

Design of Bicycle Ambulances for Zambia

by

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B.S., Mechanical Engineering (2005)

Massachusetts Institute of Technology

Submitted to the Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Mechanical Engineering

at the

Massachusetts Institute of Technology

February 2008

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ABSTRACT

In developing countries, people are dying from treatable diseases because they cannot reach medical care when they need it most. Typical methods of transport, such as wheelbarrows or motorcycles, are too slow, dangerous, or expensive. The bicycle ambulance is a locally produced and maintained, fuel-less vehicle that provides safe, affordable transport. The design of this appropriate technology varies greatly between countries because of the variability in local conditions, such as terrain, cultural stigmas, and availability of materials.

This thesis describes the development of a bicycle ambulance (Zambulance) designed for Zambia. The Zambulance is a two-wheeled trailer that carries a sheet metal stretcher, and can be towed by common bicycles. The ambulance is fabricated from standard bicycle components and steel stock, such as 25mm round tube that can be easily bent to minimize cuts and welds. A single rider can transport one patient at average speeds of 25kph for distances up to 35km on passable B-grade roads. The trailer is 200cm by 98cm and weighs 22 kg, while the stretcher is 200cm by 65cm and weighs 20 kg. The Zambulance costs 1,200,000 Zambian Kwacha or about 315USD (based on exchange rate on December 27, 2007). One Zambulance can be fabricated in about 20 hours, which are usually spread over 5 days.

There are currently forty-seven Zambulances in Zambia, and more are being produced by Disacare Wheelchair Center in Lusaka, Zambia. From January 2006 to August 2007, one bicycle ambulance was used over 125 times to transport patients from their homes to the nearby clinic and hospice. According to records, the ambulance carried men and women between the ages of twelve and ninety who were suffering from various ailments including cholera, tuberculosis, HIV/AIDS, blindness, broken bones, anemia, and pneumonia.

A production manual, user manual, and assessment material is available online for free downloading at <http://cadlab6.mit.edu/bike.ambulance>. Long-term monitoring and evaluation of the design is needed, but current data suggests that the Zambulances are already saving lives by closing the transport gap between patients and healthcare.

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ACKNOWLEDGEMENTS

The bicycle ambulance project was made possible through the sponsorship and support of the following contributors:

- Massachusetts Institute of Technology (MIT) Public Service Centre (PSC)
- MIT Mechanical Engineering Department (ME Dept.)
- Professor Wallace of the ME Dept.
- University to University (U2U) program
- Ideas Smith fund
- Whirlwind Wheelchair International (WWI).

The executive board and staff of Disacare Wheelchair Center deserve special thanks and recognition for a wonderful collaboration and partnership in designing and producing the bicycle ambulance prototypes. The following people are particularly commendable:

- Kenny Mubuyaeta, Disacare production manager
- Evans Chinganguka, Disacare wheelchair technician

Disacare and I are very grateful to Design for Development for sharing their design and experience with producing bicycle ambulances in Malawi. For more information on the Design for Development (DfD) NGO and its bicycle ambulance, please e-mail info@designfordevelopment.org or visit <http://www.designfordevelopment.org>

The design and development of the Disacare's bicycle ambulance entailed Disacare's collaboration with the following engineers from abroad:

- Jessica Vechakul (MIT)
- Allen Armstrong (MIT)
- Jason Moore (UC Davis)
- Niki Dun (DfD)
- Christopher Howard (WWI)
- Kurt Kornbluth (MIT and WWI)
- Amy Smith (MIT)
- Aaron Wieler (BEN Namibia)

The author would also like to acknowledge and thank her father Quanchai and brother Jason for their support. Dan Good was especially helpful with his endless patience and proof-reading prowess.

ABBREVIATIONS

BEN	Bicycling Empowerment Network
CHAZ	Christian Hospital Association of Zambia
DfD	Design for Development
FABIO	First African Bicycle Information Office
HBC	Home-Based Care
ITDG	Intermediate Technology Development Group or Practical Action
NHC	Neighborhood Health Committee
WHO	World Health Organization
WWI	Whirlwind Wheelchairs International

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1. INTRODUCTION

1.1. Objectives

It is the goal of this thesis to design a bicycle ambulance for Zambia. The bicycle ambulance must be able to safely transport a patient in relative comfort from his or her home to a health center. It must be attachable to a common bicycle, and powered by a single cyclist. To be sustainable, the bicycle ambulance must be locally manufactured and maintained in Zambia with readily available materials, parts, and processes. To be successful, the bicycle ambulance must be versatile enough to serve patients of various ages and illnesses, affordable by local organizations, and culturally appropriate.

Table 1 summarizes the design specifications for the *Zambian bicycle ambulance or Zambulance*.

Table 1. Design specifications

1. Functional requirements	<ul style="list-style-type: none">• Transport one patient in relative comfort.• Attachable and detachable from common bicycles
2. Manufacture	<ul style="list-style-type: none">• Must be manufactured in a regional level workshop in Sub-Saharan Africa (SSA) using processes such as metal fabrication, welding, basic woodwork, and sewing. Avoid machining.
3. Materials	<ul style="list-style-type: none">• Use materials readily available in SSA - steel tube/rod/sheet/angle, wood, tarpaulin or canvas, rubber (from inner tubes/tires).• Pre-fabricated parts only if readily available in SSA and is inexpensive – mostly limited to bicycle components.
4. Maintenance	<ul style="list-style-type: none">• Similar to bicycle repair for intuitive and familiar maintenance• Materials must be resistant to weather to avoid deterioration.
5. Safety	<ul style="list-style-type: none">• Bicycle must be able to fall on the ground without disturbing the trailer.• Must be manoeuvrable on rough rural roads, particularly on corners and slopes and when braking.• Must be stable enough to remain upright during transit.
6. Comfort	<ul style="list-style-type: none">• Suspension or mattress to provide comfort.• Option for both an inclined and lying position to accommodate various medical needs.• Protection from road debris and weather.• Ability to hide the patient from outside view – sometimes required by pregnant women or patients with stigmatized diseases (AIDS)• The stretcher must be quickly and easily secured on the trailer with minimal disruption to the patient.
7. Dimensions	<ul style="list-style-type: none">• Wide enough to accommodate one patient, but narrow enough to avoid interference with traffic on roadsides.• Long enough to allow adults to lie flat on their backs.• Ground clearance is more than 10” or 25cm.
8. Distance	<ul style="list-style-type: none">• 0 – 30 km
9. Weight	<ul style="list-style-type: none">• Less than 45 kg or 100 lbs
10. Lifetime	<ul style="list-style-type: none">• At least 5 years
11. Cost	<ul style="list-style-type: none">• No more than \$500

1.2. Background of Transport as a Barrier to Healthcare

In Sub-Saharan Africa, the nearest health clinic or hospital may be several kilometers away. Yet, less than 1% of households in Africa have access to private motorized transportation. In rural areas, public motorized transportation is scarce or non-existent. Even in urban areas, stigma against illnesses like AIDS makes it difficult for the infirm to gain access to public transport. Road networks are also generally poor. Many places, especially in remote or rural areas, do not have roads suitable for vehicles [3]. As a result of remote location and poor transportation systems, much of the population of rural sub-Saharan Africa does not have adequate access to medical facilities.

In these areas, intermediate means of transport (IMTs) exist between the traditional mode of walking (with loads carried on the head, shoulder, or back) and modern conventional motor vehicles. IMTs are intermediate between traditional and modern transportation methods, in terms of investment cost, transport capacity (speed, payload and range of travel), infrastructure requirements, complexity of maintenance, and resources (skills, facilities, materials and investment) required for manufacture [7] (see Appendix A: Intermediate Means of Transport and Their Characteristics). Although IMTs are common and aid in the transport of goods, they are not suitable for medical transport. Wheelbarrows are slow and uncomfortable, and patients may be injured or even die before reaching the health center. Animal carts or sledges may be able to transport patients more quickly, but patients must usually pay a high transport fee because these IMTs are needed for economic activities.



Figure 1. Wheelbarrows, animal-drawn carts, and ox sledges are common IMTs.

Without any suitable means of transport, people are dying from treatable diseases because they cannot reach medical care when they need it most. Often, the only way to bring ill patients or pregnant women to a health center is to be carried on foot or propped upon a bicycle. “Stretcher groups” transport the sick or injured from village to clinic by carrying them on a stretcher over long distances, which are sometimes over 30km (See Figure 3) [3]. Bicycles alone do not offer a safe or comfortable means of transport for ill or pregnant patients. If a bicycle is available, but a patient is too weak to cycle, several people sometimes help to balance the patient on the bicycle and push the bicycle to the clinic (See Figure 2). In addition to being a slow and exhausting means of medical transport, the “stretcher group” and propping-on-bicycle methods sometimes requires groups of up to twelve people to assist in the transport of the patient [3]. If the journey from home to healthcare takes several days, patients do not even attempt the journey, allow conditions to worsen, and often die before they reach aid.



Figure 2. Patient propped upon a bicycle [3] Figure 3. “Stretcher group” in Uganda [3]

1.3. Motivation for Bicycle Ambulances

Bicycle ambulances have been a proven solution to this tragic problem in several developing areas, where current methods of transport are inappropriate in speed, safety, cost, or availability [1,5]. Bicycle ambulances are an appropriate technology that consists of a trailer, which carries a stretcher and can be towed by a bicycle. Bicycle ambulances empower caretakers to provide access to healthcare without relying on the government or foreign organizations for continuous support because bicycle ambulances do not require any fuel or electricity for operation. Bicycle ambulances are more sustainable than motorized vehicles, which are easily rendered inoperable due to lack of fuel, replacement parts, or local knowledge about maintenance or repair. Local ambulance production can also stimulate the economy and ensure that all parts and processes required for maintenance and operation will be readily available.

In 2005, First Lady Maureen Mwanawasa of Zambia publicly recognized the need for bicycle ambulances in her country. There were no bicycle ambulances currently being produced in Zambia. Although there were bicycle ambulances in other countries, the designs were not available and they were not being exported. Moreover, bicycle ambulances should be designed especially for the country in which it is to be used because its success is highly dependent upon its suitability for specific local conditions, such as terrain, cultural stigmas, weather conditions, needs of patients, and availability of materials and manufacturing processes. Thus, there was a need for a bicycle ambulance design that would meet the specific needs of communities in Zambia, as well as a need for local manufacturer to produce it. Disacare Wheelchair Center in the capital city of Lusaka decided to tackle the challenge of providing cheap, locally manufactured and maintained bicycle ambulances.

Disacare was founded in 1991 and worked closely with several international organizations, such as Whirlwind Wheel Chairs International (WWI) to locally produce wheelchairs and mobility aids that would be suitable for the conditions and terrain of a developing country. Disacare has grown and developed through the years, and has the capacity to produce up to twenty wheelchairs a month in addition to providing other metal fabrication, landscaping, carpentry, and tailoring services. Disacare’s diverse and broad set of skills fortuitously meets the requirements for developing bicycle ambulances. Income from producing bicycle ambulances is also intended to help Disacare achieve financial sustainability.

1.4. Final Design

The Gamma version of the Zambulance was developed in September 2006, and is currently being produced in Zambia by Disacare Wheelchair Center in Lusaka. The Gamma consists of a two-wheeled trailer that carries a removable sheet metal stretcher and can be towed by a common 28" wheel diameter road bicycle. With a single rider, and one patient being transported by a single rider at average speeds of 25kph or 15mph for distances up to 26km on decent roads. The stretcher including the mattress weighs approximately 20 kg, and the trailer with wheels weighs approximately 22 kg. The standard bicycle weighs about 16 kg. The overall dimensions of the trailer are 200cm by 98cm, and the overall dimensions of the stretcher are 200cm by 65cm.



Figure 4. Gamma Zambulance attached to a bicycle.

The ambulance is made from standard bicycle components and steel stock, such as 25mm round tube that can be bent in a Hossfeld bender [6] to minimize cuts and welds. In order to standardize production, all the 25mm tubing Hossfeld bender and welded together on a fixture, which would hold all the parts in the proper orientation.

The features of the Gamma Zambulance are summarized below.

1.4.1. Stretcher

The stretcher is 200cm by 65cm, and the rectangular frame is made from a 25mm OD round steel tube. Although the bed of ambulances from other countries are usually made from fabric, the bed of the stretcher is made from two pieces of 0.6mm thick steel sheet metal that are brazed or MIG welded to the frame (see Figure 5). The sheet metal is more durable than fabric, and is half the price of the imported PVC-reinforced tarpaulin that was the only non-metal alternative of comparable durability.

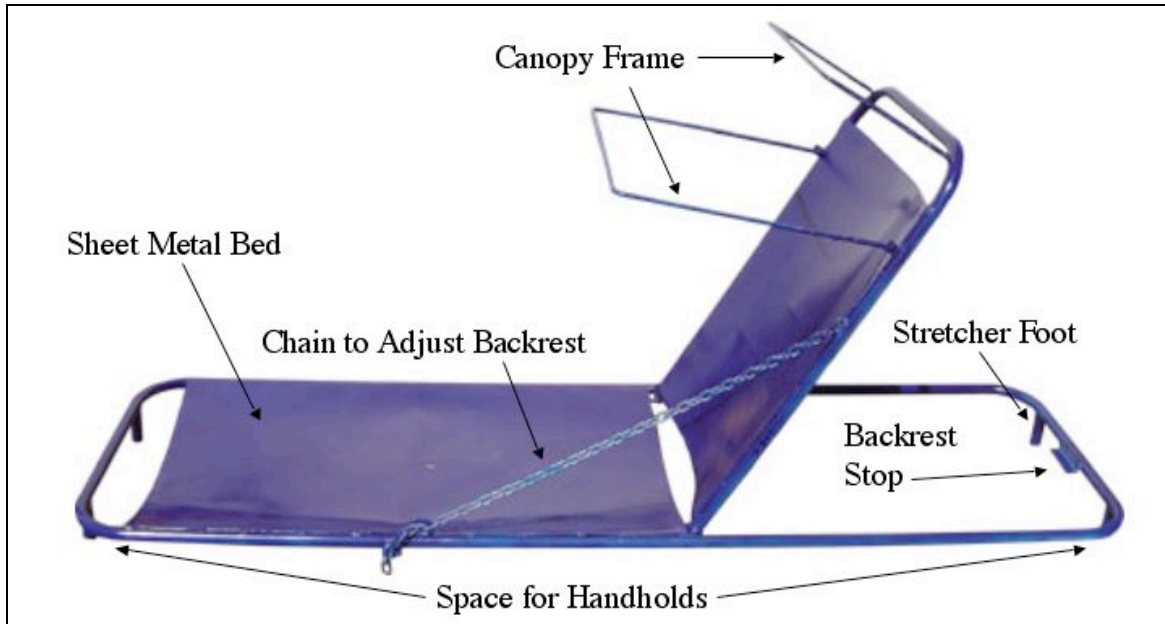


Figure 5. Gamma stretcher with main features labeled

A 2” foam mattress with a water-resistant rexine (PVC-coated cotton fabric) cover is made especially for the stretcher, and makes the journey more comfortable for the patient. Four short tubes serve as feet and elevate the stretcher off of the ground for easier lifting and to protect the mattress from abrasion. Rather than welding on separate handles, the sheet metal is cut to provide room for users to lift the stretcher from the corners of the frame. A canopy frame made out of Y8 (8mm diameter) rebar is attached to the stretcher’s backrest to allow waterproof canvas to be strapped on as rain and sun protection for the patient.

Patients with different ailments require different sitting positions. Similar to the DfD design, pivots made from concentric tubes connect the backrest to the stretcher frame, and allows the backrest to be inclined. Since it is unlikely that two chains (one on each side of the stretcher) would be under equal load at any given time, a single stronger chain was used instead of the pair of weaker chains. A 5mm chain is welded to the backrest, and is secured by a tube welded on the stretcher frame. The angle of the backrest can be adjusted to different positions by changing the apparent length of the chain.

1.4.2. Trailer

The trailer is about 200cm by 98cm at its biggest dimensions (See Appendix F: Production Manual for specific dimensions). It is made mostly from 25mm OD round steel tube. Since it is much easier to design a welding fixture for a planar two-dimensional part, the Gamma trailer was designed to be a completely flat trailer body (see Figure 6 for labeled components). This change eliminated the need for three-dimensional bends. Since the stretcher bed is made from sheet metal rather than canvas, the ribs or reinforcement tubes can also be in the plane of the trailer. The tow bar is made from two pieces of 25mm square tubing rather than round tubing because they are easier to stack. Dropouts, made out of pieces of angle iron are welded to the bottom of the wheel surrounds to hold the trailer wheels. Semi-circular fenders made from 19mm OD round tubing, and sheet metal mudguards are the only features that are not in the plane of the

trailer. They protect the patient from debris coming off the trailer wheels. A handle made out of rebar was attached to the boom to provide a means for easy steering of the trailer when the bicycle is not attached. Disacare has chosen not to produce Zambulances with this handle.

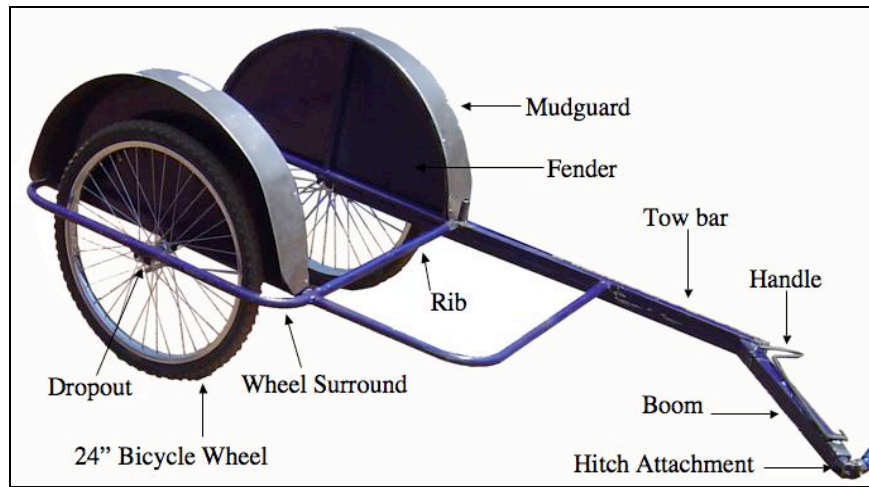


Figure 6. Gamma trailer with parts labeled

1.4.3. Bicycle Clamp and Hitch

The original seat-and-chain-stay clamp and nut-and-bolt hitch were designed by Allen Armstrong, and are shown in Figure 7. The clamp can be attached to the chain stay and seat stay of common bicycles and consists of angle iron, flat bar, nuts, and bolts. The nut-and-bolt hitch is a universal joint that is made from M16 nuts and bolts, and allows for three axes of rotation. Field assessments revealed that users sometimes attached the hitch to the clamp incorrectly since there were two possible orientations. The clamp and hitch were redesigned, as shown in Figure 8, so that the hitch could only be assembled in the proper orientation and could not be accidentally disassembled. Please refer to section 3.4.3 on page 53 for a more thorough description of the redesigned hitch.

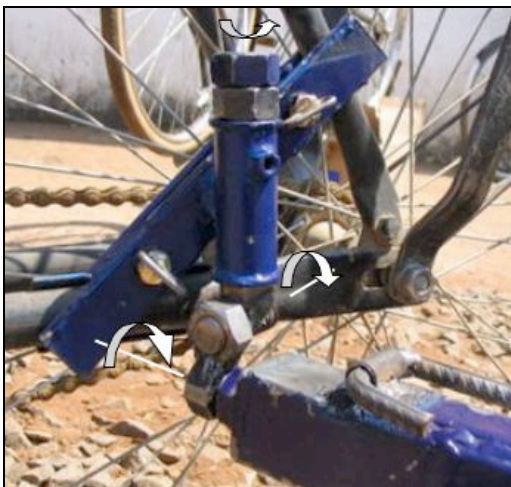


Figure 7. Nut and bolt hitch rotation

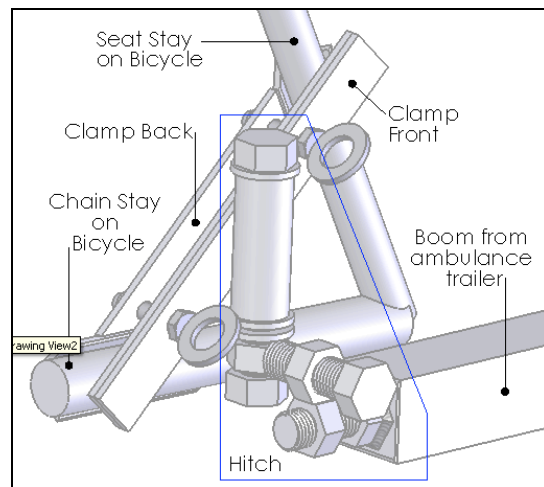


Figure 8. New Gamma hitch design in CAD

1.4.4. Welding Fixture

After standardizing the bends on the Hossfeld tube bender, a welding fixture was developed to hold all of the components of the main trailer frame in the correct orientation for welding (see Figure 10). The other side of the welding fixture could also be used for welding orienting and welding feet onto the stretcher. The welding fixture is made from 25mm square tubing (see Figure 9). The trailer components can be tied against perpendicular posts with metal wire so each component is constrained by point contacts rather than line contacts. Thumbscrews were also considered but the Disacare technicians claimed that the threads would wear out quickly, making the fixture unusable.



Figure 9. Welding fixture alone



Figure 10. Welded trailer on fixture

1.5. Project Overview

Since July 2005, I have been collaborating with Disacare on the development of bicycle ambulances, or Zambulances, for Zambia. I have visited Zambia five times for a total of about eight months to discuss the transport barrier with stakeholders, design and build prototypes, gather feedback from users, and develop a fixture to facilitate fabrication.

While researching prior art, existing designs, such as those promoted by Design for Development (DfD), Intermediate Technology Development Group (ITDG), and Oxfam, were analyzed to determine the strengths that could be emulated and areas for potential improvements. The DfD design was the foundation for the Zambulance. Niki Dun, the designer of the DfD ambulance, provided advice and a production manual which enabled Disacare and I to start with a proven design that we could modify to better suit the resources and needs specific to Zambia.

To gain a better understanding of the priorities and needs of stakeholders, I spoke to health officials at the Mpanshya Mission Hospital, the Chilanga Mother of Mercy Hospice, and Mt. Makulu Clinic. I also spoke to potential donors, and neighborhood health committee (NHC) and home-based care (HBC) volunteers who take care of HIV/AIDS patients in Chilanga, a peri-urban area of Zambia.

Based on the design specifications determined by discussions with Disacare and other stakeholders, three different generations of Zambulances (Alpha, Beta, and Gamma) were designed and prototyped between July 2005 and August 2007. The Alpha was developed in August 2005, the Beta in September 2005, and the Gamma in September 2006. Various engineers from MIT, Whirlwind Wheelchair International (WWI), Design for Development (DfD), and UC Davis have also provided technical advice regarding the design of the Zambulance.

Simple hand tools, welding and brazing equipment were used in the fabrication of the Zambulances. The earlier prototypes were field-tested, and the feedback was used to generate the final Gamma design. Cost and availability of materials and fabrication techniques, as well as ease of operation were some of the selection criteria for determining the best design.

In order to standardize production, the Gamma was designed to be made with a Hossfeld bender [6] and welded together on a fixture, which would hold all the parts in the proper orientation and ensure consistency in quality and enhanced production speed. Disacare has been using the bender and welding fixtures to produce ambulances, and claims that both have been working well.

The first trial test of the Beta began in December 2005 in Linda Compound of Chilanga, a peri-urban area of Lusaka. The first assessment was conducted in January 2006 after one month of use. The Linda compound ambulance was assessed again in August 2006 as well as August 2007. Feedback from the Beta assessments was used to design and refine the Gamma Zambulance. The Gamma Zambulance began being mass-produced in April 2007, and both production and performance in the field was assessed in August 2006 and 2007.

From January 2006 to August 2007, one bicycle ambulance was used over 125 times to transport patients from their homes to the nearby clinic and hospice. According to records, the ambulance carried men and women between the ages of 12 and 90 who were suffering from various ailments including diarrhea, cholera, tuberculosis, HIV/AIDS, blindness, broken bones, anemia, and pneumonia. The versatility of the Zambulance is demonstrated by the diversity of patients it can serve.

In December 2005 and then March 2006, an independent benefactor donated two Beta Zambulances for health centers in Chilanga, a peri-urban area of Lusaka. The Zambulances have received considerable publicity with two appearances on television, an article by the Zambian newspaper *The Post*, and a promotional movie based on the conditions in Chilanga where the two Betas are being used. In January 2007, twenty-three Gamma Zambulances were donated by the WHO and distributed by the Zambia Ministry of Health. In February 2007, the Zambian Ministry of Health also ordered eighteen ambulances and distributed them to district health centers all over Zambia. In April 2007, Africare donated four Gamma Zambulances to a rural area called Chikupi in the Kafue District just outside of Lusaka. As of August 2007, Disacare was in the process of producing eighteen Gammas that had been ordered by the Zambian Ministry of Health.

To aid in the dissemination of the design, a production manual, complete with instructions and engineering drawings, has been developed along with a user manual pictorially detailing maintenance instructions. These materials are available for free downloading at <http://cadlab6.mit.edu/bike.ambulance>. Disacare may also serve as a training center where manufacturers from other countries can learn to produce their own bicycle ambulances. In September 2007, Aaron Wieler began production of a bicycle ambulance (based on the Zambulance design) for the Bicycle Empowerment Network (BEN) in Namibia.

1.6. Outline of Thesis

In collaboration with Disacare, I designed three generations (Alpha, Beta, and Gamma) of bicycle ambulances, or Zambulances, for Zambia.

The project involved the following five phases:

- (1) background research including prior art and stakeholder analysis,
- (2) design and testing of prototypes with modifications based on user feedback,
- (3) the development of equipment and mechanisms for standardized production,
- (4) the assessment of ambulance performance, and
- (5) the dissemination of ambulance documentation, using production and user manuals.

What follows is an outline of what is discussed in this thesis. Chapter 2 provides an overview of prior art in bicycle ambulances. Chapter 3 contains a discussion of the three generations of prototypes designed for Zambia, as well as, detailed explanations of the evolution of the stretcher, trailer body, clamp, and hitch. Chapter 4 discusses the applications for which the bicycle ambulance is suitable. Chapter 5 discusses some findings of preliminary assessment of the Beta and Gamma Zambulances. Chapter 6 provides suggestions for future research, and Chapter 7 concludes.

2. PRIOR ART

Before designing an ambulance specifically for Zambia, various existing ambulance designs were evaluated to determine which would be a good foundation for the development of the Zambulance. The prior art sections briefly describe the Design for Development (DfD), Intermediate Technology Development Group (ITDG), and Oxfam ambulances, which are representative of different classes of bicycle ambulance design. After discussing the advantages and disadvantages of each, the Design for Development (DfD) ambulance designed by Niki Dunn, was chosen to be the foundation for the Zambulances.

Design for Development

Niki Dun developed the Design for Development (DfD) ambulance (see Figure 11 and Figure 12) and produced 20 ambulances in Malawi as part of a pilot project with Transaid in 2003 [2]. The DfD design was chosen to be the foundation for the Zambulance designs. The Zambulances emulated the DfD ambulance's removable stretcher with a reclining backrest and the two-wheeled trailer with a low center of gravity. The clearance between the ground and the lowest point on the trailer is 10" or about 25cm, which is adequate to accommodate rocks and ditches in the road. The DfD ambulance and Zambulance are both made from 25mm OD round steel tube with a bender to minimize the number of necessary cuts and welds.

However, there are also distinct differences between the DfD ambulance and the Zambulance. The DfD stretcher bed is a canvas material that is attached to the stretcher frame by straps made from bicycle inner tubes and sewn to the perimeter of the canvas. The DfD trailer has several reinforcement tubes and metal mesh to protect the patient from debris. The DfD hitch attaches to the seat stays of the bicycle and utilizes a car trailer ball joint. There is no mudguard or canopy on the DfD ambulance.

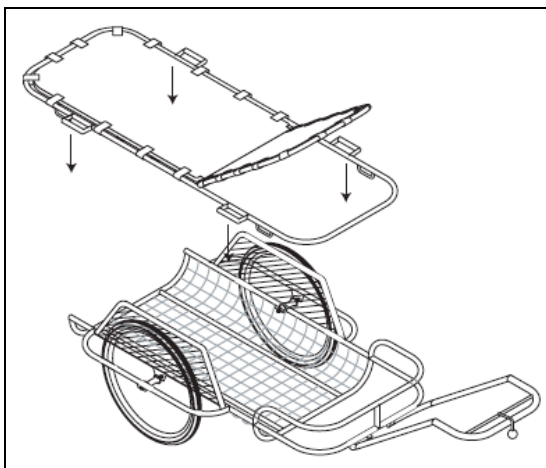


Figure 11. DfD design [2]



Figure 12. DfD ambulance in Malawi

Practical Action or ITDG:

The ITDG ambulance is currently being used in rural Nepal. The bottom of the ambulance appears to be made out of either sheet metal or wood, and can be padded with cushions to make the patient more comfortable (see Figure 13).



Figure 13. ITDG ambulance in Nepal [1] Figure 14. ITDG trailer in Nepal [1]

The ambulance is meant to seat a caretaker along with the patient. Although it is useful to have a caretaker on board, it makes it more difficult for the cyclist to pedal and the journey may take longer. Usually the caretaker is a family member who is not medically trained so there is a limit to how much medical care a patient can receive during transport. The ITDG trailer (see Figure 14) appears to be too short for a patient to lie completely horizontally, but sitting up may be uncomfortable for some patients. The trailer also seems to be wide enough to seat two people side-by-side. However, wider trailers face a greater risk of either interfering with vehicular traffic or not being able to maneuver along narrow trails and paths in rural areas.

Oxfam:

The Oxfam ambulance consists of a thin flat bed that appears to be about 55cm to 65cm (about 22” to 26”) from the ground (see Figure 15). The elevation of the bed is convenient in hospital settings so medical personnel do not have to stoop to treat patients. However, the high center of gravity of the patient on a moving ambulance makes it less stable, and patients can fall off or be injured if the ambulance tips over. High-bed ambulances are more likely to tip over when the attached bicycle tips over because the hitch cannot accommodate such a large range of motion without disturbing the ambulance.



Figure 15. Oxfam ambulance

Disacare High-Bed Ambulance:

When Disacare started their bicycle ambulance project, they had limited access to researching resources. A picture of the Oxfam ambulance, downloaded from the Internet, was the only information Disacare had about the prior art on bicycle ambulances. In June 2005, Disacare fabricated a high-bed ambulance (see Figure 16a) based on the picture. Although it looked similar to the Oxfam ambulance, it did not function well and had several areas of weakness.

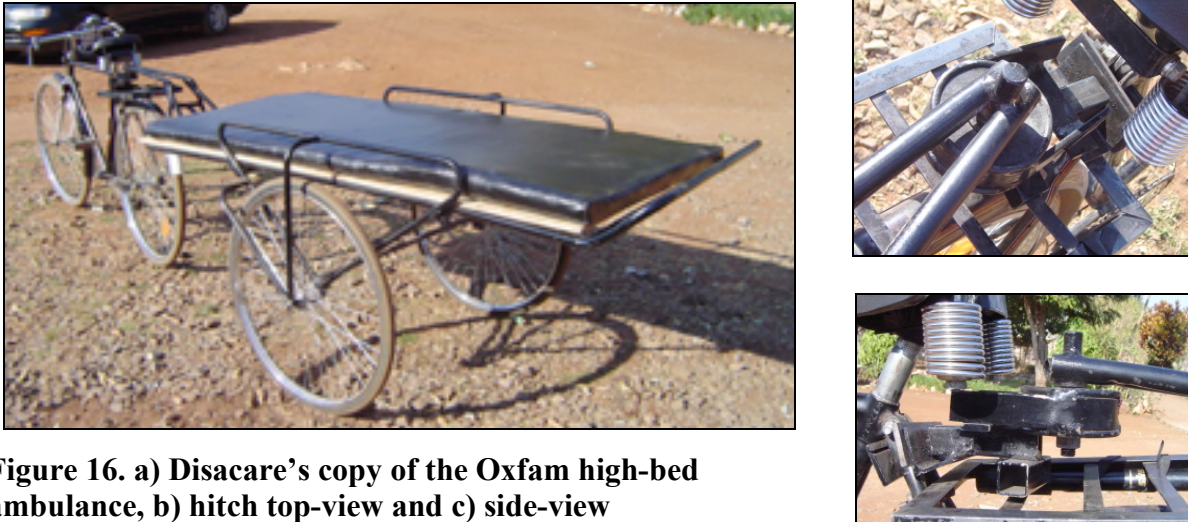


Figure 16. a) Disacare's copy of the Oxfam high-bed ambulance, b) hitch top-view and c) side-view

The hitch (see Figure 16 b and c) only allowed for yaw, or rotation about a vertical axis, which made it difficult to maneuver the ambulance safely. If the bicycle tilted too much to either side, the trailer was in danger of overturning. Due to the flexing of the tow bar and loose connections in the hitch, the trailer bed would also rock forward and backward about the pivot created by the wheel axles. This instability combined with the high center of gravity and negligible guardrails resulted in concerns that a patient could fall off the ambulance and injure himself.

3. DESIGN EVOLUTION OF THE ZAMBULANCES

Similar to the DfD ambulance, the three generations of Zambulances (Alpha, Beta, and Gamma) consist of a removable stretcher on a low-bed, two-wheeled trailer that can be attached to the back of a bicycle. To frame the comparison of the Zambulances, Figure 17, Figure 18, and Figure 19 display the hitch, stretcher bed, and trailer frame of the Alpha, Beta and Gamma.



Figure 17. a) Alpha ball joint hitch, b) canvas stretcher bed, and c) 32mm OD tube trailer



Figure 18. a) Beta U-joint hitch, b) PVC tarpaulin stretcher bed, and c) reinforced trailer



Figure 19. a) Gamma nut and bolt hitch, b) sheet metal stretcher bed, and c) planar trailer

3.1. Overview of the Zambulances

Although the main configuration was preserved throughout the generations, changes in the material, manufacturing process, and detailed design lead to significant improvements in durability, manufacturability, and comfort. After a general overview of the Zambulances, the evolution of each major component of the Zambulance will be discussed in detail.

The Alpha, Beta, and Gamma Zambulance are chronologically compared in the following section to emphasize key features and differences from the DfD design and other Zambulances. Although other designs, such as a rickshaw or sidecar, were also considered, they will not be discussed further.

3.1.1. Alpha

The main difference between DfD design and the Alpha ambulance is the Alpha's simple rectangular trailer frame, which includes the tow bar, and forms one continuous perimeter of 32mm OD round steel tubing. The motivating factor was to reduce the number of parts and bends needed to form the trailer body since Disacare did not have the appropriate dies for bending anything but 19mm OD tubing. Having one continuous piece of larger diameter tubing meant that the trailer body and tow bar would be stronger and would not need the extra U-beams and cross beams as reinforcements.



Figure 20. Alpha ambulance



Figure 21. Alpha trailer frame

The Alpha hitch was modeled after the DfD ball joint hitch. However, new car components are very expensive, and parts at junkyards are not standard, reliably available, or economical. The Alpha stretcher consists of a frame made from 25mm OD tubing. Various canvas materials were tried for the stretcher bed, but it was difficult to attach the canvas by weaving rope through straps around the perimeter of the canvas and the frame. Grommets were poor quality and would rip the fabric, and straps made from the canvas itself would rip. Nylon strapping is expensive and time consuming to sew on and reinforce. Lacing and tightening the canvas was also time-consuming and cumbersome. The canvas also sagged significantly, lowering the patient's body towards the ground. No suspension is provided other than the limited inherent elasticity in the canvas. The DfD stretcher used straps made from inner tubes to provide suspension, but Disacare found that inner tubes tore easily and also resulted in too much sag.

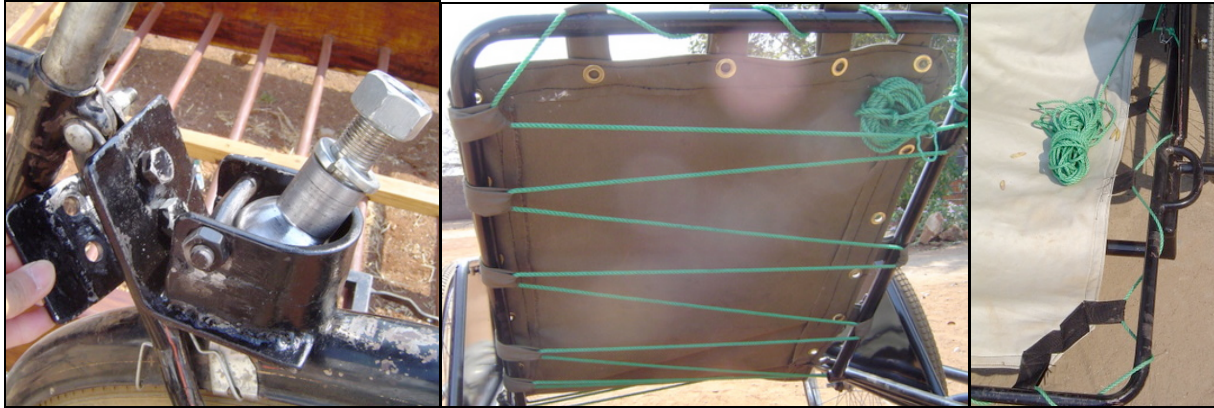


Figure 22. a) Alpha hitch is modeled after the DfD hitch, b and c) Rope attaches canvas

The trailer wheels were positioned with 4° negative camber to increase the stability of the ambulance since tipping over was a common problem faced by previous models of ambulances used in other countries. Disacare was already experienced with creating cambered wheels for their basketball wheelchairs so the complexity of camber was not as daunting as it might be for other manufacturers. Although camber was relatively easy to achieve, it is unnecessary for a trailer with such a low center of gravity.

Mitering, bending, and brazing the three-dimensional trailer frame was more difficult and time-consuming than expected. Although the geometry is simpler than the DfD design, it is difficult to manufacture accurately. Since 25mm OD tubing and the equipment needed to bend it are more commonly available than the equivalent for 32mm OD tubing in developing countries, it was determined that future designs should be made with 25mm OD tubing. The stretcher and trailer frame could then be made from the same tubing with the same equipment.

3.1.2. Beta

Similar to the DfD design, the Beta ambulance is made from 25mm round steel tubing, which is bent with a Hossfeld bender. The Beta's main design requirement was to be as robust as possible while only using 25mm OD tubing. Its reinforcement tubes are of a different geometry than that of the DfD design, and ensure less flexing of the trailer frame.



Figure 23. Beta ambulance with patient



Figure 24. Beta trailer frame

The Beta hitch was designed and made by Chris Howard of Whirlwind Wheelchair International (WWI). The hitch is a universal U-joint with three axes of rotation. However it was difficult to make accurately, and slight errors would result in interference with the bicycle (See Figure 50).



Figure 25. Beta hitch



Figure 26. Beta hitch side view

The stretcher material was changed from canvas to PVC reinforced tarpaulin for increased durability. Also, rather than tying the canvas to the frame with rope, a strip of sheet metal was sewn into the hem of the tarpaulin and bolted to the stretcher frame.



Figure 27. Bolts and nuts hold tarp to frame



Figure 28. Metal in hem causes tears

Although the PVC tarpaulin was adequately strong, it was imported and had a minimum lead-time of two weeks and was sometimes unavailable. The sheet metal strips within the hem of the tarpaulin may also wear down the material and cause the tarpaulin to tear over time. Drilling holes in the stretcher frame in order to bolt down the tarpaulin considerably weakens the frame.

The Beta ambulance geometry is more complex than the DfD design because the trailer requires three-dimensional bends and has more reinforcement tubes. This three-dimensional shape is difficult to bend accurately and fixture. The most complex region of the Beta ambulance is the tow bar. To reduce complexity in that region, the Gamma ambulance was designed with a planar rather than inclined tow bar.

3.1.3. Gamma

The Gamma trailer, including the tow bar, was designed to be planar and as simple as possible. The planar geometry made it possible to develop a fixture to align and position all the critical components of the trailer, so all critical components could be welded at once. This greatly

reduced the manufacturing time and increased the geometric precision of the trailer. Eliminating components that require three-dimensional bends also made the fabrication of the components much easier. All components are two-dimensional at most, and there are no more than two bends in any one piece. All bends are 90° bends, which are easy to check and align.

The canvas or metal mesh features (stretcher bed and fenders) on the DfD ambulance were replaced with steel sheet metal on the Gamma due to the following reasons: (1) canvas and fabric are relatively expensive and not regularly available in Zambia since they are imported, (2) sheet metal is more durable and cheaper in Zambia, and (3) Disacare is more familiar with its sources and characteristics. In addition, unlike the sagging canvas, the sheet metal stretcher protects the patient's body from falling beneath the plane of the trailer, and allows the trailer's reinforcement ribs to be in-plane with the rest of the trailer.



Figure 29. The Gamma ambulance transports a patient from her home to a clinic

Instead of attaching to the hitch to the bicycle's seat post, the hitch attaches the trailer near the bicycle's rear axle. This change eliminated the need for three-dimensional bends. A hand tow bar made out of rebar was attached to the boom to provide a means for easy steering of the trailer when the bicycle is not attached. Mudguards made out of sheet metal were also added to protect the patient from debris coming off the trailer wheels.

3.2. Design Evolution of the Stretcher

3.2.1. Stretcher frame

The stretcher frame is 200cm by 65cm at its largest dimensions, and it is narrower than the trailer (See Appendix F: Production Manual for specific dimensions). The stretcher's length was determined based on Disacare's estimate of a length that would be able to accommodate most Zambians. The width of the Gamma stretcher was adjusted to be wide enough to accommodate an adult and narrow enough to fit through an average doorframe at Disacare. Limiting the width enables only one person to lie down comfortably on the stretcher, and will discourage people from overloading and misusing it with multiple passengers.

The stretcher frame is made from 25mm OD and 1.6mm thick round steel tube since it is readily available in most developing countries, and can be bent with a Hossfeld bender. The Gamma stretcher frame is very similar to DfD's design, but the Gamma stretcher is made in two halves, and brazed at the middle of the long sides so it can be reinforced with 85cm long 21.4mm tubes. Although the reinforcement tube increases the weight by 0.7 kg, it increases the strength by essentially increasing the wall thickness (see Appendix B: Analysis). Unfortunately, Disacare sometimes does not use reinforcement tube of the proper length or diameter so it is important to emphasize the need to use materials of the proper dimensions. Another advantage of joining the halves along the long side rather than the narrow head or foot of the stretcher is that small variations (+/- 1cm) in the width of the stretcher are negligible over the length of the stretcher.

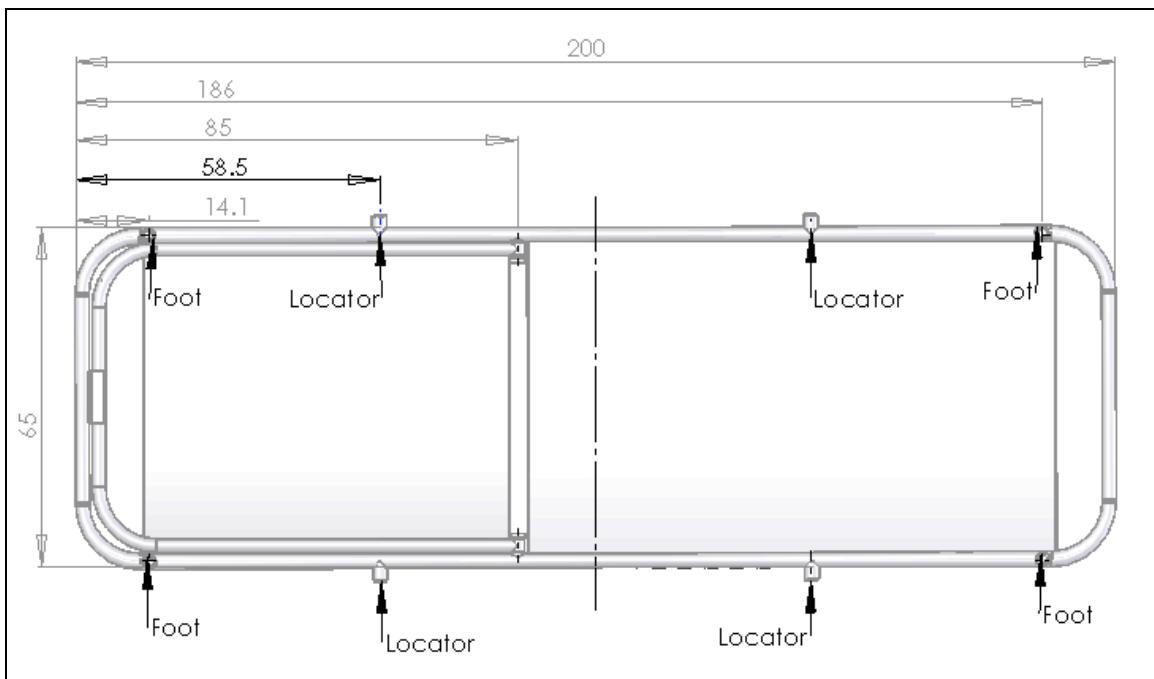


Figure 30. Overall dimensions of Gamma stretcher frame from a bottom view

3.2.2. Stretcher material

The Gamma stretcher bed was made from sheet metal that is MIG welded to the stretcher frame. Standard hospital stretchers in Zambia are also made from sheet metal (see Figure 31). Although bicycle ambulances in other countries tend to have beds made from fabric or canvas, the material found in Lusaka was not strong enough or was too expensive. PVC-reinforced tarpaulin could be ordered from Tanzania, but the lead-time was about two weeks, and it cost almost twice as much as the locally available sheet metal. A standard sheet of 0.6mm thick steel is about 2.45m² and costs about \$15 (55,300 Zambian Kwacha or ZMK) while two square meters of PVC reinforced tarpaulin costs \$27 (100,000ZMK).

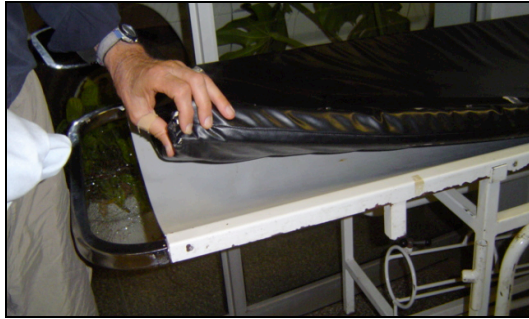


Figure 31. Hospital stretcher in Zambia **Figure 32. Mattress disinfection**

A 5cm or 2” thick foam mattress with a water-resistant rexine cover (cotton or rayon canvas with a PVC coating) is used with the sheet metal stretcher to provide a more comfortable surface for the patient. To reduce the risk for the transmission of infectious diseases, disinfecting alcohol is recommended for cleaning the mattress and stretcher bed on a regular basis. It is difficult to estimate how long the mattress would last, but it is likely that the ambulance owners would be able to make or purchase standard stretcher mattresses if a replacement were needed. The ambulance that has been in use the longest was donated in December 2005, and was still used with the mattress in good condition in November 2007. In rural areas, rats have been known to chew holes through the rexine cover.

3.2.3. Backrest adjustment

The backrest of the Gamma stretcher is similar to that of the DfD stretcher. A piece of angle iron is welded to the stretcher frame to prevent the backrest from falling below the plane of the stretcher. A lot of braze is required to fill the gap between the vertical flat face of the angle iron and the 25mm round tube, but it is too difficult to weld the 3mm thick angle iron to the 1.5mm thick tube. The pivot is made by brazing a 21.4mm OD insert to the stretcher frame, and brazing a 25mm OD sleeve to the backrest. It is recommended that the tubes fit snugly within one another to prevent the backrest from twisting in torsion.

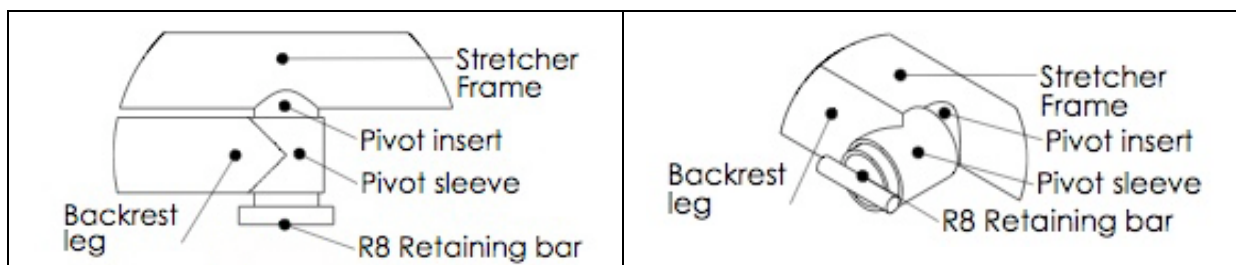


Figure 33. Gamma backrest pivot top view **Figure 34. Gamma backrest pivot profile**

The angle of the backrest can be adjusted by increasing or decreasing the effective length of a 5mm gauge chain. The DfD design uses two 15” long chains with openings bigger than 0.25” with a 1.5” long 0.25” diameter rod to fix the end of the chain [2]. The Gamma only uses a single chain on one side of the stretcher because, at any given time, it is unlikely that the weight of the backrest is being supported evenly by both chains. The worst-case scenario is that only one of the chains is fully supporting the weight and the other chain may even be unhooked.

Thus, a single chain must be designed not to fail even if it is supporting the entire weight of the backrest and the other chain is not necessary. See Appendix B: Analysis for details on how the chain gauge and length was selected.

On the Gamma stretcher, one end of a 95cm long 5mm chain is brazed to the backrest frame, and the other end goes through a short 25mm tube. A 8mm rod is brazed on the end of the chain to keep the end from falling loose (see Figure 37). To shorten the apparent length of the chain and increase the angle of recline, the rod can be pulled out from the 25mm tube, and reinserted into another link to keep the chain from slipping through and the end from hanging loosely (see Figure 36). This chain lock may not be the most intuitive or simple design, but the end of the chain will always be secured, and will not pose a possible nuisance or hazard. Assessments of the ambulance revealed that users would sometimes tie the chain around the trailer to prevent it from interfering with the wheels (see Figure 39).



Figure 35. Chain end is secured by a rod



Figure 36. Lock new link to change angle



Figure 37. Chain secured when lying down



Figure 38. Chain secured when reclined

Part of a link from a 8mm chain would be strong enough to secure the chain. However, Disacare is usually reluctant to buy chain of a different gauge only to use a few links. Instead, Disacare often uses the 3mm chain meant for their wheelchairs on the backrest or the chain hook, and it fails under use. Using the 8mm rod and tube to secure the chain is less likely to lead to manufacturing errors because both the rod and tube are standard steel stock that Disacare usually purchases. The design has an inherent safety check because the 8mm rod will only fit in the cavity of a 5mm chain so it ensures that smaller chains are not mistakenly used. See Appendix B: Analysis for details on the strength of the chain lock.

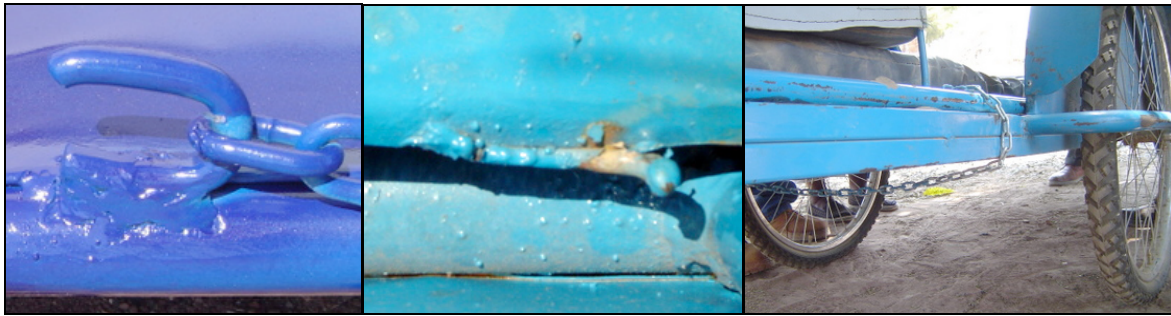


Figure 39. a) 8mm chain hook as designed, b) broken 3mm hook, c) loose chain tied on

3.2.4. Handles and feet

Rather than attaching separate handles onto the stretcher like the DfD design, the Gamma ambulance relies on the exposed corners of the stretcher frame to serve as handles. When there were separate handles on the sides of the stretcher, people preferred to hold the stretcher from its corners rather than the handles. Also, unlike the DfD stretcher's small U-shaped feet bent from 3/8" solid steel rod, the Gamma stretcher's feet are simply cut out of 25mm tubing. The feet only have to be tall enough to elevate the mattress off the ground and to provide clearance for fingers to reach under the stretcher to lift it.



Figure 40. Users lift stretcher at ends



Figure 41. Feet provide clearance for hands to lift

3.2.5. Canopy

The Gamma canopy provides shade over the patient's head. The canopy frame is shaped like a soccer goal and is bent out of rebar and welded onto the backrest and covered with canvas. It is lightweight, cheap, and easy to manufacture, but it is difficult to stack and transport the backrests without bending the canopy frame. The canopy also does not completely protect the patient from rain, sun, and stigma from the community. Privacy is especially important for pregnant women who may deliver their babies in-transit to the health center. Users have suggested a tent-like canopy that would completely surround the patient.



Figure 42. a) Canopy frame, b) and c) Canopy protects from sun, but not rain or stigma

3.2.6. Safety features

To keep the stretcher properly positioned on the trailer, locators on the stretcher sit in front and behind the fenders, and prevent forward and backward motion (see Figure 43a). The fenders on trailer also sandwich the stretcher and prevent side-to-side motion (see Figure 43b). This design allows the stretcher to be lifted easily and quickly, but minimizes the risk that the stretcher will accidentally come off the trailer. In order for an accident to occur, the stretcher would have to be raised about 35cm or 14” over the fenders and off the trailer. Disacare sometimes makes the blockers too short, and they are incorrectly squeezed against the fender sheet metal so it is important to emphasize that the blockers be the right length and properly located on the stretcher. Four blockers ensure than the stretcher cannot be improperly located on the trailer.

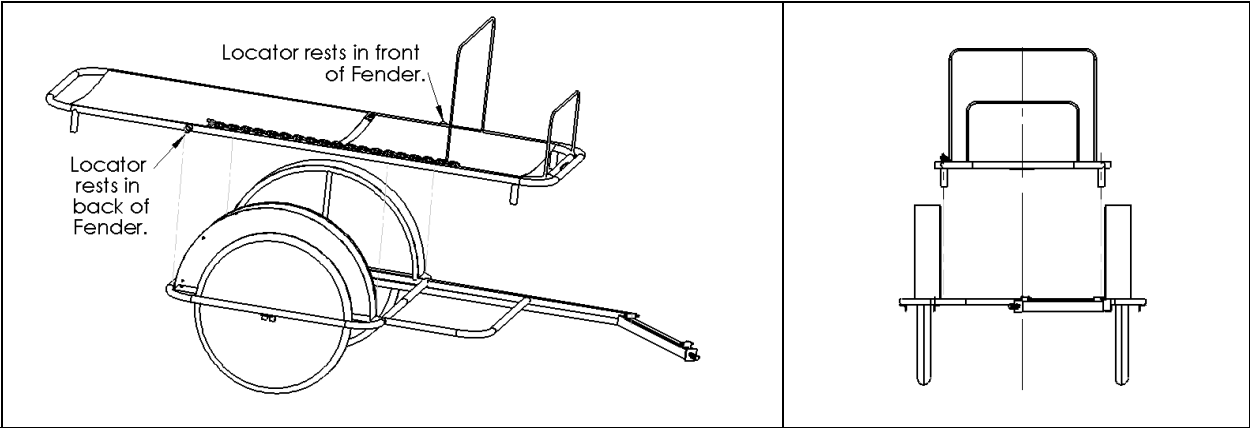


Figure 43. a) Locators position stretcher lengthwise, and b) fenders position it sideways

Seat belts made out of Velcro straps and 8mm rebar were designed for the stretcher, but Disacare decided not to manufacture ambulances with seat belts. It is unclear whether the seat belts would be used in practice since many Zambians do not wear seat belts in cars except when in the front seats.

3.3. Design Evolution of the Trailer

3.3.1. Trailer frame dimensions and height

The trailer frame is made mostly from 25mm OD round steel tube, and is about 200cm by 98cm at its largest dimensions (See Appendix F: Production Manual for specific dimensions). The Gamma trailer (98cm wide) is narrower than the DfD (107cm or 42in wide) trailer. The narrower width makes it slightly easier for the Zambulance to navigate along the sides of major vehicular roads or narrow trails in rural areas.

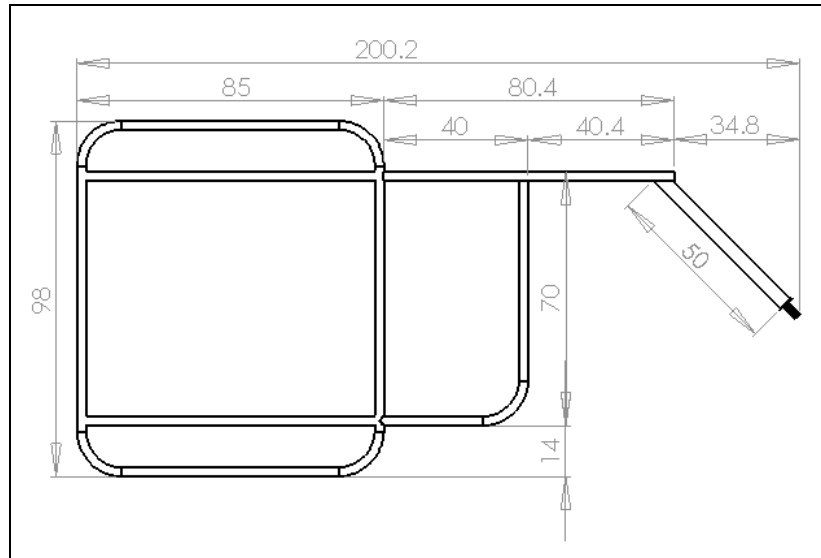


Figure 44. Overall dimensions of Gamma trailer frame

The height of the stretcher was determined by balancing benefit of being as low to the ground as possible for stability, and the risk of colliding with rocks and other obstacles if the trailer is too low to the ground. From the field test results of the DfD ambulance in Malawi, it was recommended that the ground clearance be no less than 10" or 25cm. Since the trailer's reinforcement ribs can be in the same plane as the trailer, the lowest point on the ambulance are the stretcher feet. The ground clearance is approximately 30cm.

3.3.2. Tow bar geometry and reinforcement tubes

Due to the difficulties with ensuring accurate dimensions and positioning of components for earlier ambulances, it was determined that the Gamma ambulance should be manufactured with a welding fixture. Since it is much easier to design a welding fixture for a planar two-dimensional part, the Gamma trailer was designed with a flat trailer body. The Gamma trailer has only one central reinforcement rib going across the body, and a single square tube reinforcing the tow bar. This design is minimalist compared to the DfD or Beta trailers, and is much easier to produce.

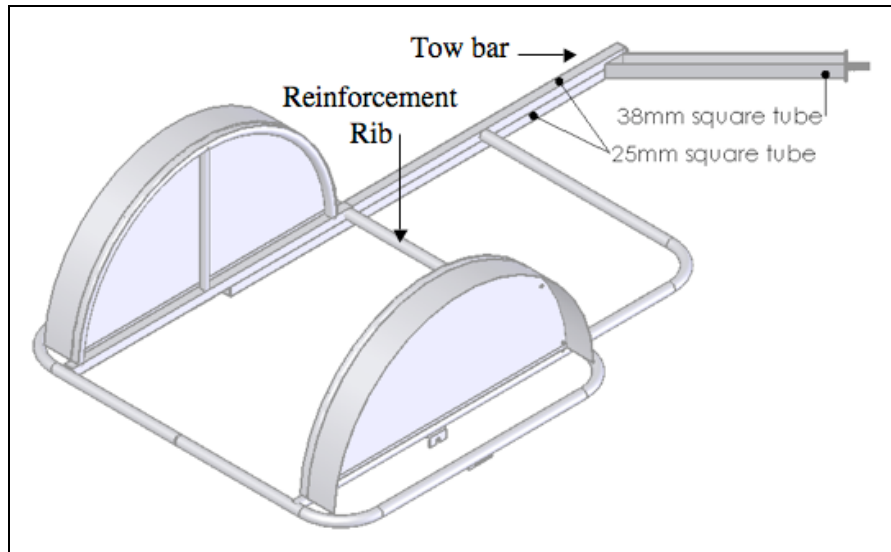


Figure 45. Gamma with reinforcement rib and tow bar

In earlier models, the reinforcement tubes and tow bar were the only precisely located components that were not in the same plane as the trailer body. The fenders are perpendicular to the trailer frame, but they can easily be located by aligning them with the trailer's side tubes. The reinforcement ribs for the DfD and Beta designs had to be in a different plane to provide space for the stretcher's canvas to sag. Changing the stretcher material from canvas to sheet metal enabled the rib or reinforcement tube to be in the same plane as the trailer. Designing a planar rather than inclined tow bar also allowed the tow bar to be incorporated into the planar trailer frame.

Designing the tow bar to be in the same plane as the trailer had many advantages. The Gamma tow bar does not require any bends or complicated reinforcements. The tow bar is made from two stacked lengths of 25mm square tube, joined at 45° to a 38mm square tube. Although the remainder of the trailer is made from round tubing, square tubing was chosen for the tow bar because the planar interfaces are easier to cut, align, and weld together.

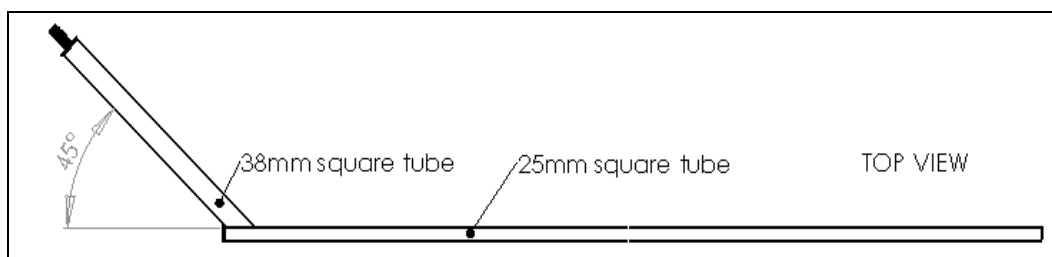


Figure 46. Gamma tow bar consists of two 25mm and one 38mm square tubes

Although the planar tow bar does not serve as a handle for pulling the ambulance by hand, it seems that it is not necessary to directly hold the ambulance by its tow bar when a bicycle is attached. According to ambulance operators, they usually leave the ambulance attached to the

bicycle and use the bicycle's handlebars to maneuver the ambulance when they cannot cycle and need to move the ambulance on foot.



Figure 47. Operator maneuvers with bicycle's handlebars rather than the tow bar

A separate handle was designed and prototyped to provide the option of towing the ambulance by hand, but Disacare decided not to include it in the final product. It was cheap and easy to manufacture, but it was not durable or robust enough to be used with a patient on the trailer (see Appendix F: Production Manual for details).

The advantages of the Gamma's planar tow bar become even clearer with a discussion of the disadvantages associated with inclined tow bar designs. Since an inclined tow bar would have to be attached to the bicycle in the space beneath the seat and above the rear wheel of the bicycle, there is a high risk that the hitch will interfere with the bicycle if there are inaccuracies or failures. Furthermore, inaccuracy in the positioning and geometry of the tow bar has significant negative consequences, such as the trailer body being inclined rather than level, or the tow bar colliding with the rear wheel of the bicycle during turns (see Figure 48).



Figure 48. Beta tow bar and bicycle rear wheel interference

If a part of the clamp or hitch bends, it may easily interfere with the bicycle frame and the ambulance may be rendered inoperable. In fact, the Beta ambulance that was donated to Mother of Mercy Hospice in Lusaka was rendered inoperable by this interference and was repaired by

Disacare (see Figure 50). Although one may suggest that a robust hitch design will prevent this interference problem, it is preferable to reduce the risk that the geometry of the trailer will exacerbate the negative impact that a damaged part has on ambulance functionality.



Figure 49. Beta hitch as designed



Figure 50. Deformed Beta hitch

In addition to the risks associated with an inclined tow bar resulting in interferences with the bicycle, there are also manufacturing challenges. These manufacturing difficulties can be illustrated through descriptions of the Alpha and Beta Zambulances.

The Alpha had a simple trailer body geometry, which required fewer parts than the DfD design. Since larger diameter tubing is stiffer, the Alpha ambulance was designed with 32mm (rather than 25mm) OD round steel tubing to eliminate the need for reinforcement tubes to brace the tow bar. However, this change from 25mm tubing to 32mm tubing did not significantly decrease the complexity of manufacturing. Since it was infeasible to make the capital investment for the specialized bending equipment, the tow bar angle was formed by mitering, bending, and brazing the manually-bent trailer frame. Mitering and brazing requires more skill and time so the simple geometry was negatively offset by the difficulty in manufacturing without specialized equipment. The transferability of the design was also a concern because 32mm OD tubing and the equipment necessary to bend it is not reliably available in all developing countries. Compared to the Alpha design, the Gamma design is easier to manufacture, does not require as many parts or bends, and can be constructed with readily available 25mm OD tubing.

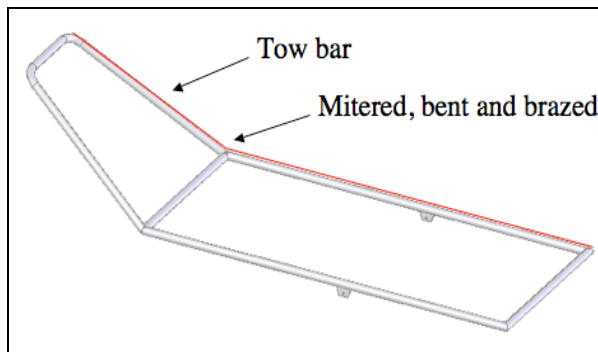


Figure 51. CAD model of Alpha trailer

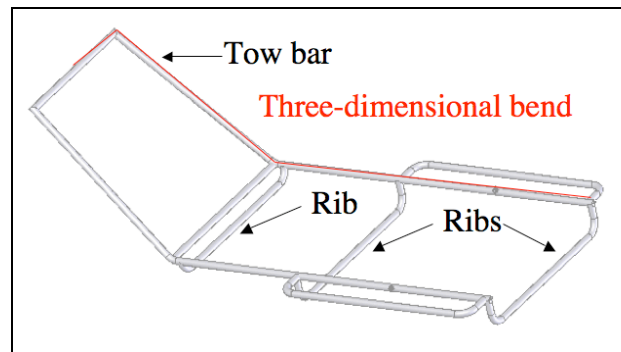


Figure 52. Original Beta trailer in CAD

The Beta trailer was originally designed to be similar to the Alpha trailer, without reinforcement ribs beneath the trailer body and no reinforcement tubes bracing the tow bar (see Figure 51). To reduce the stress concentration at the joint between the tow bar and the trailer, the tow bar was made from the same piece of tubing as the trailer. A Hossfeld bender was used to bend the

25mm tubing, but it was still difficult to obtain the correct geometry since the tow bar was designed with three-dimensional bends. While trying to correct the angle, a strong technician was able to bend the tow bar with his hands while steadying the main trailer frame with his body weight. To ensure that the tow bar would not bend during use, additional reinforcements were added (see Figure 53).



Figure 53. Beta tow bar reinforced



Figure 54. Trailer wheel rim collapse

The Beta ambulance was tested until failure with three times the typical load (with three, rather than one, adult males on the stretcher). As the rider was pedaling full-speed over a curb, the locally available 28” wheel on the trailer collapsed (see Figure 54). This result adheres to the design for failure guidelines since the weakest component (the trailer wheel) is easily replaceable, and can fail without severely damaging the other components. Moreover, it became apparent that the trailer frame did not need to be quite so robust because the trailer wheels will always fail before transmitting any significant forces to the trailer frame. The Gamma Zambulance is reinforced only where it is needed, and does not require any complex bends.

3.3.3. Wheel surrounds, dropouts, and wheels

The wheel surrounds are wide U-shaped arms that surround the trailer wheels, and protect them from being hit directly or hurting someone. The wheel surrounds also provide a mounting surface for the dropouts, which hold the trailer wheel axles (see Figure 55). The wheel surrounds (85cm long by 14cm wide) were designed to accommodate the size of the tire, and to locate the dropouts at the correct position to mount the trailer wheel axles (see Figure 56).

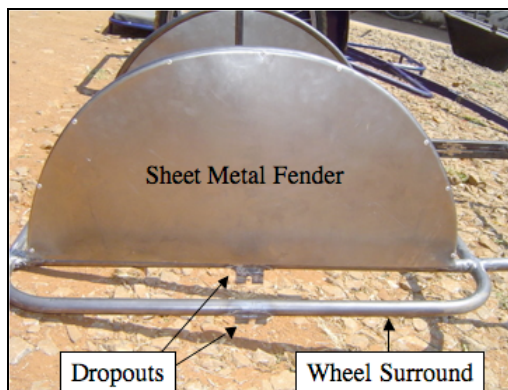


Figure 55. Dropouts mounted on surround



Figure 56. Surround fits 24” or 28” wheels

The rear leg of the Gamma wheel surrounds meet on the spinal axis of the trailer to form the rear rib of the trailer body. The other leg of the wheel surrounds butts into the trailer side beam, rather than also meeting at the spinal axis of the trailer since it is extremely difficult and

unnecessary to ensure than the width of the two wheel surrounds are accurate enough for the legs to meet (see Figure 57).

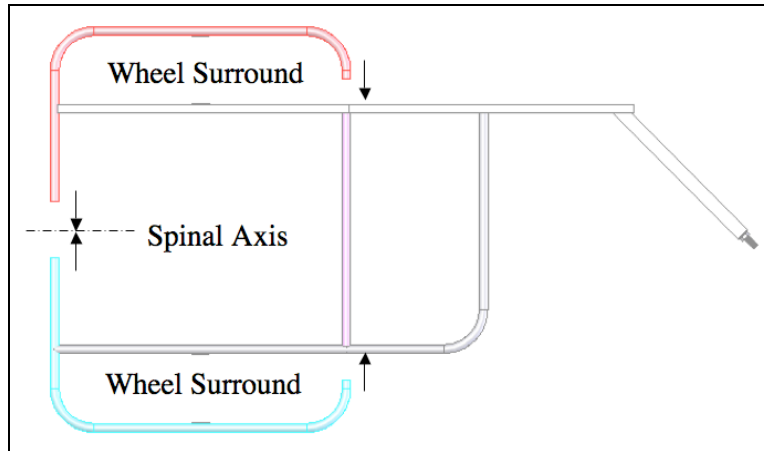


Figure 57. Wheel surround geometry in CAD

The dropouts are made by cutting a slot into a piece of angle iron in order to hold the wheel axle in the same manner as dropouts on bicycles. The dropouts are attached underneath the trailer frame, so that they can transmit forces from the wheels directly to frame (see Figure 58). All the Zambulances were designed with dropouts that would hold the trailer wheel axle 1.5cm below the bottom of the trailer. Unlike the DfD design, which uses 0.25” or 6mm flat plate, the Gamma ambulance uses 3mm thick 25mmx25mm angle iron. The angle iron provides a horizontal surface to mount to the wheel surrounds, ensuring that the face with the slot is vertical so the wheel is not cambered or misaligned. The fixture used to keep the trailer components aligned during welding, also includes a feature to align the dropouts perpendicular to and flush against the trailer tubes (Figure 59).

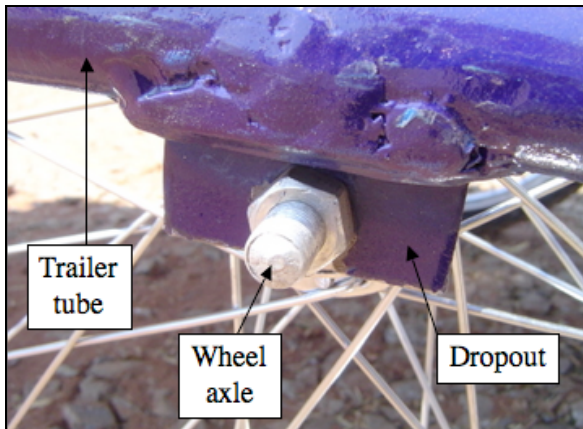


Figure 58. Gamma dropouts on trailer

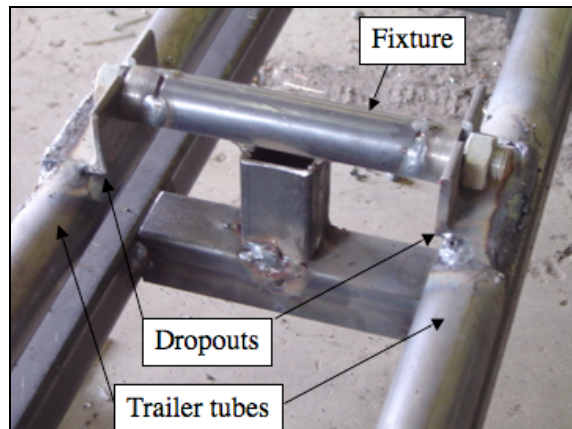


Figure 59. Welding fixture for dropouts

The trailer is designed to use common 24” wheels (see Figure 53) for cargo bicycles, rather than the 28” roadster wheels (see Figure 54), which are more prevalent but not as robust. Camber is not necessary but can be easily created by putting a spacer in between the dropout and the trailer frame.

3.3.4. Fenders and mudguards

The fenders prevent the stretcher from moving side to side, and protect the patient from the rotating wheel and debris from the road (see Figure 60a and b). The fender location was determined by the trailer body width. The Gamma stretcher (65cm wide) was designed to be narrow enough to fit through an average doorframe at Disacare, and the trailer body (70cm wide) was designed to be slightly wider so the fenders would sandwich the stretcher (see Figure 60a). One traditional birth attendant suggested that it would be preferable for the fenders to be 20cm further apart to accommodate pregnant women giving birth on the ambulance.



Figure 60. a) Fenders confine the stretcher, and b) fender and mudguard protect patient

The Gamma fender frame is made from 19mm round tube that is bent into a semi-circular shape on the same wooden fixture that Disacare uses to make hand-rims for their wheelchairs (see Figure 61). The semi-circular fender frame is about 38cm or 15” in radius and can accommodate both 28” and 24” diameter trailer wheels (see Figure 56). Bending the fender frames requires less time and material than cutting, mitering, and welding the DfD trapezoidal fenders.



Figure 61. Fender frames are bent on a jig and cut in half to form matching arches

The semi-circular fender frames are welded to the trailer after the trailer is welded on the fixture. A vertical reinforcement tube can also be welded from the center of the top of the frame to the trailer tube to transmit and distribute forces from the dropout through the fender frame to the trailer.

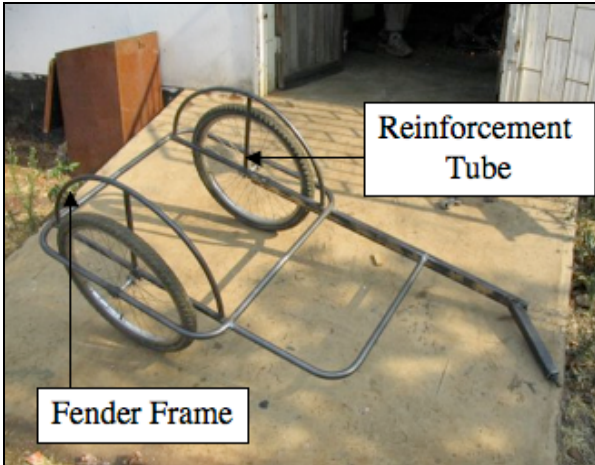


Figure 62. Fender frame welded on trailer Figure 63. Fenders made from sheet metal

The Gamma fender and mudguards are made from 0.6mm steel sheet metal (see Figure 63) because canvas or metal mesh would not adequately protect the patient. The sheet metal is brazed, rather than riveted, to the semi-circular frames. If steel rivets are available, the sheet metal can be riveted onto the fender frame. However, Disacare could only source aluminum rivets and did not realize the importance of using steel rivets to join steel sheet. Consequently, the aluminum rivets would wear and come out after time. Figure 64a shows a Beta Zambulance with a loose fender due to missing rivets. Figure 64b shows how one community fixed their rattling loose fender by tying it to the reinforcement tube with a wire.

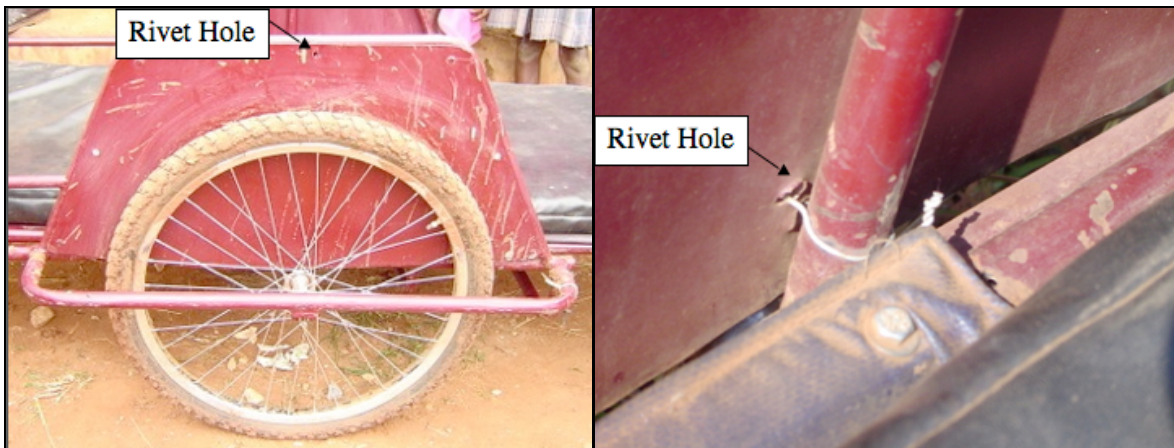


Figure 64. a) Aluminum rivets wear out, and b) communities fasten fenders with wire

Although brazing is more expensive, it is more reliable. Manufacturers who are not familiar with rivets may purchase those of the wrong dimensions or material, or drill holes of inappropriate sizes especially when correct drill bits break and are not replaced. Stick welding the sheet metal onto the frame is also an option, but welding thin sheet metal is challenging and also requires more time with grinding down the welds.

3.4. Design Evolution of the Bicycle Clamp and Hitch

The design of the clamp is strongly influenced by the geometry of the trailer because the trailer geometry dictates which part of the bicycle connects to the trailer's tow bar. The earlier ambulance designs (DfD, Alpha, and Beta) each had an inclined tow bar extending upward, forward, and inward from the front corners of the low trailer bed towards the seat post or the upper parts of the chain stays. It was assumed that an inclined tow bar was necessary to allow the operator to tow the trailer by hand. For any trailer with an inclined tow bar, the clamp had to be connected to a high point on the bicycle, such as the seat stay or seat post.

Due to manufacturing difficulties with making an inclined tow bar and user feedback from Zambia, indicating that the trailer was rarely pulled by hand, it was decided that the tow bar should be in the same plane as the trailer rather than inclined, and that the clamp should be attached near the rear axle to the bicycle's chain stay and seat stay, rather than the seat post.

The original seat-and-chain-stay clamp and nut-and-bolt hitch were designed by Allen Armstrong, and are shown in Figure 65. The clamp can be attached to the chain stay and seat stay of common bicycles and consists of angle iron, flat bar, nuts, and bolts. The nut-and-bolt hitch is a universal joint that is made from M16 nuts and bolts, and allows for three axes of rotation. Field assessments revealed that users sometimes attached the hitch to the clamp incorrectly since there were two possible orientations. I redesigned the clamp and hitch, as shown in Figure 66, so that the hitch could only be assembled in the proper orientation and could not be accidentally disassembled. Details about how the new hitch is made can be found in Appendix G: New Hitch Production Manual. The following sections detail the design of the bicycle clamp and hitch.

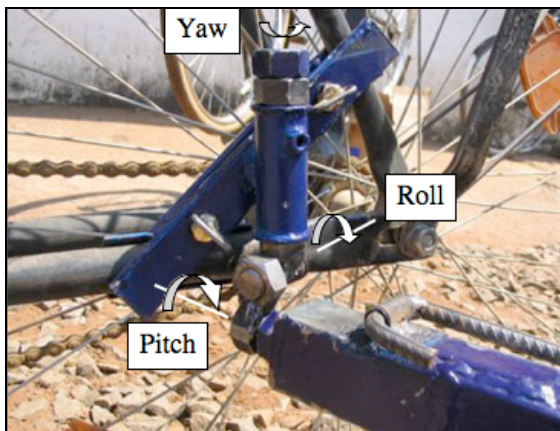


Figure 65. Nut and bolt hitch rotation

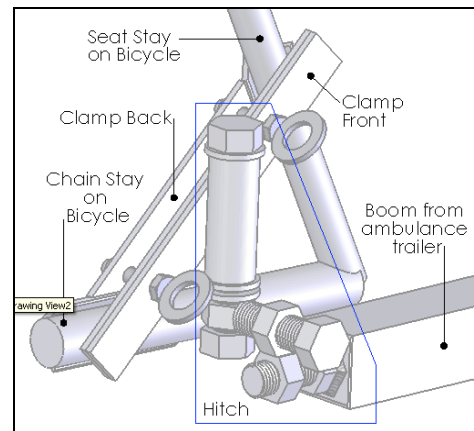


Figure 66. New hitch design in CAD

3.4.1. Seat-and-chain-stay Clamp

Armstrong's seat-and-chain-stay clamp only requires angle iron, flat bar, nuts and bolts so it can be easily manufactured and repaired anywhere with a steel industry. Figure 67 through Figure 70 show various views of the clamp back and clamp front subassemblies.

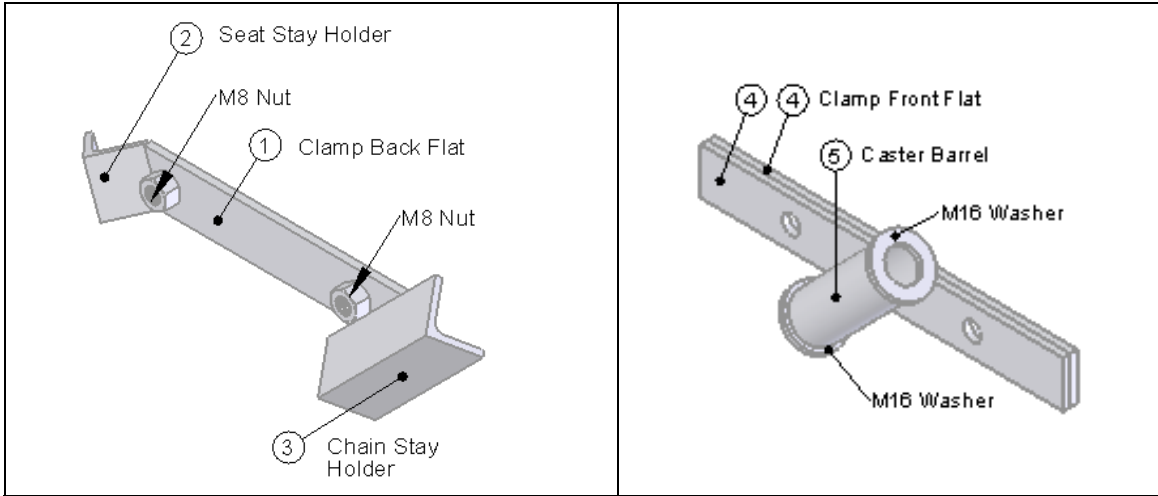


Figure 67. Clamp back CAD labeled

Figure 68. Clamp front CAD labeled

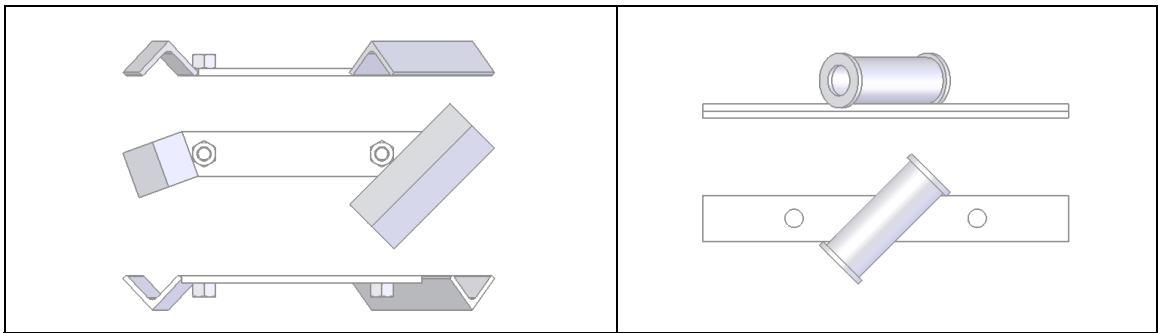


Figure 69. Clamp back views

Figure 70. Clamp front views

The bicycle's seat and chain stays are sandwiched between the angle iron pieces of the clamp back subassembly and the double layered flat bar of the clamp front subassembly (see Figure 71 and Figure 72). The clamp can only be installed in one orientation, and it can accommodate the slightly different angles between the chain stay and seat stay of common bicycles.

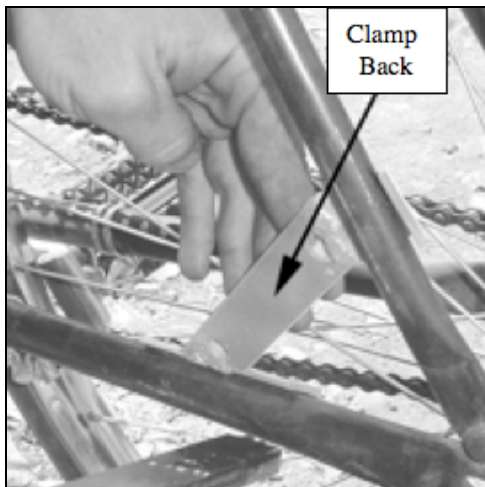


Figure 71. Clamp back fits bicycle stays

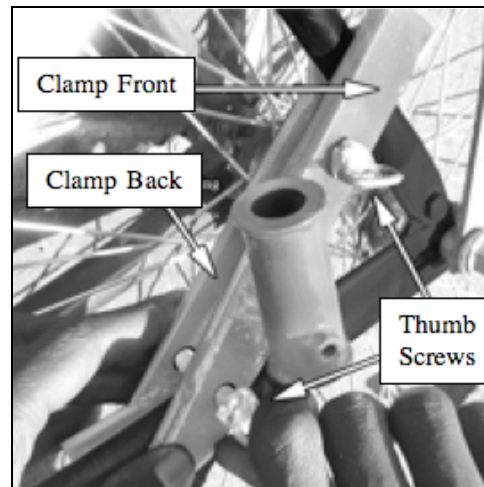


Figure 72. Clamp front is bolted to back

However, the clamp is not intuitive to install (see Figure 73) because it has no familiar counterpart in the technologies commonly found in developing countries. The clamp requires a few minutes to install and remove from the bicycle frame so it is recommended that the clamp remain on a dedicated bicycle and that the ambulance be detached from the bicycle at a joint in the hitch.



Figure 73. First-time users have a difficult time determining how to attach the clamp

Users also tend to over-tighten the clamp and collapse the bicycle frame because they assume that the two sides of the clamp should touch. To avoid this problem, the clamp was designed with wing-bolts or thumbscrews specifically so no wrench or spanner could be used to over-tighten it. However, Disacare did not understand the reason for thumbscrews and assumed that they were only for areas without wrenches or spanners. Consequently, several users over-tightened the clamp with wrenches, and damaged the bicycle frame and bent the clamp (see Figure 74 and Figure 75).

After speaking to Disacare about problems caused by the design change, they agreed to provide thumbscrews and elongate the clamp slightly to provide more room around the bolt-holes, which made it easier to turn the thumbscrews. This experience demonstrates the importance of working with community partners on the design, and ensuring that they understand the reason behind design decisions.



Figure 74. Over-tightening dents bicycle



Figure 75. Over-tightening bends clamp

Disacare also decided to change the angle of the caster barrel welded to the clamp front subassembly. It was more intuitive and easier for them to weld the caster barrel perpendicular to the flat bar (see Figure 76), rather than 45 degrees to the flat bar (see Figure 77).

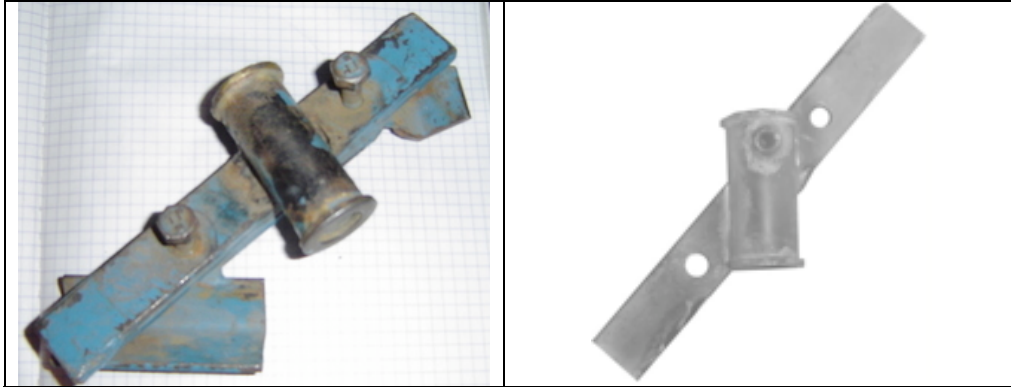


Figure 76. Clamp front modified **Figure 77. Clamp front as designed**

However, this change in the angle of the caster barrel raised the attached hitch with respect to the bicycle. This change in position resulted in interference between the hitch and the bicycle chain stays so the bicycle cannot lie completely flat (see Figure 78). It is important that the bicycle is able to fall completely flat on the ground without disturbing the ambulance (see Figure 79) so the patient will be safe even if the cyclist falls off the bicycle.

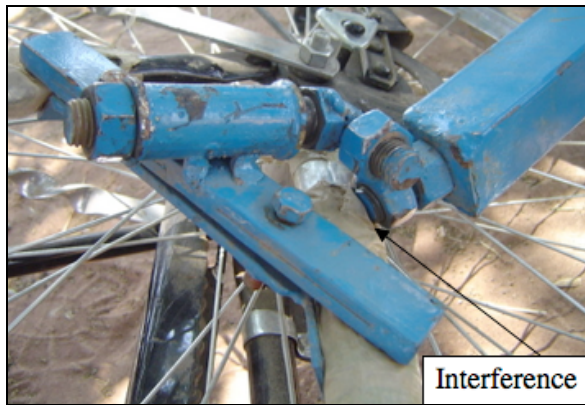


Figure 78. Angle change causes interference **Figure 79. Correct design allows bike to fall**

Several lessons have been learned from the assessment of the clamp. If possible, all components should be designed in collaboration with community partners so everyone understands the reasons behind the design. Any questions or disagreements could have been discussed and resolved by both the designer and manufacturers. The clamp and hitch were also the only critical components, which were not manufactured with welding fixtures. Creating a welding fixture for these components would also drastically decrease the risk that they would be redesigned improperly or manufactured incorrectly.

Although the changes made by the manufacturers resulted in some denting of the bicycle frame, and interference between the hitch and the bicycle, these consequences were not critical. The interference would not allow the bicycle to lie completely flat on the ground, but the ambulance was still safe and stable even if the bicycle fell. The Zambulances were still operational and maneuverable.

3.4.2. Original nut-and-bolt hitch

Mr. Allen Armstrong designed the original nut-and-bolt hitch shown in Figure 80. Since field assessments revealed that users would sometimes incorrectly connect the hitch to the clamp, I redesigned the hitch (as shown in Figure 81) to make it more intuitive to use. Both the original and redesigned hitch is a universal joint consisting of M16 nuts rotating freely on threaded rods or bolts to form three perpendicular axes of rotation: (1) yaw, (2) pitch, and (3) roll. What follows is a description of the original nut-and-bolt hitch. Section 3.4.3 provide more detail about the redesigned hitch.

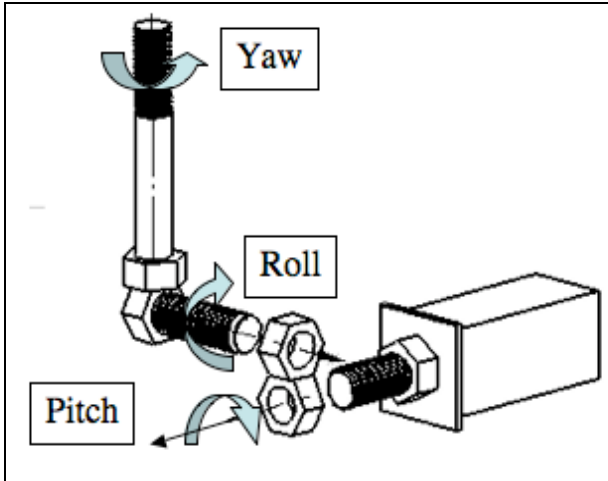


Figure 80. Original nut-and-bolt hitch

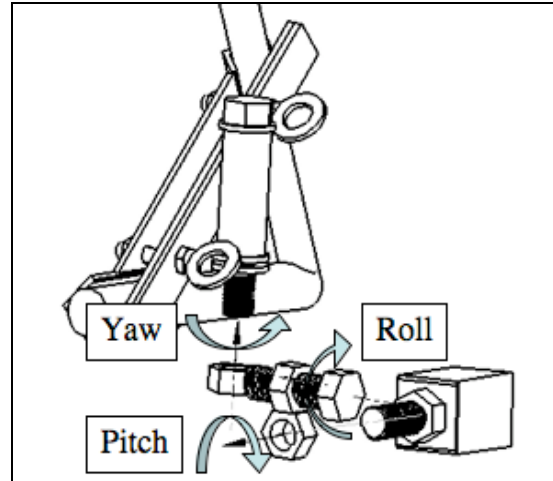


Figure 81. Redesigned hitch

Using threaded nuts and bolts is more effective than unthreaded shafts and bushings because the threads counter the moments on the shaft more effectively (see Appendix B: Analysis for details).

The nut-and-bolt hitch requires the nuts to remain approximately centered on the bolt shaft in order for the nuts to turn freely. If the nuts rotated all the way to either end of the bolts, it would either jam or ruin the threads. It was initially assumed that this would not be a problem since the nut never makes one complete revolution while it is fully assembled and in use. However, field assessments revealed that users did not understand how the hitch worked, and sometimes attempted to operate the ambulance with the nut rotated all the way to the end of the bolt shaft. When the nuts are too close to the stationary nut on the pitch axis or too close to the bolt head on the roll axis (see Figure 80 for axis definition), the nut will jam as shown in Figure 82. When the nuts are too close to the free end of the bolt, the moment on the bolt will put pressure on the end threads and damage them as shown in Figure 83.

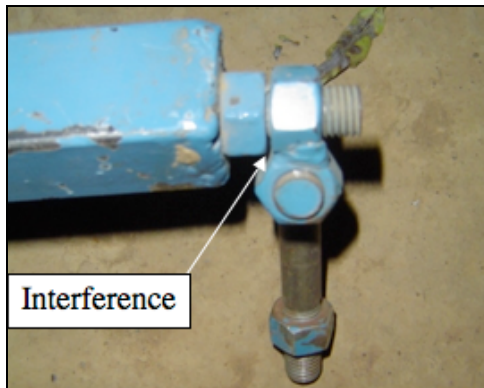


Figure 82. Hitch incorrectly inserted in top Figure 83. Roll-axis bolt has worn threads

When Armstrong and I were initially considering the design of the nut-and-bolt hitch, there was a option between welding the threads on the free ends of the bolt to prevent the hitch from being disassembled, or leaving the threads intact and enabling all bolts and nuts to be removed (as shown in Figure 80) for ease of servicing. It was decided that the end threads should not be welded so if any bolt threads or nuts were damaged, they could easily be replaced. However, the free bolt ends made the hitch easier to damage and there were also rare occasions when the trailer detached from the hitch because the nuts were too close to the free bolt ends.

It was assumed that jamming and ruining of threads could be avoided by instructing the user to make sure than the nut was always axially centered on the bolt shaft. Jason Alcaraz and I created a user manual consisting of pictorial instructions indicating that the nuts should be centered on the threaded rods after each attachment and before each use (see Appendix C: User Manual). However, Disacare did not distribute these user manuals to their customers, and no training was provided when communities received their ambulances. This experience may indicate that designs requiring even the simplest instructions are susceptible to misuse.

Neglecting to distribute user manuals or provide trainings resulted in more mistakes by users concerning the attachment of the hitch to the bicycle clamp. The original hitch can be connected to the clamp in two possible orientations: one with the M16x100 bolt inserted from the bottom of the caster barrel (see Figure 84), and the second with the M16x100 bolt inserted from the top of the caster barrel (see Figure 85). The M16x100 bolt should be inserted from the bottom of the caster barrel in order for the trailer with 24" trailer wheels to be level with the ground. The second orientation is intended to allow for the more common and prevalent 28" trailer wheels to be used as replacements if the more robust 24" trailer wheels were not available in the community. The 28" trailer wheels raise the height of the rear of the trailer, and inserting the M16x100 bolt from the top of the caster barrel raises the front end of the trailer by a corresponding height to allow the trailer to remain level.



Figure 84. Hitch inserted in clamp bottom



Figure 85. Hitch inserted in clamp top

Although offering two different orientations for attachment was meant to offer more flexibility in the range of trailer wheels that could be used, field assessments revealed that this option resulted in some users attaching the hitch to the clamp incorrectly. The ambulance is usually delivered unattached to the bicycle due to space constrictions during transport, and the users must figure out how to attach the two together. Some users inserted the M16x100 bolt from the top of the caster barrel (see Figure 86), and disregarded the fact that this caused the trailer rear to tilt downwards toward the ground (see Figure 87). This behavior is understandable because inserting bolts into the top of the caster barrel is probably more intuitive than inserting it from the bottom.



Figure 86. Hitch incorrectly inserted in top



Figure 87. Trailer rear is tilted downwards

3.4.3. Redesigned nut-and-bolt hitch

I redesigned the clamp and hitch, as shown in Figure 88, so that the hitch could only be assembled in the proper orientation and could not be accidentally disassembled. The M16x100 bolt is constrained to only rotate and not move axially in the caster barrel. When the clamp is attached to the bicycle in the only possible orientation, the M16x100 bolt is up-right, as intuition would suggest. The M16x100 bolt is not removable from the caster barrel because a washer is

welded to the shaft after the bolt is inserted. Neither the nuts nor the bolts are removable because they are constrained at each end by a bolt head, nut, or weld ruining the threads. In order to attach the hitch to the clamp, you must hold the free nut against the bottom of the M16x100 bolt while rotating it clockwise (see Figure 89). A safety nut may also be tightened onto the M16x100 bolt after the hitch has been attached to it.

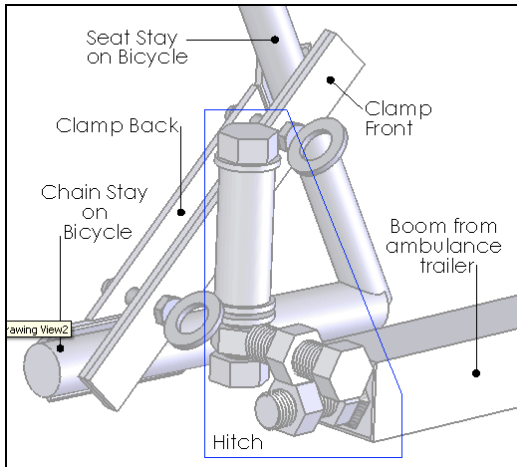


Figure 88. Redesigned hitch assembled

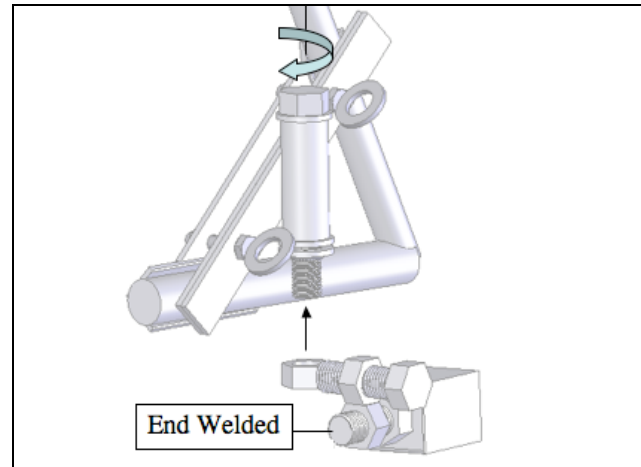


Figure 89. Assembly of redesigned hitch

In the original nut-and-bolt design, the yaw axis could potentially be jammed by inserting the M16x100 bolt into the caster barrel, and then over-tightening the nut on top (see Figure 84). The rotation of the yaw axis (which requires the greatest range of motion and allows for left and right turns) on the redesigned nut-and-bolt hitch is achieved by a bolt rotating freely in wheelchair caster barrel. A washer welded to the shaft of the M16x100 bolt prevents it from shifting axially, and prevents it from being jammed by over-tightening of the safety nut against the bottom of the caster barrel.

4. APPLICATIONS AND TECHNOLOGY TRANSFER

4.1. Appropriate Environment for Bicycle Ambulances

The Zambulance was designed specifically for Zambia. The design was heavily influenced by material availability and cost, manufacturing capabilities, terrain, and cultural values. The Zambulance may be suitable for use in other developing areas that may have similar conditions to Zambia. What follows is an outline of the conditions found in areas with thriving Zambulances. Bicycle ambulances are likely to thrive in other areas with similar conditions (see Table 2).

Table 2. Summary of properties of an appropriate environment for bicycle ambulances

Conditions	Description
Bicycle infrastructure	<ul style="list-style-type: none"> • Many people ride and fix bicycles • Many bicycles and bicycle components are available
Manufacturing infrastructure	<ul style="list-style-type: none"> • Steel stock • Bicycle components • Welding or brazing capability
Healthcare system	<ul style="list-style-type: none"> • De-centralized so distance to homes < 20km • Affordable or free services and medication • More beneficial for patient than services at home
Terrain	<ul style="list-style-type: none"> • Passable by bicycle • Not very mountainous or hilly • Does not cross many deep waterways
Competing transport options	<ul style="list-style-type: none"> • Too slow: carried on back, in wheelbarrow, on stretcher • Dangerous: motorcycles • Too expensive: private cars or taxis • Stigma: exclusion of severely ill from public transport
Cultural acceptance	<ul style="list-style-type: none"> • No stigma against riding ambulance
Community support	<ul style="list-style-type: none"> • People must respect the ambulance's purpose as medical transport • People must be willing to contribute to the maintenance and volunteer to operate it

Bicycle infrastructure:

Bicycles and bicycle components are available in most developing countries. People who are already familiar with bicycles are likely to be able to maintain the bicycle ambulance with their basic knowledge of bicycle maintenance. Basic bicycle components, such as inner tubes and tires, should also be available in areas where bicycle ambulances will operate. These items are essential for the regular maintenance of ambulances. Hubs, rims, chains, and spokes may also need to be replaced occasionally.

It is important that bicycle ambulances are introduced to areas that are already familiar with bicycles, so that they will be properly maintained and operated. If bicycle ambulances are distributed to areas without bicycles, it is possible that the ambulance will be stolen or misused for other transport needs.

Manufacturing infrastructure:

In areas where bicycle ambulances are to be produced, basic steel stock (round tube, angle iron, rebar, sheet metal, nuts and bolts) must be available, along with metal fabrication workshops able to stick weld, MIG weld, or braze. If durable weather resistant canvases, tarpaulins, or plastic sheets are also available, they may be used to make the stretcher surfaces, rather than sheet metal.

Table 3. Recommended equipment for bicycle ambulance production

Process	Recommended Equipment	
Cutting tubing	<ul style="list-style-type: none">• Measuring tape• Marker, chalk, and scribe• Protractor• Chop saw (optional)	<ul style="list-style-type: none">• Vise• Hack saw• Metal file
Bending tubing	<ul style="list-style-type: none">• Hossfeld tubing bender• 25mm bending dies• Vise grip	<ul style="list-style-type: none">• Large squares for checking 90° bends• Wooden fixture (for bending 19mm tubing into mudguards)
Drilling	<ul style="list-style-type: none">• Center punch and hammer• Drill press	<ul style="list-style-type: none">• Drill bits (8 mm and 10mm?)• Cutting oil for drilling or lubricating bender
Metalwork	<ul style="list-style-type: none">• Sheet metal shears	<ul style="list-style-type: none">• Rubber hammer and anvil
Metal Joining	<ul style="list-style-type: none">• Stick welder• Welding goggles	<ul style="list-style-type: none">• MIG welder or brazing equipment• Pliers and wire cutters (to attach and remove tubes from welding fixture)
Tailoring	<ul style="list-style-type: none">• Sewing machine	<ul style="list-style-type: none">• Scissors
Finishing operations	<ul style="list-style-type: none">• Angle grinder• Face mask	<ul style="list-style-type: none">• Angle grinder to smooth welds• Paint gun and air compressor

Healthcare system:

Transport to health centers is only effective if the health center is able to provide services or medication that is not available to the patient at their home. If the health center is poorly equipped, then it may not be beneficial to transport patients to that center. Also if people do not trust or cannot afford the healthcare system and would prefer to see traditional herbalists or witch doctors near their home, transport may not be necessary. Moreover, if the health care system is extremely centralized with very few health centers, which are more than 20km from patients' homes, motorized transport may be more appropriate than pedal power.

Terrain:

Roads in developing countries may not be suitable for motorized vehicles or fuel may be too expensive or not readily available. However, paths that may be too small or rough for cars may be manageable on bicycles and ambulances, which are narrower in width and are more maneuverable.

The bicycle ambulance is intended for areas in which bicycle use is prevalent. Any region where riding a bicycle is difficult would be even more challenging for a bicycle ambulance. In areas where it is extremely mountainous or hilly, it may be too difficult to pedal a bicycle with a heavy

load in tow. Also if paths tend to cross waterways and there are no means for transporting the bicycle or ambulance across, that area might not be appropriate for bicycle ambulances.

Competing transport options:

Often, in rural areas, the only means for patients to travel from home to health center is to be carried on the backs of others, in a wheelbarrow, or on a makeshift stretcher. These methods are often too slow and may lead to more injuries during transport if they are carried in an inappropriate position or if they should fall. Motorcycles are a faster alternative, but it may be dangerous for patients too weak to hold on or sit up. Motorized transport is usually only provided with a fee, since the cost of transport includes the cost of fuel and maintenance of the vehicle. Most patients, especially those suffering from chronic diseases, cannot afford to pay even a small fee for transport. Also, in urban areas such as Lusaka, public transport in the form of buses are available, but severely ill patients (especially those seeming to suffer from AIDS/HIV) face such a strong stigma that they are not allowed to ride the bus. Very few people have private cars or can afford to pay a taxi to transport them even 3km.

Cultural acceptance:

In some cultures, it may be inappropriate to ride upon certain types of vehicles. For example, lying down during transport may seem similar to being ferried away in a hearse. Thus, some people view transport as a bad omen that death is near. Those with severe illnesses may also be stigmatized and will need privacy during transport. If the ambulance is designed with these cultural considerations in mind, it is more likely to be accepted.

Community support:

The support and acceptance of the community is essential in the success of the bicycle ambulance. Healthcare transport must be valued over other needs for transport. For example, if there is a stronger need for cargo transport, then the purposes of the ambulance will be disregarded and it will be used to transport goods or cargo. The temptation to steal or misuse the ambulance will only be overcome if people recognize the dire needs of patients to reach health centers.

Community members must also be willing to communally pay for the ambulance maintenance or volunteer to operate it. Relatives of the ill or the patient himself cannot be expected to bear the full burden of transport in addition to their other difficulties.

4.2. Management and Operation Models

There are various ways in which to manage or operate a bicycle ambulance service. Different models may be appropriate for different conditions and environments.

Cargo trailer rentals for free ambulance service:

In Malawi, the DfD bicycle ambulance was sold in conjunction with a bicycle cargo trailer. Revenue from renting the trailer could be used to cover the cost for operation and maintenance of the bicycle ambulance. There were also concerns that the ambulance would not be available in case of an emergency if people misused the ambulance to transport goods. Requiring that people purchase a cargo trailer if they wanted to buy an ambulance, ensured that a cargo trailer would be

available to for transporting goods, and that the ambulance could then be dedicated to transporting patients.

Donated ambulance operated by community volunteers:

In Zambia, the Zambulance was donated to communities by the WHO, the Zambian Ministry of Health, local organizations like Africare, and independent donors. Neighborhood health committees (NHC) or volunteer health groups operate the ambulance for free. The villages or neighborhoods served by the community sometimes pay a small maintenance fee to make the service available to everyone for free. The NHC must also sometimes raise more money for maintenance by engaging in income-generating activities or soliciting donations. With this community model, the ambulance is usually kept at someone's home in the village or a community center, such as a school, so it is close by in times of emergency.

Health center owned and operated:

Bicycle ambulances may also be kept at health centers and shared by several communities served by the health center. For example, a Zambulance in Kafue in Zambia is being shared by three NHCs. When someone in the community is ill, an NHC member has to go to the health center to retrieve the ambulance, cycle back to the village, and then back to the health center. Sometimes the ambulance is already being used to carry a patient when someone comes to retrieve the ambulance. This centralized model increases the time before the patient reaches the health center, but it also makes the ambulance available to a larger number of people. Some communities allow relatives to operate the ambulance while others restrict use to NHC members.

Medical transport service as a micro-enterprise:

Vehicular ambulances have been used to start micro-enterprises in which an entrepreneur charges a large fee to wealthier patients, in order to subsidize or offer free transport to poorer patients. It is possible that this model may work with the bicycle ambulance to generate income for the person operating the ambulance.

5. ASSESSMENT

Long-term assessment is important in understanding how the ambulance is used, whether the design can be improved, and whether it will be useful in other areas. Disacare can use the information for marketing purposes and to accurately inform their customers about the ambulances benefits and capabilities. The volunteer health group operating the ambulance may also be able to use the data to prove to donors how they are helping their community. This data may help them to procure more funds for community service projects or to gain credibility with potential partners. Appendix D and E contain assessment materials, such as record forms and survey questions.

The following sections provide a summary of where Zambulances have been distributed, and preliminary data on assessments of the Beta and Gamma Zambulances.

5.1. Summary of Zambulance Distribution

A total of forty-seven Zambulances have been produced by Disacare (see Table 4). In December 2005 and March 2006, an independent benefactor donated two Beta Zambulances to Chilanga, a peri-urban area of Lusaka. In January 2007, twenty-three Gamma Zambulances were donated by the WHO and distributed by the Zambia Ministry of Health. Ten were delivered to health centers in Mumbwa District, while the other thirteen were donated elsewhere in Zambia. In February 2007, the Zambian Ministry of Health also ordered 18 ambulances and distributed them to district health centers all over Zambia. In April 2007, a non-profit called Africare donated four Gamma Zambulances to a rural area called Chikupi in the Kafue District just outside of Lusaka. Eighteen Zambulances that were ordered by the Zambia Ministry of Health are in production are expected to be distributed in 2008.

Table 4. Summary of Zambulance orders and deliveries

Donor	Date of Delivery	Location	Number	Zambulance Model
Cossie Findlay	12/2005	Chilanga*	1	Beta
	3/2006	Chilanga	1	Beta
World Health Organization (WHO)	1/2007	Mumbwa*	10	Gamma
	Undisclosed by WHO	Katete, Chongwe	13	Gamma
Zambian Ministry of Health (MoH)	2/2007	Undisclosed by MoH	18	Gamma
Africare	4/2007	Kafue*	4	Gamma
Zambian MoH	N/A	Still in production	18	Gamma

*Note: Zambulances in these locations have been assessed by the designer and Disacare.

5.2. Beta Assessment in Chilanga

5.2.1. Overview

In November 2005, Cossie Findlay commissioned Disacare to make a bicycle ambulance to serve Linda compound in Chilanga, a community in a peri-urban area of Lusaka. Mrs. Findlay had previously been assisting Linda compound by donating money for medicine. When she learned of Linda's difficulty with transport to health centers, she decided to donate a bicycle ambulance.

The first assessment of the Beta Zambulance was conducted in January 2006. Assessments are being conducted every six months by either Disacare or student volunteers every January or summer for the lifetime of the ambulance. Records from January 2006 to August 2007 have been analyzed to draw conclusions from the number of times the ambulance was used each month, the patient's age, the patient's gender, and the patient's illness. Subsequent sections detail how the data was tabulated. A summary follows.

A total of 124 people used the ambulance during this period of twenty months. This is equivalent to an average of eight patients per month or two patients per week. The ambulance was used most frequently during a cholera epidemic in January and February 2006. Patients were usually between the ages of twenty-one and forty, probably due to the prevalence of AIDS infection in this age group. Fifty-four percent of the patients were male while forty-six percent of the patients were female. The patients served by the ambulance have a wide range of medical conditions, ranging from gastrointestinal illnesses such as dysentery to accidental injuries or chronic illness like HIV/AIDS. Although the patients being served by the ambulance are quite diverse, the ambulance operator tends to be a male relative. It is assumed that males are viewed as being stronger and more capable of towing the ambulance behind the bicycle for several kilometers. The roundtrip journey from NHC office to patient's home to the health center usually takes about an hour and a half to three hours, depending on how long the cyclist has to wait for the patient to be treated.

5.2.2. Operation model

Disacare delivered the Beta Zambulance to Linda compound in December 2005. The Zambulance is operated and maintained by the neighborhood health committee (NHC) at Linda compound. The NHC is a group of volunteers responsible for providing some basic medical services to the community and referring patients to health centers for professional care. According to Johnny Shawa (the chairman of the NHC), when the ambulance arrived, the NHC announced to their community that free ambulance service would be provided at NHC headquarters. Volunteers or relatives usually transport the patient on the bicycle ambulance from home to the health center, waits for the patient to be treated, and then transports them back to their home unless they are admitted as in-patients. Since no service fee is charged, the NHC members reserve some of their own money for the maintenance and repair of the ambulance.

Patients are typically transported from their homes to Mt. Makulu Clinic or to Mother of Mercy Hospice. Linda compound is about 2.5 km from its center (3.5 km at the furthest point and 1.5 km at the nearest point) to Mt. Makulu Clinic, and 4km to Mother of Mercy Hospice. Mrs. Nangwale, the Sister in Charge at Mt. Makulu Clinic, stated that the bicycle ambulance has

helped the community because people otherwise have to walk, call a taxi, or hire a vehicle when they need to reach the health center. Mother of Mercy Hospice cares for patients who are typically brought to or referred to it by the home-based care (HBC) program caring for HIV/AIDS patients and orphans. Although patients may receive free medical care, room, and board at the hospice, the wards in the hospice often have empty beds. The hospice staff, patients, and HBC volunteers have agreed that lack of transport is one reason why patients are unable to reach the care they need. Although there are vehicular transport options available, the buses do not allow patients to board due to stigma and fear, and taxis are too expensive to hire. Even if a private car is available, sometimes the challenge is reaching the main paved road from within the compounds, where there are interweaving dirt paths passable only on foot or by bicycle.

During the day from 8am to 6pm, a bicycle remains attached to the ambulance and is available for use. Every night, the ambulance is detached from the bicycle and stored in the NHC's community office. Since Mt. Makulu Clinic is closed in the evening, the ambulance is not used at night. If a patient needs urgent care in the evening, they must travel 15 to 20 km to Chawamba Hospital or University Teaching Hospital (UTH). If the patient does not have money for transport, the community helps out with cost-sharing.

5.2.3. Use trends

Johnny Shawa, the chairman of the Linda NHC, has volunteered to keep records of the ambulance use. Records from January 2006 to August 2007 have been compiled and analyzed. The ambulance is sometimes used without record because some cases occur in an emergency or Shawa is not present at the time of its use. During the month of January 2006, Shawa stated that the ambulance was used at least ten times without record. For other months, there may be fewer or no records (May or June 2007) because the NHC was preoccupied with other tasks. I will attempt to draw some conclusions from the available data but there are some inaccuracies due to some inconsistencies in record keeping.

Frequency of ambulance use:

Analyzing the number of times the ambulance was used per month should indicate any seasonal trends. October to February is the rainy season, while March to September is the dry season. Water-borne diseases are usually more prevalent during the rainy season, but people are less likely to travel.

A cholera epidemic during the rainy season of January and February 2006 resulted in frequent use of the ambulance. The ambulance was sometimes needed multiple times per day. The following rainy season does not show nearly as much use (see Figure 90). It is possible that the ambulance is used less frequently during the rainy season when there is no epidemic because the muddy roads are more difficult to traverse, and patients may be more reluctant to travel in the rain.

Table 5 summarizes the number of times the ambulance was used per month from January 2006 until August 2007. A total of 124 people used the ambulance during this period of 20 months. The ambulance was used an average of 8 times per month or two times per week (May and June 2007 were disregarded because no records were kept for those months).

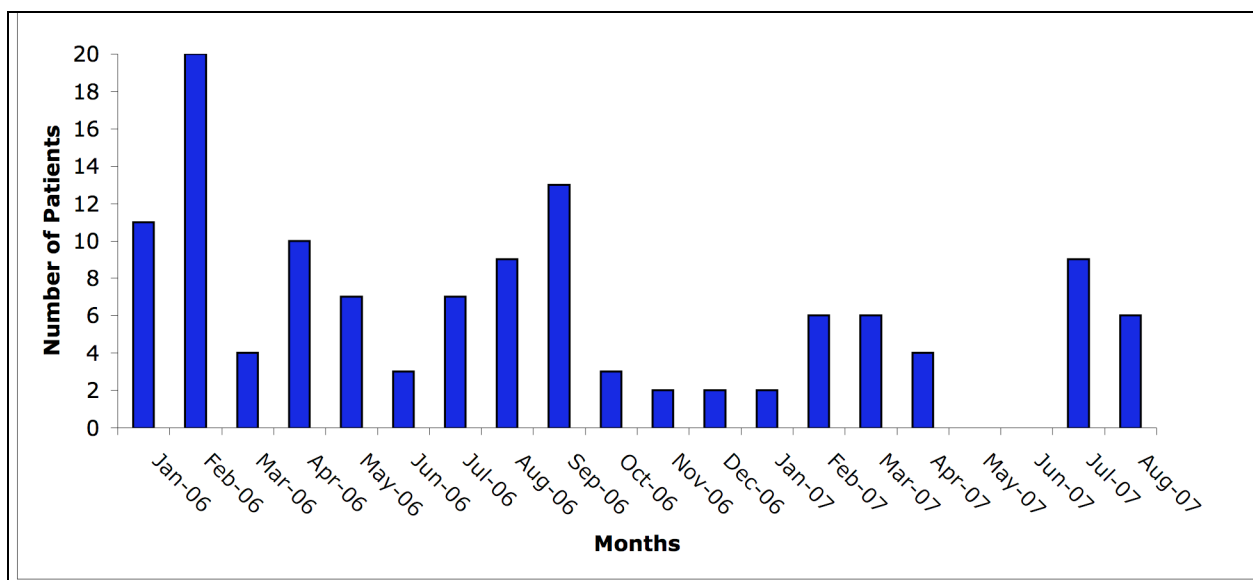


Figure 90. Frequency of ambulance use per month from January 2006 until August 2007

Table 5. Ambulance use per month

Month in 2006	Numbers	Month in 2007	Numbers
January-06	11	January-07	2
February-06	20	February-07	6
March-06	4	March-07	6
April-06	10	April-07	4
May-06	7	May-07	0
June-06	3	June-07	0
July-06	7	July-07	9
August-06	9	August-07	6
September-06	13		
October-06	3		
November-06	2		
December-06	2		

Age range:

The youngest patient to use to the ambulance is 12 years old and the oldest is 90 years old. Children are less likely to need to use the ambulance because they can be transported easily on bicycle or may be carried more easily than adults. An overwhelming 68% of the patients were between the ages of 21 and 40. This trend is probably due to the fact that people in their twenties and thirties are the most severely affected by AIDS, and thus are the most likely to need medical care. In 2003, it was estimated that 16.5% of Zambian are infected with HIV or AIDS [8]. In fact, the life expectancy in Zambia is 38 years [8]. The percentage of patients being transported

by the ambulance increases to 13% around age 60-70 because these people were in their prime after the AIDS epidemic, but were suffering from illness in their old age.

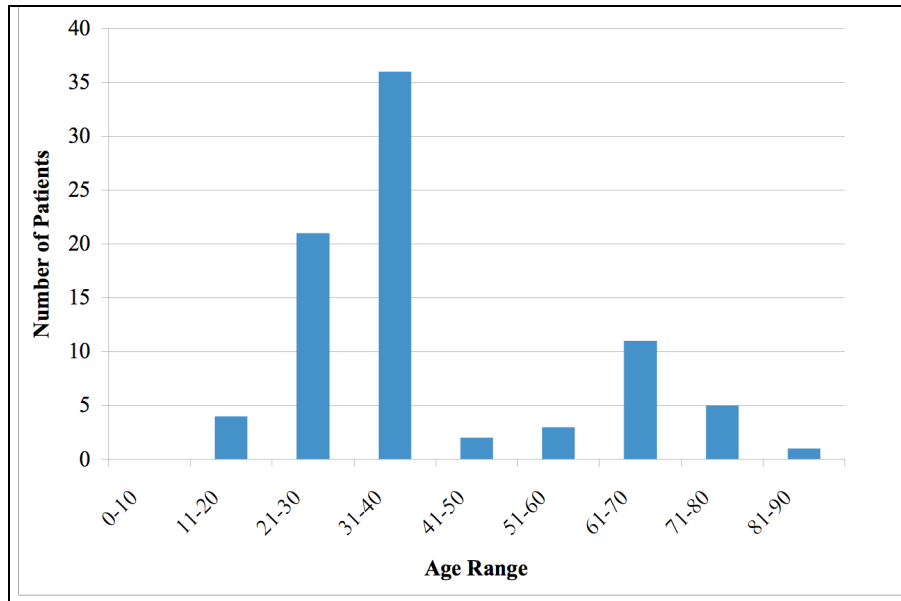


Figure 91. Distribution of patients by age

Gender distribution:

Fifty-four percent of patients using the ambulance were men, while forty-six percent were women. This is a surprising contrast to the FABIO (First African Bicycle Information Office) bicycle ambulance project in Uganda, in which 70% of the patients transported were women, 29% were men, and 1% were children [5]. The presumed reason that women were transported more frequently in Uganda is that 52% all patients transported were pregnant women [5]. In Chilanga, Zambia, none of the patients transported were pregnant women, presumably because the Mt. Makulu Clinic and Mother of Mercy Hospice do not provide obstetric services.

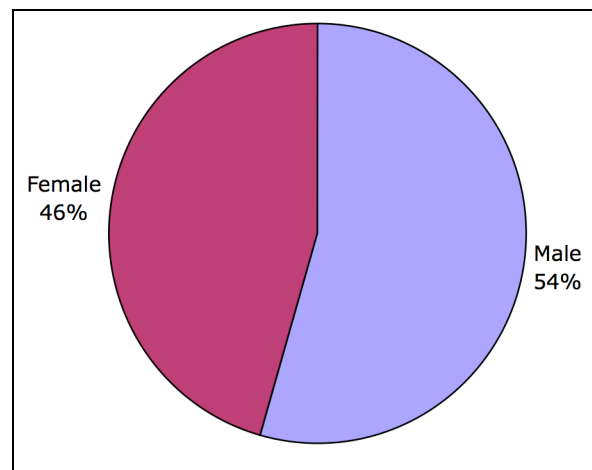


Figure 92. Ambulance use by gender

Medical conditions:

Patients using the bicycle ambulance were asked to state reasons for needing transport. The reasons were later categorized into gastrointestinal, respiratory, skin/muscle/bone, or other condition. General needs such as emergency or accident or also listed under miscellaneous. The reasons were so varied that it is difficult to determine which is the most prevalent. Irregular circumstances such as a cholera epidemic also make it difficult to make predictions for future years. It is, however, evident that the bicycle ambulance has served patients with a wide range of medical conditions and needs.

Table 6. Reasons patients stated for being transported by bicycle ambulance

Gastrointestinal	Respiratory	Skin, Muscle, or Bone	Other Conditions	Miscellaneous
<ul style="list-style-type: none">• Diarrhea• Cholera• Dysentery• Stomach pain• Dehydration• Poison	<ul style="list-style-type: none">• Chest pain• Tuberculosis• Pneumonia• Cough	<ul style="list-style-type: none">• Joint pain• Backache• Leg wound• Bone fracture• Swollen body• Swollen legs• Boils• Bed sores• Burns	<ul style="list-style-type: none">• Fever• Anemia• Malaria• Sexually transmitted infection• Epilepsy• Blindness• HIV/AIDS	<ul style="list-style-type: none">• Accident• Chronic illness• Infection• Collapsed• Emergency• Death• Operation• Medical review

Ambulance operators:

Usually, relatives or friends of the patient borrow the ambulance to transport patients. Community members or NHC members also occasionally volunteer to use the Zambulance to bring patients from their homes to health centers. The fact that relatives often use the ambulance suggests that the ambulance is easy to use since no training is required to operate it. Cyclists who operate the ambulance tend to be male since it is often quite difficult and tiresome to pull the ambulance for several kilometers over rough terrain. The standard bicycle is also usually too large for the average-size woman to ride comfortably.

Destination and travel time:

The majority of patients are transported to either Mt. Makulu Clinic or Mother of Mercy Hospice, which are respectively between 2km and 4km from most households. The roundtrip journey from NHC office to patient's home to the health center usually takes about an hour and a half to three hours, depending on how long the cyclist has to wait for the patient to be treated. This variability in distance traveled and waiting time at the health center makes it difficult to estimate how fast the cyclists are able to travel on the bicycle ambulance.

5.3. Gamma Assessment in Kafue

5.3.1. Overview

Africare was running a program on malnutrition in Kafue, and many people complained about the lack of transport to the clinic. Due to these requests, Africare donated four bicycle ambulances to communities in Kafue on April 18, 2007. An assessment of the Gamma

Zambulances was conducted in Kafue in July 2007. Disacare will not be able to conduct regular assessments at these sites because these areas are too far from Lusaka and transport is too expensive. Records forms have been distributed to community members, who have been ask to mail the records to Disacare every six months. What follows is a summary of the preliminary data that was collected.

Two of the ambulances were distributed to clinics and shared by local neighborhood health committees (NHCs). The other two ambulances were operated by a particular NHC member and kept locked in a storeroom at their home. Table 7 summarizes the locations of the ambulance and the impact of their use. The low frequency of use at Mongu Health post and Lumbaika Village suggests that ambulances kept at a person’s home are unlikely to be used as frequently as those kept at community centers. More patients can benefit from the ambulance service if multiple communities are allowed to share it.

Table 7. Bicycle ambulances in Kafue

Location	Maximum distance	Average Time [hrs]	Population	Ambulance Use (April – July 2007)	Number of NHCs Sharing
Chikupi Clinic	25km	1	10,000	30	3
Chanyanya Clinic	26km	0.5-1	11,977	100+	12
Mongu Basic School Health post	9km over hills	2.5	2,000	3	1
Lumbaika Village	12km on sand	1.5	Unknown	8	1

The Zambulance has been used for distances up to 26km, traveling at an approximate speed of 25kph on amenable terrain. When traveling over hills and on sand, the speed decreases drastically, as does the frequency of ambulance use. Although it is not recommended to travel distances further than about 25km, a Gamma Zambulance in Mumbwa has transported patients 35km when the only other alternative was hiring a private car or taxi for 180,000 Zambian Kwacha (\$45 US).

More women than men used the ambulance at Chanyanya Clinic, and Ms. Mwangala, the clinic officer, speculated that it is because women get sick more often than men. Children did not use the ambulance because they could be carried while their caretaker rode a bicycle. The patients were typically men and women between the ages of 20 and 65. The patients suffered from conditions including HIV, cholera, fractures, malaria, and complicated pregnancies. A cholera outbreak between February and March lead to an increase in the frequency of ambulance use at Chanyanya Clinic because of its close proximity to Kafue River.

5.3.2. Operation model

The location and operation model of the four ambulances were quite different. The sections below detail how the ambulances were operated at each location.

Chikupi Clinic:

Bristol Ntebeka, the Environmental Health Technologist at the Chikupi Clinic, was interviewed on July 21, 2007. There are about 10,000 people in the Chikupi area, which extends in a 25km radius from the clinic. There is no vehicular ambulance serving this community. Before the bicycle ambulance was available, people used to bring patients to the clinic by putting them on a regular bicycle, with one helper steering and pulling from the front, and two more helpers on each side of the bicycle, balancing and pushing from behind. Some patients would borrow or pay for an ox cart to bring them to the clinic.

Three of the five Neighborhood Health Committees (NHCs) in the Chikupi area share the ambulance at the Chikupi Clinic. Each NHC has ten members, and only members of the NHC are allowed to operate the ambulance. Some of the benefits of the bicycle ambulance is that it only requires one person to cycle, takes about one hour to reach the clinic, and is a free service with volunteer riders. When traveling from the furthest edges of Chikupi area (25km away), it can be estimated that the speed of the bicycle ambulance is about 25km/hr (15mi/hr). Mr. Ntebeka also mentioned that the ambulance decreased in the instances of “births before arrival.” Moreover, the ambulance has strengthened the relationship between the NHCs and the clinic, and between the NHCs and the community. According to Mr. Ntebeka, the ambulance has saved many lives, and patients praise the ambulance and have no complaints.

The Chikupi Clinic received its ambulance on April 18, 2007. The ambulance is kept indoors in a storage room and appears to be in good condition. A Classified Daily Employee is in charge of maintaining the clinic’s bicycles along with the bicycle ambulance. There is a bicycle dedicated to the operation of the ambulance. During the three months from April 2007 until July 2007, the ambulance was used thirty times to bring patients to Chikupi Clinic. The patients were men and women of all ages and suffered from ailments, such as fractures, malaria, and complicated pregnancies. The average frequency of use was ten times per month, or two or three times per week. Sometimes the ambulance was being used to ferry a patient when another patient needed it. This may suggest that the Chikupi area needs two ambulances rather than one.

Chanyanya Clinic:

The Chanyanya Clinic serves a population of 11,977, with 4,000 of those people living on small islands in the Kafue River. The clinic also serves people living in the highlands across the river. The Chanyanya area extends in a 26km radius from the clinic. There is no vehicular ambulance serving this community. Before the bicycle ambulance was available, people used to bring patients to the clinic by balancing them on a regular bicycle and pushing it.

The Chanyanya Clinic received its ambulance on April 18, 2007. Twelve neighborhood health committees (NHCs) area share the ambulance at the Chanyanya Clinic. Each NHC has ten members, some of whom volunteer to operate the ambulance. Other community members, such as relatives of the patient, are allowed to operate the ambulance. No fee is ever charged for the ambulance service.

Ms. Mwangala, the clinic officer, estimated that the ambulance was used over 100 times to bring patients to Chanyanya Clinic during the three months from April 2007 until July 2007. If the

usage was steady, the frequency of use is thirty-three times per month, or roughly once per day. Trip times vary greatly with the distance and terrain traversed. From Magowa, which is 23km away from Chanyanya Clinic, it takes 1 hour on the bicycle ambulance. However, from Bonanza, which is also 23km away, it only takes 30min.

According to Ms. Mwangala, the patients appreciate the ambulance and have no complaints. The patients were men and women from the ages of 20 to 65. More women than men used the ambulance, and Ms. Mwangala speculated that it is because women get sick more often than men. Children did not use the ambulance because they could be carried while their caretaker rode a bicycle. The patients had conditions and ailments varying from HIV treated with ARVs, cholera, and severe malaria. There was also one case with a complicated pregnancy. The ambulance was used more frequently during the cholera outbreak between February and March. Severe malaria and other water-born diseases are more common in Chanyanya area because of the proximity to Kafue River.

The ambulance was stored in a staff's house next to the clinic. The ambulance operators at Chanyanya did not know how to use or maintain the ambulance properly. For example, the clamp was not tightened onto the bicycle frame. This suggests that a user manual is critical for the safe and reliable operation of the ambulance.

Mongu Basic School and Lumbaika Village:

There is one bicycle ambulance at the health near Mongu Basic School and one in Lumbaika Village near the Kabweza Basic School. Each is operated and maintained by a member of the neighborhood health committee and kept locked in their storeroom. No one else is permitted to operate the ambulance, but the operator is not always accessible since he is often in his fields and has no phone. Of the eight patients that needed the ambulance at Lumbaika, only one was male, and two passed away. At Mongu, one patient was pregnant, another had severe malaria, and the third passed away from unknown causes.

6. SUGGESTIONS FOR FUTURE WORK

6.1. Long-Term Monitoring and Assessment

Although some preliminary assessment data has been collected, it is recommended that Disacare monitor the Gamma Zambulances, until some of the ambulances have reached the end of their useful life. Transaid, a prominent non-profit organization, recommends the following metrics as indicators of success:

- 10% reduction in mortality attributable to reduced delay in access to medical care
- Percent of total number of patients served that are transported by ambulance
- Percent of total number of patients who were previously unable to reach the health center, but could obtain access to healthcare with the help of the ambulance

Appendix D and E contain record forms and survey questions and that have been distributed to communities with Zambulances. The assessment data would be useful for design improvements as well as marketing.

6.2. Business Model Development

The Zambulance design is available online for free so any manufacturer that chooses to produce ambulances can have access to the design. The profit margin is determined by how affordable raw materials, labor rates, and overhead are in comparison to the selling price. Although Disacare has been able to produce and sell Zambulances, they make little profit because they struggle with materials sourcing, production efficiency, and marketing.

Table 8 shows the costs of materials, labor, and overhead as well as the profit for Disacare and the cost to the customer for one ambulance. Disacare does not budget their overhead and labor expenses based on the number of man-hours or resources a product requires. Instead, the overhead and labor are calculated as percentages of the material costs. Since production is usually not as efficient as it could be, with delays caused by lack of materials or power failure, the cost of producing one ambulance may be significantly more than the percentage of the materials cost. Disacare also does not change the price of their products based on changing material prices, which vary considerably with the volatile exchange rate.

Table 8. Itemized costs for one Zambulance

Expenses	Zambian Kwacha [ZMK]	US Dollars [USD]*
PAINT	300,001	\$76.43
STRETCHER	115,985	\$29.55
TRAILER	208,200	\$53.04
MATTRESS	73,000	\$18.60
<i>Labor (35% of materials)</i>	<i>247,690</i>	<i>\$63.11</i>
<i>Overhead (15% of materials)</i>	<i>106,153</i>	<i>\$27.05</i>
<i>Profit</i>	<i>138,471</i>	<i>\$35.28</i>
COST TO CUSTOMER	1,200,000	\$305.73

*Exchange rate as of May 24, 2007: 3925 ZMK/USD

Furthermore, Disacare functions primarily as a manufacturing center and does not have adequate resources for marketing or monitoring and evaluation. They have struggled in the past with convincing aid organizations to purchase their wheelchairs because they do not have data demonstrating the superior performance and durability of Disacare wheelchairs in comparison to foreign wheelchairs which may be a third or less of the cost. Disacare is the only producer of bicycle ambulances in Zambia, and none are being imported or exported. However, the demand for Zambulances may quickly decline if there is no data about their performance or effectiveness, and little or no marketing or sales efforts.

Disacare also has difficulty sourcing new materials or outsourcing phases of production. More than twice what they make in profit goes towards buying paint, which could in theory be purchased for much less or eliminated. If Disacare could source inexpensive paint, they could make up to \$100 in profit per ambulance, which is 30% of the cost to the customer. If Disacare is unable to source different materials or modify their production methods, they may choose to train others how to produce ambulances, and profit from the training rather than the production. Other manufacturers may then have the opportunity to profit from ambulance production.

6.3. Dissemination

Organizations in various countries (Malawi, Gambia, Kenya, Sri Lanka, Columbia, and the Philippines) have expressed an interest in the Zambulance design. A production manual, user manual, and record forms are available online at <http://cadlab6.mit.edu/bike.ambulance>. Aaron Wieler has used some of these materials to develop a bicycle ambulance for Namibia with the Bicycle Empowerment Network.

It would be interesting to compare the designs for the Zambulance, and the ambulance used in Namibia to determine which features should be changed to meet the conditions of the specific country in which they are used, and which designs offer the appropriate feature. A manufacturer's guide could then be produced to recommend designs based on the metrics of use.

6.4. Design Challenges

6.4.1. Possible improvements for the Zambulance

Ideas for improvements were suggested during assessment, production, field-testing, and discussions of profit-enhancing ideas. These improvements can be implemented with minimal changes to the current Zambulance design, and they are briefly discussed below.

Stretcher curtains:

The Gamma Zambulance is currently equipped with a canopy that protects the patient's head and upper torso from light rain and sun. It also provides some privacy for patient with stigmatized conditions like AIDS. Traditional birth attendants, who assist in delivering babies in rural areas, suggested that curtains be designed to entirely surround the stretcher to provide a pregnant woman with privacy in case of deliveries during transport. A full over-head canopy would also provide protection against rain. Aaron Wieler developed a canopy in Namibia that may be adapted to provide an option for curtains (see Figure 93). However, this design for a canopy does not allow the backrest to lie flat.



Figure 93. Namibia ambulance has a full-body canopy

Seat belt:

Some medical personnel recommended seat belts, and a seat belt was designed out of rods inserted into straps of Velcro, but Disacare chose not include them with the Zambulances. It would probably be beneficial to have some means of securing the patient during transport.

Kickstand:

Getting on the ambulance by stepping onto the rear of the stretcher sometimes causes the trailer to tilt backward with the front raised into the air. A kickstand could be mounted underneath the trailer to support the rear and prevent the ambulance from tipping.

Mattress straps:

The mattress occasionally slides off the ambulance when the ambulance is being used without a

patient. A cyclist suggested that straps be sewn onto the mattress to secure it to the stretcher frame.

Broader tires:

For sandy terrain, it is useful to have wider tires. However, it is important that all components are easily repairable locally with available materials so it may not be feasible to use wider tires if they are difficult to find. Aaron Wieler created a way to weld two standard bicycle rims together, and attach them to a standard hub with a non-standard spoke pattern to create a wheel with double the width from local materials (see Figure 95). The Zambulance may be adapted to use these wider tires by slightly increasing the space between the wheel surround and trailer body.



Figure 94. Namibia double-rim tire

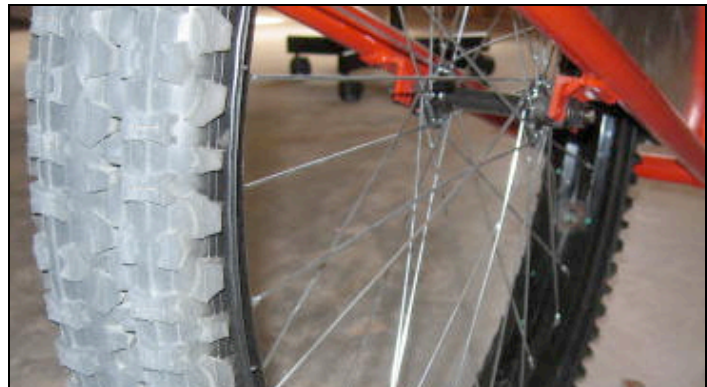


Figure 95. Two standard rims are welded together

Cargo trailer:

In Malawi, Design for Development sold a cargo trailer and bicycle ambulance as a pair, so that the revenue from renting the trailer could be used to cover the cost for operation and maintenance of the bicycle ambulance. The availability of a separate cargo trailer presumably reduces the chances that the ambulance would be misused to carry cargo, making it unavailable to transport patients.

The Malawi ambulance and trailer designs were completely different, but the Zambulance trailer could be sold separately as a cargo trailer without any changes to the design or fixtures. The Zambulance could thus be two products in one if a cargo box were designed to fit onto the trailer frame. The consumer can either purchase a cargo box or form his own to use with the Zambulance trailer.

Rust resistance:

Paint costs \$70 of the \$175 total material cost for the bicycle ambulance (see Table 8). Paint is responsible for 40% of the cost to the customer but the only value-added is aesthetics and material preservation. Disacare may consider out-sourcing the painting or surface treatment of the Zambulance to reduce internal costs.

Some materials are inherently more rust resistant. Aluminum is also more expensive and is harder to weld, but it is more resistant to corrosion. Another design could be implemented using aluminum tubing, which is threaded and connected rather than welded. The disadvantage to this design is that it may not be readily transferable because not all underdeveloped areas have access to aluminum or threaded connectors.

6.4.2. Design challenges requiring a new foundation

Appropriate technologies can be the most effective when it is designed specifically to meet the local conditions in which it is used. The Zambulance may be suitable for a wide variety of conditions common to many developing countries, but an entirely new design may be better able to address the following design challenges.

Crossing waterways:

In countries, such as Vietnam, paths between households and health centers often cross waterways. An ambulance capable of land and water transport could be designed for such regions. It is possible that the trailer could function as a boat with wheels so that it can be pulled by a bicycle on-land, and then towed by another boat across the water.

Natural materials:

In certain areas, such as Kenya, bamboo is readily abundant and is used for other construction purposes. A bamboo ambulance would be lighter and less expensive than one made of steel. It may be easier to make repairs if bamboo is available throughout remote areas as well.

Sandy terrain:

In countries, such as Namibia, the terrain is extremely sandy, and it may be difficult to ride bicycles even without a heavy load. It is conceivable that a pedal-powered vehicle with wide tracks, such as those on tanks, would be a more affective means of transport.

7. CONCLUSION

Transport to health centers is a challenge in many developing countries. Typical methods of transport are slow, unsafe, or too expensive. The bicycle ambulance is one solution to this challenge of healthcare transport. Three generations of prototypes (Alpha, Beta, and Gamma Zambulances) have been designed and built for Zambia. The Zambulance design was based on the Design for Development (DfD) ambulance that was designed by Niki Dun for Malawi. However, different material availability and cost, cultural considerations, and needs have resulted in a Gamma Zambulance that is quite different from the DfD ambulance.

The Zambulance is a two-wheeled trailer that carries a sheet metal stretcher, and can be towed by common bicycles. The ambulance is fabricated from standard bicycle components and steel stock, such as 25mm round tube. The stretcher's backrest can be adjusted to accommodate different angles of recline. A mattress also provides additional comfort. Mudguards, fenders, and a canopy protect the patient from sun, light rain, and debris.

This project has been considered a success because it is locally sustainable. The Zambulance is built, operated, and maintained by Zambians with local resources and skills. It requires no fuel or continual contributions from outside sources. The Zambulance empowers the community to help themselves by volunteering to operate the ambulance. Although it is recommended for distances less than 25km, it has been used for distances of up to 35km. The Zambulance can travel at an approximate speed of 25kph on reasonable roads. The Zambulance has helped men and women between the ages of twelve and ninety, at a frequency of about twice per week if kept at a community center. It also serves patients with a diversity of conditions, including cholera, malaria, pregnancy, HIV/AIDS, and broken bones.

There are currently forty-seven Zambulances in Zambia, and more are being produced by Disacare Wheelchair Center in Lusaka, Zambia. The design may be disseminated and adapted for countries such as Colombia, Sri Lanka, the Philippines, and Gambia. The Zambulance could be improved with seat belts, wider trailer wheels for navigating sandy terrain, and a curtain for the patient privacy. New bicycle ambulances could also be designed to cross waterways or to be made from natural materials, such as bamboo.

In addition to saving lives, empowering local health groups, and providing an economic opportunity for local manufacturers, this project has demonstrated that it is possible for a technology designed by a student to be implemented and used in developing countries. If case studies of this project and others like it could define what features are necessary for successful design and dissemination to developing countries, a new methodology for design for development can be created. This could inspire academic institutions to encourage more students to tackle more socially relevant projects.

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APPENDIX A: INTERMEDIATE MEANS OF TRANSPORT AND THEIR CHARACTERISTICS

This table provides order-of-magnitude figures only. The costs, prices, loads, speeds and distances vary greatly with the country, the people, the environment, the infrastructure and the vehicles or animals. It is not uncommon for the transport systems mentioned to carry much greater loads and to travel much longer distances. The figures are simply indications of what is commonly achieved. The costs per ton-kilometer are very approximate, and highly sensitive to assumptions on costs, loads and distances (mainly based on 5 km journeys) [7].

Transport Type	Indicative Characteristics				Some Important Requirements				
	Cost price (\$ relative)	Load (kg)	Speed (km/hr)	Range (km)	Cost/ton/km (\$ relative)	Foreign exchange	Animals and vet services	Mechanics	Good roads or tracks
Carrying/head load	0	20	5	10	1.50	Low	None	Low	Low
Sledge	10	100	4	3	0.80	Low	High	Low	Low
Wheelbarrow	30	100	4	1	0.40	Low	None	Low	Low
Hand cart	60	150	4	5	0.35	Low	None	Low	Medium
Pack donkey	60	80	7	20	0.70	Low	High	Low	Low
Bicycle	100	60	10	20	0.60	Medium	None	Medium	Medium
Cycle rickshaw	170	150	8	15	0.60	Medium	None	Medium	High
Donkey cart	300	400	6	15	0.60	Medium	High	Medium	Medium
Ox cart	500	1000	5	10	0.20	Medium	High	Medium	Medium
Motorcycle	900	100	50	50	1.30	High	None	High	Medium
Power tiller trailer	5000	1000	10	15	0.70	High	None	High	High
Pickup	12000	1200	80	200	0.70	High	None	High	High
Truck	60000	12000	80	200	0.50	High	None	High	High

APPENDIX B: ANALYSIS

1.1 Analysis of stretcher reinforcement

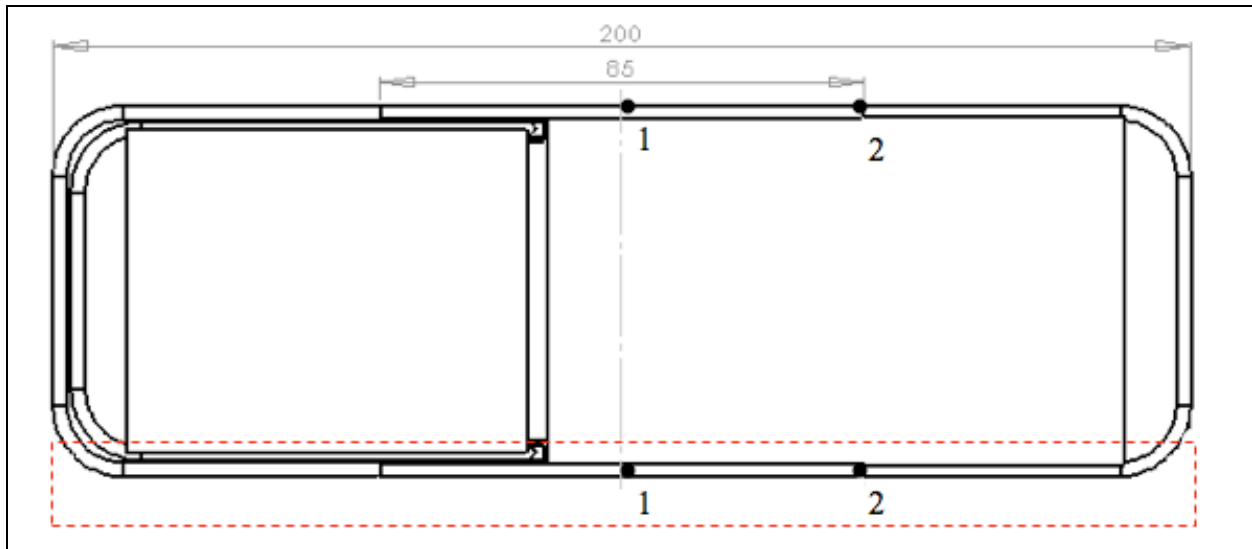


Figure 96. Diagram of stretcher frame for analysis of strength and length of reinforcement

The stretcher frame is analyzed based on a scenario of misuse in which a person of weight $2W$ is standing in the middle of the stretcher frame with both of his feet on the stretcher tubes. It is assumed that half of the person's weight is on each of the long stretcher tubes at the center (denoted by points 1 in Figure 97) of the tubes, which is 100cm from each end. A reinforcement tube made from 21.4x1.6mm tube is centered inside the 25x1.6mm tube, and is assumed to double the wall thickness of that section (see Table 9).

Table 9. Dimensions of available stretcher frame materials

Round tube	25x1.6 mm	21.4x1.6 mm	21 inside 25mm
Outer Diameter (Do) [mm]	25	21.4	25
Inner Diameter (Di) [mm]	21.8	18.2	18.2
Thickness (T) [mm]	1.6	1.6	3.4

The bending stress is analyzed at points 1 and 2, which are likely to be the areas of the highest stress since point 1 is at the center of the beam, and point 2 is at the end of the reinforcement tube. In order for the bending stress to be approximately the same at points 1 and 2, the length of the reinforcement tube must be about 83cm. This number was rounded up to 85cm, which can support a person of almost 112kg or 250lbs before failing at point 1, which is in the center of the beam. Table 10 shows more results of the analysis. If the stretcher frame were made only from 25mmx1.6mm tubing without reinforcements, it would be barely strong enough to support a person weighing about 60kg or 130 lbs.

Table 10. Assumptions and results of the stretcher reinforcement analysis

Assumptions:				
Total Weight of Person (2W) [kg]	60	100	110	120
Applied Force (Fa) [N]	294	490	539	588
Reaction Force (Fr) [N]	147	245	269.5	294
Results:				
Stress at center with 25mm tube [Mpa]	227	379	417	454
Stress at center reinforced tube [Mpa]	133	222	244	267
Stress at interface [Mpa]	131	218	239	261

Note: Bold values exceed the assumed yield stress

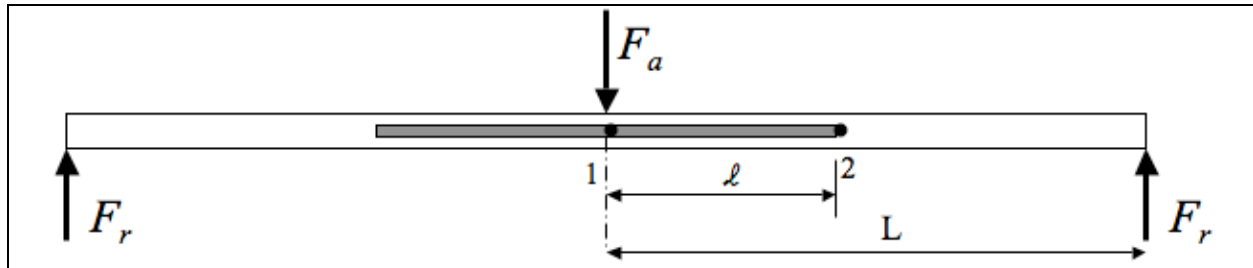


Figure 97. Stretcher frame schematic of area in the red dashed box in Figure 96

The load on half of the stretcher frame is modeled as a point load on a simply supported beam as shown in Figure 97. The applied force F_a is equal to two times the reaction forces F_r . The beam bending stress is calculated at point 1, which is a distance L from the reaction force. The beam bending stress is also analyzed at point 2, which is a distance l from the center of the tube, and a distance $L - l$ from the end of the tube.

Beam bending is analyzed with the Euler-Bernoulli beam equation (see Equation 1.1). The classic formula for determining the bending stress in a member is:

$$\sigma = \frac{My}{I} \quad (1.1)$$

- where
- σ is the bending stress
 - M is the moment at the neutral axis
 - y is the perpendicular distance to the neutral axis
 - I is the area moment of inertia about the neutral axis

The moment due to the reaction force F_r (see Equation 1.2) acts at a distance x . By force balance, the reaction force F_r is equal to half of the applied force F_a .

$$M = F_r x = \frac{F_a}{2} x \quad (1.2)$$

where M is the moment at the neutral axis
 F_r is the reaction force at the end of the beam
 F_a is the point load applied force at the center of the beam
 x is the distance between the reaction force and the point at which the moment is being taken

For a cylinder, the distance from the point of maximum stress to the neutral axis (see Equation 1.3) is half of the diameter of the cylinder.

$$y = \frac{D_{outer}}{2} \quad (1.3)$$

where y is the perpendicular distance to the neutral axis
 D_{outer} is the outer diameter of the tube

The area moment of inertia about the neutral axis for a cylinder is:

$$I_{cylinder} = \frac{\pi}{64} (D_{outer}^4 - D_{inner}^4) \quad (1.4)$$

where I is the moment of inertia for a cylinder about the neutral axis
 D_{outer} is the outer diameter of the tube
 D_{inner} is the inner diameter of the tube

Combining all the equations into the bending stress equation, we can derive the general expression for bending stress (see Equation 1.5).

$$\sigma = \frac{My}{I_x} = \left(\frac{F_a}{2} x \right) \left(\frac{D_{outer}}{2} \right) \left(\frac{1}{\frac{\pi}{64} (D_{outer}^4 - D_{inner}^4)} \right) \quad (1.5)$$

1.2 Analysis of the backrest chain

The backrest of the stretcher can either lie flat, or it can be inclined and held in position with a chain. The angle of the backrest with respect to the horizon can be adjusted by shortening the apparent length of the chain. The chain gauge is selected by analyzing the chain's tensile stress.

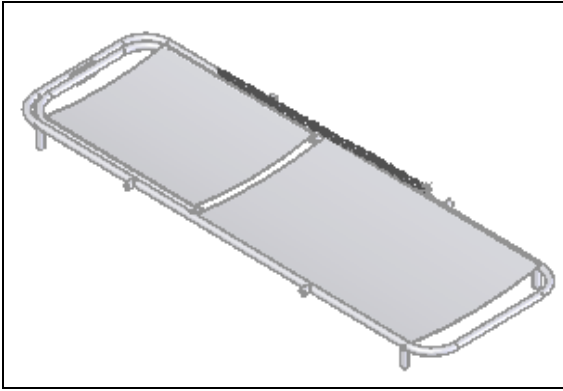


Figure 98. Backrest can lie flat

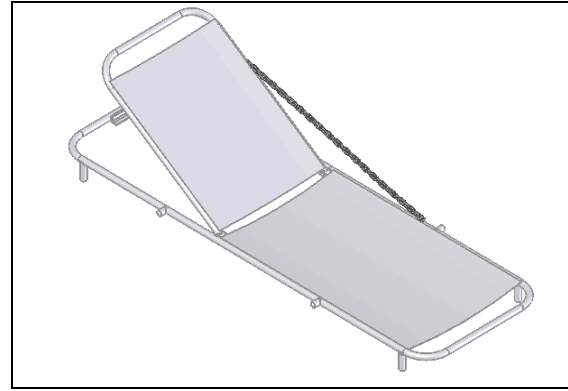


Figure 99. Chain secures inclined backrest

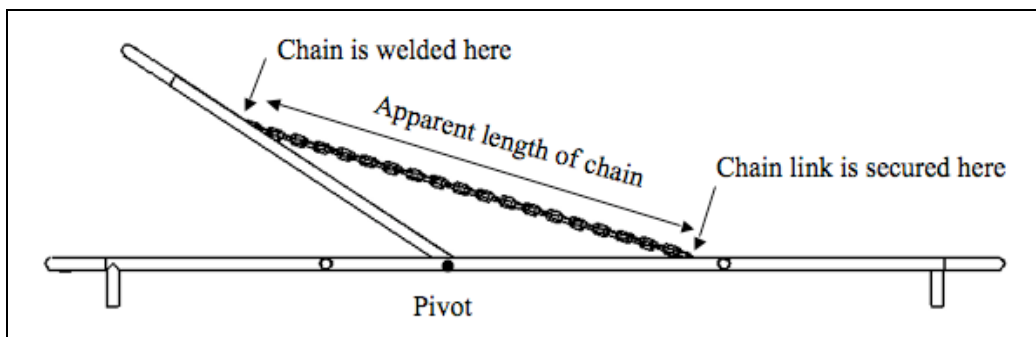


Figure 100. Schematic of stretcher with an inclined backrest

The apparent length of the chain is the distance from where one end is welded on the backrest frame to where a chain link on the other end is secured on the stretcher frame (see Figure 100). The chain is located by placing its midpoint directly above the pivot, and welding one end to the backrest when it is flat, and securing the other end in the chain lock (see Figure 101a). Chain is sold in one-meter lengths, but the longest apparent length ($2a$) of the chain is about 95cm since a few centimeters are lost due to welding or being enclosed in the chain lock (see Figure 101a).



Figure 101. a) Chain secured when backrest is flat or inclined, b) Chain gauge schematic

Three chain gauges (3mm, 5mm, and 8mm) are readily available where Disacare purchases their other metal components. The chain gauge is determined by the diameter of the cross-sectional area of one link (see Figure 101b). The 5mm gauge chain was selected for the backrest by analyzing the tensile force (F_t) in the chain due to an applied force (F_a), acting in the direction normal to the surface.

It is assumed that the chain is most likely to break when the user steps on the end of the backrest with the backrest at the minimum angle of 15 degrees from the horizon. The applied force (F_a) acts at the end of the backrest which is a distance x from the backrest pivot. The applied force is countered by the tensile force in the chain. Dividing the tensile force by the cross sectional area of one leg of a chain link will provide the tensile stress σ_t in the chain link.

The equation for tensile stress is derived based on the following assumptions, calculations, and equations. From geometry, it is possible to relate the distances and angles shown in Figure 102. Since the chain is located with its midpoint above the pivot, it is secured a distance c (half of the maximum apparent length) in either direction from the pivot. The line that is perpendicular to the chain and intersects the pivot, divides the chain in halves of length a (half of the apparent length at that time). The angle that the backrest makes with the horizon is θ , while the angle that the chain makes with the horizon is α , which is half of θ by geometry.

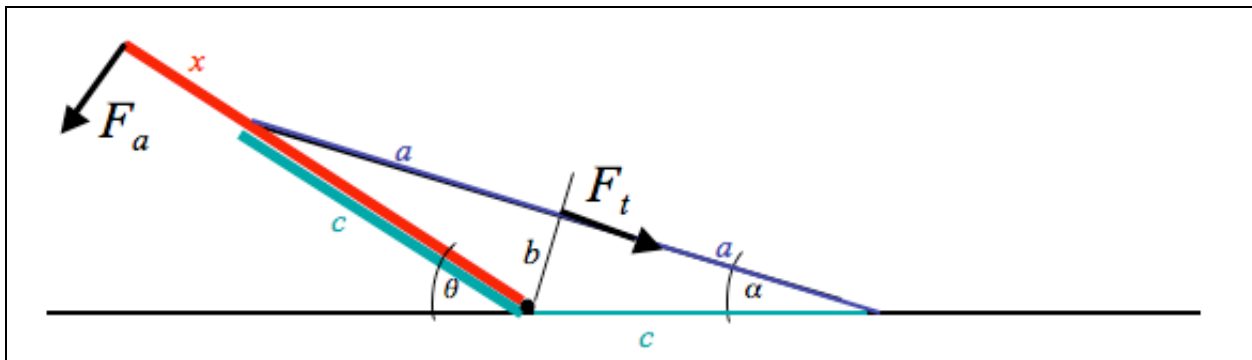


Figure 102. Basic force diagram of backrest, stretcher, and chain

By balancing the moments about the pivot, the applied force F_a can be related to the tensile force F_t (see Equation 1.6).

$$F_a x = F_t b \quad (1.6)$$

where F_a is the applied force at end top of the backrest
 x is the distance from the pivot to the applied force
 F_t is the applied force at end top of the backrest
 b is the perpendicular distance from F_t to the pivot

By geometry, b can be expressed in terms of L and θ (see Equation 1.7), and substitution will result in the tensile force F_t (see Equation 1.8).

$$b = c \sin(\alpha) = c \sin(\theta/2) \quad (1.7)$$

where c is the distance between the pivot and the point at which the chain welded to the backrest
 α is the angle that the chain makes with the horizon
 θ is the angle that the backrest makes with the horizon

$$F_t = \frac{F_a x}{c \sin(\theta/2)} \quad (1.8)$$

where F_a is the applied force at end top of the backrest
 x is the distance from the pivot to the applied force
 c is the distance between the pivot and the point at which the chain welded to the backrest
 θ is the angle that the backrest makes with the horizon

By dividing the tensile force F_t by the cross sectional area of the chain link, the equation for tensile stress σ_t can be derived (see Equation 1.9).

$$\sigma_t = \frac{F_a x}{c \sin(\theta/2) * (\pi d^2/4)} \quad (1.9)$$

where F_a is the applied force at end top of the backrest
 x is the distance from the pivot to the applied force
 c is the distance between the pivot and the point at which the chain welded to the backrest
 θ is the angle that the backrest makes with the horizon
 d is the diameter of the cross sectional area of the chain link

Using the equation for tensile stress and the assumptions and dimensions shown in Table 11, the tensile stress for chain gauges 3mm, 5mm, and 8mm are shown in Table 12 for values of theta ranging from 15 to 90 degrees at 15-degree increments. The 3mm chain is inadequate to withstand 70kg or 150lb person pushing with all their weight against the top of the backrest. The 5mm chain is just adequate to sustain this scenario of misuse. The 8mm chain would be unnecessarily robust, and it would increase weight and cost needlessly.

Table 11. Assumptions and dimensions for chain analysis

Assumptions:	
Weight of Person (W) [kg]	70
Yield Stress (Y) [Mpa]	250
Dimension of stretcher components:	
Backrest length (x) [cm]	85
Length of chain ($2c$) [cm]	95

Table 12. Results of chain analysis

Angle (θ) [degrees]	Chain Gauge (d) 3mm chain	Chain Gauge (d) 5 mm chain	Chain Gauge (d) 8 mm chain
15	665 MPa	239 MPa	94 MPa
30	335 MPa	121 MPa	47 MPa
45	227 MPa	82 MPa	32 MPa
60	174 MPa	63 MPa	24 MPa
75	143 MPa	51 MPa	20 MPa
90	123 MPa	44 MPa	17 MPa

Note: Bold values exceed the assumed yield stress

1.3 Analysis of the lock for the backrest chain

It is assumed that when a patient is lying down, half of his weight is on the backrest, acting at about one-third the length of the backrest ($x/3$) from the pivot point.

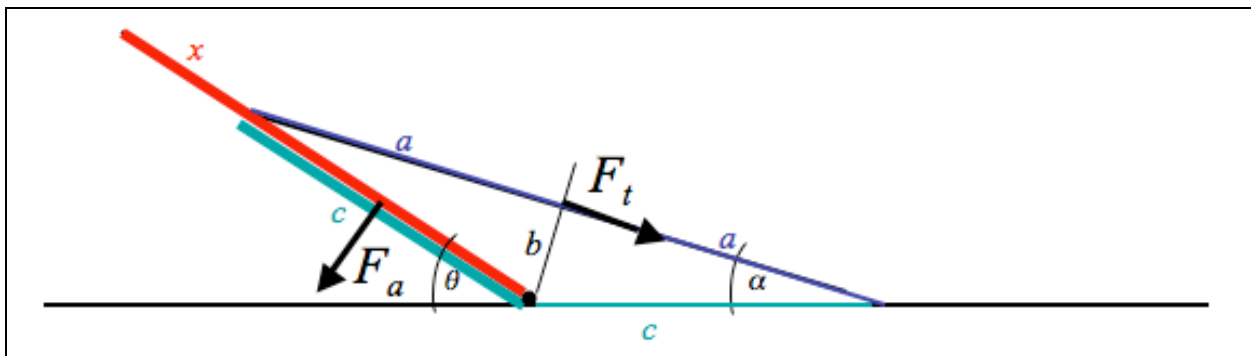


Figure 103. Basic force diagram of backrest, stretcher, and chain

From a moment balance described in more detail in section 1.2, the tensile force F_t in the chain can be expressed in Equation 1.10.

$$F_t = \frac{F_a(x/3)}{c \sin(\theta/2)} \quad (1.10)$$

where F_a is the applied force at end top of the backrest
 x is the distance from the pivot to the applied force
 F_a is the applied force due to half of the patient's weight
 $x/3$ is the distance from the pivot to the applied force
 c is the distance between the pivot and the point at which the chain welded to the backrest
 θ is the angle that the backrest makes with the horizon

The chain lock can be modeled as a simply supported beam with a central point load. The expression for bending stress is shown in Equation 1.11.

$$\sigma = \frac{My}{I} = \left(\frac{F_t}{2}\right)\left(\frac{D}{2}\right)\left(\frac{d}{2}\right)\left(\frac{1}{\frac{\pi d^4}{64}}\right) \quad (1.11)$$

where σ is the bending stress
 M is the moment at the neutral axis
 y is the perpendicular distance to the neutral axis
 I is the area moment of inertia about the neutral axis
 F_t is the tensile force in the chain
 D is the diameter of the tube encasing the chain
 d is the diameter of the solid lock rod



Figure 104. Chain lock schematic of a simply supported beam with a central point load

The parameters listed in Table 13 were used to calculate the results shown in Table 14. The chain lock is able to support the weight of a person that is almost 90 kg or almost 200lbs.

Table 13. Properties and dimensions of chain and chain lock components

Yield Stress (Y) [Mpa]	250
Backrest length (x) [cm]	85
Length of chain ($2c$) [cm]	95
Angle between backrest and horizon (θ) [degrees]	15
Diameter of chain lock (D) [cm]	2.5
Diameter of locking rod (d) [mm]	8

Table 14. Results of chain lock analysis with different loads

Input: Weight of person (W) [kg]	70	80	90
Applied Force (F_a) [N]	343	392	441
Tensile Force (F_t) [N]	1567	1791	2015
Stress at center [Mpa]	195	223	251

1.4 Analysis of the hitch

The hitch was designed with M16 nuts rotating upon threaded bolts because the threads provide a mechanical advantage over a nut whose threads have been removed, or a smooth shaft. This concept can be exemplified by analyzing the moment about the center of rotation of the shaft.

If a torque T is exerted on the shaft, the edges of the nut can exert reaction forces F_r in the radial direction, acting at a perpendicular distance y to the center of rotation (see Figure 105). If the same torque T is exerted on a threaded bolt, the nut can exert reaction forces F_N in the direction normal to the faces of the threads (see Figure 106). These normal forces act at a distance z from the center of rotation.

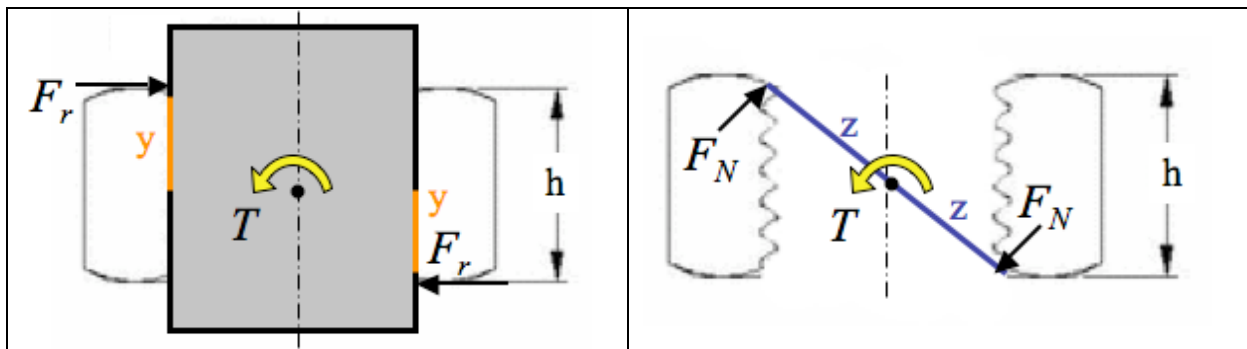


Figure 105. Analysis of smooth nut

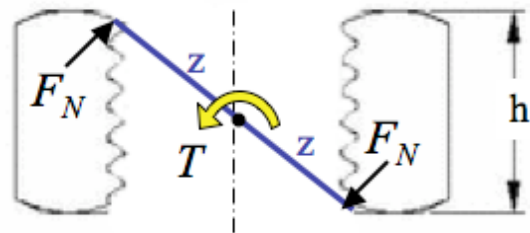


Figure 106. Analysis of threaded nut

Since the moment produced by the reaction forces must counter the applied torque, the moments can be set equal to each other to compare the radial force F_r and normal force F_N (see Equation 1.12).

$$F_r y = F_N z \quad (1.12)$$

where F_r is the radial force exerted by the edges of a smooth nut
 y is the perpendicular distance from the pivot to F_r
 F_N is the normal force exerted by the faces of the nut thread
 z is the perpendicular distance from the pivot to F_N

By geometry, y can be related to z since d the diameter of the nut is 16mm (see Equation 1.13).

$$(d/2)^2 + y^2 = z^2 \quad (1.13)$$

where d is the diameter of the hole in the nut
 y is the perpendicular distance from the pivot to F_r
 z is the perpendicular distance from the pivot to F_N

The ratio of F_r to F_N is shown in Equation 1.14.

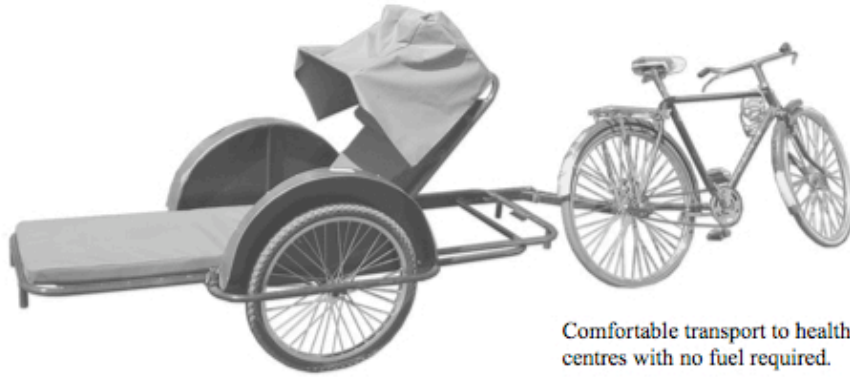
$$\frac{F_r}{F_N} = \frac{z}{y} = \frac{\sqrt{(d/2)^2 + (h/2)^2}}{(h/2)} \quad (1.14)$$

where F_r is the radial force exerted by the edges of a smooth nut
 F_N is the normal force exerted by the faces of the nut thread
 z is the perpendicular distance from the pivot to F_N
 y is the perpendicular distance from the pivot to F_r
 d is the diameter of the hole in the nut
 h is the height of the nut

For an M16 nut with a diameter of 16mm and a height of 12mm, the ratio of F_r to F_N is 5:3. The unthreaded shaft and nut will be able to withstand a little more than half the force that a threaded bolt and nut can withstand. If the threads on the bolt contact more than one thread on the nut, the forces that the hitch is able to withstand before failure or jamming, is even greater.

APPENDIX C: USER MANUAL

The Zambulance (BICYCLE AMBULANCE) USER MANUAL



Comfortable transport to health centres with no fuel required.

Attaching the Trailer to the Bicycle



Figure 1:

- The CLAMP should STAY on the BICYCLE.
- The NUTS and BOLTS should stay with the TRAILER.
- The TOP TWO NUTS should NOT MOVE.
- All other BIG (M16) NUTS should TURN FREELY on the threaded part.
- Nuts should be at the CENTER of the THREADED part.

Attaching the Clamp to the Bicycle

Parts involved:



Figure 3: Clamp Backing



Figure 4: Clamp Face



Figure 2: Winged-bolts (2)



Figure 5: Bolt Assembly

Manufactured by:
DISACARE WHEELCHAIR CENTRE
Plot 11305, Libala
Off Chilimbulo Road Behind Libala High School

P.O. Box 50091 RW,
LUSAKA, Zambia.
Telefax: (+260) 1 261712
E-mail: disacare@zamnet.zm

Designed by:
JESSICA VECHAKUL
E-mail: bike.ambulance@gmail.com
<http://cadlab6.mit.edu/bike.ambulance>



Figure 6: The clamp backing should be on the INSIDE of the frame on the LEFT side of the bike, (LONG ARM is on the BOTTOM, & SHORT ARM is on the TOP).



Figure 7: Tighten the clamp face to the clamp backing with the winged-bolts. CLAMP should NOT MOVE. DO NOT OVERTIGHTEN or bicycle frame will be dented.



Figure 8: Put the LARGE (M16) BOLT into the BOTTOM of the TUBE and screw on the nut until there is only a SMALL GAP. The BOLT should TURN freely.



Figure 9: Hold the 1st nut, & tighten the top nut against the 2nd nut so the TWO NUTS DO NOT MOVE.



If the threads are damaged, show the bolts and nuts to a local welder, and he should be able to make a replacement with three M16x50 bolts, one M16x100 bolt, and 2 M16 nuts. Cut off the old bolts and replace with new ones.

IMPORTANT: When attaching the bolts, make sure they form an "L" shape as shown to the left.

Placing the Stretcher onto the Trailer



Figure 10: At least two people are required to carry the stretcher.



Figure 11: One TUBE should be in FRONT and one BEHIND the half circle FENDERS to keep the stretcher from sliding or moving.

Adjusting the Backrest



Figure 12: Lift the backrest and hook the chain to the hook to hold the backrest in a comfortable position



Figure 13: Hook the chain even when it is not in use to prevent it from dragging or hitting the wheel

If the hook breaks, have a local welder attach the largest piece of metal that will fit in the chain link in the same place as the hook. R8 rebar or solid steel rod is recommended.

If there are any cracks between parts or if any welds break, have a local welder repair it before any pieces fall off.

- **The *Zambulance* should last for several years unless it is misused.**
- **The *Zambulance* can carry ONE passenger at a time from their homes to health centers.**
- **The *Zambulance* should only transport PEOPLE, not heavy objects.**

Maintenance of the *Zambulance*



Figure 14: The mattress should be CLEANED with SOAP or DISINFECTING SPIRIT or ALCOHOL after carrying patients with blood wounds or disease.



Figure 15: Store the Zambulance in a SAFE and DRY location that is NOT in the sun

Mounting and Removing the Wheels

The wheels to the *Zambulance* are attached to the trailer the same way that wheels are attached to a bicycle. To change a wheel, turn the trailer upside down and loosen the nuts with a spanner, as shown in *Figure 16*. To avoid losing the nuts, do not remove them from the axle completely, but just enough to remove the wheel. To remove the wheels, loosen the nuts until the axle is free to slide out of the slots, as shown in *Figure 17*.



Figure 16: Use front hubs with 36 spoke holes. Make sure the wheels are straight before tightening.



Figure 17: Push the axle as far into the slots as possible and tighten the nuts so the wheel does not fall off.

If a new mattress or canopy is needed, or if you have any questions about repairs or spares, please contact Disacare Wheelchair Centre with information shown below.

Manufactured by: DISACARE WHEELCHAIR CENTRE Plot 11305, Libala Off Chilimbulu Road Behind Libala High School	P.O. Box 50091 RW, LUSAKA, Zambia, Telefax: (+260) 1 261712 E-mail: disacare@zamnet.zm	Designed by: JESSICA VECHAKUL E-mail: bike.ambulance@gmail.com http://cadlab6.mit.edu/bike.ambulance
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APPENDIX D: RECORD FORMS

Bicycle Ambulance Registration Form

Please fax, post, or e-mail this form to Disacare Wheelchair Centre to register your ambulance.
P.O. Box 50091, Telefax: (+260) 1 261712, E-mail: bike.ambulance@gmail.com

Disacare can better assist you with your ambulance questions if you register.

Name of Community Group/ Health Center: _____

Postal Address: _____

Name of Manager: _____

Phone Number: _____ **E-mail:** _____

Date Ambulance Was Received: _____ **Donated or Purchased by:** _____

Please describe your community or organization:

1. When was your group established?
2. What is the purpose of your group?
3. How many people are in your organization and what are their roles?
4. What type of people do you serve (age, occupation, gender, location, illness, etc.)?
5. How large of an area does your group serve?
6. Please describe how your group operates financially. Do you do any activities to raise money? Which of your activities require funds?

Please describe the impact of the bicycle ambulance:

7. How did patients travel to health centres before the ambulance became available.
8. Is the ambulance cheaper, faster, or safer than these other methods?
9. What do people say when they hear about the bicycle ambulance? Or when they see it?
10. Who is able to access the ambulance? How do people access the ambulance?
11. How much has the number of patients visiting the health center increased since the ambulance became available?
12. How many times was the bicycle ambulance not usable during the last 2 months? Why?
13. Is there anything you would change about the bicycle ambulance?
14. Do you think your area needs another bicycle ambulance? If yes, how many?

Please describe the maintenance of the bicycle ambulance:

15. How many people paid for a trip on the bicycle ambulance? How much? What was the money used for?
16. What has broken on the ambulance? How was the repair paid for?
17. How do you clean the stretcher or mattress? How often do you clean it? Where is the ambulance stored?
18. Who is allowed to use the ambulance as the bicycle rider?

Bicycle Ambulance Record Form

Name of your group: _____ P.O. Box _____, City: _____ Tel. Num.: _____
 Please fax, post, or e-mail this form to Disacare Wheelchair Centre every 3 months. P.O. Box 50091, Telefax: (+260) 1 261712, E-mail: bike.ambulance@gmail.com

No.	Date	Bicycle Rider	Rider's Relation	Patient's Name	Sex	Age	Pick-Up Location	Drop-Off Location	Distance traveled	Time for Trip	Reason for Transport
Ex.	13/8/07	John Phiri	NHC volunteer	Jessica Vechakul	F	23	Zone 5	Mt.Makulu clinic	9km	1hr 20min	pregnancy
Ex.	14/8/07	John Banda	patient's brother	Brighton Banda	M	34	NHC Ofce	Hospice	5km	1hr 20min	malaria
1											
2											
3											
4											
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Please copy this table onto the back of this page or onto another page if you need more space. Please send all forms to Disacare.

APPENDIX E: SURVEY FORMS

Bicycle Ambulance Operator Registration Form

Name of your group: _____ P.O. Box _____, City: _____ Tel.: _____

Please fax, post, or e-mail this form to Disacare Wheelchair Centre every 6 months.

P.O. Box 50091, Telefax: (+260) 1 261712, E-mail: bike.ambulance@gmail.com

The following questions need to be answered every 6 MONTHS by each ambulance operator.

Name: _____ Age: _____ Occupation: _____ Date: _____

1. How many times did you personally operate the bicycle ambulance to transport a patient?
2. Usually, how is transport with the ambulance requested? Telephone? Sending a family member? Home-based care visit? Neighborhood health Committee?
3. How many times was the ambulance not available when you needed it? Why?
4. How far (in kilometers) is a typical trip on the bicycle ambulance, and how long does it take (in minutes)?
5. What was the terrain or road like? Gravel Paved Dirt
6. What obstacles did you encounter? Sand Hills Ditches (How deep?)
7. What difficulties did you have with controlling the bicycle while pulling the ambulance? Was it hard to turn or to pedal or stop or to keep your balance on the bicycle?
8. On how many trips did you have to pull the ambulance by hand? Why? (example: uphill)
9. On how many trips did you use the stretcher separately from the trailer or wheels to transport the patient? Why? (example: path to house was not bicycle accessible)
10. On how many trips did you transport a patient who was sitting up? How many times were they lying flat on their back? Sitting: _____ Lying down: _____
11. How would you improve the bicycle ambulance?
12. What do people say when they hear about the bicycle ambulance? Or when they see it?
13. Please describe what you think of the following bicycle ambulance parts, and what you would change.

Clamp onto bicycle frame	
Hitch between bicycle & trailer	
Canopy to protect from sun/rain	
Removable stretcher	
Sheet metal bed on stretcher	
Foam mattress	
Chain to adjust backrest	
Fenders and mudguards	
Small 24 inch trailer wheels	
Other	

Bicycle Ambulance Patient Survey

Name of Health Centre: _____ P.O. Box _____, City: _____ Tel.: _____

Please fax, post, or e-mail this form to Disacare Wheelchair Centre.

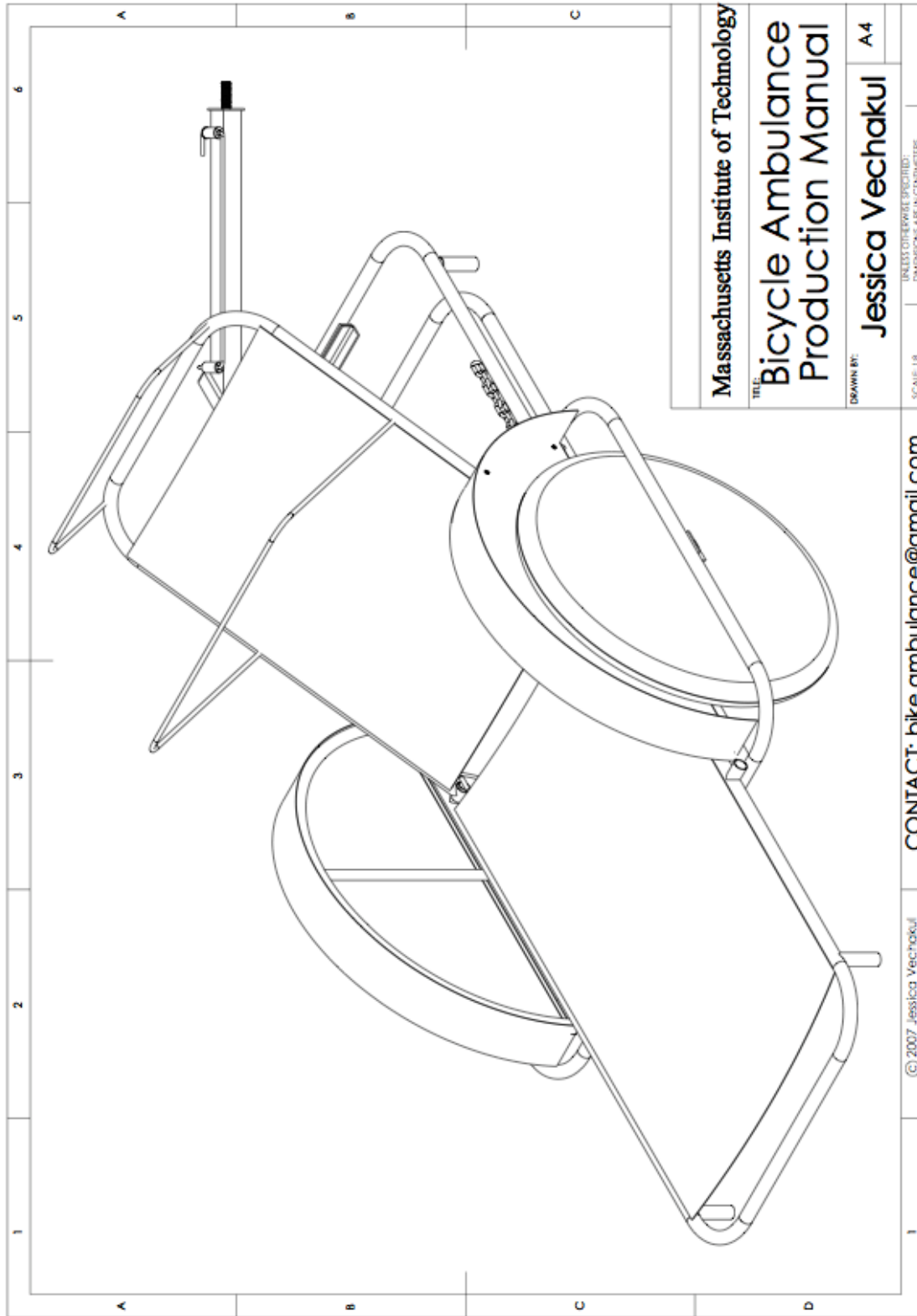
P.O. Box 50091, Telefax: (+260) 1 261712, E-mail: bike.ambulance@gmail.com

The following questions should be answered by any patient who is willing to comment on the ambulance.

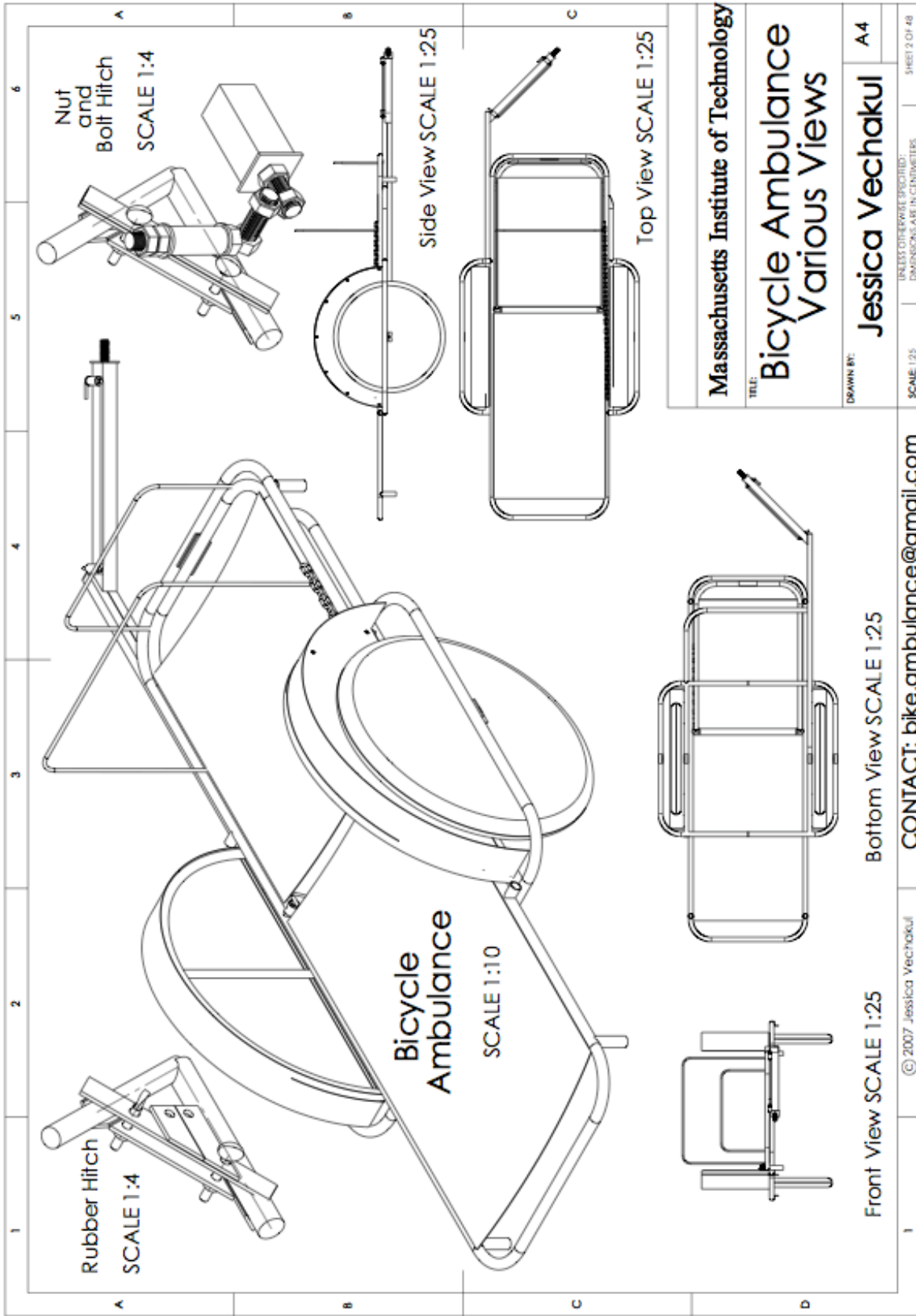
Name: _____ **Age:** _____ **Occupation:** _____ **Date:** _____

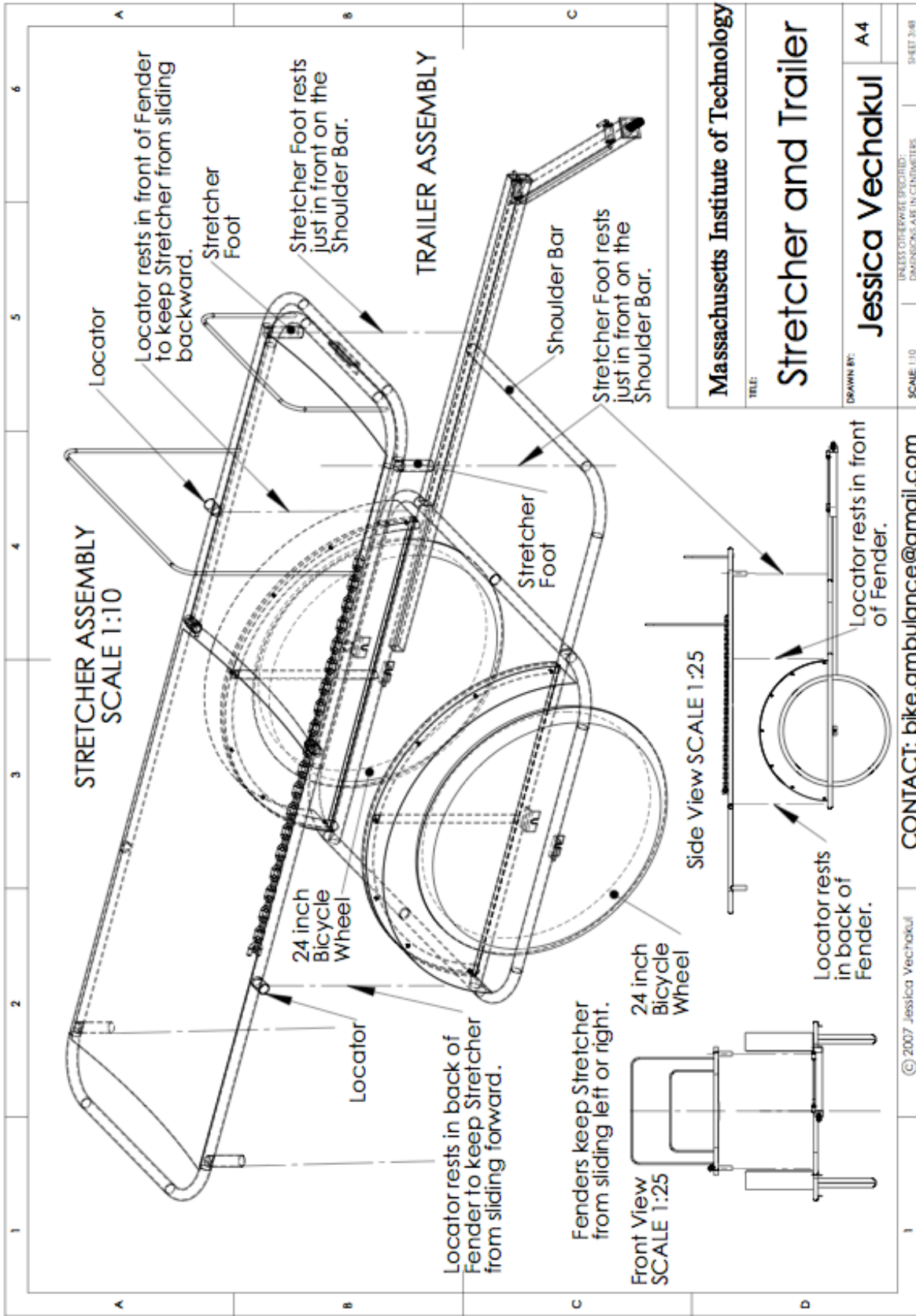
1. What kind of area do you live in? Urban Peri-urban Rural
2. For what symptoms or illness would you go to the health center (diarrhea, malaria, dysentery, etc.)
3. What, if anything, prevents you from going to the hospital when you are sick (cannot afford the fees, no transport, no time, etc.)?
4. How far (in kilometers) is your home from the health center?
5. How much time (in minutes) does the journey from your home to the health center take?
Walking: _____ minutes, By car: _____ minutes, By bicycle ambulance: _____ minutes
6. How do you normally get to the health centre (by bus or taxi)? How much does it cost?
7. How much money would you be willing to pay to use the bicycle ambulance?
8. How did you hear about the bicycle ambulance?
9. What did you think when you 1st heard about the bicycle ambulance?
10. Did you have any fears about how the bicycle ambulance? If yes, what were they?
11. Please describe your journey: (example: slow going uphill, comfortable all the way, scary crossing big road, etc.)
12. How comfortable was the journey? Did you feel safe riding on the ambulance?
13. How would you improve the bicycle ambulance?
14. Would you use the bicycle ambulance again or recommend it to others?

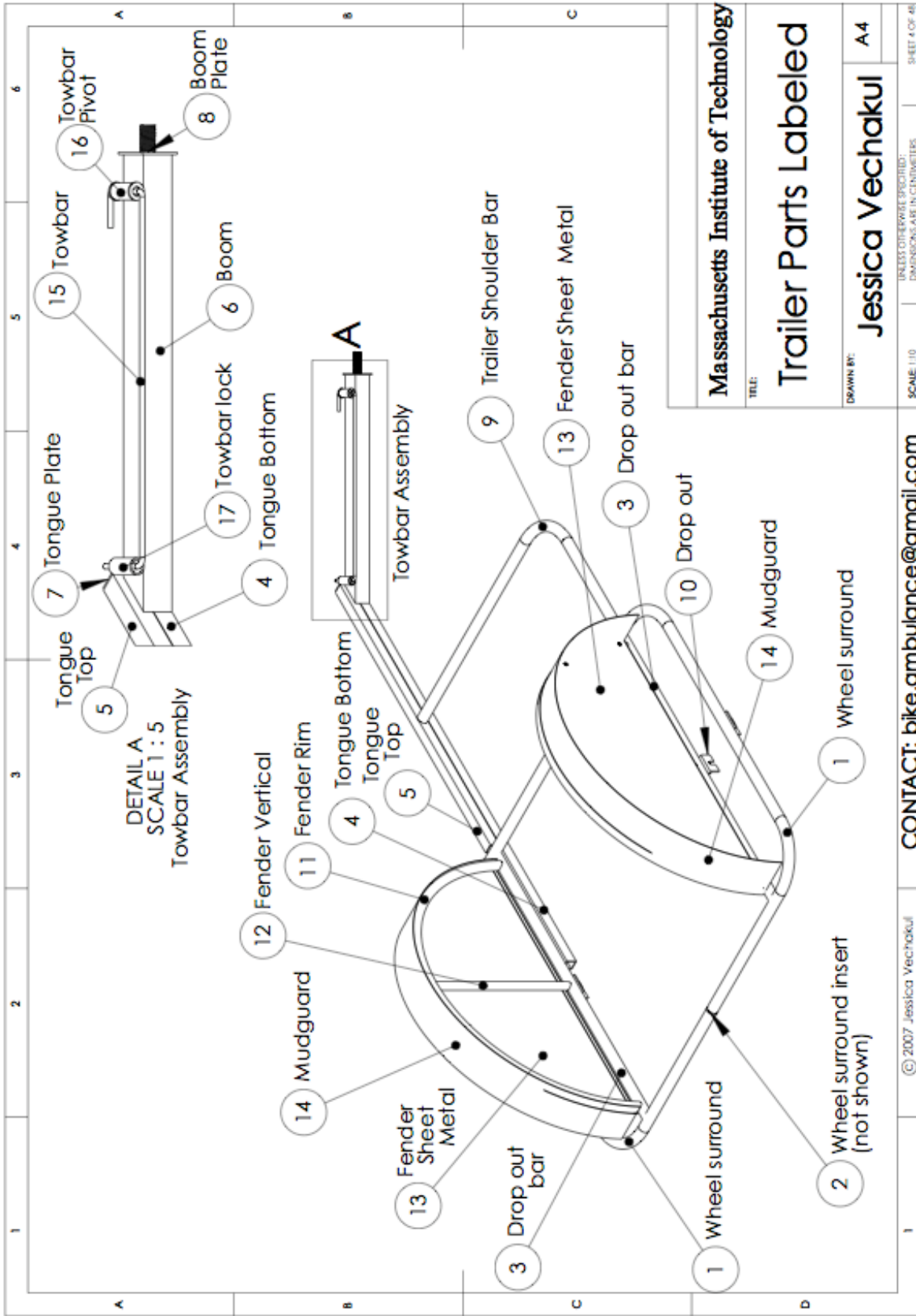
APPENDIX F: PRODUCTION MANUAL



1	2	3	4	5	6
A	<p>Executive Summary: In several developing countries, bicycle ambulances have been used to transport people in need to health centers in rural areas, where current methods of transport are inappropriate in speed, safety, cost, or availability. The bicycle ambulance in this manual was designed especially for fabrication and use in Zambia.</p> <p>Local conditions and needs vary, and the designers welcome any advice or feedback about modifications or specific needs you face in your area. Instructions and materials for the canopy cover, mattress, and rain cover have been excluded because fabrics and tailoring skills vary from country to country.</p> <p>All comments may be directed to bike.ambulance@gmail.com.</p> <p>However, we are NOT a funding agency. Any requests for funds will not receive a reply.</p>				
B	<p>Acknowledgments: The bicycle ambulance project was made possible through the sponsorship and support of the following contributors:</p> <ul style="list-style-type: none"> • MIT Mechanical Engineering Department (ME Dept.) • MIT Public Service Center (PSC) • MIT International Development Initiative (IDI) grant • University to University (U2U) program • Whirlwind Wheelchair International (WWI) 				
C	<p>The executive board and staff of Disacare Wheelchair Center in Lusaka, Zambia deserve special thanks and recognition for a wonderful collaboration and partnership in designing and producing the bicycle ambulance prototypes. The following persons are particularly commendable:</p> <ul style="list-style-type: none"> • Kenny Mubuyaeta, the production manager, for helping to coordinating the project amidst other obligations at Disacare, and for sound materials sourcing and manufacturing advice. • Evans Chinganguka, a wheelchair technician, for his tremendous dedication and effort, beyond the call of duty in helping to design and in fabricating the prototypes. • Dennis Chiwe, an expert in all types of metal fabrication, for his assistance in design and welding the ambulance prototypes. • Mbonga Mwanza, the official production welder, for learning to use the fixture and welding the first ambulance made with the fixture. Instructions for how to make and use a welding fixture will be available in the future. <p>The design and development of the Disacare's bicycle ambulance entailed Disacare's collaboration with the following engineers from abroad:</p>				
D	<ul style="list-style-type: none"> • Jessica Vechakul (MIT) • Jason Alcaraz (MIT) • Jason Moore (UC Davis) • Allen Armstrong (MIT) <ul style="list-style-type: none"> • Kurt Kombluth (WWI) • Chris Howard (WWI) • Niki Dun (DfD) <p>© 2007 Jessica Vechakul CONTACT: bike.ambulance@gmail.com</p>				
<p>Massachusetts Institute of Technology</p> <p>TITLE: Bicycle Ambulance Project Description</p> <p>DRAWN BY: Jessica Vechakul A4</p> <p style="text-align: right;">SHEET 1/48</p>					







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TITLE:

Trailer Parts Labeled

DRAWN BY:

Jessica Vechakul

A4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTIMETERS

SCALE: 1:10 CONTACT: bike.ambulance@gmail.com

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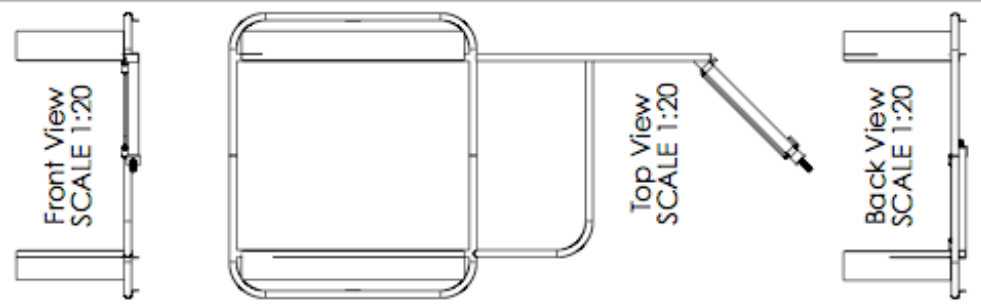
SHEET 4 OF 48

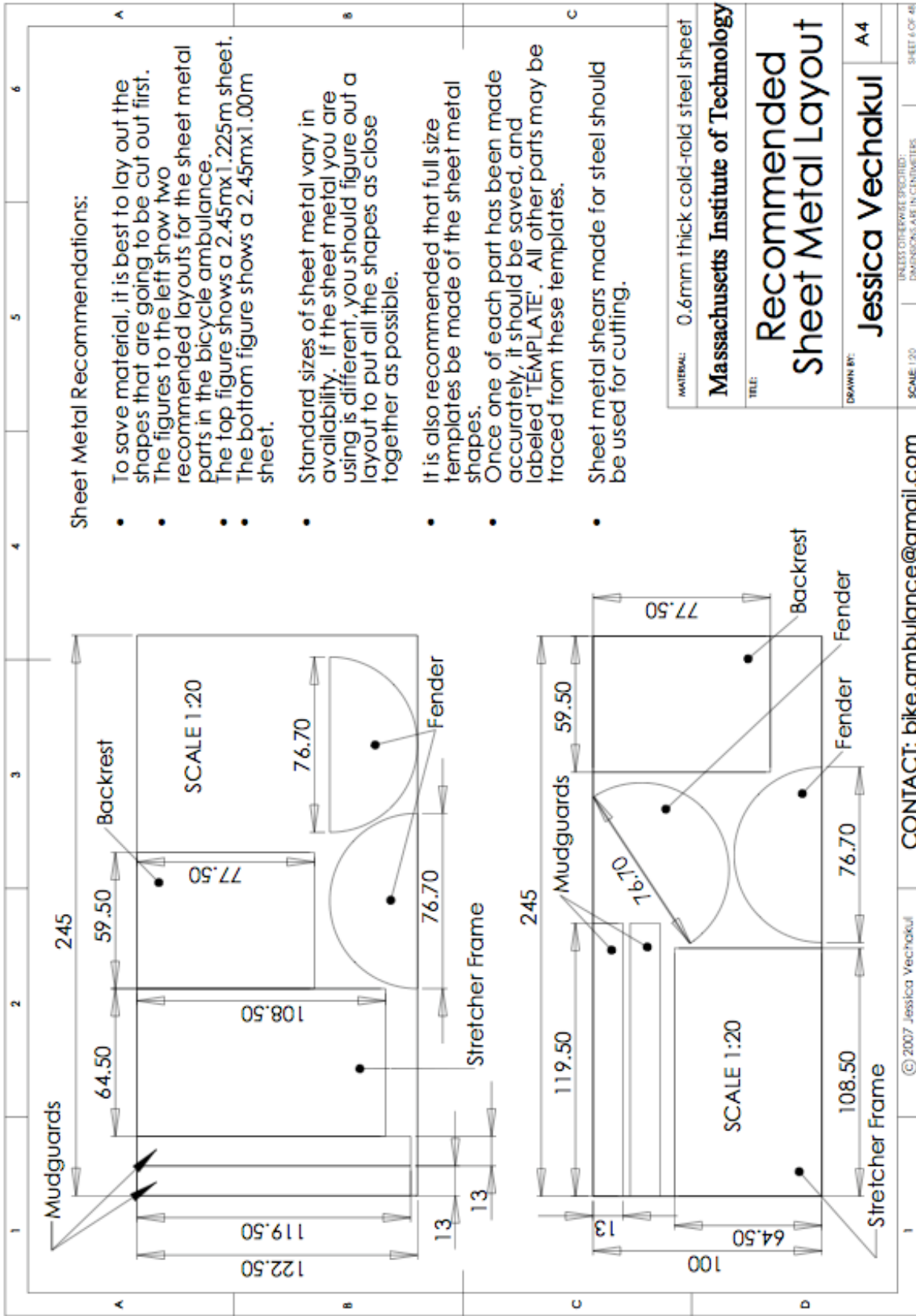
Bicycle Ambulance: Trailer Cut List

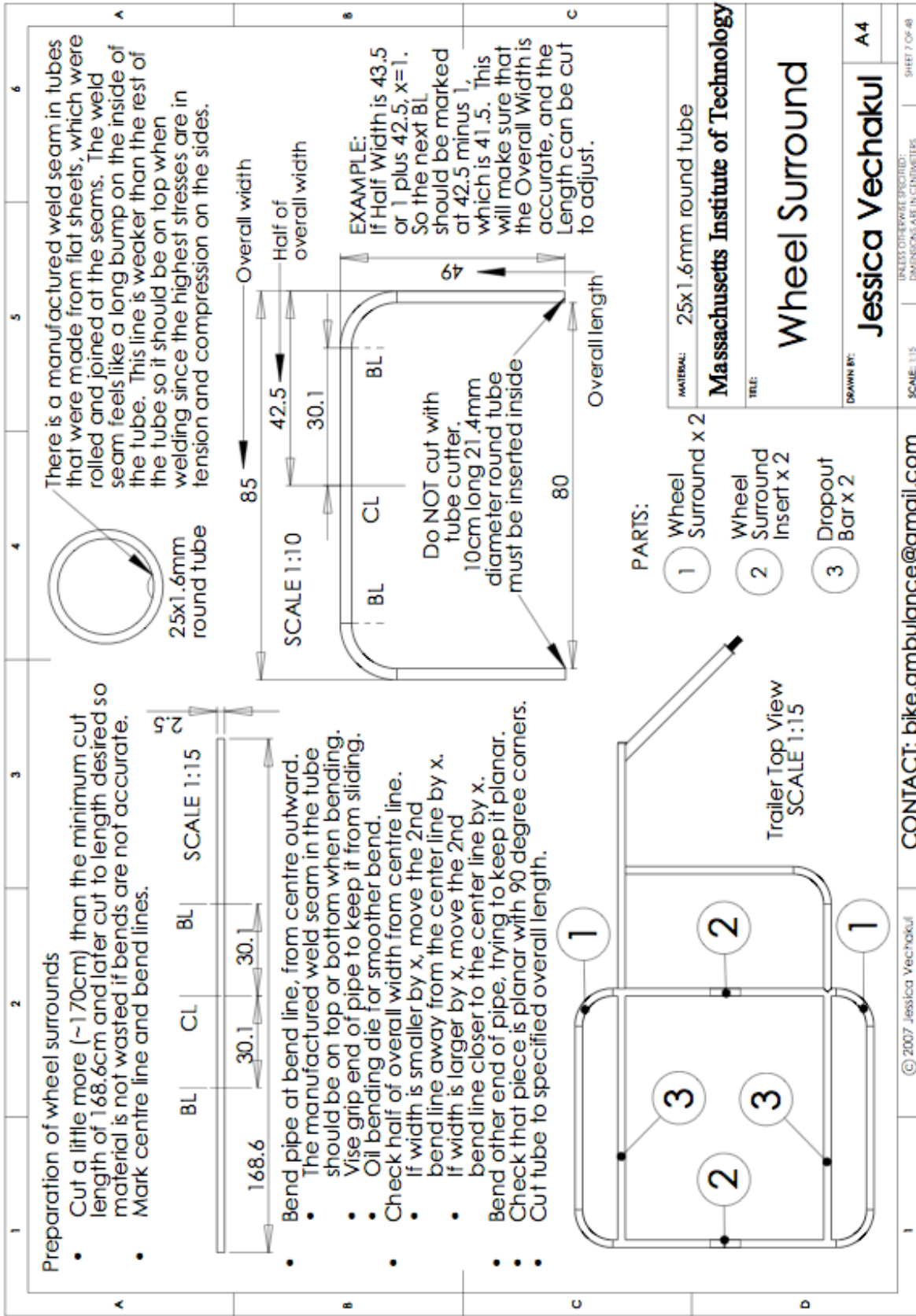
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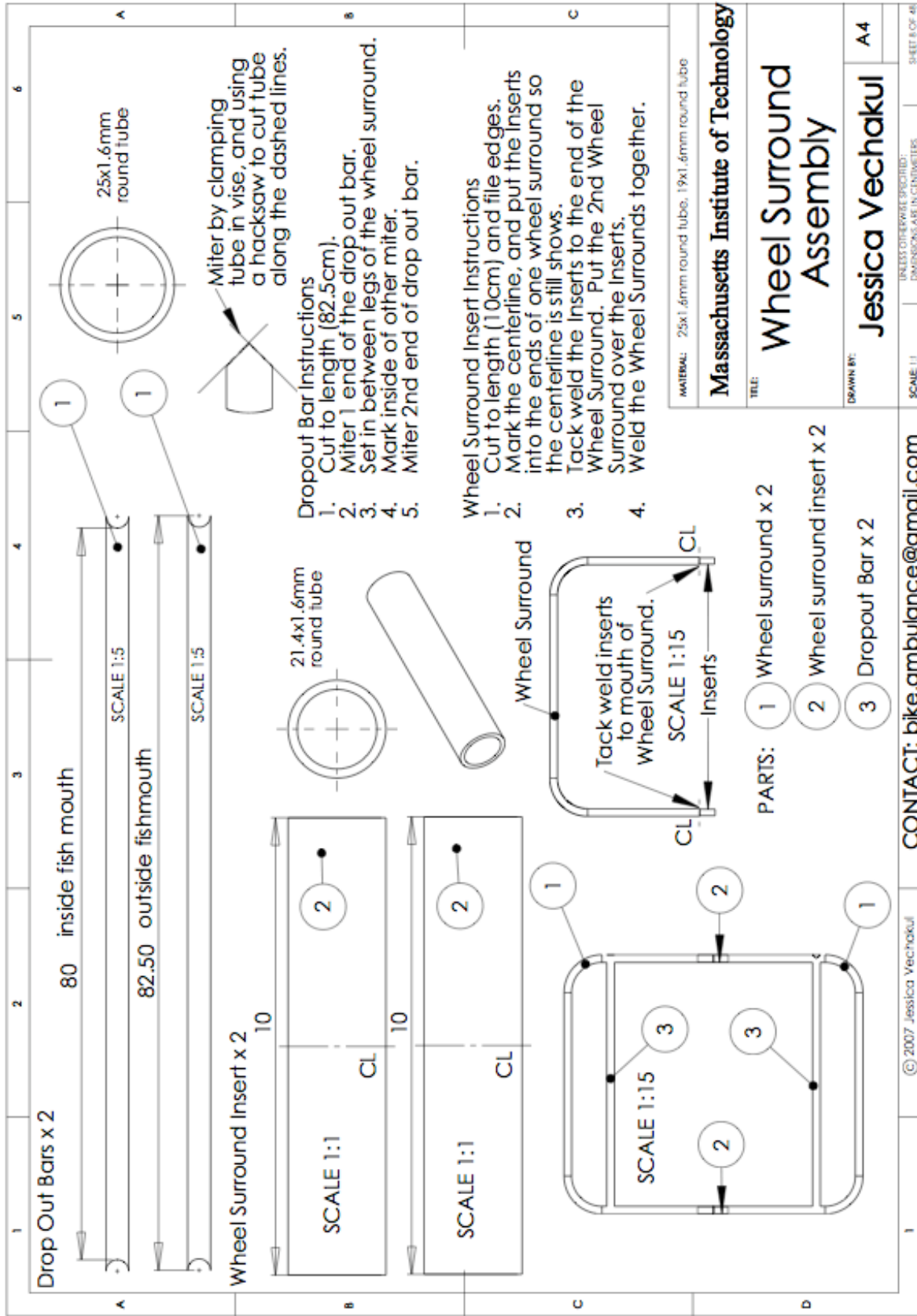
NO.	PART NAME	MATERIAL	QTY.	CUT LENGTH	PROFILE	DESCRIPTION
1	Wheel Surround	25x1.6mm round tube	2	170cm *	25	Do not use pipe cutter.
2	Wheel Surround Insert	21.4x1.6mm round tube	2	10cm	21	Mark centerline.
3	Drop Out Bar	25x1.6mm round tube	2	82.5cm	25	Miter for 25mm round tube
4	Tongue Bottom	25x1.6mm square tube	1	116.5cm	25	-
5	Tongue Top	25x1.6mm square tube	1	80.5cm	25	Miter for 25mm round tube
6	Boom	38x1.6mm square tube	1	50cm	38	
7	Tongue Plate	3mm thick steel sheet	1	4.8cmx2.9cm		Weld to front end of Tongue and side of Boom.
8	Boom Plate	3mm thick steel sheet	1	4.6cmx4.6cm		-
9	Trailer Shoulder Bar	25x1.6mm round tube	1	101.5cm *	25	Miter short end for 25mm round tube.
10	Drop Out	25x25x3mm angle iron	4	5cm	L	Mark holes carefully, and make sure all slots line up.
11	Fender Rim	19x1.6mm round tube	2	120cm	19	Cut length is for 1 Fender Rim. Make 4 Fender Rims at once.
12	Fender Vertical	19x1.6mm round tube	2	36cm	19	Miter for 25mm round tube
13	Fender Sheet Metal	0.6 thick cold-rolled steel sheet	2	76.7		-
14	Mudguard	0.6 thick cold-rolled steel sheet	2	13cmx19.5cm		-
15	Towbar	8mm round rebar (reinforcement bar)	1	57cm	8	
16	Towbar Pivot	19x1.6mm round tube	1	4cm	19	Weld washers on ends.
17	Towbar Lock	19x1.6mm round tube	1	4cm	19	-
-	Rivet	4mm OD x 8 long steel rivet	30	-	-	
-	Bolt	M8x50 hex head bolt	1	-	8	
-	Washer	M10	2	-	-	

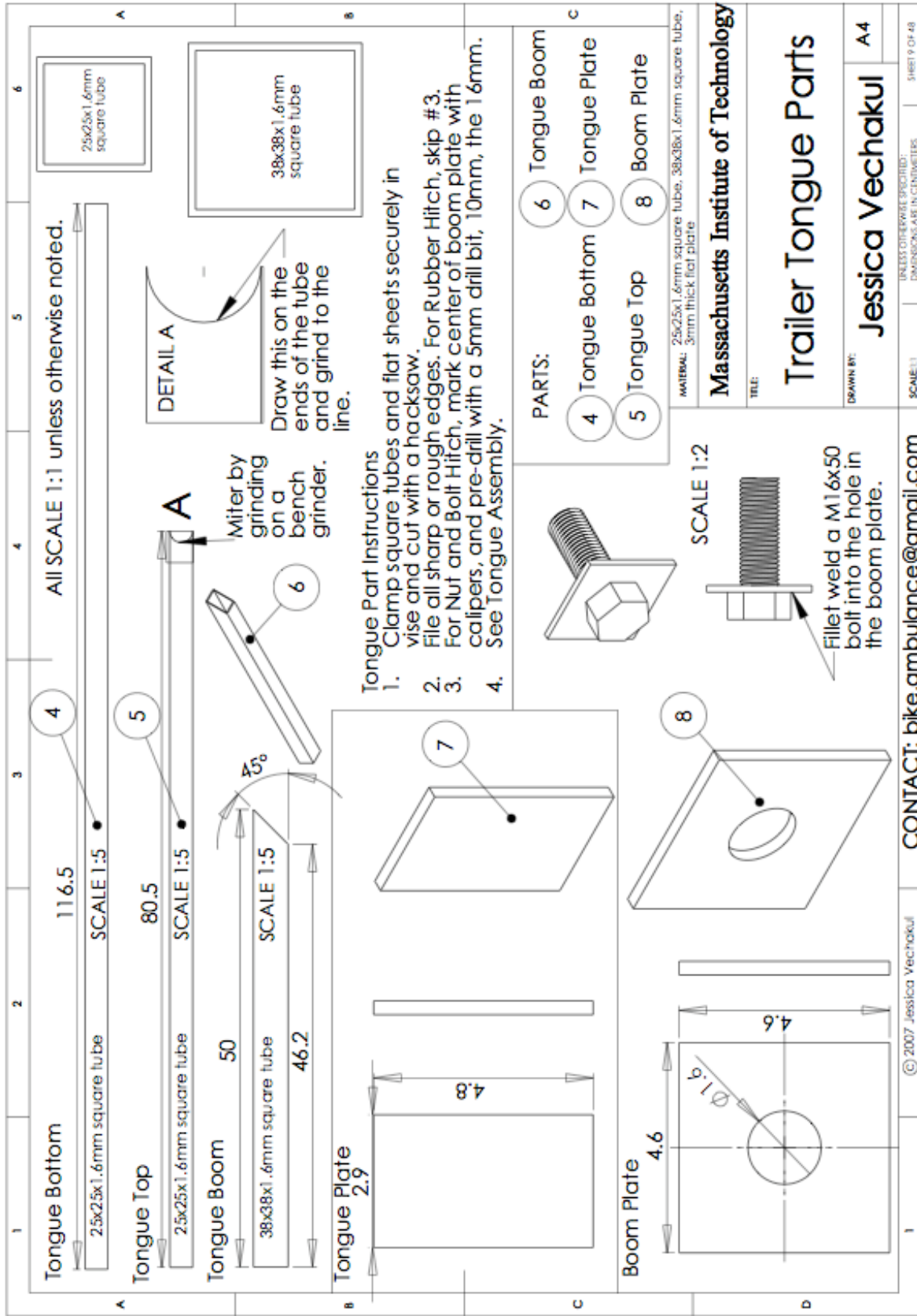
* Cut lengths dimensioned for use with a 10cm radius pipe bender.

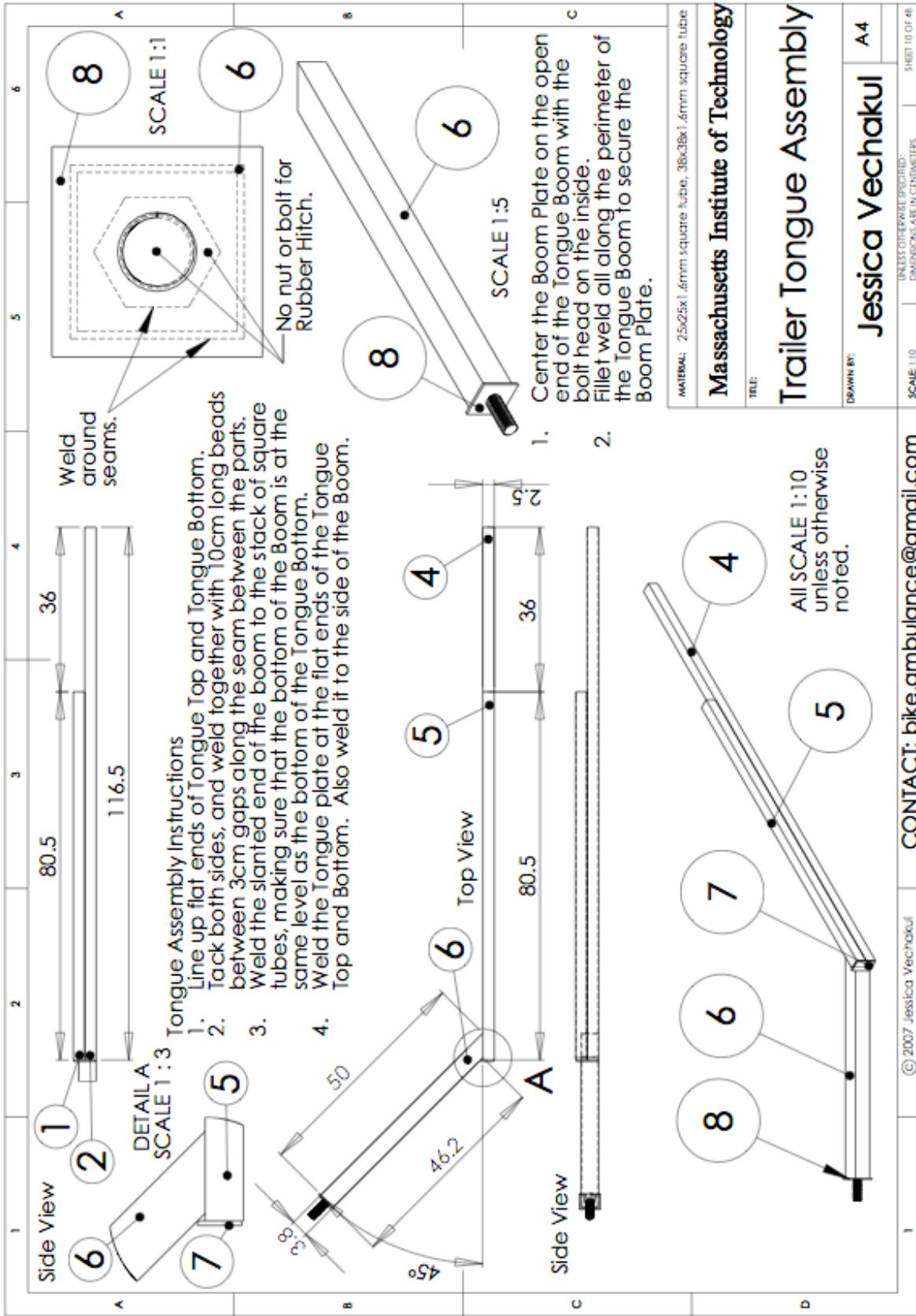


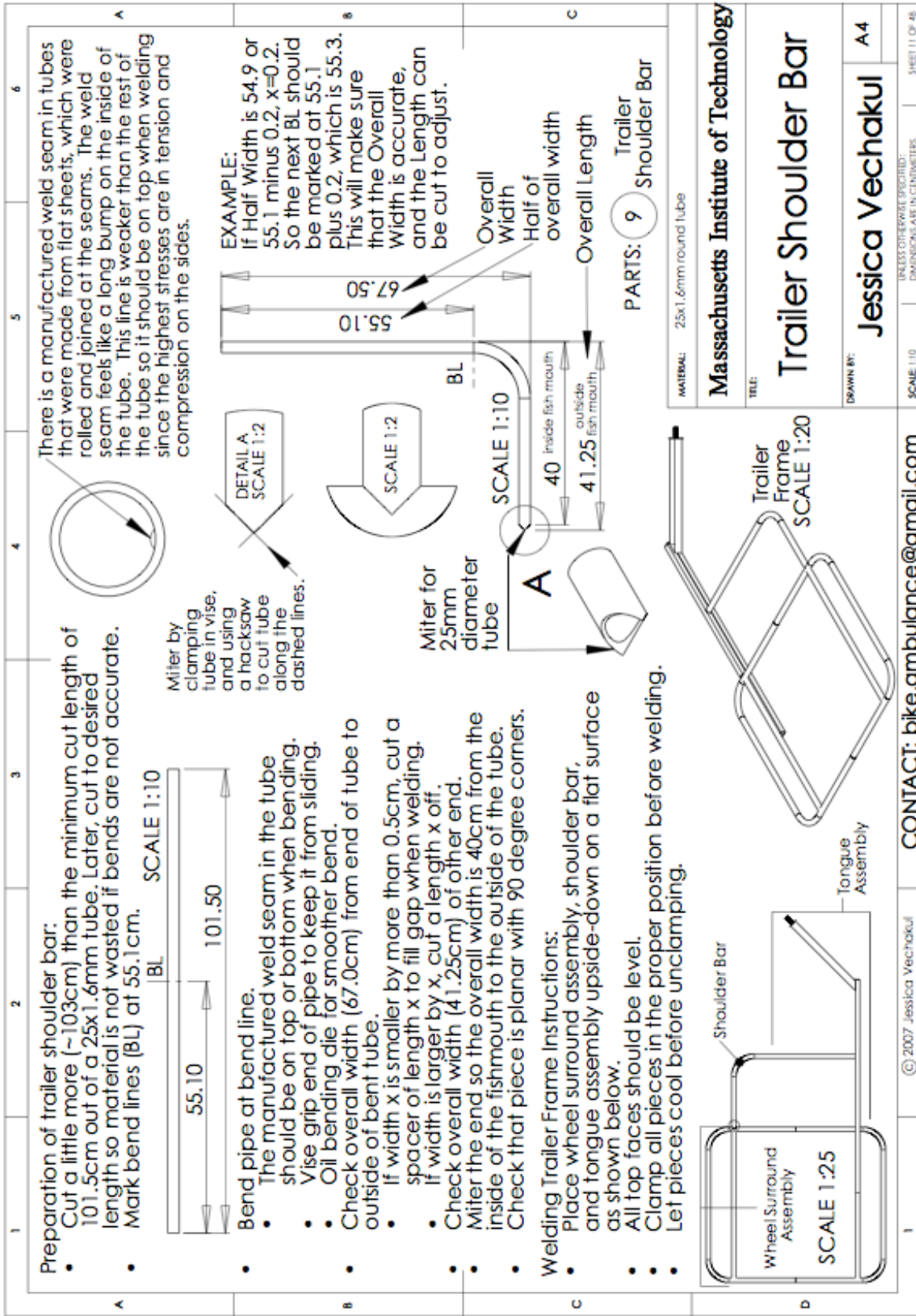


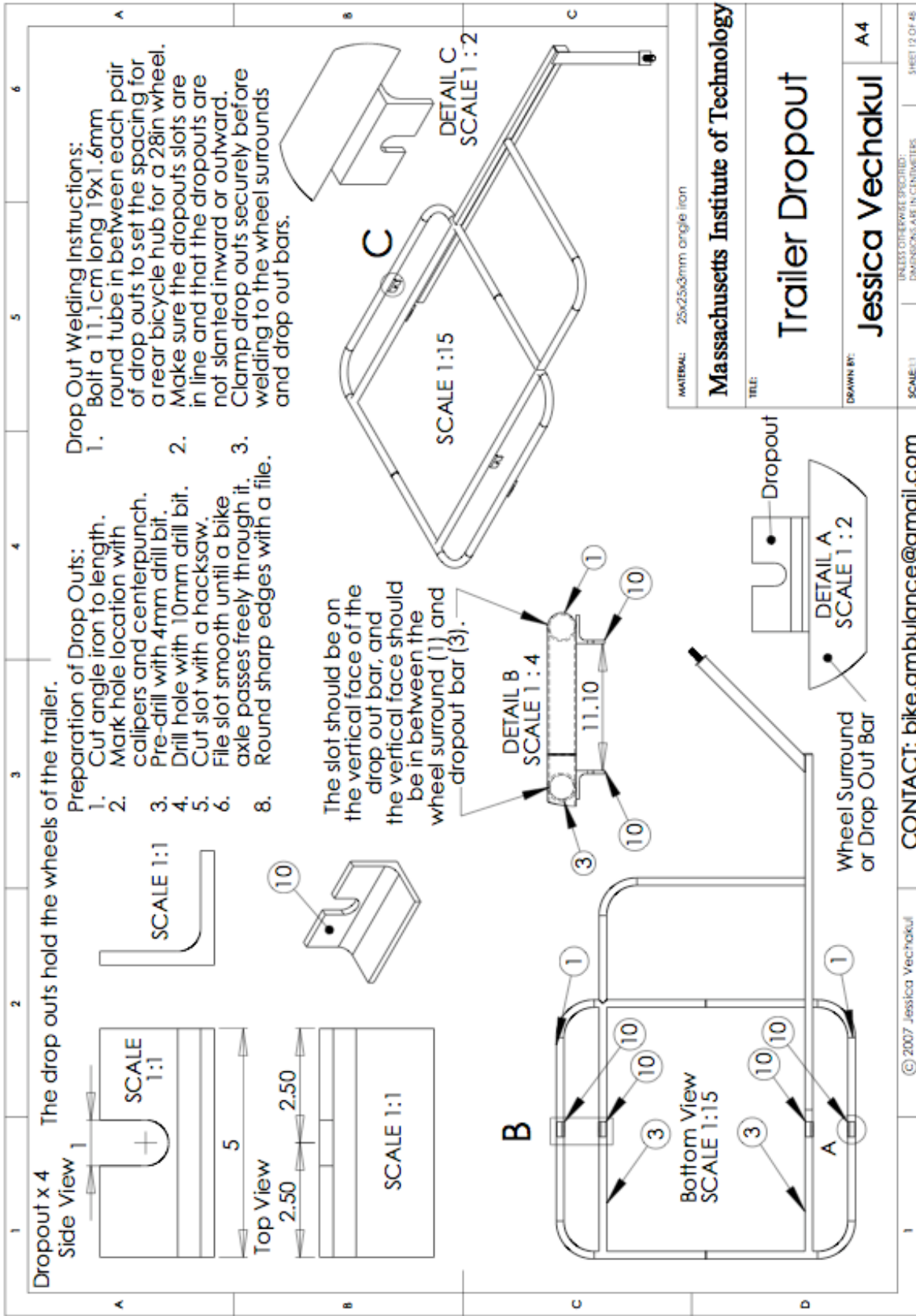


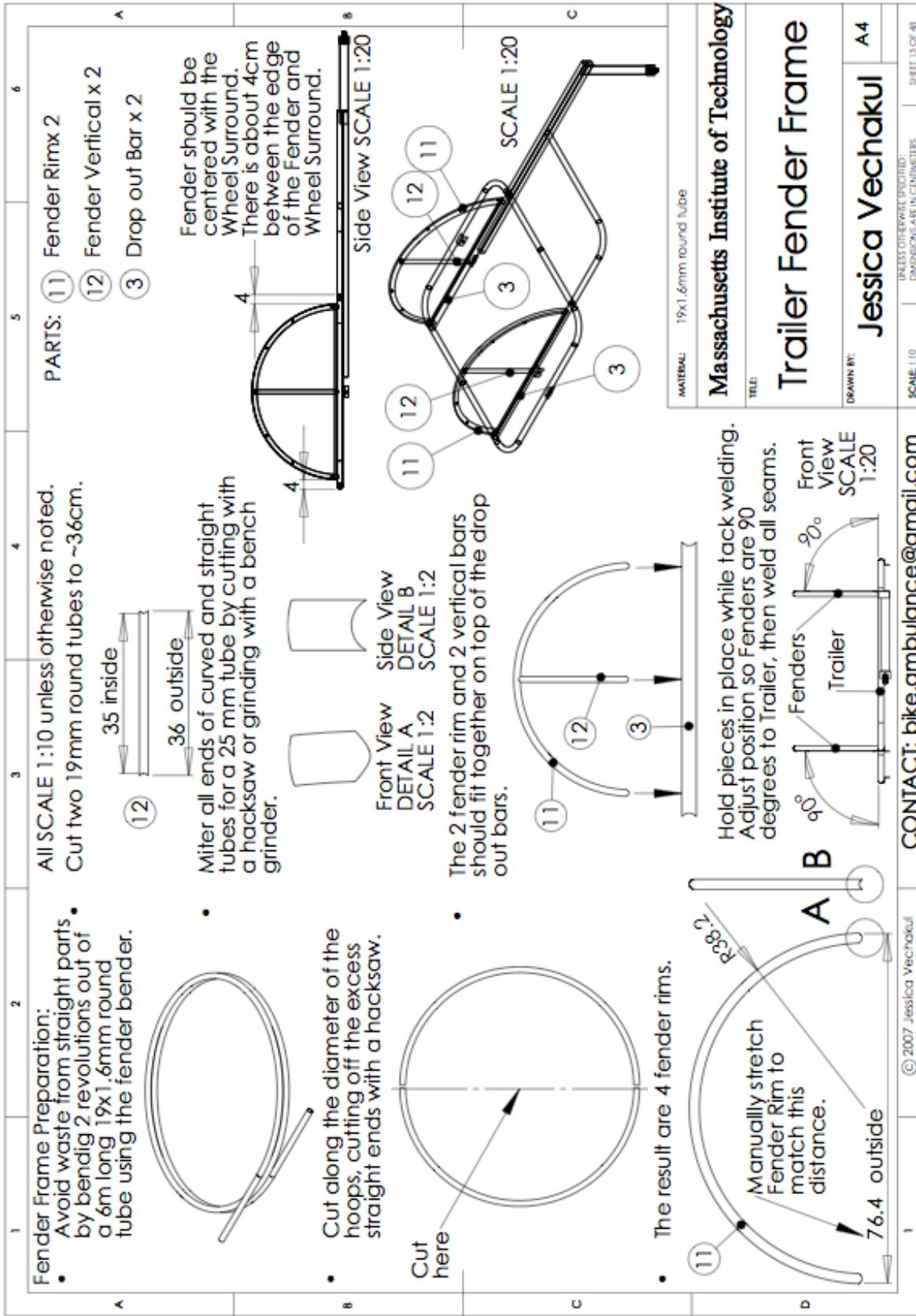


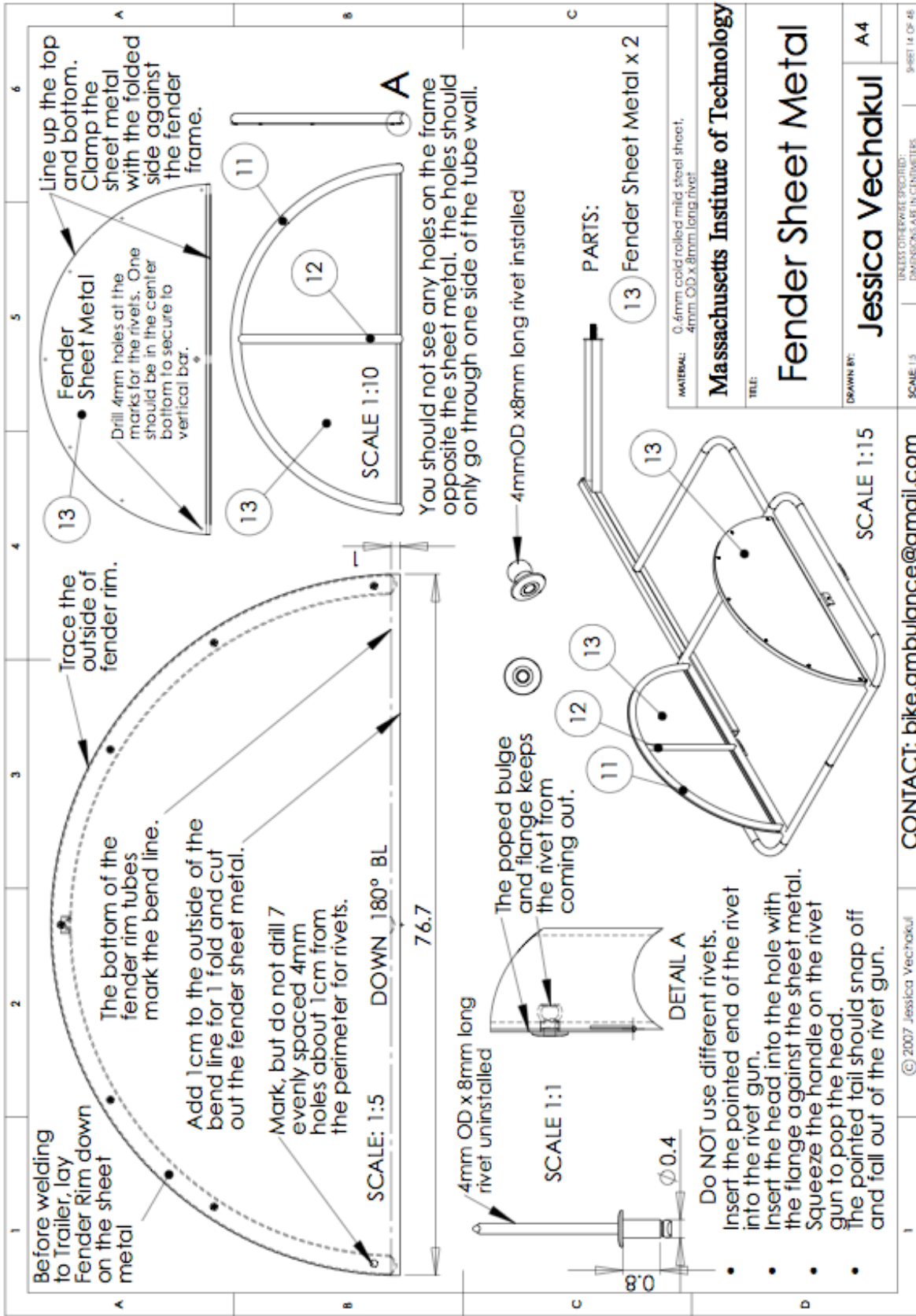


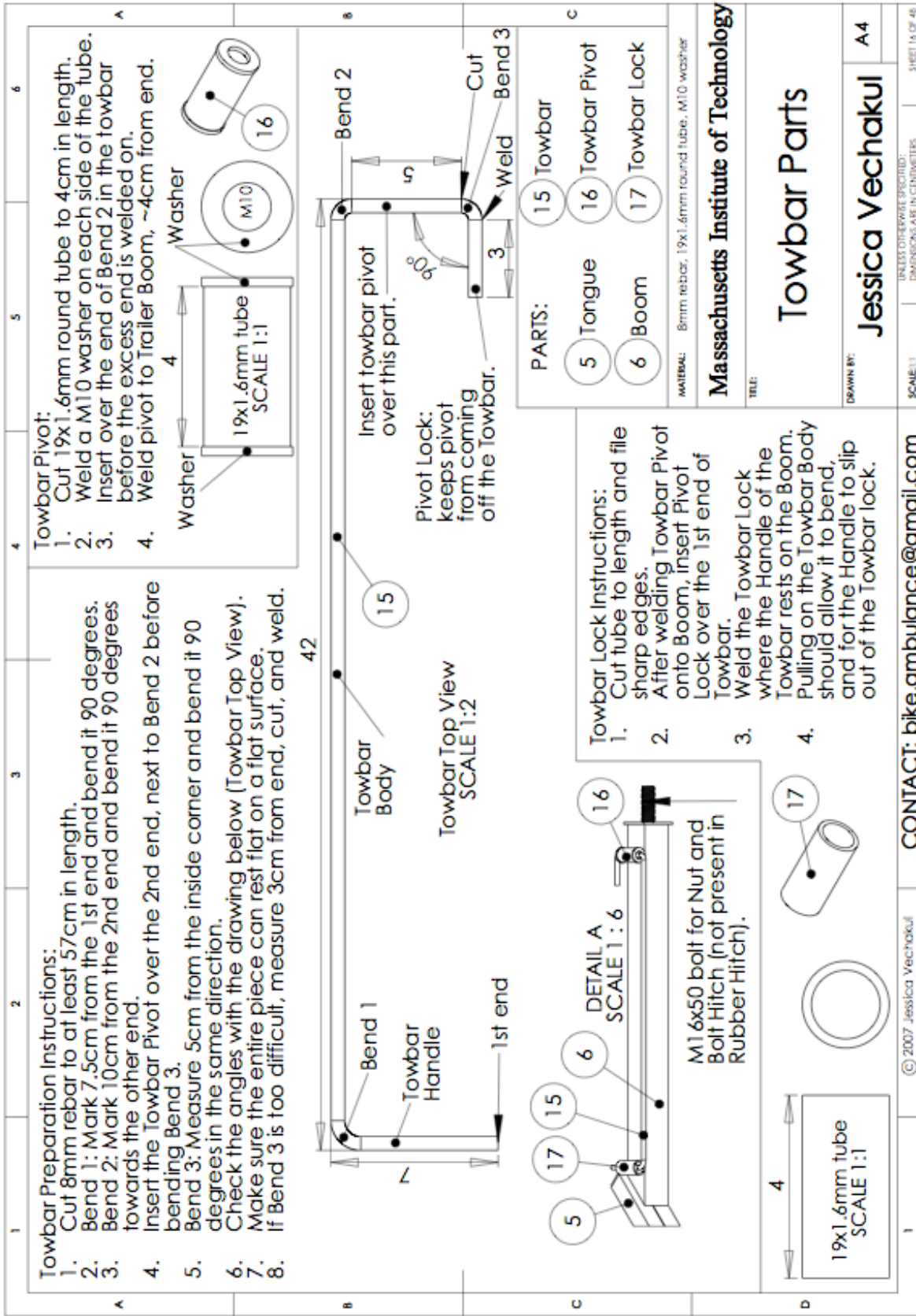


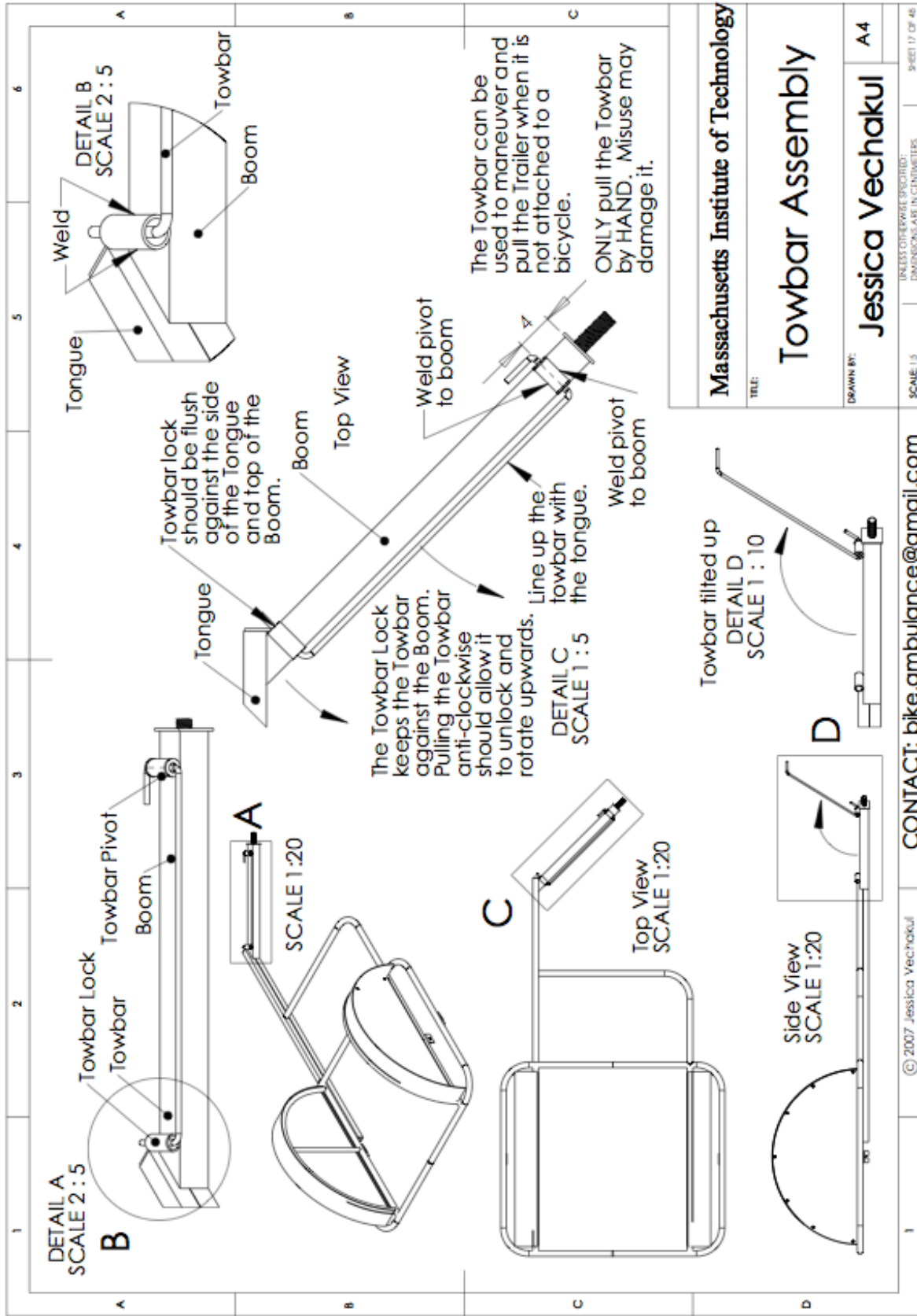












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TITLE:

Towbar Assembly

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Jessica Vechakul

A4

SCALE 1:5

















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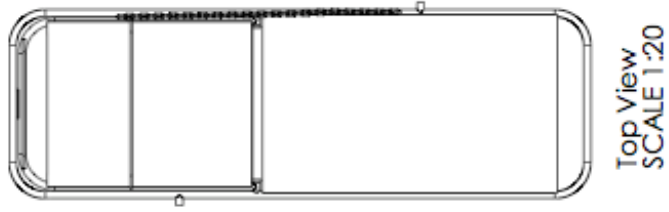
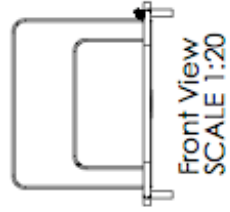
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SHEET 17 OF 48

Bicycle Ambulance: Stretcher Cut List

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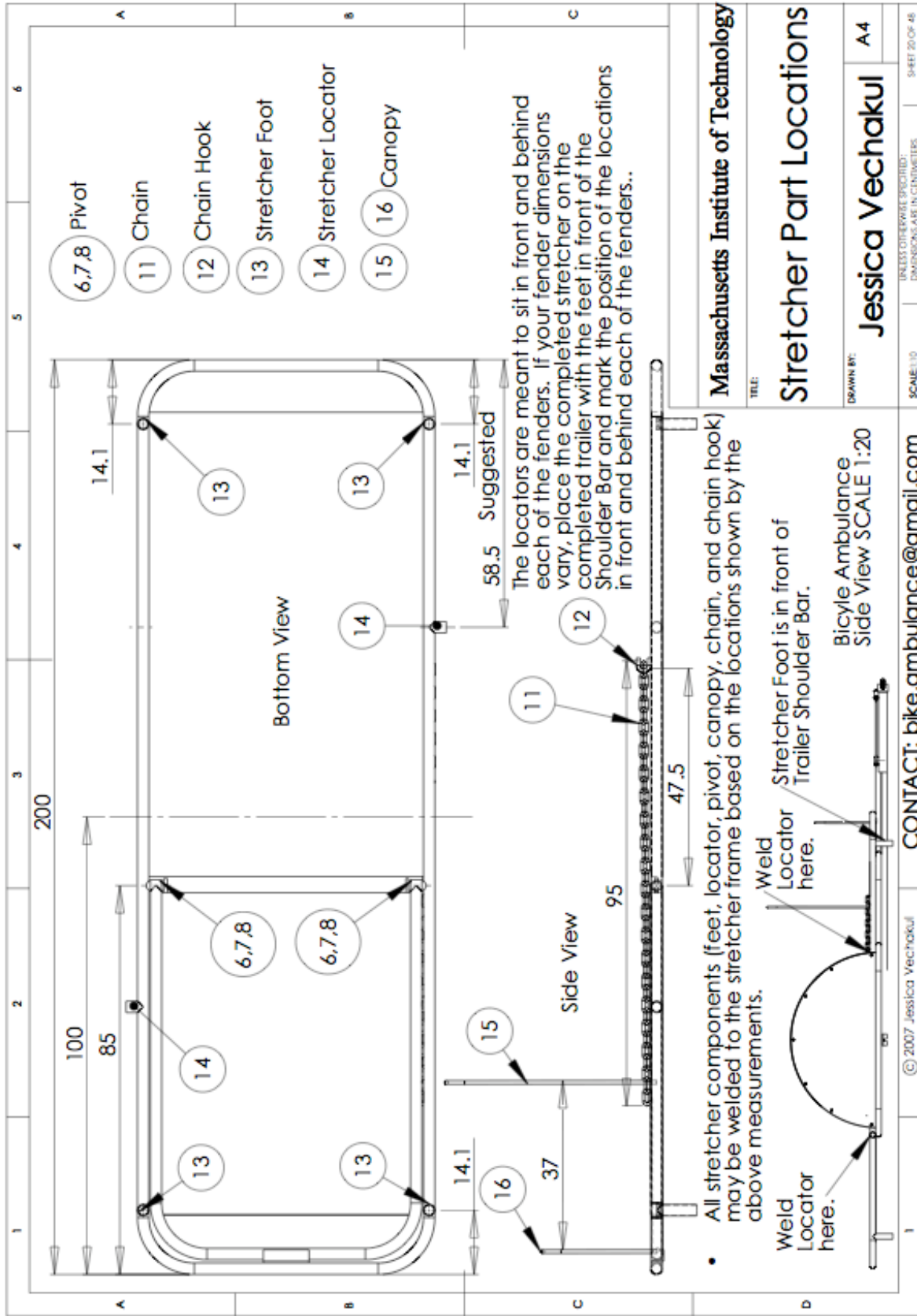
NO.	PART NAME	MATERIAL	QTY.	CUT LENGTH	PROFILE	DESCRIPTION
1	Stretcher Half	25x1.6mm round tube	2	252cm *	25 	Do not use pipe cutter.
2	Stretcher Insert	21.4x1.6mm round tube	2	85cm	21 	Mark centerline. Do NOT shorten.
3	Backrest Frame	25x1.6mm round tube	1	210cm *	25 	Miter for 25mm round tube
4	Backrest Spacer	25x4mm flat bar	1	10cm		-
5	Backrest Support	25x2.5x3mm angle iron	1	10cm		-
6	Pivot Insert	21.4x1.6mm round tube	2	4.5cm	21 	Miter for 25mm round tube
7	Pivot Sleeve	25x1.6mm round tube	2	3cm	25 	Make sure not to weld Pivot Sleeve to Pivot Insert.
8	Pivot Retaining Bar	8mm round rebar (reinforcement bar)	2	3.5cm	8 	Make sure not to weld Pivot Retaining Bar to Pivot Sleeve.
9	Backrest Sheet Metal	0.6 thick cold-rolled steel sheet	1	77.5cmx59.5cm		Edges with 1 fold are welded to centerline of tube. Free edges have 3folds.
10	Stretcher Frame Sheet Metal	0.6 thick cold-rolled steel sheet	1	108.5cmx64.5cm		Edges with 1 fold are welded to centerline of tube. Free edges have 3folds.
11	Chain	5mm steel chain	1	95cm		Do NOT shorten. Weld to Backrest, not Stretcher.
12	Chain Hook	8mm steel chain	1	1 link		Cut off curved end.
13	Stretcher Foot	25x1.6mm round tube	4	8cm	25 	Miter for 25mm round tube or hammer 1 end.
14	Stretcher Locator	25x1.6mm round tube	2	2.5cm	25 	Miter for 25mm round tube or hammer 1 end.
15	Canopy Frame-Large	8mm round rebar (reinforcement bar)	1	146cm	8 	Clamp in a vise and slide 19mm tube over free end to bend.
16	Canopy Frame-Small	8mm round rebar (reinforcement bar)	1	90.6cm	8 	Clamp in a vise and slide 19mm tube over free end to bend.

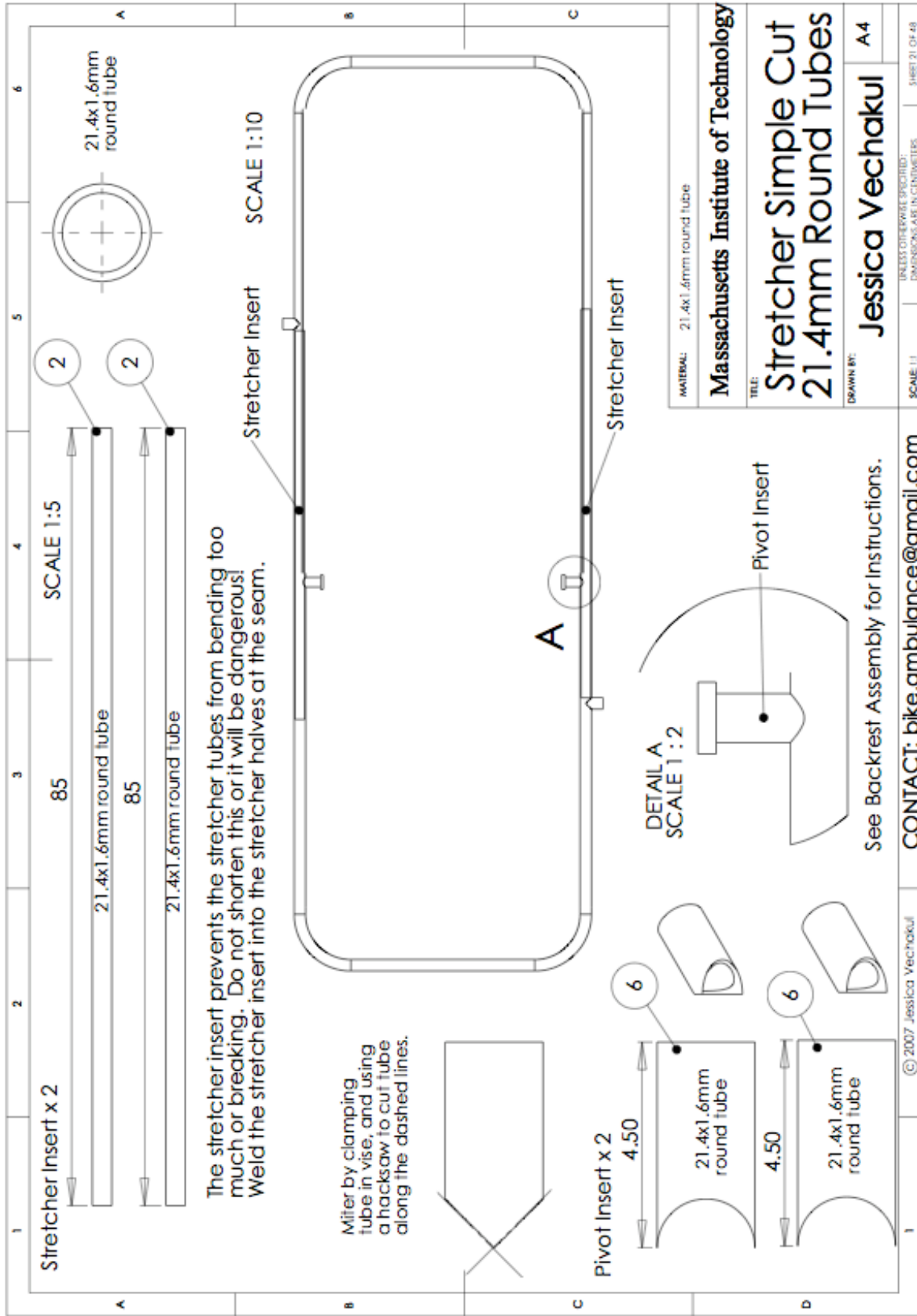


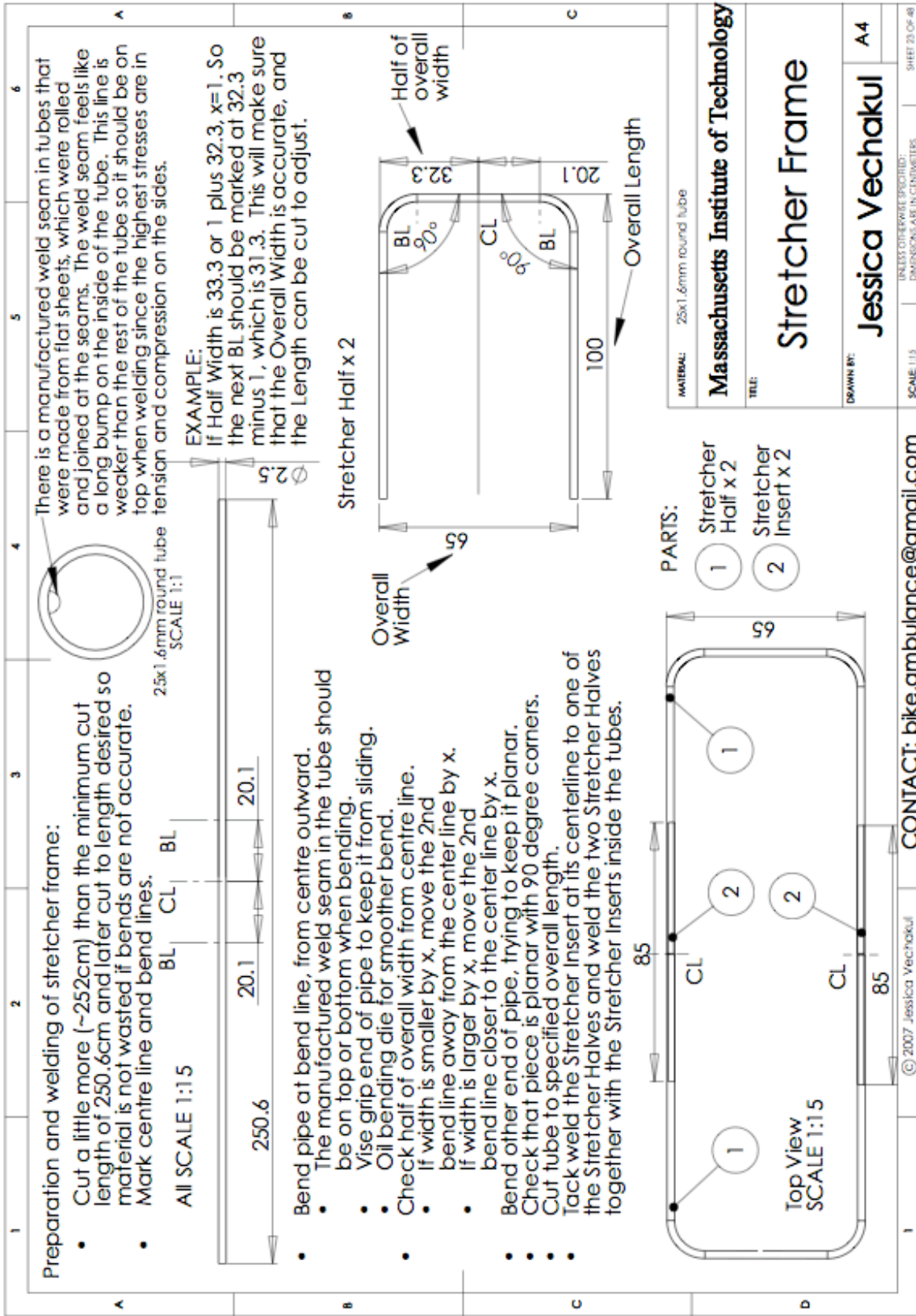
* Cut lengths dimensioned for use with a 10cm radius pipe bender.

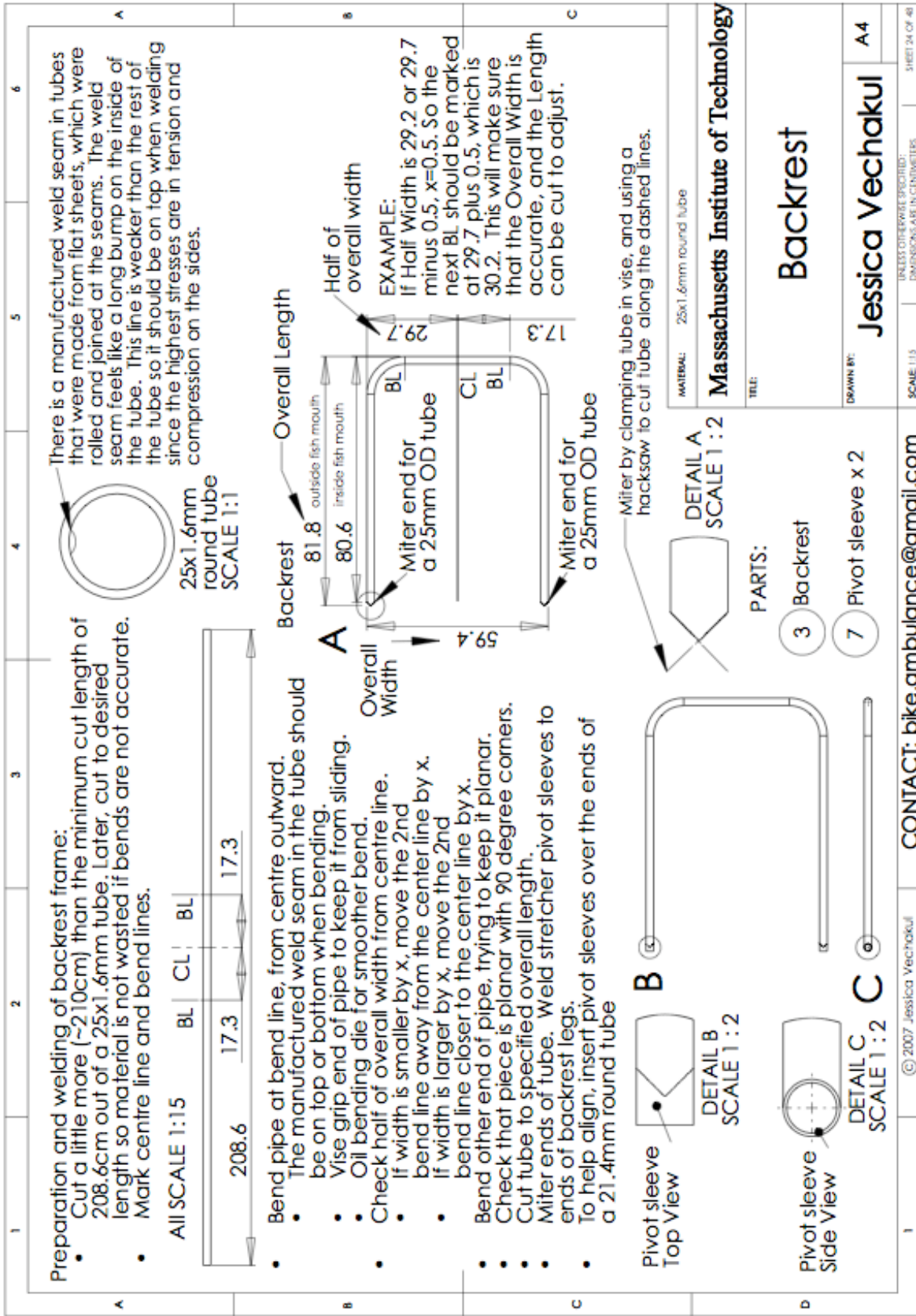
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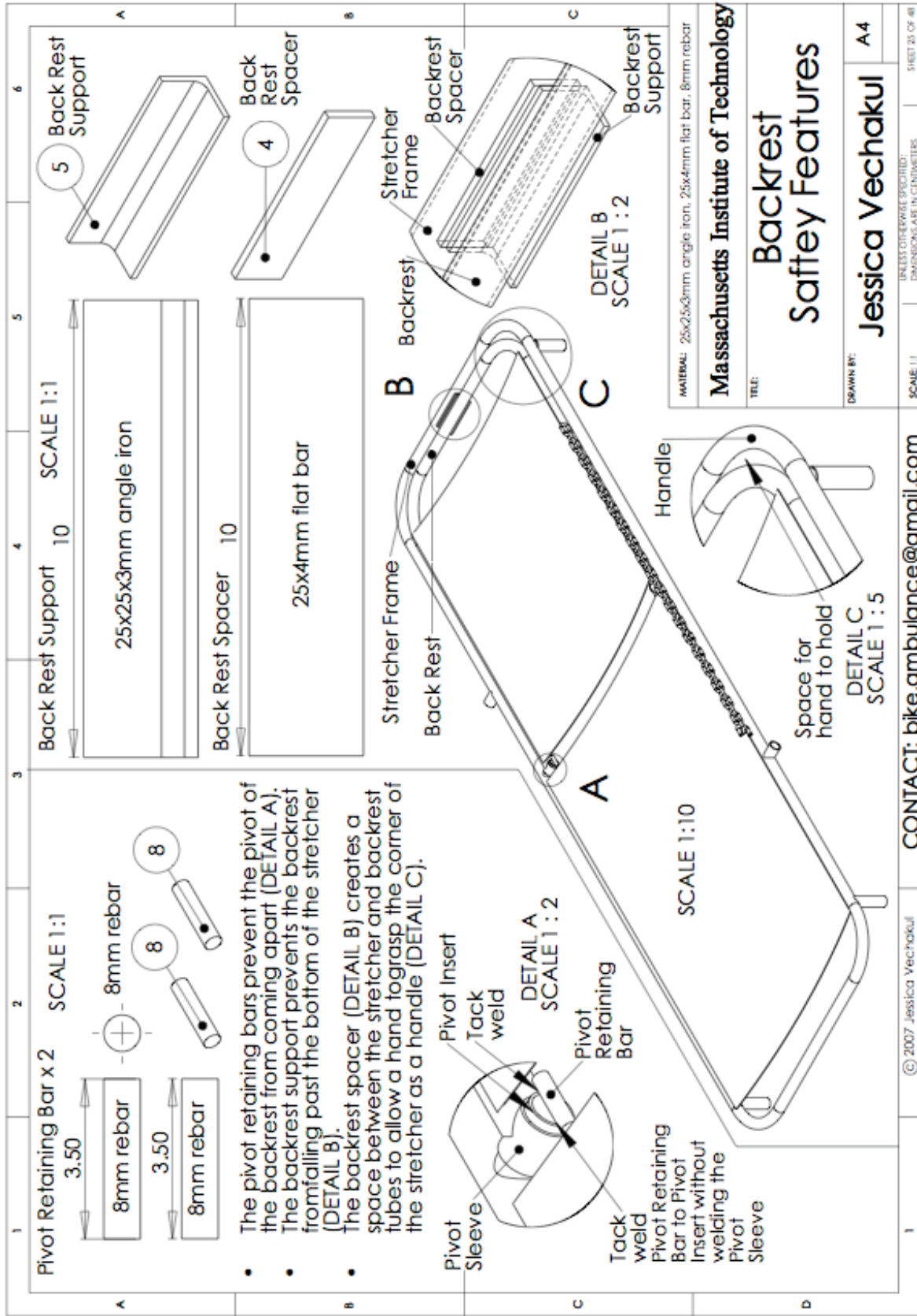
A4 | SHEET 19 OF 48

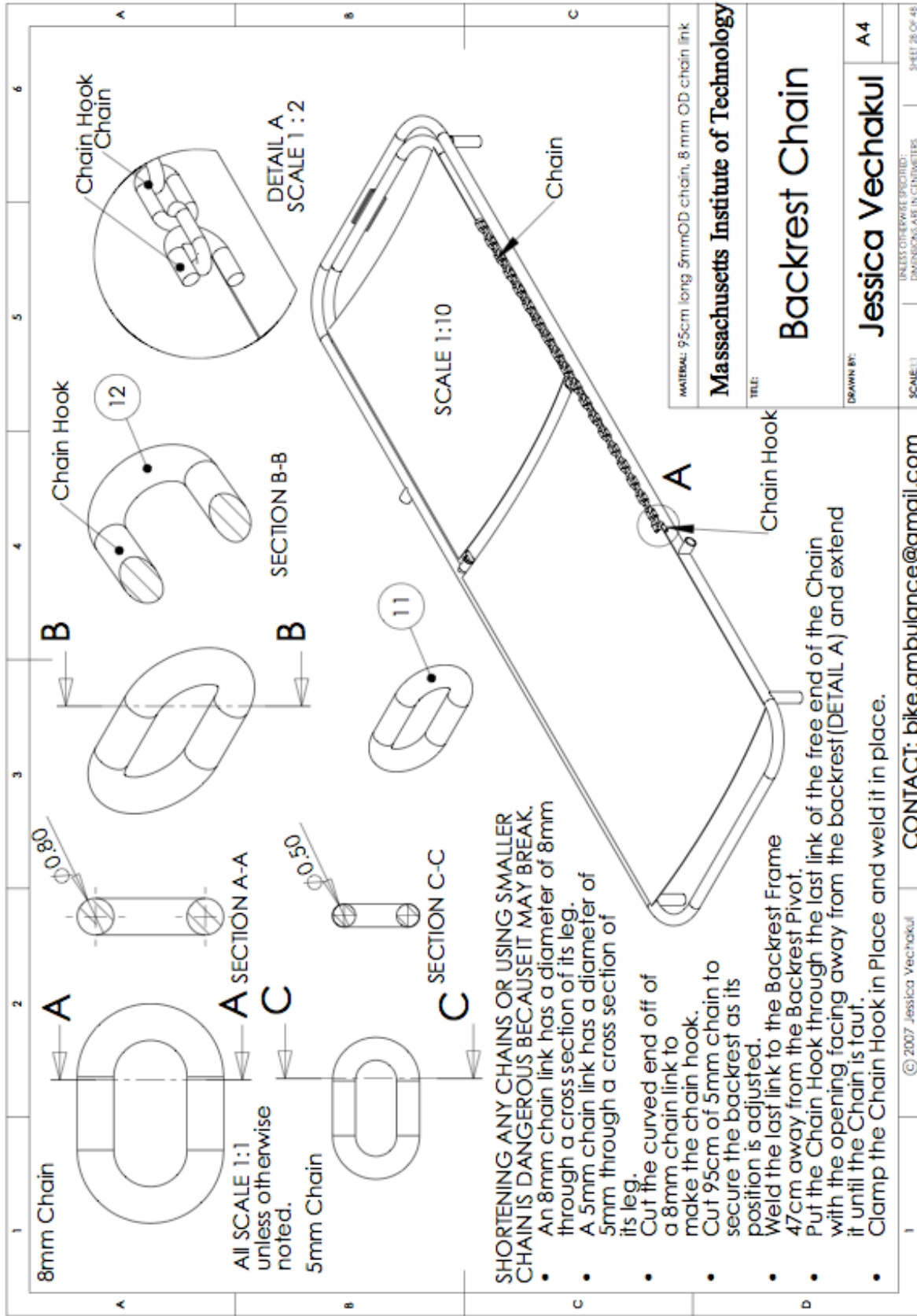








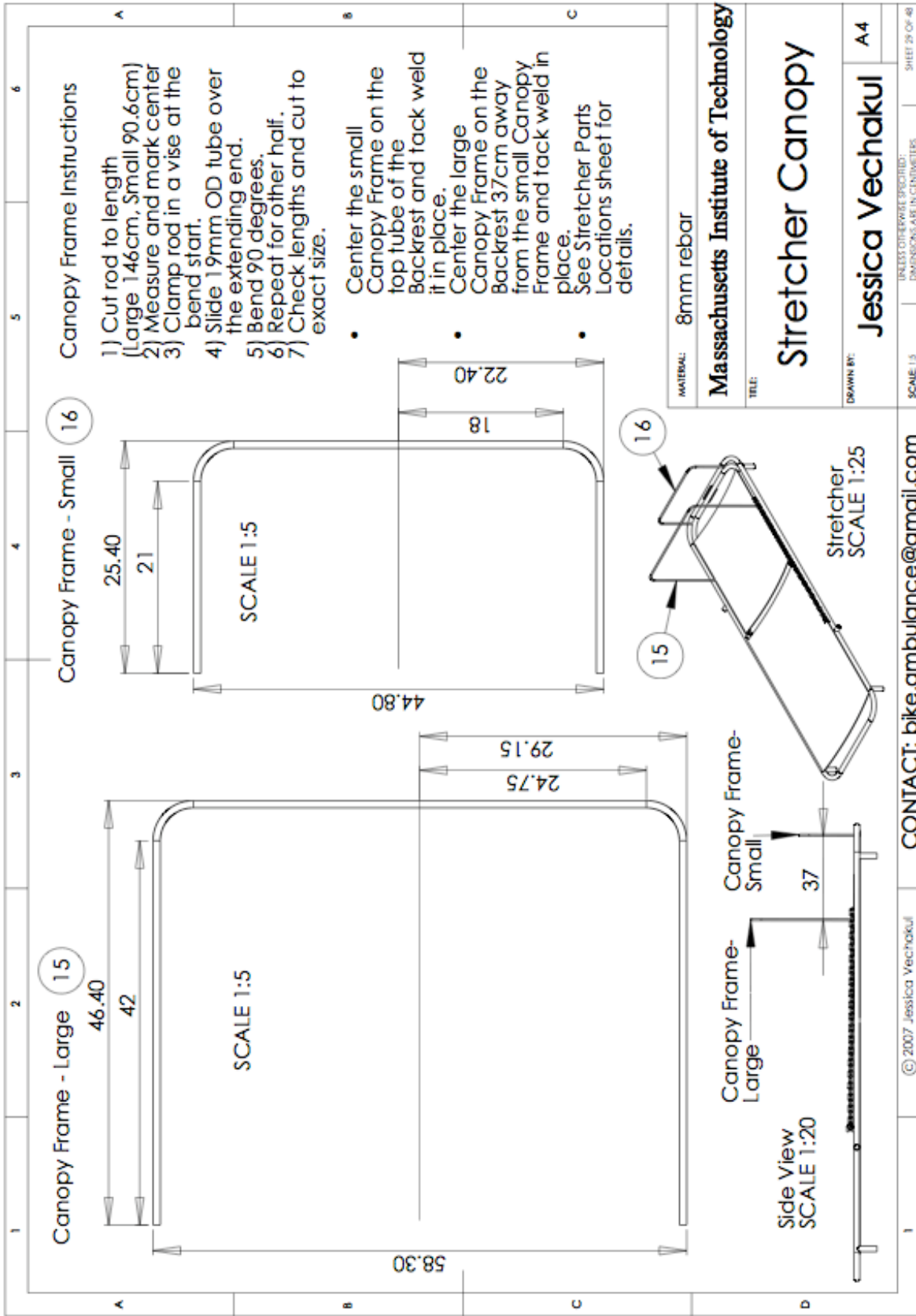


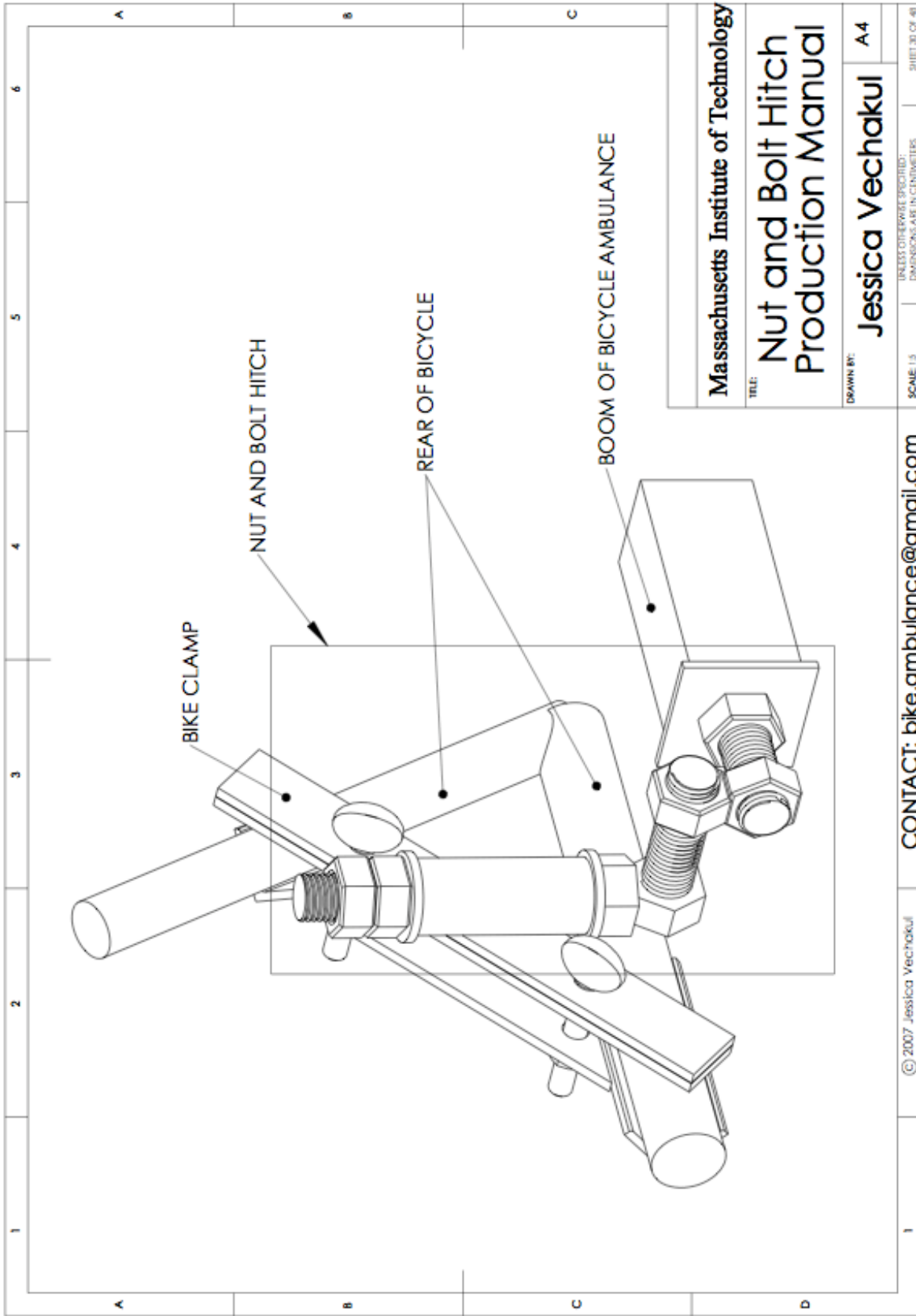


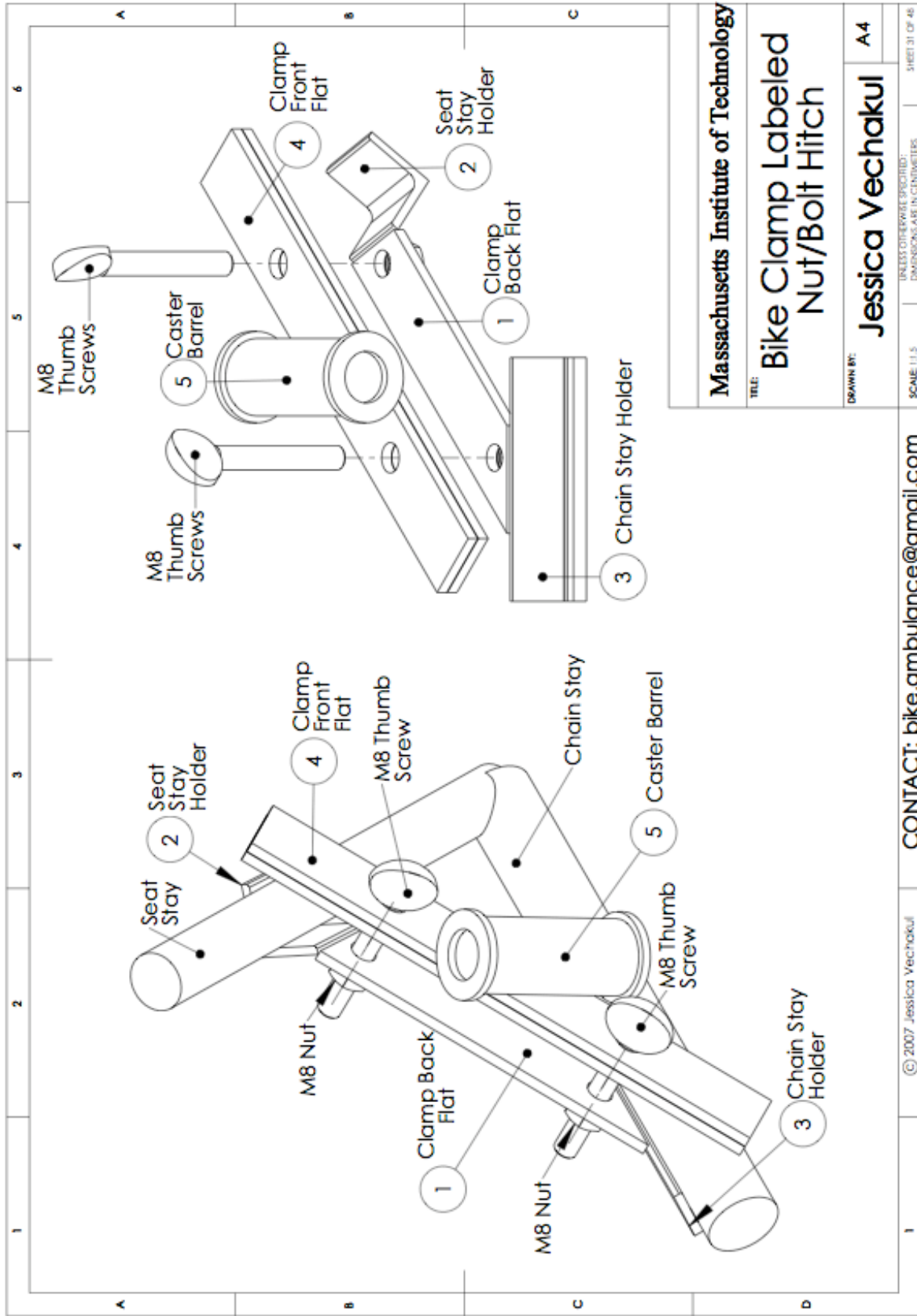
MATERIAL: 95cm long 5mmOD chain, 8mm OD chain link	
Massachusetts Institute of Technology	
TITLE:	
<h1>Backrest Chain</h1>	
DRAWN BY:	Jessica Vechakul
SCALE: 1:1	SHEET 28 OF 48

- SHORTENING ANY CHAINS OR USING SMALLER CHAIN IS DANGEROUS BECAUSE IT MAY BREAK.**
- An 8mm chain link has a diameter of 8mm through a cross section of its leg.
 - A 5mm chain link has a diameter of 5mm through a cross section of its leg.
 - Cut the curved end off of a 8mm chain link to make the chain hook.
 - Cut 95cm of 5mm chain to secure the backrest as its position is adjusted.
 - Weld the last link to the Backrest Frame 47cm away from the Backrest Pivot.
 - Put the Chain Hook through the last link of the free end of the Chain with the opening facing away from the backrest (DETAIL A) and extend it until the Chain is taut.
 - Clamp the Chain Hook in Place and weld it in place.

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TITLE: **Bike Clamp Labeled Nut/Bolt Hitch**

DRAWN BY: **Jessica Vechakul** A4

SCALE: 1:1.5 UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN CENTIMETERS SHEET 31 OF 48

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Bicycle Ambulance: Bicycle Hitch Cut List

General Bicycle Clamp:

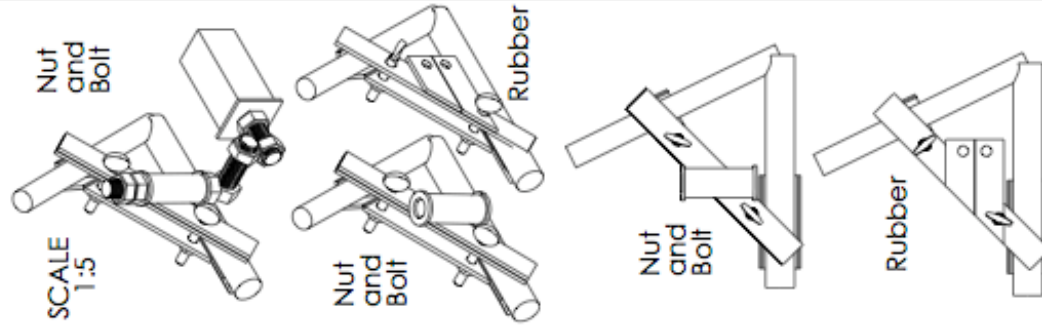
NO.	PART NAME	MATERIAL	QTY.	CUT LENGTH	PROFILE	DESCRIPTION
1	Clamp Back Flat	25x4mm flat bar	1	12.5cm		Use drawing to mark 45° and 110° angles carefully. File all edges. Tape inside to protect bicycle frame.
2	Seat Stay Holder	25x25x3mm angle iron	2	2.6cm		File all edges. Tape inside to protect bicycle frame.
3	Chain Stay Holder	25x25x3mm angle iron	2	8cm		File all edges. Tape inside to protect bicycle frame.
4	Clamp Front Flat	25x4mm flat bar	1	19cm		Clamp to Back Flat and drill through both to align holes. Position on Front Flat carefully. See Drawing.
5	Caster Barrel	25x1.6mm square tube	1	5.9cm		Weld to both ends of Caster Barrel. Use bolts to align.
-	Washer	M16	2	-		Weld 5mm rebar to head or bolt to make Thumb Screw.
-	Thumb Screw	M8x50	2	-		Use M8 bolts to align when welding to Back Clamp Flat.
-	Nut	M8	2	-		

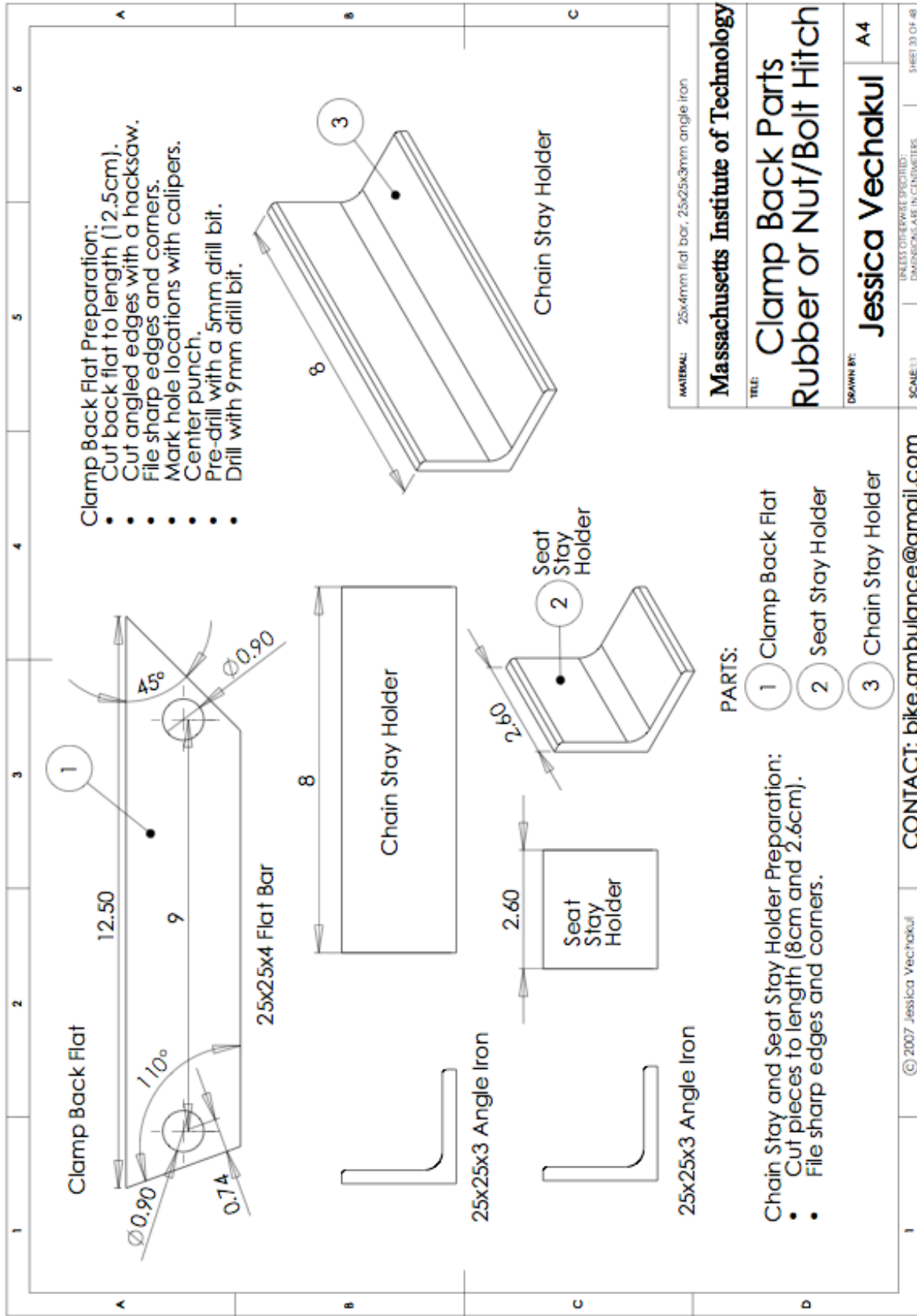
NUT AND BOLT HITCH:

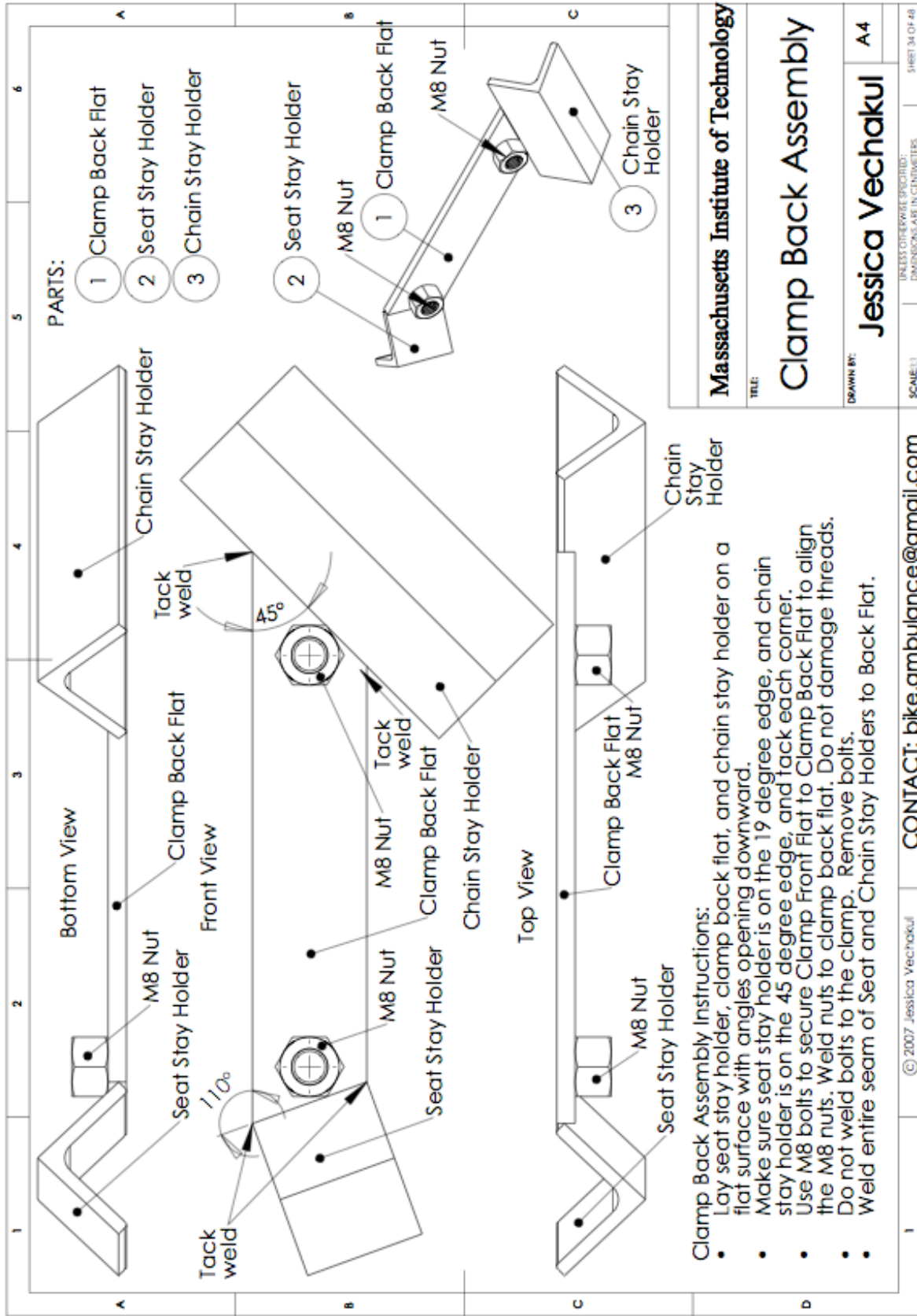
NO.	PART NAME	MATERIAL	QTY.	CUT LENGTH	PROFILE	DESCRIPTION
-	Hex Head Bolt	M16x100	1	-		Only 38mm threaded. Smooth part turns free in Caster Barrel. Do not damage threads when welding.
-	Hex Head Bolt	M8x50	2	-		Turning 2 nuts against each other locks them in place.
23	Nut	M16	5	-		

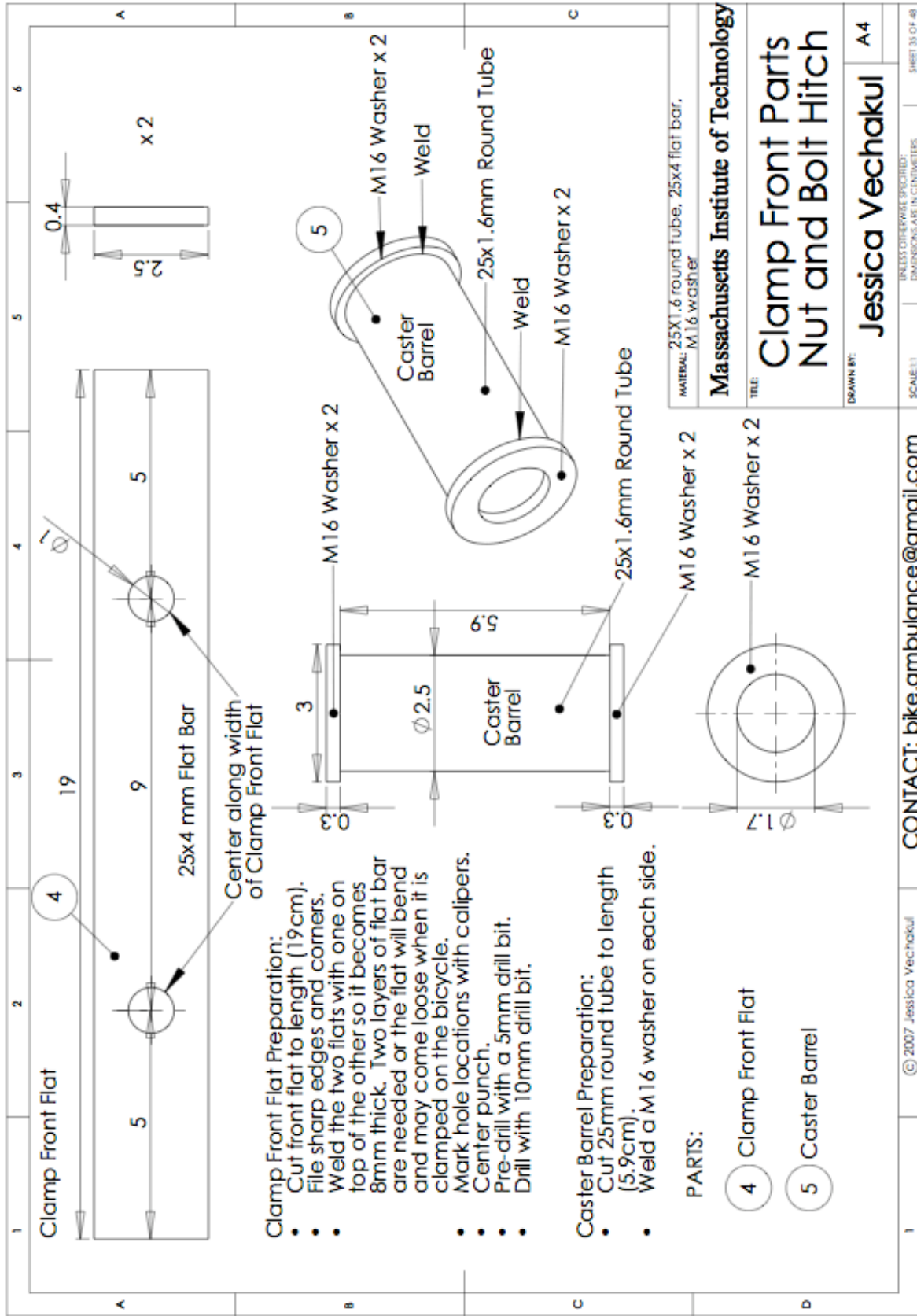
RUBBER HITCH:

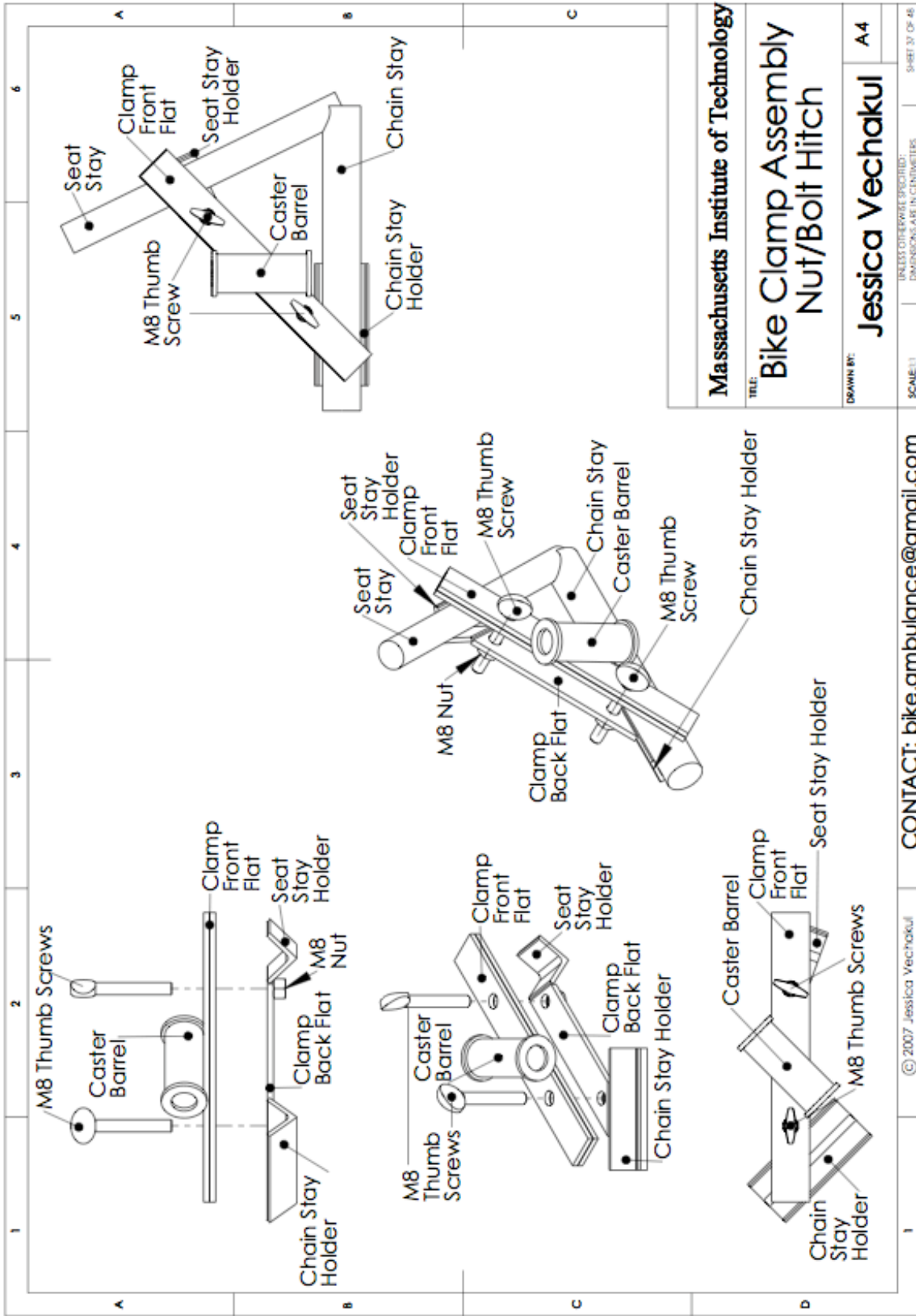
NO.	PART NAME	MATERIAL	QTY.	CUT LENGTH	PROFILE	DESCRIPTION
-	Rubber	7mm thick multi-layer fiber-reinforced rubber sheet	1	14cmx5cm		Do NOT use rubber without multiple layers of reinforcement.
-	Bolt	M8x25 hex head bolt	4	-		Do NOT use smaller bolts. Larger OD is better.
-	Washer	M8	8	-		
-	Nut	M8	4	-		2 welded to Boom. 2 are free.

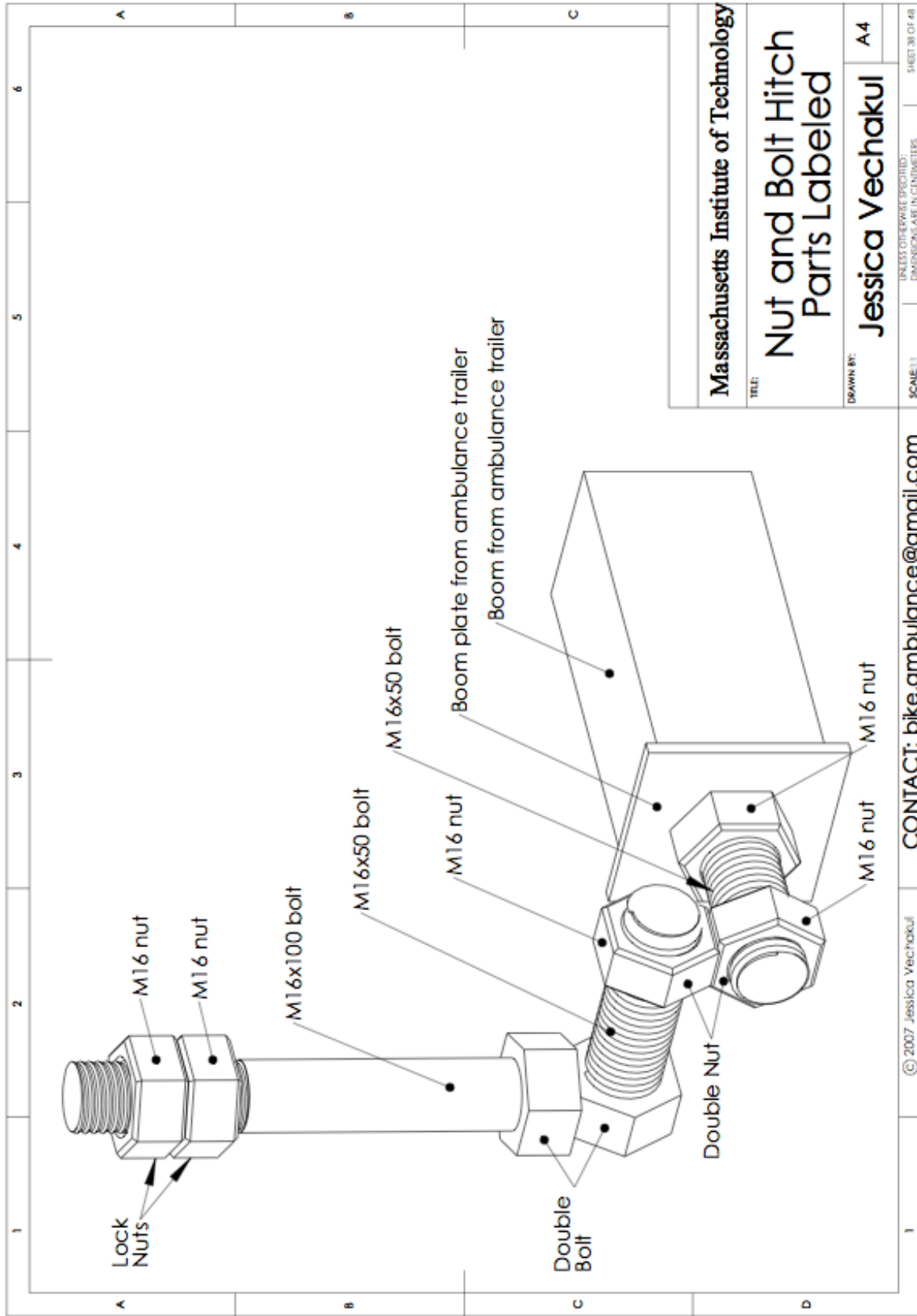


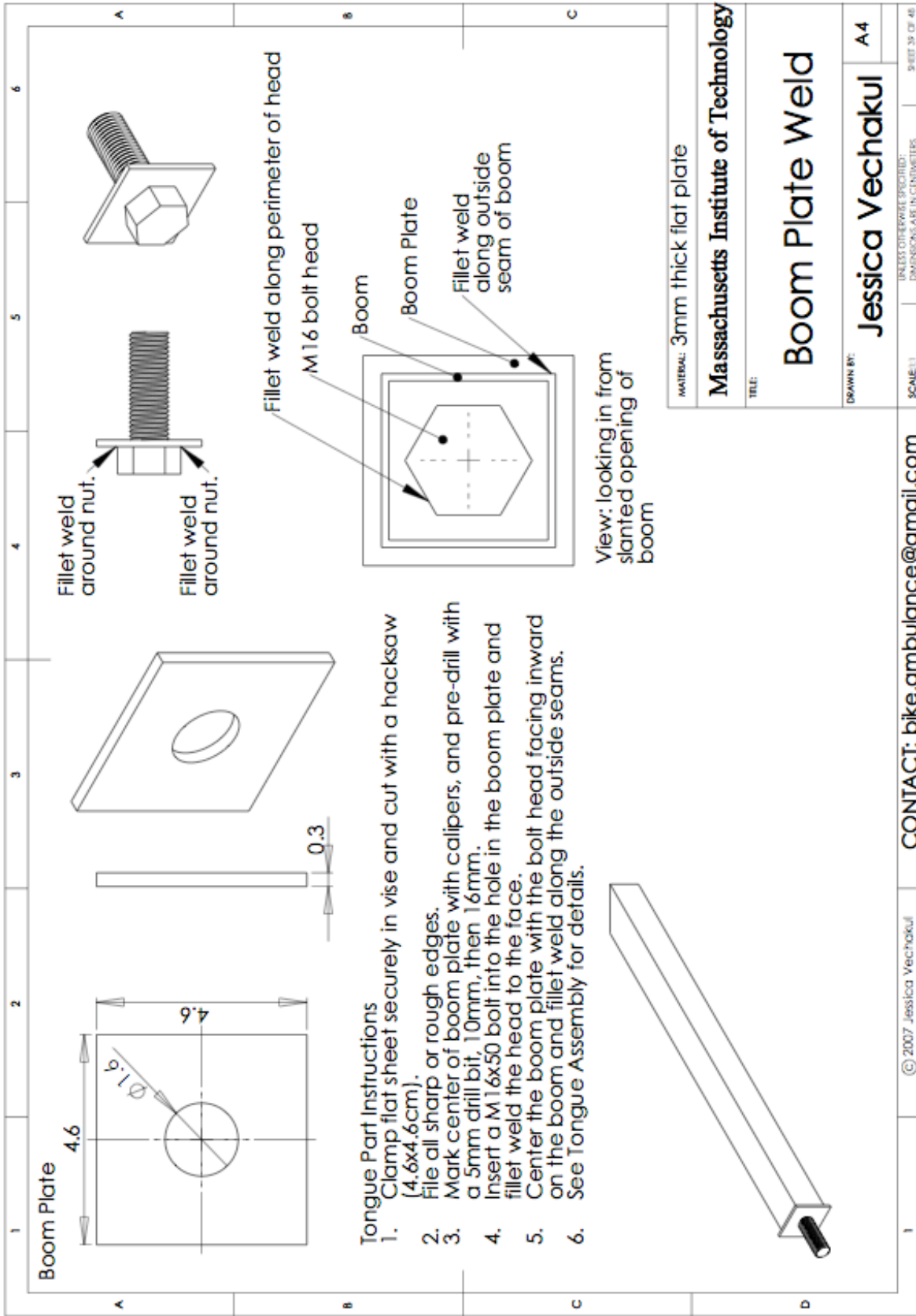


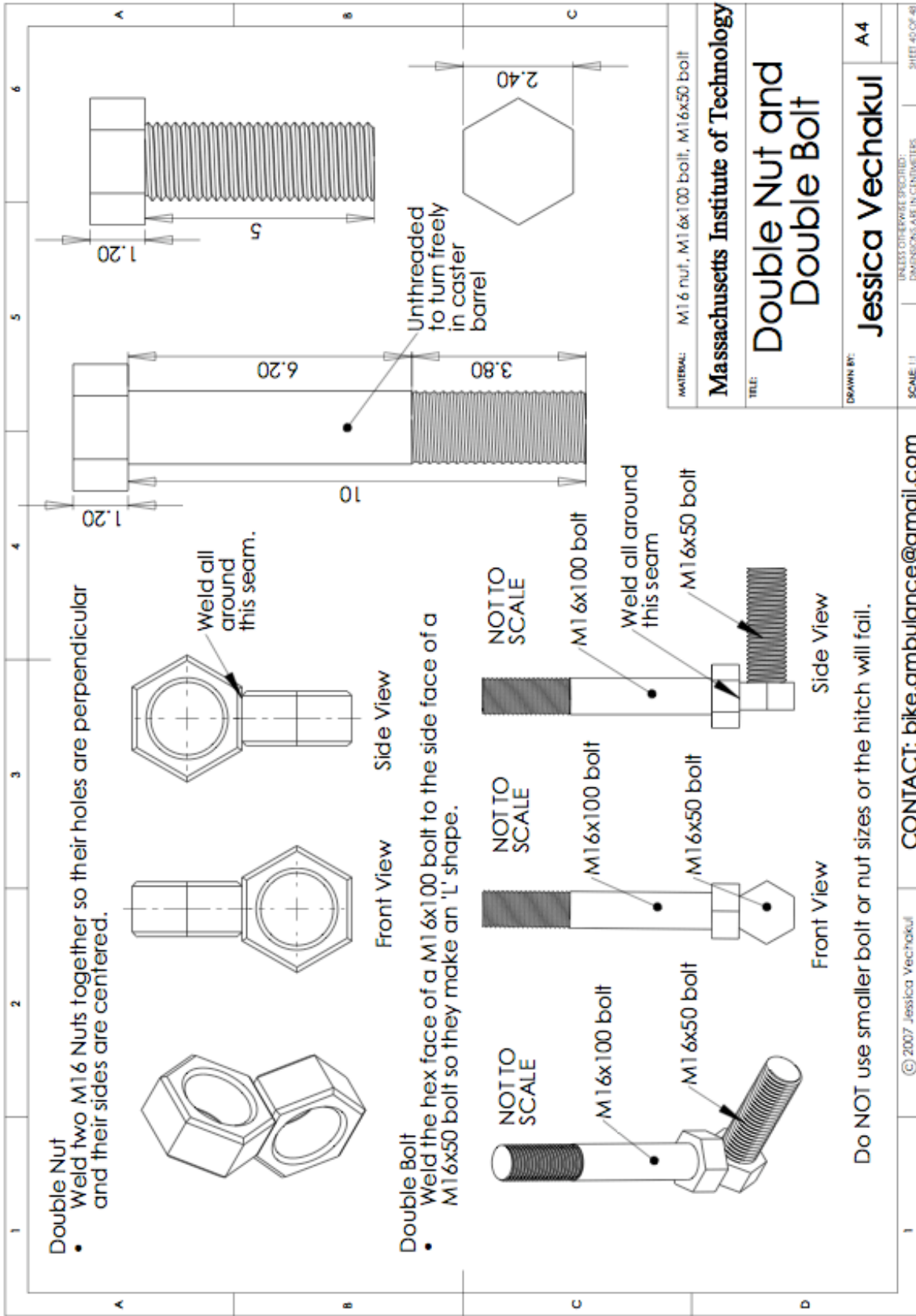


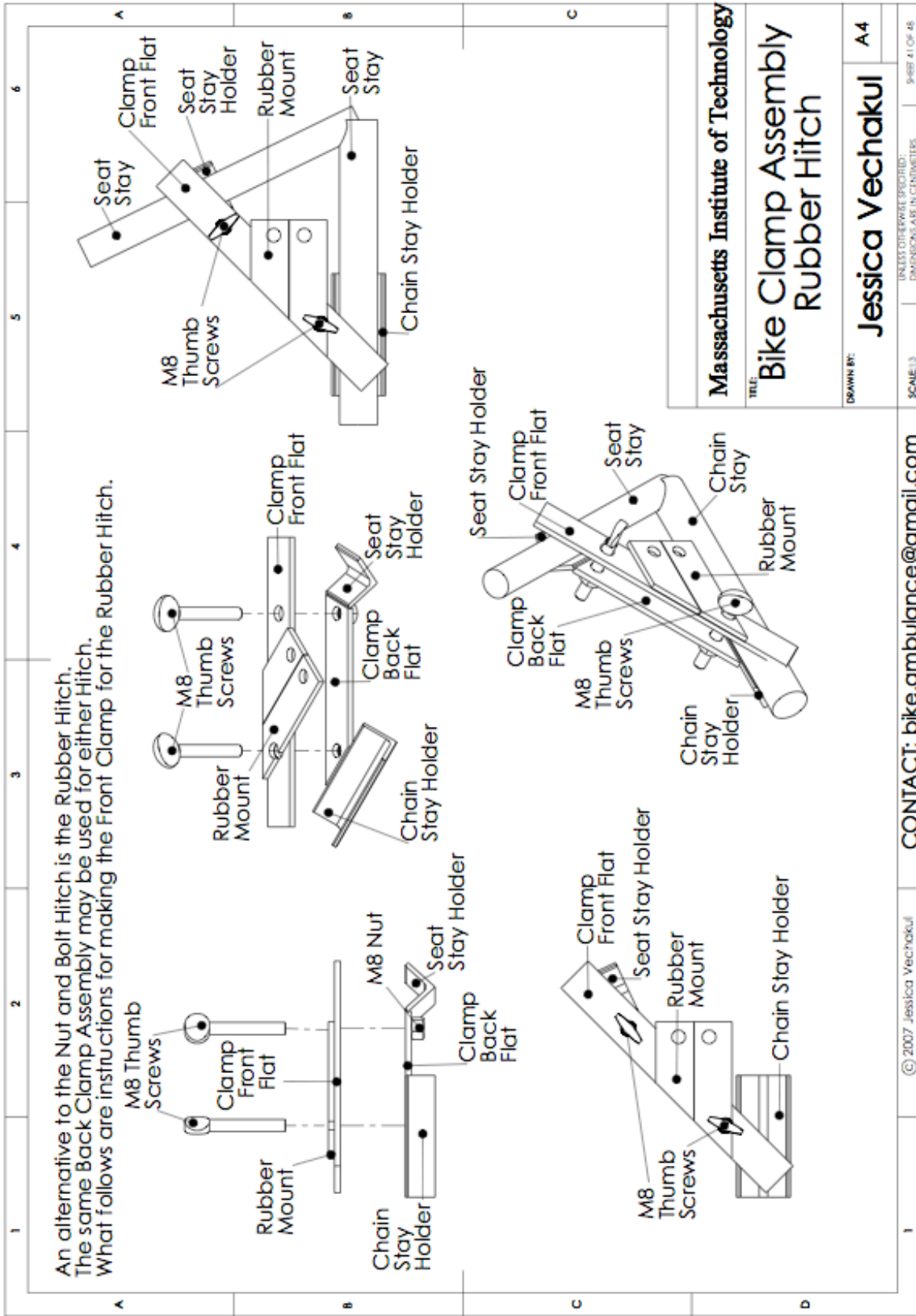


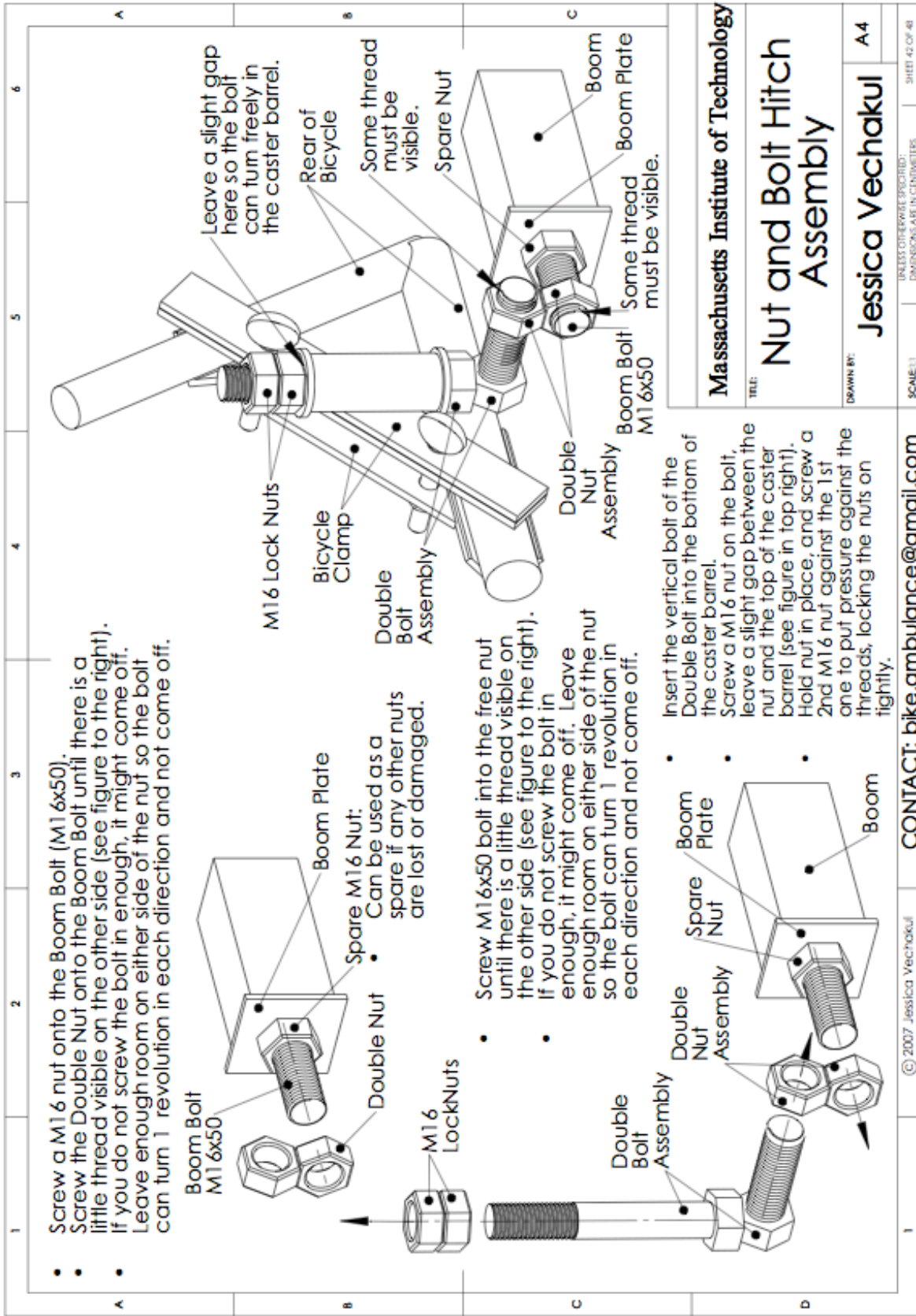












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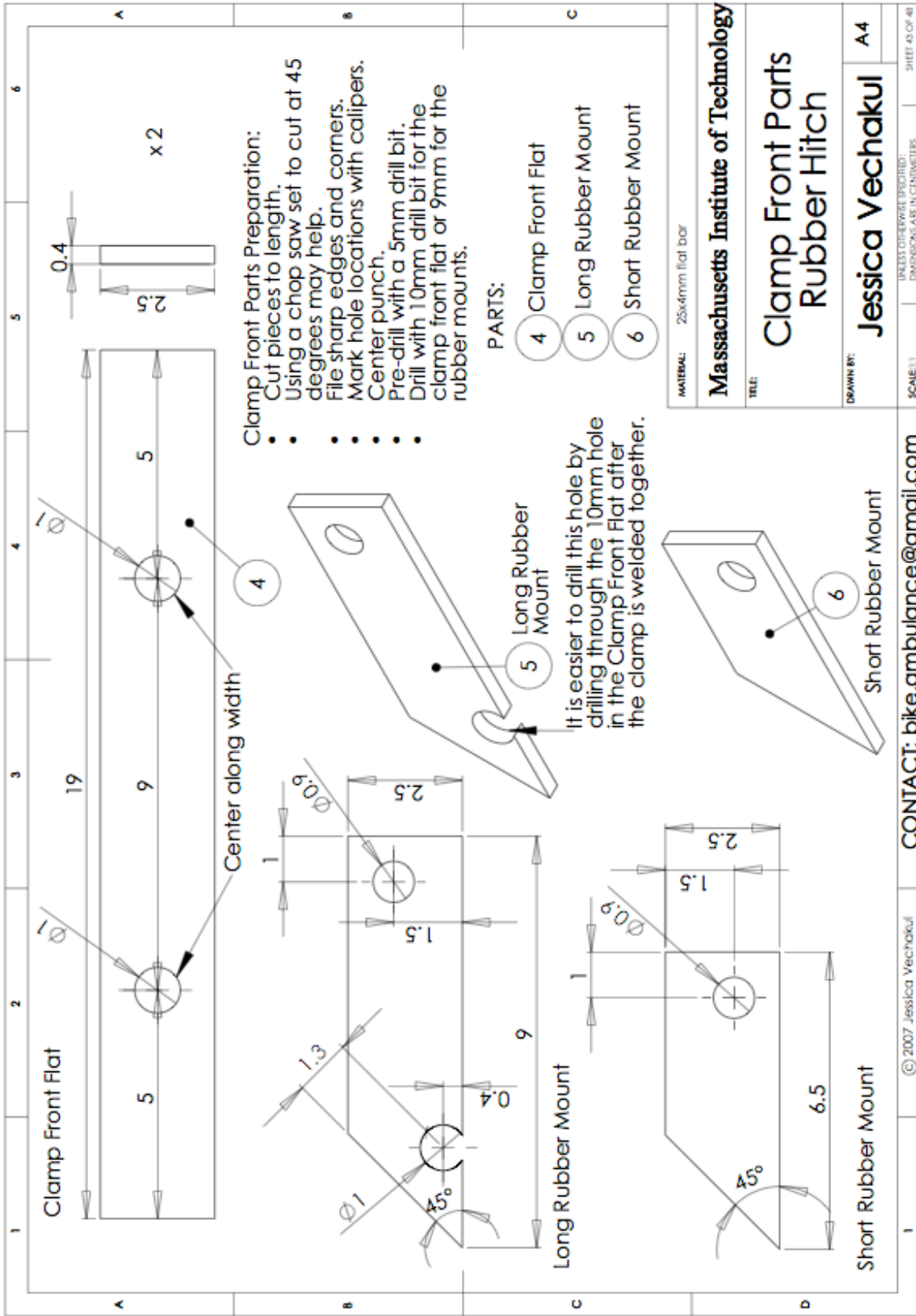
Nut and Bolt Hitch Assembly

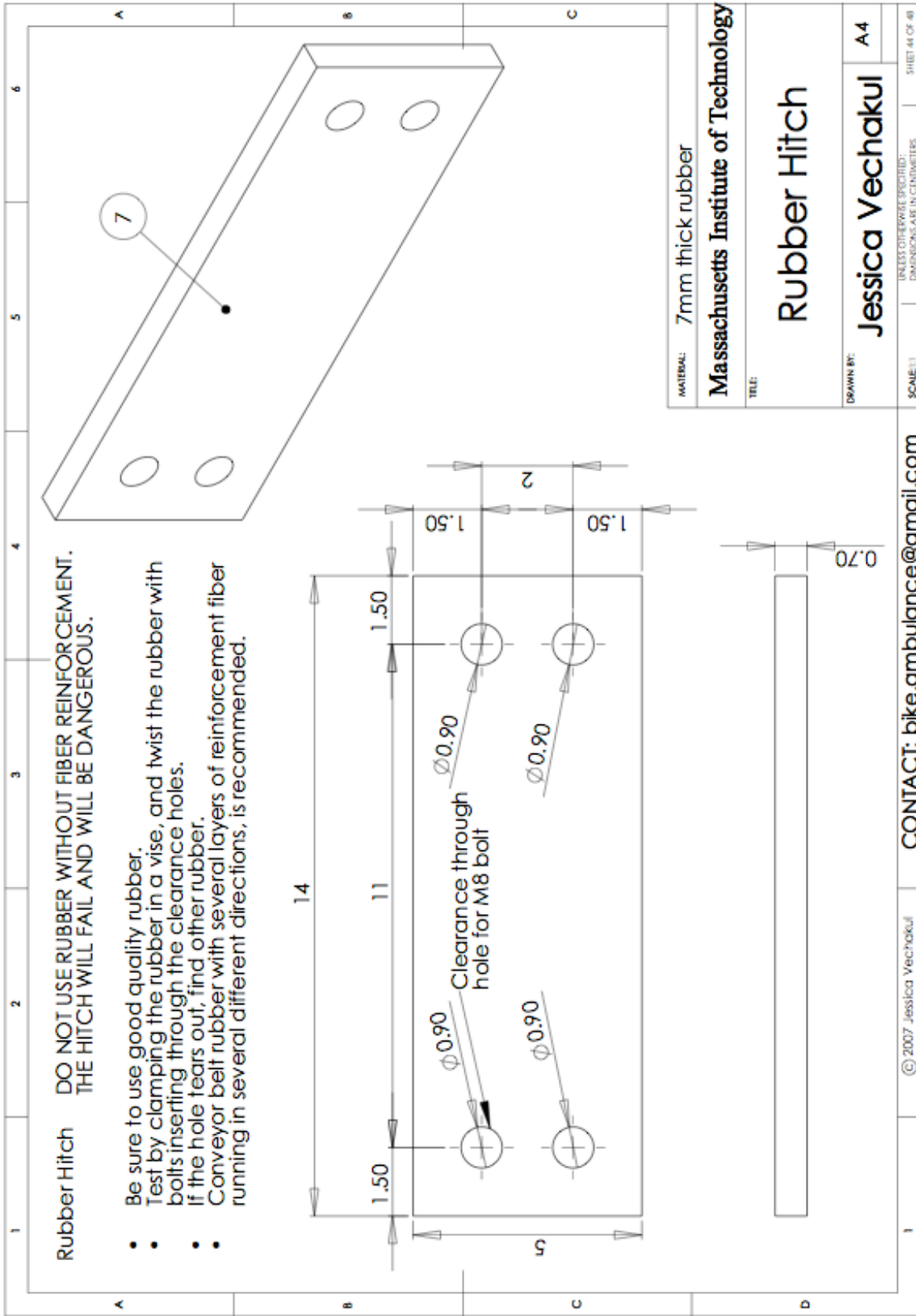
DESIGNED BY: Jessica Vechakul

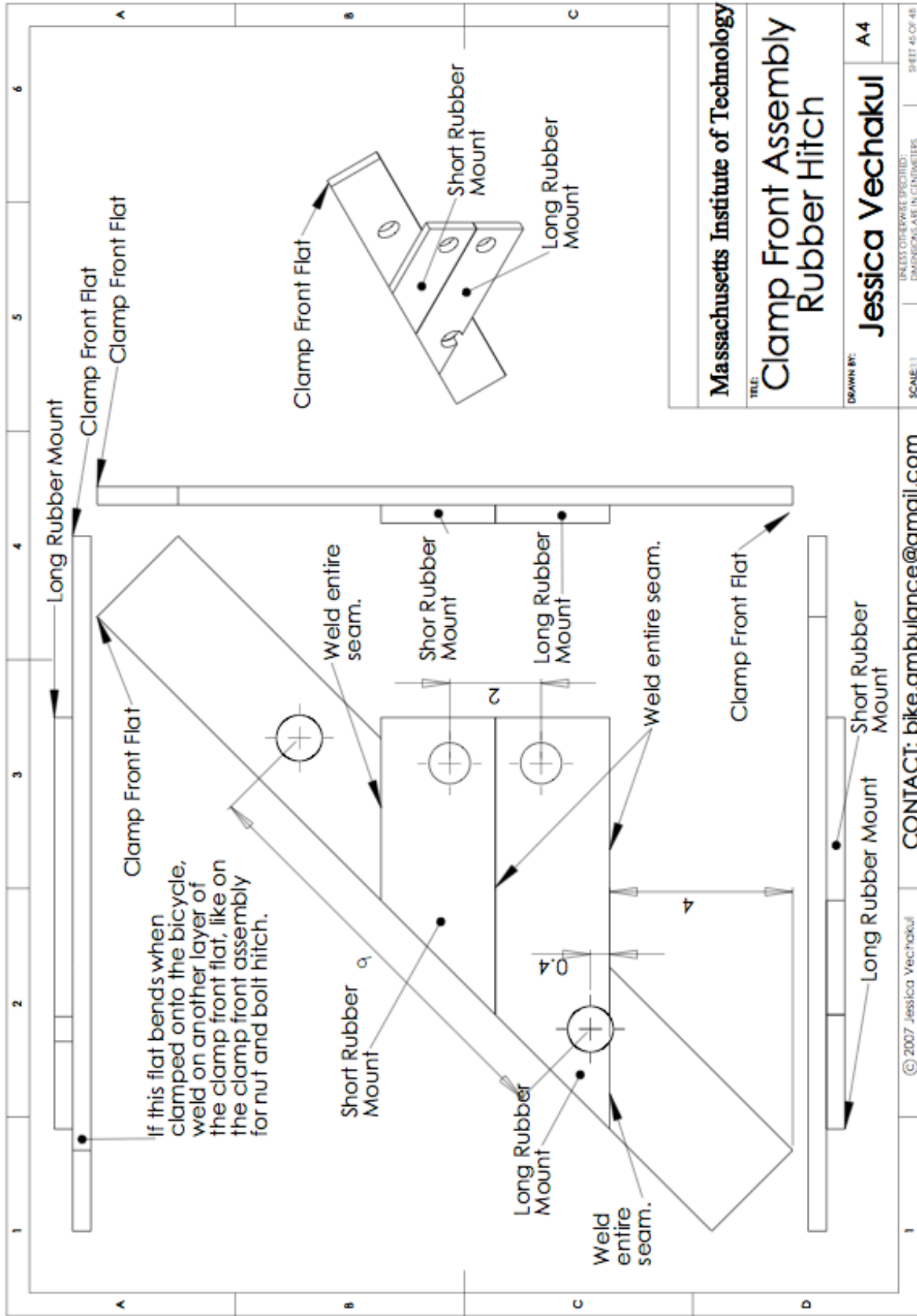
SCALE: 1:1 UNLESS OTHERWISE SPECIFIED; DIMENSIONS ARE IN CENTIMETERS SHEET 42 OF 48

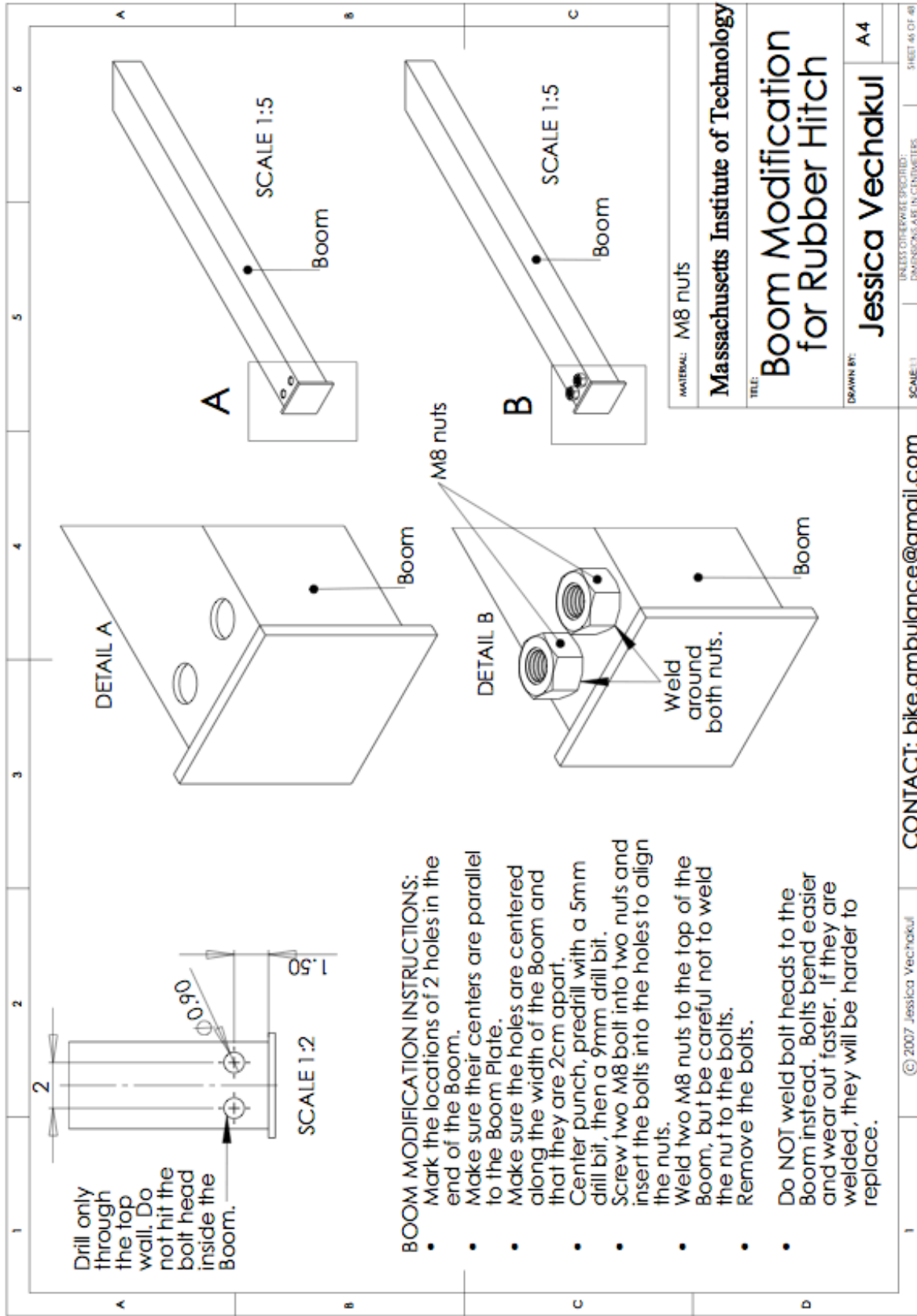
CONTACT: bike.ambulance@gmail.com

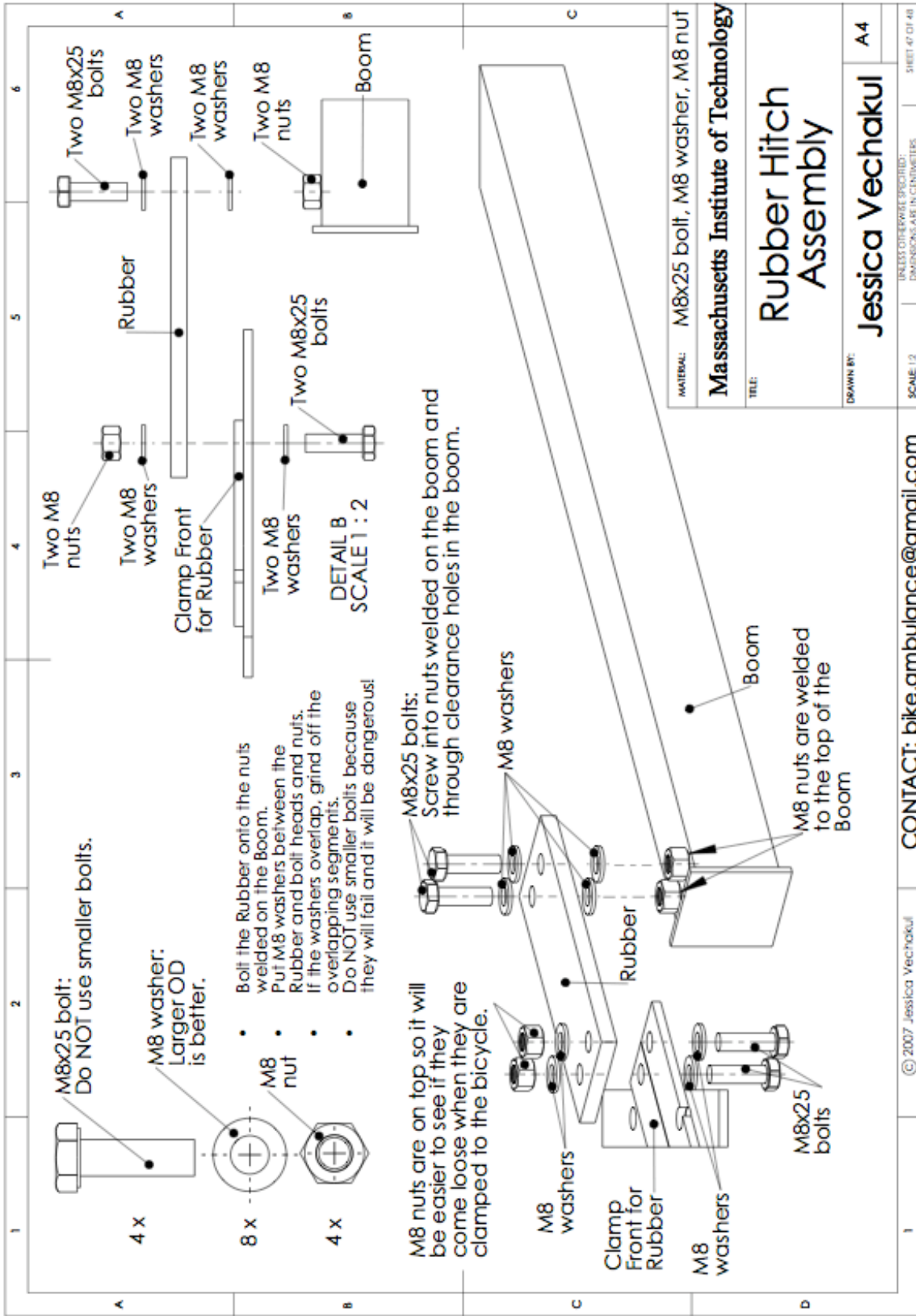
© 2007 Jessica Vechakul

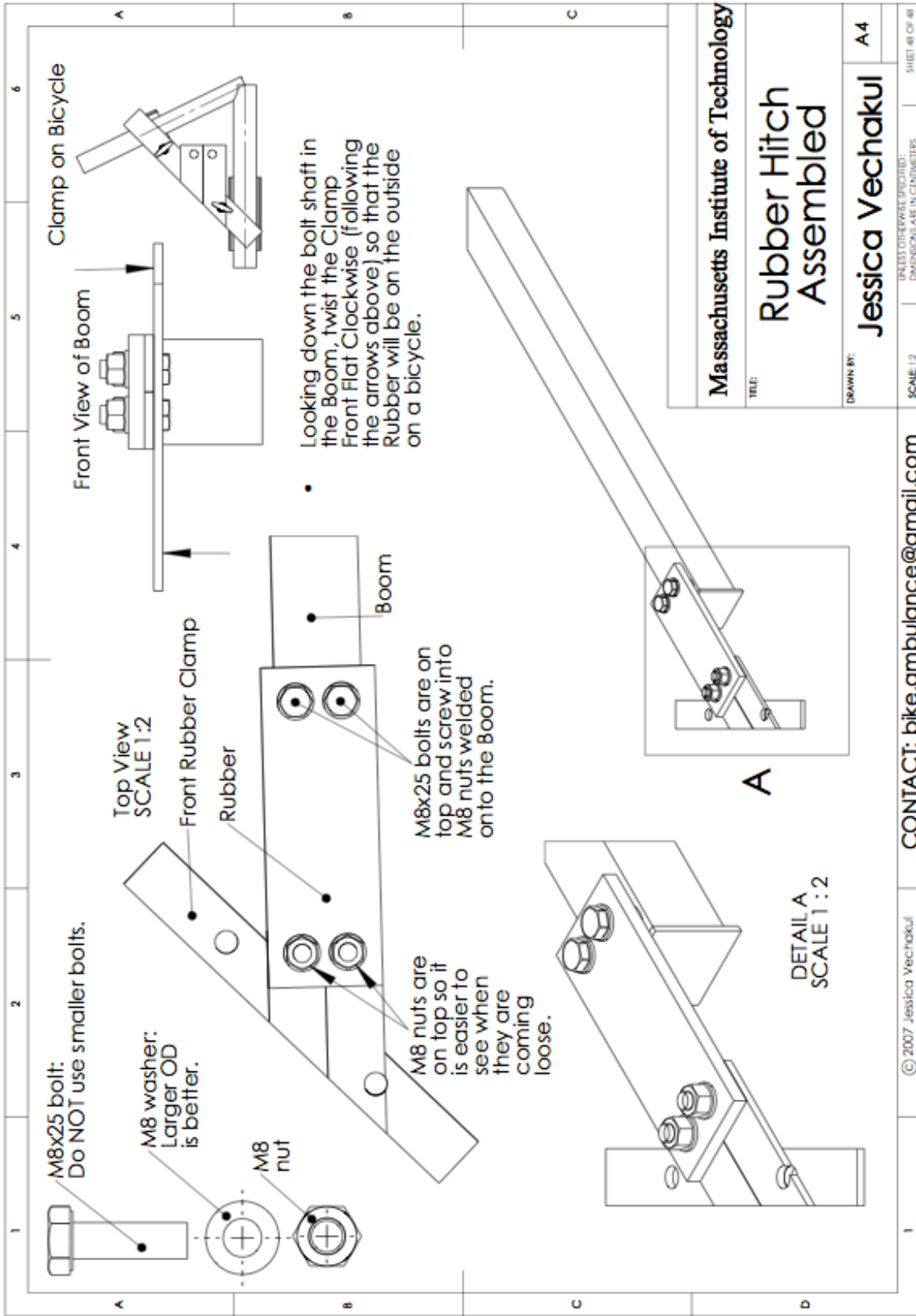












Massachusetts Institute of Technology

TITLE:
Rubber Hitch Assembled

DRAWN BY:
Jessica Vechakul

SCALE 1:2

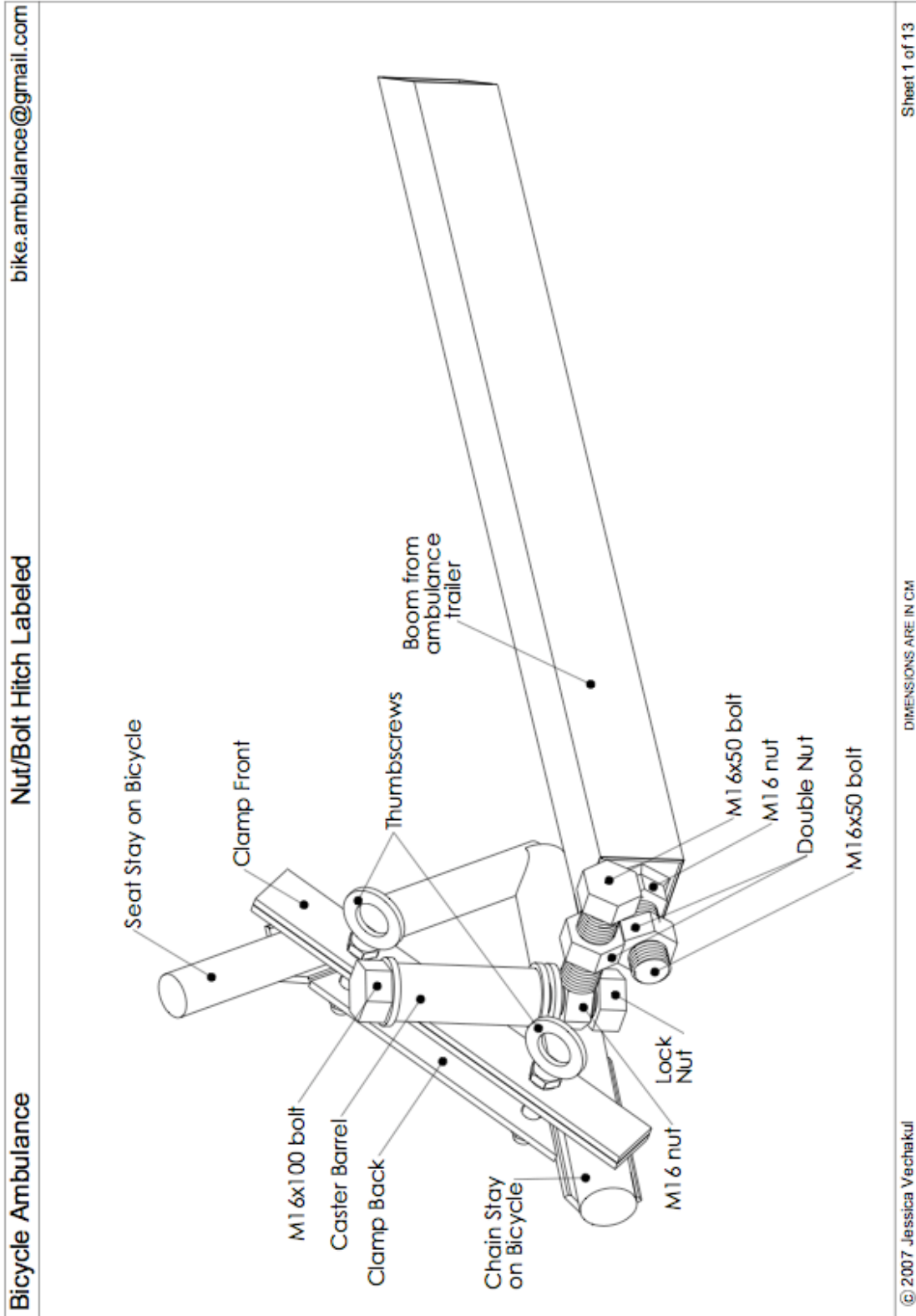
CONTACT: bike.ambulance@gmail.com

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SHEET 48 OF 48

A4

APPENDIX G: NEW HITCH PRODUCTION MANUAL



bike.ambulance@gmail.com

Nut/Bolt Hitch Labeled

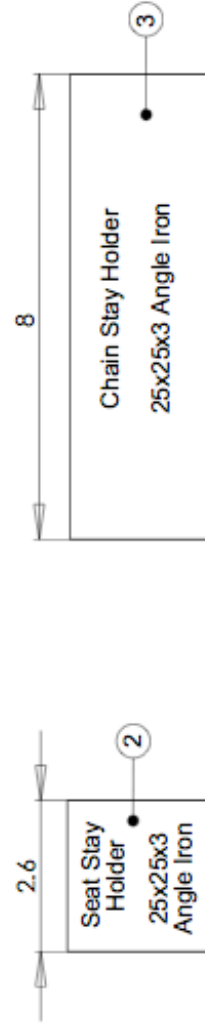
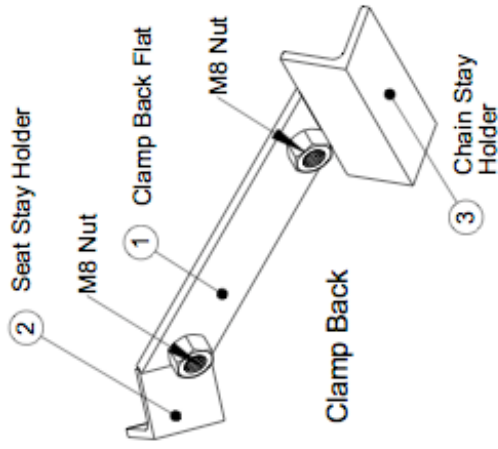
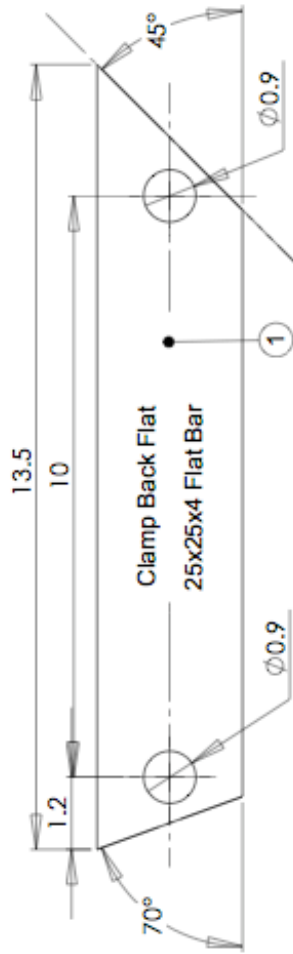
Bicycle Ambulance

Sheet 1 of 13

DIMENSIONS ARE IN CM

© 2007 Jessica Vechakul

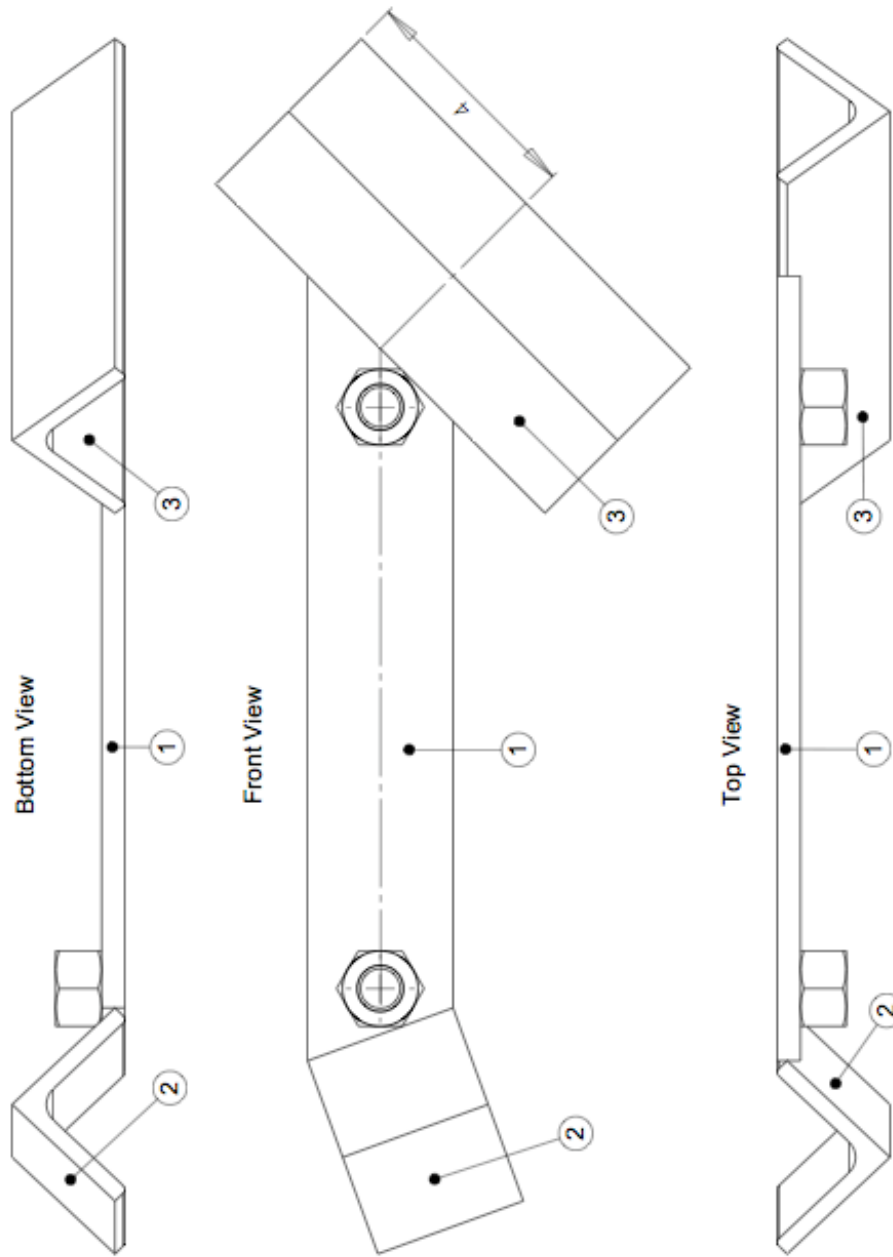
PARTS: Clamp Back



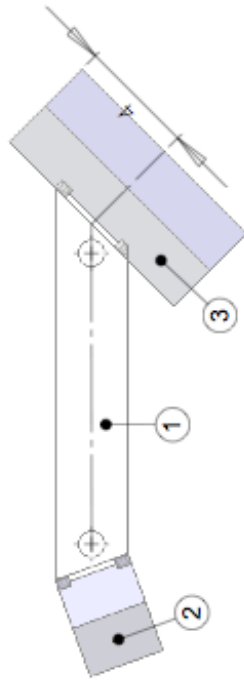
Cross Section 2 and 3

25x25x3 Angle Iron

VIEWS: Clamp Back



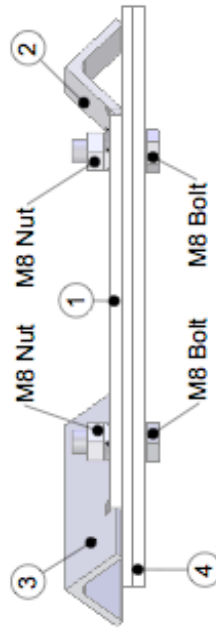
TACK: Clamp Back



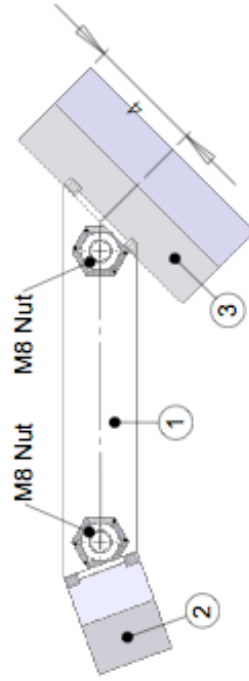
Remove: M8 bolts from Clamp Back



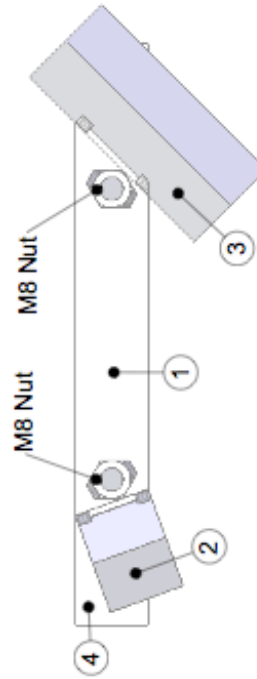
LOCATE: M8 Nuts on Clamp Back



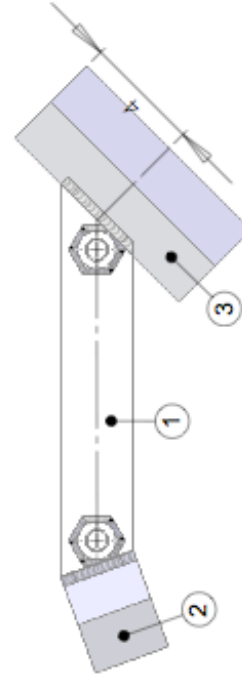
WELD: M8 Nuts to Clamp Back



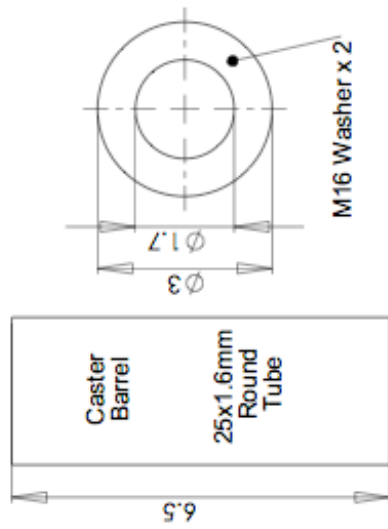
TACK: M8 Nuts to Clamp Back



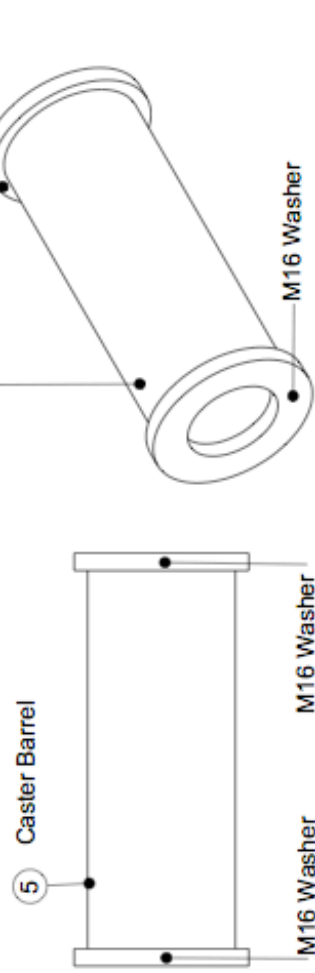
WELD: Clamp Back



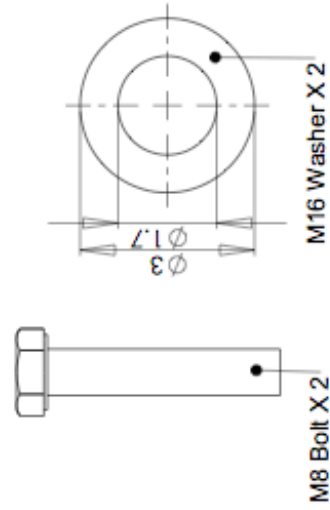
PARTS: Caster Barrel



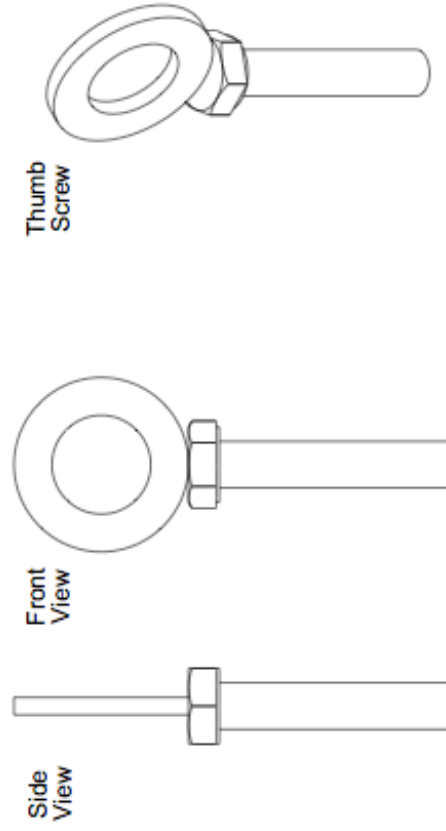
ASSEMBLY: Caster Barrel



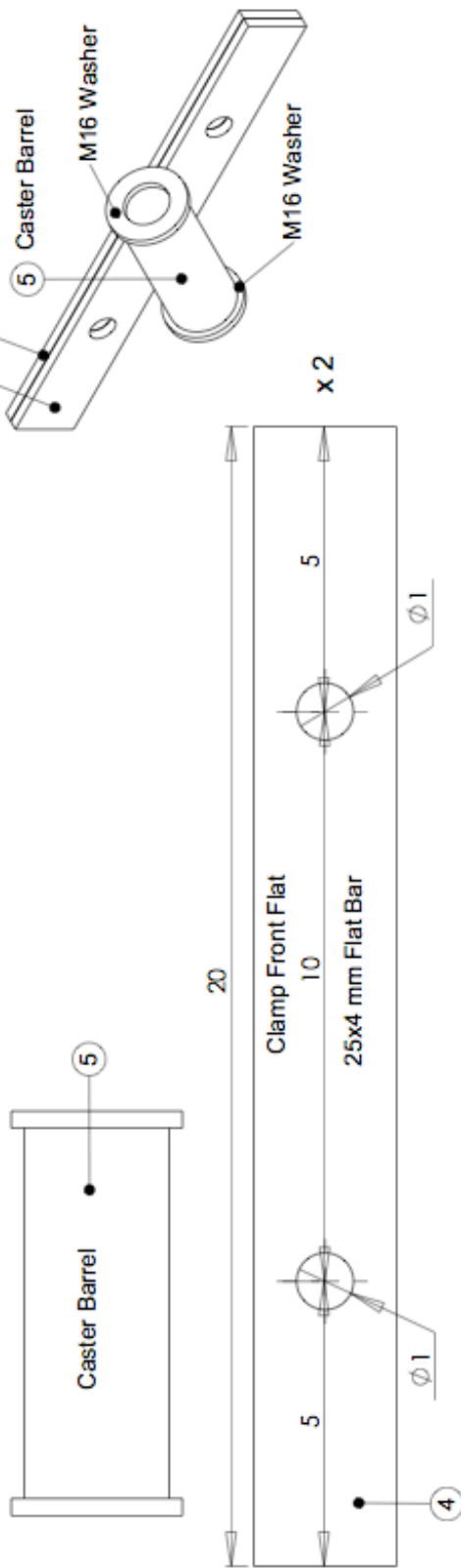
PARTS: Thumb Screw



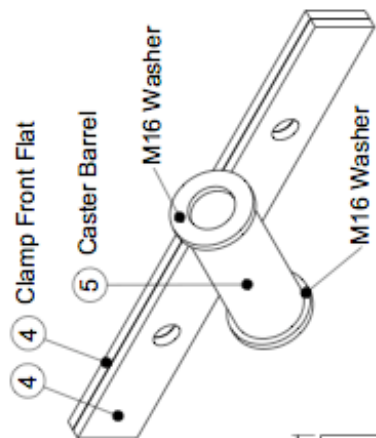
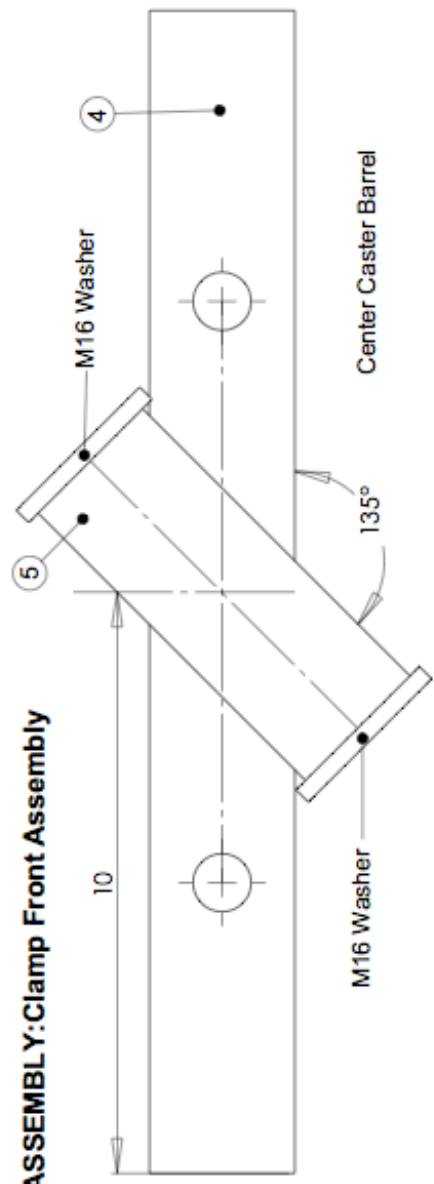
WELD / BRAZE: Thumb Screw X 2



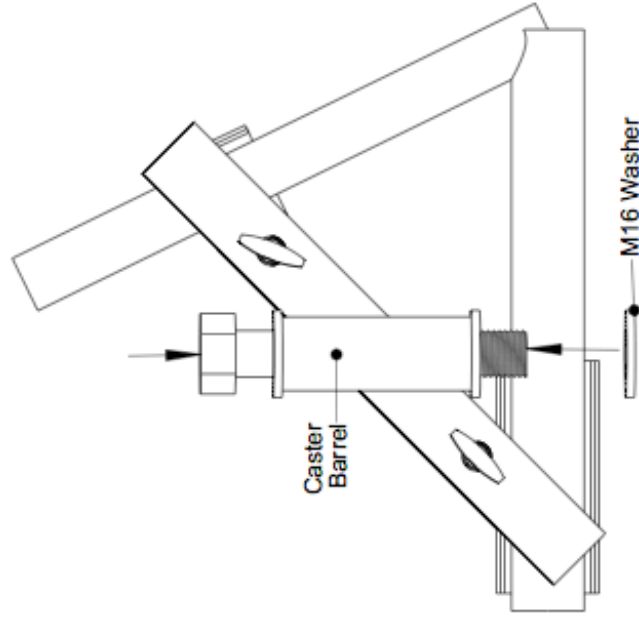
PARTS: Clamp Front Parts



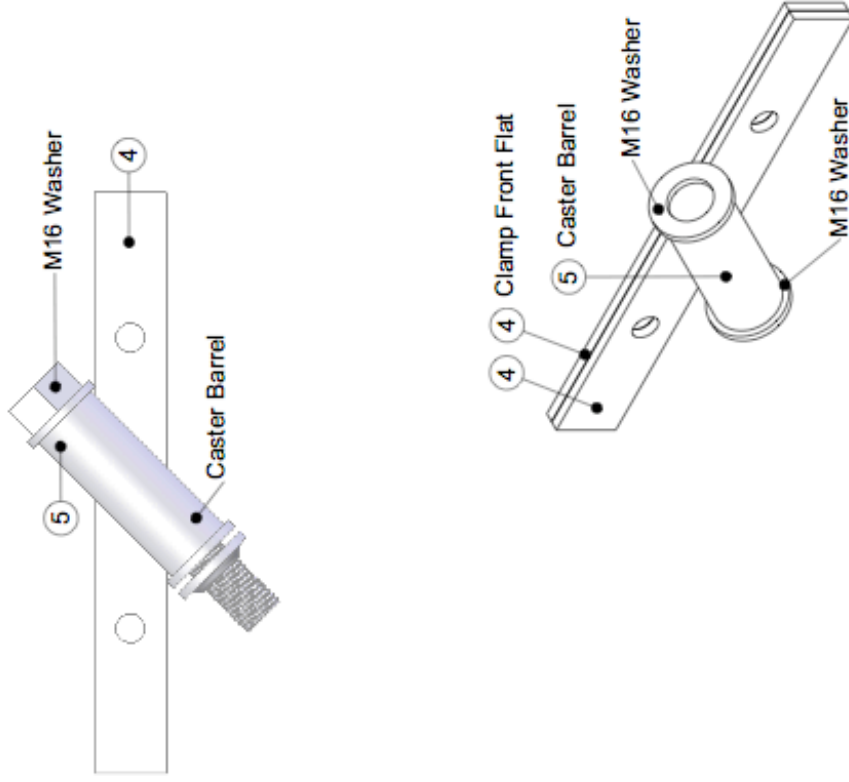
ASSEMBLY: Clamp Front Assembly



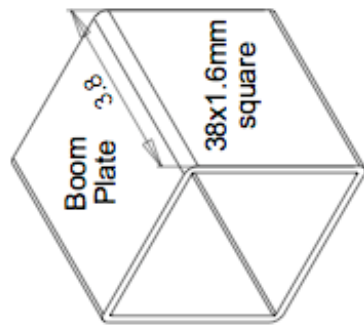
INSERT: M16x100 Bolt into Caster Barrel and M16 Washer onto Bolt



WELD: M16 Washer onto M16x100 Bolt



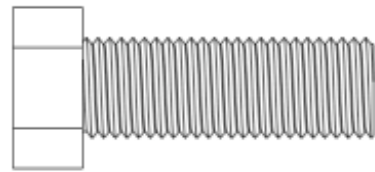
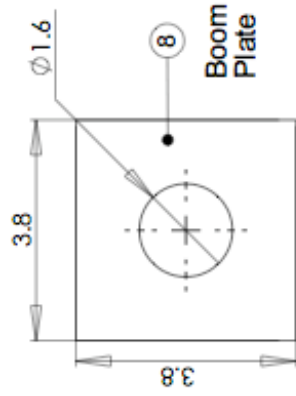
PARTS: Boom Plate



Drill Holes



Cut

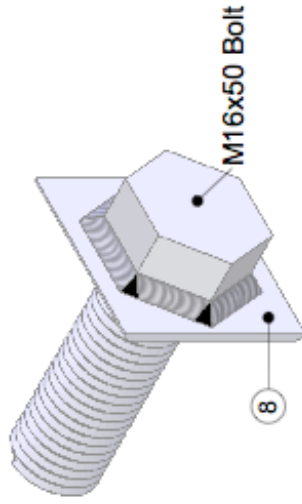
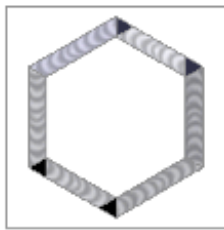


M16x50 Bolt

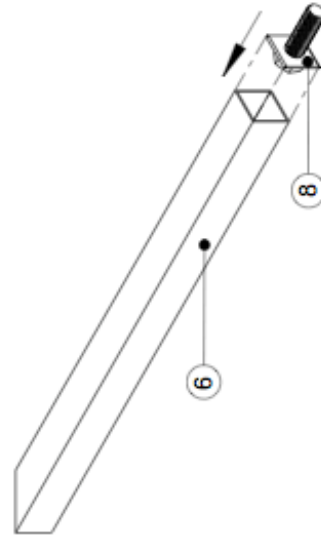


M16 Nut

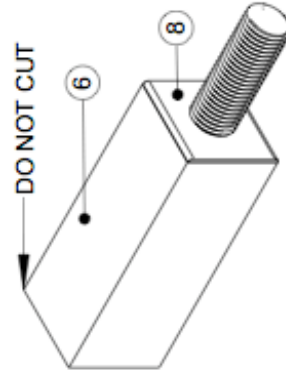
WELD: M16x50 Bolt to Boom Plate



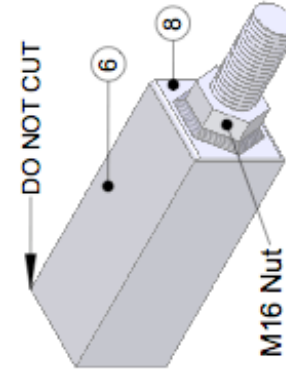
ALIGN: Boom to Boom Plate



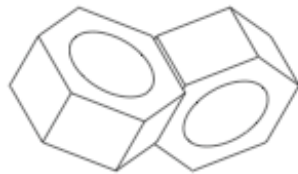
WELD: Boom Plate to Boom



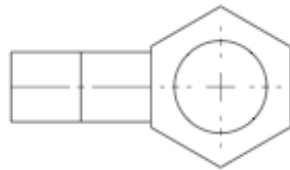
WELD: M16 Nut to Boom Plate



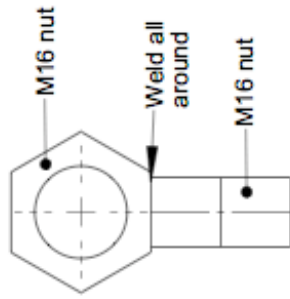
WELD: M16 nut to M16 nut to make a DOUBLE NUT



DOUBLE NUT

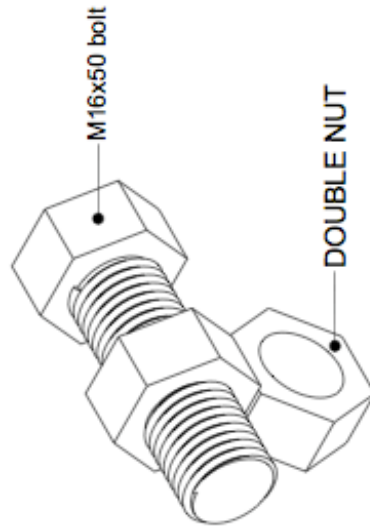


Front View

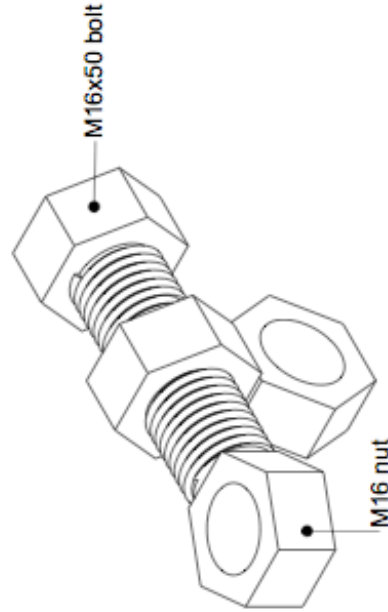


Side View

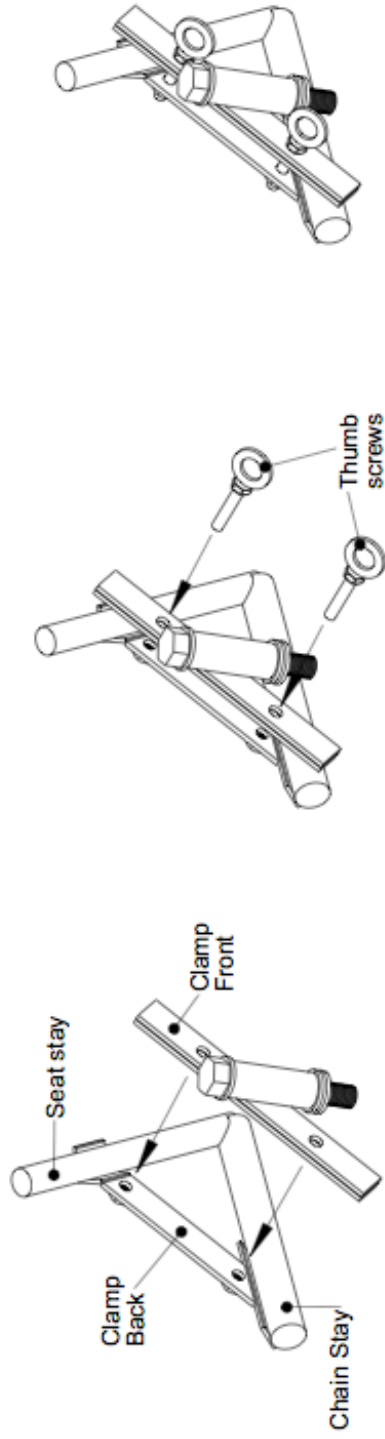
INSERT: M16x50 bolt into the DOUBLE NUT



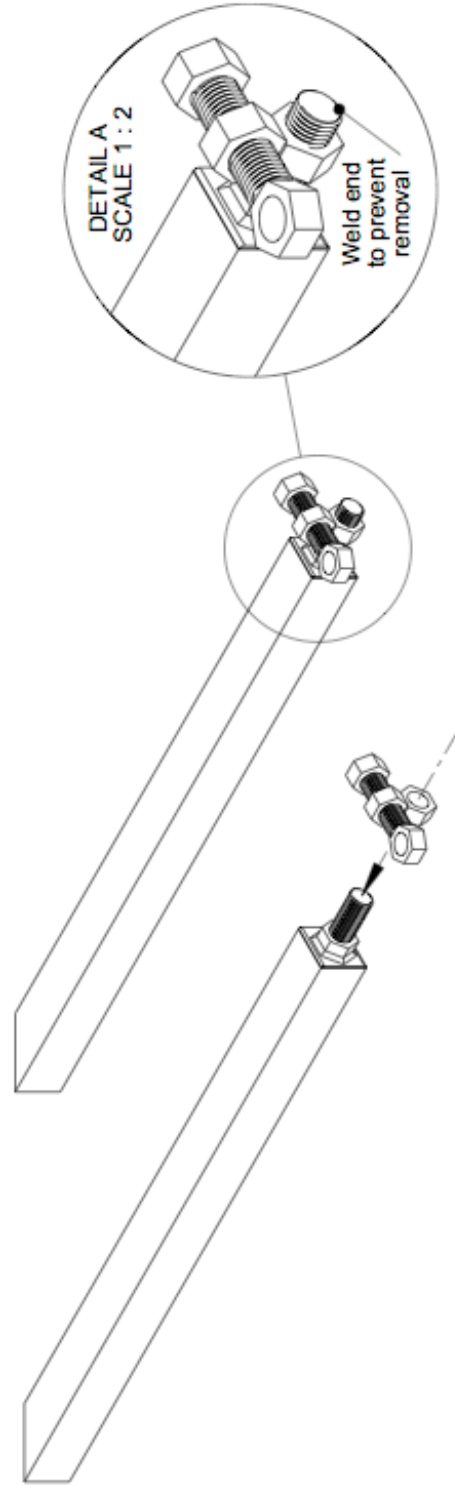
WELD: M16 nut to the M16x50 bolt



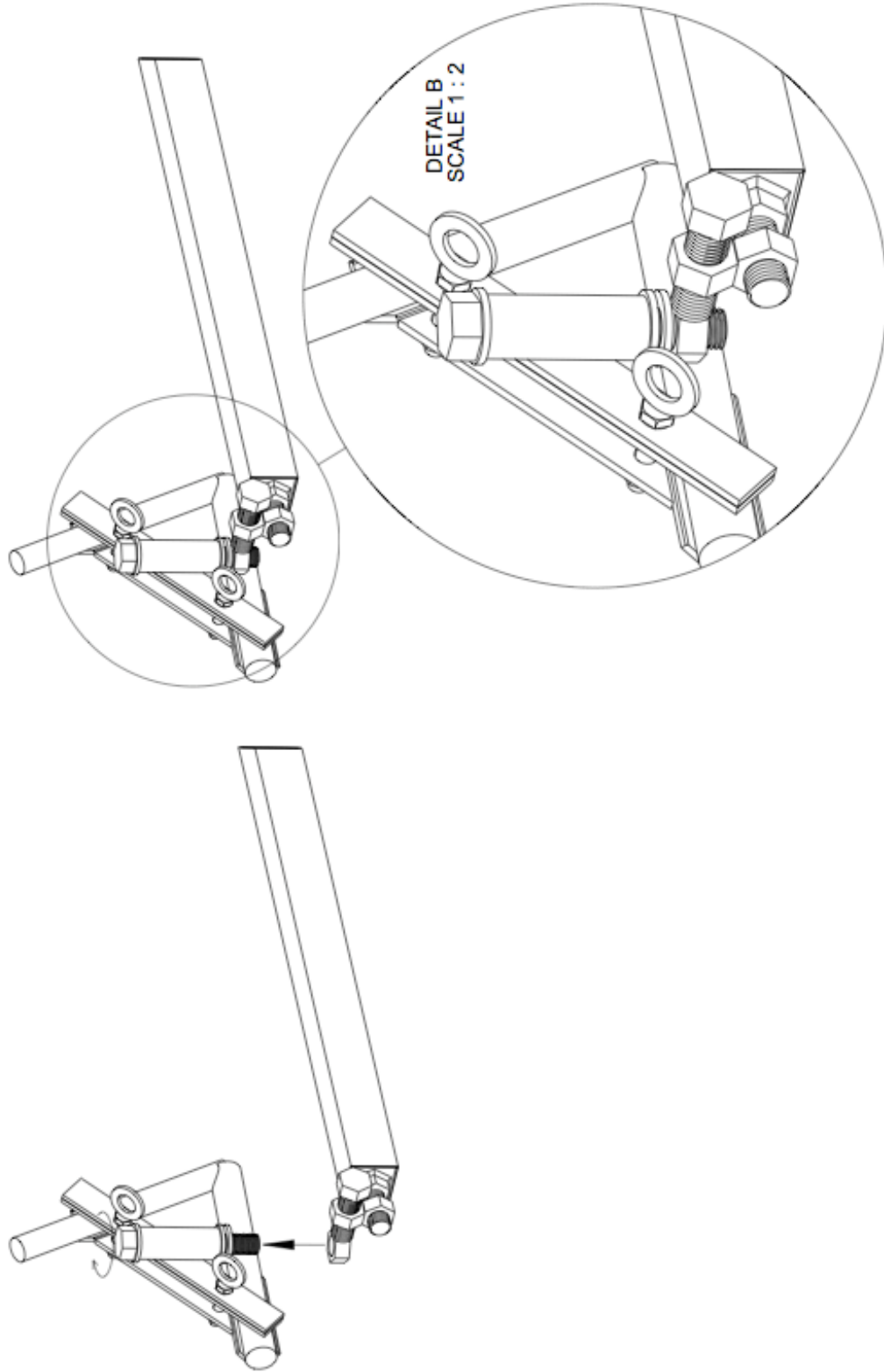
Bolt: Clamp Back and Clamp Front onto Bicycle



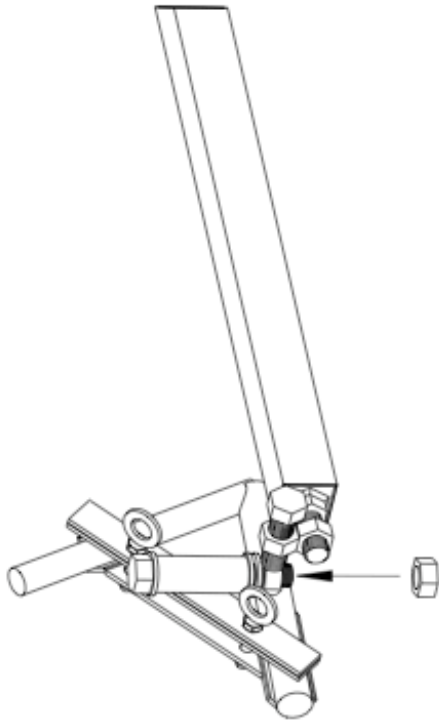
Screw: Double Nut Assembly onto Boom



Turn M16x100 bolt to attach M16 nut on bottom



Tighten: Lock nut onto Hitch



**FINISHED ASSEMBLY:
NUT AND BOLT HITCH**

