5" monitors at significant additional cost. In addition, the number of displays at this size range were difficult to locate at prices that would fit within the team's budget. Due to the limited budget for the team, this display size range was rejected.

Two separate video controllers were compared as they were both familiar to the design team members. These were a Raspberry Pi and an Arduino. The Arduino is a simple to use processor that has an abundance of documentation and guides. The significant differences with a Raspberry Pi and Arduino are cost, processing power, IO pins, Operating System, and relative size. Arduinos can cost as low as $5 while Raspberry Pi's typically are at least $30. The difference in processing power of the two considerations is massive. The new Raspberry Pi 3s boast 4 cores at 1.2 GHz while the Arduinos are typically single core running at either 8 or 16 MHz. Not only does the Raspberry Pi have a clock speed at least 75 times faster, it also contains multiple cores for true multi-tasking. Both the processors have IO pins that are programmable, but the Arduino has both digital and analog IO pins while the Raspberry Pi only has digital. To use a Raspberry Pi, an Operating System, commonly referred to as an OS, must be installed to be able to use the functionality of any of the boards systems.

Multiple image and video processing libraries were assessed for use within this project. The first of these is Ozeki Camera SDK. This is a powerful SDK for camera applications and is very easy and intuitive to use. The major problem with this is that it needs a windows operating system. The second alternative we looked at is called Webcam Capture API. This library is well documented and looked very easy to implement. This software package looked very promising until a very important problem with this package was noted. The software runs into issues when compiled and run on an ARM processor. A package that was considered briefly was mjpeg-camera. This package comes with scripts and examples that would have kicked off the project with little to no programming needed. The problem with this library is that it only works for mjpeg-cameras. One of the first libraries that we researched is OpenCV. This library is very well documented and has a large and active community along with support for both Python and C++.

Two main languages were considered for the programming of this project. The first was C++ and the second was Python. C++ is a language that the Calvin College Computer Science department teaches many of its computer science classes in and so is the language that both electricals have the most experience using. The major disadvantage of C++ in relation to the project is its implementation of multi-threading and multi-processing. Python is a language that the Calvin College Computer Science department uses for its intro to computer science class and so both electricals have some experience although it is less significant than that of C++. Python is a very easy language to learn and use and is very easy to read and understand. The languages implementation of multi-threading and multi-processing is simple and easy to write and understand.

8.3 Design Decisions

The front cameras will feed to 5" LCD displays within the truck cabin. Five inch displays were chosen for the front camera displays because they will provide a better perceived viewing area than the current convex mirrors due to the difference in viewing distance from inside the cab to the nose of the truck. Apparent angular size measurements were calculated to support this decision. Video capture cables connected to a Raspberry Pi 3 will allow the front camera feeds to be processed and recorded for future viewing. A Raspberry Pi 3 was chosen because video processing can be very intensive and the Pi 3 models are capable of intensive operations due to their 4 cores at 1.2GHz. All displays and cameras are operational, display correctly and video is successfully being recorded. The display for the rear camera adds a whole new angle of visibility for the truck driver. All of these combined will increase visibility for the driver and thus increase their awareness of the road around them.

OpenCV was the library chosen to provide the support for all camera capabilities. This software library provides all the basic functionality needed to make the system work. It can construct and read video streams, capture frames, display videos, and write videos to a file. The library can be implemented in both Python and C++ which were the two main languages considered by the team. This library is compatible and in many instances, optimized for a Raspberry Pi implementation, which is the process that was chosen as the controller. To implement this library, Python was chosen as the language to write in. The main reasons of this selection are primarily, the simple and efficient multi-threading and multi-process implementations Python is capable of. Very early on, it became clear that multi-threading or multi-processing would be essential as capturing video data as IO bottlenecks it. Multi-threading and multi-processing both provide massive speedup for IO intensive operations. The multi-processing capabilities was the deciding factor on choosing Python as it is the core of the code. A last benefit of choosing OpenCV is that it has a large community base along with several beginner tutorials and code examples.

Figure 11: Example Cab Layout

9 Integration, Test, Debug

The main testing that the system underwent was drag testing to compare the fuel efficiency of the camera versus the convex mirrors. Drag testing was completed using 3 methods: EES calculations using the drag equation and estimated drag coefficients, SolidWorks flow simulations, and real world road testing. For all tests and simulations velocity was set at 60 mph. A complete test report has been appended to this document, and the results are outlined below.

9.1 Calculated Test

The calculated test in EES was calculated using the drag equation shown in the appended drag test report (Equation 1). Drag coefficients were estimated using similar shapes. A drag coefficient of .7 was used for the mirror, and .6 was used for the camera case. Forces for mirror and camera were calculated to be 21.24 [N] and 1.207 [N] respectively. These calculations gave some reference values for other trials and simulations.

9.2 SolidWorks Flow Simulation

Mirrors, and the camera case were modeled in SolidWorks, and a flow simulation was run on the models. The force on the object was measured using a SolidWorks feature, and the drag force was calculated in the simulation using the drag force equation (Equation 1) solving for drag coefficient. Drag coefficients for mirrors and cameras were found to be .813 and .536. Drag force was found to be 22.77 [N] for the mirror, and 1.09 [N] for the camera.

9.3 Road Test

Tests were performed on the road using a force gauge and Arduino, used as a data acquisition unit (DAQ), to measure force created from the drag on the object. The force gauge was less accurate for lower forces, so the mirror test came out close to expected, but there was a significant amount of noise when testing the camera case. What we could gather for this is that our SolidWorks simulations were proven accurate by the validity of our mirror test.

9.4 Drag Test Results

The SolidWorks simulation was determined to have the least uncertainty in calculations because nothing needed to be estimated. Road tests, and preliminary calculations were good verification for the drag forces and drag coefficients. Force was converted into power, which was converted into how much fuel it would take to move the object against the drag force. This fuel use was compared to the fuel efficiency of the vehicle. The mirrors were found to use 0.1% of the total truck's fuel. Using cameras in place of mirrors created 4.7% of the force that mirrors created. This 0.1% may seem insignificant but applied on every semi-truck in the united states it accounts for 104.9 million gallons of fuel. Implementing a camera system on semi-trucks would save 99 million gallons of the 104.9 million gallons of fuel.

10 Business Plan

The business plan is divided into three different parts: a marketing study, a cost estimate, and profitability. The marketing study describes the current demand for our product, as well as competition of similar systems. The cost estimate section describes the specifics of starting the production of our product. The profitability section describes the payoff of the system compared to the cost of the system.

10.1 Marketing Study

The marketing study for the industrial trucking camera system includes a comprehensive study of both the completion of our product and a market survey to determine the potential of our product.

10.1.1 Competition

There are current systems that are available on the market. Most of them are built around a backup camera and use that as the focus in their design. Single systems that only include a backup camera are around $300 for the base system. Larger systems that can have multiple cameras, similar to our system, range from $600-$900. Many of the systems for sale currently are not designed for optimal aerodynamics on the road. They tend to consist of re-purposed security cameras and are often sold as individual parts, not as a complete system. Upon research of patented technology, no patents were found for rear or side cameras on the use of semi-trucks.

10.1.2 Market Survey

Team Semi-Pro met with a Inontime which is a trucking company in Zeeland. A main focus of the meeting was to gauge interest in a camera system such as ours in real life. We were able to meet with the head of operations, as well as the equipment expert in the company. The Inontime employees stated that they often remove the convex mirrors, or only use one mirror to increase fuel efficiency. There was interest in a side camera system, but more interest was expressed for an integrated system that would be on the truck when the truck was purchased. Inontime was interested in a few features that our system did not offer, such as the ability to adjust the camera direction from within the truck cab. They were, however, excited by the idea of being able to locate the screens inside the cab, near the side mirrors. They stated that currently if you want to merge lanes, you have to switch between looking at the side mirrors and the front convex mirror, and having the screen close to the side mirror would keep everything in the same view for the driver.

The Inontime drivers were under the impression that the hood mirrors had a larger impact on the fuel efficiency of the truck than our team calculated. Inontime disclosed to our team that the convex hood mirrors cost $205 per pair on a new truck that they purchased. After consulting with Inontime, it was clear that there was a need for this product. With some modifications to the project scope and achievements, this would be a very marketable product and will likely be standard on trucks in the near future.

10.2 Cost Estimate

The cost estimate includes both the summary of the development costs during the project for the school year and the production costs of a system in an industrial setting.

10.2.1 Front System

Here, the front system refers to two front cameras, two displays, and electronics to digitally record the video feeds. The cost of the front system was tabulated using estimated costs of electronics in bulk. In the prototype, team Semi-Pro used 3D printed acrylic for the case. The cost of one case was $53.50, and it took 10 hours to print. This is obviously not a long-term and sustainable way to fabricate the case for the camera. The 3D printed acrylic was a brittle material and broke in a few places. In the long-term, the case would be made by injection molding ABS plastic. The tradeoff between the price of the case at different quantities produced can be seen in the figure below. Team Semi-Pro used a low production volume of 5,000 as a basis for cost estimation. Including mold tooling, production cost, and material cost, the case would come out to $45.23 per case, and multiple parts would be able to be produced per minute. With cameras, processors, and electronics the total cost of the front cameras would be $196.77. The market price of this system would be $400 to cover upfront cost as well as profit.

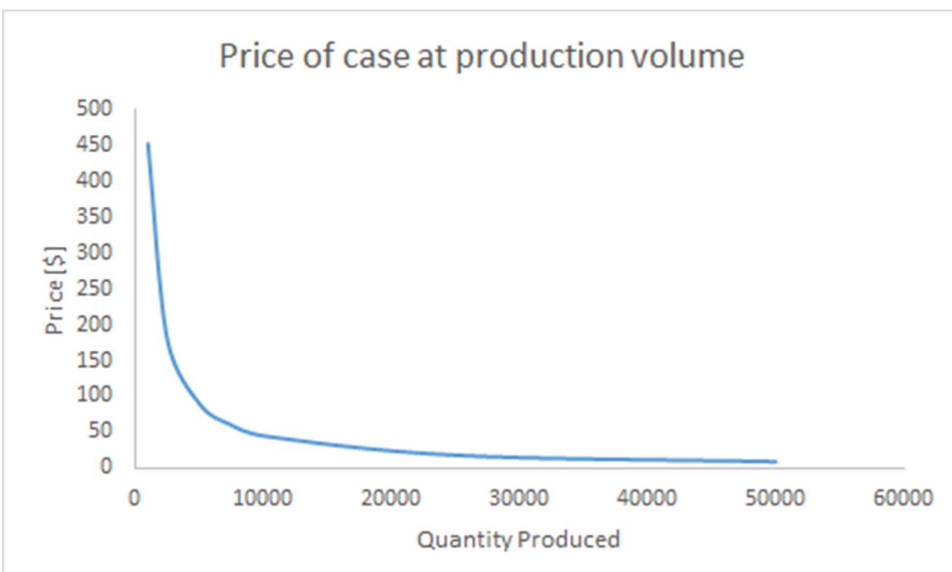


Figure 12: Price of Case at Varied Quantities Produced

Table 1: Cost of Front System Components

Component costs	Per piece	Quantity	Total
IR LED Ring	3.12	2	6.24
Go pro mount	3.54	2	7.08
camera	6.42	2	12.84
Controler	39.95	1	39.95
Electronics	5	1	5
Display	17.6	2	35.2
Total Case Cost	45.23	2	90.46
Total	**196.77**		

10.2.2 Rear System

The cost of the rear system was created with the estimated cost of components bought in bulk. Although we have determined that the rear system would be integrated into the trailer, the cost of a case and the cost of converting a trailer for the camera and components is not easily obtainable. The cost of components for the rear system is approximately $71.60. The primary cost is due to the Raspberry Pi, with the directional antenna and additional electrical components forming the remaining cost. The market price of the rear system would be approximately $150 to cover upfront costs and profit.

Table 2: Cost of Rear System Components

Component Cost	Per Piece	Quantity	Total
Ethernet Camera	15.12	1	15.12
Raspberry Pi	41.99	1	57.11
Directional Antenna	4.49	1	61.60
Misc. Electrical	10.00	1	71.60
Total	**71.60**		

10.3 Profitability

The camera system has an indirect payoff of accident prevention, but it is extremely difficult to quantify the accident prevention savings, so it will not be estimated financially in this report. The side cameras have a direct payoff with the drag reduction. With the 95% reduction in drag force of the side cameras there is a quantifiable amount of money saved. It was assumed that semi-trucks get 120,000 miles per year, and a mile per gallon average of 5.88 [mpg]. With these assumptions, the payoff of the system can be seen below in the figure below. An estimated fuel cost of $2.50 which is fairly close to the price of fuel 5/1/2017 was used for payoff assumptions. The payoff was found to be 1.7 years. The cameras would save $299 per year in fuel comparted to the convex hood mirrors.

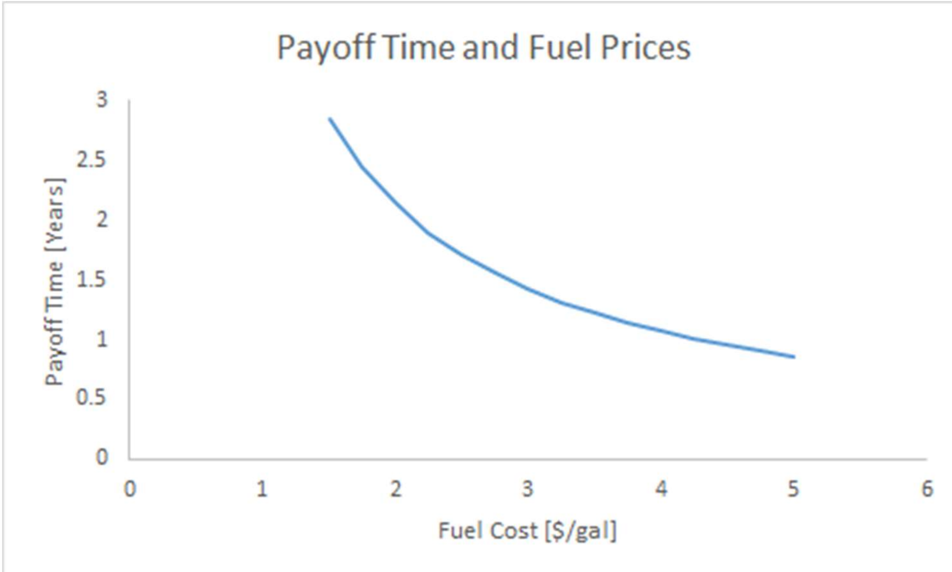


Figure 13: Payoff Time at Various Fuel Prices

11 Conclusion

The development of this camera system on semi-trucks showed that replacing the convex mirrors with cameras is a viable option, and would save a small fraction of fuel for the truck. Although it is not a huge fuel savings, small gains are important to make on large systems such as this. The increased visibility with the camera is also an added benefit for this project. This system, if implemented, will increase driver's visibility and reduce the number of accidents caused by semi-truck blind spots. An affordable system was achieved at a total cost of $485.10 which will pay itself off in fuel savings when compared to convex mirrors. With a larger budget, more cameras, electrical components, and cases could have been tested and optimized. Future work to do on this project could include testing a larger range of cameras, looking into integrating cameras into the side panel of the truck, and integrating displays into a re-designed interior of a truck. Future projects could include improving communications and other components associated with the rear camera. Overall the camera system was proven to be a possible implantation and beneficial to the trucking industry.

12 Acknowledgements

Semi-Pro would like to thank Eric Walstra from Gentex for his experience and generous donation to the success of Team 16.

Semi-Pro would like to thank Ned Nielsen for his experience and support as Team 16's team advisor.

Semi-Pro would like to thank John Lanning and Eric Bruins from Inontime for their generous donation and experience over the course of the project.

Semi-Pro would like to thank Michelle Krul, Bob DeKraker and Phil Jaspers for their assistance and planning of senior design.

Semi-Pro would also like to thank the families of Team 16 for their support of the project.

13 References

1. https://www.fmcsa.dot.gov/safety/data-and-statistics/large-truck-and-bus-crash-facts-2014
2. https://techcrunch.com/2012/04/05/study-61-of-u-s-households-now-have-wifi/
3. http://www.tadibrothers.com/products/semi-trailer-backup-camera-system-7-monitor-with-a-wireless-battery-mounted-box-camera
4. https://www.adafruit.com/product/3055
5. http://www.buydisplay.com/default/5-inch-lcd-screen-tft-module-800x480-vga-video-av-driver-board
6. http://www.banggood.com/DC12V-13-Sony-960H-CCD-700TVL-2_8mm-Lens-Camera-for-FPV-QAV250-p-974381.html
7. http://www.banggood.com/ICR18650D1-3000mAh-3_7V-Rechargeable-Lithium-ion-Battery-p-936283.html
8. http://www.truckinfo.net/trucking/stats.htm
9. http://www.newegg.com/Product/Product.aspx?Item=N82E16882850075
10. https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&ty=HTML&h=L&mc=true&=PART&n=pt49.5.393#sp49.5.393.d
11. http://www.opencv.org/
12. http://www.camera-sdk.com/
13. http://webcam-capture.sarxos.pl/
14. https://pypi.python.org/pypi/webcam-streamer/1.0.5
15. https://www.npmjs.com/package/mjpeg-camera

Table of Appended Documents

Drag Test of Conventional Convex Truck "Blind-spot" Mirrors and Proposed Replacement Camera System

For Calvin College Senior Design Team 16, 2017

Adam Christensen

Robert Lanser

4/18/2017

Purpose:

The proposed camera system for commercial trucking designed by senior design team, 16, is claimed to reduce drag when compared to conventional convex mirrors trucks implement to increase blind-spot visibility. To prove this statement, the drag coefficient of each component shall be mathematically calculated using physical testing. These results can be compared with Solidworks fluid simulations. With the drag coefficient, force can be quantified for the camera system. This force can then be converted into power, then the power can be compared to the fuel efficiency of the semi-truck. The following report outlines the methods and results of such tests and calculations.

Procedure:

$$F_D = A\, C_D \frac{\rho V^2}{2}$$

Equation 1

The drag equation above calculates a drag force present on an object based on its area, shape, fluid density, and fluid velocity. The drag coefficient, C_D, is a dimensionless quantity which represents the resistance an object has when moving through a fluid based on the complexity of the shape. Since the area of each component is known, the drag coefficient can be calculated for mirror and camera if the drag force is measured as the respective components pass through the air at a constant velocity. The following rig was constructed to measure the drag force.

Figure 1: Testing Rig

The above rig is designed to be loaded onto most vehicles with a roof-rack. The testing components are loaded onto the pivoting arm when the arm is vertical, it will press against a force sensitive resistor (FSR) sensor connected to an Arduino. See appendix for wiring and Arduino code. Since the components are loaded at the contact point of the sensor, the distance to the pivot point is equal for both and the moments are equal. The rig was calibrated by loading known masses onto the sensor. Due to large temperature differences between the testing days, the sensor had to be calibrated each time. The calibration curves can be found in the appendix. The loaded rig is taken down the road at a constant velocity and the force data is collected from force sensor.

Figure 2: Mounted Rig with Loaded Camera

After collecting the drag forces for both the mirror and camera, the drag coefficients can be calculated using Equation 1. With the drag coefficient, and the equations below, the power required to move the object can be calculated.

Force was converted into power using the equation P=F*v. Power was then converted into the work required to move the object. Power was then divided by the energy density of fuel, which resulted in how much fuel the object used per distance (liters/km). This was then calculated as a percentage of the total fuel efficiency of the truck, based on average fuel efficiency.
The camera case, and the convex blind spot mirror were modeled in solidworks, and flow simulations were done to see how the air would move around the objects at 60 MPH. A calculation was created within solidworks to measure both the force on the object, and the drag coefficient. Pictures of the flow simulations can be seen in the appendix.

Results and Analysis:

The results from the three trials, were tabulated and can be seen in the table below (Table 1). The calculations in EES were done with an estimated drag coefficient based on similar shapes. The forces were similar to the solidworks simulated forces. The road test was similar to expected on the mirror test. The camera case test showed different than simulated because of low sensitivity of the arduino sensor that was used. Based on these results we determined that the Solidworks was the most reliable model, and would give us the most accurate estimation for drag on the trucks.

Table 1: Calculated, simulated, and tested results.

	EES Calcs (Cᴅ estimated)		Solidworks Sim		Road Test	
	Drag Coef	Force (N)	Drag Coef	Force (N)	Drag Coef	Force (N)
Mirror only	0.7	21.24	0.813	22.77	0.966	15.5
Camera	0.6	1.207	0.5368	1.097	0.1827	0.22

The largest gain in aerodynamics we found was a reduction in area. The mirror was found to have an area of 97.19 in^2 while the camera was found to have an area of 7.31 in^2. This means that the mirror area was 7.5% of that of the mirror assembly, or a 1:13.2 size ratio.

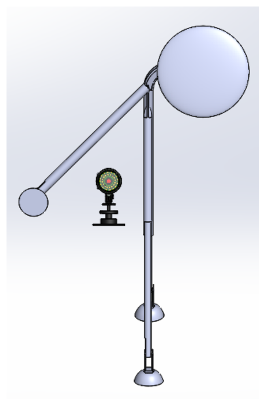
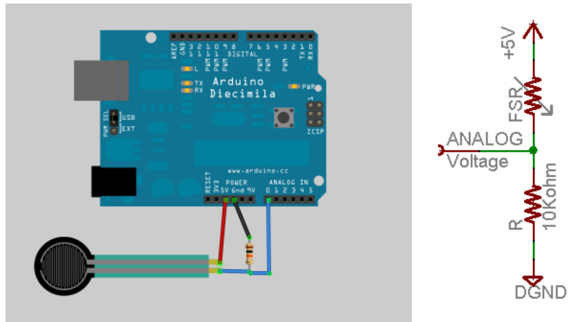


Figure 3: Area of camera compared to area of the mirror

The next gain was in the drag coefficient. The camera had a drag coefficient that was 35% better than the mirror(from .813 to .536). The total force was reduced to 4.81% of that of the camera, or about 1:20.75 ratio of forces. This total drag force reduction was resulted in a fuel efficiency savings of about .1% for the truck.

Appendix:



https://learn.adafruit.com/force-sensitive-resistor-fsr/using-an-fsr
Figure 4: FSR & Arduino Wiring

```
/* FSR testing sketch.

Connect one end of FSR to 5V, the other end to Analog 0.
Then connect one end of a 10K resistor from Analog 0 to ground
Connect LED from pin 11 through a resistor to ground

For more information see www.ladyada.net/learn/sensors/fsr.html */

int fsrAnalogPin = 0; // FSR is connected to analog 0
int fsrReading;      // the analog reading from the FSR resistor
divider

void setup(void) {
  Serial.begin(9600);   // We'll send debugging information via
the Serial monitor
}

void loop(void) {
  fsrReading = analogRead(fsrAnalogPin);
  Serial.println(fsrReading);

  delay(100);
}
```

https://learn.adafruit.com/force-sensitive-resistor-fsr/using-an-fsr
Figure 5: Arduino Code

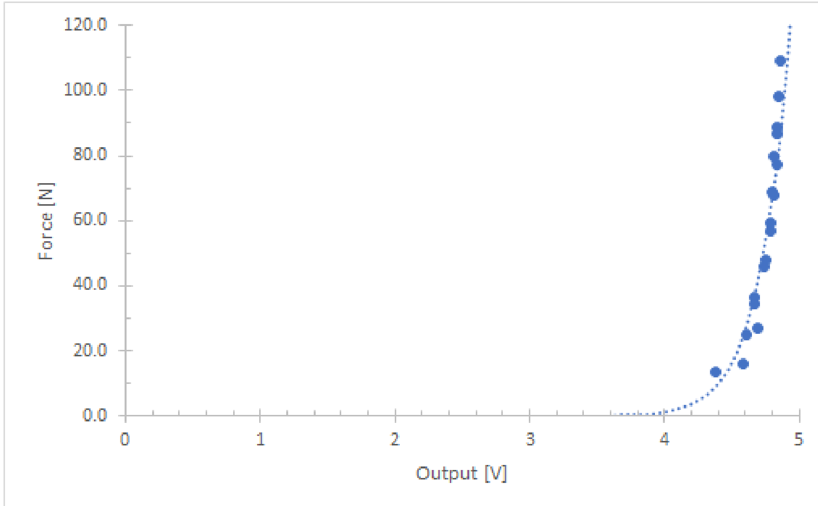


Figure 6: FSR Calibration Curve for Mirror Test

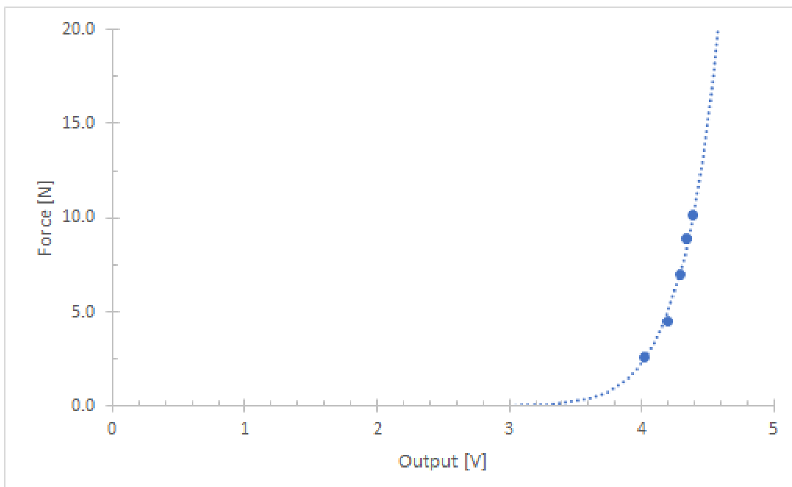


Figure 7: FSR Calibration Curve for Camera Test

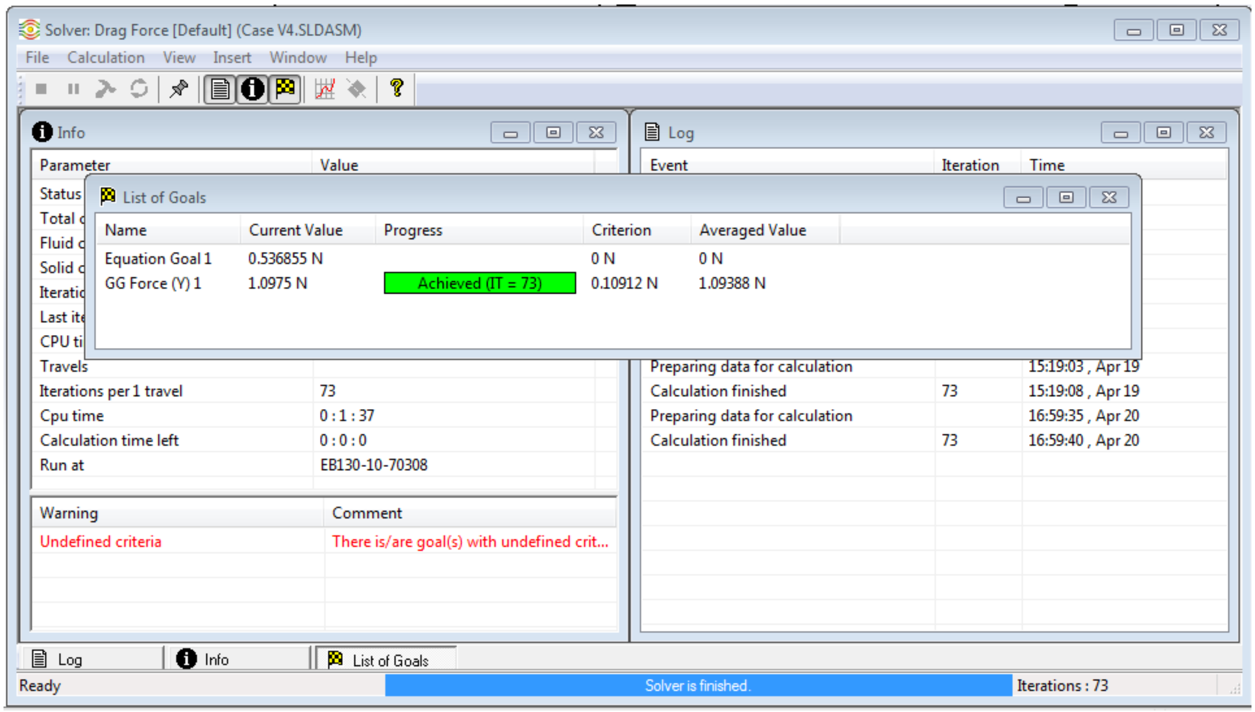


Figure 8: Solidworks drag simulation for camera

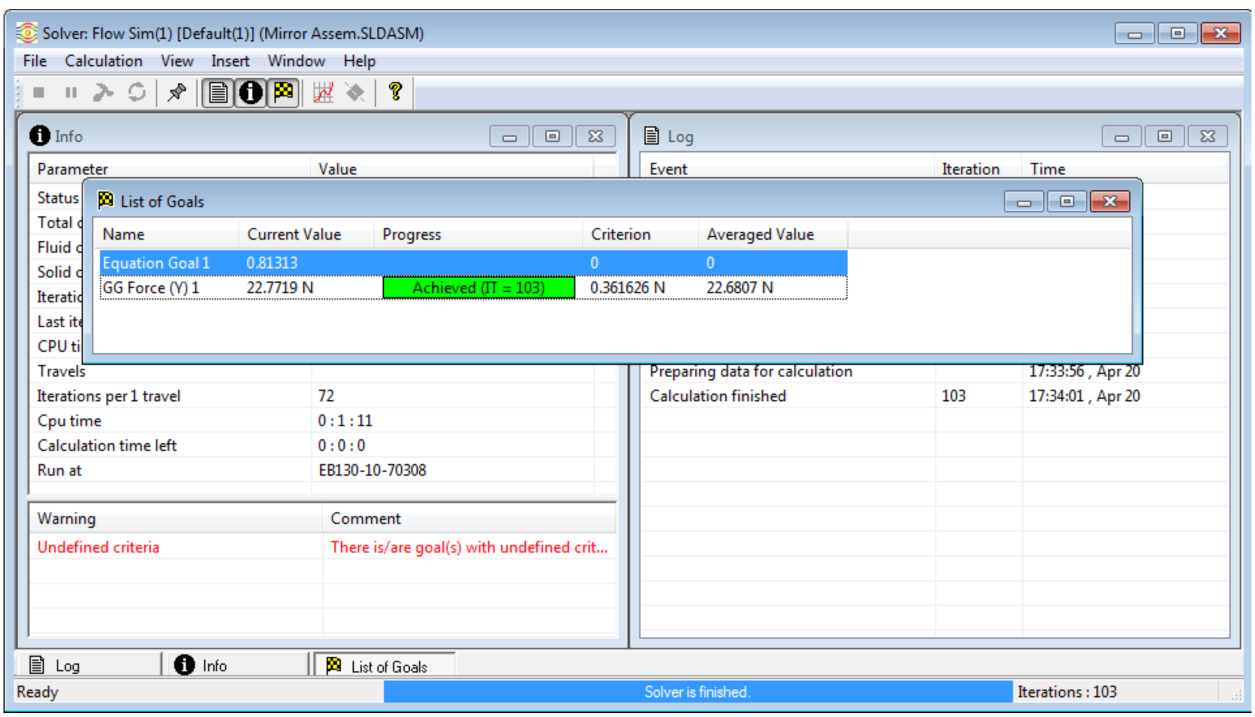


Figure 9: Solidworks drag simulation for Mirror

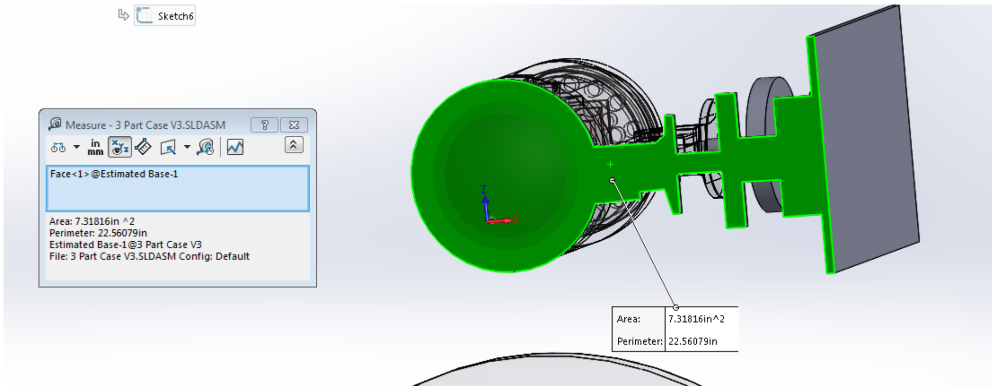


Figure 10: Area of camera case

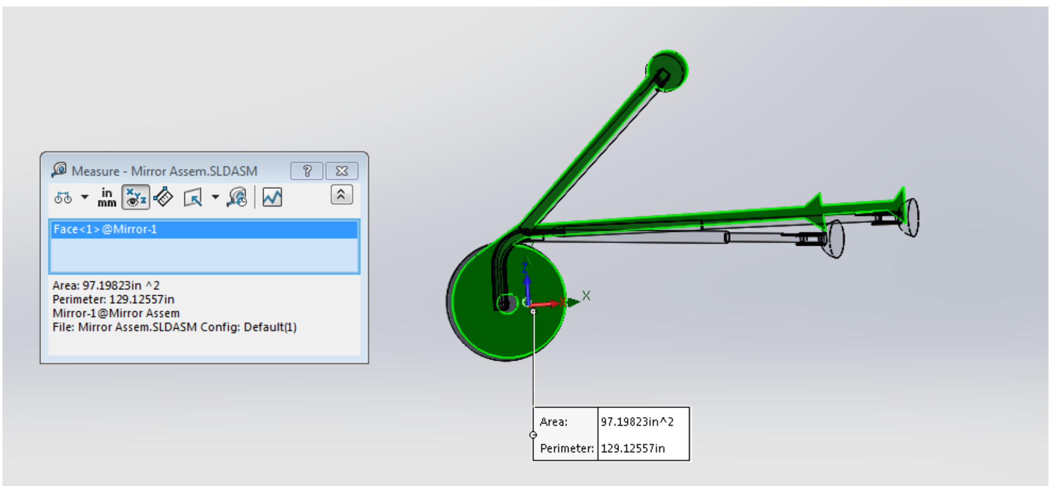


Figure 11: Area of mirror assembly

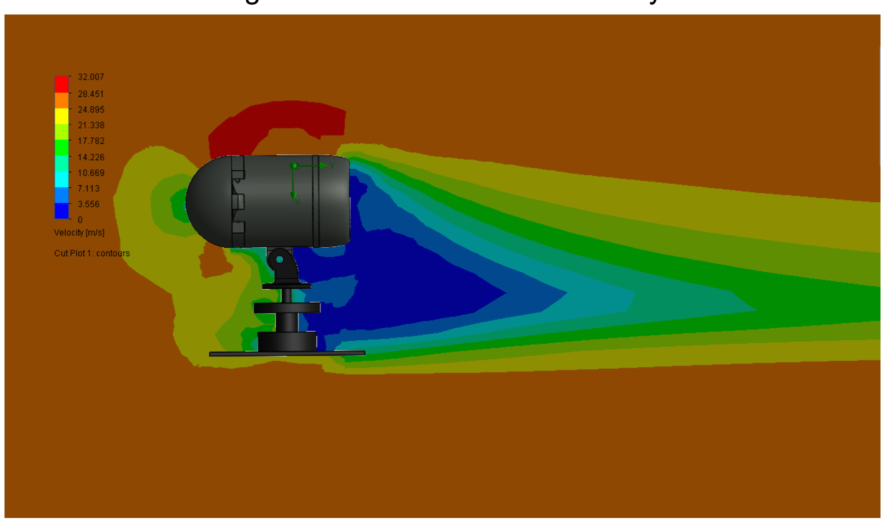


Figure 12: Flow simulation of camera case

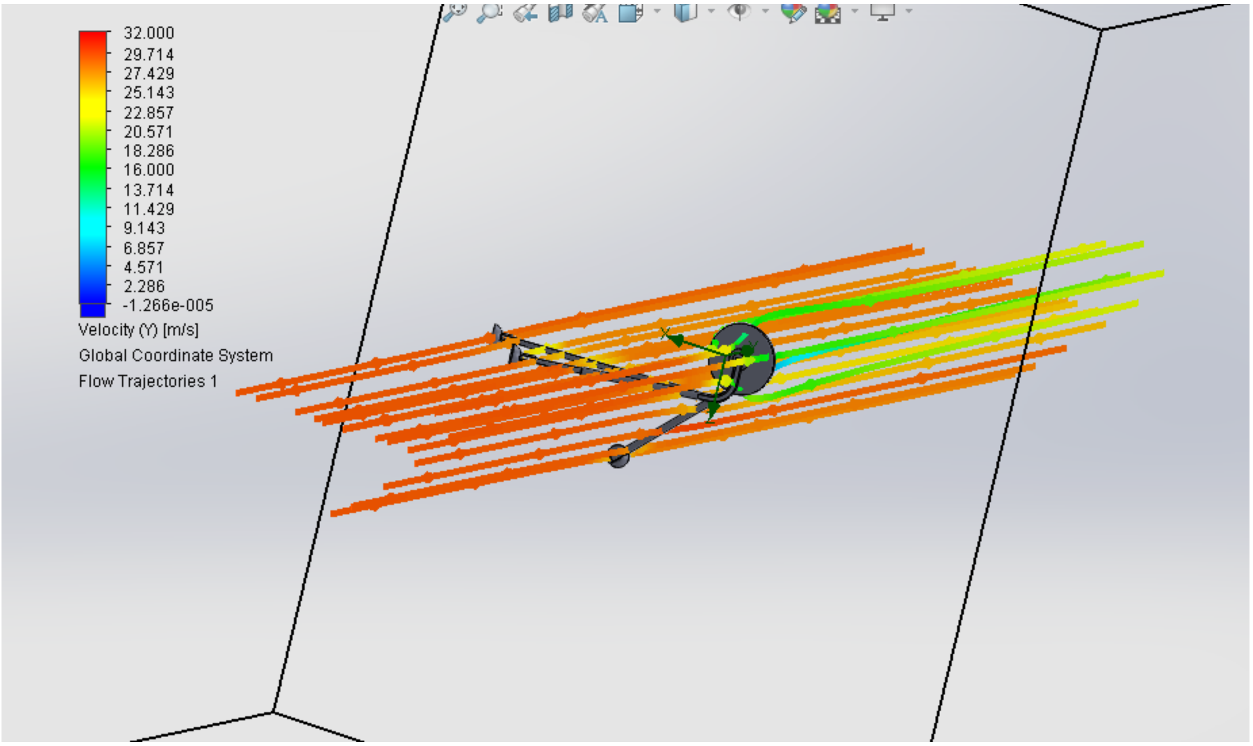


Figure 13: Flow simulation of mirror

Display Sizing Calculations
For Calvin College Senior Design Team 16, 2017
Isaac Embertson
4/19/2017

Purpose:

The objective of these calculations is to determine the minimum distance that a 5” LCD display screen must be positioned to achieve an apparent width similar to that of an 8”, convex circular mirror.

Procedure:

It was estimated that the distance is 65 to 80 inches from the driver-side (left) mirror to the driver and 85 to 100 inches from the passenger-side (right) mirror to the driver. The following measurements were taken and recorded.

Mirror Diameter = 8”
Display Width = 4.31”
Display Height = 2.46”
Display Diagonal = 4.96”

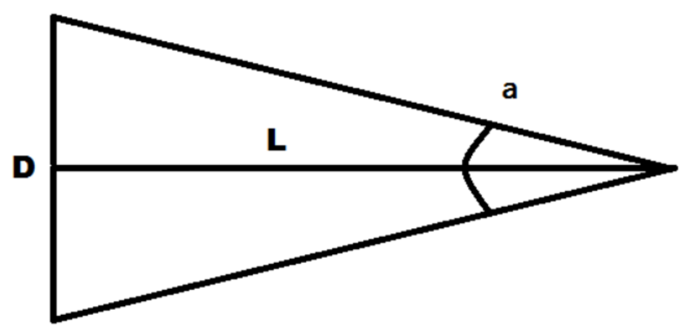


Figure 1: Angular Size Visualization

$$\alpha = 2arctg\frac{D}{2L}$$

Figure 2: Angular Size Relations

Results and Analysis:

Driver-Side

Using the equations for angular size (see Figure 2), the display should be approximately 35”-43” (35.02”-43.10”) from the driver. Using a measurement of 32” (distance from Robert’s head to the driver-side A-frame) and a average measurement of 84” (measured on a physical semi-truck cabin), the mirror would appear to be 3.05”. The display would then appear to be 41.4% wider than the apparent mirror width.

Passenger-Side

Using equation for angular size (see Figure 2), the display should be approximately 46”-54” (45.79”-53.98”) from the driver. Using a standard estimate of 60” from the driver’s head to the passenger-side A-frame and an average measurement of 110” (measured on a physical semi-truck) as the distance to the mirror, the convex mirror would appear to be 4.17” wide. The display would be 3.9% larger than the apparent width of the mirror.

Conclusion:

The calculations completed demonstrate the feasibility for the positioning of the displays within the cabin of the truck. If the displays are positioned at the minimum required distances, the displays will have the same apparent width of the convex mirrors. If the displays are positioned at a shorter distance, their apparent width will be greater than that of the mirrors.

Sources Cited and Consulted:

https://planetcalc.com/1897/