

Agricultural Mobile Irrigation System Engineering Senior Design Report

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EBS 170C, D-Lab II: AMIS Final Report
Agricultural Mobile Irrigation System
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Executive Summary

This report has been compiled with the intent of summarizing the progress made on the AMIS (Agricultural Mobile Irrigation System) and includes the problem scope and development, current design specifications and how they came about, the benchmarks for evaluation, and the results. The main objectives were to build and evaluate the performance of a complete AMIS system.

By examining the state of the project at the beginning of the quarter, we determined that for the successful commercialization of the AMIS, two problems had to be addressed. The first was that the current iteration did not have a viable frame system for efficient deployment and transport of equipment. The second problem was that, for the development of the design, the AMIS team did not have a physical prototype to perform tests on. The lack of a prototype hindered qualitative and quantitative operational tests, and was a vital issue to address.

Furthermore, a number of basic models detailing the physical phenomena taking place during operation of the MIS needed development to further our understanding of the design. Models of the hydraulic performance of individual components were experimentally determined. Frame and spool models were developed during Winter Quarter, and indicate that current prototypes are overbuilt for strength, and are too heavy. Further work, with detailed assumptions about the loads on the reel and frame, will be undertaken. These dynamic models will provide the means for the optimization of dimensions and materials used in the load-bearing parts, so that we have a safe, robust, and economic design.

Having strong models of our system, along with the evaluation data of the system, gives a good idea of its overall performance as compared to its potential. In the most recent trial, the system met its criteria for setup time, weight, and ability to fit effectively on the motorcycle. Though the system fell short in breakdown time and spray range (over by 4 minutes and under by 12 feet, respectively), it is likely that both standards can be met with a few modifications to procedure and equipment.

Work on the project will continue during the summer months, and will largely focus on the optimization of materials, additional fabrication considerations for in-country building, and bug-fixing so that our eventual deployment in Uganda will be successful.

Score Breakdown

Noelle Patterson: 0.333 Process (Academic Relevance, Description and Engineering Analysis)
Wayland Singh: 0.333 Process (Problem Framing, Constraints, Compiling and Misc.)
Charles Wong: 0.333 Specifications (Design Description, Performance Documentation, and Budget)

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Recognition and Evaluation of the Problem

The AMIS project began with a vaguely worded request to optimize a prototype design for the AMIS in preparation for commercialization. As we researched and learned about the current state of the project, we realized that a clear definition for the problem we hoped to tackle would be essential to our success. Though suggestions from third parties have indicated that there will be a number of secondary problems including layflat hose patching, maintenance cycles for the AMIS, and commercial profitability analysis, we have focused on a number of technical objectives.

The first major problem with the AMIS as it stands is an inability to deploy efficiently. The components are stacked haphazardly on the back of a motorcycle, with all the tubing inside a sack. This method of storage leads to longer set-up times for the equipment, as well as longer pack-up times.

The second major problem with the AMIS progress is that it is difficult for us to evaluate the overall performance of the design without a working model. Without a working prototype, it will be difficult to predict issues that may arise during operation.

Development of Solutions

Due to the difficulty of building and operating a trailer-type attachment for the motorcycle in Uganda, we concluded that a rack mounted to the frame would allow for more efficient equipment storage and prolong equipment life by ensuring that parts are not damaged in transit. A frame made of steel tubing will be able to be sourced and fabricated locally.

In order to perform realistic operational tests and evaluate the possibilities of other issues cropping up, as well as a demonstration of the viability of the project, we will be assembling a complete AMIS. Given that shipping the actual motorcycle (Honda CG-125), our version of the prototype has been assembled using a very similar motorcycle, the Honda CB-125. Given that disparity however, we will be closely noting any potential problems arising from the difference in models.

The decision to mount the equipment on the motorcycle itself, along with a few other aspects of the solutions generated were made by the client. In doing so, a number of additional issues cropped up during the project, and solutions as well as justifications are included in the analysis below.

Constraints and Criteria

There were various constraints and criteria that we considered in the design of the AMIS and its construction. One of the most difficult things that this project entailed was designing this system with only the resources that will be available in Uganda. Additional constraints were that the system (without the motorcycle) weigh less than 100kg, cost less than 4000USD, and have a setup/breakdown time of 15 minutes). Additional criteria to be considered were ease-of-riding, durability of parts, and maintenance.

Goal of the Design

Our goal as the Agricultural Mobile Irrigation System project team was to build a prototype of the AMIS that improves upon design features of the Ugandan prototype, created by our client Abraham Salomon. The main improvement required of the prototype is to increase the efficiency of system setup and breakdown time while maintaining usability, functionality, and low cost. Additionally, the process of building a complete prototype allowed us, the student team, to become familiar with every aspect of the design so we can collaborate effectively with builders and designers in Uganda. The expected end product of our collaboration was a marketable AMIS product, which could be sold and used in Uganda. The primary engineering aspects of the design we focused on were the design, strength and functionality of the frame and components. Detailed constraints for the design provided by Salomon are as follows:

- The entire system, including the motorcycle, costs less than \$4000 USD.
- All components excluding the motorcycle weigh less than 100kg and fit onto a 100 cc Bajaj Boxer, a type of motorcycle readily available in Uganda.
- The frame weighs less than 20 kg, while still supporting the weight of the volume pump, booster pump, tripod, spools, and accessories like a toolbox.
- The frame cost is under \$200 USD.
- Frame and component orientation allow for set-up and take-down time of less than 15 minutes each of a complete irrigation procedure using the maximum 100m of lay flat hose.

In addition to the building the design in Davis, our client expressed interest in our continued assistance during the summer in Uganda, where we would help build and test the system in field conditions. Our team received a Blum Grant award for undergraduate work abroad, and additional funding from the Biological and Agricultural Engineering Department and UC Davis D-Lab have guaranteed that all three student team members will be able to travel to Uganda in summer 2014. We plan to work with Abraham Salomon for one month, building and designing another prototype and then testing it in field sites around Uganda.

Social, Environmental, and Economic Implications of the Design

As a design for development, our project will have direct beneficial impacts on the lives of Ugandans if implemented as intended. The concept of affordable irrigation addresses the problem of low agricultural productivity, which is a major economic issue in Uganda. Irrigation is cited as the primary means of increasing agricultural output in Uganda, which will in turn give farmers access to more income. This data was reported in the AMIS proposal written by Dr. Kurt Kornbluth. The social consequences of the design are mostly related to the opportunity for jobs and increased income made possible by the AMIS. The system is targeted for purchase by entrepreneurs who can rent their irrigation services to local farmers, securing themselves an income based on the success of the AMIS. We understand that the AMIS could be potentially harmful to buyers if they were unable to gain a market or if the AMIS broke beyond repair, but this summer we will be working to prevent this by conducting field tests and interviewing farmers, and by improving the durability of the design. The environmental implications from the AMIS will be minimal compared to large scale irrigation schemes, because this design is targeted at small scale agriculture. The areas we will be working in are not in drought, so using river and lake water for irrigation should not present a serious issue. Using a motorcycle in vegetated areas may cause some damage, but motorcycles are already ubiquitous in Uganda so it will at least not present a new problem.

Four Lenses Analysis - Methods of Analyzing Impact (Prof. Kornbluth)

Environmental Factors:

The development of the AMIS will have some environmental effects, including pollution from the manufacture and operation of the system. Fortunately, the number of systems is low, and each system won't produce more pollution than the sum of its individual parts. The overall lifecycle of an AMIS is projected to take place as follows: production by assembly of parts; operation and maintenance; decommission, and disassembly. In addition, there are a number of salvage options for the equipment associated with the AMIS in the event of decommission, as each piece of equipment can be used by itself in a number of applications. Finally, the AMIS will be operated in agricultural areas, which presumably have been cleared for use as such, so the development of the system will not contribute to habitat losses, unless such a system encourages the clearing of additional space for agricultural use.

Social and Development indicators:

Overall, the Ugandan industrial sector and its focus on agriculture is an unstable area that requires investment, a more consistent infrastructure, and a cheap and easier way of providing irrigation to the average farmer. Although the majority of the workforce is employed in the field of agriculture, most of these farmers work in personal-style farms rather than large plantations. Due to the expensive nature of more modern equipment, farmers are forced to rely on basic equipment for their harvesting means and typically do not have the ability to obtain materials such as fertilizers and pesticides. (Maryinez). This reliance on more primitive tools limit the farmer's ability to effectively grow their crops which has a direct negative effect on not only the country's export, but also the country's ability to feed its own people. Currently, there are no new technological advances that will allow Uganda to quickly fix these problems. New inventions aim to solve the problem in the short-run rather than the long-run which only prolongs

the problem. Significant changes must be made on the core infrastructure to ensure positive change will occur. However, affordable projects like AIMS, will help farmers out in order to provide a slightly more stable crop output with technology that is already accessible to these farmers.

Unfortunately another issue is presented, as there is a lack of significant domestic and foreign investments in these industries. Bright Rwamirama acknowledges the problem in May of 2013 and stated that investors believed the agricultural sector was seen as too risky and that there needed to be changes to that sector in order to make it more stable for future investment (Prossy). Without these investments and cash inflow the various companies are unable to lessen the costs of expensive machinery and work on creating more effective and affordable ways to help the Ugandan farmers out.

Financial & Dissemination Strategy

Agriculture is one of the most important aspects of the Ugandan economy. It currently accounts for 24.2% of GDP composition, while employing 82% of the country's labor force (Uganda Economy Profile). Farmers in various agricultural regions of Uganda and other developing countries are dependent on rainfall for irrigation of their crops. Additionally many small-scale farmers do not have the funds for the initial investment in an irrigation systems that would ensure higher crop yields. The Agriworks Mobile Irrigation System (AMIS) guarantees small-scale farmers a way of irrigating their crops even without rainfall. This service is being made available to farmers for only the operational costs, allowing struggling farmers to increase their crop yields without paying for an entire irrigation system.

Technical & Available Resources

Uganda has the ability to expand their manufacturing industries in relation to agriculture and its agricultural market as well. While there are definite problems that must be solved for long-term growth, the AIMS project provides a quick and cheap solutions to farmers who are unable to afford the expensive cost of modern machinery and long-term irrigation. Although the government has made attempts to fix these problems, their solutions ideally require the farmers to pay for sixty percent of the costs and aims to fix the problem over twenty-five years. (Kavuma) .

Technology that is used around the world to provide more electricity to an area would aid in providing a more stable infrastructure, but these technologies require a great deal of money. Solar panels, wind energy, and other forms could help provide the industrial plants with the energy that they need but in a country that is plagued by a GDP of \$1,400 (Uganda Economy Profile), it seems unlikely that this will be feasible to implement on a large enough scale to be effective. Newer technology to aid small-scale farmers through micro-transactions rather than state-sponsored projects are gaining more support as investors are less at risk in losing a great deal of money.

Review of Progress made in Winter and Spring Quarter

Winter quarter:

- Built the first prototype of the AMIS frame
- Procured the Honda motorcycle, volume pump, booster pump, and sprinkler head
- Performed preliminary strength tests on the first spool model
- Practiced winding and unwinding hose on the spool to inform design decisions for a future model

Spring quarter:

- Built a second, improved frame prototype
- Built a second spool with improvements upon the original design
- Built a tripod to mount the sprinkler head
- Built frame attachments on the motorcycle to mount the new frame onto
- Had a booster pump attachment machined for us by the Bainer machine shop staff and built a metal clamp to reinforce the booster pump
- Bought bags to hold the tripod and booster pump, and rope to secure the volume pump in transit
- Assembled the entire AMIS and performed timed trials of setup and takedown
- Performed experiments to collect hydraulic data on the booster pump, the two pump system, and sprinkler range depending on different levels of motorcycle RPM

Issues during the Build Phase

During the building process in Spring Quarter, a number of issues cropped up that necessitated solutions before additional progress could be made; the first of these was that of the Booster pump interface. Due to the design of the Booster pump, a plate needed to be fabricated that would allow the pump to mount onto the engine case of the motorcycle. By taking measurements of the existing, but incompatible, mounting plate, and the engine cover, we were able to draft a design to solve our compatibility issue. With assistance from the machinists in the Bainer shop, we were able to get a part that solved this issue (see attached).

A number of other challenges presented themselves. Creating a frame to mount on the motorcycle was made more difficult by the tight tolerances required by our choice of material size. Sizing that barely fit inside another piece for the frame to mount to the motorcycle was changed to allow more room for error in seating the frame. Certain portions were ground, bent, cut open, and otherwise modified until the frame could easily be taken in and out of the mounts. The tripod for the sprinkler head needed shaft collars to prevent the legs from sliding out from one another due to the reactive force of the impact sprinkler, and plates that would allow the legs to be staked into the ground were fabricated so that the entire assembly didn't get overturned during operation.

The final hurdle was one that didn't restrict itself to the build phase. Given that the motorcycle was an older model, performance issues seemed inevitable, and the motorcycle didn't disappoint. At numerous times, even on the day of the Design Showcase, it proved difficult to start the motorcycle, but thanks to assistance from Professors Kornbluth and Jenkins on different

occasions, the system was fully operational for important tests and demonstrations.

Engineering Design Analysis

Frame: Strength and Material Selection

The first frame prototype was built during winter quarter based upon blueprints created by Ben Geva of D-Lab, fall 2014. Our decision for the size and type of steel to purchase was based on the recommendations from Ben Geva's earlier work, and the materials available in Uganda.

A main concern when designing the frame was finding an optimum sizing for the steel frame which ensures adequate strength yet stays under the maximum weight criteria. Special consideration must be given to part 5 of the frame, the crossbar which holds the spools, shown in the frame blueprint. This piece must hold the weight of the spool on each side, and is only connected to the rest of the frame by welding it directly on top of the two perpendicular bars, parts 6. This design leaves a very small surface area available for the weld, which creates a weaker joint. However, the main force at this joint, the downward weight of the spools, is supported by the perpendicular bars which the crossbar rests upon (parts 6). The welds primarily prevent force in the range of motion from side-to-side, in the plane parallel to the ground. We expect this force, which does not occur statically, would be caused by jostling of the spools and frame while the bike is traveling.

A shear moment diagram of the static crossbar from winter quarter revealed that the bar experienced maximum shear of 50lbf at the two weld points. The maximum stress in the tube's cross section at the weld was calculated at 322.2 psi, occurring along the diameter of the tube. For comparison, the ultimate strength of 4130 steel at room temperature is 125,000psi, according to testing by Ronald Favor et al. from the US Air Force in 1957. These calculations can be found in detail in the design notebook.

When building a new frame in spring quarter, we improved upon the design by choosing smaller, lighter steel tubing at 0.75" OD/0.5" ID, instead of 1" OD/0.75" ID. Because our original frame was well within the boundaries of ultimate strength, we concluded that we could reduce the weight of the frame without compromising strength. A similar stress calculation was performed on the smaller size tubing, and the maximum stress in the cross section of the tubing was determined to be 441.4psi, an increase of 119.2 psi from winter quarter's model. This value is still safely within the ultimate strength of 4130 steel at 125,000psi.

Considering this, our crossbar design is still extremely conservative, and there is further opportunity to reduce the steel sizing. We must, however, stay mindful of the context in which the frame is to be used; it could be subjected to loads greater than the 50lb spool weight if it was dropped by accident or the loaded motorcycle fell over. Additionally, when the frame is being produced in Uganda, the level of fabrication expertise or tubing quality will not be consistent and weaker frames could be produced as a result. When finalizing our specifications for the frame, it will be crucial to keep a large safety margin to allow for imperfect circumstances, which will

inevitably happen. Furthermore, our design will be limited to the sizes of tubing available in Uganda.

Frame: System Logic

In addition to changes made in the size of steel used for the second frame prototype, the fundamental shape of the frame was modified to better fit onto the motorcycle and hold the spools. Drawings of the new frame can be found in the appendix. This frame is designed to be taken on and off the motorcycle, instead of the original design of bolting the frame on in a semi-permanent fashion. This solution allows the frame to be used as a stationary holder on the ground to unroll hose from. Keeping the hose spools mounted on the motorcycle while unrolling was another option, but removing the spools from the bike is safer because there is less risk of tipping the motorcycle over when tugging at the hose. In order for the spools to roll freely, they needed a clearance of more than 13.75" (the radius of the spools) from the ground. To achieve this, a grounded frame would need legs more than 13.75" in length. We achieved this by taking advantage of vertical height; the "legs" of the frame face up while mounted on the bike, and then the entire frame flips upside down when put on the ground to hold the spools. The legs were built 18" high to give the spools a wide range of clearance while unloading. This was especially important because in the process of unrolling the hose, the camlocks would occasionally interfere with smooth rolling, and drag on the ground with each turn. The frame model with upward-pointing legs also allows for flexibility in design; the design can be modified for longer legs and the extra length will not obstruct other components on the motorcycle.

Spool Construction:

The spool used for these analyses was fabricated by Ben Geva for previous AMIS work in D-Lab. The outer wheel of the spools was fastened together by brazing, and the spokes were tacked on. The tacking method was relatively quick compared to the time it would take to completely weld the spool, so preliminary testing was conducted to determine its strength. We inferred that the most stress to the spool would occur in a dynamic setting, in transit on the motorcycle. Based on pictures from testing of the first prototype in Uganda, the roads used by the bike will be bumpy and unpaved. Therefore, we focused on damage that would occur from sudden applied forces such as bumping and jostling on unkempt roads. The durability of the spool was tested using three trials of dropping from approximately 1m height. Although the force caused by a drop of this height outweighs the damage that would be caused when the spool is secured on its axle, accidents involving dropping the spool from the axle are possible if the end cap securing them slipped off. Simple analysis of the force caused by the drops is presented with the other calculations in the appendix. The penetration distance of the spool into the ground is needed for calculation of the impact force, and we have a conservative upper limit estimation of this distance at 4 inches. The impact force value with a 4in estimate of penetration distance is 492lbf, and we have assumed through observation that the penetration distance is some value smaller than the 4in estimation. 492lbf may be considered as a lower limit to the actual force, since the impact force is inversely proportional to the penetration distance. Because spokes broke from the

spool during the drop tests, we concluded that a more stable spool using complete welds instead of tacking is required for our design.

The other situation in which the spool is subjected to forces is in winding and unwinding, which we tested qualitatively. The spool was fixed onto a stable steel tube and the hose was wound and unwound by a single person. Winding the spool was considered easy by the user, and no tugging or jerking was required. Because the force on the spool from winding and unwinding was clearly far less than that of dropping it, we concluded that damage to the spool from winding will not be an issue.

In spring quarter, we constructed a spool with complete welding instead of tacks, so it was both stronger and safer to use, because there were no sharp edges jutting from the spool's surface. As an additional improvement, the spool was constructed with only four spokes instead of six. This reduced weight while maintaining the strength of the design. Because the spools are not rolling on the ground, they do not need spokes for the purpose of supporting weight.

Spool Orientation on Motorcycle:

In the beginning of spring quarter, the AMIS team considered different spool orientations than the model with spools on the side, as recommended by previous work in D-lab. This was due to concerns voiced by Salomon that keeping the hose in separate pieces divided up on two spools would increase setup and breakdown time, since pieces would need to be connected with camlocks for every use. To help frame our options, we created a weighted decision matrix with options for five different orientations of the spools and volume pump. We assigned point values to each parameter to the best of our abilities, using drawings and discussion to consider each option.

Design	Balanced on both sides of the motorcycle	Weight	Minimizing hanging weight	Easy to build	Setup time is low	Space for the rider is adequate	Total
1	1	3	5	2	1	2	14
2	5	2	5	4	4	2	22
3	5	2	5	4	4	4	24
4	3	3	3	1	1	3	14
5	3	3	1	3	4	4	28

Table 1. Decision matrix for spool and volume pump orientation

Design 1 – Pump is on one side of the motorcycle, to counterbalance one large spool.

Design 2 – Pump is placed in center of motorcycle seat with long end along seat, taking more seat space than side-to-side space. Spools hang off sides.

Design 3 – Pump is placed on the motorcycle seat with the long end perpendicular to the seat, taking more side-to-side space and less seat space. Spools hang off sides.

Design 4 – Spool is stacked on top of the pump.

Design 5 – Spool hangs off the back of the motorcycle.

Based on the decision matrix, Design 3 was the best option, and this is what we decided to base our next frame blueprint off of. This design called for the spools to hang off the sides of the motorcycle, and for the volume pump to sit in the frame on the bike seat, in an orientation which used more side-to-side space than seat space. While this means the spools stand further out from the bike, there are a few more inches of seat space available for the rider.

Spool bearings:

The next design element considered was the interface of the spool with the axle. The spool was designed with a hollow tube at the hub, into which an axle with some sort of sleeve or bearing may be inserted. Based on general knowledge of material mechanics, we decided not to simply insert the axle into the hub tube, because the friction caused by the rub of the two metal pieces is expected to cause wear at the location where the metals contact. Our original considerations included needle bearings, ball bearings, or an inexpensive material such as PVC. According to our advisors in D-Lab, ball bearings would be an expensive part to source in Uganda, and their susceptibility to breaking would present issues when the systems are used in the field. PVC has

been used in the current prototype because of its low cost, simplicity, and convenience. PVC may be replaced when worn down, and if the exact size isn't available it can still be cut down to size. We may need to consider alternative buffer materials, however, as PVC is not readily available in Uganda. Our client has mentioned that plastics are generally difficult to access in Uganda, so the solution we used for our prototype may be different from what we implement while working in Uganda.

Booster Pump:

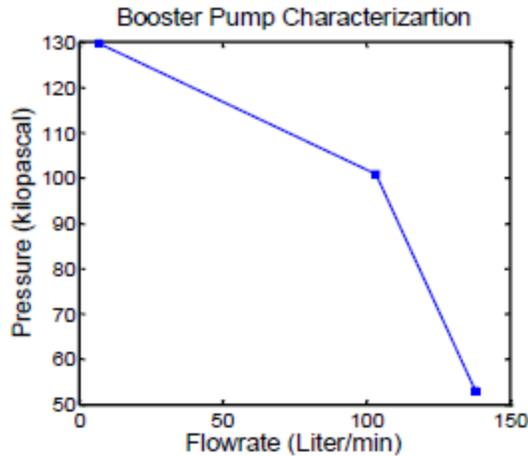
The purpose of the AMIS booster pump, according to Abraham Salomon, is to provide pressure just before the sprinkler head, ensuring maximum range by the sprinkler. The booster pump, however, is considered the “weakest point” in the system. It is made cheaply, of completely plastic parts, and proved its fragility already in the field, when the O-ring popped out and it leaked along the seams. We have reinforced the booster pump with an aluminum interface, allowing it to fit onto our Honda motorcycle, and a frame which clamps onto the piece preventing leaks.

Because this component has given us problems in the field, we needed to demonstrate its contribution to the system to justify keeping it as part of the design. Our first idea was to analytically solve for the pressure boost required by the booster pump in order to achieve the desired sprinkler range. Our energy balance for the pipe system looked like:

$$(P/\rho g + V^2/2g + z)_1 = (P/\rho g + V^2/2g + z)_2 + h_{\text{friction}} - h_{\text{pump}}$$

Where state 1 is after the volume pump and state 2 is after the booster pump. This equation had unknowns in flow rate (the V term), pressure (P term), and the energy lost due to friction and gained by the pump. We could have found pressure using gages and approximated flow rate with large tanks, but the friction term was harder to calculate because losses occurred due to surface roughness, pipe bends, and passage through nozzles and camlocks. These unknowns would have required numerical analysis in order to solve for the h_{pump} term, and the error due to approximation would have likely been quite high. Therefore, we chose to gather empirical data from our pipe system.

We decided to make a pressure-flowrate curve for the pump, and characterize the pump's performance by experimentation. In order to find the general flow parameters of the booster pump, the pump curve was empirically found by varying the pressure using a pressure valve and measuring the flow rate by finding the amount of time that it takes for the booster pump to fill up a calibrated tank. This pump curve is shown below:



Pressure-Flow rate of Booster Pump

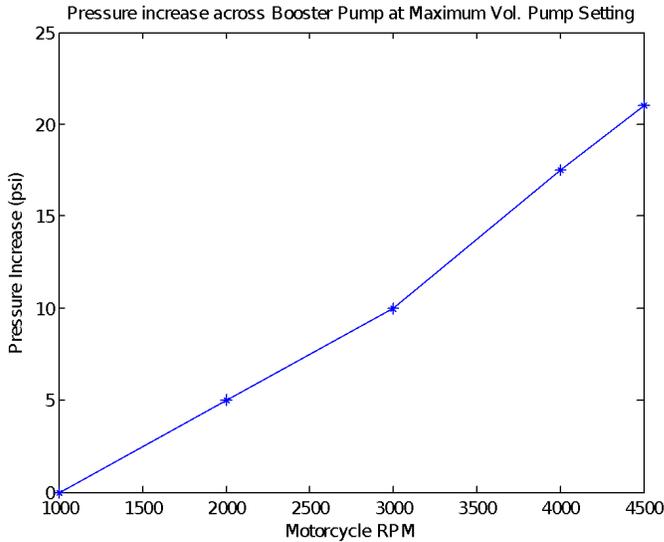
Furthermore, when the booster pump and the volume pump were connected in series with minimal tubing, pressures in excess of 60-70 psi were recorded. As shown, at relatively low flow rates the pressure increase due to the booster pump can be considerable. According to the specifications of the sprinkler head, it needs an inlet pressure of 71.1psi in order to reach 100 feet, which is necessary to achieve the goal of ¼ hectare of coverage. If the system cannot reach this range without the booster pump, then we are justified in keeping it in the system. When introducing the volume pump into the system at maximum speed, we collected data as follows:

Booster pump RPM (with vol. pump at max)	Pressure (psi)	Flow Rate (gpm)
4000	55	40
5000	60	52

Table 2. Pressure and flow rate for the combined volume and booster pump configuration

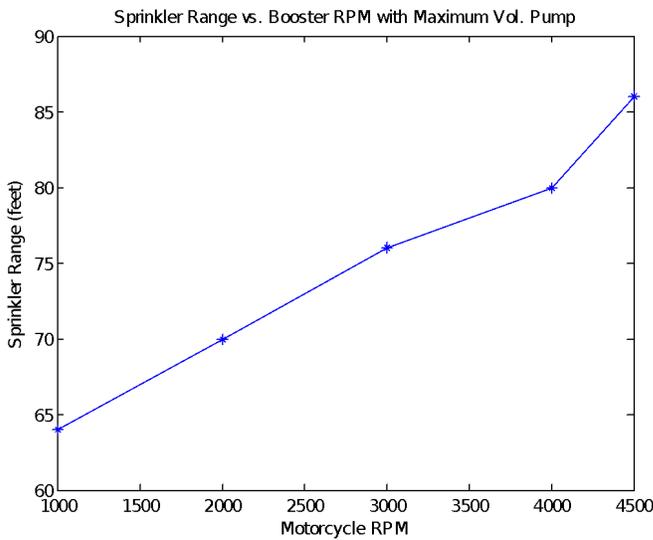
Even with a small amount of data, it was clear from this trial that the booster pump adds a significant amount of pressure to the system in ideal conditions (our ideal conditions were using a short length of rigid hose instead of a long lay flat hose).

We also gathered data to find the pressure increase the booster pump contributed to the system out in the field at different RPMs, but we did not have a reliable way of measuring flow rate so the results are more of a qualitative indication of booster pump performance. The following pressure information was found by comparing the readings of a pressure gage placed before and after the operating booster pump. The results suggest a substantial increase in pressure from the booster pump in field conditions.



Pressure increase of Booster Pump.

It is difficult to identify exactly how the two pumps interact, because both pressure and flow rate may be affected in each, but according to our qualitative observations the sprinkler range increased significantly when the booster pump was introduced. A final test we conducted was measuring the range of the sprinkler while changing the booster pump RPM and keeping the volume pump at maximum speed. A linear relationship between the pump RPM and sprinkler range was found, which corresponds to a relationship with the ground coverage squared. Therefore, the booster pump has been found to considerably increase the irrigated area and we are justified in keeping it in the system.



Performance curve(empirical).

Additional work in this area will include characterizing the two pumps together in a more detailed analysis, and testing a higher range of booster pump RPM's. We were conservative with the operational RPM due to damage risk. Another area of study, however, would be to determine the RPM sustainable before causing failure the booster pump.

Applied Coursework

The testing and analysis used in the spool drop experiment required fundamental concepts first developed in the Physics 9 series. The calculation of impact force of the spool into the ground is derived from the basic energy equation for rigid bodies.

Analysis of the frame is based on coursework from ENG 104, Mechanics of Materials. Shear-moment diagrams and the calculation of cross sectional stress were both used extensively in this class. Concepts of strength and safety margins for beams were also introduced in ENG 104, which we will explore next quarter when making decisions on what steel to buy for a second prototype.

We have made extensive use of the shop skills and safety practices we learned in EBS 170A while building our widget.

We have covered topics introduced in EBS 1 such as drawing in AutoCAD, formulating design criteria and goals, and creating timelines for a project.

The D-Lab course which all three team members were enrolled in has given us a context for our project by covering the challenges and considerations of development abroad. Special emphasis was given to the various perspectives of clients and stakeholders, economic viability, and use of local materials.

Theoretical Calculations/Considerations

In order to calculate the theoretical pressure delivered to the sprinkler head due to a hydrodynamic system, the energy balance of the system must be considered as follows:

$$\Delta P + \rho g * \Delta h + \frac{1}{2} \rho * \Delta(v^2) = \text{frictional losses and pump heads}$$

$$P_o - P_{atm} + 0 + 0 = P_{\text{volume pump}}(v) + P_{\text{booster pump}}(v) + \sum \frac{\lambda L d v^2}{2g} + \sum \frac{\xi v^2}{2g}$$

$$P_o = P_{\text{volume pump}}(v) + P_{\text{booster pump}}(v) + \sum \frac{\lambda L d v^2}{2g} + \sum \frac{\xi v^2}{2g} + P_{atm}$$

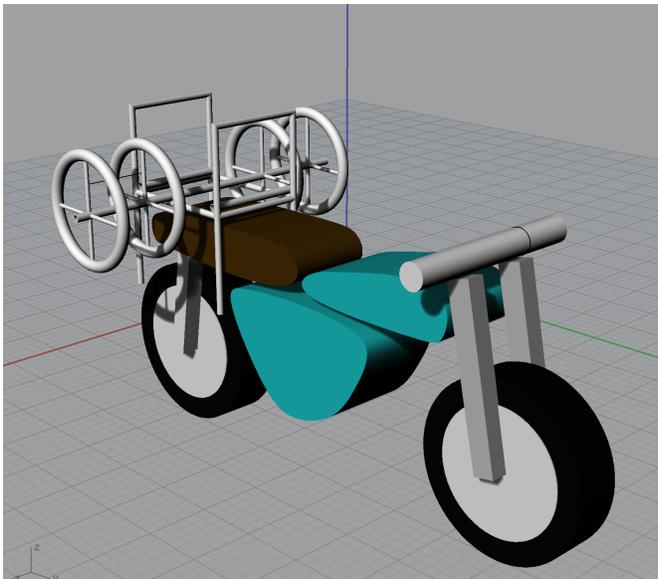
However, this problem is actually indeterminate since the pump pressures vary with flow rate (velocity). The problem can be solved iteratively if the pump curve for the booster pump was determined, but this is left to future work.

Description of the design

The AMIS system is a mobile irrigation system designed to move water from one place to another. The basic layout is that the reservoir pump will pull water from a water reservoir such as a lake. This water will be fed through a length of layflat hose to a booster pump which interfaces with a motorcycle. The booster pump will then serve to increase the pressure of the water and feed it into a sprinkler mounted on a tripod – which will be used to irrigate a field.

The entire system was designed to be mounted onto the back of a motorcycle with a motor size as small as 100cc. In particular, much of the focus was on making the system more time efficient, more easily manufacturable, and safe/stable (with respect to the loads applied to motorcycle due to the weight of the AMIS itself). The design necessitated the use of 100 meters of flat hose, which was composed of several smaller hoses connected together with quick-release cam lock couplers. Although much modeling was done theoretically by Ben Geva and other members of the D Lab, many of the dimensions of the system can only be found empirically. For example, the dimensions of the spool were found by rolling up the layflat hose and measuring its diameter (work done by Nadya Alexander and Jing Luo) and individually testing spools of different diameters.

Although many concerns have been raised over the initial design proposed by Ben Geva, Dr. Kornbluth has advised that the first prototype strictly follow his design as a proof of concept. This prototype was fabricated, and then a second prototype was made that was tailored specifically to match the dimensions of the CB 125 motorcycle by Honda.



3-d Model of Motorcycle and Frame

Motorcycle

The motorcycle proposed in the initial prototype was the 100cc Bajaj Boxer. This model was chosen because it is a common motorcycle in Uganda. However, Abraham Salomon has decided that a better model to use would be the CG 125 motorcycle by Honda. Unfortunately, it proved quite difficult to acquire a CG 125 motorcycle in the United States, so the project will be conducted with the precursor to the CG 125 (the CB 125). The motorcycle was purchased, and the frame was designed to be compatible with this model.

Reservoir pump

In the initial prototype, the SEV-80x pump by Koshin was considered. However, due to the client's preference, the SEV-50x pump was purchased instead. This model was specified due to its low price and ability to provide the required performance to operate the system.

Booster pump

The MTC booster pump, from Hunan Tongda Pump, was used to interface with the motorcycle. Purchase of this device has proven difficult, so it was sent from Uganda by Abraham Salomon. In addition, several modifications were made to the pump. An aluminum interface was drawn in Solid Works and fabricated with the help of Jed Roach. In addition, four pieces of angle iron were cut and holes were drilled in them such that the pieces of metal fit onto the booster pump itself. This was done to minimize flexion of the plastic due to high pressure loads in the booster pump. Finally, the O-ring was ultimately replaced with simple RTV that was manually applied. This is shown below:



Booster Pump Assembly.

Sprinkler Head

The HT-42G sprinkler head from Pelican was used to spray the water onto the fields. The

sprinkler head is 1½” in diameter. This device was also sent from Uganda by Abraham Salomon.

Tripod

The tripod will be used to hold the sprinkler head. A 6 ft high tripod was constructed from steel tubing and PVC pipe. The central shaft was made of 1 ½ inch diameter, 1/8 inch thick PVC pipe and the individual lengths were coupled together using camlock couplers. The three tripod legs were made from 0.5 inch diameter, 0.083 inch thick steel tubing. The lower section of steel tubing was partially covered with 0.84 inch diameter, 0.11 inch steel tubing to act as a sleeve in order for the frame to be collapsible. In addition, 0.5 inch shaft collars were welded onto each of the sections of steel tubing in order to tighten the fittings. Finally, a steel collar was attached to the PVC pipe and was attached using steel bolts that tighten onto the PVC itself. In order to ensure that the tripod did not tip over due to the reactive force of the impact sprinkler, the bottoms on the tripod legs were cut at a 30° angle and flat metal with a ¼ inch hole was welded on. This allowed stakes to be driven through the bottom of the tripod legs and stabilize the setup. This entire setup is shown below:



Tripod Set-up.

Frame

Frame version 1.0

Detailed drawings of the frame design and part numbers are shown in Appendix A. The suggested dimensions of steel tubing were as follows:

Parts# 1, 2, 4, 6, 7, 8

0.84" diameter, 0.11" thick steel tubing

Parts# 3 and 5

1" diameter, 0.11" thick steel tubing

However, because the dimensions of the tubing were not critical to the design, and it was desired to use material that was thicker (and thus, easier to weld), the following dimensions were used instead:

Parts# 1, 2, 4, 6, 7, 8

0.75" diameter, 0.12" thick steel tubing

Parts# 3 and 5

1" diameter, 0.12" thick steel tubing

During the fabrication of the frame, a few compromises were made. The entire process will be detailed: Fabrication of the frame started by cutting Parts#1 and following the 45° cut as shown in Appendix A. Similarly, Parts#4 were cut with two 45° angles. However, it is important to note that there was difficulty in aligning the 45° cuts in Part#4 correctly since the tube was circular. Thus, the alignment of these two cuts was approximated; note that this led to a slight error in the angle between Parts#1 and Part#4. However, the error proved to be negligible. Next, Parts#7 were cut, but an adjustment was made; instead of the angled cut suggested in Appendix A, the bottom of Part#7 was cut as a fish mouth – to be joined directly to the top of Part#6. Then, Parts#6 were cut; again the ends of these parts were modified; this time with a ~30° cut on one end (to be welded to Part#8) and a straight 90° cut (to be welded to Parts#1). Afterwards, Part#2 was cut with two fishmouths (again, instead of an angled cut) and Part#8 was cut at a ~30° cut. Finally, Parts#3 and Part#5 were cut with 90° cuts.

Concerning welding, first Parts#1 were welded to Part#4, and Parts#7 were welded to Part#4. Next, Parts#7 were welded to the top of Parts#6. Then, Part#3 was welded between Parts#1. Afterward, Parts#1 were sanded down to provide a more flat surface so that Parts#6 could be welded flat onto them. Once this was completed, Parts#8 were welded to Parts#6. Finally, Parts#6 were sanded down to provide a flat surface for Parts#3 and Part#5 to be welded to the top of it.

Frame version 2.0

However, the first frame design was found to be incompatible with the Honda CB 125. Therefore, a custom frame was made according to the dimensions of the motorcycle itself. In addition, several changes were made to the final design of the frame. For example, Parts #8 were removed, and instead parts #7 were extended such that they were identical to Parts #1. In addition, the lengths of Parts #6 were decreased.

To minimize the use of unnecessary materials, Parts #3 were removed, and Part #2 was replicated on the other side of the frame (between Parts #7). In addition, Part #5 was moved such that it was 25% of the distance from the front side of the frame, and a part similar to Part #3 was added 75% of the distance from the front side of the frame.

In order to make this frame fit on the motorcycle, ¼ inch holes were drilled in angle iron, and that angle iron was attached to certain parts of the motorcycle frame using already existing screws. Finally, 1 inch diameter, 0.11 inch thick steel tubing was welded onto the angle iron to create fixtures for the frame to slide on and off. The front fixtures were vertical, but were free to rotate. In contrast, the back fixtures were angled slightly backward and not free to rotate

Because these fixtures did not have the exact dimensions needed (due to accumulated angle changed introduced through welding), shims were used to change the angle of the back fixtures, and the back fixtures were cut and re-welded with larger tubing. Finally, additional tubing (1.25 inch diameter) was added onto the back legs of the frame in ensure that the frame was oriented approximately parallel to the ground. The fixtures are shown below:

Note that although many of the difficulties that arose in welding the frame could be solved by using square tubing instead of circular tubing, the choice of circular tubing was maintained because square tubing of the desired dimensions is not currently readily available in Uganda.



Mounting Rack for Motorcycle.

Another important thing to note is that the choice to fishmouth many of the ends of the steel tubing and modification of the design was done in anticipation of the working conditions in Uganda. Because precise machinery to cut precise angles is not readily available in Uganda (Dr. Kornbluth has stated that large machinery may not be may be available at times) the corners and connections were simplified such that they could be made with only a hacksaw and a grinder.

Two spools

The specifications of the spools used are provided in Appendix B. This design was chosen such

that two lengths of layflat hose could be placed side by side. This design was loosely based on previous spool designs by Ben Geva, Nadya Alexander, and Jing Luo, and some preliminary test data was taken with Ben Geva's prototype. The spools have been optimized to have a smaller diameter and have only four spokes. This was done to reduce the amount of materials used and make the fabrication process easier. In addition, small sections of tubing were added to act as dividers so that the process of rolling up the hose would be easier.

Lay-flat hose

Vinyl layflat hose with a 2 inch diameter was used to connect the pumps. In total, two lengths of 30 meter layflat hose, and two lengths of 20 meter layflat hose were used to reach the desired length of 100 meters. This part of the design was determined by previous work (by Nadya Alexander and Jing Luo) as optimal and further discussion of this choice can be found in reference (10).

Entire System

Altogether, the entire system was seen to be successful with regards with its ability to effectively fit all the needed parts onto the motorcycle. The tripod materials and the booster pump are to be carried in bags. The heaviest components of the system loaded onto the motorcycle (minus the parts carried in bags) is shown below:



Major Components on Motorcycle.

Parts list

Below, a list of the parts that have been purchased are shown:

Part	Price	Contact info.
Steel Tubing	\$676.23	www.mcmastercarr.com
Booster Pump	\$691	Abraham Salomon. Significant amount of cost was for shipping from Uganda
Sprinkler Head		
Motorcycle	\$1,300	(donation)
Volume Pump	\$665.79	Larry, 916-781-9553
Camlock Couplers	\$185.10	http://www.camlock-fittings.com/type-e-adapter-stainless-steel-male-adapter-x-hose-shank.html
		http://www.camlock-fittings.com/type-c-coupler-stainless-steel-female-coupler-x-hose-shank.html
Sprinkler Tripod	34.99	http://www.northerntool.com/shop/tools/product_200376062_200376062?cm_mmc=Google-pla-_-Grounds%20Maintenance-_-Sprinklers-_-375908&ci_src=17588969&ci_sku=375908&gclid=CLTPxdSr6LwCFYdgfgod_VAADg
2 ft. sections of rope x6	\$6.00	http://www.mcmaster.com/#3828t23/=s0yqkz
10 ft. sections of rope x2	\$10.00	http://www.mcmaster.com/#3828t23/=s0yqkz
Drawstring bag	\$20.00	http://www.amazon.com/Port-Authority-Cinch-Backpack-Trim/dp/B00BNQRLG6/ref=sr_1_13?ie=UTF8&qid=1400465830&sr=8-13&keywords=drawstring+backpack
Speaker stand bag	\$20.00	http://www.sweetwater.com/store/detail/GPASPSTDBG50?utm_source=Google&utm_medium=PPC&utm_campaign=livesound&device=c&network=g&matchtype=&gclid=CIDH_8T-rr4CFZRcfgodkFgAZA
Hose Clamp	\$14.54	http://www.mcmaster.com/#5415k21/=rn33oq
Aluminum, 3" Long	\$34.00	http://www.mcmaster.com/#1610t47/=rn33y3
Layflat hose	\$66.00	http://www.mcmaster.com/#5295k35/=rn36dh
Spool tubing thin (6 ft, x5)	\$174.60	http://www.mcmaster.com/#89955k569/=re4oea
Spool tubing thick (3 ft, x1)	\$26.88	http://www.mcmaster.com/#7767t51/=re4pej

Polypropylene Cam-and-Groove Hose Coupling, Plug, A Adapter, 1-1/2 Coupling Size, 1-1/2" Female NPT	2.84	http://www.mcmaster.com/#5535k33/=s66c6j
Polypropylene Cam-and-Groove Hose Coupling, Socket D Coupler, 1-1/2 Coupling Size, 1-1/2" Female NPT	15.36	http://www.mcmaster.com/#5535k31/=s66cfe
Polypropylene Cam-and-Groove Hose Coupling, Plug, F Adapter, 1-1/2 Coupling Size, 1-1/2" Male NPT	2.99	http://www.mcmaster.com/#5535k23/=s66ck0
Standard-Wall White PVC Pipe Fitting, 1-1/2 Pipe Size, Male Adapter, Pipe End x NPT Male	1.81	http://www.mcmaster.com/#4880k655/=s66cpy
Worm-Drive Hose Clamp with Zinc-Plated Steel Screw, 1-13/16" to 2-3/4" Clamp Diameter Range, 1/2" Band Width, packs of 10	\$14.54	http://www.mcmaster.com/#5415k21/=rn33oq
Aluminum, 3" Long	\$34.00	http://www.mcmaster.com/#1610t47/=rn33y3
Layflat hose	\$66.00	http://www.mcmaster.com/#5295k35/=rn36dh
2 ft. sections of rope	\$6.00	http://www.mcmaster.com/#3828t23/=s0yqkz
10 ft. sections of rope	\$10.00	http://www.mcmaster.com/#3828t23/=s0yqkz
Drawstring bag	\$20.00	http://www.amazon.com/Port-Authority-Cinch-Backpack-Trim/dp/B00BNQRLG6/ref=sr_1_13?ie=UTF8&qid=1400465830&sr=8-13&keywords=drawstring+backpack
Speaker stand bag	\$20.00	http://www.sweetwater.com/store/detail/GPASPSTDBG

		50?utm_source=Google&utm_medium=PPC&utm_campaign=livesound&device=c&network=g&matchtype=&gclid=CIDH_8T-rr4CFZRcfgodkFgAZA
TOTAL PRICE	\$4,118.67	

Documentation of Performance

Spool Performance

1. Functionality: the spool effectively and **smoothly winds and unwinds** the hose, and accommodates for all the lengths of hose. (Qualitative)

The spool was found to smoothly wind and unwind. A steady amount of force was used the entire time without any yanking, and the layflat hose stacked upon itself quite easily. The hose also did not interfere with the second hose next to it.

2. Portability: assessed by manually lifting the system and setting it up. (qualitative)

The spool was seen to be moderately uncomfortable and heavy to carry, so this was undesirable. However, because of the frame design proposed, the spool will be moved by one person only for short periods of time

3. Durability: assessed by dropping the apparatus from 1 meter and noting damages (notes)

The spool was dropped a total of three times, and damages were noted (see pictures in Appendix C). A summary of the damages is shown below:

Trial	Damages (qualitative)
1	No damages were seen
2	One spoke detached, but the spool was still functional
3	A second spoke detached, but the spool was still functional.

Table 3. Summary of spool drop test damages.

The durability of the design was quite satisfactory. Even though the spool was dropped three times, only minor damages were noted. In addition, the spool used in this testing was not fully welded (only tacked). Thus, it is expected that when the spool is fully welded, the durability of the design will increase even more.

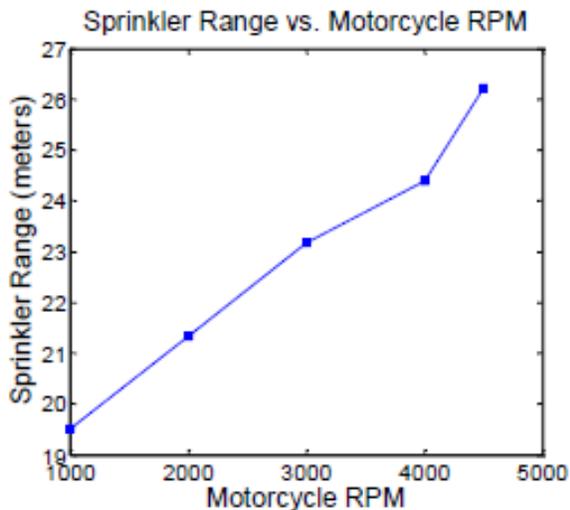
4. How will the spools be mounted? Is it ok to keep them on the sides? **Yes**

Because it was desired to keep the spools out of the way, it was decided that it would be

best to keep the spools on the sides of the frame. Another significant advantage of this design choice is that the center of mass of the system would be lower than if the spool was mounted on a higher place on the frame.

Hydraulic Performance

The performance of the system was measured so as to relate the booster pump operation to the sprinkler range, as this gave the most direct input variable and desired output. With other factors in the system (reservoir pump operation, hose length, sprinkler head) constant, the following figure shows the change in range correlated with higher booster pump speeds.



Sprinkler Performance at different engine speeds.

Only a single trial was done, so no measure of the variance can be found. However, empirical data show a pressure drop of ~ 3 psi for every 50 meters of hose. Therefore, the standard error of the curve shown in Figure 7 is not expected to be large and the linear relationship between booster pump RPM and range of the sprinkler is most likely accurate. However, a full validation of the variance of the AMIS system is left to future work.

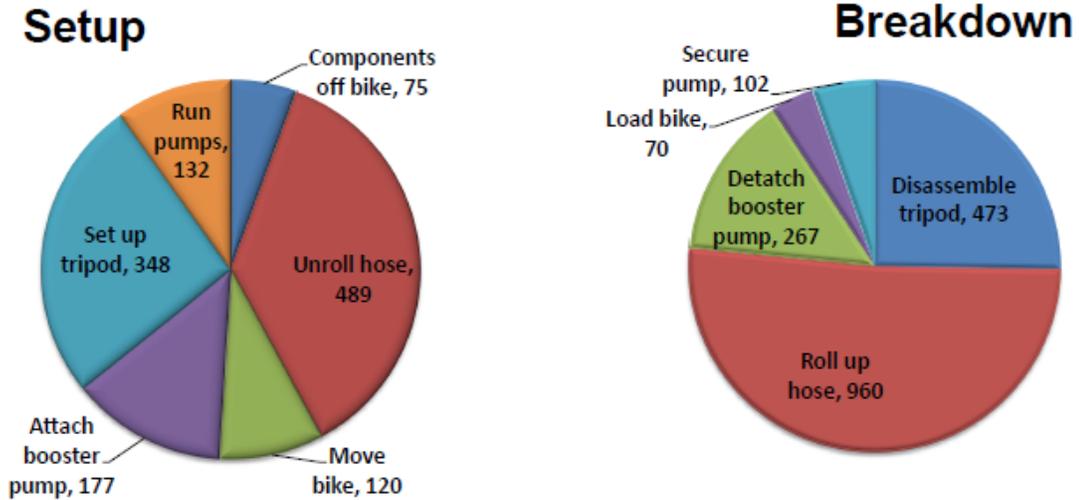
Concerning the max range, the range at 4500 RPM was found to be approximately 86 feet. Unfortunately, this was below the desired goal of 100 ft. However, if the RPM of the motorcycle was increased above 4500 RPM, and if the data in Figure 7 can be used to extrapolate for data above 5000 RPM, then it is very reasonable to expect that if the RPM was increased to 6000 RPM or 7000 RPM, then the desired range of 100 ft could be achieved. This was not done in our trials due to fear of damaging the booster pump interface (since the O-ring had ruptured in previous trials) but if the booster pump interface is improved, then this problem is easily solvable. However, this is left to future work.

Timing Performance

In order to address the criteria of interest to our client, the setup and breakdown time of the

system were measured and the times of individual steps were also recorded. The comprehensive results are shown below:

Time Trial Results



The setup and breakdown times were recorded in seconds for a complete system run-through using 100m of layflat hose.

These results show that although the setup time (~14 min) met our desired goal of being less than 15 minutes, the breakdown time (~19 min) did not. The higher breakdown time can be attributed to the fact that once the AMIS system is run, the lengths of hose will be filled with large quantities of water. This water greatly increases the weight of the system and must be removed in order for the hoses to be rolled up properly. However, it is expected that with practice the breakdown time can be decreased simply because the workers will become more familiar with the system.

Another important consideration that must be made is that the setup and breakdown time can be significantly reduced if the tripod is designed to be more easily collapsible.

Finally, it is noted that the system (minus the motorcycle) met the design requirements because it was under the desired weight. That is, the weight was: $200 \text{ lb} < 220 \text{ lb}$.

Consultation with the Client

Consultation with Abraham Salomon revealed that prototypes of the AMIS system already exist. However, the system has not yet been optimized. That is, the spool designs and the frame designs have not yet been used or tested. Abraham Salomon has expressed great interest in constructing the frame as soon as possible without regard for the functionality of the rest of the system because he believes that all other problems are secondary and/or have already been solved. To this end, our team was worked with Ben Geva to adapt and modify his frame design. In the coming summer, additional prototypes will be built in order to find the optimal design.

Future Work

Although the design was moderately successful, there are many improvements that must be made. For future work, we recommend that the following ideas be considered:

- *Rider tests* – thus far, no safety or ergonomic assessments of the system have been made. In order to quantify how convenient/safe it is to ride the AMIS design, rider tests with psychometric feedback in addition to ergonomic tests such as the RULA are recommended.
- *Smaller spools* – the spools are still too large. In order to allow for more room on the back of the motorcycle (particularly for the easier storage of tripod legs) it is recommended that the diameter of the spools be reduced by ~ 2 inches.
- *Redesign with thinner metal to reduce weight* – much of the system (including the frame, tripod, and spools) is actually overdesigned with a safety factor that is too large. In order to reduce both the cost and weight of the system, it is recommended that the thickness of the steel used be reduced to ~ 2 mm.
- *Possible improvement of booster pump interface* – Currently, RTV is being used as a replacement for the O-ring. This is an easily replaceable part and is very convenient to use. However, it may be advantageous to explore other options for the booster pump interface.
- *Improvement on tripod* – some improvements could be made to the tripod to make it more easily collapsible. For example, ordering pre-made tripods may make this part of the design both simpler and more effective.
- *Work on changing the system for other motorcycles* – as it is now, the system is designed for used solely with the Honda CB 125. In order for this system to be used with other motorcycle models, it is ultimately recommended that the system be mounted onto a semi-universal luggage carrier instead of the motorcycle itself.

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Additional material, notes, calculations and part diagrams