ME210 PaperBicycle '99:

some assembly required

"Old Ironsides"

- Patriotism -

Fleet Wheels Design Requirement Document

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Section: 1 Introduction

1.1 Executive Summary

At the beginning of Fall Quarter, the students of ME210 were presented with the task of designing and racing a bike constructed mostly from paper products. The project time line spanned approximately 2.5 weeks and culminated in an afternoon race in the Stanford Quad on October 23, 1998. The main differences between this year's race and those of previous years were the addition of a Client Team aspect and the extension of the high weight penalty to cover all non-paper materials.

The Paper Bike Project was a warm-up exercise to expose ME210 students to engineering design (Figure 1) and engineering design in teams. The teams were formed by the teaching staff, who sought to balance the teams in terms of the Wilde personality profiles.

Our team, Fleet Wheels, spent approximately one week brainstorming ideas and constructing mock-ups to test critical functions. We then spent the next week on detailed design and fabrication. Due to the short time span of the project, the Fleet Wheels members met almost everyday and worked closely with one another. We also explored different methods of just-in-time documentation and information sharing within our team.

Fleet Wheels focused on making a reliable bike that was robust and capable of surviving the race in the same shape in which it started out. To do this, we purchased durable paper tubes and strong adhesives. We also sought to keep weight to a minimum. However, a mistake early during the construction phase resulted in wheels made from sawdust-pressed boards instead of paperboard. This increased the weight of our bike at least threefold and seriously impeded our performance.

The final product of the Paper Bike Project was "Old Ironsides" and this design requirement document. We delivered our bike to Dream Team on Monday, October 19, 1998 and they raced it on the 20th. Our average speed was 2.54 m/s; the class average was 2.08 m/s. Our weighted cost was 539 lbs.; class average was 234 lbs. Due to our high cost, we finished second to last with a score of 0.372. However, we were quite pleased that our bike survived the race in the same shape it was designed in and had no failures.

The design and production of Old Ironsides is outlined in this document.

FIGURE 1. Engineering design accept inputs, perform a function, and generate outputs. The Paper Bike Project provided a background from which we can explore engineering design in a team-based manner.

1.2 Glossary

Dimensional Weight

A weight defined by the volume of an object. The exact relation is: Dimensional Weight = (length)(width)(height)/166.

Double-laminate

Bonding two or more layers of a material together using an adhesive such as epoxy.

External User Requirements

Who will use the product, or be responsible for its use, and how it will be used?

External Environment Requirements

Where will the product be used? What are the functional and physical conditions and constraints on usage?

Functional Requirement

This variable, word, or equation defines what a machine should do. It should not specify how the function is accomplished. This distinction is critical to the generation and evaluation of alternative solutions to a given functional requirement.

Paper Bike

A vehicle propelled by rolling on one or more wheel and constructed primarily from paper products.

Physical Requirement

This variable, word, or equation defines how a machine accomplishes a specific function. The distinction between what and how a machine should operate are crucial to the generation and evaluation of alternative solutions.

Wilde Profile (and North, East, South, West)

Please see http://me210.stanford.edu/98-99/me210-web/private-index.html

Section: 2 Context

In response to their government’s ban on all non-recyclable, non-biodegradable, and fossil fuel powered modes of transport within major cities, transport companies in Narnia turned to cheaper alternative modes. The high cost of electric vehicles in relation to the average citizen’s earnings, together with the sudden disappearance of public transportation vehicles, led these companies to focus their efforts on designing inexpensive, disposable personal transportation modules (preferably bicycles) out of environmentally friendly and recyclable materials (preferably paper). The bikes had to be shipped in large quantities because they were needed urgently to appease the restive masses demonstrating in the streets; they were angry about the long distances they had walk since they could not afford electric vehicles. The Narnian Automobile Manufacturer’s Association contracted with the Fleet Wheels design firm, along with several other design firms (whose workers all coincidentally belonged to the ME210 class at Stanford University) to provide full-sized prototypes of collapsible paper bikes by October 20th, 1998, the date by which COGSO (Coalition Of former Gas Station Owners) had threatened to incite a rebellion if alternative modes of transportation were not found.

2.1 Problem Statement

The design team was required to deliver to a client team a fully-functional “paper bicycle” capable of carrying each member of the client team around the Stanford Main Quad.

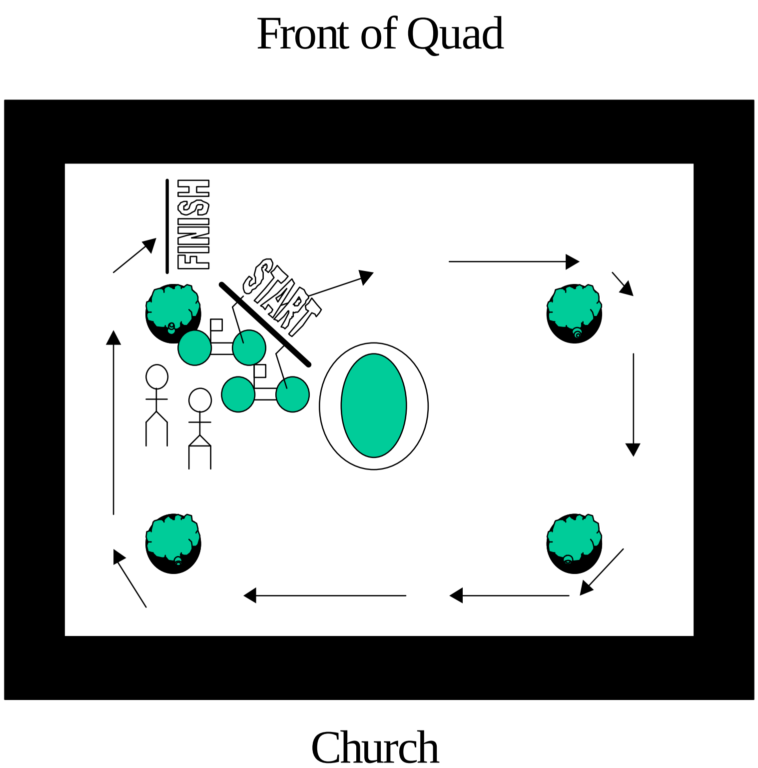
2.1.1 Design Assignment

Paired teams acted as both a client and a build team for the other team. The build team had to finish and ship their paper bikes to the client team on 9:00 AM by October 19th,1998. The client team had to receive, assemble, test, and make any necessary adjustments to prepare for the race on October 20th, 1998.

The bike was to be mostly paper, where ‘paper’ referred to any paper product. All non-paper parts were subject to substantial weight penalties.

Each Client team member raced the bike around the Quad once and had 15 minutes to complete his/her lap (Figure 2). Technical assistance and repairs were allowed during the laps and during the 10 minute intermission between laps.

FIGURE 2. Race course outline for the Paper Bike race.



2.1.2 Scoring

To encourage customer service, teams were given a weighted score which depended 70% on the performance of the bicycles they designed and 30% on the performance of the bicycles they raced. The scoring of each bicycle was as follows:

$$\text{Score} = \text{Normalized\_average\_speed} / \text{Cost} \qquad \textbf{(EQ 1)}$$

Where normalized average speed was defined as the ratio of the average value of course speed (course length / course time) for all four team members to the average speed of all the bicycles in the competition. A bicycle scored zero for a heat if it failed to race, complete the lap within 15 minutes, or was carried or walked for part of the course.

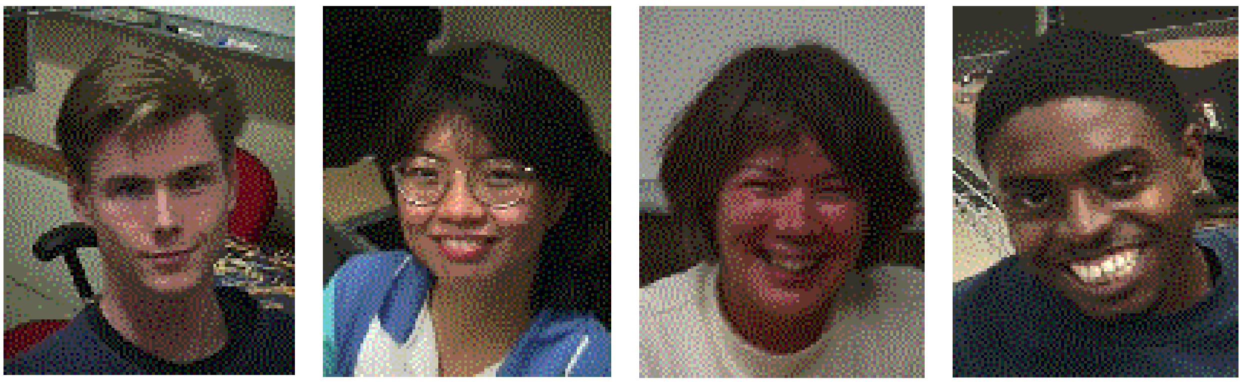
Cost was defined as:

(total weight of bike + 20 * non-paper weight) / (average weight of bicycles in class in kilograms). (EQ 2)

2.2 Design Team

2.2.1 Team members

FIGURE 3. Team members (from left to right): Chris, Wendy, Juli, Nsikan.



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2.2.2 Team circumstances

Our team was diverse, both ethnically and in terms of Myers-Briggs personality profiles. We were comprised of two Norths, an East and a West, according to the Wilde's attitude domain mapping results (Figure 4). In the perception domain we appeared to lack someone to fill the mock-up maker role. We discussed this issue, and found that even though we did not have someone who was especially interested in prototyping and building, our team possessed the experience, skills, and dedication necessary. In addition, the project and its short time span did not lend itself to extensive prototyping.

In the judgment domain, the team lacked members in the critic and the needfinder roles. Wendy chose to fill the needfinder role and created a survey to identify the requirements of the client team. We discussed the role of the critic and decided that it was not an essential role for the Paper Bike Project. Our team's performance did not suffer from the unbalanced domain roles. It was also useful that Ray occasionally fulfilled the critic role.

FIGURE 4. Team profile for the Team Fleet Wheels (Carlson, Cheng, Satoh, Udoyen) using the Wilde attitude mapping method. (a) perception domain. (b) judgement domain.

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Section: 3 Design Requirements

The design requirements discussed here were categorized as functional or physical, and internal or external. The internal functional requirements defined what the paper bike should do on its own, and the external functional requirements defined what the paper bike must do in its interaction with the environment (i.e. rider, ground). The internal physical requirements dealt with what was included in the bike's internal structure and composition. The external physical requirements were physical constraints associated with the outside world. For each type, specific requirements, opportunities, assumptions, and constraints are discussed below.

3.1 Functional Requirements

The paper bike project goal was to build a bike capable of safely carrying riders from our client team around a pre-defined race track in the Stanford Quad on October 20, 1998. A different member of our client team rode the bicycle against 8 other bikes in each of the 4 laps of the race. The outdoor race course was more than 200 yards long and on relatively flat terrain overlaid with bricks. The situation required the bike to fulfill the following functional requirements.

Internal functional requirements

The bicycle had to (be):

- propelled through rolling. This was a defining characteristic of a paper bike as stated by the teaching team.
- able to support a 250 lb. person. The heaviest person on our client team weighed 215 lbs.
- usable by someone under 5' tall and by someone 5'10". Our client team has a member who was 5' tall. She had to be able to operate the bike as easily as the other members of the team.
- dynamically stable. One of the main concerns of backward-steered tricycles was instability at high velocities. To ensure safety, our bike could not tip when turned 20^{o} at 6 miles/hour.
- able to survive being ridden more than 1000 yards on outside terrain. The bike had to show little wear or structural or mechanical damage for the duration of the race (as well as any mileage put on by build-team tests and client-team practices).
- have a right-turn radius of less than 10 ft. The race track required only right turns with large turning radii.

External functional requirements

The bicycle had to (be):

- easily assembled by the client team. A new theme for this year was "some assembly required," and our client team carried out the final assembly of the bike.
- able to go backwards as well as forwards and be steerable in both directions. In the past, the beginning of the race meant traffic jams at the starting line; bikes had to be maneuverable to disengage. Large turning radii (20 ft.) and limited ability to move backwards would be acceptable. These abilities also increased the robustness of the bicycle and its ability to handle unforeseen circumstances.

3.1.1 Opportunities

The paper bicycle functional requirements gave the build team the opportunity to explore both the technical arena and the interpersonal relations. We had the chance to investigate various driving mechanisms (pulley, chain, direct drive) and power options (human power, animal power, wind, electricity, pressure). We also had the opportunity to explore what paper products were available on market and the limits of what the teaching team considered 'paper.' This knowledge would be passed onto future ME210 students or used in future projects.

The paper bike project was also a forum for team members to get to know each other and other members of the class. It provided a common experience to refer to and topic of discussion. The bicycle project also presented opportunities for ME210 students to meet other Stanford persons – while testing the bicycles curious people wander over and investigate. The paper bicycle project also provided future opportunities to meet and impress others; the project and experience translate to hours of entertaining stories for any cocktail parties that we may choose to frequent.

The paper bike project also presented opportunities that could be exploited by future parties. The paper bike may be used as a replacement for real bikes and a way to recycle paper products. It can also be an exercise device that forces the user to use more energy than usual for transportation. The paper bike can be an educational tool used to attract students to and engage young minds in engineering. It might even be a good advertising tool, as few people have ever considered the idea of the paper bikes and are fascinated by it when told of the project.

3.1.2 Assumptions

The following assumptions were made regarding functional requirements during the project.

- No sharp turns would be required.
- Simplicity in design translated to simple construction, assembly, and operation.
- A reliable design that completed all four laps would finish in the top 1/2 to 1/3 of the competition.
- A reclining position was more comfortable than a prone position.
- Pedaling by feet provided better performance than pedaling by the hands.
- Operators would practice rear-wheel steering.
- Operators would be approximately the same physical condition as when they were matched with us.
- The bike would function without intentional impedance from other bikes or persons.

3.1.3 Constraints

The constraints that limited the function of our bicycle included:

- Limited experience of build team. We had little experience working with paper products as construction materials.
- Limited time. The bike was built, delivered, and raced in 1.5 weeks. This limited the amount of design iterations, testing, and debugging that we could conduct.
- Limited size. The finite size of the bike limited the heights and sizes of riders that it could accommodate.
- Simple assembly of the bike for shipping. The desire to keep assembly simple meant that we had to reduce the amount of disassembly required to ship the bike.
- Customer desires. Customer descriptions and desires are outlined in Appendix C.

3.2 Physical Requirements

The teaching team expressed a desire to see the paper bike built of largely paper. A heavy penalty was instated for non-paper items. The teaching team also stated that the physical weight of the bike must be less than 166 lbs. and that the disassembled bike must fit within the oversized shipping carton constraints of UPS (less than 166 dimensional pounds). Other physical requirements were associated with the racing environment, on the outside tracks at 3-5PM on a mid-October day. These conditions translate into the following physical requirements.

- Weigh less than 166 lbs.
- Constructed from mostly paper items.
- Dimensional weight of less than 166 lbs.
- Operable under various environments. It was unclear if the afternoon would be sunny, cloudy, clear, or rainy. There were also wide temperature ranges (50 ^{o}F to 80 ^{o}F) for mid-October.
- Fully functional on the brick surface for at least 4 laps around the race track.
- Must be able to withstand possible collisions with people, planters, and bikes. The bike should be robust enough to survive unforeseen stresses.

3.2.1 Opportunities

The physical opportunities of this project were to investigate possible resources for the construction of prototypes. We also had the chance to gain and practice skills needed to expand these resources (i.e. lockpicking skills to get into the model shop and charisma lessons to convince store proprietors to part with their valuable pieces of cardboard). This knowledge can be used in future projects.

3.2.2 Assumptions

- A direct drive ratio of 3:1 or 4:1 was reasonable for the drive. This number was derived from conversations with veterans of the Paper Bike project.
- A double-laminated body tube would not fail from fatigue before or during the race. We tested the tube statically and dynamically but lacked the time and funds to put the body tube through a fatigue test.
- Rubber-coated wheels provided sufficient friction and wear protection for the wheels.
- Three thin wheels (1 to 1.25 inches in width) were sufficient for stability and wear considerations.
- We would still race with mildly bad weather, but with severe weather the race would be rescheduled. This meant that the bike will need to be able to survive some rain, but not a storm.

- Large amounts of water or large obstacles would not be on the race track on race day
- There would be sufficient light to see.

3.2.3 Constraints

- Limited funds. We budgeted $280 for the materials used for the bike.
- Types of adhesive materials usable. Building the bike in the ME210 loft means that we could not use highly volatile or strong-smelling adhesives.
- Limited materials. We were largely unfamiliar with the Palo Alto area, and we had limited funds and time.
- Limited manufacturing resources. Stanford's model shop is open approximately 4 hours per day; the ME210 loft has limited tools available.
- Limited size of the shipping package. Choosing to ship via UPS defined the size of the largest possible shipping carton.
- Customer desires. Customer descriptions and desires are outlined in Appendix C.

Section: 4 Design Specifications

4.1 Vision

Historically, approximately 70% of the competing paper bikes failed mechanically before the end of the race; thus, Fleet-Wheels quickly placed finishing all four laps of the race as the top priority. This decision led the team to emphasize simple yet robust designs and extensive testing of each part beyond its projected operating conditions.

4.2 Development Strategy

The principle strategy for idea development was to make a clear statement of each design goal known to all team members for at least one day before discussing it as a group. This strategy allowed leisurely and subconscious contemplation of each problem statement before the beginning of each brain storming session. The group would then listen to and understand each proposed solution before choosing one idea or combination of ideas by consensus.

Once the solution was solidified, we broke it down into specific tasks and listed them on a large graphical medium (whiteboard); this allowed us to complete many of the design components in parallel. Each team member would then choose or accept a number of tasks based on their experience, time available and the even distribution of labor. As the members completed tasks, they crossed them off the list and begun new ones immediately. The completion of most of the available work would lead to another design meeting or dynamic task redistribution.

Newly manufactured parts or assemblies were extensively tested as soon as possible so that unexpected failure modes could be detected. Whenever a failure mode was suspected, the part was immediately modified or redesigned to ensure that it would not fail. Although this process often led to a slightly heavier design, it allowed the team to meet its reliability goals.

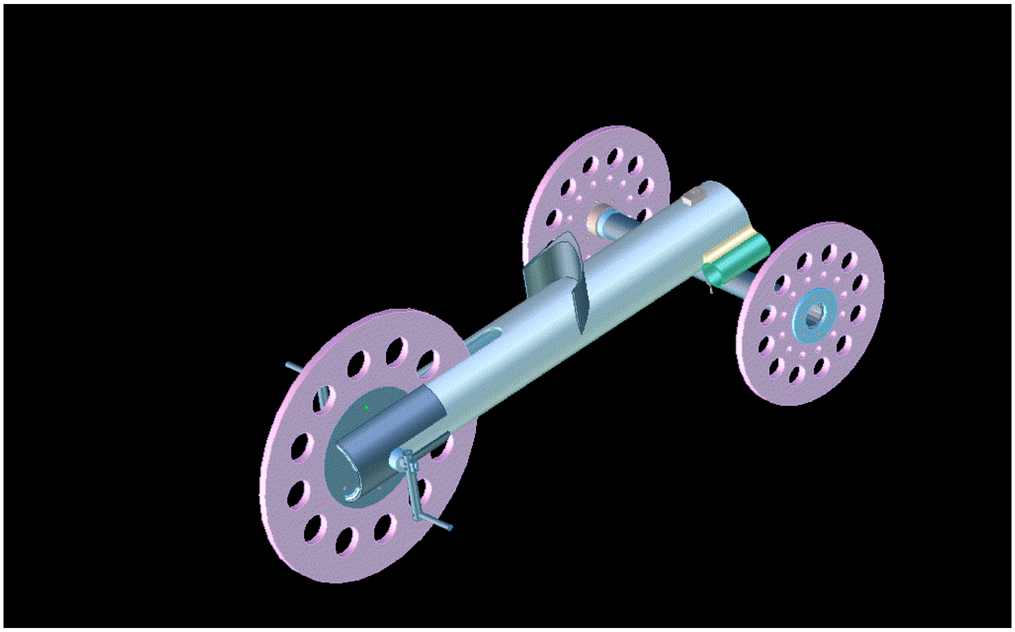
Towards the end of the product development, it became impossible to allow the full incubation period for idea generation. In these cases, as many team members as were available would be brought together to quickly brainstorm and graphically record solutions to the current issue. Once again, consensus solidified major design decisions.

The above development strategy maximized the efficiency of available resources. To work effectively, each team member had to come to the meetings prepared and feel personally responsible for the tasks and the project. Otherwise, the advantage of this strategy could be lost as members waste time and energy on unproductive meetings and tasks.

4.3 Functional Specifications

The final design developed into a tricycle with a direct drive crank assembly. The three wheel configuration was chosen to ensure stability with inexperienced riders. A direct drive pedal assembly simplified manufacturing and lead to a robust design without the alignment problems associated with belt or chain drive systems. Not depicted below in Figure 5 are the two steering rods that control the angular orientation of the rear axle. This push/pull steering system was, unfortunately, inherently unstable and required about 15 minutes of practice to master.

FIGURE 5.



4.4 Physical Specifications

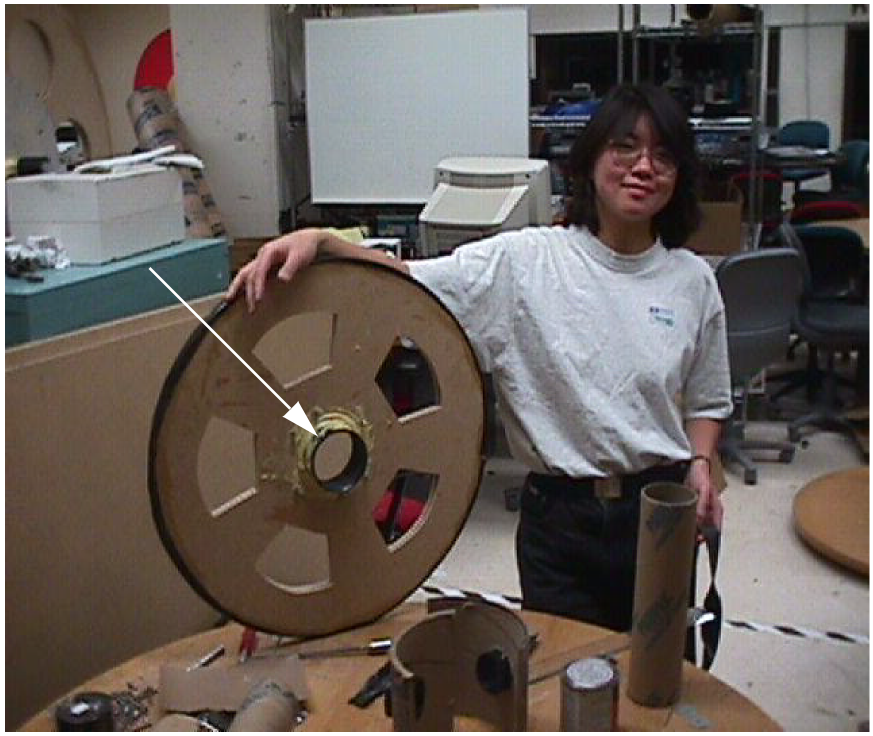
The body and rear axle were double laminated cardboard tubes with an epoxy resin binder. The resulting tubes were made more than twice as strong as an off-the-shelf tube by doubling their second moment of area and introducing a thin layer of epoxy to the internal structure.

The crank assembly was machined out of 6061 aluminum and turned to a wall thickness of 125 thousandths. The resulting parts were extremely strong, capable of transmitting more than 200 pounds of force on the pedal, and light weight, weighing in at under one pound. Figure 6 shows a close up photograph of our cranks.

FIGURE 6. 6061 Aluminum cranks were machined for our custom application.

All rotating parts were manufactured with ABS plastic bushings and custom machined to fit our application. These bushings allowed for the use of a large-diameter rear axle and provided a smooth sliding surface that would last the life of the vehicle. We found that ABS and lithium grease tend to gall after a few days, however. As a result it became necessary to replace the grease once before race day. Figure 7. is a picture of Wendy modeling our rear wheel with ABS bushing.

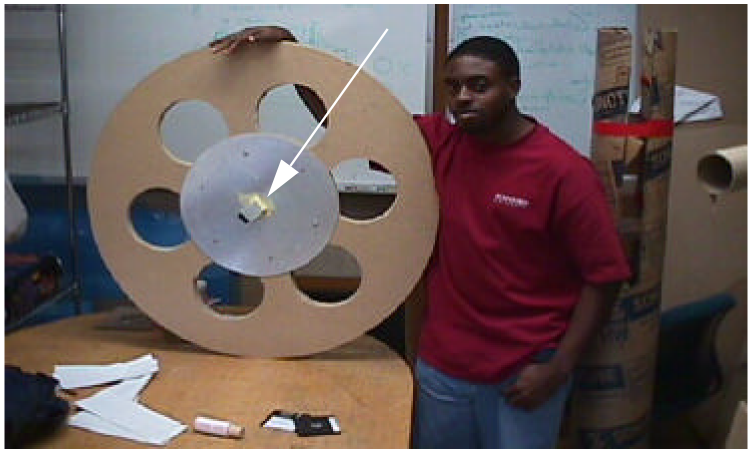
FIGURE 7. Note the ABS bushing in the center of the HDPE wheel



The wheels for the trike were constructed out of high density particle board (HDPB). This material was mistaken for sound board, which is mostly a paper product with very little binder. HDPB, however, is a sawdust/binder composite with greater strength and stiffness than sound board. As a result, we were able to remove approximately half of the material from the wheel bodies and significantly reduce their weight. But the weight penalty of 20 to 1 brought our equivalent vehicle weight up to 540 pounds. Figure 8 is a picture of Nsikan modeling our front wheel. Note the large diameter which yields a 3 to 1 mechanical advantage with our 6" cranks. Also, note the rectangular axle that the slots in the cranks (Figure 6) mount to.

FIGURE 8. Notice the excitement exhibited by a Fleet-Wheels team member. Also note the square shaft

.



Please consult Appendix A for a full exploded view of the tricycle along with our assembly instructions.

4.5 External Specifications

Old Ironsides was fairly easy to ride, once one became accustomed to the steering. The tricycle was designed to run a minimum of four laps around the Stanford main quad by all standard adult weights and heights. Figure 9 below is a picture of our tricycle in action.

FIGURE 9. Juli riding at full steam.

Paramount to developing a robust design is failure analysis. Figure 10 is a picture of the team evaluating a bearing failure due to misalignment.

FIGURE 10. Trouble shooting a bearing failure

Section: 5 Project Planning

A complete project schedule in Gantt chart form can be found in appendix B.

5.1 Deliverables

TABLE 1. Project Deliverables

Deliverable	Description	Date
Meyers briggs test.	Each team member was required to complete the Meyers-briggs test. The results of the test were used to form the design teams	9/23/98
Critical function Prototypes	Each team member was responsible for creating a working prototype of a system or subsystem of the paper bike	10/2/98
Design Review	A functioning paper bike was reviewed by the client team and teaching team.	10/16/98
Completed paper bicycle	The completed, disassembled bike was shipped to client team with assembly instructions.	10/19/98
Paper bike epilogue	We discussed team dynamics, design problems and race results with teaching team and client team	10/22/98
Completed paper bike report	Hard copy of report to Instructor and electronic copy posted to the ME210 web page	10/26/98

5.2 Project Milestones

TABLE 2. Project Milestones

Description	Date Projected	Date Actual
Critical Function Prototype	10/8/98	10/8/98
Meet with client team- send out customer survey	10/8/98	10/10/98
Freeze Design- begin fabrication of bicycle subsystems	10/10/98	10/11/98
Assemble bike- start initial testing and required redesign	10/13/98	10/15/98
Design review- bicycle fully assembled and functional	10/15/98	10/15/98
Final modifications completed- bicycle ready for shipment	10/18/98	10/18/98
Ship Bike	10/19/98	10/19/98
Race Bike	10/20/98	10/20/98

5.3 Project Budget

The project budget was not to exceed $280, or $70 per person. This figure was based on information from the team coach, Ray, whose bike the previous year had cost approximately $250. Table 3 lists the purchased materials, this list does not include scavenged materials.

TABLE 3. Project Expenditures.

Item	Quantity	Cost
Cardboard Tube	1- 10’	$ 28.79
Drill Rod	1- 10-32 x 3’	$ 0.99
Contact cement	1 can	$ 4.99
Polycel foam	2 cans	$ 5.98
Plastic putty knife	1 each	$ 0.69
Epoxy	2 box	$ 13.98
Sand paper	3 sheets	$ 3.96
Brush	1 each	$ 0.28
Fender Washers	4 packages	$ 1.96
Machine Screws	1 package	$2.49
ABS (misc.)		$20.64
Tape	1 roll	$6.49
Bike tire inner-tubes	2 each	$5.98
wood glue	1 bottle	$ 3.99
Threaded rod	1 3/8” x 3’	$2.18
Epoxy (2 part)	1 each resin and hardener	$ 44.86
Fiber glass cloth	2 yards	$9.58
Hex nuts	1 package	$ 2.79
Graphite	1 tube	$2.49
Fiber board	6 sheets (4’x4’)	$62.94
Hack saw blades	4 each	$7.68
Total		**$ 233**

Section: 6 Epilogue

6.1 Retrospective analysis of the bicycle assembly and performance

Our bike was relatively easy to assemble. All that was required was the attachment of two wheels to the rear axle and the mounting of that axle into the body tube. Some technical assistance was required to tie the axle to the main tube. The bike completed the race in almost the same condition it started in, with only a slightly bent steering rod. Our bike also finished in the top two thirds of each lap (unweighted score).

Our average speed was 2.54 m/s; the class average was 2.08 m/s. Our weighted cost was 539 lbs.; class average was 234 lbs. Due to our high cost, we finished second to last with a score of 0.372. However, we were quite pleased that our bike survived the race in the same shape it was designed in and had no failures.

TABLE 4. Race Results.

Lap	Actual Speed (meters/second)
1	3.13
2	3.07
3	1.90
4	2.06

TABLE 5. Paper Bike Weight

Material	Actual Weight	Weight Penalty	Corrected Weight
Paper	18 lbs 10 oz.	1 X	18 lbs 10 oz.
Non Paper	26 lbs 6 oz.	20 X	527 lbs 8 oz.
Total			546 lbs 2 oz.

6.2 Retrospective on the design process

Chris Carlson: Information exchange is essential. The web-based document folders as well as e-mail made asynchronous information exchange easy. Using this technology, the team was able to communicate ideas to all members without being in the same place at the same time. Make the time, ASAP to get the new group together and form reliable information channels.

Especially in small design teams, consensus is worth working for. A verbal commitment or affirmative from each member after each design decision is made is a good way to cement team direction. If many such commitments are made at one meeting, minutes and a bulleted list are a great way to keep a record of decisions made.

All team members should know what the other members are contributing to the design. Detailed understanding is not necessary, but at least a cursory knowledge of what everyone is doing is important for team integrity and systems integration.

It is extremely important to work on several ideas in parallel. Each team member should have at least three things to do at any given time. That way, one task's delay is an opportunity to work on something else and minimal time is wasted.

Get some people in the design shop ASAP. It is essential to know what kind of facilities are available before making any design decisions based on technical complexity. Our team over-emphasized simplicity largely because we didn't know what was technically feasible in terms of manufacturing.

Wendy Cheng: Our team started a bit later than other teams in formally finalizing the design of our tricycle. Part of this was due to our desire to see the critical function prototypes constructed for general ideas before the discussing the final design. This gave us more time for development of concepts and didn't hurt us during the build stage, but may have limited our ability to investigate design alternatives more fully.

Early in the design process, we figured that the prone-position tricycle may be easier to pedal and steer than our design, but we dropped the concept because of comments from our client team regarding the relative discomfort of riding it.

We did most of our construction in the loft and the model shop. Juli had access to Hewlett Packard resources, which was also very useful. Though none of us were profiled as model-makers, everyone functioned well as builders.

I wish we had a better idea of what construction materials and resources were available and where they could be found. The time spent finding this out may have limited our design somewhat.

Delivery was coordinated well. The document drop function of the web page was very helpful as Juli revised and pasted the assembly document off-site the night before delivery so Chris could download it and print it in time for delivery. Assembly went well, though technical assistance was required to tie the ropes around the back axle. Racing was fun; like everyone else, I wished I could have ridden our bike in the race. However, the client team idea was an interesting one and it was worthwhile to see another team ride our bike and note its strengths and weaknesses.

Our team appeared to be well-matched with each other and functioned very well for the duration of the project. We had many discussions, everyone worked diligently, and we all enjoyed working with each other. The only thing I might note is that it might have been helpful to schedule and divide up the work more distinctly so work could be conducted more in parallel. However, for a short project like the paper bikes, it was perhaps worth more to have others around to provide input and team-decision- making ability than what we may have lost in terms of efficiency. Besides, having others around made it more fun to work!

Juli Satoh: Our group was very diverse, culturally, several personality preferences were represented, and both genders. I did not observe any other group in the loft that was so well balanced on all these points. This balance may be one of the reasons the group functioned as well as it did.

I hesitate to label the group as a team, even though the class was set up with teams, team names and 'coaches'. The team concept evokes thoughts of autocratic leaders, team captains, adversaries, and unquestioning followers. This group, instead, operated on the concept of compromise and collaboration, both within the group and with other teams.

The group members also shared a strong commitment to the project, no one person complained of putting in more time into the project than other group members, which was a common theme among other teams in the loft. The practice of having the group meet at specified time, reviewing the list of items to do, discussing the challenges to be addresses that day, and allowing people to choose which tasks to complete was extremely successful. Each person in the group was aware of major decisions as they were being made, had a chance to enter into the discussion, and all the members bought into the final solution, or more alternatives were explored.

Our team started cutting material several days later than many of the other teams, but it seemed important to talk to our client team before we finalized the design. After surveying them, yes, actually talking to the client, we chose the design path we though best suited their needs.

Reliability became the design focus very early, so we chose a very conservative bike (actually, tricycle since it was more stable than a bicycle) as well as choosing to use a direct drive system. We decided to pattern the tricycle after one of the tricycles in the ME210 loft with the intent of making our design lighter (which we did) and to improve the steering mechanism (which I'm not sure we did). We lifted the body above the rear axle, rather that having the axle go through the body, which introduced a new problem to the design. The body wobbled while the bike was being pedaled. Fortunately, we were only a few days into manufacturing the bike and still nearly a week to figure out a fix. The amount of test driving we did on the bike was what saved us from some catastrophic failures during the race.

It took us several tries to get the bike into ride-able condition. Words for the wise: test early and often.

Nsikan Udoyen: Our design process was very intensive as numerous ideas and approaches were explored. Our decision to emphasize simplicity and reliability required us to abandon potentially complex designs that may have raised interesting design challenges, but it was taken in good faith for practical reasons. The assumptions that shaped the final design were so sound that the steps taken to address these assumptions made it almost certain that the bike would work. The predictable level of success didn’t hurt because it left us with only minor adjustments to make.

The construction of the bike was carried out as a team effort. While it might have been more efficient if carried out in parallel, the presence of team members allowed consensus on minor design issues which could have held up production as they arose during the construction phase.

We ended up building our own box to ship our final product, since the shapes of disassembled sections made it hard to fit into the standard box provided. Our construction was efficient so no last-minute adjustments held up shipping. The race was more of a fun experience than anything else. I competed with the usual glee that accompanies the end of construction (and beginning of finalized paperwork) in any project.

In retrospect, this project would have been a lot easier if we had an idea where to get materials earlier on. However, the sharing of information on sources between teams made the search less tedious for some. Team dynamics also enabled us to complete this project successfully, though I feel that even if our personality profiles had all been identical, maturity and responsible reasoning would have made personality issues redundant.

Section: 7 Reference Material

7.1 References

URL's

- http://me210.stanford.edu/98-99/me210-web/private-index.html

  General information regarding bike race guidelines, bibliographies, and project document.

- http://me210abc.stanford.edu/97-98/PR/projects/TEAMS/team98/Files/Documents/PBengineer.html

  Paper Bike Engineering notes and some reflections compiled by Jon Stewart in 1997.

- http://me210abc.stanford.edu/97-98/PR/projects/TEAMS/Paper_Bikes

  Final Paper Bike Documents from 1997

- http://www.stanford.edu/~neko/me210/

  Web page outlining the Fleet Wheels experience.

7.2 Physical Resources Accessed

Product Realization Laboratory:

http://me210.stanford.edu/98-99/PR/safety/#sec10

ME210 Loft

http://me210.stanford.edu

7.3 Human Resources Accessed

Names: ME210 Teaching Team, Vic Scheinman, PRL TA's

Addresses: http://me210.stanford.edu, vds@leland.stanford.edu

7.4 Vendor Resources

1. Peninsula Construction Supplies (Cardboard Tubing, 8” to 36” OD) 109 Seaport Blvd., Redwood City, CA. 650-365-8500.
2. West Marine Inc., (Epoxy, fiberglass, paint) 850 San Antonio Road, Palo Alto, CA650-494-6660.
3. Orchard Hardware Supply, 2555 Charleston Road, Mountain View, CA, 650-691-2000.
4. Orchard Hardware Supply, 2110 Middlefield Road, Redwood City, CA, 650-365-7373.

Appendix A Product Specification Sheets

The next few pages include the following:

Project Time line (2 pages)

Design Sketches (9 pages)

Final Assembly Documents (3 pages)

Race Results (1 page)

Appendix B Client Notes

"I liked the robustness of your design- and the reliability- we made it around all four laps! I felt that the steering mechanism was a little too sensitive, resulting in some unstable turns. However, it did get the job done. I also felt the bike was built for someone taller than myself b/c the seat rest was somewhat uncomfortable- for the reclined position that we were sitting in. Thanks for the effort!"

-Neeta

"I found that the bike was very stable, particularly in the straightaway. I had to keep turns small to avoid tumbling over, so I would slow down before coming to the curve. The steering mechanism was a bit awkward... some sort of grips fashioned on the ends might have helped more. Also, they might have been adjustable in length, since they felt as though they went a little too far forward for me. Overall, a very satisfactory design, and I enjoyed riding it in the race. It deserves a spot on the ceiling! :-)"

-Andy

"Receiving the bike was no problem of course, I just walked to the other side of the design loft.

"Assembly of the bike was very easy, and the instructions were quite clear. The additional support provided by your team to tension the rear axles with rope was more than enough to get the bike together for race day, and was very helpful.

"We didn't get much of a chance to test the bike, and basically ran it right out of the box on race day. The bike performed excellently, and in fact it could easily double as an exercise machine! Steering was sensitive and a little tricky to get used to, but functioned well.

"No debugging was necessary because there were no failures. Thanks again for a great product!"

-Mike

Appendix C Client Survey Results

3.1 Summary

Customer Description:

Skill Level:	Average to Good
Height:	under 5’ to 5’10”
Weight:	100 to 220 lbs
Inseam Length:	26” to 31”
Arm Length:	21” to 32”

Customer Preferences: Our client team desires reliability and robustness in the paper bike. They want to win, but they prefer to not take major risks in bike design and operation.

High Customer Priorities:
Reliability
Robustness
Safety
Speed
Maneuverability

Medium Customer Priorities:
Ease of Use
Comfort

Low Customer Priorities:
Low Weight
Easy Assembly
Small Size
Fashionable Styling

3.2 Survey Responses

> >(1) Name: Mike Eodice
> >(2) Address: 902 Blaire Avenue, Sunnyvale, Ca. 94087

> >(3) Phone: (408) 732-8071
> >(4) Email: mte@leland.stanford.edu
> >(5) Year: 2nd year Ph.D.
> >
> >(1) How good a biker are you? (c) AVERAGE
> >(2) What is your approximate height? (d) 5’ 8”
> >(3) How much do you approximately weigh? (b) 100-150 lbs
> >(4) What is your inseam length? 31”
> >(5) How long is your arm? 32”
> >(6) Do you have a preferred bike (please select as many as applicable)?
(c) TRIKE

> >(7) Please remark on your desires by prioritizing the following list.
speed, maneuverability, low weight, safety (stability), ease of assembly, ease of use, simplicity of construction, small size, comfort, fashionable styling

> >(1) Name Andrew Milne
> >(2) Address123 Press Bldg. (Ofc)
> >(3) Phone723-3803
> >(4) Emailamilne@stanford.edu
> >(5) Year2nd Yr. Ph.D.
> >
> >(1) How good a biker are you?d. Good ... though with safety in mind. :-)
> >(2) What is your approximate height?(d) 5’ 8” to 6’
> >(3) How much do you approximately weigh?d. -- 215lbs
> >(4) What is your inseam length?30
> >(5) How long is your arm?~25in from armpit to fingertip

> >(6) Do you have a preferred bike (please select as many as applicable)?
Mountain Bike

> >(7) Please remark on your desires by prioritizing the following list.
maneuverability, speed, safety (stability), comfort, ease of use, low weight, fashionable styling, ease of assembly, simplicity of construction, small size

1. Neeta Verma
2. Rains Apt. 18D
3. 650-497-9612
4. neetav@leland.stanford.edu
5. 1999

> >(1) How good a biker are you? (c) AVERAGE
> >(2) What is your approximate height? (a) under 5’
> >(3) How much do you approximately weigh? (b) 100-150 lbs
> >(4) What is your inseam length? 71” (probably a typo)
> >(5) How long is your arm? 21”
> >(6) Do you have a preferred bike (please select as many as applicable)?
(a) normal bike
7. speed, ease of use, comfort, low weight, maneuverability, safety,
simplicity of construction, ease of assembly, small size, fashionable
styling