

High Compliance All-Terrain
Transport and Heavy Cargo
Hybrid Bicycle

by

Orlando Soto
In collaboration with
Andres Pino

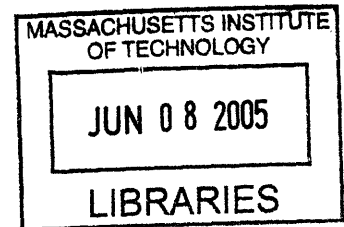
Submitted to the Department of Mechanical
Engineering in Partial Fulfillment of the
Requirements for the Degree of

Bachelor of Science

at the

Massachusetts Institute of Technology

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A handwritten signature in black ink, appearing to be "Orlando Soto".

Signature of Author _____
Department of Mechanical Engineering
May 6, 2005

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Ernesto Blanco
Adjunct Professor of Mechanical Engineering
Thesis Supervisor

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Ernest G. Cravalho
Chairman, Undergraduate Thesis Committee

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ABSTRACT

A design project was carried out which involved the design, manufacturing, and assembly of a hybrid bicycle. The bicycle was required to operate between two modes, one that permitted fast transport of the operator from one location to another, and a second configuration which could permit the operator to carry large amounts of cargo, or a wounded individual, easily.

The design was found to be effective in both configurations. Further investigations into mass production and Design for Manufacturing should be pursued.

Thesis Supervisor: Ernesto Blanco
Title: Adjunct Professor of Mechanical Engineering

1.0 Introduction

Bicycles have been a part of everyday human life since their invention in the 1800's, and have become a necessary mode of transportation in many countries of the World. From the High Wheel bicycle to modern day touring bikes, the evolution of new materials and manufacturing processes, as well as the needs of individuals, has had a great impact on bicycle design. However, the general design of the bicycle as we know it today is stigmatized by design constraints that have been imposed since its conception.

The goal of my research has been to break these stigmas, and in doing so produce a new vehicle that operates with the same principles as a bicycle, but easily shifts into another mechanical configuration that allows for the transport of a great deal of cargo (approx 200 lbs) when compared to the transport capabilities of the traditional design. In addition, the design proposed within this document allows for the transport of not just general cargo, but also of a passenger (when the vehicle is in cargo-mode). The ability of carrying a passenger as the payload was developed, in part, as a means of fast-evacuation of a wounded individual. Military personnel, Park Rangers, and recreational outdoorsmen, as well as inhabitants of developing countries, will benefit greatly from a design that incorporates the simplicity of modern bicycle design and components, as well as the added capacity to carry a substantial load of cargo.

In the following sections I discuss what needs the bicycle was designed to fill since its conception. I will also show how, historically, the needs the bicycle caters to in everyday use have changed very little. Even though modern society constantly demands a lot more from its vehicles and modes of transportation (as the automotive industry clearly shows), the design of modern bicycles has not changed at all in the last 100 years. Modern bicycles are all about newer, more lightweight materials, more complex suspension systems, and advanced ergonomics and geometries that reduce air drag. However, the application and use of bicycles has remained the same since their invention: A vehicle that transports a single person. Never has the ease with which a bicycle can be made to carry a large cargo load been realized. Bringing this fact to light, as well as proposing a design with which to do it is the purpose of my research.

1.1 History of the Bicycle

The first version of what would later become the modern bicycle was invented in 1817 by Baron von Drais. His device was designed with the purpose of making walking easier, and lacked the pedals and gearing of subsequent models. The vehicle was driven by pushing off from the ground “in a sort of gliding walk”, much like the scooters we know today. However, due to materials and construction techniques of the time, it was very rigid, and the ride proved to be very rough, especially over the cobblestone streets of the time.



Figure 1: Illustration of “The Walking Machine”¹

The High Wheel Bicycle of 1870 was among the first attempts of producing an all-metal machine. The pedals were attached directly to the front wheel, and it incorporated a solid rubber tire in order to make the ride smoother. In addition, the huge front wheel was designed in an attempt to provide a mechanical advantage to the pedaling process, since the larger the wheel, the farther the vehicle could travel on one rotation of the pedals. This mechanical advantage, however, had its limits, as the wheel could only be as big as the operator’s leg. The need for a gearing system was becoming more evident.

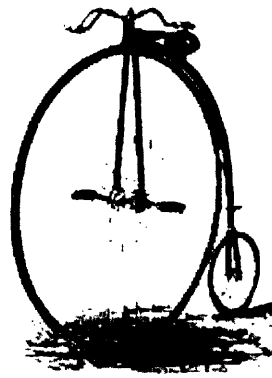


Figure 2: High Wheel Bicycle

¹ Illustrations and information from <http://www.pedalinghistory.com/PHbikbio.htm>

The High Wheel Bicycle also had some inherent flaws. The approach of using a huge wheel in order to meet the design parameter of extracting a mechanical advantage from the pedaling process required the operator to sit high above the ground, thus raising the machine's center of gravity considerably. This meant that any sudden obstruction of the vehicle's forward motion, say hitting a curb or bump, would flip the bike over its front axle. The fact that the operator's legs were constrained by the handlebars (as can be seen by the bend in the handlebars in order to accommodate the legs in Fig. 2) only added to an already unsafe design.



Figure 3: Failure mode of the High Wheel Bicycle

Although these High Wheel Bicycles were deemed by many to be unsafe, it was the issues regarding their safety that led to the development of the bicycle as we know it today. One of the first attempts at solving the inherent instability of the High Wheeler was to move the smaller supporting rear wheel forward. Although this solved the problem of the bike flipping forward, now it was possible for it to flip over backwards, as can be observed from the configuration in the illustration below. Although the flipping problem had only partially been solved, this new configuration was dubbed the High-wheel Safety.

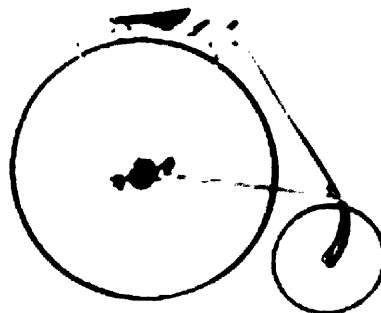


Fig 4: High Wheel Safety bicycle

Constant advances in metallurgy and manufacturing processes, as well as the advent of the pneumatic bicycle tire by Dunlop, came to produce the design of the bike we know today. The idea of a huge wheel as a means to provide mechanical advantage was abandoned for the modern chain and sprocket. In addition, many of the design aspects of today's bicycles that we consider to be modern amenities, such as full front and rear suspension and even a drive shaft in place of the chain were all components in bicycles as early as the 1890's. By the early 1900's, bicycles had already begun to play an important role as a faster, more efficient alternative to walking and, more importantly, as the first choice of mechanical transportation by people who could not afford a motorized vehicle.

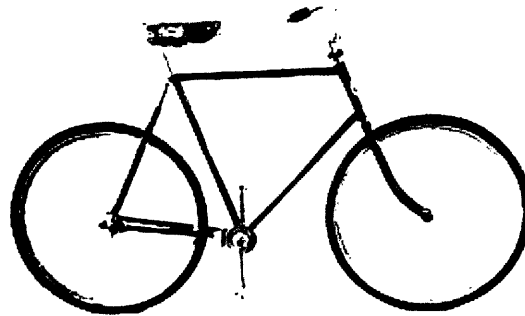


Figure 5: Pneumatic-tired safety bicycle, 1898. Note driveshaft

1.2 Applications of Bicycles

Modern applications of bicycles focus primarily on getting people from one place to another. Many companies have begun research and production of state-of-the-art electric bicycles, which tend to be very expensive. There have also been many breakthroughs in material technologies, such as carbon fiber and titanium alloy frames, and there are many bicycle designs with extraordinary ergonomic options, but none of them attack the issue of getting more cargo area from the standard, two-wheel configuration.



Figure 6: Modern electric Bicycle

Some manufacturers have begun producing “bike trailers”, but these extend the overall dimensions of the bicycle too much, hindering turning capability and handling. They are also permanent, which means that once you hitch the trailer onto the bike, you will have something hanging off the back whether you use it or not.



Figure 7: Bike trailer attached to rear wheel.

Since these bike trailers invariably add an extra wheel (or two) to a bicycle, some manufacturers have opted for scrapping the two wheel design in an attempt to get the necessary cargo room from a tricycle. This strategy requires a more complex driving mechanism as well as an enlarged frame, which adds to manufacturing costs. Tricycles also have poorer handling capabilities than bicycles, and are likely to tip on sharp corners.

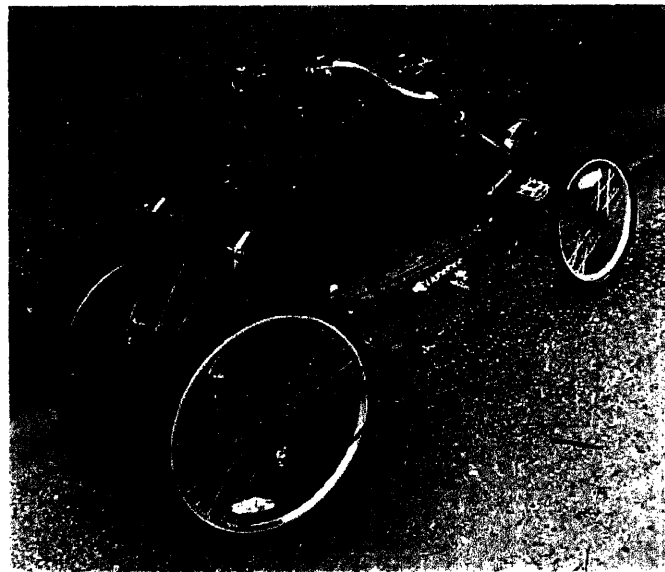


Figure 8: Tricycle with rear cargo hold. Note inherent complexity of frame and driving mechanisms

2.0 Current Bicycle Design

Bicycles today come in many shapes and sizes. Some have extreme ergonomics, designed in some cases to be pedaled with the arms instead of the legs. Others are made for racing and keep weight and drag to a minimum. Regardless of how they are built and operated, they all serve a single function: to take people from one place to another. In the following section I will analyze the design of the modern bicycle in detail in order to show how, with very little modification to the modern design, the applications of a bicycle can be greatly expanded.

2.1 Design Specifications and Detail

The frame of the modern bicycle has not changed for the past 100 years. Its design is simple and effective and has remained constant because not much more has been required of a bicycle other than as a means of transportation. Shown below is a drawing of the standard bike frame with components labeled.

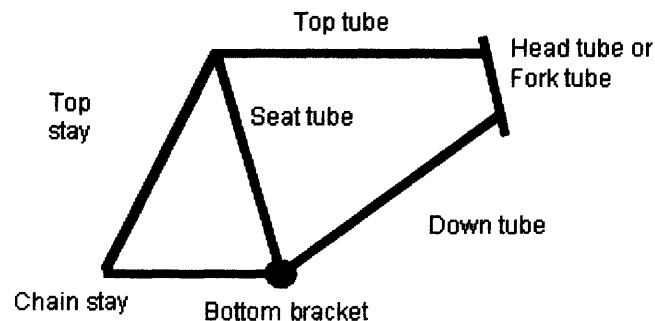


Figure 9: Standard Bike frame²

A crucial component of modern bike design is the head tube, which holds the fork in place. The head tube allows the fork to swivel 360 degrees (or until the brake cables restrain movement). The main component of force that the head tube is submitted to is supporting the thrust that the ground exerts on the wheel. This thrust is transmitted to the fork and, in turn, the head tube. Ball bearings are used in the headset assembly, which holds the fork in the head tube, to minimize the friction that would be greatly magnified

² drawings and schematics from www.howstuffworks.com

by the large thrust they have to support. A detail of the head tube and bearing assembly is shown below.

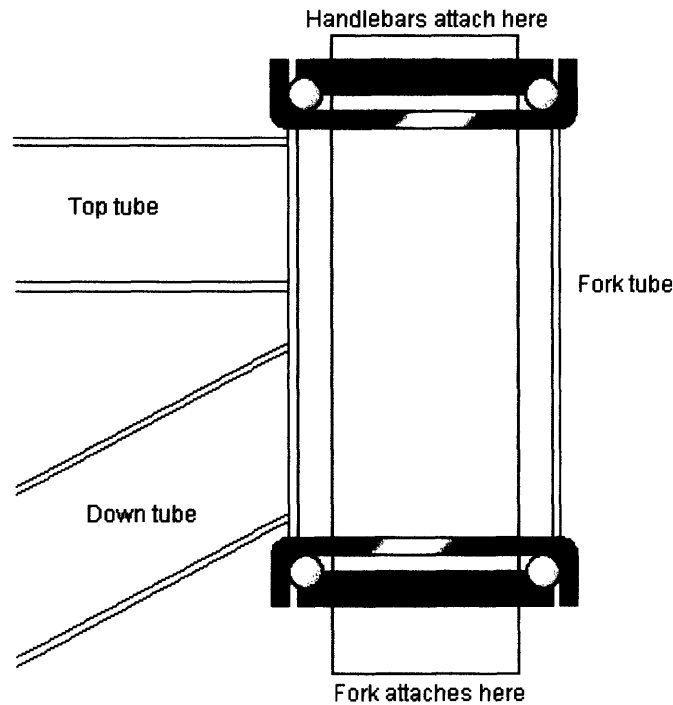


Figure 10: Head tube Detail

3.0 Proposed Bicycle Hybridization and Design

3.1 Overview

The principle behind the design of our proposed hybrid bicycle is simple. If a bicycle frame consisted of a symmetrical arrangement of two head tubes and two forks, then it is conceivable to design a lock-and-pin mechanism in order to keep the rear wheel locked in place and the front wheel free. In this mode of operation the vehicle looks and operates like a normal bicycle, aside from it having two forks rather than a rear wheel that is attached to the frame. In the alternate configuration, the rear wheel pin is unlocked and the wheels are rotated 90 degrees and locked into this new position. Now the wheels are at right angles to the plane of the frame, and the frame itself can be tilted down and used as a cargo area. Armatures that are an integrated part of the frame swing out to provide handles for a person to steer the new rickshaw-like configuration, as well as to provide a more ample cargo area. When the ability to transport cargo is no longer needed, the

vehicle can switch back to its bicycle configuration in order to provide fast transport for the operator.

3.2 Design Constraints

For the proper operation of the vehicle it is necessary that certain criteria be met. For instance, both configurations of the vehicle (bike and cargo) must be seamlessly integrated. This means that there should be no external pieces that need to be carried around in order for the vehicle to be able to operate between modes. In order to do this, the armatures that deploy when the bike changes into a rickshaw must be self-contained as an integral part of the frame. These armatures must also not interfere with normal operation of the vehicle when it is in bike mode.

The vehicle must also have the capacity to go from one configuration to the other easily. This means that the amount of steps that it takes for the bicycle to go from transport to cargo mode must be kept to a minimum. One way of approaching this problem is by making sure that the geometries shared by both the cargo mode and the transport mode are as similar as possible. The more they have in common, the less changes it takes to go from one state to the other, and thus the complexity of the process is minimized. As the design stands, it takes five steps to go from one configuration to the other: the front wheel must be locked, the rear wheel must also be locked, the chain must be disengaged, the foldable arms are extended, and the cargo area is deployed. To go from cargo mode to transport mode, the process is reversed.

Another design constraint includes robustness of frame and assembly. The frame should be sturdy enough to support the weight of an average adult (approx. 150 lbs) in both configurations. The welds must be strong enough to withstand loads in the direction normal to the plane of the frame, loads which normal bicycles typically don't have the need to address. Material thicknesses must be chosen with these loads in mind. In addition, the frame must be simple in design and easy to manufacture.

3.3 Design Evolution

One of the most important aspects of merging the frame of a bicycle and that of a rickshaw-like transport vehicle is that the resulting design requires the frame to be symmetric. A non-symmetric configuration would be difficult to stabilize and awkward to operate in cargo mode. A symmetric frame configuration also maximizes the cargo area when the vehicle is in cargo mode and provides an excellent way of housing the required armatures that are used when the vehicle is in the cargo configuration. A solid model of the proposed frame is shown below.

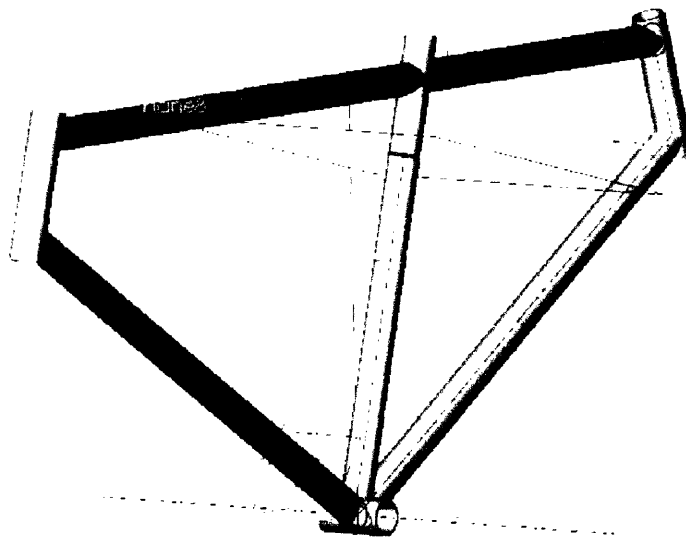


Figure 11: Isometric model of the proposed bike frame.

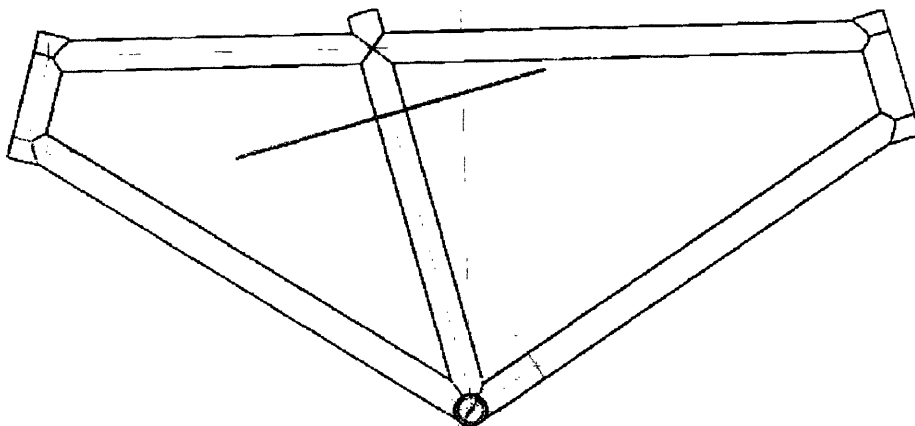


Figure 12: Schematic of the proposed frame. Note symmetry of design.

One of the elements that is critical to the proper function of the vehicle are the extendable arms that are used as handles by the operator when the vehicle is in cargo mode. Among the requirements for this component are that they fold up and attach unobtrusively to the frame. In addition, the arms must not interfere with the operation of the vehicle while it is in transport mode. During the initial sketch phase, I considered the option of using telescopic tubes, but the idea was abandoned due to the excessive amounts of slack and play that are usually associated with telescopic mechanisms. The ease with which a foldable armature could be manufactured, as well as the ability for a folding mechanism to self-lock was found to outweigh the relative benefits of a telescopic mechanism. A sketch of the proposed armature mechanism is shown below.

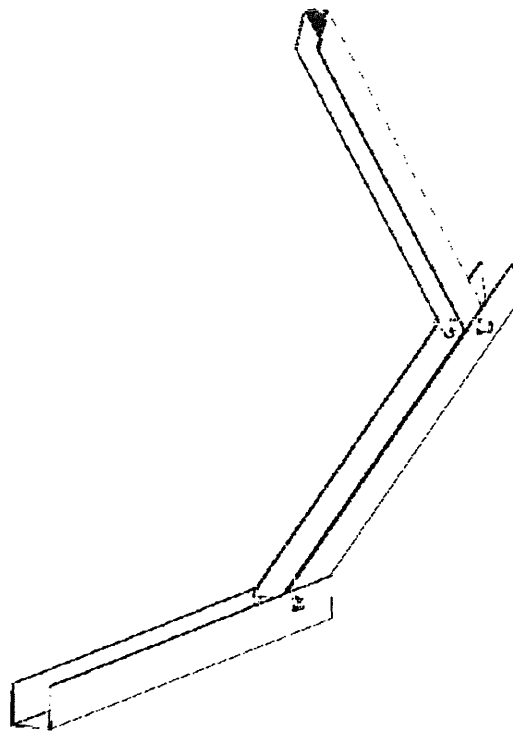


Figure 13: Model of foldable arms that serve as handles and steering in cargo mode

Because both wheels are required to rotate, a dual fork design is almost intuitively obvious to be the most efficient way of providing a means of rotation for both wheels. A design that incorporates two identical forks can also be designed to have state-specific locking positions, depending on whether the cargo or the transport mode is desired. The model below illustrates how the forks and frame interact, as well as give a sense of what the final design should look like at a glance.

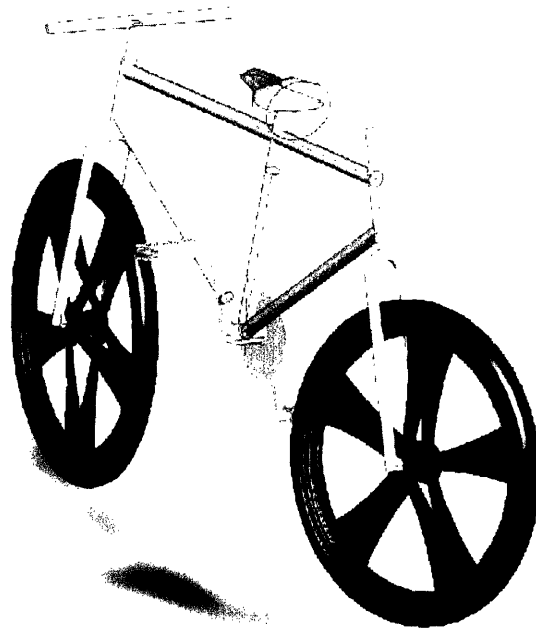


Figure 14: Isometric view of proposed design

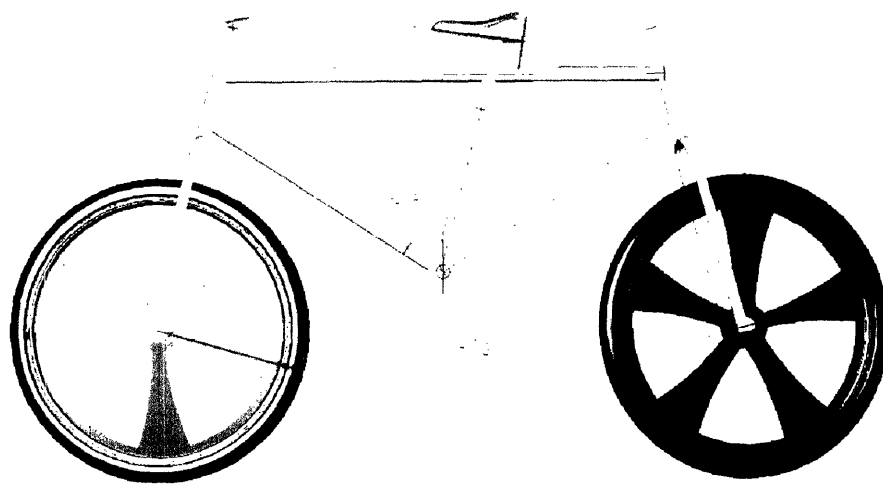


Figure 15: side view of proposed design

The locking mechanism that locks both forks in place is designed to be a simple bolt-action lock-and-pin. The front wheel will have a single locking position at 90 degrees to the plane defined by the bike frame. This will allow for the fork to be fully moveable when the vehicle is in the bicycle configuration, and thus provide steering in the same way a traditional front fork does on a bicycle. The rear fork will have two discreet locking positions. One locking position is in plane with the frame, thus simplifying steering and providing pedal assisted power to the rear wheel. In this configuration there is no difference between this design and that of a traditional bike, other than the fact that this proposed design has two forks. The other locking position of the rear wheel is 90 degrees from the plane of the frame, thus lining up with the locked front wheel and providing the necessary undercarriage for the cargo mode.

4.0 Building Process

In order to test for soundness of design, we initially built one of the most important features of our design, the foldable arms of the cargo configuration. We made the arms out of aluminum sheet metal that was bent into shape. Afterwards, we through-holed the U-shaped pieces and placed axles in order to join them. We avoided metal-on-metal contact by using nylon bushings. Among the benefits of folding arms is their self-locking nature once in the extended position. After the arms were built they were tested for slop and play in the extended position. Naturally, it exhibited some slop, but not nearly as much as a telescopic design would have. In addition, the slop was limited to non critical directions, and once locked, the arm remained stiff in the direction of the main load, exhibiting little or no hysteresis.

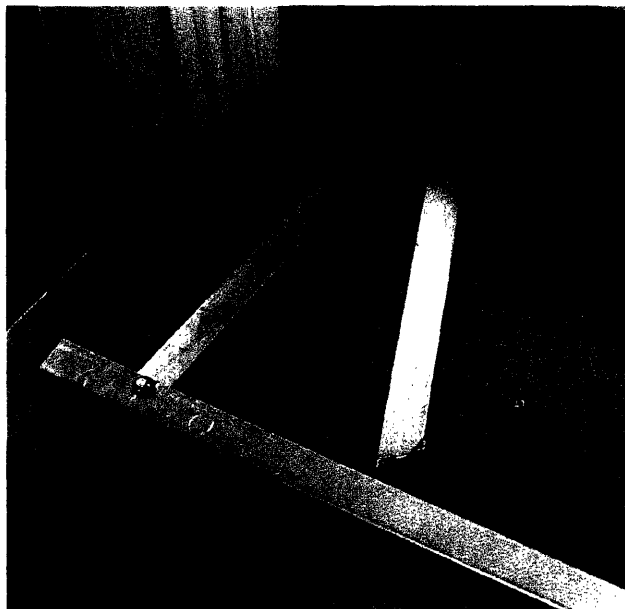


Figure 16: Foldable arm in near-open position



Figure 17: Foldable arm in the near-closed position

In this picture we can see the design constraint on compactness illustrated (approx dimensions are 1"x1"x24"). These arms are to be placed on the down tubes of the bike.

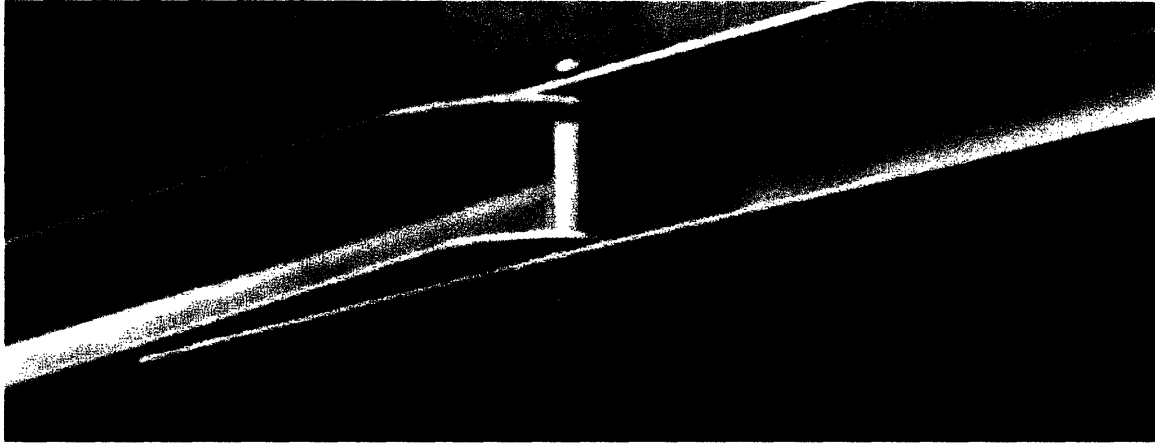


Figure 18: Detail of folding mechanism lock in open position

The first thing we did to make sure the prototype design for our frame matched our proposed design was to transfer the initial design onto paper in 1:1 scale. We cut the pieces of stock as specified in the design parameters and matched them up to the full-scale blueprints and traced out their relative positions. The rake angles on the head tubes were measured out to 10 degrees and the remaining pieces of the frame were matched up and sketched one piece at a time.

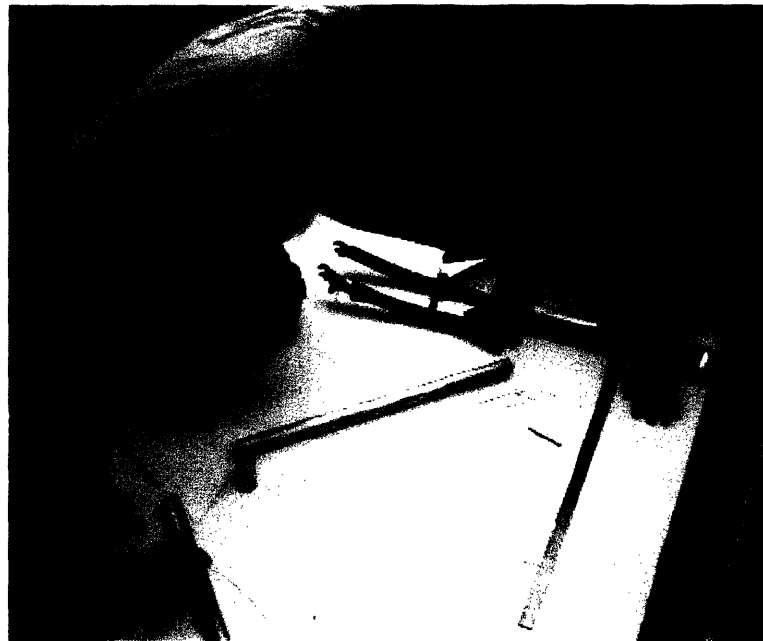


Figure 19: Matching the pieces to paper sketch

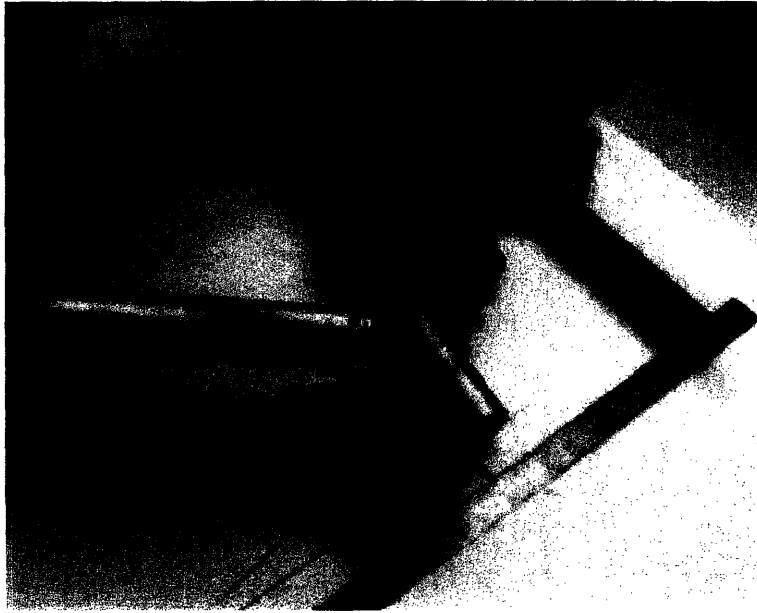


Figure 20: Alignment of the head tube

Once we had measured all the components we had to fish-mouth any flat surfaces that met rounded geometries like the top and down tubes to the head tube, for instance. In order for the fish-mouthing to work, each of the tubes had to be properly aligned in the mill. To do this, we made sure that any known planar geometries were kept in plane by using a level to match up the inclination of the piece to the inclination of the mill table (the mill may not be perfectly level with respect to the floor). We also ensured the fish-mouths were guaranteed to be set to the proper inclination by using angle blocks to align the piece to its holder on the mill.



Figure 21: Fish-mouthing at an angle
(note angle block in back)

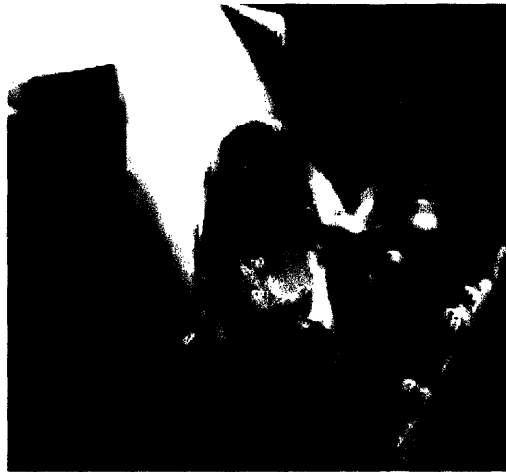


Figure 22: Completed fish mouth

After all the pieces were cut and grooved in the proper places, they were cross-checked for precision with the full scale sketch that had been transferred onto the paper. The head tubes were tacked on to the down tubes to ensure proper alignment of the rest of the frame. Although the material removal process of fish-mouthing can make bars an inch or two shorter once cut, we had planned for losses of approx 1 inch on each of the tubes that required grooving, and gave our cuts the extra inch that the fish-mouthing would later take away.

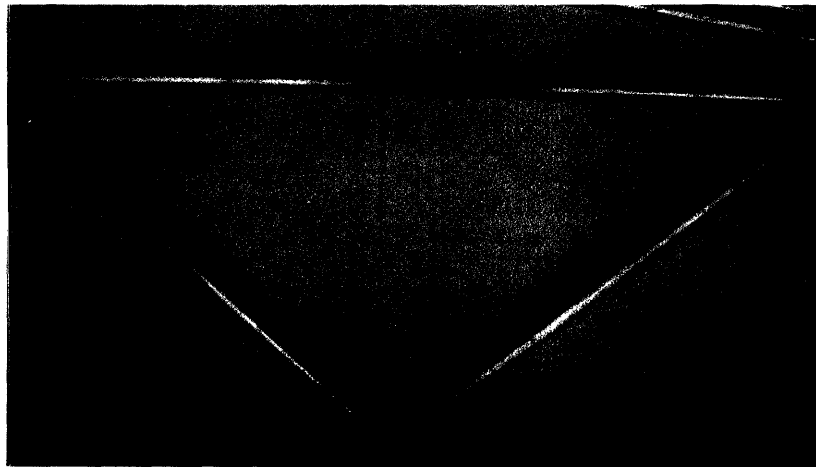


Figure 23: Finished cuts on the outer frame.

Once the outer frame was cut, the parts that were internal to it, like the seat tube, could be cut by using the already cut parts as a reference. Since the fish mouth on the upper horizontal bar that meets the seat tube (sketched above) would have to be fish-mouthed on either side of the seat tube, it can simply be cut at the known angle of incidence of the

seat tube and machined to ensure a proper fit without any changes in overall length. After all the cuts and parts were fitted and checked, the frame was sent out to get welded.



Figure 24: Welded Frame

As we built the prototype, we made slight adjustments to the design in order to not exceed the capabilities of the machinery we had available. We found creative solutions to difficult problems, which included the alignment of the slots that had to be machined into the forks and the alignment of the locking pins. The slots on the forks were machined to be aligned with their respective locking positions by using a level to ensure the slots were in the correct places. The level was matched to the fork and the worktable, in much the same way as it was used to cut and fish-mouth the aluminum tubing.

After the frame was welded, I slotted and aligned the fork tubes to their proper locking positions. I also built the pin mechanism that would fit into the slots in the forks and lock the wheel in place in the desired orientation. After test fitting the pin assembly for proper fit and action, I had the pin housing welded in place. Holes were tapped and drilled into the frame in order to place screws which would specify the range of motion of the pins and lock them in place. Figure 25, below, shows the pins and housing.

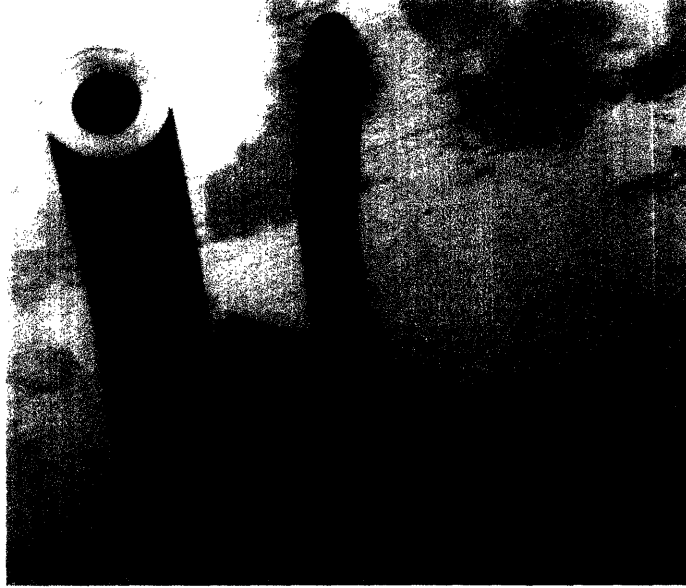


Figure 25: pin and housing detail

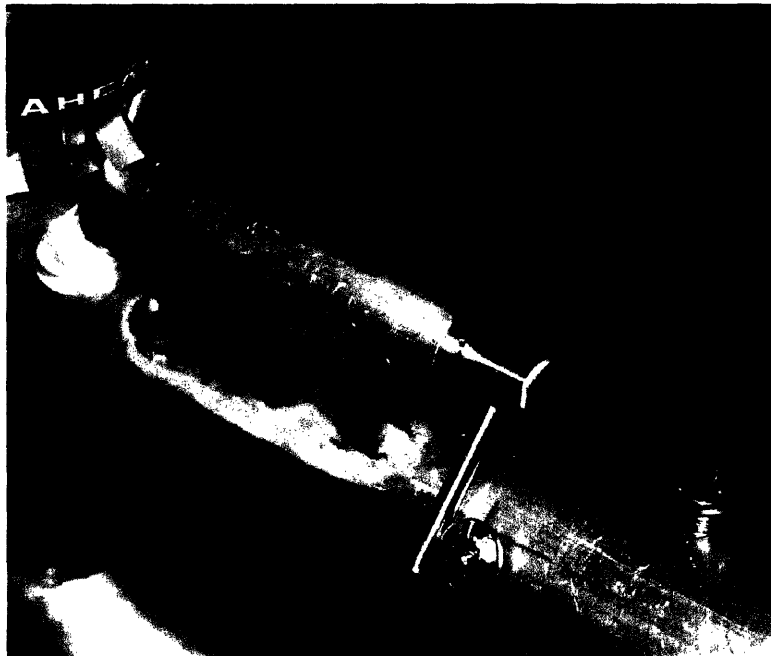


Figure 26: Pin and stoppers in final assembly

After the pins were placed and the conversion process from one configuration to another was successfully tested repeatedly, the final assembly of the armatures was done. Swivel pins were drilled into the frame and the bicycle was at last finished. The following pictures illustrate the final version of the bike. The canvas cargo area had not yet been installed in these pictures.

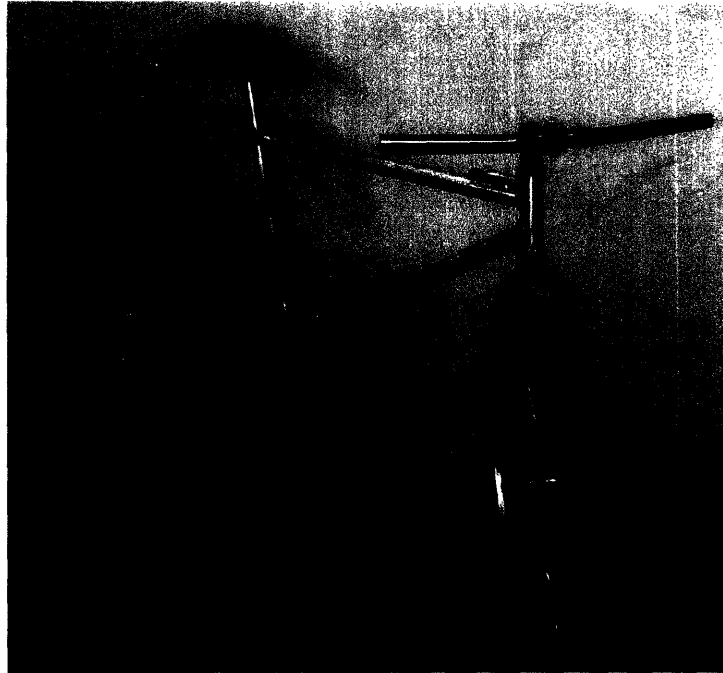


Figure 27: Final bike design



Figure 28: Final Prototype (alternate view)

5.0 Conclusion

The design process and production of a successful prototype prove that it is indeed possible to build a bicycle that doubles as a cargo carrier. There is an immediate need for such a cargo carrier in the military, where troops are limited by the amount of cargo they can carry on their backs. More importantly, this vehicle could serve a role in quick evacuation of wounded individuals, since the cargo area is designed to accommodate an average sized adult. Other applications of this design include US park rangers, where there is a need for an efficient personal transportation and cargo device. Civilian use of this product is also expected, since the need for a bicycle that can, for example, take you to the grocery store *and* bring your groceries back has been enthusiastically expressed by fellow classmates. Developing countries, which rely heavily on bicycles as a means of transportation, also have a clear need for a product that can expand on a technology that they have already come to depend on. A vehicle that has the versatility demonstrated by our prototype to be a bicycle *or* a cargo carrier depending on the situation, and the fact that it does so without substantial modifications to the modern bike frame, will no doubt find many uses in outdoor, urban, and even military applications.

6.0 Suggested improvements and Further Research

Although the prototype demonstrates that our original concept of a hybrid bicycle is possible, it also showed us what design features were critical to its proper performance. Among these manufacturing aspects that are critical are the draft angles on the head tubes, the slotting and alignment of the forks, the alignment of the pedal sprocket with the rear sprocket, and the alignment of the pin housing on the frame.

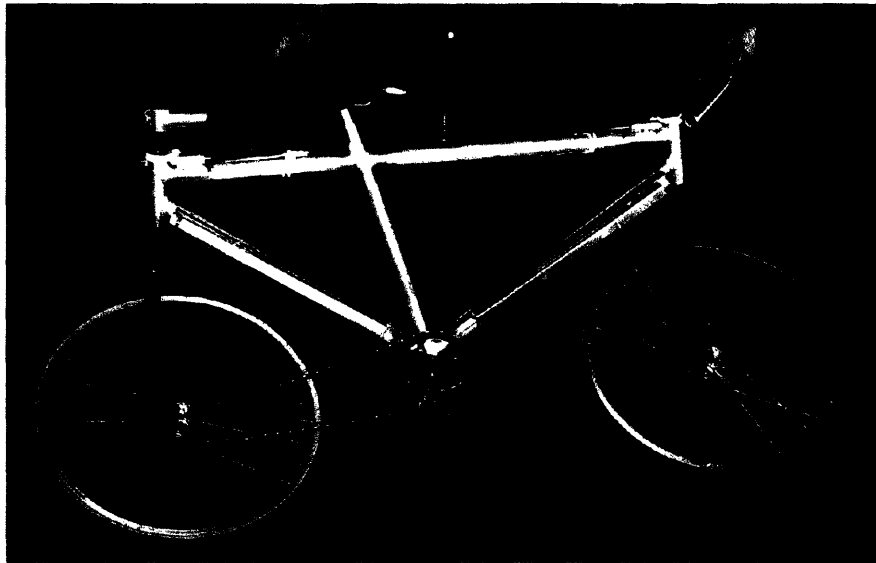
We found that even a slight draft angle on the head tubes makes the vehicle wedge into itself in cargo mode. Although the effect is minor, it nonetheless creates a vibration as the distance of the point of contact with the floor between both wheels widens, reaching a point where the contact with the floor is lost for a second as the rubber jumps to a new position. This effect can easily be solved by setting the draft angles on the head tube to no more than one degree from vertical, rather than the 10 degrees we had specified in the design. In order to compensate for this, the forward placement of the wheel contact point can be accomplished by the rake of the forks. This would allow the wheels to be placed slightly farther out without compromising performance in either configuration.

In our finished prototype, one of the locking pin housings was misaligned when it was welded, thus throwing off the measured slots in the fork. The resulting misalignment of the rear wheel was resolved by widening the slot and taking out the resulting large slop by adding an extra locking pin to the rear wheel. This pin only compensates for the

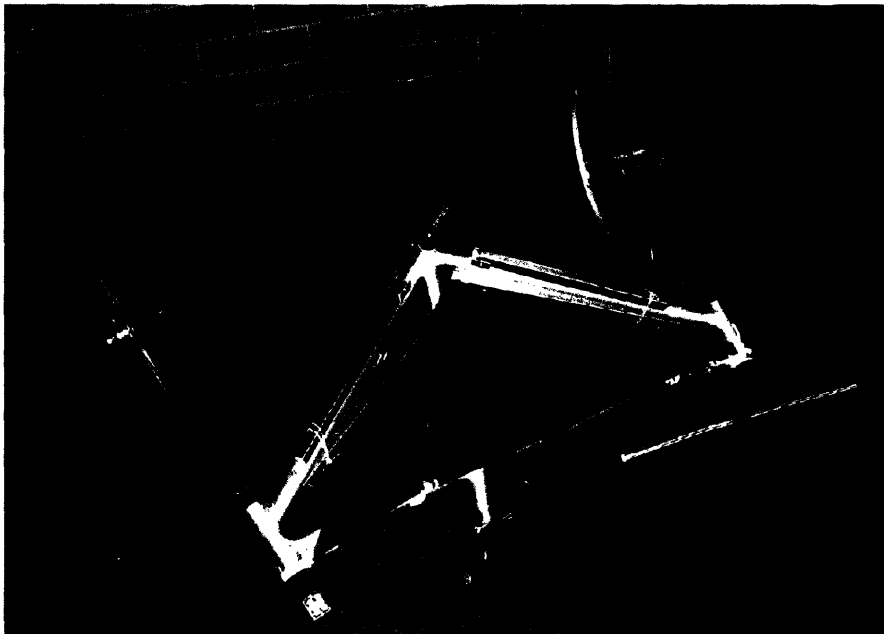
housing's misalignment, and would have been unnecessary had the housing been properly aligned. The alignment of the rear wheel is critical because if it is only slightly misaligned, the sprocket spits the chain and you lose power in bike mode.

Further optimization of the design can be accomplished by reducing the number of steps necessary to go from one configuration to the other. For example, a spring loaded locking mechanism could be pursued, since it can be designed to release both pins simultaneously as well as automatically engage one the slots in the forks have reached the required position.

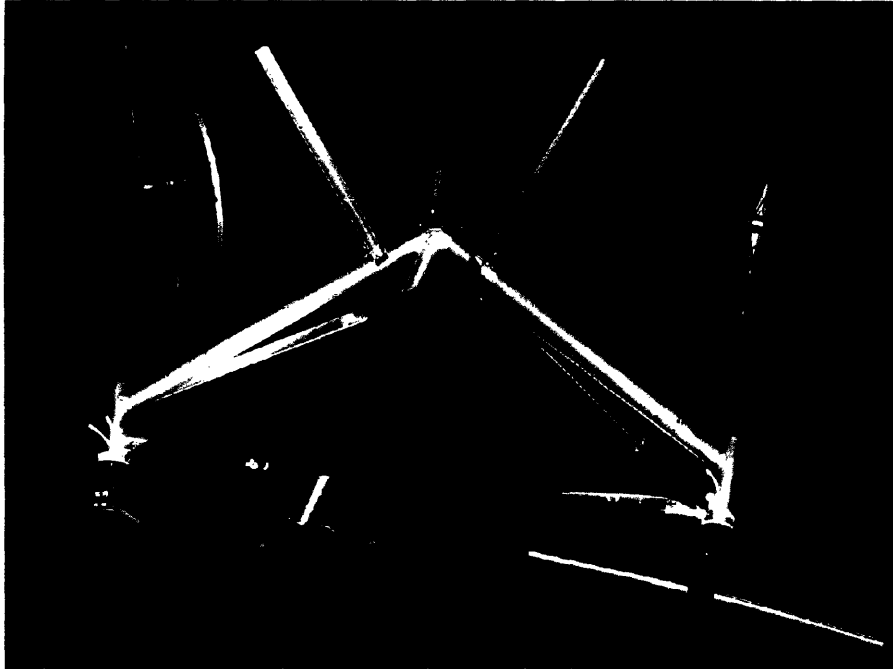
7.0 Stop Frame of Full Bike-Cargo Conversion Process



bike mode



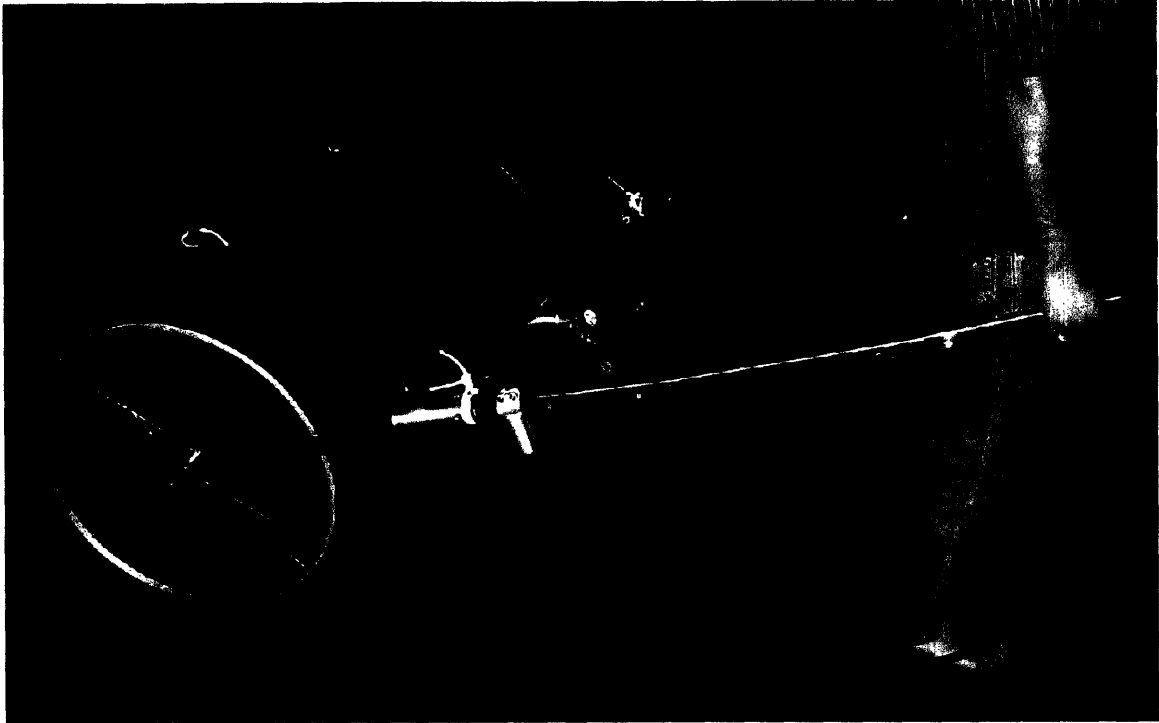
wheels turned and locked



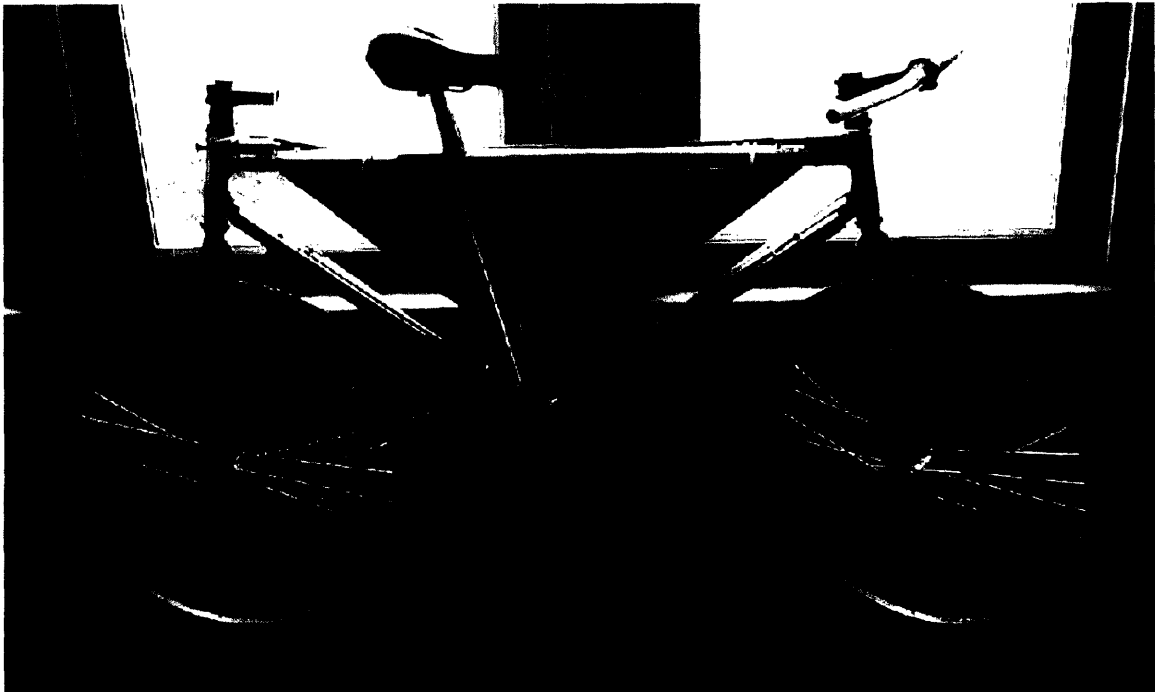
cargo arms extended



Cargo area deployed



Full Cargo mode with steering arms extended



Bike mode



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