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Thermoelectric cookstove

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Date: June 12, 2013

Signature Page

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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ENTITLED

THERMOELECTRIC COOKSTOVE

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

MECHANICAL ENGINEERING

THESIS ADVISOR, Dr. Hohyun Lee

DEPARTMENT CHAIR, Dr. Drazen Fabris

THERMOELECTRIC COOKSTOVE

By

Christine Horman, Matthew Lee and Mark Wagner

SENIOR DESIGN PROJECT REPORT

Submitted in Partial Fulfillment of the Requirements for the
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FUEL EFFICIENT COOK STOVE

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ABSTRACT

A fuel efficient cookstove tailored to the needs of Nicaraguan small business owners that incorporated insulation and thermoelectric power generation was built and validated. There is a 4 inch layer of pumice rock insulation around the combustion chamber, which significantly reduces convective heat losses to the environment. The stove's ventilation system is powered by the electricity generated by thermoelectric generators. Preheated air is forced into the combustion chamber, which increases the combustion efficiency, reducing the fuel consumption and the harmful smoke produced. Through various testing methods, we found that the controlled airflow to the charcoal fuel allows the stove to maintain the desired cooking temperature 38% longer that the standard inefficient stoves. This longer burn time translates directly into fuel savings, as the operator requires less fuel to accomplish the same cooking task. It is estimated that a customer could save at least $200/year on fuel, which represents two month's salary in Nicaragua. Compared to uninsulated stoves, our design reduces the outer wall temperature by 700° F, which is a significant safety improvement. The voltage generated by the TEGs, typically between 1.5-2.5 volts, is enough to power the fans; however, more work needs to be done to optimize a power management circuit that would facilitate device charging.

ACKNOWLEDGEMENTS

Team Matador would like to thank several individuals whose knowledge, input, and guidance helped support our efforts and led to our success. We would first like to thank our project advisor, Dr. Hohyun Lee for his tireless efforts to push our team to succeed. By holding us to a high standard of work and setting ambitious goals, he motivated us to strive for higher levels of success than we thought possible.

We would like to express our sincere gratitude for the generous $2500 from the Center for Science, Technology and Society (CSTS) grant and $1500 from Santa Clara University's School of Engineering. Without the financial support our project would not have been able to be completed. With the inspiration from our financial supporters we decided to travel to Nicaragua to learn from the local communities, but also, to share with others our passion for helping others that we learned from CSTS and the School of Engineering.

We would also like to thank Dean Mungal and the School of Engineering for their support of our trip to the ETHOS conference in Kirkland, Washington, and to Nicaragua, which were both excellent and educational experiences. Along with the School of Engineering's financial support for our trip to Nicaragua, we appreciated the generosity from the Provost's Office and the Ignatian Center. Without the financial support our trip would not have been possible. Also, we would like to thank Miguel Gomez, a graduate student at Santa Clara University, who traveled to Nicaragua with our team as an interpreter.

We would like to acknowledge Opeta Henderson for diligently tracking our project's budget, and helping us organize our spent funds in Nicaragua. Also, we thank Patti Rimland for helping us plan, and arrange our travel itinerary. We thank Susan Kinne and Victor Tijerino from Grupo Fenix who were very helpful both here in the United States and during our trip to Nicaragua. Finally, we would also like to thank our Dr. Tim Hight, our academic advisor, for his interest and useful insights concerning our project development.

--Team Matador

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1.0 INTRODUCTION

1.1 Motivation

This project is a continuation of a previous senior design project that focused on a small efficient cook stove sized for the individual family. Research gathered in Nicaragua by the previous group (Team MASAH) concluded that individual families are often reluctant to spend extra money on new cooking units, as they are more comfortable with the traditional methods. Many prefer to spend their saved money on other luxuries, such as televisions or stereos. Culturally, these items are more important. Improved cookstoves are more sophisticated and thus more expensive than traditional stoves. Even small improved stoves are beyond the economic reach of impoverished families. However, scaling up the size does not drastically increase cost giving large improved cookstoves better value and a greater cooking capacity than small stoves. Marketing improved yet expensive cookstoves to low-income families is difficult. Larger fuel-efficient stoves have more capability for the same amount of money and would be appealing to small businesses and farms. Many of the food stalls and small-scale tortilla makers in Central America may find fuel saving stoves to be an attractive investment. These local businesses provide a convent service to their communities by supplying locals with fresh tortillas and other foods on a daily basis. Encouraging this division of labor in rural communities will free women from the kitchen and enable them to explore other economic opportunities. Also, farms in Nicaragua are required by law to cook large amounts of food and feed their workers. Since these businesses operate on a relatively high production scale and use large amounts of fuel, improved cookstoves are seen as a good investment. Considering that the women who operate these facilities have to stand over stoves for much of the day, having a fuel efficient stove that has effective emissions management would benefit both the business's financial and the workers' physical health. Reducing the outer temperature of the stove is also important, as the women, especially those who are pregnant, are wary of exposing themselves to high temperatures for extended periods of time. Incorporating heat shielding and insulation will make these stoves safer and more comfortable to use, decreasing the chance of receiving burns.

1.2 Background on Nicaragua

1.2.1 Conditions of Poverty

Nicaragua was selected as the target customer country because of the previous work of Team MASAH, as they were able to gather a large amount of data and customer feedback concerning their cookstove and how it related to Nicaraguan communities. Nicaragua is the second poorest country in the Western Hemisphere. A majority of the population lives in poverty and there is limited access to gas, electricity, and running water. For many communities in Nicaragua, the lack of infrastructure leads to wood and charcoal being a primary fuel source even though it represents a health risk, an economic burden and leads to deforestation. It is common for Nicaraguans to use inefficient wood burning stoves to cook food and heat their homes. These stoves are simple to construct and typically consist of a metal cooking surface supported by bricks or scrap metal. They typically have poor insulation or and inadequate emissions management systems. Women suffer under smoky cooking conditions and it is common to observe walls and ceiling blackened with carbon buildup. These poorly ventilated kitchens present a serious respiratory health risk and a dangerous cooking environment.

1.2.2 Local Cookstoves

Table 1 depicts three commonly encountered cookstoves in Nicaragua and Central America. These stoves are used to cook a variety of foods, however they are generally poorly constructed, inefficient, and create unnecessary amounts of smoke.

Table 1. An overview of inefficient cookstoves currently being used in Nicaragua.

Local Stoves	**Design Issues**
	Open Comal: • Open, non-portable • Poorly insulated • Considerable heat loss to environment

<table>
<tr><td></td><td>Tire Rim:
Outer temperature: over 800 °F on wheel
Requires heat shield to operate comfortably
Heat shield temp: 200 °F</td></tr>
<tr><td></td><td>Fogonero:
Unprotected, unsafe, often used at schools, around children
Lifespan: 3-6 months</td></tr>
</table>

In the designs with no insulation, the outer wall temperature reaches up to 900 F, which is extremely uncomfortable to stand next to. Improvised heat shields are erected to make cooking tolerable, but even these shields reach up to 200 F on the surface The second style, called the Fogonero, is similar to the rim stove. However, instead of using a flat cook top, a pot is placed directly on the charcoal to boil beans or rice. Both stoves have a short life of only 3-6 months, because they are cheaply put together. This can be particularly dangerous when used around children, as the stoves can fall apart without warning, spilling hot liquids and lit fuel. The third type of stove is an open griddle (also known as a comal or plancha) which is used to cook many tortillas at a time. It often lacks a complete enclosure around the fuel, allowing for significant heat losses and very smoky cooking conditions. None of these stove designs is ideal and can be improved.

1.3 Literature Review

1.3.1 Market resistant to new stoves

An in depth study of the implementation and adoption of efficient cookstoves found that programs that attempted to get communities to use more efficient cooking methods were often unsuccessful. This study, entitled, “Who Adopts Improved Fuels and Cookstoves? A Systematic Review”, by Jessica Lewis and Subhrendu Pattanayak found that nearly half of the global population relies of solid fuel, such as wood, coal, or dung for cooking. Indoor air pollution caused by inefficient stoves that use these fuels cause 2 million premature deaths per year.[1] The inefficiencies of traditional cooking methods also result in higher fuel costs and/or more time and energy spent gathering fuel. These facts illuminate the importance of using fuel efficient stoves in developing and poorer countries. Lewis' and Pattanayak's study found that the success of an efficient cookstove program hinged on multiple aspects. An important factor was educating the target community about the benefits of cooking with greater efficiency. Another important factor is the effectiveness of the social marketing of the stove itself, and the need to extend the supply chain of stoves into as many communities as possible. Programs that allowed customers to purchase stoves on a credit system also had substantially higher stove adoption success rate.[2]

1.3.2 Prototype testing of new stoves proved promising

The previous cookstove team (Team MASAH) traveled to Nicaragua and gathered important research about cookstove usage. A common cookstove was constructed from a scrapped car wheel. These wheels were modified to have a fuel reservoir, and the circular shape conveniently accommodated larger pans. Other styles of stoves make no attempt to regulate airflow to increase fuel burn efficiency or use insulation to direct more heat to the cooking surface, as opposed to being lost out the sides of the stoves. Team MASAH's research found that individual families would be willing to purchase efficient stoves if offered at a price of around \$50. MASAH also found that small food businesses and community tortillas suppliers would be interested in purchasing stoves that could save on fuel costs, as they use more fuel than the average household because of their volume of production.[3] During their time there, they tested efficient cookstoves produced by a Nicaraguan company called Proleña. Food vendors operating out of their homes who fried plantains and meat found that using the Proleña cookstove reduced fuel consumption by 30% and cut the amount of oil used by 50%. More importantly, the stove stayed cooler and took less time to cook, reducing the cook's discomfort. Efficient cookstoves were also tested in a Mercado or marketplace. The women who make tortillas were initially skeptical of the compact size of the Proleña stove, and thought it would be incapable of

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[1] Lewis, Jessica J., and Pattanayak, Subhrendu K. "Who Adopts Improved Fuels and Cookstoves? A Systematic Review", 2012

[2] Lewis, Pattanayak,

[3] Gomez, Miguel. "Nicaragua Research Implementation" 2011

producing enough heat to cook large 9 inch diameter tortillas. The stove did lack the surface area to cook larger tortillas evenly, but cooked 7 inch diameter tortillas very well. The reduction in fuel usage attracted many of the tortilla makers, and after the demonstration, there was more interest in acquiring the efficient stoves, although a larger surface area would be preferable.

1.3.3 Energy harvesting integration

While the integration of energy harvesting systems, such as thermoelectric generators (TEGs), into cookstoves is not common, there has been some research into the effectiveness of this combination. A study by C. Lertsatitthanokorn found that a temperature difference of 150 °C achieved a power output of 2.4 W, resulting in conversion efficiency of 3.2%. This power generation was enough to drive an incandescent light bulb or small radio.[4] This study gives us confidence that TEGs can provide a viable source of power from cookstove use.

Thermoelectric power generators operate on the Seebeck effect[5], through which electricity is generated directly from a temperature difference. Temperature difference between the front face of the module (contacting a hot wall of the stove body) and the back side allows for charge carriers in the module to diffuse from one end to the other. This diffusion of charge generates electricity. If the rate of diffusion from the hot to the cold side, and vice versa, is equal, (meaning there is no temperature difference between the front and back) then no electricity is produced. This means that efficient cooling of the back side of the modules is essential for energy production.

1.4 Project Objectives and Goals

The project developed a charcoal-burning cook stove for use in impoverished and developing countries. The stove was tailored to fit the needs of people in Nicaragua; there is enough surface area to cook multiple tortillas and pots of food at the same time. Thermoelectric generators (TEGs), which use the heat of the combustion of fuel to generate electricity, further increases the energy efficiency. The power that is generated is used to power air circulation fans, which make more oxygen available for combustion, increasing the combustion efficiency and decreasing the amount of harmful emissions. These high efficiency fans are made with brushless DC motors and have a voltage boosting circuit, which allows the fans to be run at a higher speed

[4] Lertsatitthanakorn, "Electrical performance analysis and economic evaluation of combined biomass cook stove thermoelectric (BITE) generator" 2007
[5] Civie, Victor. *The Seebeck Effect in Semiconductors*. Thesis. University of Connecticut, 1980. N.p.: n.p., n.d. Print.

if necessary. Pumice stone, which is a locally available resource in Nicaragua, was used as insulation to decrease heat loss and increase the longevity of the fuel burn time. In addition to these features, the power generated from the thermoelectric generators can also be used to power a light or charge a cell phone.

2.0 SYSTEMS-LEVEL CHAPTER

2.1 Customer Needs

Before building a fuel efficient cookstove it is important to research potential users and make sure that the final project adequately meets their needs. Interviews with thouse knowledge about the cookstove field were conducted and the results are displayed in Table 2.

Table 2. Summary of Costumer needs based on interviews of cookstove researchers and literature review

Rank	Need	Importance
1	Improved Fuel Efficiency	Improved/more efficient fuel combustion is the most important objective. It will save the user money and reduce their exposure to smoke
2	Cost	Families and/or companies are reluctant to spend more money on a cookstove than what they currently pay for. Thus it is important to reduce the cost of the cookstove to a minimum.
3	Portability	After cooking, it is useful if the cookstoves are able to be transported or stored away.
4	Easily Built/ Repaired within Country	To reduce cost, it would be best to construct and the stove in the costumers' country, working closely with a community. This would reduce the transportation costs and the costs of buying material goods outside of the country, and give the locals pride of ownership.
5	Energy production	It is more of a perk of the system for the cookstove to produce extra energy to charge a cell phone or power a stereo system. However, this is not a function of the current cookstoves, so it is not crucial that our stove have this function.

The contents of Table 2 were assembled from interviewing researchers at Lawrence Berkeley National Labs, the designers of the Darfur Stove, and Miguel Gomez, who developed an efficient cookstove for use in Nicaragua with Team MASAH at Santa Clara University.

2.2 Company Contacts:

There the course of our research we encountered many people and organizations that were helpful with our project. They are listed in Table 3 for future cookstove teams.

Table 3. List of the major contacts encountered by Team Matador.

Contact	Company	Description
Susan Kinne (Directora, Programa Fuentes Alternas), susankinnefenix@gmail.com Phone: 2278-3133	***Grupo Fenix Nicaragua*** Totogalpa, Sabana Grande, Nicaragua	• Non-Governmental Organization • Community development programs • Builds solar panels and solar ovens • Employs, educates, and empowers locals • Susan acted as a guide while in Nicaragua • Employees helped evaluate our stove
Paul Lee sjpolygon@yahoo.com Phone: (408) 727-7303	***Paragon Mechanical Inc.*** 445 Robert Ave, Santa Clara, CA 95050	• HVAC and landscaping company • Large stocks of sheet metal • Able to supply most of our metal needs at excellent prices • Processed metal our shop could not handle
Judy Kennedy jkennedy@marlow.com Phone: (877) 627-5691	***Marlow Industries Inc.*** 10451 Vista Park Rd, Dallas, Texas 75238	• Produces thermoelectric generators in a variety of sizes • Provided discounted TEG's for our project
Dan Wilson dlwilson@berkeley.edu insearchofthekey@yahoo.com info@darfurstoves.org	***Lawrence Berkeley National Laboratory*** 1 Cyclotron Road Mail Stop, Berkeley, CA 94720	• United States Department of Energy Office of Science National Lab • Provided initial support with stove design concepts • Has stove validation facilities • Designs and iterates the Darfur Stove
Marlyng Buitrago Santamaría prolena20@turbonett.com.ni mbprolena@hotmail.com mbprolena@yahoo.com	***Proleña*** Location: Villa Arlen Siu, Del Nuevo, Nicaragua.	• Produces improved cookstoves • Previous cookstove team (MASAH) worked with them in Blue Fields, Nicaragua • Highly capable of making stoves • Could be a useful partner for

2.2.1 Grupo Fenix Nicaragua

Grupo Fenix is a Non-Governmental Organizatoin that operates out of Totogalpa, Nicaragua. Grup Fenix assisted with our travel and organizational plans while in Nicaragua. Grupo Fenix specializes in solar energy harvesting, developing solar ovens and building solar panels. While in Nicaragua, the women who build the solar cookstoves were a primary source of feedback concerning our stove's performance.

2.2.2 Paragon Mechanical Inc.

Paragon Mechanical Incorporation is a local design-build heating, ventilation and air conditioning contractor. They process their own sheet metal and were able to supply Team Matador at a discounted rate.

2.2.3 Marlow Industries Inc.

Marlow Industries provides customers with high quality thermoelectric technology. Marlow Industries develops and manufactures thermoelectric modules and provide services to a variety of corporations and technologies. Marlow Industries provided a discount on our thermoelectric modules.

2.2.4 Lawrence Berkeley National Laboratory

Lawrence Berkeley National Laboratory (LBNL) is a United States Department of Energy Office of science national lab that brings science solutions to the world. LBNL provided initial support while in the design concept phase of our project. LBNL showed us their facilities and current Darfur Cookstove (LBNL's improved cookstove).

2.2.5 Proleña

Proleña is a Nicaraguan company that makes and markets fuel efficient stoves. They manufacture a range of wood burning stoves of different sizes and robustness. The previous cookstove team (MASAH) worked with them when they travelled to Nicaragua. This company possesses the manufacturing capability to assemble stove bodies and perhaps the other technical components. If our stove is implemented or put into production, this company's local knowledge of the costumers will be very important.

2.3 System Sketch

The system level sketch of the design shows how the stove and its components interact. The arrows in Figure 1 indicate the intended flow of energy and materials during operation. Charcoal is combusted in the cookstove, which then produces heat that is distributed along the thermoelectric generators, and energy is either stored in a battery or powers a fan. The air flow from the fan passes over a heat sink, thus maximizing the temperature difference of the thermoelectric generator. Finally, the heat of the combustion allows for tortillas to be made and the remaining heat is dissipated through the chimney.

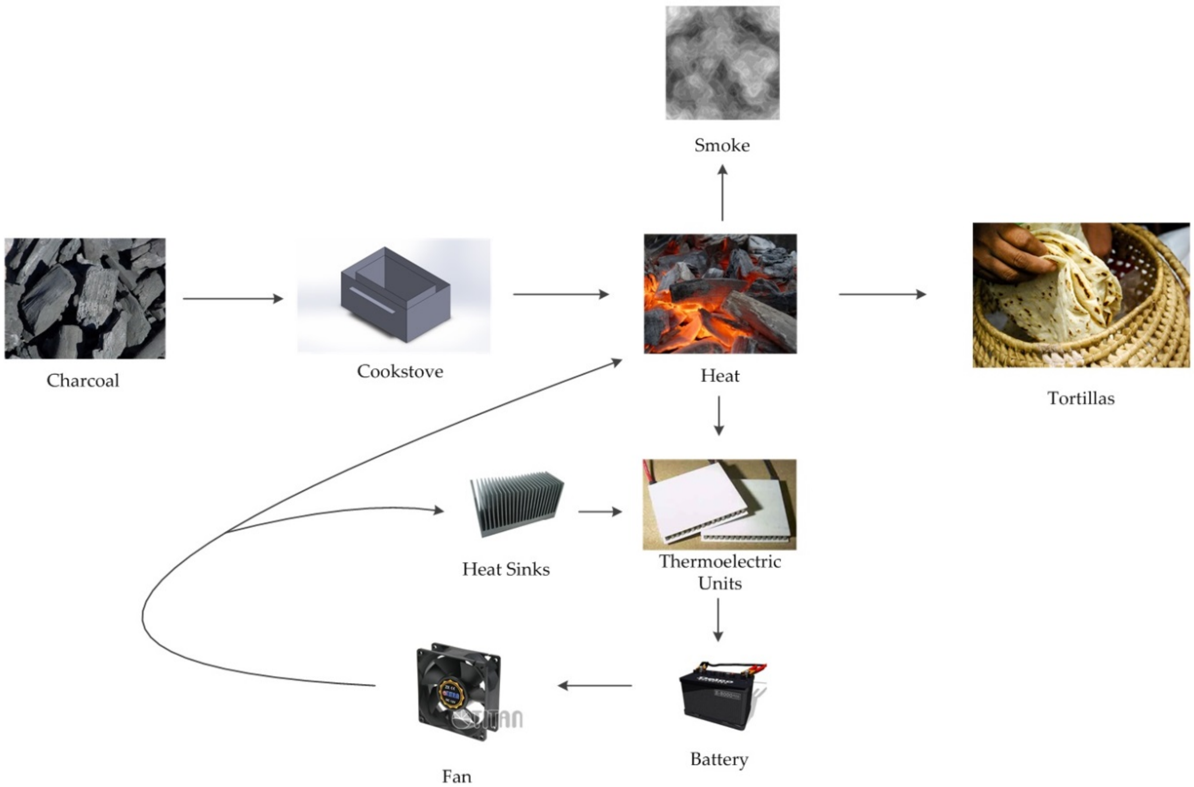

Figure 1. System level sketch, detailing the inputs, outputs, and intermediate components of our stove.

The purpose of the cookstove is to provide Nicaraguan small businesses with a cleaner, safer, more fuel efficient way to make tortillas and other dishes. Forced airflow is introduced into the stove's combustion chamber by fans. Increased air flow improves the combustion efficiency of fuel, leading to higher burn temperatures achieved with lower amounts of fuel. Also, less ash and smoke is produced. Cooks are exposed to lower levels of smoke while saving money on fuel. The fans are powered by thermoelectric generators, which are attached to heat probes that extrude into the combustion chamber of the stove. The thermoelectric generators convert the heat generated by combustion into electricity. Air flowing past the heat sinks attached to the TEGs further increases the efficiency of the thermoelectric generators, maximizing the temperature difference across the thickness of the generator.

2.4 Functional Analysis

2.4.1 Functional decomposition

The efficient cookstove consists of a stove top, stove body, ventilation system, and a power generation system. As shown in Figure 2, each of the above components has key features.

Figure 2. The key features of the stove body, ventilation system and power generation system.

Insulation in the stove body directs heat from the combustion chamber to the cooking surface, decreasing heat losses laterally out the sides of the stove, and reducing convective losses. The power generation system comprises two TEGs that are protected and uniformly heated with heat probes. Thermoelectric generators convert heat into electricity. When the generators are exposed to a heat source on one side, and cooled on the other side, a temperature difference is created. When the temperature difference is applied to the 100's of n-p semi-conductor pairs within the generator, electricity is created from charge carrier diffusion. This is known as the Seebeck effect.   Maximum efficiency is achieved when a uniform temperature is applied to the hot side. And the Voltage that is generated is proportional to the temperature difference between the heat source and cool side. Thus effective cooling is necessary to maintain a large temperature difference and voltage output.

The heat probe is exposed directly to the burning fuel, conducts heat away from the immediate combustion site, decreasing the likelihood of the TEG overheating or melting. The power generated from the TEGs is used to run high efficiency custom fans. The forced air that is generated from these fans is used to accomplish two tasks simultaneously. In the first stage, the air passes over heat sinks attached to the back sides of the TEGs, cooling them down in order to maintain a temperature difference and electricity generation. In the second stage this air is directed into the combustion chamber via the duct system. Each duct has five, one inch diameter holes that focus the air at the base of the fuel. An abundance of air increases the fuel's combustion temperature and efficiency. Higher cooking temperatures are maintained while less fuel is used.

2.4.2 Specific lists of inputs/ outputs, constraints

Using the information gathered by Team MASAH during their research trip two years prior, we determined that charcoal would be an appropriate fuel to test with. Initially, we tested with commonly available compressed charcoal briquettes. However, we found that this fuel generated a lot of excess ash, as it is made with various fillers and chemicals. Therefore, we transitioned to using natural, uncompressed mesquite charcoal. While in Nicaragua ourselves, we found that there is regional variation in the types of fuel used, and only used wood during our cooking demo's in the communities around Totogalpa. In addition to the fuel, air is also a vital input in order for the combustion process to take place. Another input is uncooked food. After cooking, the outputs are cooked food, heat (stored energy), carbon emissions, and ash. The stove should be used in a well-ventilated area, and the ash should be cleaned out after several uses. The size of the fuel that is added to stove is constrained by the size of the fuel chute and the length of the stove. We found that while in Nicaragua, pieces of wood that were longer than the stove were not ideal, as the ends stuck out the stove and were a potential hazard when lit and not contained within the body of the stove. However, the stove performed well with both charcoal and wood. The cooking capacity is constrained by the surface area of the cooktop (2'x3'), although we found that when used to cook food during large festivals in Nicaragua, the stove was capable to cooking 4-6 pots of food at a time, which provided food for 50-100 people. Controlling temperature is tricky, as the cooktop can become too hot to cook on directly. However, the outer edges of the cooktop that are not directly over the burning fuel can be used to cook tortillas and meat directly.

2.5 Improved Cookstoves

Many people have recognized cooking conditions in the developing world are a problem and they actively working on improved cookstoves. Four examples can be seen in Table 4; all of these stoves have been successful because they are tailored to their target markets, consistently taking into account local needs and user feedback.

Table 4. Improved cookstoves currently being deployed around the world.

	Stove & Price	**Details**
	Mega Ecofon Produced by Proleña in Nicaragua *USD $203.00*	• Pumice stone insulation • Sheet metal body • large cast iron cooktop • High cooking capacity • Semi-portable • Competes with Matador cookstove
	Darfur Stove Produced in India and regions in Africa Designed by Lawrence Berkeley National Lab *USD $20.00*	• Stamped sheet metal • Accommodates only one pot • Saves up to $160/year • Spacing for optimized airflow • Portable
	BioLite Homestove Designed by BioLite, an American company *In Beta Testing, price pending*	• Thermoelectric power generation • Fan that delivers forced air to combustion chamber • Claimed: 50% less wood consumed • Claimed: 95% smoke reduction

	ONIL Plancha Stove Designed / Produced in Guatemala *USD $122.00*	• Permanent • Concrete body • Pumice stone insulation • Claimed : 60-70% reduction in wood consumed • Competes with Matador cookstove

2.5.1 Mega Ecofon

The Mega Ecofon is a model recommended for small businesses, although a family can easily use it for the home. With double the surface of its predecessor and equipped with two combustion compartments. It is excellent for making nacatamales, soups, cooking beans, fritangas, bahos and tortillas. Comes with a 2.7 meter high chimney.

2.5.2 The Berkeley Darfur Stove

Lawrence Berkeley National Lab has developed an efficient stove for use in the Darfur region of Sudan. The purpose of the stove is to reduce the amount of fuel used and emissions released from the stove. The Darfur stove saves up to $160 per household per year and it has the following attributes:

1. A tapered wind collar that increases fuel-efficiency in the windy Darfur environment and allows for multiple pot sizes.
2. Wooden handles for easy handling.
3. Metal tabs for accommodating flat plates for bread baking.
4. Internal ridges for optimal spacing between the stove and a pot for maximum fuel efficiency.
5. Feet for stability with optional stakes for additional stability.
6. Nonaligned air openings between the outer stove and inner fire box to accommodate windy conditions.
7. Small fire box opening to prevent using more fuel wood than necessary.

2.5.3 BioLite HomeStove

BioLite has developed a wood burning cookstove for family use. Like the CampStove it utilizes a thermoelectric unit to power a fan and charge anything that can be hooked up to a USB port. The stove's space coupled with the increased airflow that the fan provides reduced the stove's carbon emissions. It is similar in size to the Berkeley Darfur stove and is slated for use in the developing world. The stove is currently being field tested and is not available to the general public, but it will eventually be available for purchase.

2.5.4 ONIL Plancha Stove

The Onil Plancha Stove is currently being deployed in Guatemala and reports fuel savings over 60%. Indoor smoke exposure is reduced by 99% when emissions are vented outside of the home. It has a large cooking surface that enables users to cook tortillas and other staples of a Central American diet.

2.6 Key System Level Issues

Given the problems with existing solutions, we embarked on a design that incorporated forced air and thermoelectric power generation for Nicaragua and Central America. Each system was designed to optimize fuel usage and enhance the user experience. The overall system review follows here in section 2.6 and the subsystem detail in presented in Chapter 3.0.

2.6.1 Stove top designed for multiple purposes

Two different cooktops were created, each with heavy duty handles for ease of removal from the stove. The large griddle top, locally known as a comal or plancha, is a 10 gage thick piece of mild steel, measuring 2'x3'. We found that even with this thickness and angle iron reinforcements, this surface still bowed in the center, causing the whole surface to lose its uniform flatness. This slight deformation prevents the combustion chamber from being perfectly sealed, allowing from some leakage of smoke and heat under adverse conditions. The warping also prevents ideal surface contact with flat pots and pans, which do not match the subtle curvature of the plancha. A second, smaller cooktop was created to specifically boil water, feature a circular cutout, allowing for a pot to be placed directly over the burning fuel, and a smaller surface area (covering only the inner combustion chamber) to reduce convective losses. This surface also suffers from warping. Despite these issues, both surfaces allow for a flexible cooking surface that can accommodate many different types of cooking, including boiling, frying, steaming, grilling, and sautéing.

2.6.2 Stove body designed for easy assembly and repair

The simple box shape of the stove body was chosen because of its ease of manufacturability. Because the inner and outer chamber both have several openings that need to be cut out of them in order to accommodate fuel chutes, ductwork, and fans, utilizing flat pieces of metal that can be easily cut with cheers and punches is advantageous. The body was fastened together with nuts, bolts, and washers, which makes it easy to take apart for flat transport. However, the use of pop rivets in a final product may make production faster and cheaper.

2.6.3 Power Generation and energy harvesting system

The most significant problem with using multiple TEGs connected in series is the issue of load and internal resistance imbalance, which severely degrades performance. The internal resistance of a TEG changes based on the temperature applied to it. If an uneven temperature gradient exists across the face of the generator, the internal resistance increases and the power generation efficiency decrease. Therefore, only one TEG is used for each fan in our design, eliminating load balancing issues. The use of aluminum heat probes is also employed to moderate the temperature applied to the TEGs. The extra thickness of the aluminum between TEG and the wall of the combustion chamber decreases the possibility of the TEGs being exposed to hot spots and meltdowns. The aluminum blocks also make the temperature that the TEGs contact more uniform. Uniform temperature increases generator efficiency. The heat probes also act as supports for the grate that the fuel sits on. In this way, the probes are only heated by convection and radiation from the burning fuel, which limits the possibility of the probes sustaining damage.

2.6.4 Ventilation system directing of air flow

There are two sets of duct and fan assemblies that run in opposite directions on the long sides of the stove. The duct and chimney systems, which direct the flow of air in the stove, are constructed from thin gage roofing aluminum. This was chosen over galvanized steel because it does not present of risk of releasing dangerous fumes when subjected to extreme heat. The light gage of the material also makes it easier to work with, but there are also several drawbacks to this material. It suffered some deformation under the weight of the pumice stone insulation; however this was only a cosmetic issue. The durability of the material was harshly tested while in Nicaragua, when wood was used in the stove for the first time. When pieces of wood that were too long were used, parts of the fuel chute and chimney were damaged by the aggressive flames coming off of the wood. In this situation, flames can be inadvertently placed directly under the thin aluminum parts, causing them to partially melt. This testing demonstrated that a heavier gage material should be investigated.

2.7 Layout of System

The layout of the system is depicted in Figure 3 and shows how energy, raw material and the design interact.

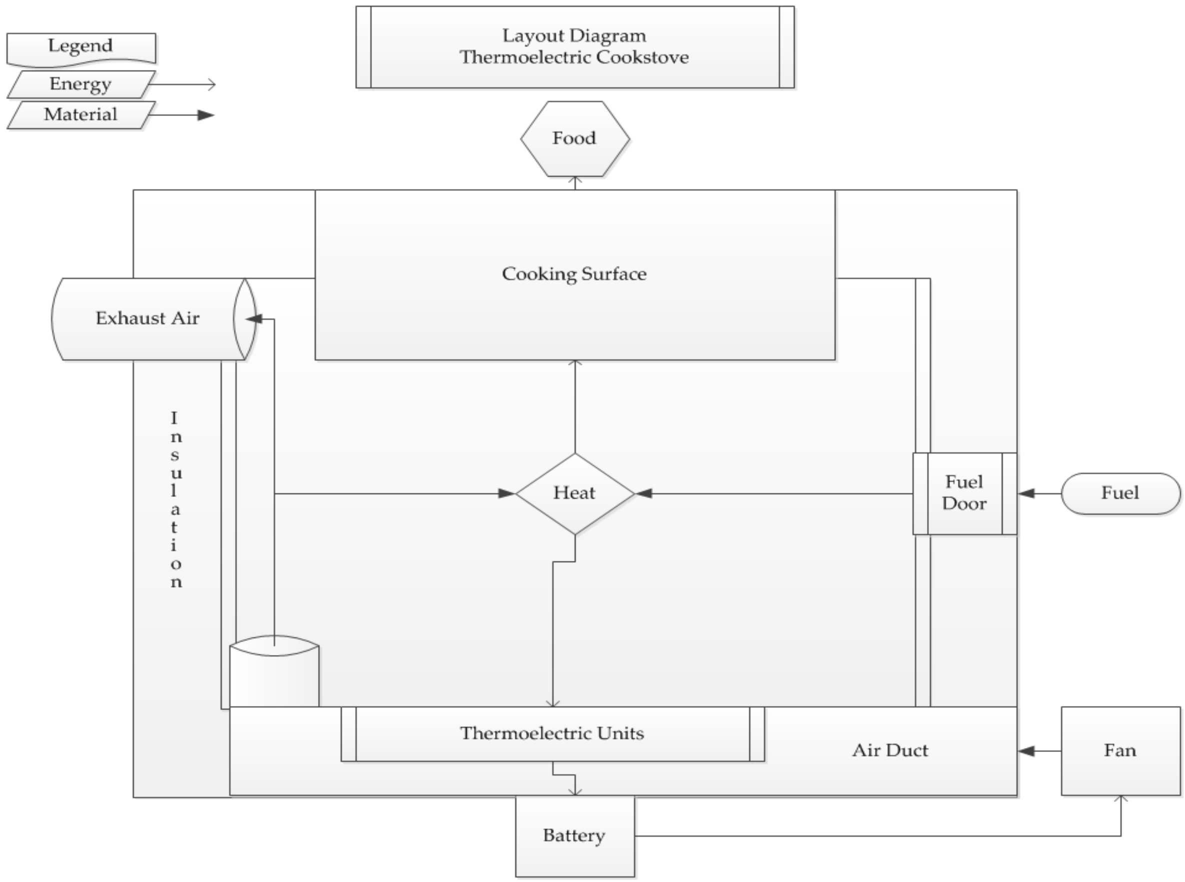

Figure 3. Layout of stove system, detailing the sequencing of how inputs produce outputs in the stove.

The cookstove consists of four subsystems: the stove top, stove body, ventilation system, the power generation system. The combustion chamber is insulated by the stove body and pumice rock. This insulation directs more heat toward the cooking surface. The use of large amounts of fuel is reduced by redirecting the heat toward the cooking surface. The stove top is removable so fuel can be easily ignited. Referencing Figure 3, the thermoelectric generator cooling and duct system generates electricity that can be stored by a battery. The duct system's fans are driven by the power generation of the TEGs. Air is forced through the duct system, cooling the thermoelectric generators and ventilating the combustion chamber; because of this airflow, the efficiency of the generators and combustion is increased.

2.8 Team and Project Management

2.8.1 Project Challenges and Constraints

There were several challenges encountered during the building the testing of our improved cookstove. The first was the limited communication capability we had with our potential customers while designing the stove. Since our target customers live in Central America, it was nearly impossible to have useful discourse about exactly what they wanted in a stove, and what kinds of design elements and ergonomics they wanted incorporated in the design. Thus, we had to use the information gathered by the previous cookstove team (MASAH) from their trip to Bluefields, Nicaragua, in order to ascertain some of the important features of Central American cookstoves. We also used our collective cooking and fire-starting knowledge to design a prototype that we felt was relatively intuitive and easy to use. We incorporated several features that made the stove modular and fairly easy to assemble and reassemble. The second main challenge came during testing. Santa Clara University lacks the appropriate indoor facilities to test stoves, thus our testing was greatly affected by the weather. It was impossible to keep variables such as wind and ambient air temperature consistent. We found that a strong wind would cool down our large aluminum pots faster than they could be brought to boil. This meant that when conducting the same test under slightly different weather conditions, water would boil in less than ten minutes or not all. Thus several lengthy tests had to be thrown out. Also, without a fume hood, we could not gather carbon emissions concentration data.

Due to the complexity of our tests, which involved managing many different variables, such as weighing and lighting charcoal, measuring temperatures, tracking times, and extinguishing/saving fuel remains, we had to develop very strict test timelines and checklists in order to make sure there was no loss of fidelity. In order to maintain some level of consistency, several strategies were enacted. The first was using commercially available charcoal chimney starters to light our natural charcoal fuel. By using a chimney starter, we could ensure that the charcoal was lit to a similar degree in each test. We also found that it was very important to chop the charcoal into roughly uniformly sized pieces, as large pieces did not light well. In order to solve the wind-convection problems, we made a simple wind shield out of sheet aluminum and rivets. This shield was placed around our pot during boiling tests. This reduced the effects of the wind cooling down the pots due to forced convection.

The metal working tools at the SCU machine shop limited us to certain sheet metal thicknesses and sizes (up to 16 gage and only pieces less than 36” in length). We decided to create a rectangular design to limit the amount of challenging cuts. Despite these challenges, testing with the Nicaraguan people during a week-long trip was successful, and many people expressed interest in the stove. The stove was used on several occasions to cook food for over fifty people, with satisfying results.

2.8.2 Budget

A detailed budget for the material costs of the cookstove is provided in Appendices A and E. Fortunately several design changes have made it possible to reduce the number of TEGs used, which significantly reduces costs. Initially we estimated that it would take at least eight TEGs in series to provide enough voltage to run two air circulation fans, there were also plans to cool these TEGs with a combination of heat pipes and heat sinks. In the final design, the low efficiency computer fans were changed to high efficiency custom fans made with brushless DC motors. Needing only 1-3 volts to run, only one TEG was needed for each fan, bringing the total down from eight to only two. The heat pipes were also deleted, further reducing costs. The cost of the prototype was round $320 dollars. Our advisor suspected that if produced in Nicaragua, material costs could be reduced by as much as 85%, bring the material/assembly costs to under $90. Considering that Proleña offers similarly sized stoves at $200-$450, we feel that our stove could be offered at a competitive price of $150-$200.

2.8.3 Timeline

In order to stay organized and on task while designing and building our cooksotve, the timeline in Table 5 was developed.

Table 5. General timeline of tasks to be accomplished throughout the school year

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Research Existing Cookstove Designs										
Research TEG's, Heat Pipes, Insulation										
Preliminary Heat Transfer Calculations										
Fundraising										
Preliminary Design										
Begin Purchasing Materials										
Full Analysis of Design, Heat Transfer, Energy Requirements										
Prototype Design										
Purchase Materials										
Construction of Cookstove Prototype										
Test Other Cookstove Performance										
Iterate Prototype										
ETHOS Conference										
Create Testing Protocol										
Begin Testing on Complete Cookstove										
Finalize Cookstove Design										
Organize Final Report and Presentation										
Complete Testing on Complete Cookstove										
Perform Final Tests on Proleña and Open Comal										
Prepare and Present at Conference										
Complete Final Thesis										

The timeline above provides a general layout for our goals. In the first months of this project we spent our time searching and applying for funding opportunities. Also, during this stage, we spent time researching and gathering information for our design process. This included learning from Miguel Gomez, a previous Cookstove (MASAH) team member, gathering contacts and educational materials from him, as well as establishing contact with Grupo Fenix, Lawrence Berkeley, blueEnergy, the Santa Clara University Frugal Lab, and Proleña. Finally, in the first months we brainstormed possible cookstove designs. In November we finalized an initial cookstove design. The projected timeline through June is detailed in Appendix C.

2.8.4 Design process

Our design was developed by considering the previous team's results, customer needs, manufacturing constraints, and heat transfer and computational fluid dynamics (CFD) predictions. Team MASAH's research gathered from Nicaragua two years earlier helped give us a basic idea of what kind of cookstove will be successful, what design aspects needed to be improved upon, and what aspects of their stove did not work. Due to expensive components, such as TEGs and power control circuitry, we decided that a thermoelectric augmented cook stove may be too expensive for the average family to purchase. Therefore, we hypothesized that small food businesses that use much more fuel that an average household would be able to afford and justify the purchase of a more expensive improved cookstove. A food service business would be able to recover its initial investment much faster as well. With this type of customer in mind, we designed a stove with a fairly large cooking surface area (2'x'3) in order to accommodate multiple pots and pans at one time.

The placement of the TEGs evolved over time as well. Initially, we planned on using at least four TEGs, connected in series, to generate enough voltage to run computer fans to force air into the combustion chamber. We also planned on using heat pipes to shift the position of our heat sinks. Both of these overly complicated ideas were deleted in favor of simplified solutions. Deleting the inefficient computer fans and replacing them with highly efficient custom fans reduced the number of TEGs from four to one, for each fan. It was also decided that shifting the placement of the heat sinks with heat pipes was unnecessary, thus the heat sinks were placed directly onto the TEGs. With this design change, only one duct system was necessary per TEG.

In order to reduce the amount of heat lost to the environment, as well as reduce the outer wall temperature, we surrounded the combustion chamber with pumice stone insulation, which is a volcanic rock that is a naturally occurring resource in Nicaragua.

The airflow from the fans is directed into the combustion chamber via ported duct system. The position and size of these ports was modeled in a CFD analysis, using a simplified model in SolidWorks FlowXpress. The use of five, 1" diameter holes along the length of the duct was compared to having a single 3.5" square opening at the end of duct. Based on the flow patterns and air movement, we decided that the circular ports would focus the air at the base of the fuel, providing more benefits than a larger opening at the end of the duct, which would only blow are at the extremities of the burning fuel.

The rectangular geometry, material, and material thickness were also chosen around the capabilities of our machine shop. Initially, we wanted to use 16 gage stainless steel for the cooktop, because of its corrosion resistant properties. However, we found that it was too thin and warped far too much under the heat. Therefore we opted for a 10 gage mild steel cooktop with angle iron reinforcements to reduce the degree of warping. The depth of the stove body was also reduced by 7 inches, as we found that there was a lot of dead space in the stove that contributed to heat loss. We also manufactured smaller cooktop with a circular cutout that was used for water boiling tests. Because the warping of the cooktop created contact issues with flat bottom pots, we thought that a cutout that put the pot directly over the burning fuel would have better heat transfer. In general this hypothesis proved true. However, while in Nicaragua we found that pots of liquid boiled despite the warping, but this may have been due to using wood for fuel, which burned hotter.

2.8.5 Risks and mitigations

Table 6 lists the risks that we anticipated before working on our cookstove. With these risks in mind were able to anticipate and avoid any accidents.

Table 6. Risks associated with performing a senior design project.

Risks (In order of descending importance)
Possibility of accidents in machine shop
Dangers of working with fire
Focusing on too many goals – threatens completion of project
Difficulty communicating with customers – inadequate design
Stove too expensive for target market

Despite the concept of this project being fairly straightforward, there were several risks that we had to be aware of. There were physical dangers that we had to consider. The first was the inherent danger in building the stove, which required cutting sheet metal, drilling, and using lathes and mills. We made sure we were properly instructed on the use of these tools and made sure to have a plan before starting our work. The second danger came from our work with fire. We always worked with temperature resistant gloves and safety glasses, and kept buckets of water on hand to douse out of control flames. However, due to careful attention, we never had any accidents.

We also had to set realistic design goals and expectations; otherwise we would have run the risk of not completing our project. We knew we could not do everything perfectly and exactly how we wanted, so we needed to focus on certain design aspects. We focused on optimizing the placement and layout of our TEG and fan systems in order to achieve acceptable power generation. The previous team was not able to generate enough power to run their fans, and since having self-sufficient power generation was the whole point of the stove concept, we wanted to make sure this aspect functioned.

Without the availability of customer feedback, we ran the risk of creating a stove that functioned as design, in terms of power generation and safer ergonomics, yet did not function well as an actual stove. In order to mitigate this risk, we cooked with stove as much as possible, making a variety of dishes, cooking Nicaraguan inspired food to ensure stove's functionality. During the initial phases of our testing, we found that our thin, stainless steel cooktop warped significantly, and thus did not have good surface contact with flat bottomed pots. Making observations such as this was important in finalizing the design of the stove. Thoroughly testing our stove with many cooking tests helped ensure that our cookstove was usable, an objective that is easy to lose sight of with so many other technical goals to achieve.

A final project risk was designing a stove that would be too expensive or complex for the Nicaraguan people. In order to mitigate this risk, we scrutinized our design in order to eliminate all unnecessary components, and were able to remove around $200 from the prototype costs by reducing the number of TEGs to only two, and eliminating heat pipes all together. These frugal concerns simplified the construction of the stove as well.

2.8.6 Team management

Due to our small group size of only three members, we had to be very organized and efficient with our time. In order to organize goals and stay on task, we created a share drive spreadsheet that tracked and organized everything we did, so that important information was accessible from any location with internet. We created pages that tracked materials and supplies, contacts lists, budget, order history, and most importantly: weekly goals. By logging the tasks from our advisors and ourselves, we tracked the completion rate throughout the weeks, which allowed us to focus on the most important things without getting overwhelmed.

Good verbal communication was also key for keeping transparency and maintaining the flow of ideas. We attempted to create a "roundtable" atmosphere, where all ideas were shared and heard. While there were conflicts about design and procedure, we always made sure that a solution that satisfied all members was achieved.

We also attempted to allocate work evenly, and encouraged members to speak out if they felt they had too much or too little work. Although we all shared most the tasks equally, there was some specialization of tasks. For example, Mark Wagner handled organizing the design drawings, Christine Horman took the lead organizing the Nicaragua trip, and Matthew Lee acquired much of the raw materials and led the cooking tests. Since the group was small, we were able to maintain a high level of accountability, and our system of equal leadership and project ownership worked well.

3.0 SUBSYSTEM CHAPTER

3.1 Subsystem Introduction

3.1.1 Stove Top

The stove had two cooking surfaces as depicted in Figure 4. Each other surfaces optimized a specific cooking task. The comal surface allowed for large quantities of tortillas and meat to be cooked while the cut out allowed water to boil effectively.

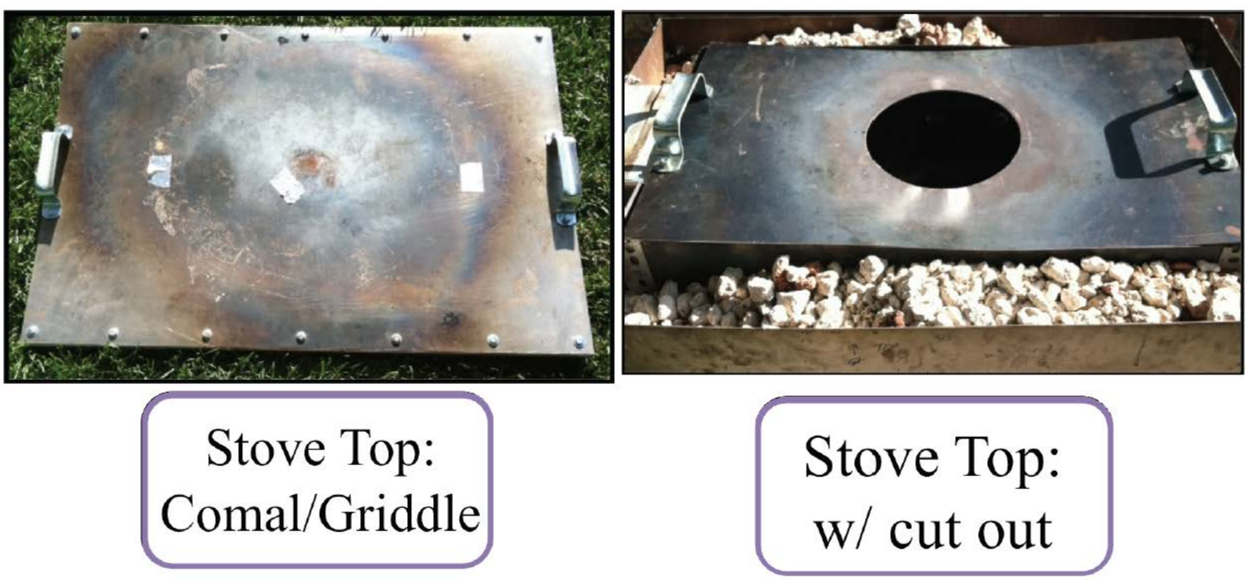

Figure 4. The two stove tops. The griddle was used to cook meat and tortillas while the cutout was used to optimize the boiling of water.

The large flat griddle, known as a “plancha” in Central America is constructed of 10 gage mild steel, and covers the entire top of the stove, which measures 2’x3’. The surface area of the plancha is maximized for cooking large amount of tortillas or sautéing vegetables or meat. The cooktop has heavy duty handles to facilitate lifting on and off the stove body, and has angle iron reinforcement ribs to reduce the amount of heat warping. This design is an improvement over the first cooktop which was made of 16 gage stainless steel. The thinner stainless steel warped too much and was also difficult to work with, as it was too hard for several of the metal working tools in the machine shop. A second cooktop with a circular cutout was created to facilitate cooking with pots, as we found that the warping in the large cooktop led to poor surface contact and heat transfer with flat-bottomed pots. With a whole that was slightly smaller than the bottom of the test pots, we could have the flames from the fuel directly hitting the bottom of the pot, which lead to be better heat transfer and boiling results. With these two cooktops, we achieved a higher degree of cooking capability and flexibility. During testing, stove top temperatures typically reached between 500 and 850 F. There was a temperature gradient across plancha, as the outer border sat over the insulation layer, thus it was not directly heated. We found that with a reduced fuel load of 2 kg, the stove could be kept between 550-750 °F, which the perfect temperature for cooking tortillas very quickly.

3.1.2 Stove Body

As depicted in Figure 5, the stove body consists of two chambers, constructed from 16 gage mild steel and galvanized angle iron, bolted together.

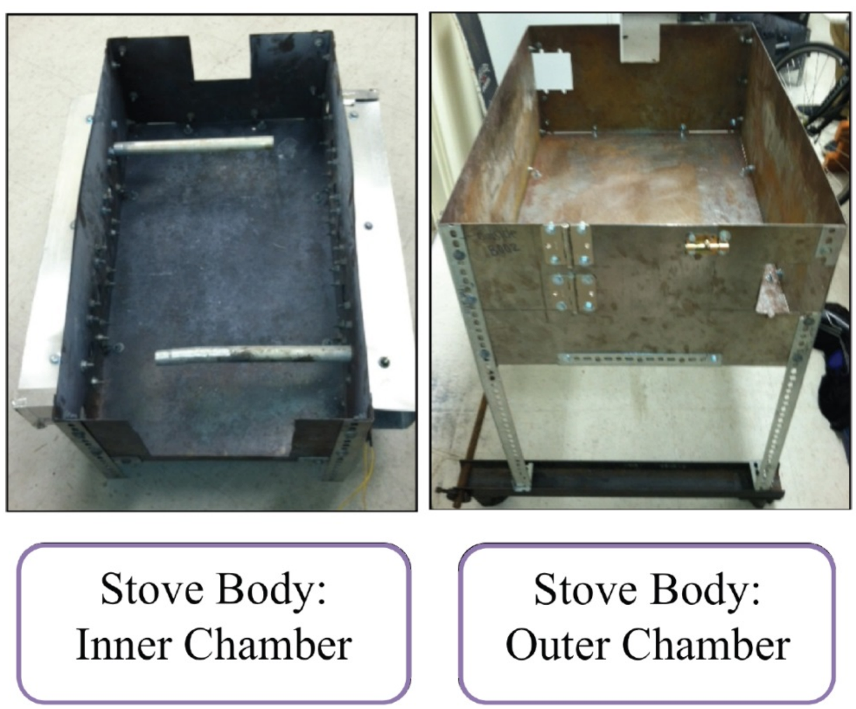

Figure 5. The inner and outer chambers of the cookstove with ducts and heat probes attached.

The purpose of the larger outer chamber is to hold the pumice stone insulation against the inner combustion chamber, which reduced heat loss. The inner chamber has two sets of five - 1 inch diameter holes that allow forced air from the fans to move to the combustion site. These ports and forced air are necessary, as the surrounding insulation cuts off much of the air flow that would be present in a normal open design. The outer and inner chamber also has square cutouts, allowing for the placement of a fuel chute and chimney. The fuel chute walls prevent insulation from falling into the area where fuel is added, and also acts as another ventilation port, if the forced air from the fans is not enough. The chimney helps regulate the movement of air in the combustion chamber, ideally making sure that hot air and waste gases have somewhere to exit, instead of going out the fuel chute or into the duct system. While testing the stove in Nicaragua, we found that the light gage of the fuel chute walls and chimney sustained some damage when exposed to burning wood that was not positioned in the stove correctly. We concluded that heavier gage steel sheet metal was necessary. We made field repairs in Nicaragua with galvanized sheet steel, with an approximate gage of around 30. Although there is some concern about the toxicity of galvanization, the harmful layer does come off after one - two uses, a poses no further health threat. When used outdoors, as we did, this is a minor problem.

The pumice stone insulation creates layer of air pockets between the inner and outer chamber, which reduces the conduction from the inner chamber to the outer chamber, decreasing the heat loss, reducing the amount of fuel needed to maintain the desired temperature. Compared to an uninsulated metal body stove, our system reduces the outer wall temperature from 850+ F to fewer than 150 F. This is a significant improvement that makes the stove safer for children and pregnant women to be around, as accidental skin contact does not lead to a serious burn.

3.1.3 Thermoelectric Power Generation Assembly

The heat that is applied to the TEGs is moderated with heat probes. These aluminum probes extend into the body of the stove, where they are evenly heated by the burning charcoal. The probes transfer heat from away from the immediate combustion site, where the TEGs are less likely to be melted by hot spots. This standoff distance allows for a more uniform heat distribution on the hot side of the TEG, which maximizes generator efficiency. This is an improvement over placing the TEGs directly on the combustion chamber, which had led to uneven temperature distributions and poor generator efficiency and reliability. There are only two TEGs in the stove, one for each duct/fan system. The generators typically output between

1.75-2.5 volts, which was enough to run the brushless DC fans. A voltage booster would have been a good addition in order to run the fans at a higher speed, for increased electricity output.

3.1.4 Ventilation System

The ventilation system in Figure 6 allowed farced air to enter the combustion chamber and increase combustion efficiency. The chimney directed harmful emission away for the user.

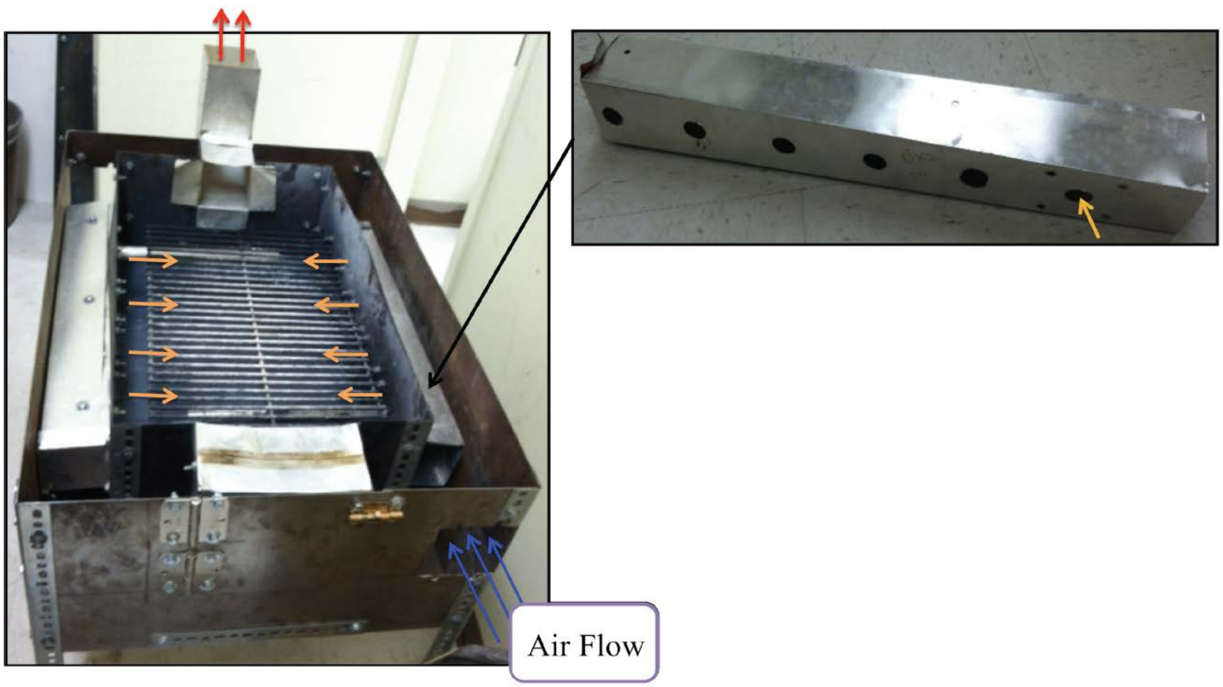

Figure 6. The cookstove's duct and ventilation system with airflow indicated by arrows.

The ventilation fans are run on the power generated from the TEGs. Team MASAH used a computer fan to force air downward into the combustion chamber. However, we concluded that computer fans were too inefficient, needing between 5 and 12 volts to run. Instead, we made our own fans, using brushless DC motors, which need only 1-3 volts to run. Team MASAH also found that in this orientation, their air channel acted like a chimney, with rising hot air overcoming the force of their fan. Thus MASAH was not able to effectively cool TEGs, so their power generation suffered. Thus we changed the orientation of our duct to horizontal instead of vertical, and made an actual chimney to fix this issue. The fans themselves were held in place by milled aluminum mounts. Initially, the fan blades were plastic propeller blades,

It is important to note that our fan and duct system accomplishes 2 tasks simultaneously. In the first stage, the air from the fans passes over the heat sinks attached to the TEGs, cooling the back side down, which improves power generation. In the second stage, this air is then directed into the combustion chamber via the duct system, introducing more oxygen to the combustion site. Each duct has 5 - 1 inch diameter holes which focuses the air at the base charcoal.

3.1.5 Energy management system

There were plans to integrate a power management and voltage boosting circuit into the stove. Ideally, the power generated by the TEGs would be stored in an external battery pack. The power storage would allow for a device to be charged via a USB cable, even while the fans are running. However, because we were short on manpower, and lacked an electrical engineer, we did not perfect this system. We attempted to use a premade circuit from the Biolite Camp Stove, however the reliability was poor. The power generated from the TEGs was enough to run the fans.

3.2 FloXpress Simulation

3.2.1 Duct Design Considerations

Forced air is known to increase the combustion efficiency of charcoal, but cold air blown onto coals may have a negative effect. To counteract this, we designed a long horizontal duct in order to preheat the air and have it enter the combustion chamber at or below the level of the coals. Ideal combustion occurs when air moves in a swirling motion around the fuel. Initially, a one port design was developed because it seemed to meet all of the requirements perfectly. As air moved along the length of the stove it would receive the maximum amount of heat possible and the opposing ducts would force air to move in the ideal fashion around the stove. However, there was a concern that there would be significant friction losses in the duct and that air would stagnate before entering the combustion chamber. With this in mind, a five port duct was designed to allow air to enter the combustion chamber earlier. We forwent the benefits of maximum heat transfer to the air in favor of assured early airflow to the coals. The ports were also one inch in diameter and could accommodate the heat probe. This allowed us to alter configurations during testing and determine ideal heat probe placement.

3.2.1 FloXpress Analysis

In order to justify our design revision, we performed an airflow analysis on the two designs using FloXpress in SolidWorks. The full results are displayed in Appendix D, the scale in 7 indicated that the velocity of the air entering the combustion chamber is much higher in the five port model than the one port model. This was expected since the cross sectional areas of the ports were greatly reduced. Since significant amounts of air would enter the combustion chamber early at high velocity, we were assured that friction losses would not cause the air to stagnate. Even though the five port design did not lead to a uniform swirling motion in the combustion chamber, the model showed that there was adequate mixing and we moved forward with the five port design.

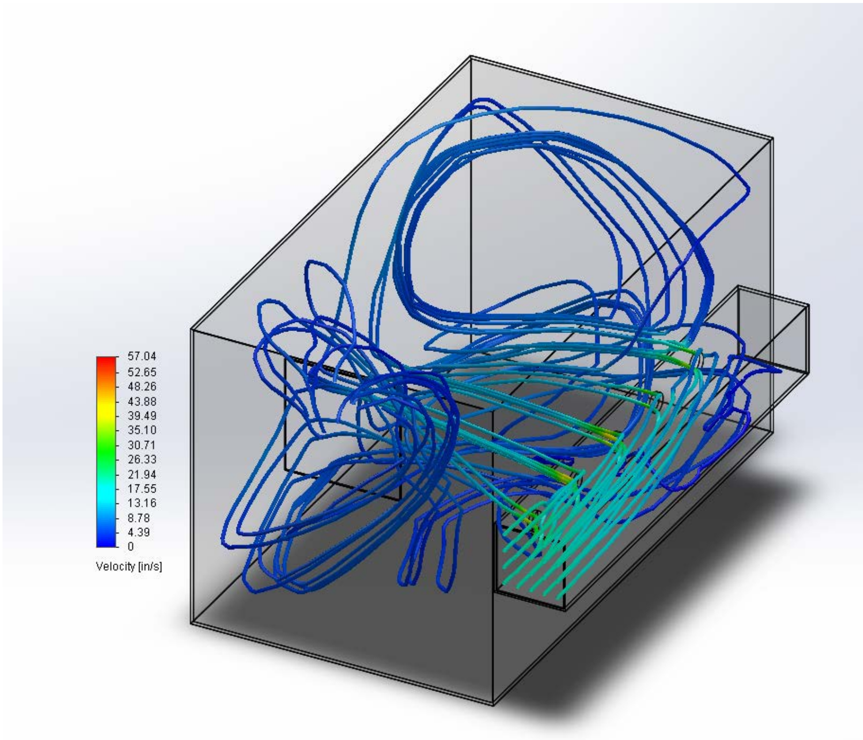

Figure 7. The FloXpress model of the single port duct attached to the combustion chamber. The air temperature was 300°F and the volumetric flow rate was 245 $\frac{in^3}{s}$.

3.2.3 Simulation Limitations

The model was limited in its ability to simulate real conditions. FloXpress only allows for one entrance and exit in its flow and the stove was modeled with only one duct on the side instead of two. The effects of temperature distributions and the combustion reaction could not be modeled using the program even though they would have greatly altered the airflow. The five port duct system actually had a sixth hole that was occupied by the heat probe and the effect of that obstruction on the flow was not analyzed. Despite these modeling limitations, the goal was to compare the one port design to the five port design and the results allowed us to justify moving forward with the latter design.

4.0 TESTING AND RESULTS

4.1 Testing

4.1.1 Stove Testing

Standardized data in order to compare cookstoves and see the benefits of subtle design changes. When engineers in different regions are looking at each other's stoves, they need to know exactly what data means and have confidence that the results can easily be repeated. To this end, the Global Alliance for Clean Cookstoves maintains several standard cooking tests. We modified these tests so that they could be performed with the equipment that we had available. When performing these tests, we chose to use charcoal instead of wood and stimulate the cooking tasks that Nicaraguan street vendors would normally perform. Table XXX lists a summary of the relevant tests.

Table 7. Summary of the standard cooking tests that Team Matador performed.

Water Boiling Test (WBT)	• 2 liters of water • 3 and 4 kg of charcoal fuel • Tracked Time to boil, simmered for 15 minutes • Immediately extinguish fuel, dry fuel • Weigh fuel consumed
Controlled Cooking Test (CCT)	• Cook 40 tortillas • 2 kg of charcoal fuel • Tracked total time to cook • Immediately extinguish fuel, dry fuel • Weigh fuel consumed
Temperature Duration Test (TDT)	• Measure temp of cooktop (4 thermocouples) • 2 kg of charcoal fuel • End test / extinguish fuel when temp drops below 550° F • Weigh fuel consumed

4.1.2 Water Boiling Test

The Water Boiling Test (WBT) is a simulation of a simple cooking task and allows testers to evaluate stoves in a controlled setting. Testers boil water in pots in order to simulate the preparation of rice, beans and other staples that are feeding the world's poor. Ideal tests are performed under hoods so that emissions data can be collected, but due to limited access to emissions testing equipment, we developed a modified WBT. During each test, two liters of water were boiled and a simmer was maintained for fifteen minutes. The remaining fuel was immediately extinguished following each test so that it could later be dried and measured. The time to boil and the fuel used were recorded.

4.1.3 Controlled Cooking Test

Developed in conjunction with the WBT, the Controlled Cooking Test (CCT) is a laboratory simulation of a typical cooking task that users in a target market would perform daily. Therefore, tests tend to vary greatly in protocol, but the goal is always to generate a fuel consumption comparison between improved stoves and traditional stoves. It remains up to the individual cook to determine if a piece of food is fully cooked, but a high level of consistency is desired so, the same cook is used over and over again when comparing two stoves. During our Controlled Cooking Tests, we kept track of the amount of fuel used and the time elapsed when preparing forty tortillas. Qualitative user feedback was also taken into account and used to characterize the overall stove experience.

4.1.4 Temperature Duration Test

Along with our modified WBT and CCT, we developed a Temperature Duration Test or (TDT) in order to see how long ideal cooking temperatures could be maintained when a set amount of fuel was used. We qualitatively determined the optimum temperature range for cooking tortillas to be between 550 & 750 degrees Fahrenheit. Thermocouples were attached to the center and the sides of the cooking surface to record the temperatures. The fuel was allowed to burn in the stove until the temperature dropped below 500 F and the total time was recorded.

4.1.5 Field Testing

When our team travelled to Nicaragua, we had several local cooks use our stove and give us feedback. They did not perform any standard tests, but by observing how they used the stove and listening to their comments we were able to see the potential for many design changes. The locals in Sabana Grande use wood instead of charcoal as their primary fuel source and the stove was not used the way that we had envisioned. We still saw how rural cooks actually use stoves and received comments on how street vendors would potentially use our stove.

4.1.6 Testing Limitations

We lacked the testing equipment needed to keep track of fuel emissions and were limited in our ability to control variables like wind speed and ambient air temperature. We found that weather conditions had a significant impact on our results and not every test that we performed lead to useable data. By adding a wind shield around our pot and being as consistent as possible with our charcoal chimney starter, we saw stark improvements in the repeatability of our results. Regional testing centers like Aprovecho Research Center in Cottage Grove, OR perform indoor cooking tests with specialized fume hoods, allowing them to track emissions and eliminate most environmental factors. The highly controlled tests are crucial in the design process, but at the same time, the more controlled each test is, the less it resembles real world cooking. A stove that performs well in the laboratory may not generate significant fuel savings in the field. In-home tests and customer feedback surveys remain the best ways to analyze stove performance.

4.2 Results

4.2.1 Water Boiling Test Results

Water boiling tests we conducted using our stove, the Matador, an open comal and one of Proleña's stoves. While the Matador and the open comal are better suited for cooking tortillas and other foods, the water boiling test was an important comparison allowing us to see how effectively heat was transferred to the surface of the stove. Initially heat loss due to wind was a big problem and we could not bring the water to a boil. We added a wind shield around our pot and using 3 kilograms of fuel we were able to boil water on the Matador, but not on the Comal or the Proleña. Since water only boiled on one of the stoves, the results were inconclusive. We increased the fuel used from 3 kilograms to 4 kilograms and had successful tests using each of the stoves. While the Proleña stove performed unexpectedly well, boiling water the water on average under seven minutes, the Matador proved to be the most fuel efficient with only 58% of the fuel consumed on average.

4.2.2 Controlled Cooking Test Results

During our Controlled Cooking Tests, we compared the Matador to an open comal. Our cook reported that the Matador was more comfortable to use and less smoky. The average side temperature of our stove was about 150 Fahrenheit, a good value when compared to the 900 Fahrenheit side temperature of the used tire rim stove. We concluded that during short cooking tasks, fewer than 30 min, the two stoves behaved similarly, and no significant differences in the cooking time for 40 tortillas or in the amount of fuel used. We remained confident that longer tests would illuminate the advantages of our stove.

4.2.3 Temperature Duration Test Results

The Temperature Duration Test was used to further compare the Matador to an open comal. Our target temperature range lay between 550F and 750F and the graph in Figure X. shows that the Matador outperformed the comal. The Matador was able to stay within the target range for an average of 80 mins while the comal only lasted for 50mins. The comal also reached unnecessarily high temperatures at the beginning of the test, wasting fuel and making it likely that users would end up burning tortillas.

4.2.4 Field Test Results

When the locals in Sabana Grande used the Matador, they were able to cook a large amount of food in pots and grill meat at the same time. When wood was used, the cooking surface got much hotter and had a more even temperature distribution than when charcoal was used. Flames tended to lick the steel, as seen in Figure 8, which was good for maintaining high cooking temperatures, but durability became a major concern where it had not been before. The locals talked about how the cooking surface is usually the first part of a wood burning stove to fail and this could be seen as a large amount of residue was left on the underside of the steel.

One of Proleña’s stoves, a Mega Ecofogon, was being used by cooks at a local restaurant. They complained about heat being directed toward their stomachs when using Proleña’s stove and concluded that our stove was more comfortable to use because the fuel was loaded from the side. We were unable to accurately quantify the wood fuel efficiency of our stove during the trip and the best way to do so would be to leave a stove with a family and ask them to log their fuel use over an extended, perhaps month long period of time.

Figure 8. The Matador being field tested in Sabana Grande.

4.2.5 Field Research

The women in the community have started to build permanent, efficient adobe stoves as seen in Figure 9. Wood is loaded from the side and enters an L-shaped combustion chamber, lined with brick that effectively directs heat to the cooking surface. The women preferred their own stoves over any that we or Proleña had developed, but they did see the need for efficient portable stoves. A family may occasionally wish to travel to a fair and cook. Hot food was only served at one of the cultural events that we attended because our stove was present. Without portable that our stove offered, the cooks would have been tethered to the stoves in their homes. To meet the needs of this wood burning community, a portable, side loading stove that takes advantage of the fuel efficient L-shaped combustion chamber could be developed. Further study could also be conducted to assess the advantages of attaching thermo electric powered fans to the existing efficient adobe stoves and a potentially redesigned portable stove.

Figure 9. Efficient adobe stove that the women of Sabana Grande are constructing in their community.

5.0 COST ANALYSIS

5.1 Prototype

Table 8. Itemized estimation of prototype cost.

Item/Process	**Cost/Stove**	**Assembly Cost in Nicaragua**
Stove Body	$225	$33.75
TEG (x2)	$30	$20
Power Generation Components	$20	$7.50
Ventilation System	$45	$6.75
Machining	$ -	$20
Total	$320	$83.50
Target Product Cost	**$150-200** Investment Return < 1 Year	

In reference to Table 8, the cost estimate for the prototype is $320, assuming production costs and labor (to be completed by our team in the SCU machine shop) are free. Reverencing Appendix A, our total budget, including materials, fuel, and travel is $3247. The amount that is allocated to stove materials is approximately $2000.

Similarly sized improved cookstoves produced by Proleña are priced between $200 and $540, depending on the model and portability factor, which compares well to our prototype cost. By assuming most material costs can be reduced by 85% if assembled in Nicaragua, we estimate the production cost of our stove to be around $88 dollars. We would like to offer the stove in the $150-200 range, which means that the purchase costs could be recovered in under a year with the fuel savings of the stove. The most prohibitive cost come from the electrical and power generation components which would have to be imported. Complications also arise from with our custom fan mounts and heat probes, which require skilled machining. Redesigning of those parts or using castings could significantly reduce the costs and increase manufacturability. For a more detailed list of the prototype costs, see Appendix E.

6.0 BUSINESS PLAN

6.1 Product Description

The Matador Cookstove is an industrial sized cookstove, capable of meeting the cooking needs of a large family, small restaurant, food stall operator, or farm. It uses thermoelectric generators to power ventilation fans to blow air into at the burning fuel, increasing the completeness of the combustion process. Pumice rock (a naturally occurring resource in Nicaragua) is used as an insulation material, reducing heat loss to the environment, directing more heat to the cooking surface, and reducing the outer wall temperature. By reducing the heat loss, less fuel is used to accomplish the same cooking task. The cooking surface itself measures 2’x3’, giving ample room to cook tortillas and meat, as well as boil or fry foods in pots. The height of the stove is 30”, and with insulation, the stove weighs approximately 100 pounds when filled with insulation.

6.2 Potential Markets

The stove was designed with a large flat top griddle, known as a comal or plancha in Central America, that is large enough to cook multiple types of food at once. It is especially suited for the cuisine of Central American, and was tested in Nicaragua. Cooks in Nicaragua were able to boil beans and rice in separate pots, while meat was grilled and tortillas were browned on our stove. The size and flexibility of this cooktop makes it appropriate for restaurants, food stall operators, and farms. These types of businesses exist both in cities and rural areas. Wood and charcoal are still very common fuel sources, because the infrastructure of Nicaragua and most Central American countries is not developed enough to where gas or electric stoves are common. Businesses that cook food use more fuel than the average family home, thus they could easily justify spending more money on an efficient stove that will save them money in the long run.

6.3 Competition

There are several companies in Central America that have garnered attention for building efficient cookstoves. These stove range in size, price, and portability, but a Nicaraguan based company, Proleña, does produce stoves of a similar size and cooking capability. They make a semi-portable model call the "Mega-Ecofon," which is similarly constructed out of sheet metal and incorporates pumice stone insulation, and costs $203. While in Nicaragua, we interviewed women who use this stove in their restaurants, and found that while it does reduce fuel consumption, it can be very uncomfortable to use because the fuel chutes open at the front. This position allows for heat to escape out the front, exposing the cooks to extreme heat at stomach level. Proleña also makes a non-portable stove out of mortar and brick, which also incorporates insulation, and has a similar cooking surface area compared to our design. This model costs $540. None of these designs incorporate thermoelectric power generation, and are not heavily distributed. The inefficient methods of using non-insulated structures to support the cooking surface are still very popular because of their low cost, despite the lack of ergonomics and durability.

6.4 Sales/Marketing

Marketing an improved cookstove or other improved technology, like sand filters, solar pumps, or dry latrines, is a huge undertaking. Implementing these products is not a simple manufacture and sales task; it requires a significant amount of background work to lay the foundation for a community to be accepting of the new technology. Partnering with a Non-Governmental Organization (NGO) that has a relationship with several communities would be essential for marketing the benefits of an improved stove. Involving the locals, especially the women, with the manufacturing of our stove would generate a lot of publicity and acceptance for the stove, much more than any foreigners could ever do on their own. Considering that NGO's and fledgling manufacturing companies are usually short on money, the people who build the stoves could be paid with credits. These credits could be used to purchase an efficient cookstove or any other improved product that the NGO has access to. This system appeared to work well with Grupo Fenix, an NGO that we worked with while in Nicaragua.

6.5 Manufacturing Plans

If our stove were to become a working product, several design changes would need to be made in order to make the stove more suitable for manufacturing. For example, the use of bolts, nuts, and washers as fasteners would be replaced by pop rivets, which are faster to use and weigh significantly less. The body may also have to be redesigned to accommodate the local sheet metal stocks. While in Nicaragua, we found galvanized sheet metal of a comparatively thin gage was common, while thicker gage mild steel (we used 16 gage mild steel) is harder to come by and work with. Our design uses thicker sheet metal in a load bearing capacity, which would have to be changed if thicker sheet metal is not available. A frame connecting the supporting angle iron legs would have to be designed in order to support the stove body. Despite these challenges, we are confident that the stove body could be built in Nicaragua, provided that workers can be adequately trained. The TEGs would have to be imported, and the mounting system would have to revise in order to ensure complete reliability. The TEGs are currently held in place by high-temperature double sided tape, which can fail under adverse conditions. We would also have to approach a TEG company for a discounted rate on TEGs bought in bulk, as they are fairly expensive when bought in small quantities. The element that would be most difficult to produce is the custom fans, which currently cannot simply be bought. Milled aluminum mounts hold the brushless DC motors in place, these mounts are probably beyond the capability of most of the machine shops at any NGO in Nicaragua. If these mounts were redesigned to be made out of stamped sheet metal, the manufacturability would be significantly increased. With a team of 5-6 people, a production rate of 1-2 stoves per week would probably be enough to keep up with demand.

6.6 Product Cost and Price

The prototype cost is around $320, as outlined in section 4.0 Cost Analysis. Without talking with materials vendors in Nicaragua, it is difficult to make an accurate estimate of how much an actual production model would cost. Our academic advisor estimated that materials costs of sheet metal and fasteners could be reduced by up to 85%, which would bring the assembly costs to under $90. Assuming the a production model would cost around $100, we would like to offer the stove at $150-200, which is less than what an equivalently sized Proleña improved stove would cost ($200-540). With the fuel savings we calculated for our stove, the owner could recover his/her investment cost in less than one year.

6.7 Service or Warranties

A member of the production team would need to inspect the distributed stoves every couple of months, to ensure that the mechanical components, like the fans and TEG mounts are still properly positioned. While in Nicaragua, we found that cooking surfaces usually need to be replaced after several years, due to high temperature fatigue. So this is a common wear and tear occurrence, and our cookstove manufacturers could sell replacements at an appropriate price. If the stove is properly maintained, regularly cleaned and not abused, the body itself should last for up to 10 years. It is not certain how long the TEGs will last, extensive high temperature durability tests have not been well documented. Hopefully, the TEGs last for at least 3 years before they need to be replaced, which can be done for just the cost of the component. If any components fail prematurely due to defects, and not user error, they should be replaced free of charge. Again, having a technician to inspect the stoves every couple of months would be important in ensuring proper functioning and consumer confidence in the company.

6.8 Financial Plan/ Investor's Return

Based on interviews with food stall operators, we calculated that our stove could save the user $195/year on fuel, meaning that their investment of could be recovered in under a year with a stove price of under $200. While working with the NGO, Grupo Fenix, we observed an interesting business model based on volunteer work. The women who built solar ovens and worked on building the facilities of Grupo Fenix were paid in hours, which they could use to buy solar ovens, improved stoves, or other solar devices produced at the NGO. A similar system could be used with our stove, the employees who make them could earn their own stoves. This would gain more visibility in the community and help popularize the design. Once distribution starts, and friends and family see the fuel savings and increased comfort that improved cookstoves offer, they will want to purchase the stoves too. Payment plans could be set up such that a customer does not have to pay for the stove in full, instead paying it off over a year or two. Or they can do volunteer work for the organization to help decrease the monetary cost.

7.0 ENGINEERING STANDARDS AND REALISTIC CONSTRAINTS

7.1 Health & Safety

Our team has a responsibility to make our cookstove as safe as possible; both for our consumers and for those who assemble the product. Our design is ergonomic and fairly intuitive to use. While in Nicaragua, we observed improved adobe and brick cookstoves that incorporated a chimney in order to vent fumes outside of the house. Even the experienced female cooks needed some time to get use to the new chimney feature, as many of them burned themselves on the chimney, forgetting that it got hot. It is important to warn users about even obvious dangers like contact burns. The outside wall temperature is kept to under 150° F, which is much safer compared to the local metal stoves that reach up to 800° F. If this stove design were to be implemented, we also have a responsibility to teach our customers about the proper use of the cookstove through training and product documentation. Creating manuals in the Spanish language, as well as having customer help staff available would essential for the success of the stove. Consumers can be educated about the risks of using the cookstove through training sessions and a simple, illustrated user's manual that makes use of graphics and basic text to show potential dangers. If this stove were to be used inside, we would need to design an extended chimney system. Since the stove is portable, it has a low profile chimney that directs smoke out of the users face while cooking outside. A permanent chimney would have to be installed for the inside cooking space, with an adapter sleeve that can be slipped onto the low profile chimney. This would allow for effective emissions management, virtually eliminating carbon emissions inside the cooking area. Our design does have moving parts and features that might entice children to touch out of curiosity. The fan intakes would need better screen protectors, to prevent fingers from caught by the fan blades, which do have sharp edges.

7.2 Environmental Impact

Unfortunately, our charcoal/wood burning cookstove does create greenhouse gases, but the amount of fuel used was reduced by up to 38% compared to current cooking methods. Since the stove reduces the amount of fuel used, it could negatively impact the sales of fuel vendors in the community. However, in interviews with the women who used improved cookstoves, they expressed no issues with buying less fuel. Deforestation is also a huge problem not only in Nicaragua, but across the globe. Implementing a stove that significantly reduces fuel use has huge implications, giving forests more time to recover from devastating logging operations. We calculated that a single stove could save around over 6,000 kg of charcoal per year. Although there is limited data concerning the harvesting rate of trees in Central America, we estimated that the use this fuel savings equates to around 30 trees saved per year, per stove. If dozens of stoves are fielded, forest conservation efforts would be greatly assisted. We also are aware of the toxicity of the materials that are used in the stove (such as the composition of electrical components and circuits) as there could be contamination dangers if the stoves break down and parts are scrapped. The use of lead solder should be avoided. We have an obligation to educate the consumers on the proper use and handling of the stoves, which will hopefully reduce any negative consequences of its use.

7.3 Manufacturability

Manufacturability is important because we are designing product that must be built in a simple, cost effective manner, considering the limited availability of advanced machines in Nicaragua. The cookstove would be manufactured in Nicaragua, to reduce shipping and labor costs. During our trip, we worked with an NGO, called Grupo Fenix, which hires local women to manufacture solar ovens, which are sold in the community. The quality of their work was high, and they demonstrated impressive ingenuity, which gives us hope that a similar operation could be started to manufacture our stoves. The stove design is still in prototype phase, and does require some maintenance and inspections to ensure that it functions properly. In a production model, there should be no need for the customer to maintain or tune the mechanical components of the stove. A technician should inspect the distributed stoves every couple months to ensure proper functioning. The customer would be responsible for cleaning out ash, which is common to all cookstoves. A Nicaraguan based company, called Proleña, makes improved cookstoves of a similar construction, incorporating pumice rock, but lacking thermoelectric power generation. They offer similarly sized stoves for $200-540. We would like to offer our stove between $150-200. Overall, developing an efficient, reliable, and cost effective manufacturing production process is essential to the success of the efficient cook stove.

7.4 Social and Economic Impact

The implementation of an improved cookstove is not simply about providing a product to the customer. It is not enough to merely give a community or region with stoves, and expect beneficial changes to happen. The implementation of cookstove should be considered a community development project, which empowers locals to think for themselves, solve problems, and become more self-sufficient through learning about the cookstoves. As mentioned previously, Grupo Fenix employs women from the community to manufacture and implement solar ovens, as well as raise awareness about sustainability and green technology. Using this same business/manufacturing plan would create jobs, empower women, and benefit the community overall. Grupo Fenix also acts as a de facto community center, holding English lessons and providing a safe place for kids. Pairing the manufacturing with education has a profound social and economic impact. Women, who are usually marginalized, can be taught important communication and manufacturing skill sets. Their enthusiasm for the products they are making, such as our efficient cookstove, can be spread throughout the community and the whole organization benefits greatly. In order to track the stoves' performance, we would also need to establish a dedicated customer relations team, which would check in with customers, collect user feedback, and troubleshoot any problems that arise. Good communication between a product manufacturing group and the customer ensure that stoves maintain a solid reputation for reliability and value. Communication, teaching and education are essential for propagating interest in sustainability, technology, and innovation. The money that is saved from using less fuel can be put back into the community, allowing for development of infrastructure. One of the most important aspects that can be improved is the sewage/latrine systems in rural areas. During the rainy season, traditional latrines can become flooded, causing raw sewage to be washed into the water table. Using the fuel savings to invest in dry latrines would be a very significant improvement, and could prevent the spread of disease during floods. Dry latrines separate urine and feces, allowing for the feces to compost, which makes excellent fertilizer. The urine can also be used as fertilizer. Pairing the efficient cookstove with dry latrines would be a very beneficial, socially and economically.

8.0 SUMMARY

Wood burning fires are an exceedingly common way to generate heat for cooking in much of the developing world. During the combustion process carbon and other harmful emissions are emitted into the atmosphere and into the lungs of those who cook. Clean burning, efficient cookstoves drastically reduce the fuel that is required and the harmful emissions that are necessarily generated when families and small businesses in impoverished countries cook. In Nicaragua, Proleña manufactures and distributes cookstoves that are changing lives and our cookstove will incorporate advanced thermoelectric energy generation into a similarly fuel efficient cookstove design. Electricity is used to run a fan, forcing air into the combustion chamber, increasing the burn efficiency of the fuel; less ash will be produced and less fuel will be consumed. If implemented, Nicaraguan small business owners will see their lives dramatically improve as they spend less money on fuel and are exposed to lower concentrations of smoke. Excess electricity generated by the thermoelectric units may be used to charge small electrical devices. Nicaraguans with limited access to electricity will be able to readily charge their cell phones and other useful small devices. In the future, thermoelectric generation technology should be capitalized on and further study of implementation on current cookstove designs should be researched. Ultimately, cutting edge technology will be used to enhance classic cookstove designs and reduce the cost to cook food in Nicaragua, one of the western hemisphere’s poorest nations.

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APPENDIX A: Budget Breakdown

Expenses				
Item	**Cost Per Unit**	**Quantity**	**Total**	**Description**
Thermoelectric Generator (TEG)	$ 20.17	15	$ 302.55	generates electricity from heat of burning fuel
sheet steel (16 &10 gage stock)	$ 220.00	1	$ 220.00	used to construct cooktop and stove body
Aluminum sheet metal	$ 32.37	2	$ 64.74	used for ducts
Charcoal (bag)	$ 10.00	15	$ 150.00	fuel
motors	$ 8.00	6	$ 48.00	improve airflow and combustion effeciency
fan blades	$ 8.00	10	$ 80.00	improve airflow and combustion effeciency
nuts and bolts (set of 100)	$ 10.00	3	$ 30.00	fasten components together
thermal paste	$ 7.00	1	$ 7.00	improve conduction between important components
insulation (pumice stone)	$ 10.00	4	$ 40.00	reduce heat loss
Thermocouple	$ 334.03	1	$ 334.03	measure temperature
aluminumstock (rods and blocks	$ 20.00	2	$ 40.00	will be machined to make TEG mounts
Heat sinks	$ 2.00	10	$ 20.00	increase TEG effeciency
Biolite stoves (for testin/comparison	$ 110.00	3	$ 330.00	Use TEG technology
Chimney starters	$ 17.00	4	$ 68.00	used to light fuel
BBQ / cooking equipment	$ 40.00	1	$ 40.00	assist with cooking
handle set	$ 11.90	2	$ 23.80	used to remove cooktops
slotted angle iron (72")	$ 17.00	8	$ 136.00	holds stove body together, reinforcements
Batteries	$ 8.00	2	$ 16.00	power fans when not using TEGs
Battery boxes	$ 3.00	5	$ 15.00	holds batteries
scale	$ 20.00	1	$ 20.00	weigh charcoal
tortilla press	$ 10.00	1	$ 10.00	makes tortillas
grate material	$ 10.00	3	$ 30.00	what fuel sits on
steel buckets	$ 12.88	5	$ 64.40	used to extinguish fuel
insulated wire spools	$ 15.00	2	$ 30.00	connect TEGs to fans
Posters	$ 140.00	2	$ 280.00	for displays and conferences
scrap tire rims	$ 7.00	3	$ 21.00	used to simulate Nicarguan stove
Travel to Nicaragua	$ 2,500.00	1	$ 2,500.00	cost of flights and homestay for 4 people
		Total Sum:	$ 4,920.52	

APPENDIX B: Project Design Specification

Design Project Matador: Thermoelectric Cookstove

Team: Thermoelectric Cookstove Date: April 17, 2013 Revision: 3

Datum description: Various Cookstove Projects

A. Proleña B. Comal and Fire Pit C. Kitchen Stove Top

*A, B, or C refer to the related cookstove being compared

Elements/ Requirements	Yes	No	Reason	Units	Datum	Target Range
Time to Boil Water	X		One of the methods that we plan to use to test the efficiency of the cookstove is to measure how quickly water can boil using the cookstove. We plan to reduce the current time it takes to boil water.	Minute	A: 20	10-15
Time to Cook Tortillas	X		Another method we are using to quantify the food cooked on the surface. We will use local cuisine (homemade tortillas) to measure the success of the cookstove.	Minute	C: 2	2-5
Thermal Efficiency	X		If we make our cookstove more thermally efficient than our competitors, than we will ensure that our cookstove has met our requirements.	%	A: 20/ B: 10	20-30

Outer Wall Temperatures	X		Our cookstove has the benefit of added insulation, thus reducing the wall temperatures. This addition makes our cookstove safer than the current cookstove options in Nicaragua.	Fahrenheit	B: 900	100-150
Average Surface Temperatures	X		It is essential that the cooking surface reaches a particular temperature in order to be able to cook tortillas, and other local cuisine. But also not too hot that food will be burned.	Fahrenheit	B: 600/ C: 650	600-700
Average Daily Fuel Usage	X		If less fuel is used per cookstove usage, than this is another example of efficiency and in result, the cookstove is serving the purpose of saving consumers money.	Lbs.	A: 20/ B: 40	20
Charcoal Remains	X		Our goal is to completely burn the charcoal down to only ashes remaining, thus maximizing the fuel combustion.	Lbs.	A: 2/ B: 2	2
Weight	X		Although the cookstove will be built out of metal and contain pumice rocks in the interior, it is important that our cookstove may be moved if necessary. However, being able to carry around the cookstove is not a project goal.	Lbs.	A: 30	100-175

Overall Size	X		Our cookstove is not designed to be portable, rather it is designed to be able to be moved, but also large enough that 12 tortillas may fit on the stove surface top.	Feet	A: 1x2x2	2x3x3
Product Cost	X		Our goal is to make our cookstove less expensive than competitors; however, it will remain more expensive than most since our design includes a thermoelectric module.	$ U.S.	A: 50	150-200
Selling Price	X		The purpose of this design is to help develop countries, not make a profit off of the cookstoves; therefore the price listed will just cover expenses made to manufacture 1 stove and extra 10 dollars for shipping and maintenance purpose.	$ U.S.	A: 70	200-225
Customer	X		Our team will be targeting Nicaragua, but hopefully we will extend our cookstove design to other developing countries.	# of Countries	A: Limited	Multiple countries
Manufacturing Processes	X		Considering that Nicaragua is still a developing community, Proleña will only have the some tools and raw material to manufacture so if a machinery breaks or raw material runs low, then it can	Day	A: 30	10-15

			potentially stop the manufacturing process until the problem is fixed.			
Shipping	X		Since Proleña has an establishment already out there and they have agreed to manufacture and distribute, shipping will not be needed. The only part that will need shipping is the thermoelectric modules, which will not be an inconvenience because TEMs are already assembled and only require installation.	$ U.S.	A: 1	5-15
Disposal	X		Nicaragua is not very concerned with recycling. However, since most of the cookstove's material is made out of metal, it can be reused for other applications. In addition, the parts can be reused with newer products.	Cookstove elements	A & B: Landfill waste	Landfill waste/ batteries Recycled and used as scrap metal
Politics	X		People in different parts of the region have different views on receiving help from outside people so we will have to focus on providing them with our help as politically conscious as possible.	Design acceptance	A: Limited acceptance	For our design to be welcomed and an essential cooking device
Market Constraints	X		The main distributor would be our partner, Proleña, since they	Available	A: Proleña	Proleña and others

			have an establishment of designing efficient cookstoves in Nicaragua.	distributors		if possible
Maintenance	X		An objective our team is to allow the cookstove maintenance to be free. Since most developing countries do not have the appropriate knowledge to maintain a sophisticated system. Also, consumers would be unable to afford replacement parts.	Manual labor/ user interaction	A: Minimal consumer inputs B: Disposal only	Minimal consumer inputs
Competition		X	Currently, there are various cookstoves in practice, but our objective is to improve the current cookstoves in Nicaragua.		A, B	
Packing	X		Reducing shipping costs to a minimum is goal of our team, thus we will aim to pack all goods in the most cost effective methods.	$U.S.	A:10	20-50
Quality and Reliability	X		Once a prototype is built, tests will be conducted to determine the quality and reliability.	Cookstove performance	N/A	Minimize failure and optimize performance
Shelf Life Storage	X		Cookstoves will be manufactured depending on requests will be stored depending on product demand.	Month	A: 8-12	Depends on product demand

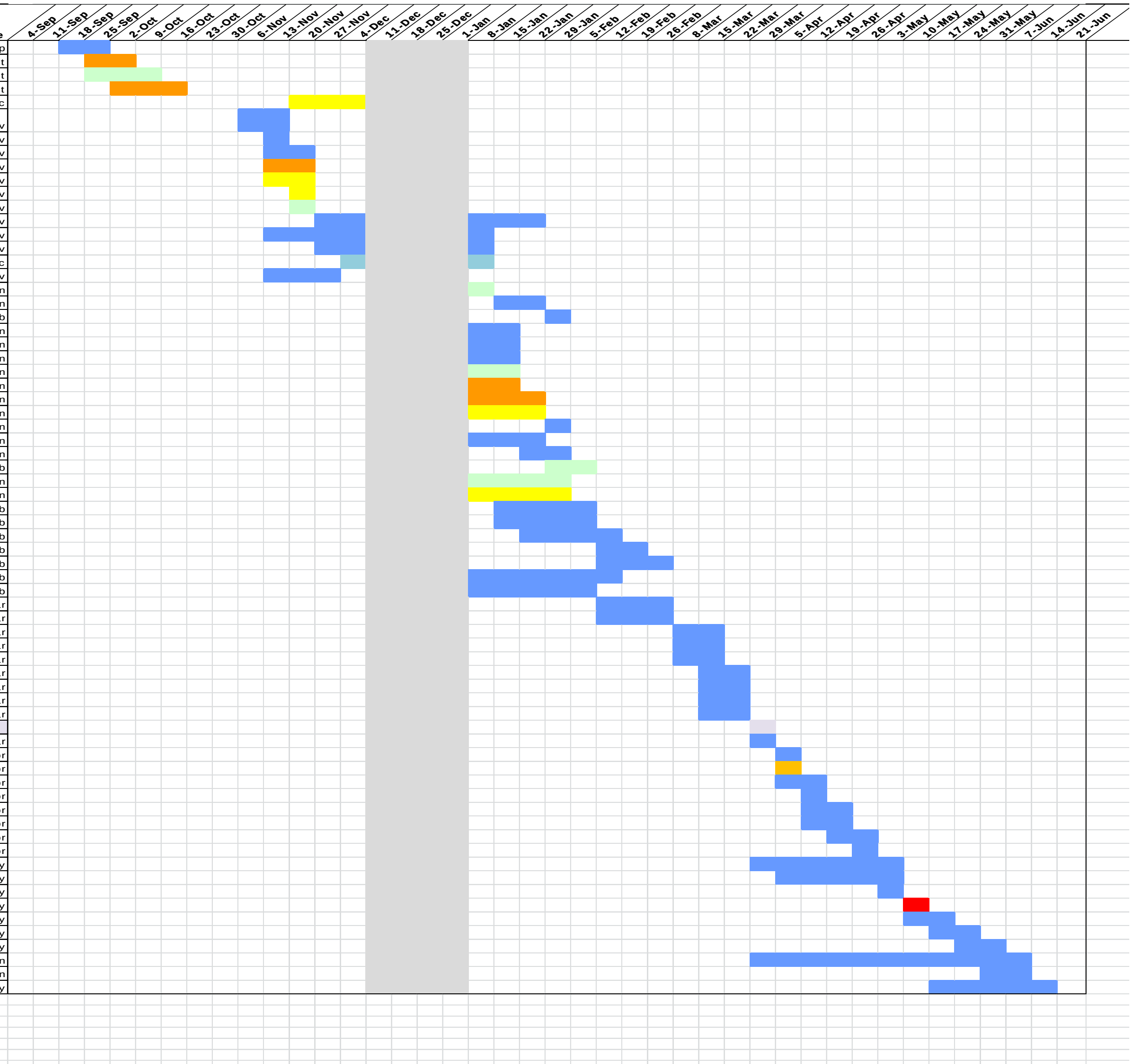
Environment	X		Efficient cook stove positively affects the environment especially by minimizing the stove’s carbon monoxide emission.	Environmental effects	A & B: Little concern with environmental impact	Limit negative effects on the environment
Testing	X		Multiple temperature testing has been conducted to determine the stoves temperature to adequately adapt the thermoelectric modules and to appropriately choose a heat sink.	Computational analysis/ Temperature measurements	A: Thermocouple data testing B: Thermocouple data testing	Have a complete set of results, store data using Labview program and thermocouple set up
Safety	X		Efficient cook stove positively affects the safety by minimizing hazardous carbon monoxide. Also, appropriately fine tune the stove design to minimize the risk of getting injured due to touching the stove and getting burnt.	Health and wellness effects	A: More efficient system reduces hazardous byproducts using a chimney and insulation B: Unsafe exposed charcoal with hot surfaces	More Efficient System that maximizes combustion and reduces hazardous byproducts and the cookstove has a safe design.
Legal	X		Less strict environmental laws in Nicaragua than in the USA. Cookstove does not use any illegal components.	Laws	A: Locally found materials B: Scrap material	Cookstove does not use any illegal components, and focuses on environmentally friendly parts.

Documentation	X		To be completed at the end of project, but updated constantly in members’ design notebooks. Complete documentation in design notebook.	Notebooks	N/A	Each member is required to keep a notebook that they all update regularly with all important dates and design details.
Quantity	X		First, our team will build one cook stove for testing purposes, and then we will build iterations of products eventually discovering a final product to be shipped to Nicaragua for advertising purposes. If we are successful in implementation, more cook stoves will be manufactured on the basis of demand. Purchase similar stove to compare the efficiencies.	Stove count	A: On the market	1-2
Product Lifespan	X		Due to the poverty in developing countries, consumers cannot afford replacing the product frequently so the team’s objective is to maximize the products lifespan.	Year	A: 7 B: 0.5-1	10
Materials	X		We are using mild steel sheet metal for the cookstove body and stainless steel for the top surface because it is readily available and inexpensive. Also, steel will be	Metal	A: Iron, steel, ceramic B: Sheet metal	Stainless steel; Aesthetically pleasing and dependable material

			able to withstand many tests.			
Ergonomics	X		The stoves will be designed to be easily used while standing and any health risks will be reduced. Also, harmful emissions will be directed out of a chimney, rather than the sides of the cookstove.	Harmful emissions released	A: 20-30% B: 50%	0-10%
Standards/ Specifications	X		The stove has to be able to cook the food more efficiently than the current Nicaraguan cookstoves.	Hour	A: 7	4-6
Aesthetics	X		Cookstoves will not have shiny surfaces so that they look similar to the current cookstoves.	Surface finish	A: Iron, ceramic, mild steel	Mild steel and stainless steel; Similar look to existing cookstoves
Installation	X		Minimize the time to install cookstoves into small businesses. After assembly, no installation should be required.	Minute	A: 0	0
Expected in Service Lifetime	X		The cookstove body might break down sooner than the devices such as the thermoelectric module. But all materials should be recycled to reduce costs and maximize product lifetime.	Year	A: 5-7	15

APPENDIX C: Timeline

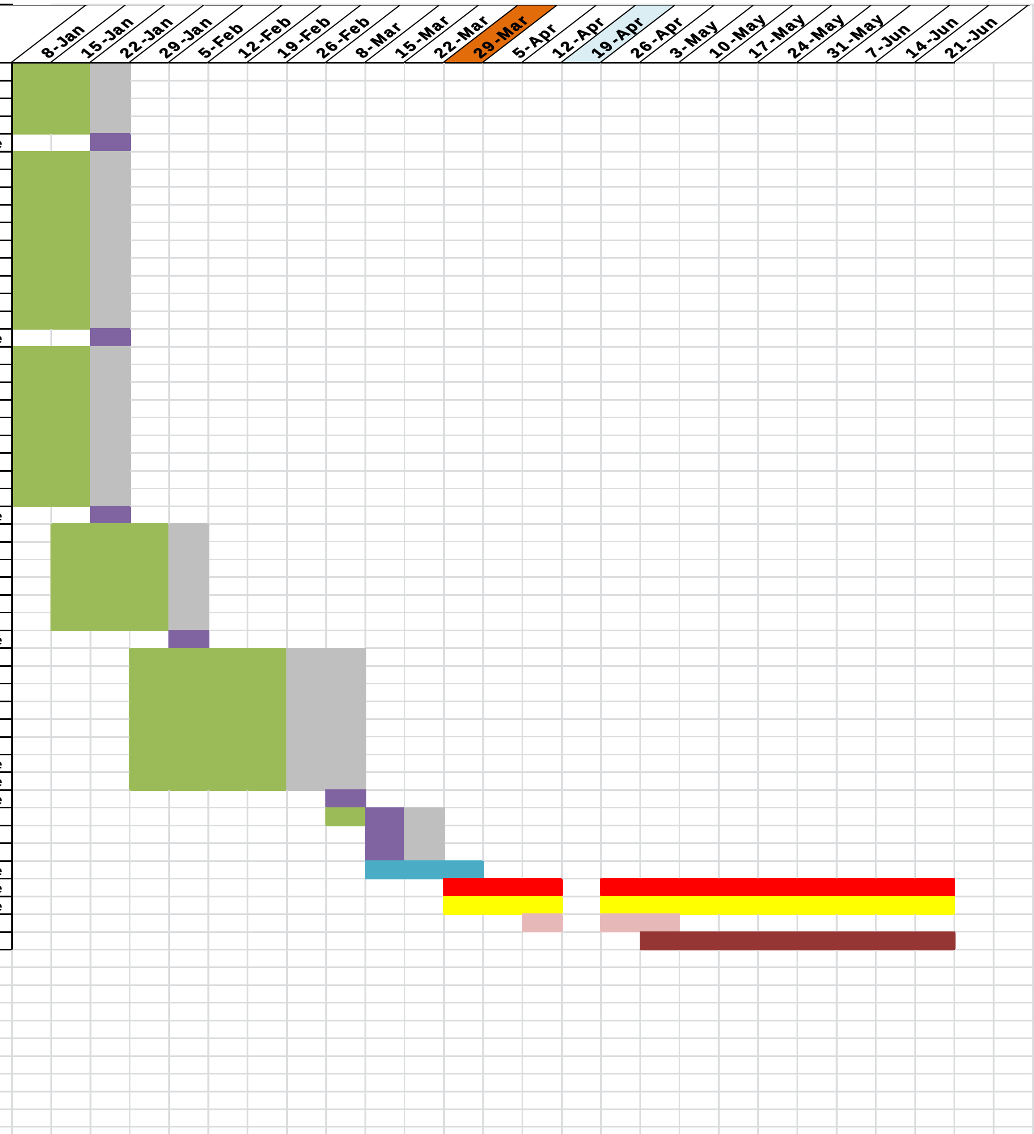
	Task	Team Member	Due Date
1	Research Existing Cookstove Designs	Group	25-Sep
2	Preliminary Heat Transfer Calculations	Mark	2-Oct
3	Fundraising	Christine	9-Oct
4	Preliminary Design Drawings	Mark	16-Oct
5	Begin Purchasing Materials	Matt	4-Dec
6	Full Analysis of Design, Heat Transfer, Energy Requirements	Group	13-Nov
7	Test heat sinks	Group	17-Nov
8	Create a homemade heat sink/heat pipe assembly	Group	17-Nov
9	Research TEMs	Mark	27-Nov
10	Research heat pipes	Matt	27-Nov
11	Order a heat pipe	Matt	27-Nov
12	Order Biolite cookstove	Christine	27-Nov
13	Test Biolite cookstove	Group	29-Nov
14	Test Proleña cookstove	Group	14-Nov
15	Test MASAH's cookstove	Group	27-Nov
16	Create a preliminary cookstove design for construction	Mark/Matt	8-Dec
17	Prepare and Finish documents for CDR	Group	28-Nov
18	Order sheet metal for cookstove body	Christine	8-Jan
19	Construct cookstove	Group	15-Jan
20	Test cookstove	Group	12-Feb
21	Test Biolite cookstove	Group	15-Jan
22	Test Proleña cookstove	Group	15-Jan
23	Test MASAH's cookstove	Group	15-Jan
24	Purchase Angle Iron and Bolts	Christine	15-Jan
25	Acquire Thermoelectric Modules (purchased)	Mark	15-Jan
26	Assemble Heat Sink (purchased)	Mark	22-Jan
27	Construct Heat pipe Mounts	Matt	22-Jan
28	Test Heat Sink and Heat pipe Mounts	Group	29-Jan
29	Prepare for ETHOS Conference	Group	22-Jan
30	Travel to Washington ETHOS Conference	Group	27-Jan
31	Organize Information Gained from ETHOS Conference	Christine	5-Feb
32	Purchase Insulation Materials	Christine	29-Jan
33	Finalize Assembly Drawing	Matt	29-Jan
34	Assemble Thermoelectric Cookstove	Group	19-Feb
35	-Construct the Outer Chamber	Group	5-Feb
37	-Construct the Inner Chamber	Group	12-Feb
38	-Mount Heat Sink/Thermoelectric Modules	Group	19-Feb
39	Test Thermoelectric Cookstove	Group	26-Feb
42	Prepare to Travel to Nicaragua	Group	12-Feb
43	Apply for Travel Grant to Nicaragua	Group	5-Feb
44	Prepare for Winter Quarter Design Presentations	Group	5-Mar
45	Create PowerPoint and Rehearse Presentation	Group	5-Mar
46	Finish TEG mounts	Mark	11-Mar
47	Finish Fan mounts	Goup	15-Mar
48	Finalize Test protocol	Matt	15-Mar
49	Boiling tests with other stoves	Group	16-Mar
50	Boiling/cooking test with our stove	Group	17-Mar
51	Fully assemble stove	Group	20-Mar
52	Evaluate all stoves	Group	22-Mar
53	Spring Break		
54	Draft Testing plan and goals for Nicaragua	Group	31-Mar
55	Evaluate all stoves	Group	5-Apr
56	Purchase shipping crate	Matt	5-Apr
57	Finish Thesis table of Contents + Intro	Group	8-Apr
58	Finalize Itinerary + Travel Goals	Group	10-Apr
59	Experimental Protocol + updated PDA	Group	15-Apr
60	Nicargua Trip	Group	20-Apr
61	Debrief and organize data from trip	Group	24-Apr
62	Reevaluate Cookstove Design	Group	26-Apr
63	Fuel Effeciency testing	Group	3-May
64	Finalize Draft of Conference Presentation	Group	5-May
65	Rehearse presentation	Group	8-May
66	Senior Design Conference	Group	9-May
67	Societal/environmental impact report	Group	15-May
68	Thesis Draft	Group	20-May
69	Patent Search/Business Plan	Group	29-May
70	Experimental Results	Group	3-Jun
71	Open house (hardware due)	Group	5-Jun
72	Final Thesis due	Group	14-May



Group
Christine
Matt
Mark
Matt/Mark
Break

Gantt chart detailing task breakdown from September 2012 to June 2013.

Task	Due Date	Part Number	Group Member
Assemble Cooktop	25-Jan	T001	Matt
		T002	Matt
		T003	Matt
		T004	Matt
		TX1	Mark, Matt, Christine
Assemble Body	25-Jan	B001	Matt
		B002	Matt
		B003	Matt
		B004	Matt
		B005	Matt
		B006	Christine
		B007	Christine
		B008	Christine
		B009	Christine
		B010	Christine
		BX1	Mark, Matt, Christine
Assemble Chamber	25-Jan	C001	Mark
		C002	Mark
		C003	Mark
		C004	Mark
		C005	Mark
		C006	Mark
		C007	Mark
		C007	Mark
		C008	Matt
		CX1	Mark, Matt, Christine
Assemble Duct	15-Mar	V001	Matt, Christine
		V002	Matt, Christine
		V003	Matt, Christine
		V004	Matt, Christine
		V005	Matt, Christine
		V006	Matt, Christine
		VX1	Mark, Matt, Christine
Complete TEM	22-Feb	P001	Mark, Matt
and Heat Sink Assembly		P002	Mark, Matt
		P003	Mark, Matt
		P004	Mark, Matt
		P005	Mark, Matt
		P006	Mark, Matt
		P007	Mark, Matt, Christine
		P008	Mark, Matt, Christine
		PX1	Mark, Matt, Christine
Finish duct and fan interface	22-Mar	V005	Mark, Matt
Install handles on new comal	22-Mar	TX1	Matt, Christine
Pot cutout on old comal	22-Mar	TX1 - stainless	Matt, Christine
Water Boiling Testing			Mark, Matt, Christine
Controlled Cooking Testing			Mark, Matt, Christine
TEM Assembly Testing			Mark, Matt, Christine
Develop Lab View program			
Over all fuel effeciency test			



Drawings
Construction
Assembly
Stove Voltage Testing
Water Boiling Testing
Controlled Cooking Testing
Lab View Development
Overall Effeciency Testing

Gantt chart detailing the construction schedule from January 2013 to June 2013.

APPENDIX D: FloXpress Simulation

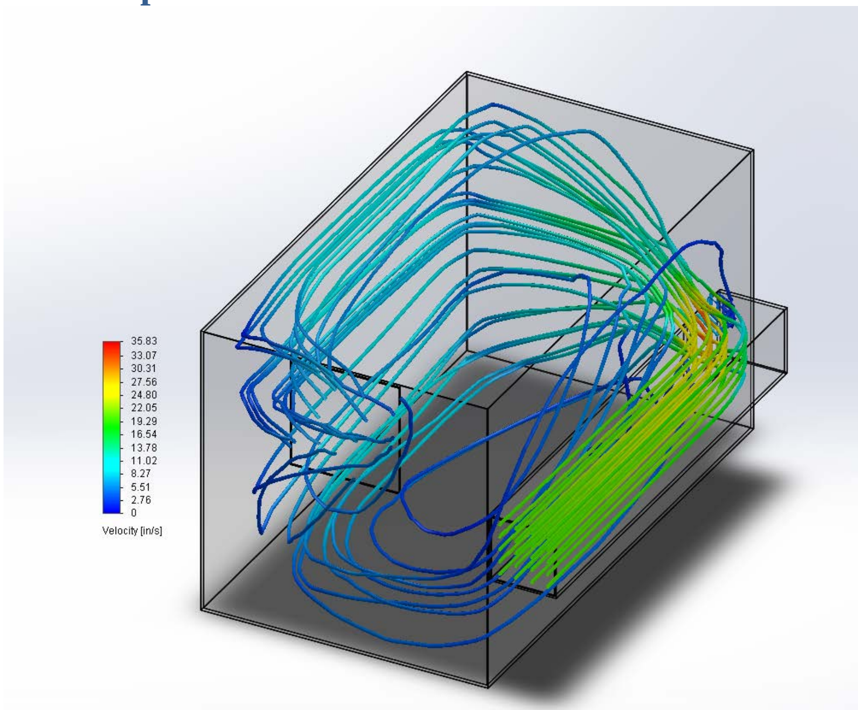


Figure 1D. The FloExpress model of the single port duct attached to the combustion chamber. The air temperature was 200°F and the volumetric flow rate was 245 $\frac{in^3}{s}$.

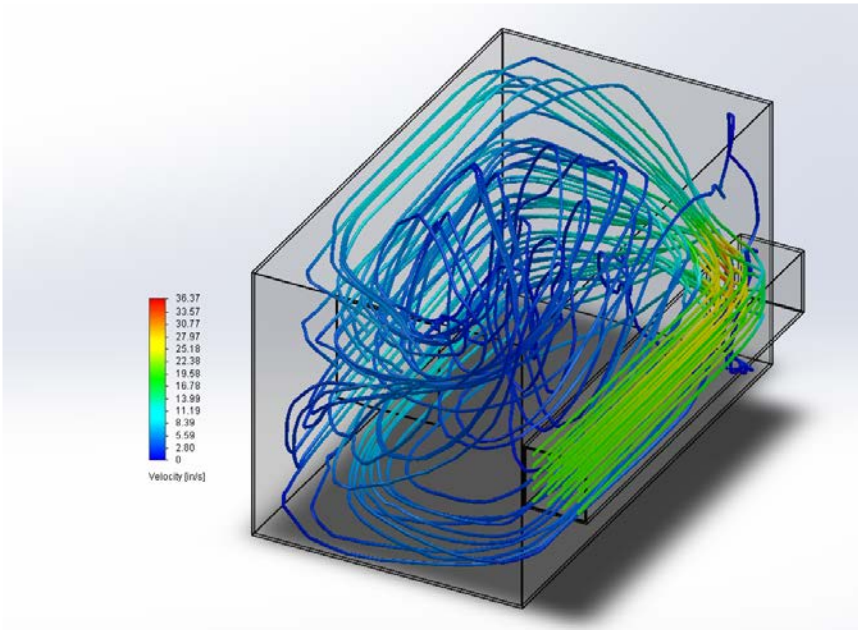


Figure 2D. The FloExpress model of the single port duct attached to the combustion chamber. The air temperature was 300°F and the volumetric flow rate was 245 $\frac{in^3}{s}$.

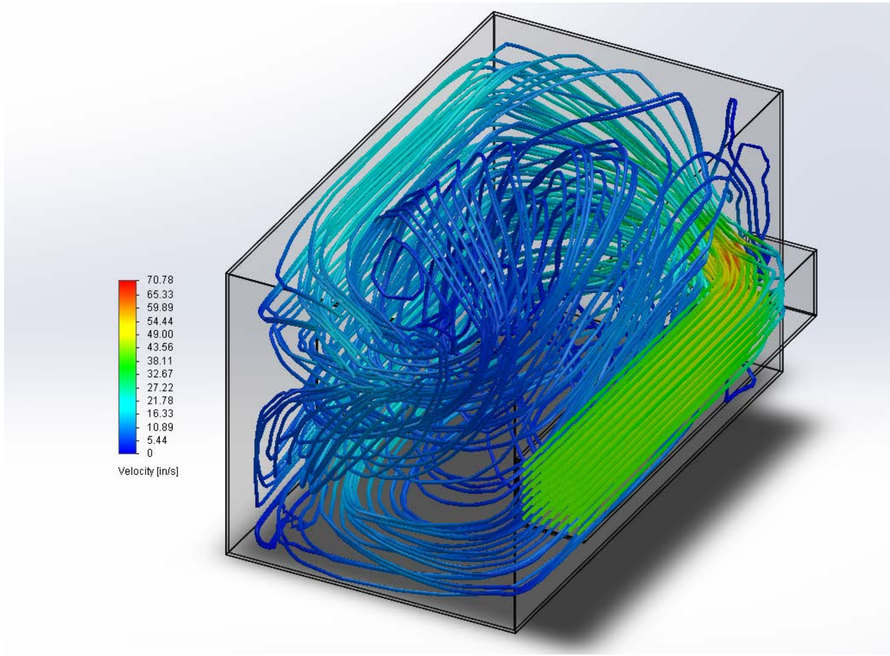


Figure 3D. The FloExpress model of the single port duct attached to the combustion chamber. The air temperature was 200°F and the volumetric flow rate was 490 $\frac{in^3}{s}$.

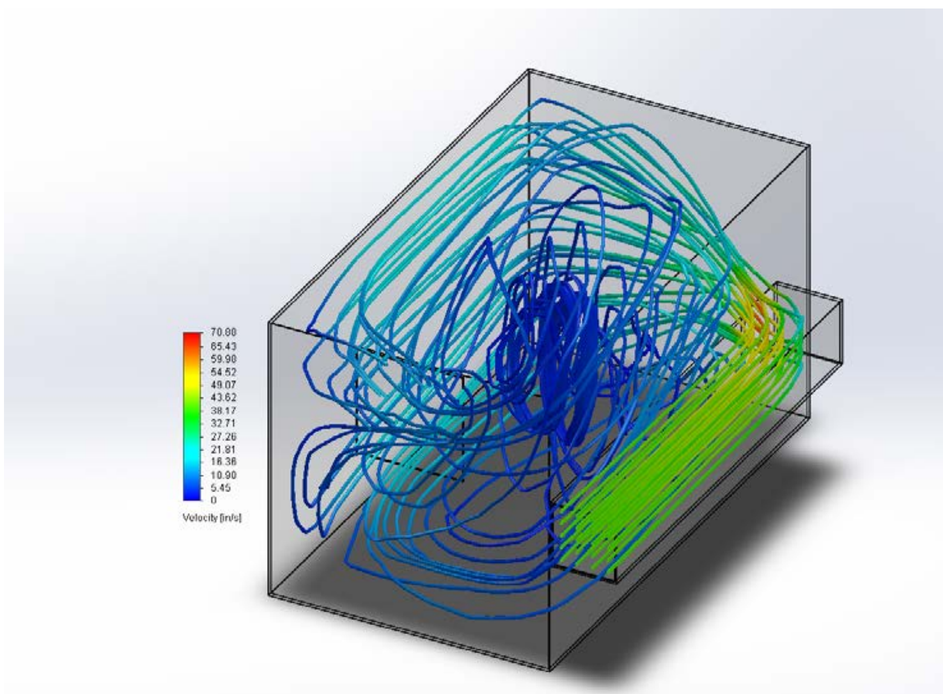


Figure 4D. The FloExpress model of the single port duct attached to the combustion chamber. The air temperature was 300°F and the volumetric flow rate was 490 $\frac{in^3}{s}$.

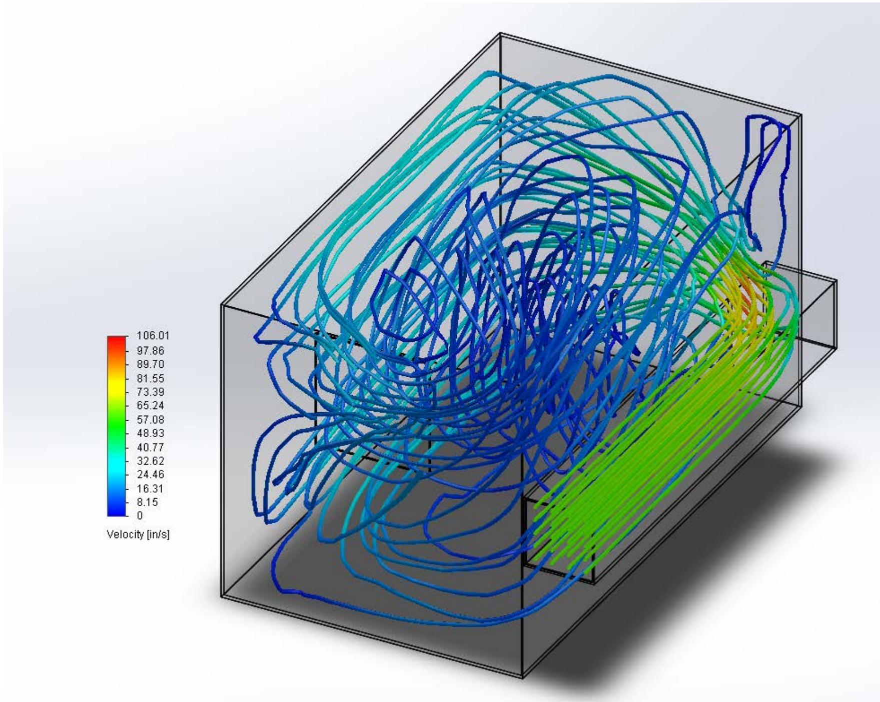


Figure 5D. The FloExpress model of the single port duct attached to the combustion chamber. The air temperature was 200°F and the volumetric flow rate was 735 $\frac{in^3}{s}$.

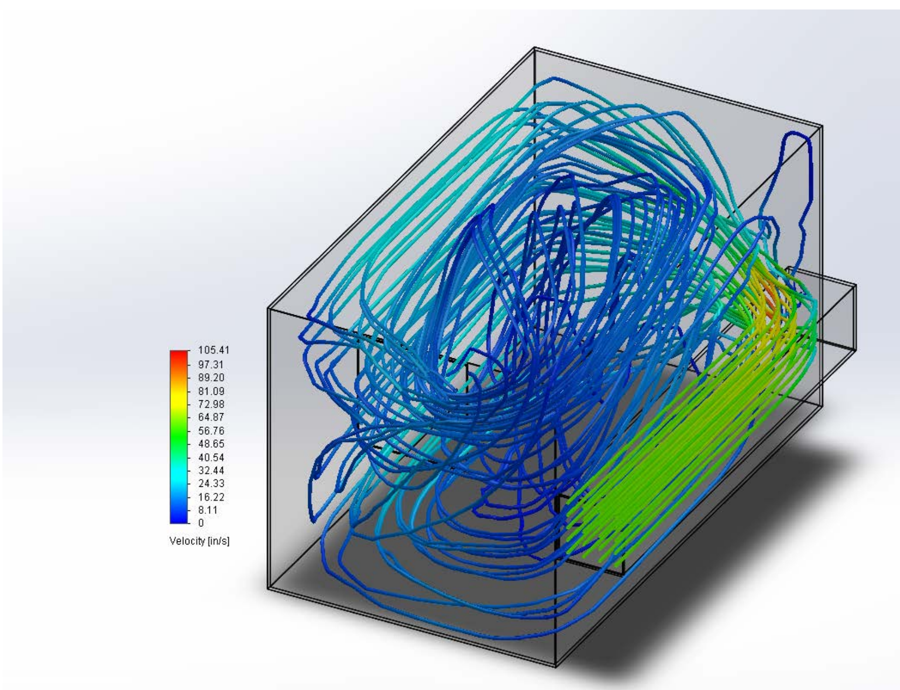


Figure 6D. The FloExpress model of the single port duct attached to the combustion chamber. The air temperature was 300°F and the volumetric flow rate was 735 $\frac{in^3}{s}$.

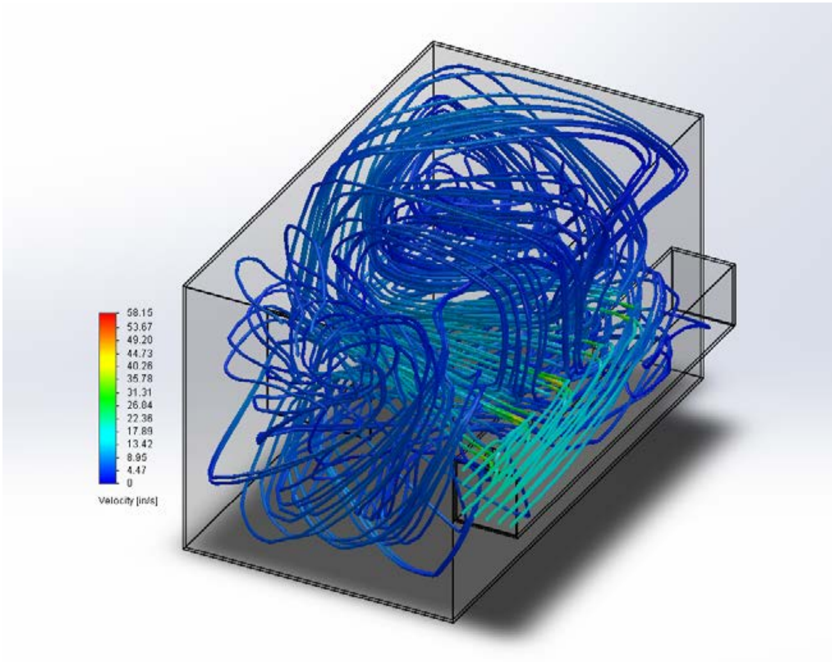


Figure 7D. The FloExpress model of the single port duct attached to the combustion chamber. The air temperature was 200°F and the volumetric flow rate was 245 $\frac{in^3}{s}$.

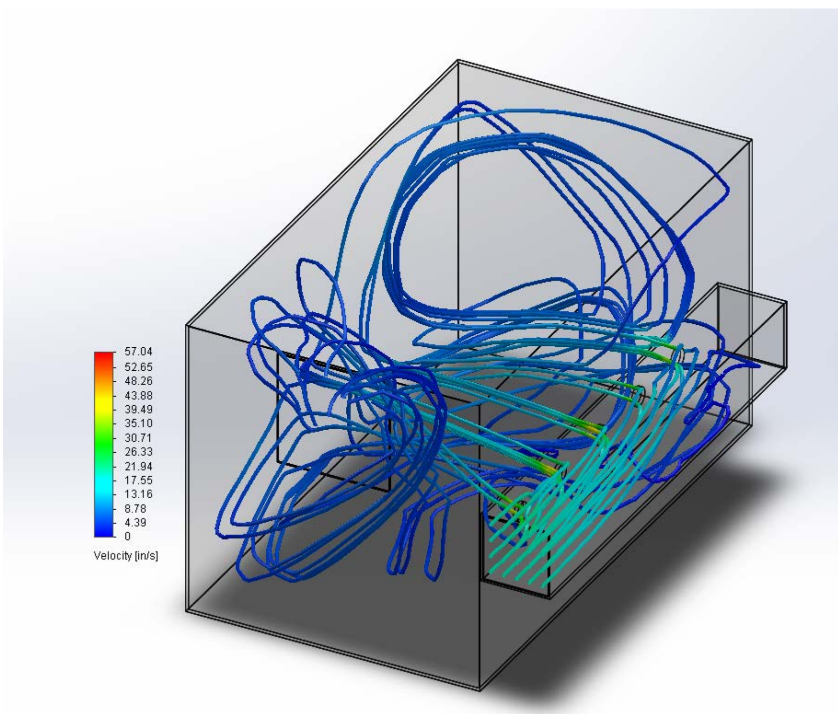


Figure 8D. The FloExpress model of the single port duct attached to the combustion chamber. The air temperature was 300°F and the volumetric flow rate was 245 $\frac{in^3}{s}$.

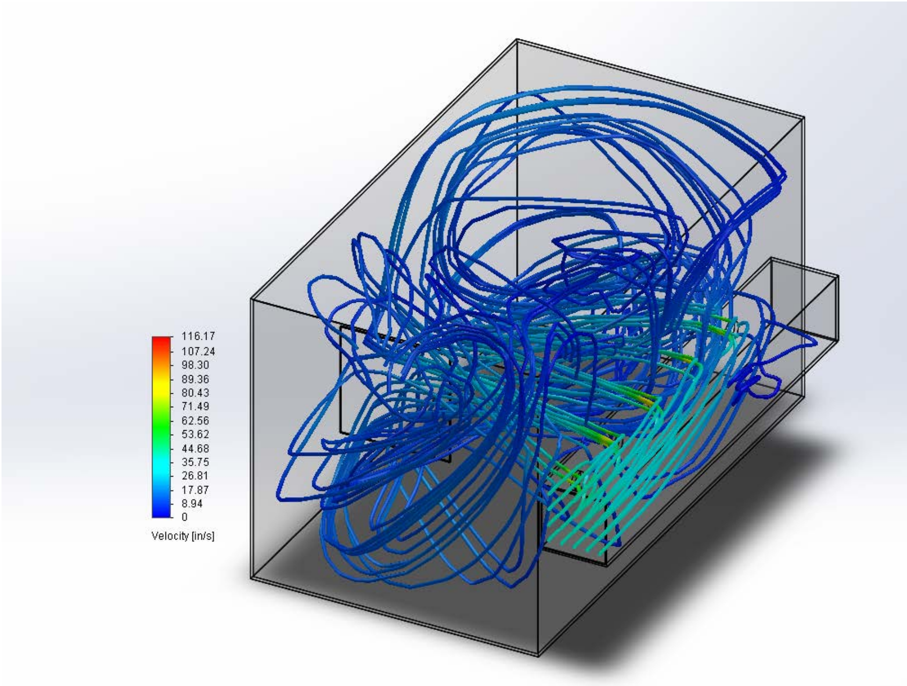


Figure 9D. The FloExpress model of the single port duct attached to the combustion chamber. The air temperature was 200°F and the volumetric flow rate was 490 $\frac{in^3}{s}$.

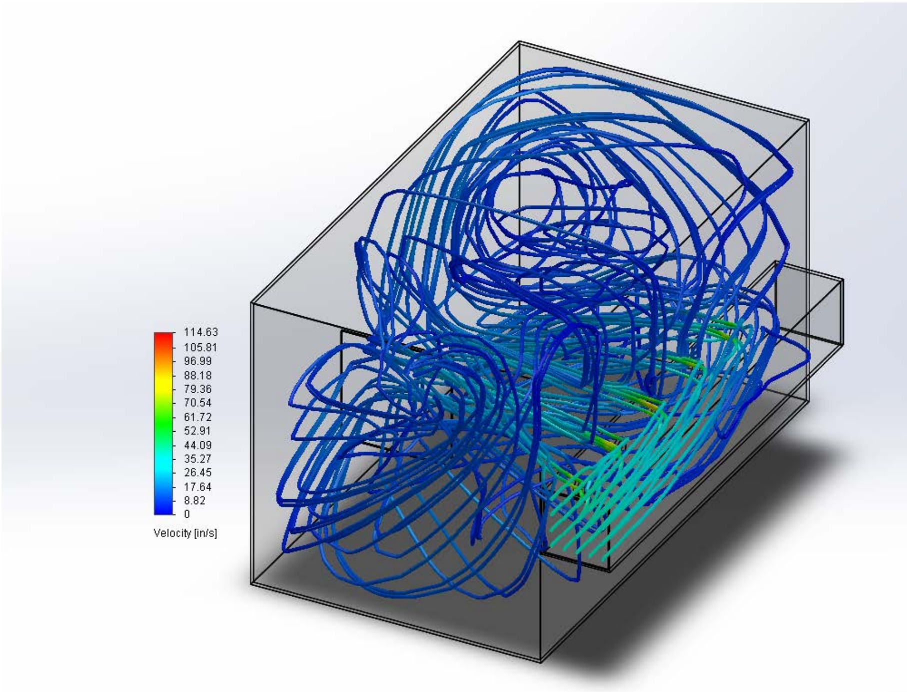


Figure 10D. The FloExpress model of the single port duct attached to the combustion chamber. The air temperature was 300°F and the volumetric flow rate was 490 $\frac{in^3}{s}$.

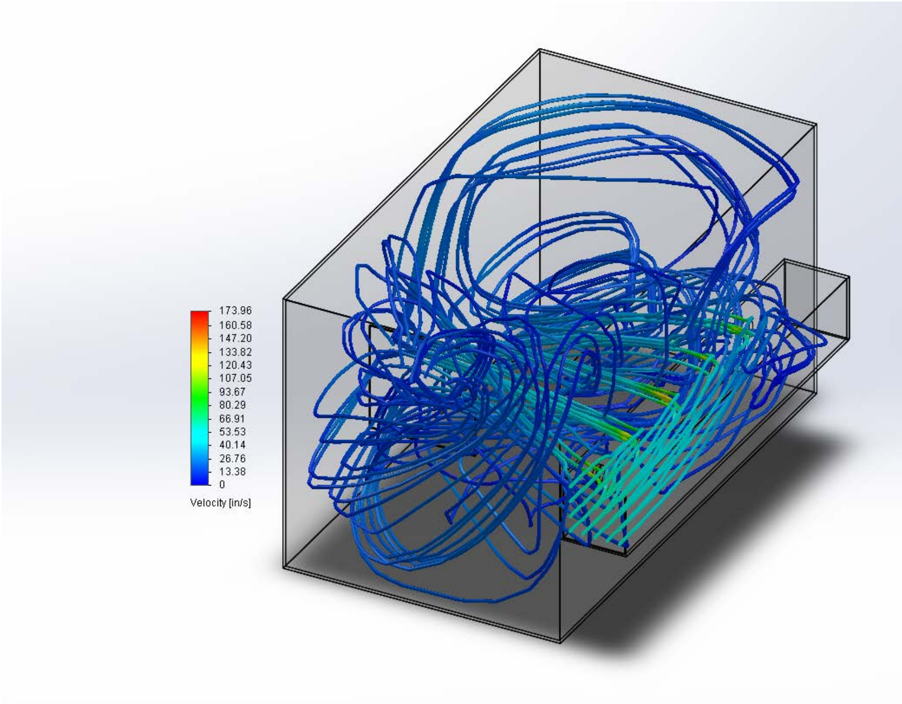


Figure 11D. The FloExpress model of the single port duct attached to the combustion chamber. The air temperature was 200°F and the volumetric flow rate was 735 $\frac{in^3}{s}$.

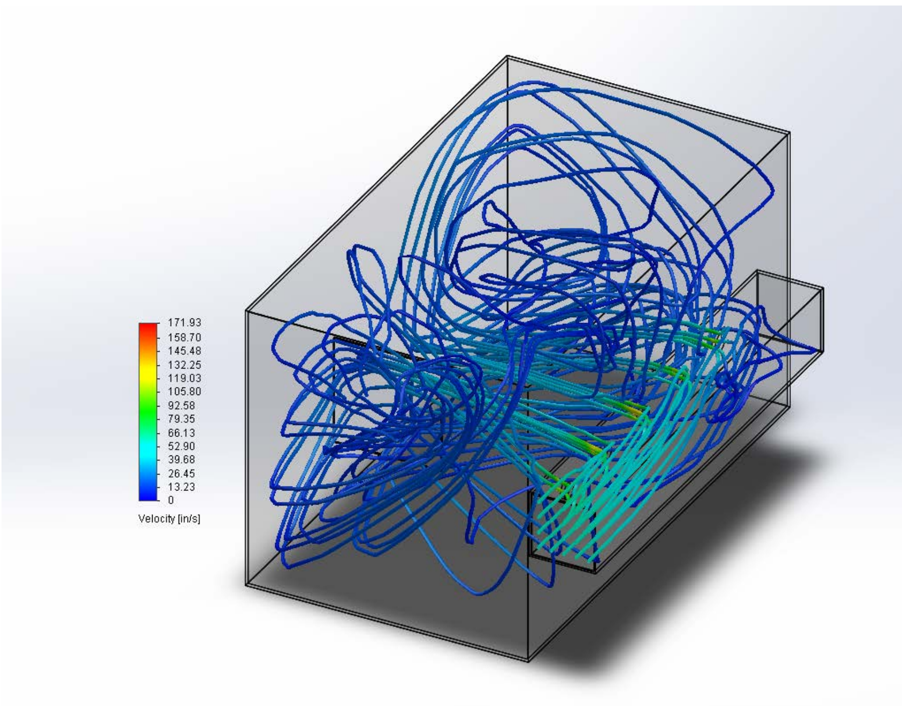


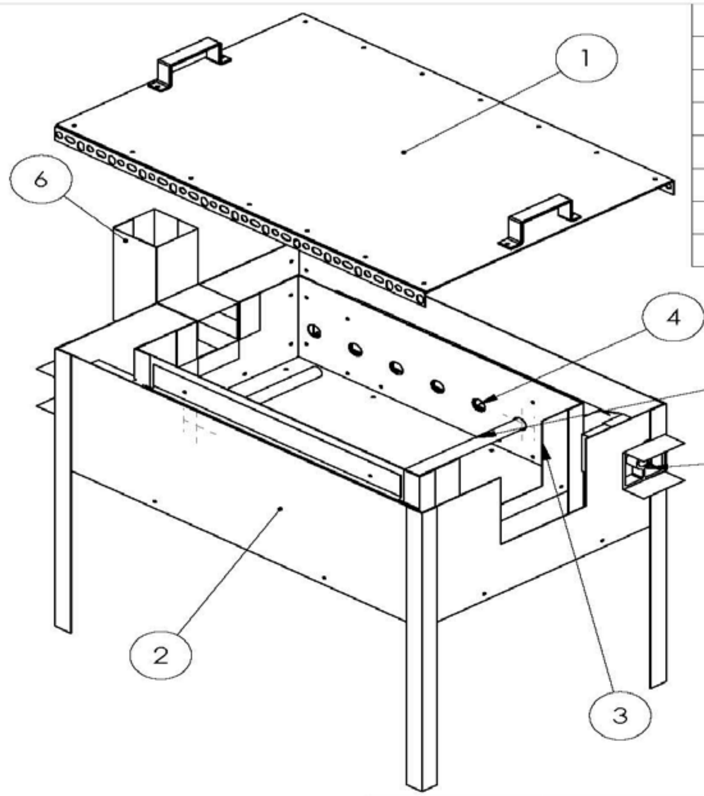
Figure 12D. The FloExpress model of the single port duct attached to the combustion chamber. The air temperature was 300°F and the volumetric flow rate was 735 $\frac{in^3}{s}$.

APPENDIX E: Prototype Cost

Table 1E. List of prototype costs

Item / Process	Cost / Stove	Target cost for Nicaragua
Sheet Metal - steel	$125.00	$18.75
Nuts/bolts/washers	$15.00	$2.25
conduction rod (2x)	$10.00	$1.50
grate	$6.00	$0.90
TEG (2x)	$30.00	$20.00
heat sink (2x)	$10.00	$1.50
aluminum ducts	$9.00	$1.35
handles	$4.00	$0.60
angle iron	$75.00	$11.25
motor (2x)	$8.00	$1.20
aluminum fan blade (2x)	$20.00	$3.00
aluminum mount (2x)	$8.00	$1.20
machining	-	$20.00
Total	$320.00	$83.50

APPENDIX F: Detailed Drawings



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	TX1	Griddle Assembly	1
2	BX1	Outer Body Assembly	1
3	CX1	Combustion Chamber Assembly	1
4	DX1	Duct Assembly	2
5	FX1	Fan Assembly	2
6	VX1	Vent Assembly	1
7	PX1	Power Generation Assembly	2

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FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

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	NAME	DATE
DRAWN	MWF	3/20/2013
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Team Matador

TITLE:

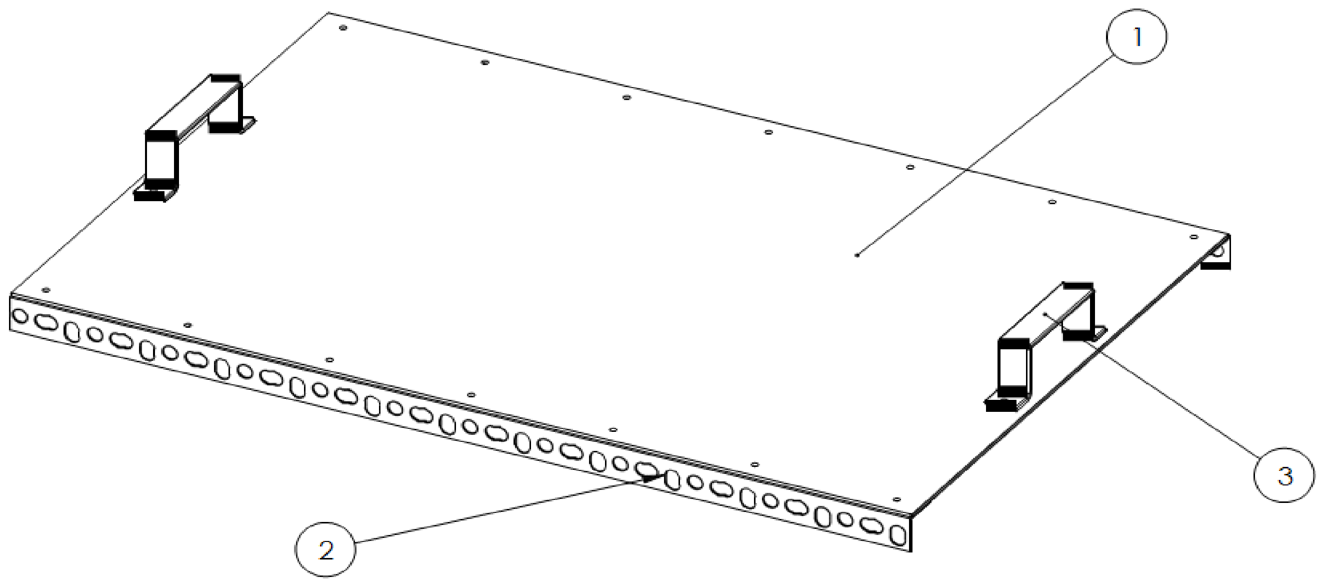
Stove Assembly

SIZE A | DWG. NO. SX1 | REV 1

SCALE: 1:24 WEIGHT:

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	T001	Griddle Top	1
2	T002	Griddle Support	2
3	T003	Griddle Handles	2



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ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MFW	3/20/2013
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Team Matador

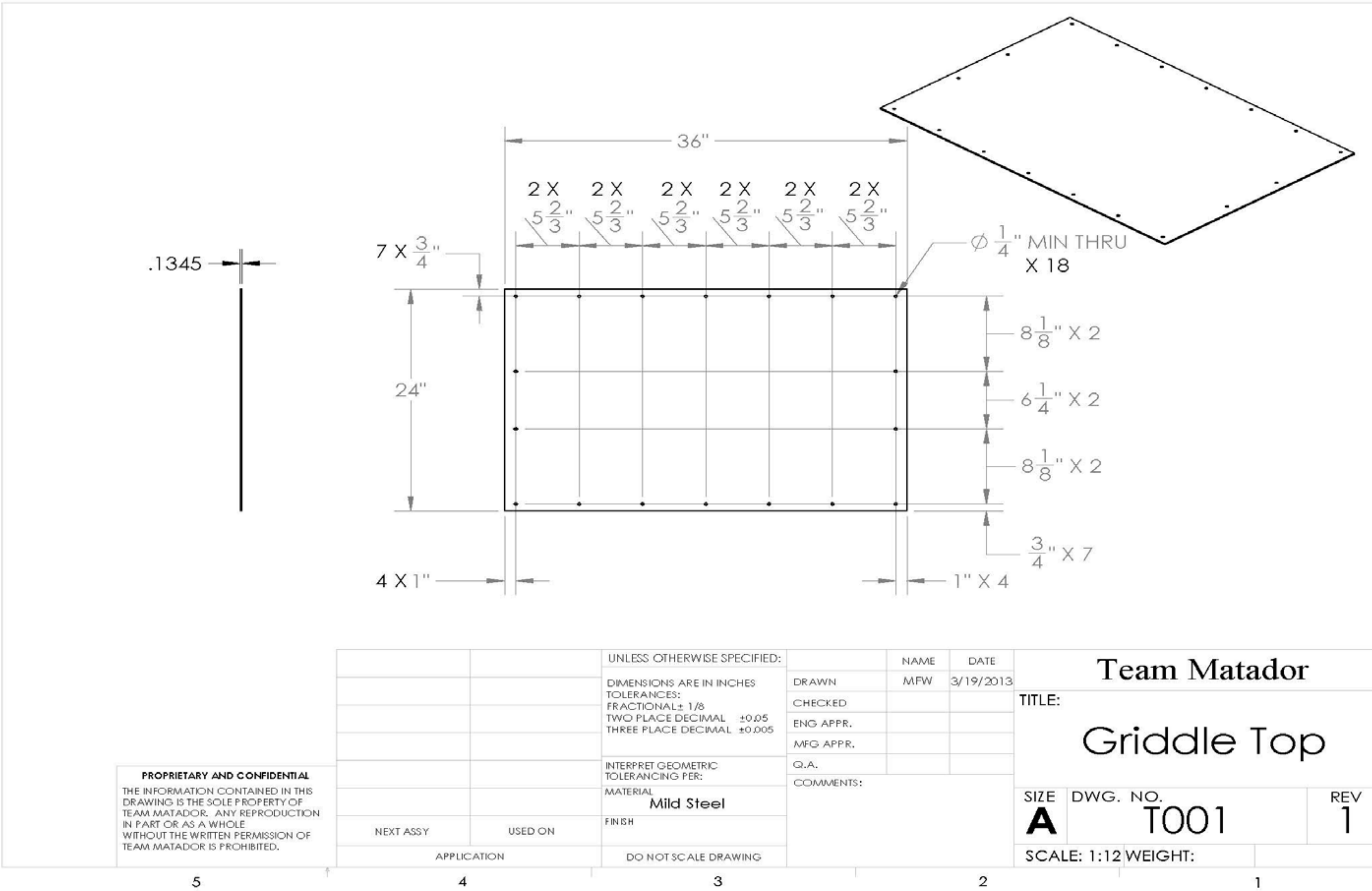
TITLE:

Griddle Assembly

SIZE A | DWG. NO. TX1 | REV 1

SCALE: 1:12 WEIGHT:

5 4 3 2 1



36"
2 X $5\frac{2}{3}$"
$\varnothing\frac{1}{4}$" MIN THRU X 18
.1345
7 X $\frac{3}{4}$"
24"
$8\frac{1}{8}$" X 2
$6\frac{1}{4}$" X 2
$8\frac{1}{8}$" X 2
$\frac{3}{4}$" X 7
4 X 1"
1" X 4
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TOLERANCES:
FRACTIONAL± 1/8
TWO PLACE DECIMAL ±0.05
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Mild Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
MFW
3/19/2013
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Team Matador
TITLE:
Griddle Top
SIZE
A
DWG. NO.
T001
REV
1
SCALE: 1:12
WEIGHT:
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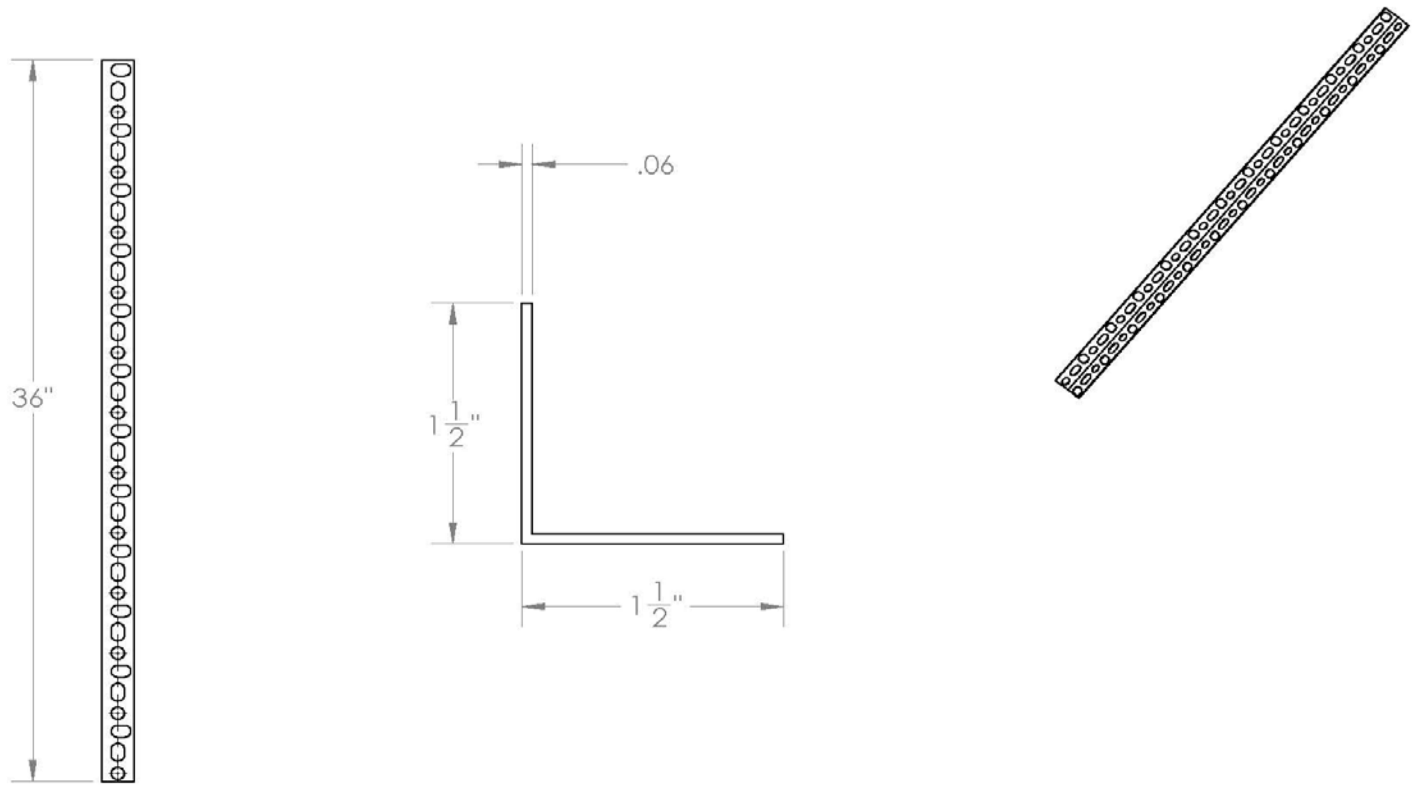
4
3
2
1



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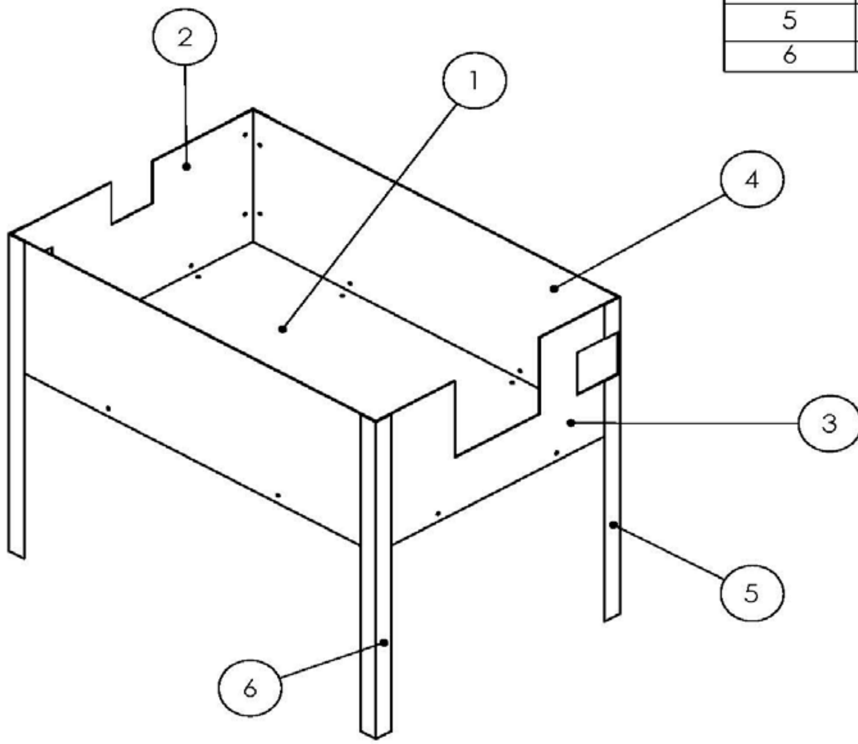
			CHECKED			Griddle Support
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL Steel	COMMENTS:			SIZE A DWG. NO. T002 REV 1
NEXT ASSY	USED ON	FINISH Zinc				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:12 WEIGHT:

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	B001	Outer Body Base	1
2	B002	Outer Body Vent Panel	1
3	B003	Outer Body Fuel Shoot Panel	1
4	B004	Outer Body Side Panel	2
5	B006	Outer Body Duct Leg	2
6	B007	Outer Body Soild Leg	2



	NAME	DATE
DRAWN	MFW	3/20/2013
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
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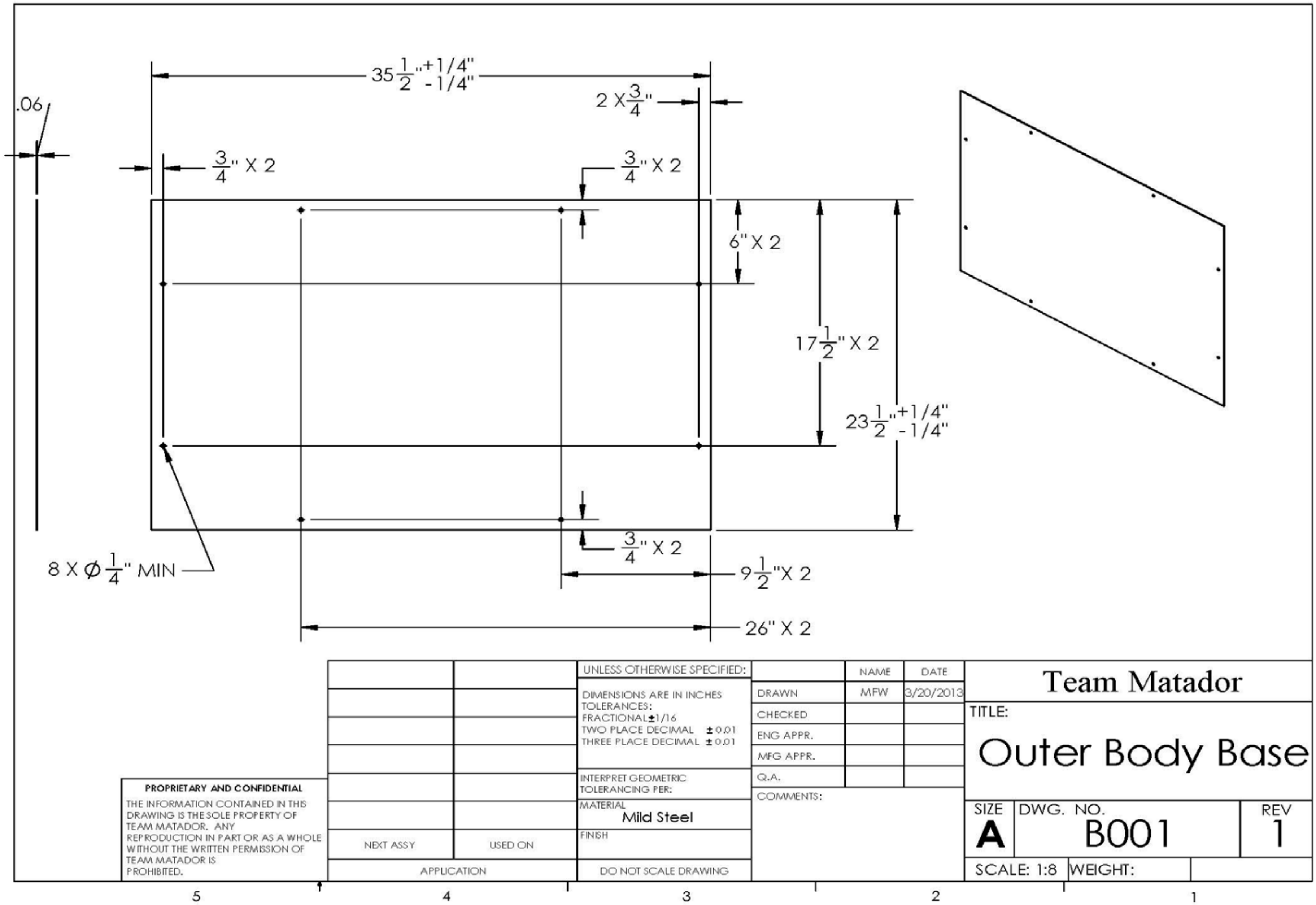
Team Matador

TITLE: Outer Body Assembly

SIZE: A | DWG. NO.: BX1 | REV: 1

SCALE: 1:12 | WEIGHT:

5 4 3 2 1


35 1/2" +1/4" -1/4"
.06
2 X 3/4"
3/4" X 2
3/4" X 2
6" X 2
17 1/2" X 2
23 1/2" +1/4" -1/4"
8 X Ø 1/4" MIN
3/4" X 2
9 1/2" X 2
26" X 2
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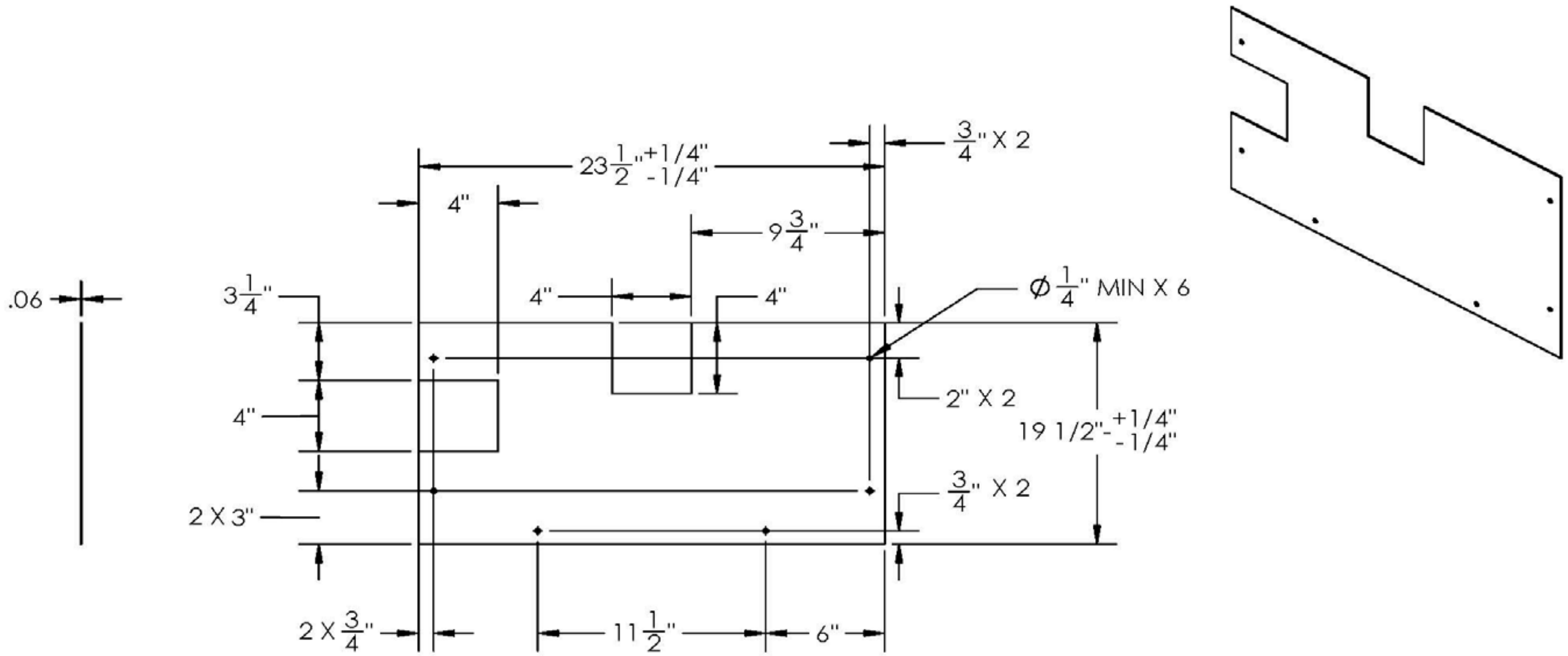
TOLERANCES:
FRACTIONAL ±1/16
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.01
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Mild Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
MFW
3/20/2013
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Team Matador
TITLE:
Outer Body Base
SIZE
A
DWG. NO.
B001
REV
1
SCALE: 1:8
WEIGHT:
5
4
3
2
1



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TOLERANCES:
FRACTIONAL ± 1/16
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.001

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Mild Steel

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MFW	3/20/2013
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

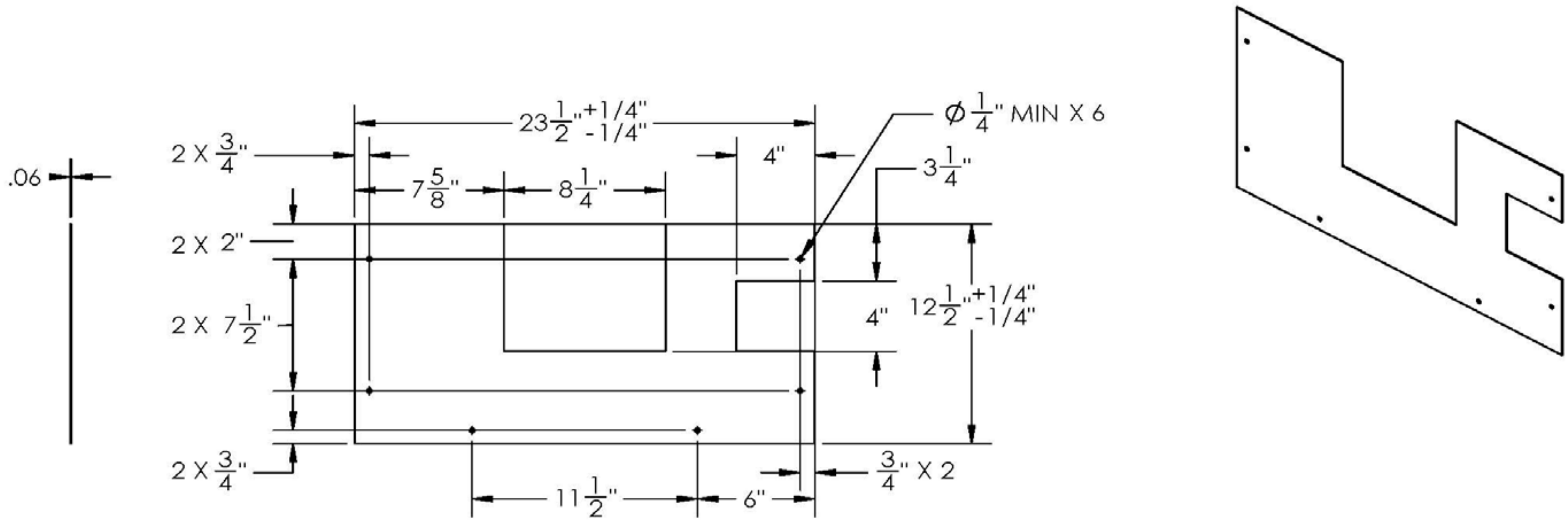
Team Matador

TITLE: Outer Body Vent Panel

SIZE	DWG. NO.	REV
A	B002	1

SCALE: 1:8 WEIGHT:

5 4 3 2 1



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	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL Mild Steel	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

NEXT ASSY | USED ON

APPLICATION

PROPRIETARY AND CONFIDENTIAL

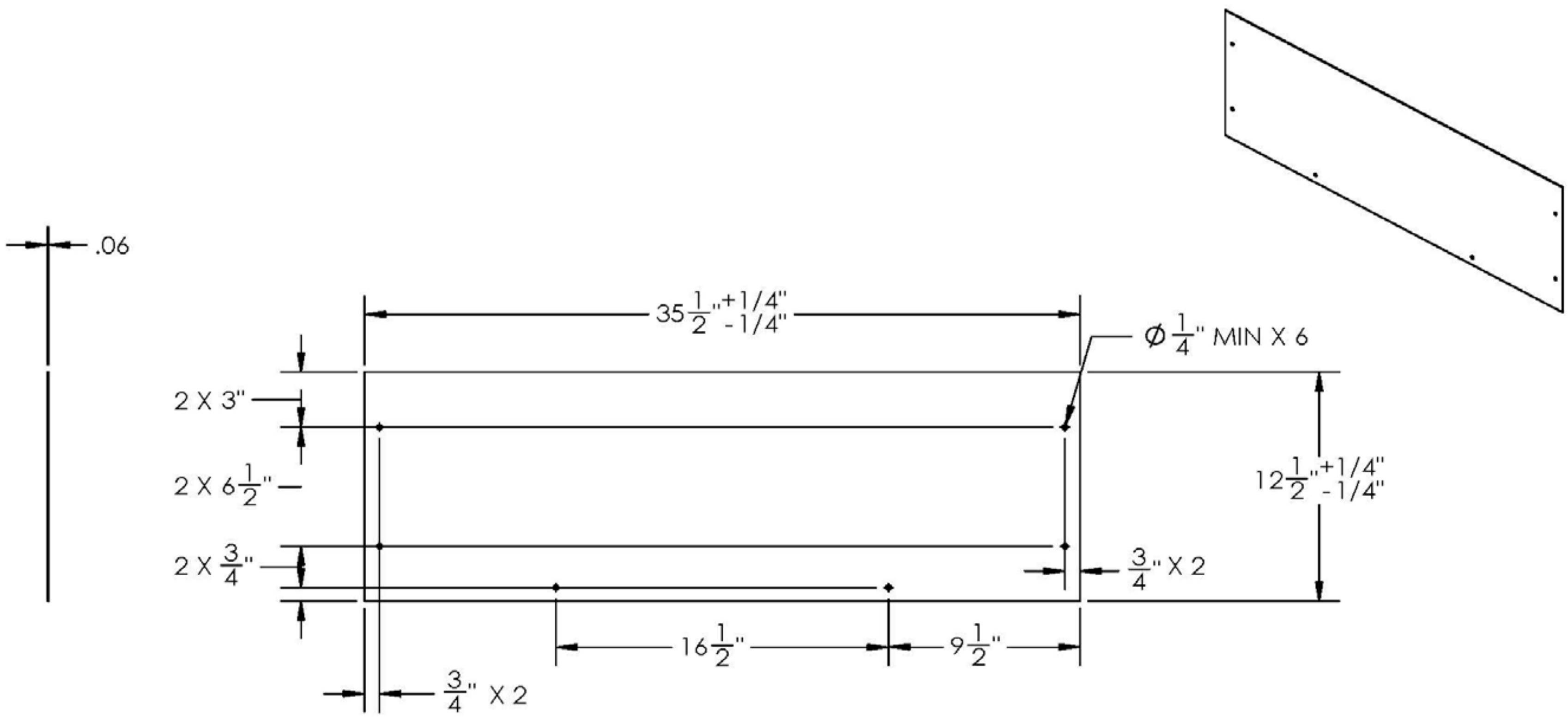
Team Matador

TITLE: Outer Body Fuel Shoot Panel

SIZE	DWG. NO.	REV
A	B003	1

SCALE: 1:8 WEIGHT:

5 4 3 2 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
TWO PLACE DECIMAL ± 0.05
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Mild Steel

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MFW	3/20/2013
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Team Matador

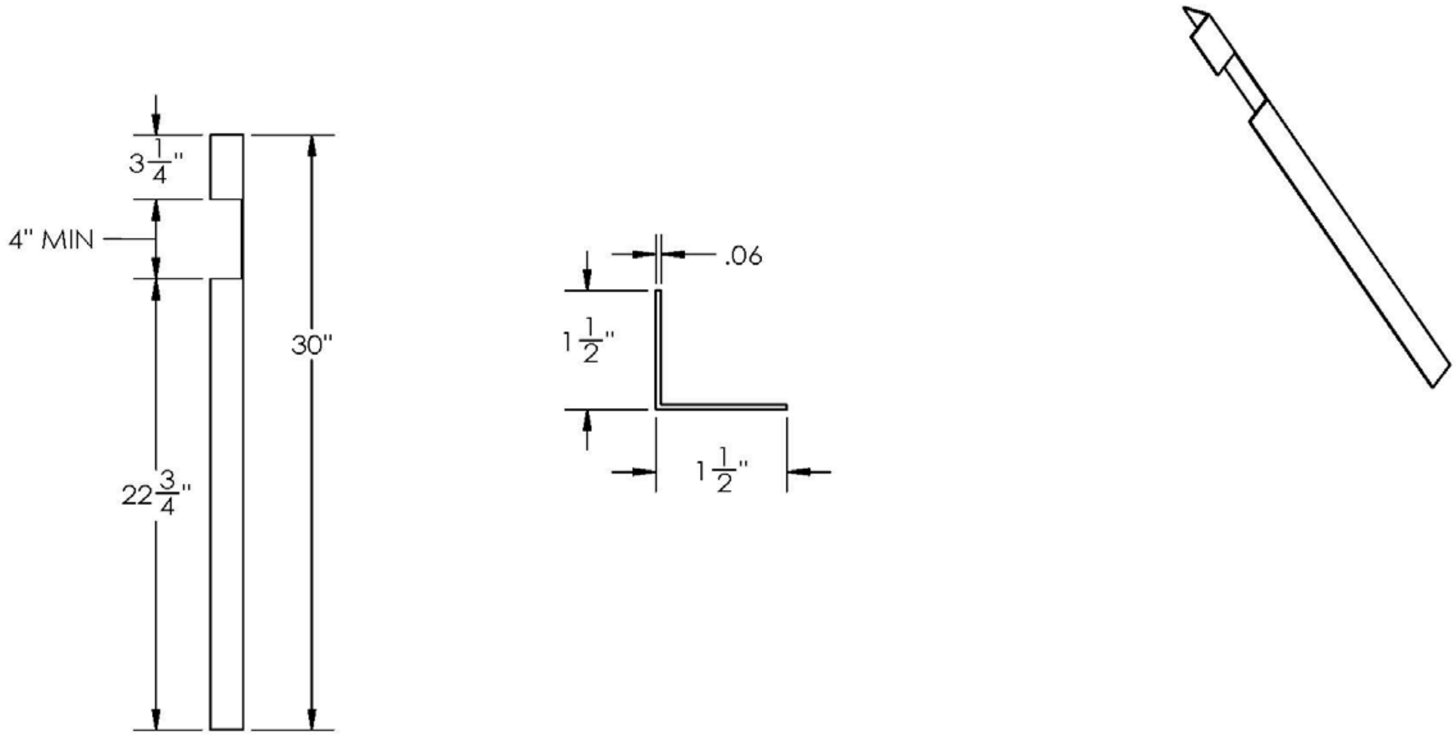
TITLE:

Outer Body Side Panel

SIZE	DWG. NO.	REV
A	B004	1

SCALE: 1:8 WEIGHT:

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Team Matador	
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	CHECKED				
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL Steel	COMMENTS:			SIZE A / DWG. NO. B006	REV 1
FINISH Zinc					
DO NOT SCALE DRAWING				SCALE: 1:8	WEIGHT:

NEXT ASSY	USED ON
APPLICATION	

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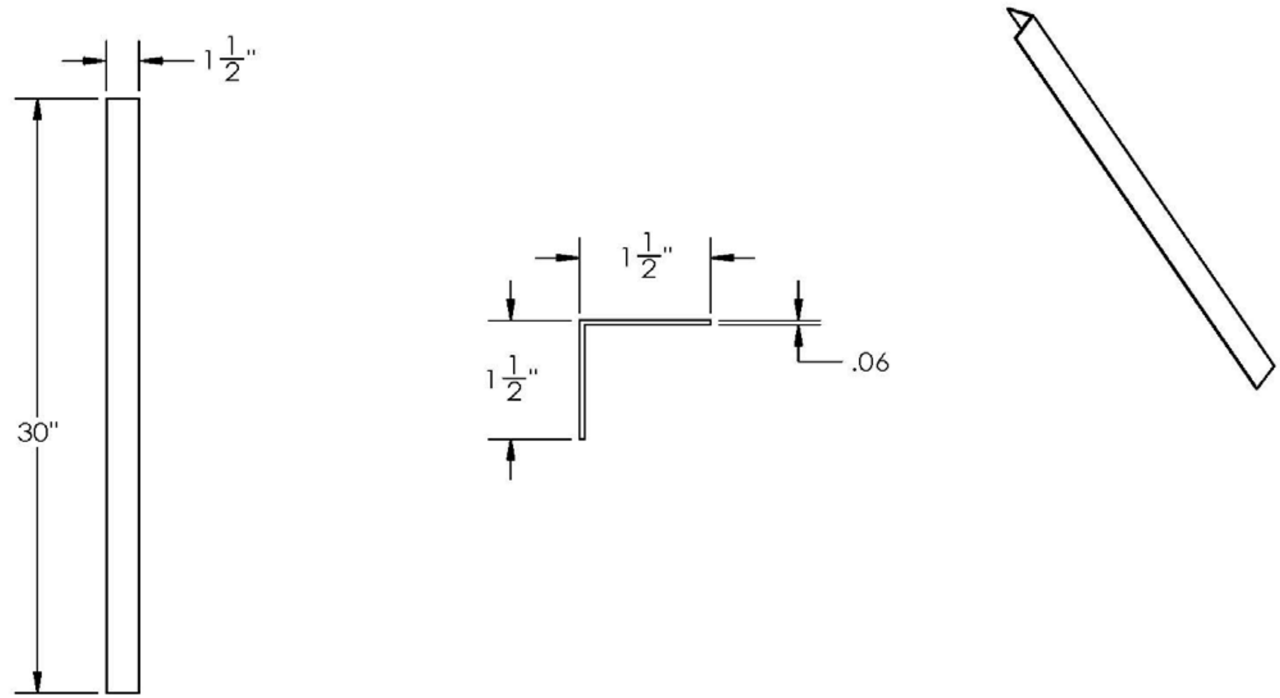
5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
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	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL Steel	COMMENTS:		
FINISH Zinc			
DO NOT SCALE DRAWING			

NEXT ASSY | USED ON

APPLICATION

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Team Matador

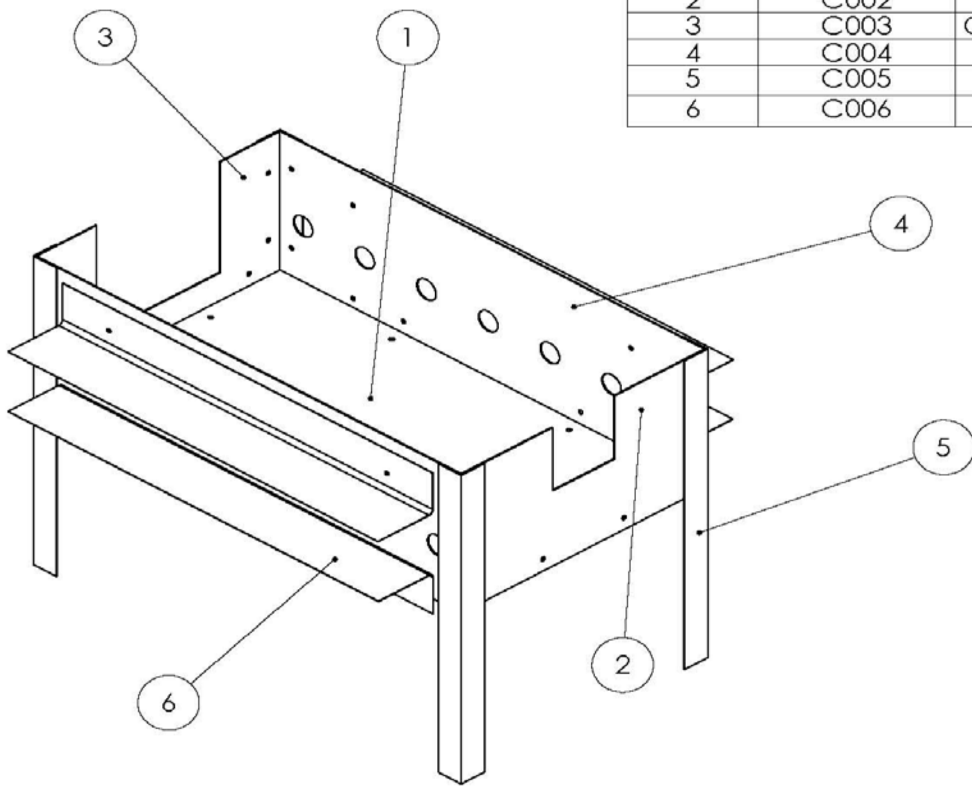
TITLE: Outer Body Solid Leg

SIZE	DWG. NO.	REV
A	B007	1

SCALE: 1:8 WEIGHT:

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	C001	Combustion Chamber Base	1
2	C002	Combustion Chamber Vent Panel	1
3	C003	Combustion Chamber Fuel Shoot Panel	1
4	C004	Combustion Chamber Side	2
5	C005	Combustion Chmaber Legs	4
6	C006	Duct Support	4



PROPRIETARY AND CONFIDENTIAL

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NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MFw	3/20/2013
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Team Matador

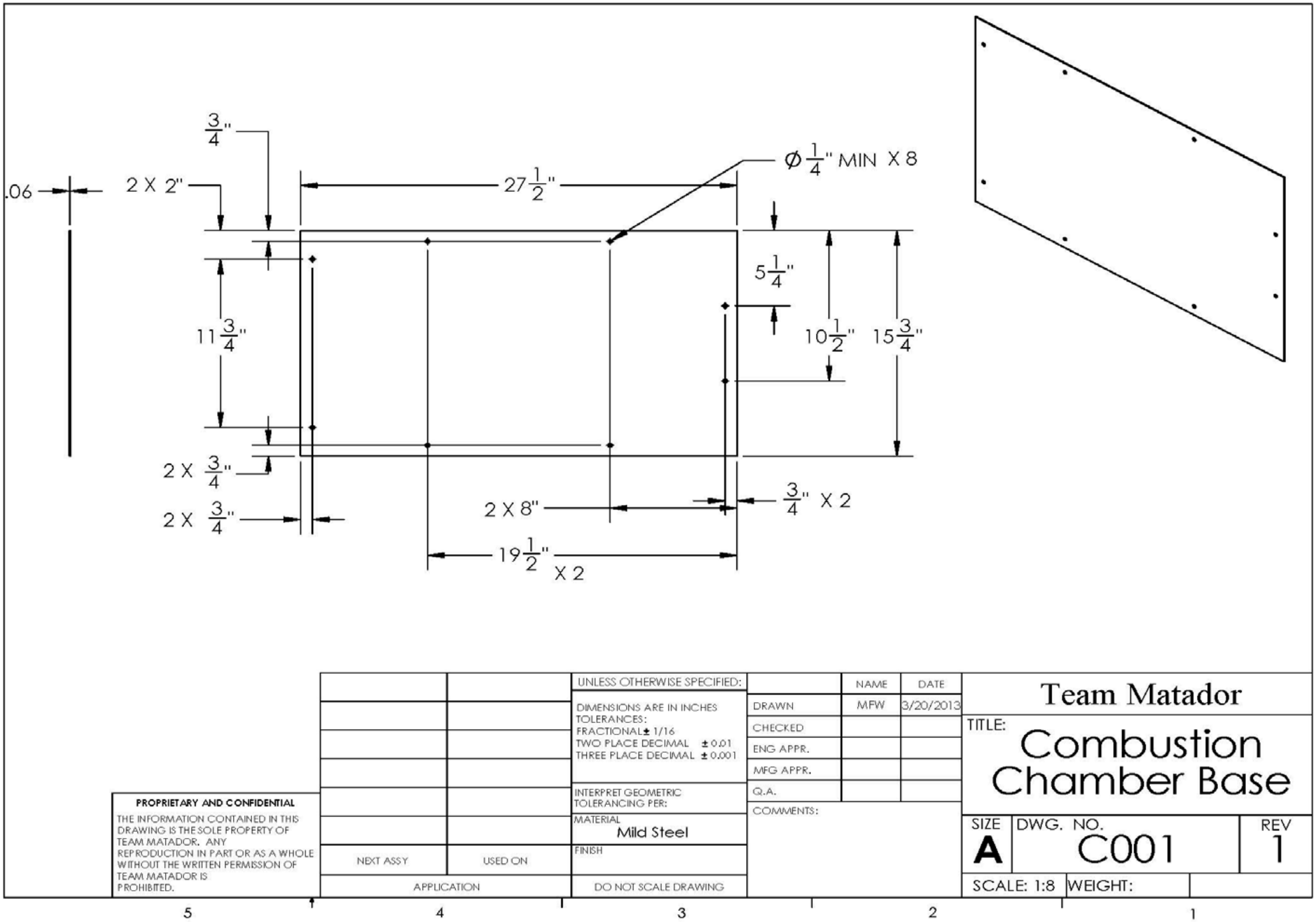
TITLE:

Combustion Chamber Assembly

SIZE A | DWG. NO. CX1 | REV 1

SCALE: 1:12 | WEIGHT:

5 4 3 2 1



3/4"
.06
2 X 2"
27 1/2"
Ø 1/4" MIN X 8
5 1/4"
11 3/4"
10 1/2"
15 3/4"
2 X 3/4"
2 X 3/4"
2 X 8"
3/4" X 2
19 1/2" X 2
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.001
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Mild Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
MFW
3/20/2013
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Team Matador
TITLE:
Combustion Chamber Base
SIZE
A
DWG. NO.
C001
REV
1
SCALE: 1:8
WEIGHT:
PROPRIETARY AND CONFIDENTIAL
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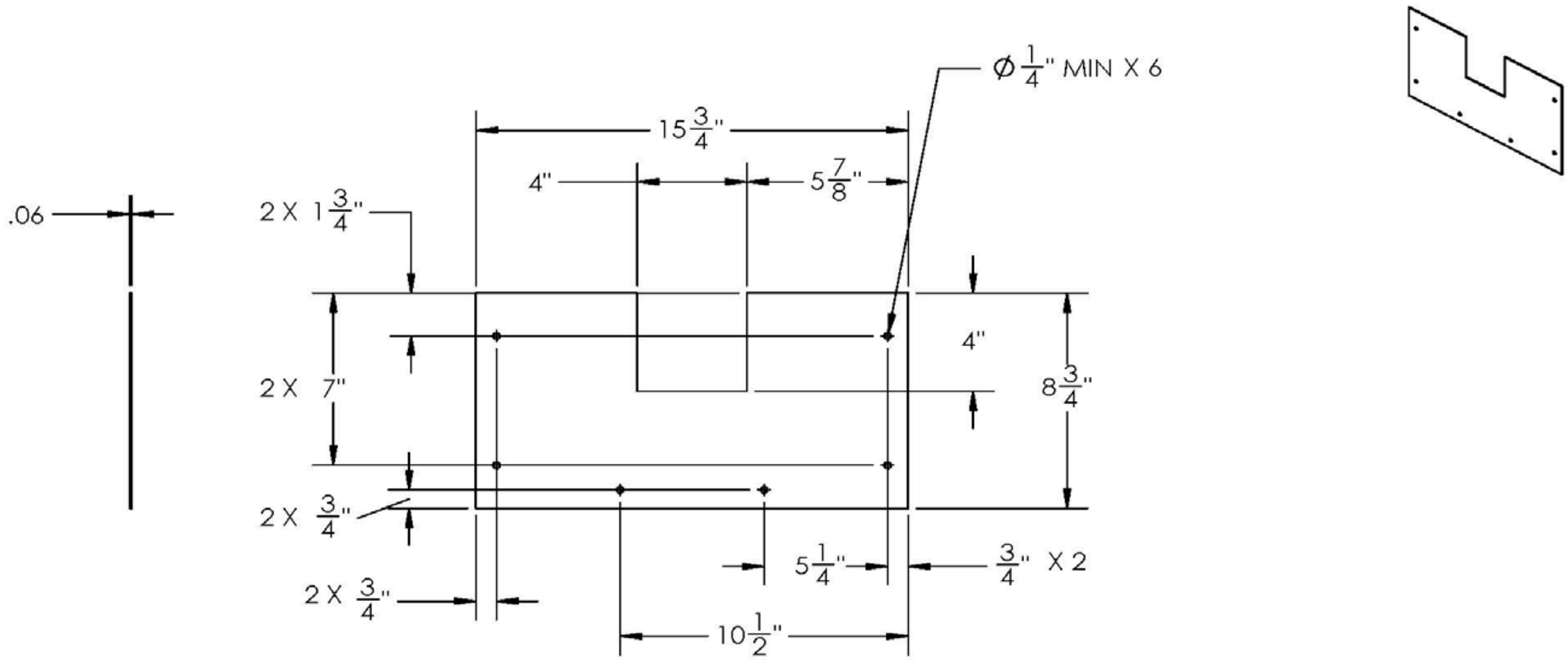
5
4
3
2
1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	**Team Matador**
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/16 TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.001	DRAWN	MFW	3/20/2013	TITLE: Combustion Chamber Vent Panel
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL Mild Steel	COMMENTS:			SIZE A — DWG. NO. C002 — REV 1
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:4 — WEIGHT:

PROPRIETARY AND CONFIDENTIAL

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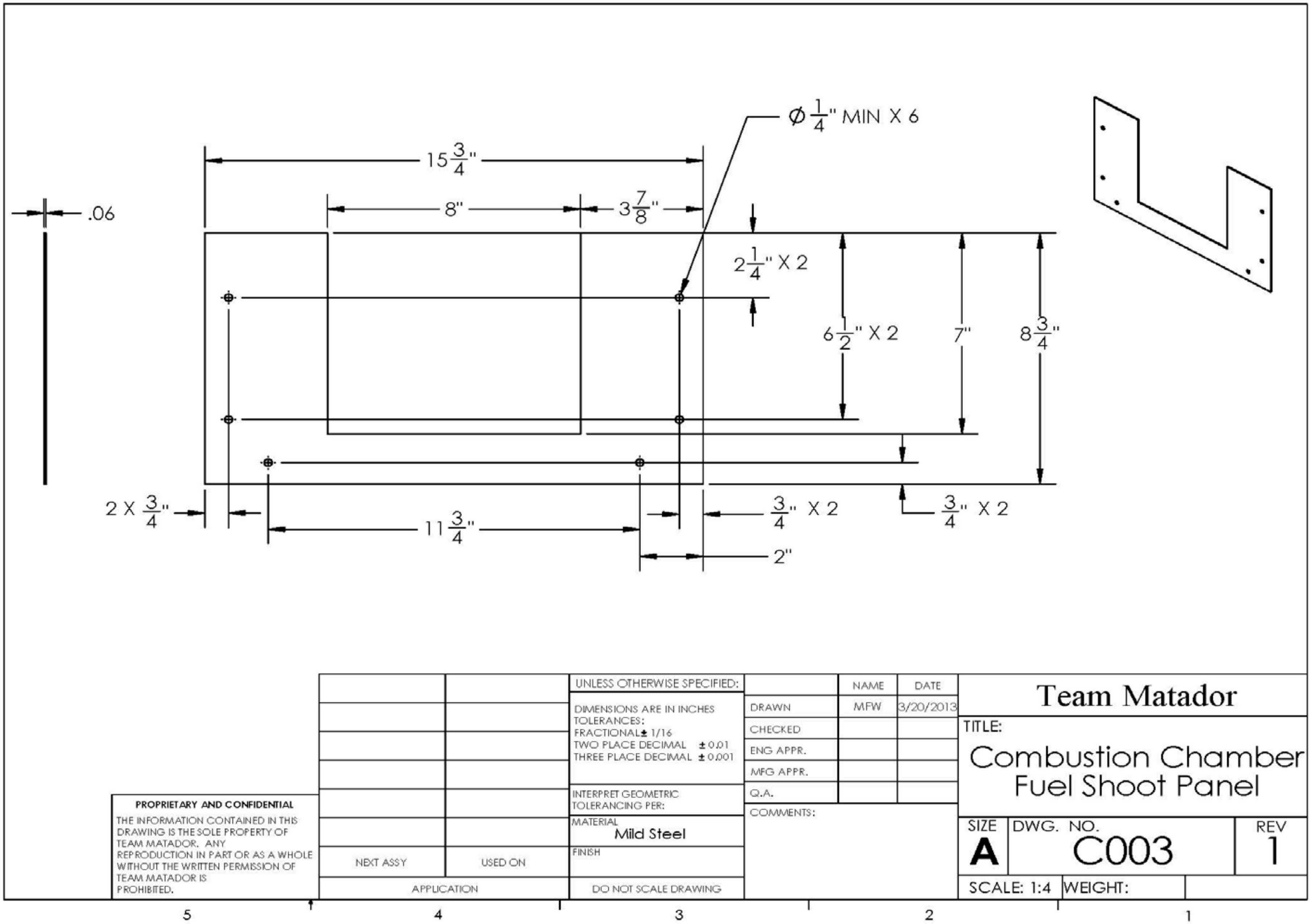
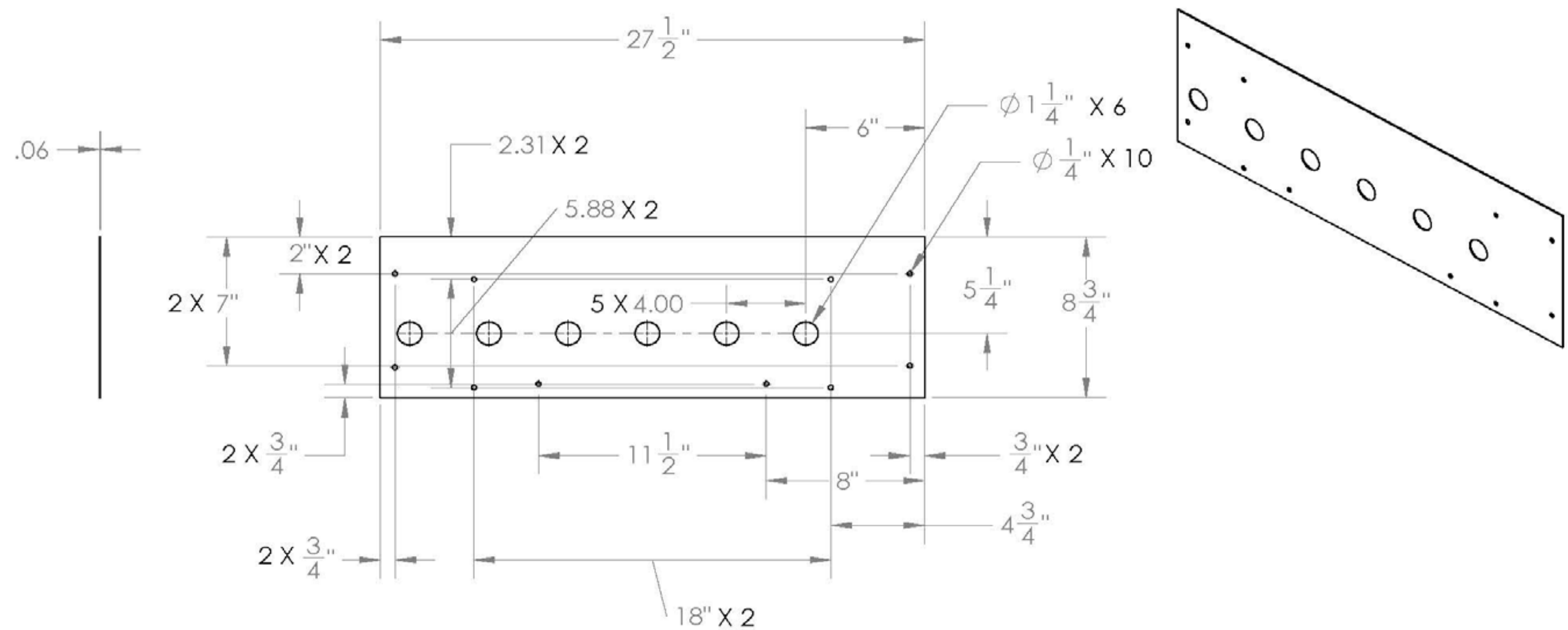
5 4 3 2 1


Ø 1/4" MIN X 6
15 3/4"
8"
3 7/8"
.06
2 1/4" X 2
6 1/2" X 2
7"
8 3/4"
2 X 3/4"
11 3/4"
3/4" X 2
3/4" X 2
2"
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.001
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Mild Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
MFW
3/20/2013
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Team Matador
TITLE:
Combustion Chamber Fuel Shoot Panel
SIZE
A
DWG. NO.
C003
REV
1
SCALE: 1:4
WEIGHT:
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF TEAM MATADOR. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF TEAM MATADOR IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
5
4
3
2
1



		UNLESS OTHERWISE SPECIFIED:
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/16 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.001
		INTERPRET GEOMETRIC TOLERANCING PER:
		MATERIAL Mild Steel
NEXT ASSY	USED ON	FINISH
APPLICATION		DO NOT SCALE DRAWING

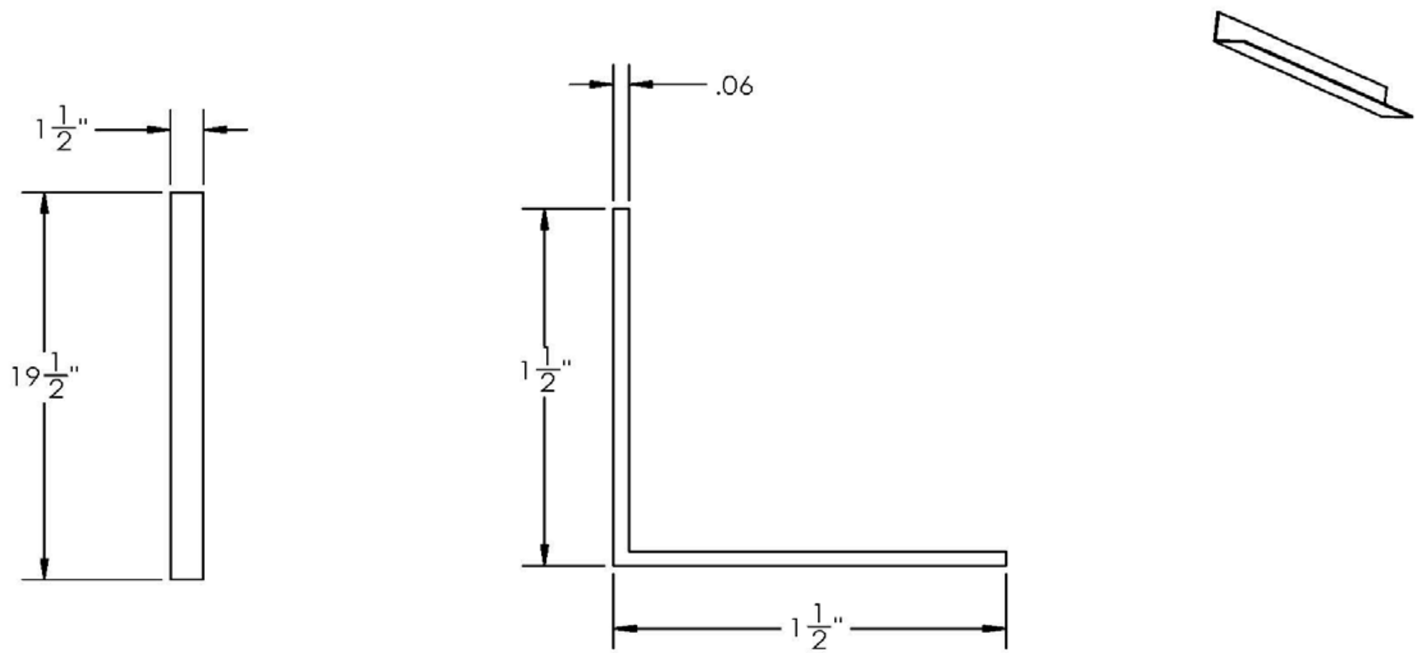
	NAME	DATE
DRAWN	MFW	3/20/2013
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Team Matador

TITLE: Combustion Chamber Side

SIZE	DWG. NO.	REV
A	C004	1
SCALE: 1:8	WEIGHT:	

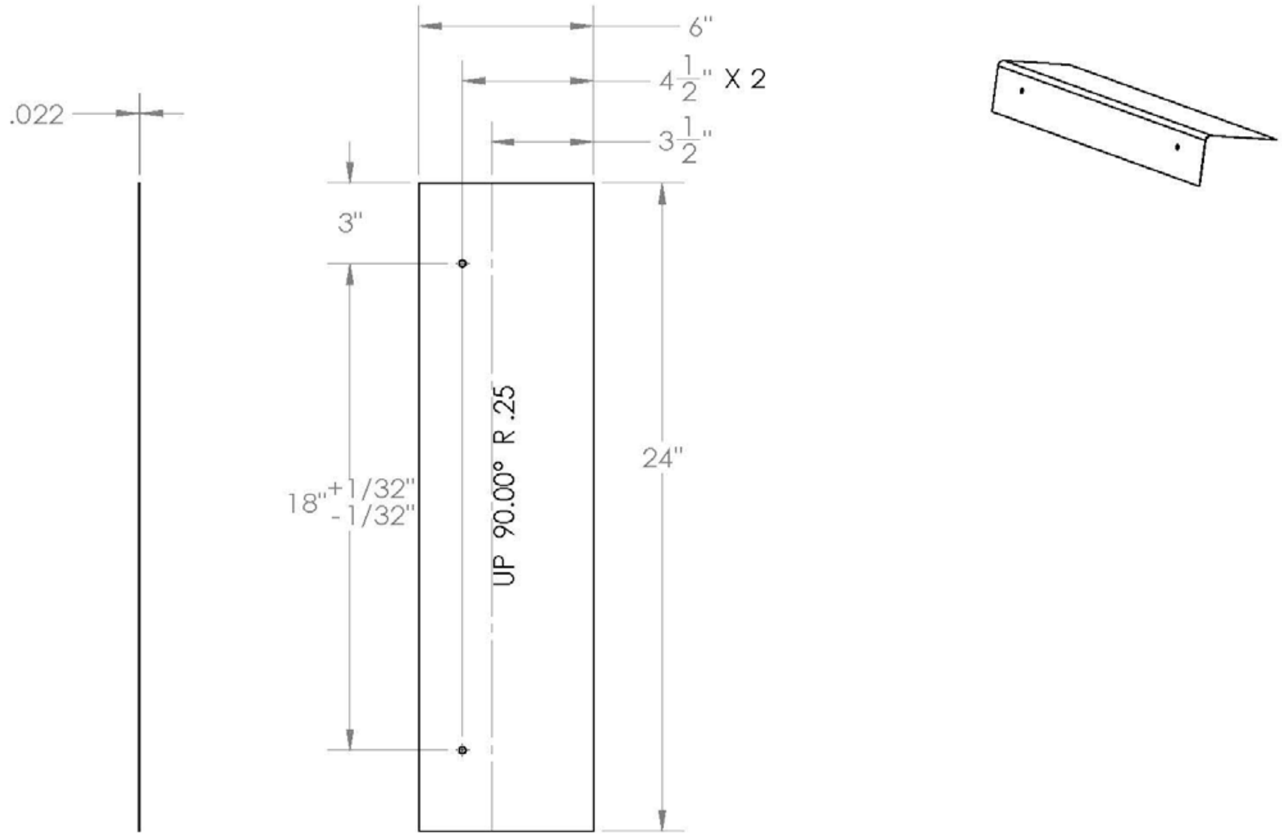
5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Team Matador	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± 1/16 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.001	DRAWN	MFW	3/20/2013	TITLE: Combustion Chamber Legs	
	CHECKED				
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL Steel	COMMENTS:			SIZE A DWG. NO. C005	REV 1
FINISH Zinc					
DO NOT SCALE DRAWING				SCALE: 1:8	WEIGHT:

NEXT ASSY	USED ON
APPLICATION	

5 4 3 2 1

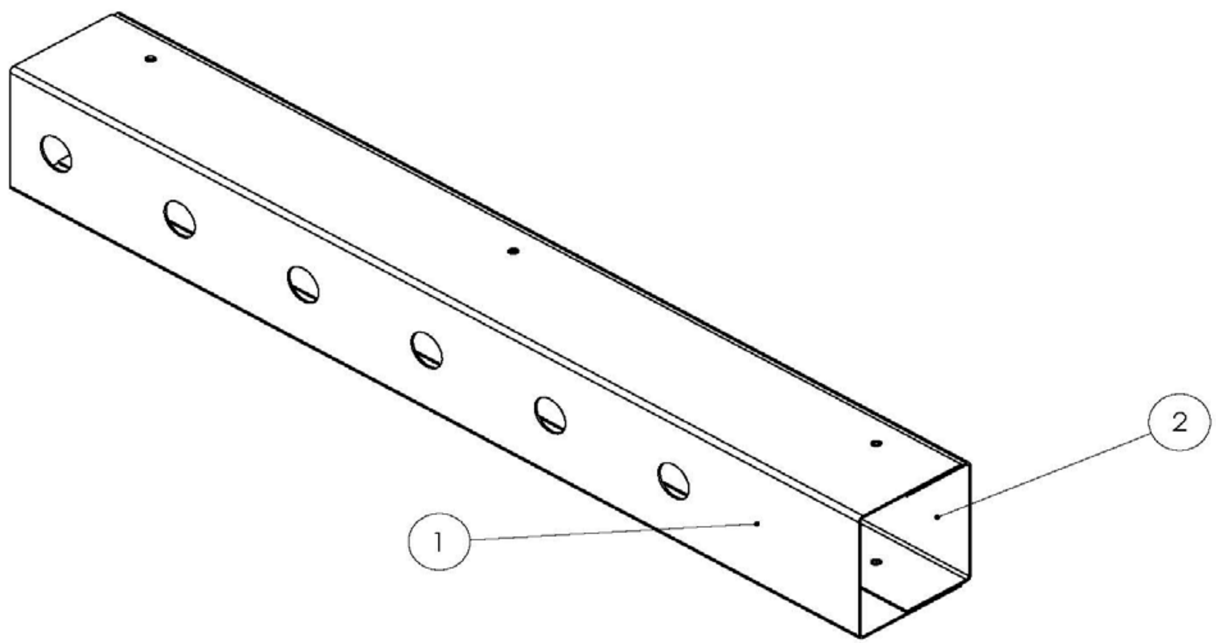


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Team Matador		
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± 1/16 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.001	DRAWN	MFW	3/20/2013	TITLE:		
	CHECKED			Duct Support		
	ENG APPR.					
	MFG APPR.					
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.					
MATERIAL Aluminum	COMMENTS:			SIZE A	DWG. NO. C006	REV 1
FINISH						
DO NOT SCALE DRAWING				SCALE: 1:8	WEIGHT:	

NEXT ASSY	USED ON
APPLICATION	

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	D001	Duct Outer Panel	1
2	D002	Duct Inner Panel	1



	NAME	DATE	
DRAWN	MFW	3/19/2013	
CHECKED			
ENG APPR.			
MFG APPR.			
Q.A.			
COMMENTS:			

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
DO NOT SCALE DRAWING

NEXT ASSY | USED ON
APPLICATION

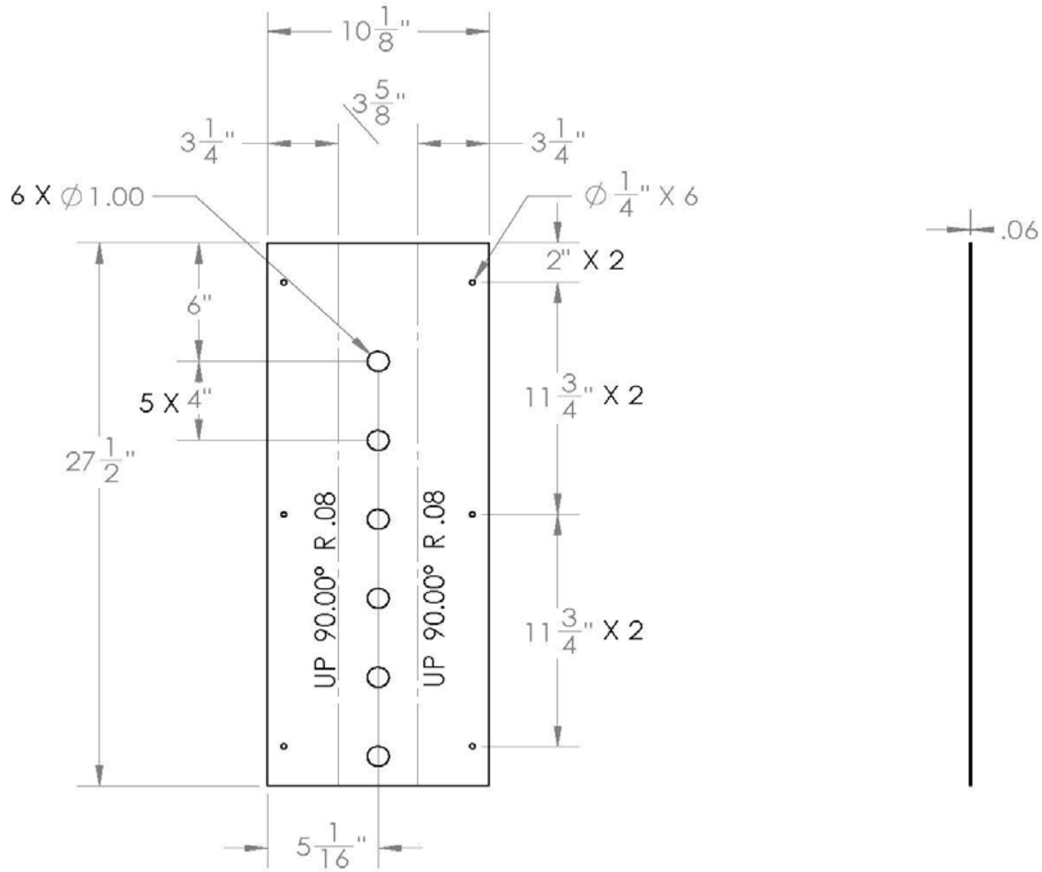
Team Matador

TITLE:
Duct Assembly

SIZE A | DWG. NO. DX1 | REV 1

SCALE: 1:8 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Team Matador	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± 1/16 TWO PLACE DECIMAL ±0.05 THREE PLACE DECIMAL ±0.005	DRAWN	MFW	3/19/2013	TITLE:	
	CHECKED			Duct Outer Panel	
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL Aluminum	COMMENTS:			SIZE A	DWG. NO. D001 / REV 1
FINISH					
DO NOT SCALE DRAWING				SCALE: 1:10	WEIGHT:

NEXT ASSY	USED ON
APPLICATION	

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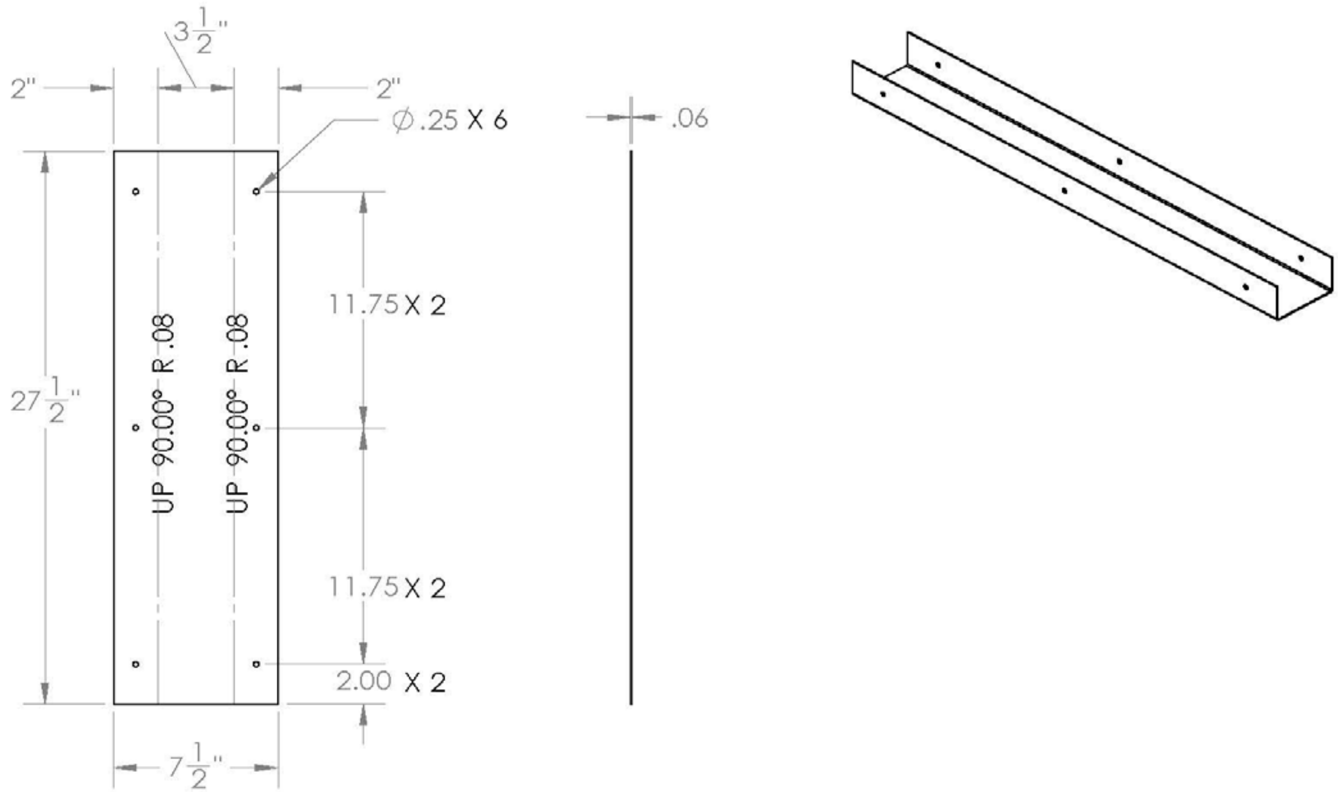
5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/32 TWO PLACE DECIMAL ±0.05 THREE PLACE DECIMAL ±0.005	DRAWN	MFW	3/19/2013
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL Aluminum	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

Team Matador

TITLE:

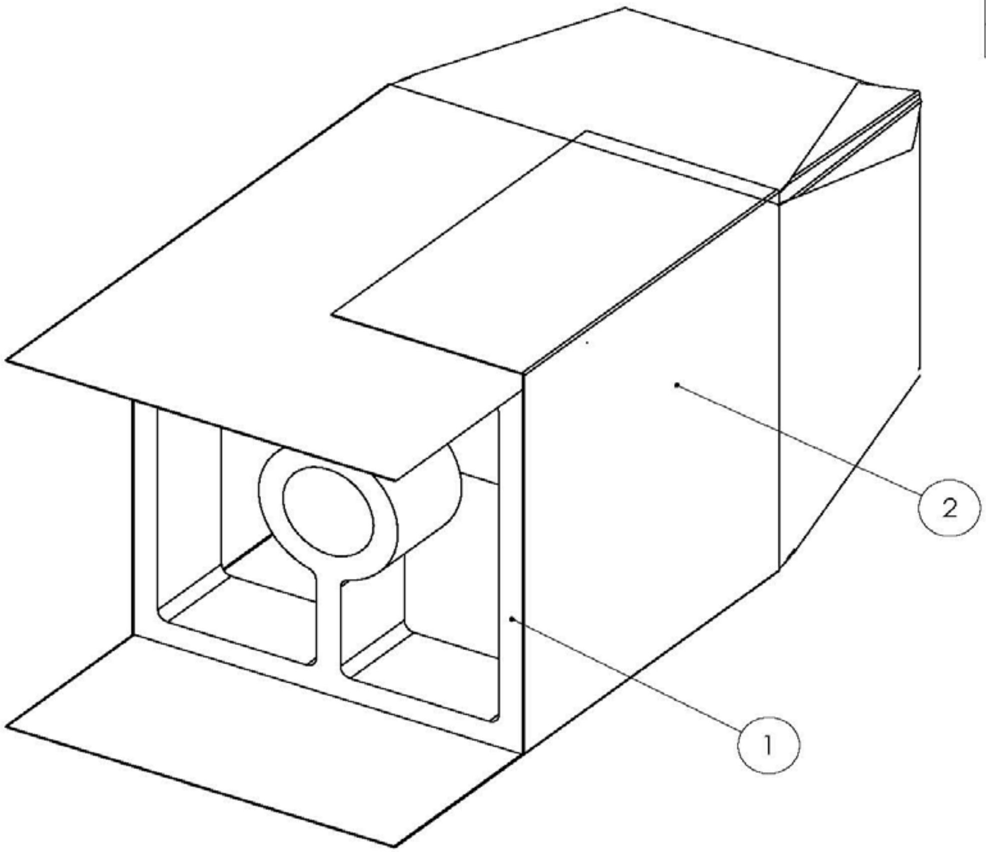
Duct Inner Panel

SIZE **A** | DWG. NO. D002 | REV 1

SCALE: 1:8 | WEIGHT:

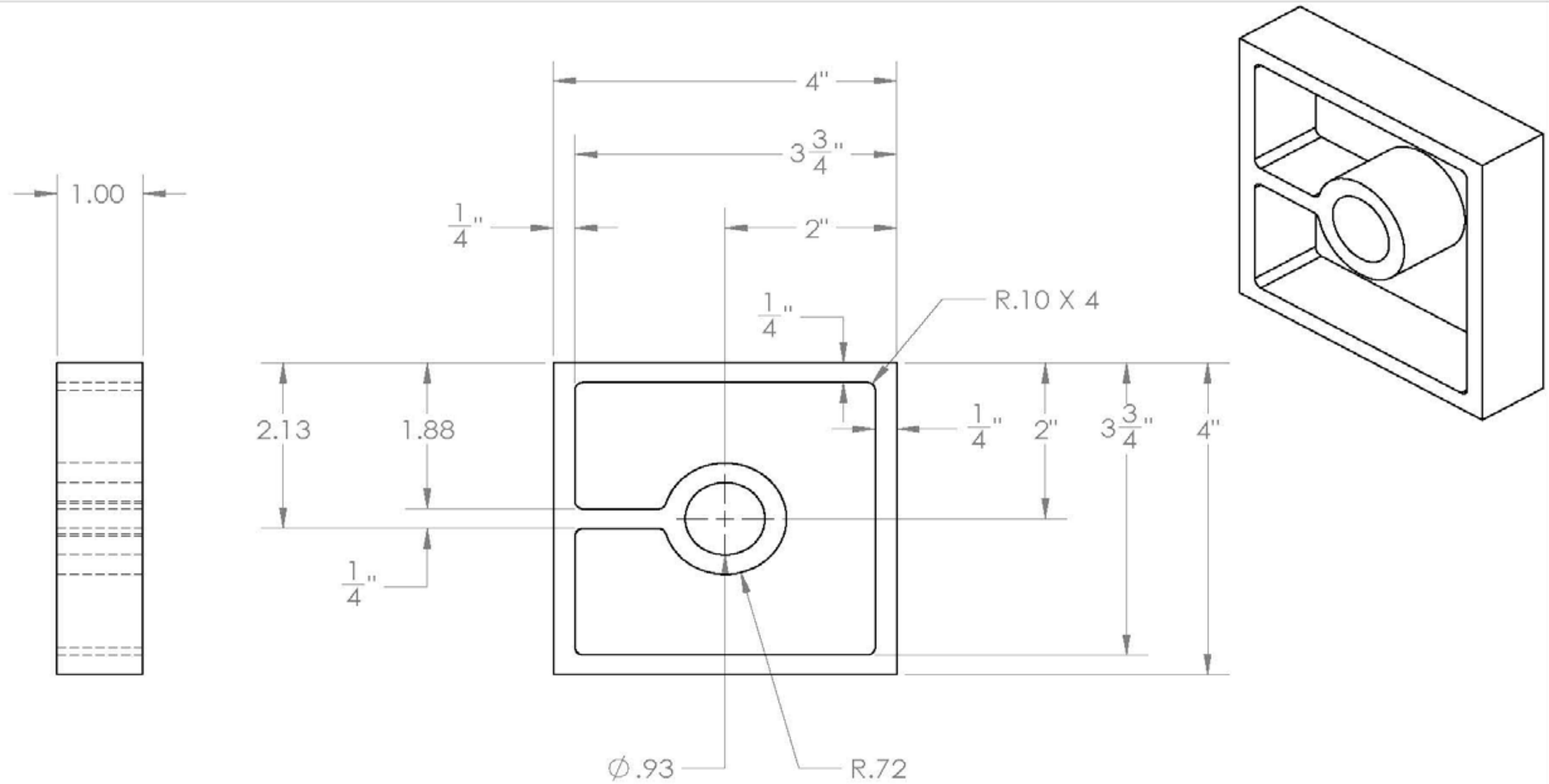
5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	F001	Fan Motor Mount	1
2	F004	Fan-Duct Interface	1



	UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Team Matador
	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	MML	3/20/2013	TITLE:
		CHECKED			Fan Assembly
		ENG APPR.			
		MFG APPR.			
	INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
	MATERIAL Aluminum	COMMENTS:			SIZE A · DWG. NO. FX1 · REV 1
NEXT ASSY · USED ON	FINISH				
APPLICATION	DO NOT SCALE DRAWING				SCALE: 1:8 · WEIGHT:

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Team Matador	
DIMENSIONS ARE IN INCHES TOLERANCES:	DRAWN	MFW	3/13/2013	TITLE:	
TWO PLACE DECIMAL ±0.005 THREE PLACE DECIMAL ±0.005	CHECKED			Fan Motor Mount	
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL Aluminum	COMMENTS:			SIZE A	DWG. NO. F001 · REV 1
FINISH					
DO NOT SCALE DRAWING				SCALE: 1:2 · WEIGHT:	SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

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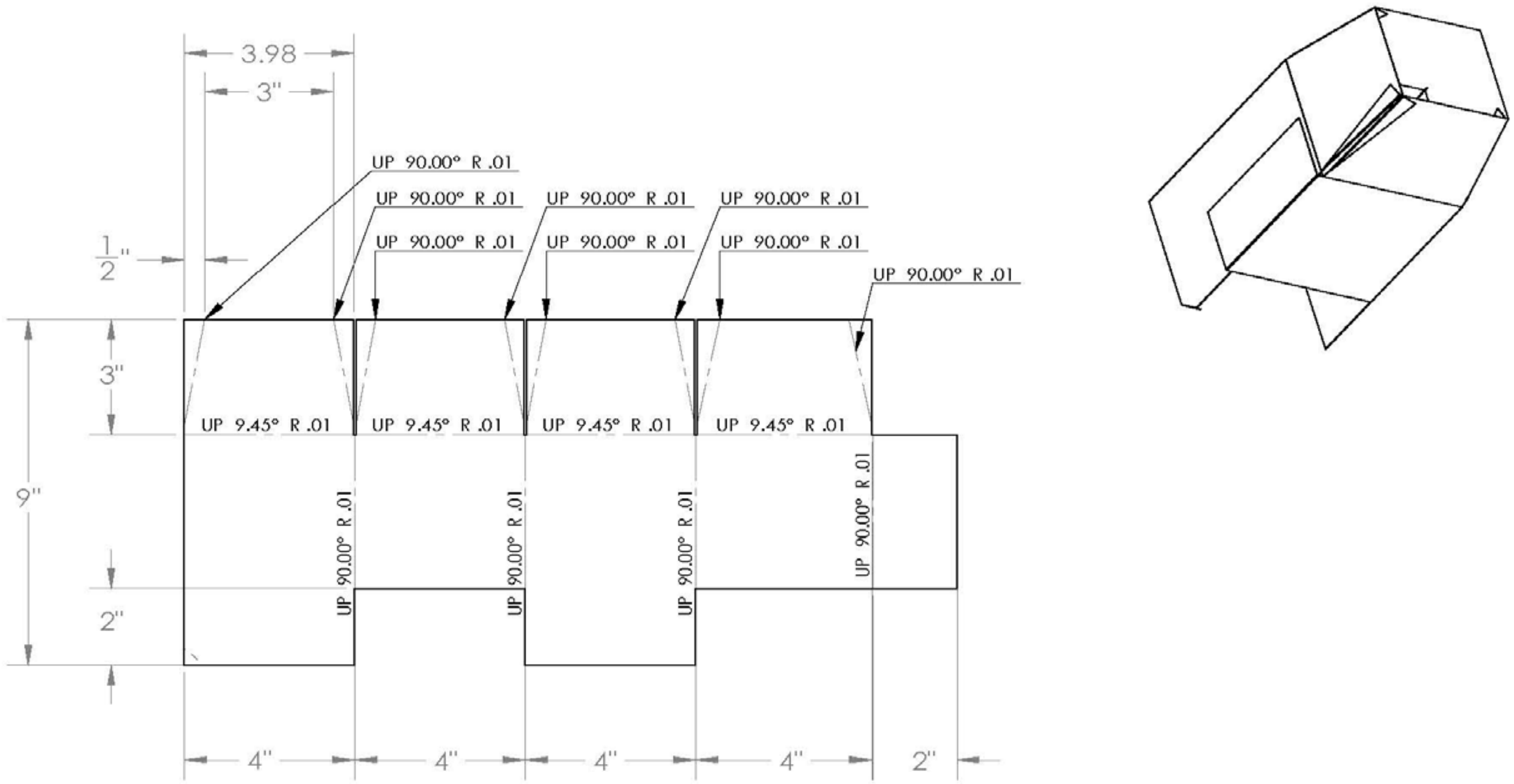
5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Team Matador
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± 1/16 ANGULAR: ± 1 degree TWO PLACE DECIMAL ±0.0625	DRAWN	MML	3/20/13	TITLE:
			CHECKED			Fan-Duct Interface
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL Aluminum	COMMENTS:			SIZE A | DWG. NO. F004 | REV 1
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:4 | WEIGHT:

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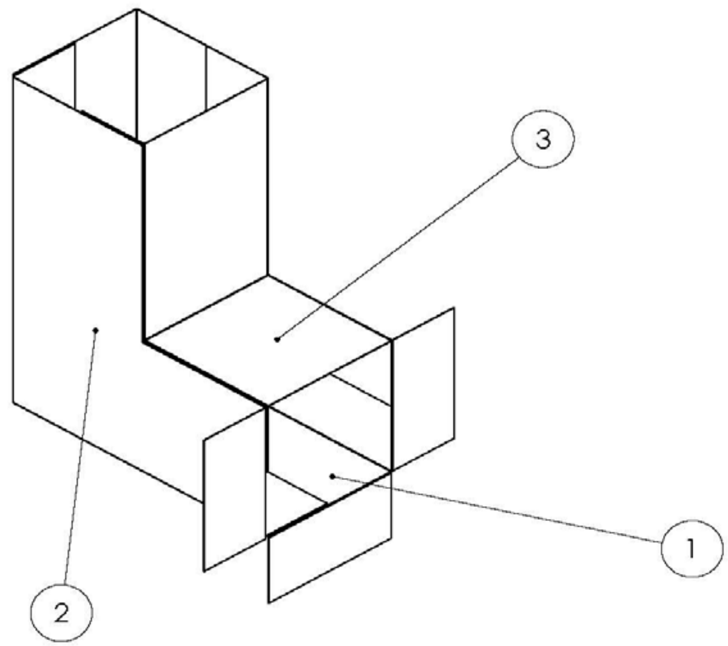
5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	V001	Vent Side 1	1
2	V002	Vent Side 2	1
3	V003	Vent Cover	1



	NAME	DATE
DRAWN	MFW	3/20/2013
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Aluminum

FINISH

NEXT ASSY | USED ON

APPLICATION

DO NOT SCALE DRAWING

PROPRIETARY AND CONFIDENTIAL

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Team Matador

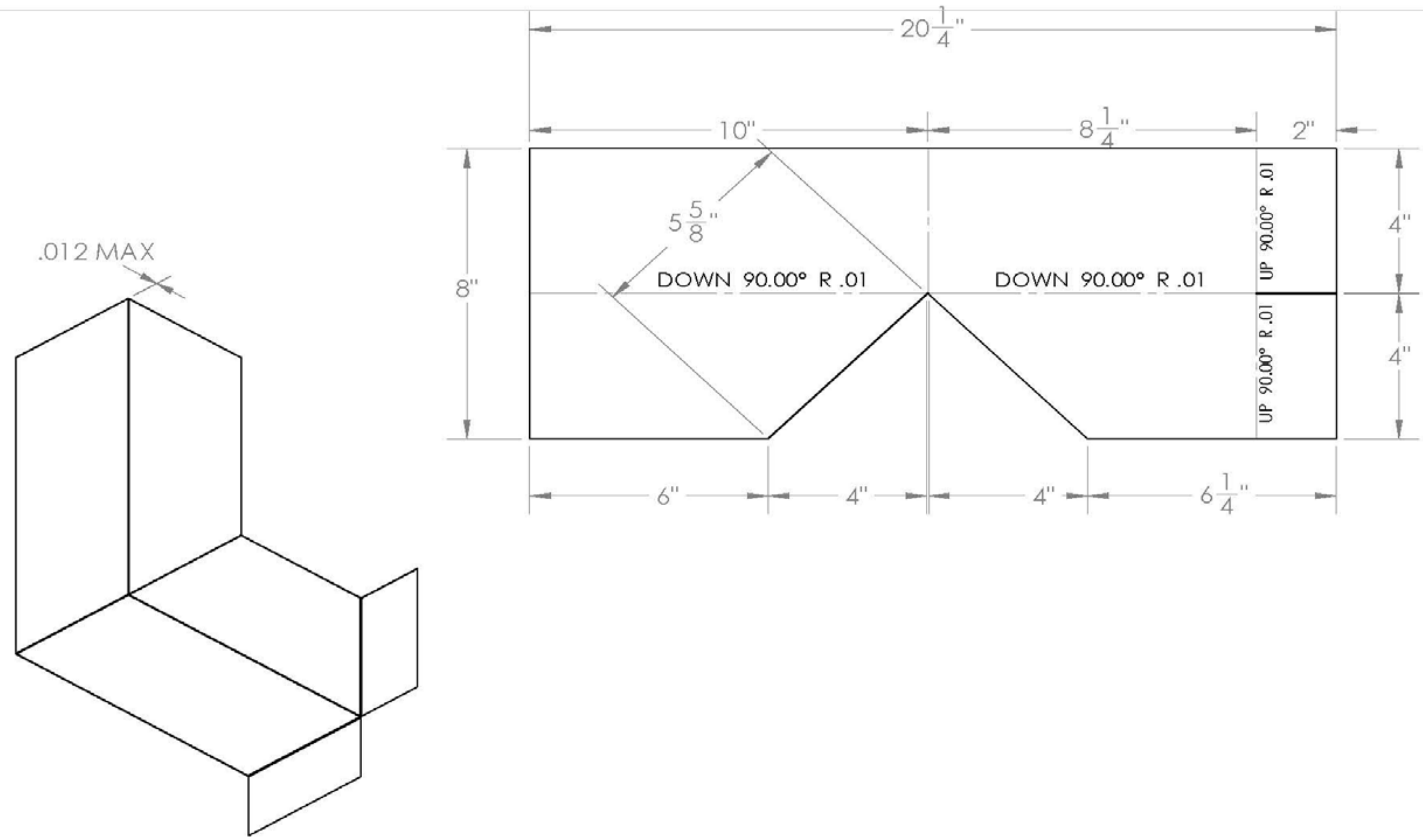
TITLE:

Vent Assembly

SIZE A | DWG. NO. VX1 | REV 1

SCALE: 1:8 | WEIGHT:

5 4 3 2 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/16
TWO PLACE DECIMAL ±0.05
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Aluminum

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MFW	3/6/2013
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Team Matador

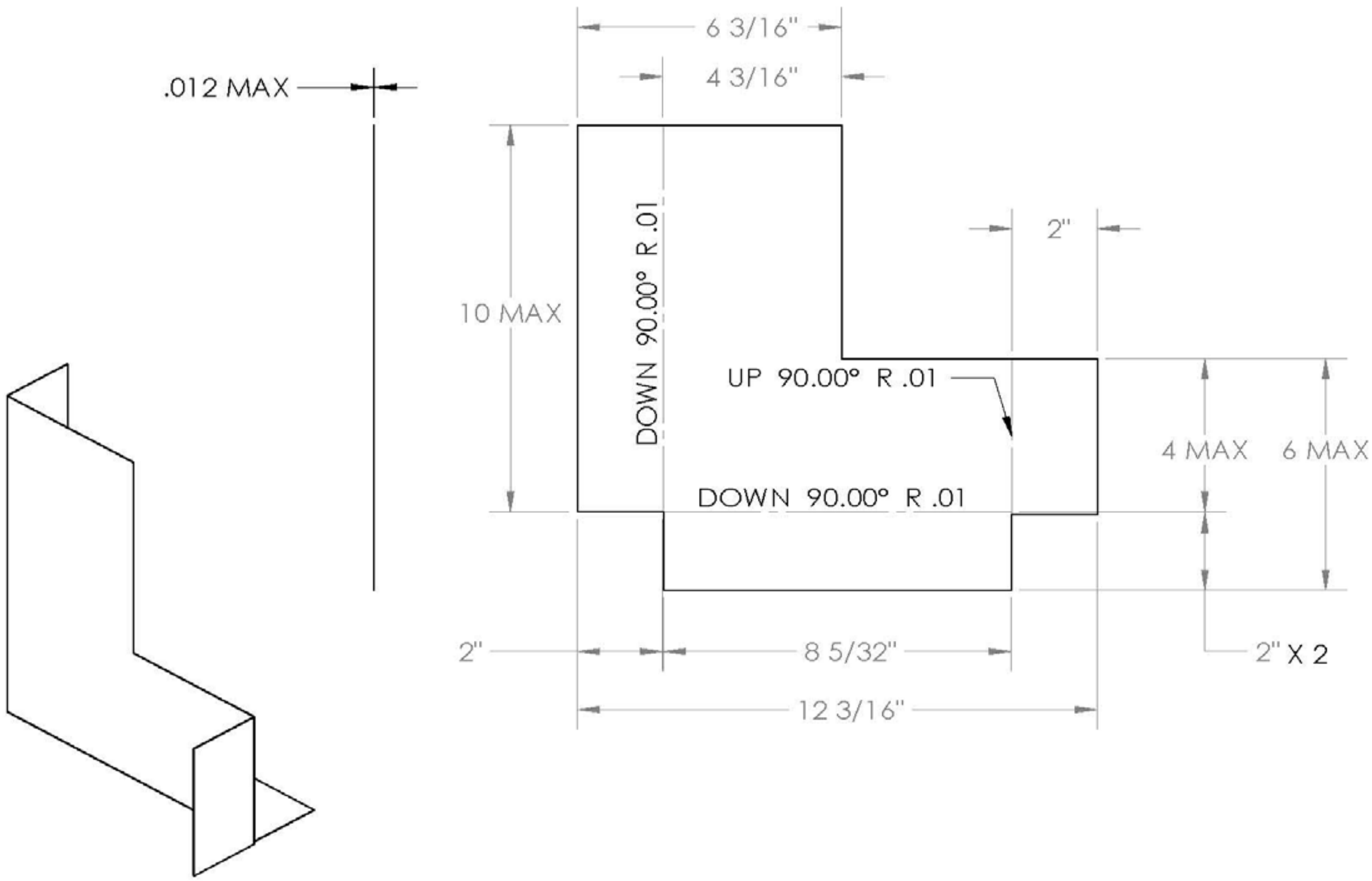
TITLE:

Vent Side 1

SIZE	DWG. NO.	REV
A	V001	1

SCALE: 1:4 WEIGHT:

5 4 3 2 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ± 0.05
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL Aluminum

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MFW	3/6/2013
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Team Matador

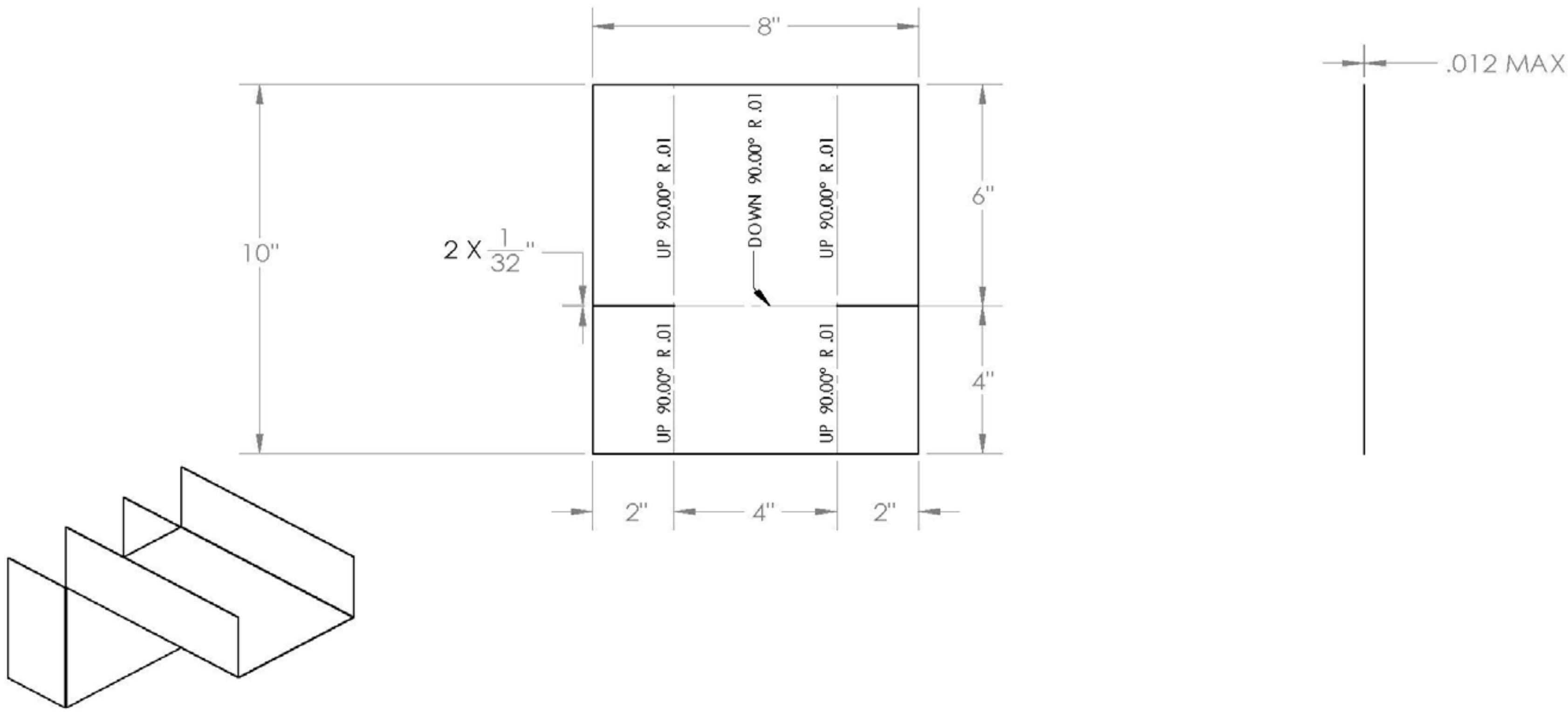
TITLE:

Vent Side 2

SIZE	DWG. NO.	REV
A	V002	1

SCALE: 1:4 WEIGHT:

5 4 3 2 1



Team Matador

TITLE: Vent Cover

	NAME	DATE
DRAWN	MFW	3/6/2013
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±1/32
TWO PLACE DECIMAL ± 0.05
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL Aluminum

FINISH

DO NOT SCALE DRAWING

NEXT ASSY | USED ON

APPLICATION

SIZE A | DWG. NO. V003 | REV 1

SCALE: 1:4 | WEIGHT:

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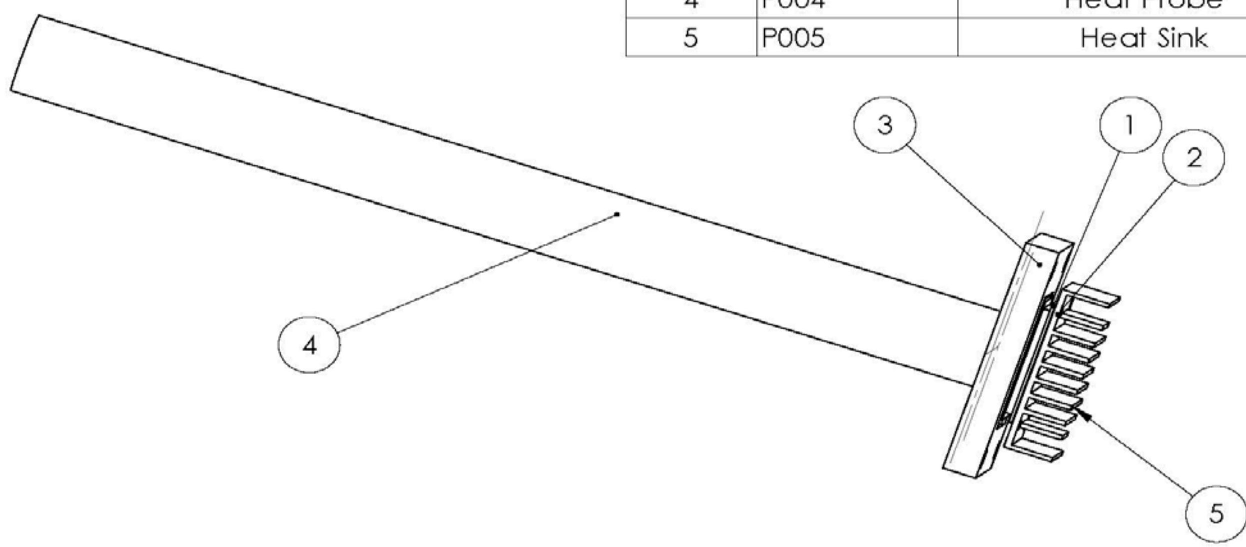
5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	P001	Thermoelectric Generator	1
2	P002	High Temperature Double Sided Tape	2
3	P003	TEG Mount	1
4	P004	Heat Probe	1
5	P005	Heat Sink	1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MFw	3/20/2013
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

NEXT ASSY | USED ON

APPLICATION

PROPRIETARY AND CONFIDENTIAL

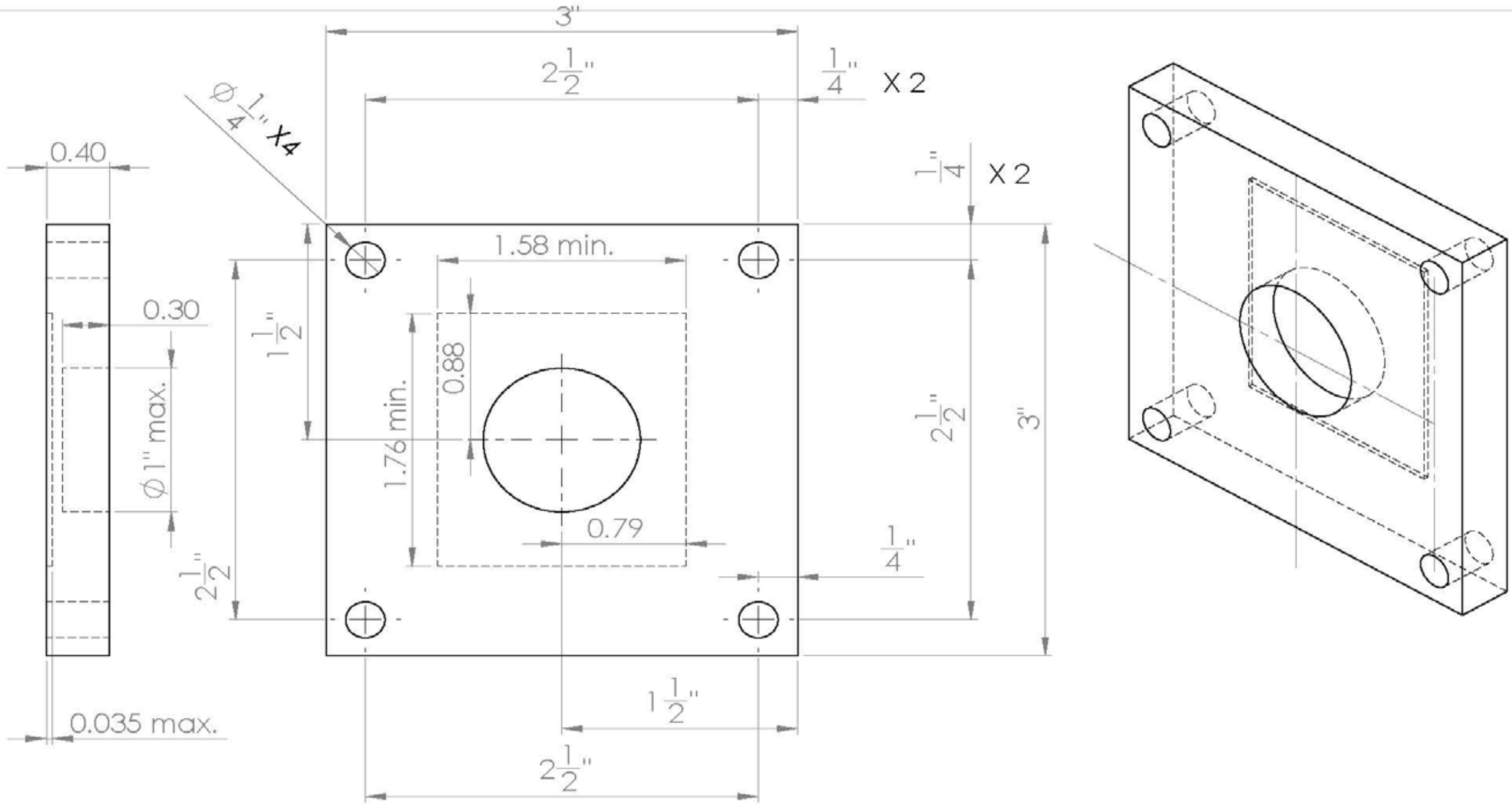
Team Matador

TITLE:
Power Generation Assembly

SIZE A | DWG. NO. PX1 | REV 1

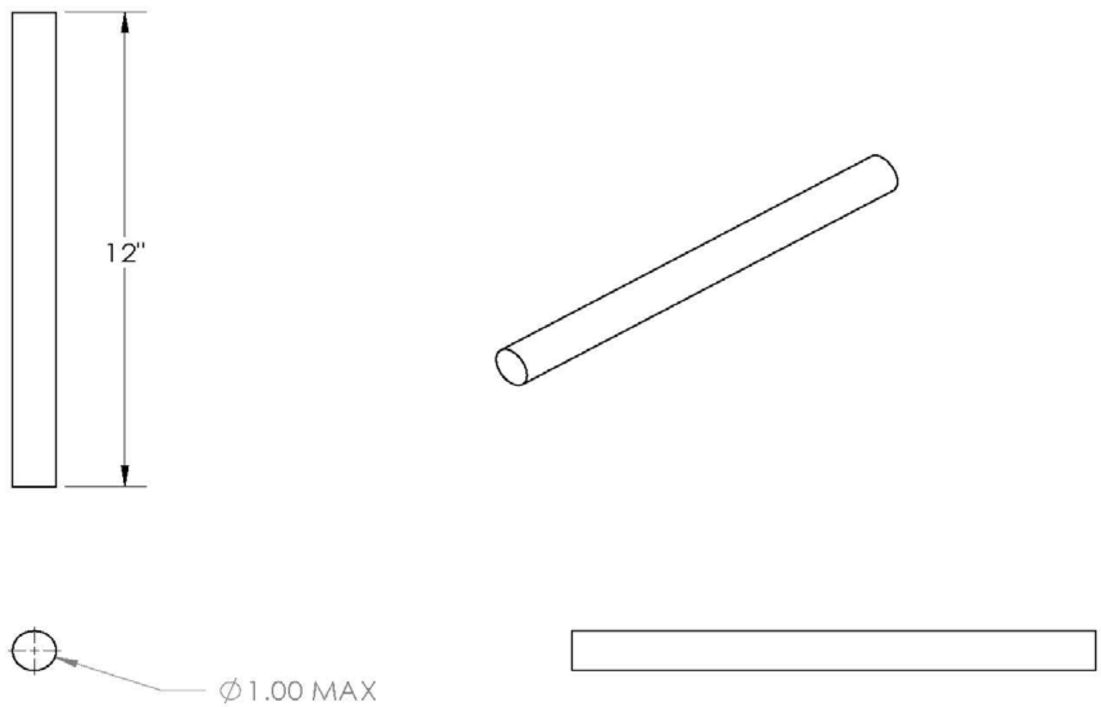
SCALE: 1:8 | WEIGHT:

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Team Matador
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± 1/16 ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ±0.01	DRAWN	MML	3/7/2013	TITLE:
			CHECKED			TEG Mount
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL Aluminum	COMMENTS:			SIZE A · DWG. NO. P003 · REV 2
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:1 · WEIGHT:

5 4 3 2 1



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NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/16
TWO PLACE DECIMAL ± 0.05
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Aluminum

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MFW	2/25/2013
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Team Matador

TITLE:

Heat Probe

SIZE A | DWG. NO. P004 | REV 1

SCALE: 1:4 | WEIGHT:

5 4 3 2 1