Self-Actualizing Biomimetic Paper Bicycle for Individual Well Being

Engineering 310
Paper Bicycle Design Document

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1 Executive Summary

The executive summary is, word for word, the most important part of the document. Assume it is the only part of the document that your corporate liaison's boss will read.

- Include one or two key images that capture the gist of your design.
- Briefly provide the background or context for the project
- Describe your teams' vision and approach. Focus on what was special about your approach, (what
- you emphasized).
- Describe the key features of your design and refer to one or two figures included in this section
- (they can be duplicates of figures later in the document). One could show how the design is
- used; the other could be a CAD rendering that shows key components (with labels).
- Summarize results and lessons learned.

Note: This MS Word template is several years old. The formatting is essentially the same as for 2016 but some of the sections are now abridged, so please use the Latex PDF printout as a guide for what sections to include and how long to make them.
When using this template set Word to View/Styles – the template heavily uses defined styles for headings, captions, etc.
When importing text use Paste/Special/Unformatted Text to avoid corrupting the Styles.

Example Text

The text in this section is adapted from [BuggyBumpers06].

Who in their right mind would build a paper bike to compete in a polo match? Well, that is exactly what this team has done. The Casterbike was designed to be a light, maneuverable and robust vehicle that can be pushed easily across a grassy field while supporting a rider armed with an over-sized mallet. The Casterbike team determined early on that a paper polo vehicle must satisfy three related functional requirements: maneuverability, ergonomics, and playability.

The team focused on maneuverability, with the implementation of a novel rear caster wheel set (**Error! Reference source not found.**), made entirely of cardboard. This design allowed the team to turn sharply to follow the flow of the game. The desire to implement this design feature was fanned by the teaching team's skepticism. They asserted that no other team, in over a decade of ME310 paper bike history, had successfully demonstrated a working caster.

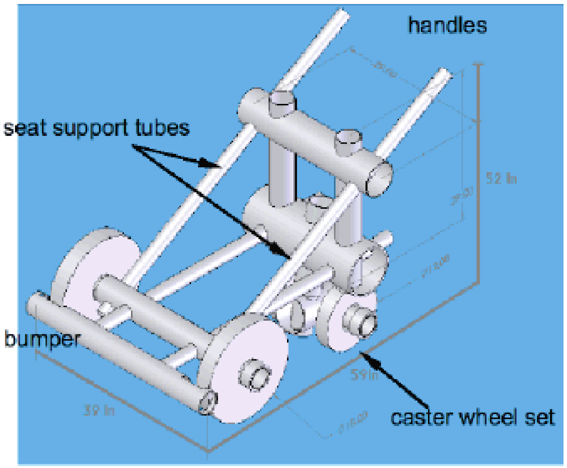

Figure 1. Casterbike construction showing tube connections and key functional elements (caster wheel, bumper, handles and support tubes for the adjustable seat).

The Casterbike team addressed rider ergonomics and playability with a variety of features including an innovative three-position seat that allowed the rider to make trade-offs between stability and the ability to reach balls with the mallet (Figure 2). At low speeds and tight quarters, reachability is at a premium; while traversing the field, stability is emphasized.

Figure 2: The Casterbike at play: kneeling position (left) gives enhanced access to ball; low position (right) gives enhanced stability.

Due to the nature of the competition, no vehicle was individually scored. However, the Casterbike did maintain its structural and functional integrity throughout the polo match. There were no incapacitating failures. In fact, the paper bike could easily have participated in another polo match. The ultimate measure of success was the amount of fun the team had in creating this bicycle and playing in the polo match.

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1.1 Glossary

Briefly define any non-obvious terms associated with your design. For example, if you used some special kind of glue or paper product, that might be a glossary term. Sometimes teams invent names to describe a special feature of their design—define such terms here. Don't bother defining obvious stuff (wheel, axle, steering bar). This section will be much more extensive and important for the corporate projects.

Example Text

- **Foot peg:** Foot support that extends outward from frame (parallel to the axles).
- **Frame tubes:** Structural members of heavy cardboard that connect the axles, saddle, and push bars.
- **Gorilla® Glue:** a type of polyurethane glue that expands as it sets, ideal for filling the gap between concentric tubes.
- **Papier-mâché:** A sculpting material made by taking wet paper confetti and glue or paste to create mixture that can be molded by hand when wet and then allowed to dry to achieve a cardboard-like consistency.
- **Push bar:** Tube assembly that extends from the rear of the frame of the vehicle that allows the driver to propel and turn the vehicle.
- **Pull bar:** Tube that extends from the front of the frame of the vehicle that allows the driver to pull and turn the vehicle.
- **Reins:** Straps attached to the front of the vehicle that the driver uses to pull and turn the vehicle.
- **Saddle:** Part that the rider sits on.
- **Stirrups:** Foot support that consists of loops that hang down from the saddle.

2 Context

2.1 Need Statement

Who wants your product? Why do they want it? What need does the product area address? What evidence do you have to substantiate the need. This section is the high-level result of your user needfinding. It defines the “point of view” or hypothesis that guides your ongoing work. For Paper Bikes, we dictated to you the need (by specifying the project) so you can be a little creative.

Example text from 2006-07 paper bike documents

The text in this section is adapted from [BuggyBumpers06], [SteamChariot06] and [Man o' Board06].

Polo. It is known as the sport of the rich, practiced by the likes of Winston Churchill and Prince Charles, a rarefied diversion accessible only to the highest echelons of the world's elite.

To the American public, polo is more recognizable as a fashion brand and a mildly irritating men's cologne than it is as a sport. Clearly, the primary reason is cost. A moderate quality polo horse is simply too expensive for the typical primary school athletic program, making the sport inaccessible to those who rely on pubic education as their main avenue for sports training. Considering that an average polo pony costs over $8,000, it would require over 160 bake sales (figuring $300 income per sale) to raise enough funds to buy the horses for a polo game, not including costs for feeding and housing the horses, or for purchasing a field that is three times larger than a football field. Even the clothes are too expensive for the general public.

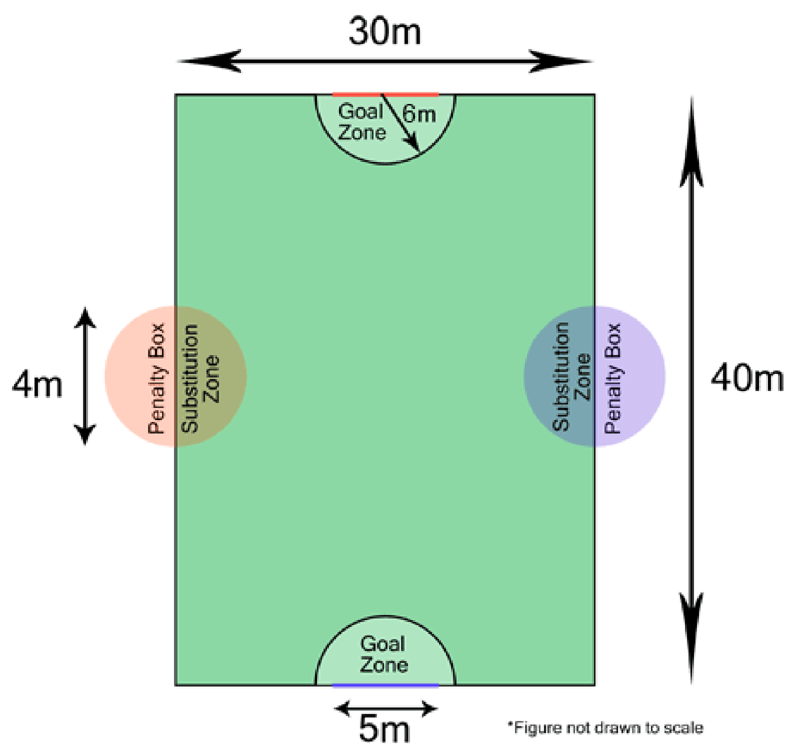


Figure 3: The paper bicycle polo playing field dimensions and zones

Fortunately, a far more cost effective alternative exists: paper bike polo. Created primarily from surplus industrial materials, the paper bike is accessible to all economic strata. It is low maintenance, requiring no feeding or waste disposal, and is easily recyclable. With the advent of the paper polo bike, every child in America can experience the thrill of a chukka, just like Prince Charles. To paraphrase early 20th Century politics, what this country needs is a good $30 polo pony. The answer is the paper bike.

2.2 Problem Statement

As you can see in Fig. **Error! Reference source not found. ---**

The challenge for the paper bike polo game is to build a human-powered vehicle out of paper products (e.g. cardboard, paperboard) to carry a rider who hits a ball using a mallet, also consructed of paper products. The paper bike polo game has two teams of five bikes, each with a player and a power source who pushes or pulls the vehicle. The game is played on a rectangular grass field (Figure 3, Roble Field). The goal is to score more goals than the other team.

The game rules are as follows:

- The paper bike must fully support one rider during the time of play (players cannot touch the ground).
- The paper bike must be powered by a single puller or pusher.
- The game is divided into four chukkas, of five minutes each.
- Each design team member must participate as "power source" or "passenger" for one or more chukkas.

The entire project, from brainstorming to prototyping to design completion, took place over two weeks.

2.3

3 Design Requirements

Background

The formulation of design requirements is a critical task facing a design team that starts with a broad problem area and needs to determine **what** they should design. After need-finding, and technical and user benchmarking, the team proposes a *class of design solutions* that fulfill requirements associated with the problem. In the Fall design document, the initial Requirements Definition is the main item of value that design teams can deliver to sponsors.

As the design process continues, requirements become concrete and detailed. New *de facto* requirements are discovered. This is an important contribution and should be documented. Ultimately, competing designs are evaluated with respect to the requirements. (If you can't tell whether a design satisfies the requirements, the requirements are too vague.)

To promote concrete thinking, we encourage the Functional/Physical and Internal/External decomposition of Figure 4 and we distinguish explicitly in the subsections of this document among *Requirements* versus *Constraints* versus *Opportunities*.

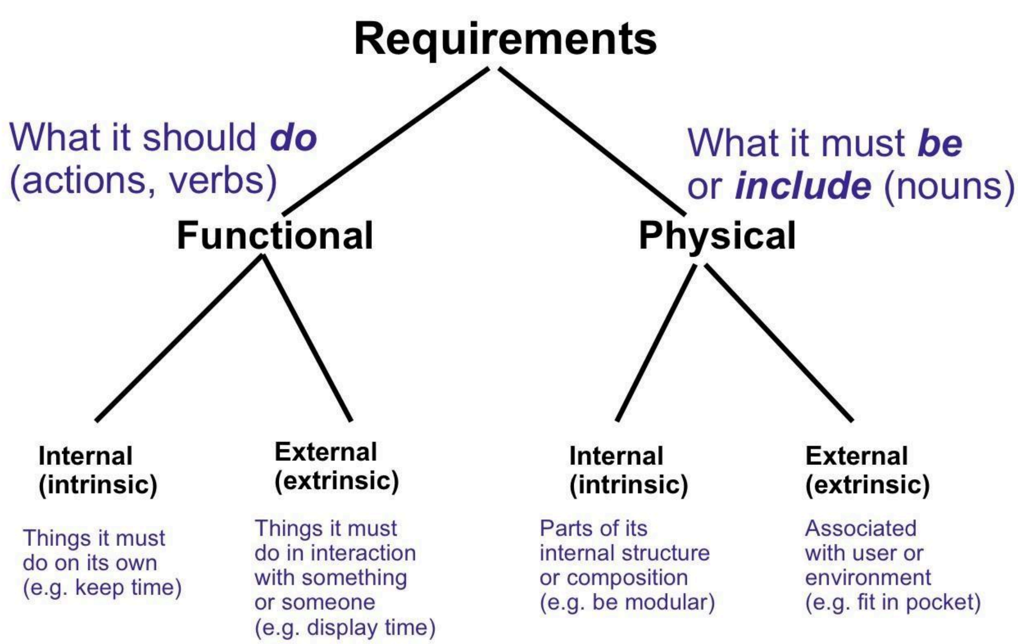


Figure 4: Decomposition of functional and physical requirements (using a pocket watch as an example). Source: [Cutkosky99].

Try to make everything as concrete and quantitative as possible. The more you are able to do this, the better you understand your design domain. Consider the physical requirement "fits in a pocket". This is an "operational definition" and, actually, a bit lazy. What kind of pocket are we talking about and under what circumstances? Is a device that measures 2cm x 5cm x 10cm too big or not? We force the reader to decide. If we've really done our homework, and we know the user profile and context, we should be able to give dimensions or perhaps a target value and range. Sometimes there is not a single number, but a target value and an acceptable range. "Fits in a pocket" could indicate a target value of ≤ 1 cm thick x 4 cm wide x 8 cm long, with anything up to 1 x 5 x 10cm being acceptable. If this is the case, say so.

In the case of the Paper Bicycle exercise, the major requirements are given. This is in contrast to E310 corporate projects. Even so, Paper Bicycle design teams discover de facto requirements as they work, and should document them.

Suggested procedure

1. Brainstorm with your team-mates to draw up a **large list** of requirements that may apply to your design. Use standard brainstorming methods: go for quantity and don't worry (yet) about validity.
2. **Cluster** the requirements into related groups and eliminate redundancy. Recognize that requirements are often *hierarchical*, with several low-level requirements corresponding to a high-level requirement.
3. **Organize** your requirements and sub-requirements according to whether they are Functional or Physical. ***Functional*** requirements describe what the design must do or accomplish. ***Physical*** requirements concern the size, shape, configuration, materials, etc. A useful way to understand the decomposition is shown in Figure 4; however one should not get hung up on the distinctions. For example, it may be ambiguous whether the requirement that something be "easy to hold and operate with one hand" is primarily functional or physical. To take this example a bit further, there are both *physical* requirements having to do with the overall envelope that it occupies and its weight and *functional* requirements having to do with where the buttons, etc. are placed with respect to the fingers and thumb. (When you get to this level of detail you are really thinking about the design!)
4. Consider which of the requirements are "primary" (i.e., part of the essential purpose of the design, or its *raison d'être*) and which are secondary constraints that should be respected or accommodated—while the design is fulfilling its primary requirements. *Limitations on power consumption* and the need to *survive ambient environmental conditions* are often examples of **constraints** on a class of designs.
5. Finally, consider what **opportunities** are associated with the design problem statement. Responding to these opportunities could make the difference between a really exciting or innovative design versus one that is simply satisfactory. The point is to document such opportunities here before they are lost and forgotten. Examples in the paper vehicle domain are numerous! There is the opportunity to create a ferocious design that intimidates opposing players. There is an opportunity to harness wind power to increase your speed...
6. Going a step further, we recommend using the 3-column table format shown below for clusters of related requirements, partly to make the metrics and rationale explicit, while keeping the text brief.

Requirement	Metrics	Rationale
Brief description of what the requirement or objective is	*Measurable quantities associated with requirement* (how to assess if a design satisfies the requirement)	*Why this requirement is important or valid*

Table 2: Three column table format recommended for requirements (can make a separate table for each cluster of related requirements).

Sample Text

The remainder of this section contains sample requirements (not an exhaustive set but enough to give an idea of what a good Requirements section might look like). These are adapted largely from the 2006-07 Team 8 [BuggyBumpers06] and Team 7 [SteamChariot06] bicycle design documents.

3.1 Functional Requirements

The main functional requirements of the paper polo vehicle are to safely and securely support the rider, to be maneuverable and to enhance the ability of the rider and pusher team to control the ball. In addition, the vehicle itself must be stable and must survive a few hours of rough use. These requirements are further defined in Table 3 and Table 4.

Rider support and ergonomics	Metrics	Rationale
Support rider during high speed travel and low speed play with no ground contact.	Accommodate riders from 64 to 72 inches (162-183cm) tall and from 100 to 180 lbs (45-82Kg).	Must accommodate all team members as riders.
Hold rider securely during maximum accelerations.	Rider remains seated during bumps and crashes of 2.0 G (2 x gravity) – See Appendix 8.1 for analysis.	Rider will be focused on game. and not attending to stability. Vehicle must keep rider stable.
Provide rider comfort for ~20 minutes of play	Riders report that they are comfortable while seated, swinging mallets, etc.	Uncomfortable positions and awkward reach can hamper performance
Allow riders to reach balls easily	Riders can reach balls in front and on either side without leaving the seat, using a mallet $\leq$ 1.5 meters long	

Table 3: Functional requirements: rider support and ergonomics

Maneuverability and pusher ergonomics	Metrics	Rationale
Vehicle must be easy to push, accelerate and stop.	Maximum sustained push or pull forces of 50 lbf (250N); peak forces of 100 lbf (500N).	Lightness, low rolling resistance, and will give a competitive advantage and reduce crashes.
Vehicle must turn quickly and stably in abrupt maneuvers.	Turn radius of < 4 feet (1.2m).	Confers a competitive advantage and enhances safety
	Remains stable for turning rates of up to 2 radians/second	
Vehicle provides room to push, pull and reorient without getting in the way.	Approximately 2ft x 2ft (0.6m x 0.6m) area needed for the pusher to adopt various postures to lever the vehicle into position	Confers competitive advantage and promotes safety.

Table 4: Functional requirements: maneuverability and pusher ergonomics

3.1.1 Functional constraints

- Must be human-powered: All motive power must come from either the pusher or rider during the course of the event (no stored energy).
- No ground contact: The rider must not touch the ground at any time during the game. (Provisions such as footrests may therefore be needed.)
- Stability: The bike should not tip over for accelerations or decelerations of 2G (20m/s2).
- Safety: The bike must not endanger any other riders or pushers.
- No grabbing: The vehicle and mallet cannot grasp or restrain the ball – only nominal point contact and elastic collisions are permissible.
- Endurance: The vehicle must withstand a few hours of combined testing and play, including periodic collisions with other vehicles.

3.1.2 Functional assumptions

- The polo match will be played in relatively dry conditions.
- The bike will only compete in one official polo match.
- Wheels and axles that copy the designs of recent paper bikes will be adequate for the polo application.
- Collisions will occur.
- Supporting a portion of the passenger’s load (e.g. as with a wheelbarrow) would detract substantially from maneuverability and playability.
- The passenger is a competent polo player.

3.1.3 Functional opportunities

- The power source may push or pull the paper bike.
- Either the power source or the passenger may control steering.
- The seat can be made highly adjustable enabling the passenger to optimize his or her stance.
- Various surfaces on the bike can be made to control, push, and bump the ball to assist the rider.
- Safety features can be implemented to protect the bike in collisions.

3.2 Physical Requirements

The main physical requirements concern the size, weight and material composition of the bicycle and mallet. The vehicle and mallet should be made almost entirely of paper products. For the purposes of this project, “paper products” include paper, corrugated cardboard, paperboard, cardboard tubes, crepe paper, paper tape and paper twine (as used in shopping bag handles). Additional physical requirements are as follows:

- The operational vehicle is required to fit within a box measuring 1.5m x 1.5m x 1m for transportation and to preclude long designs that would block the goals.

- The main components of vehicle can only be made from paper products, as described above. A maximum of 0.5 kg of non-paper materials is permitted.
- A mallet must be provided that is made of paper products and weighs no more than 0.7 Kg.
- The polo mallet must fit in a bounding box volume of 0.25 x 0.25 x 1.25m.

3.2.1 Physical constraints

- Vehicle cost should not exceed $100 for all components.
- Repairs during the polo match can only be done during the 5 minute intervals between chukkas.

3.2.2 Physical assumptions

- Normal amounts of glue will not be counted toward the 0.5 Kg non-paper limit.
- The 5 minute limit on repair time means that the bike should be easy to repair quickly.
- The $100 budget implies that many materials will be salvaged or scavenged. Consequently, the design should be flexible enough to allow for variations in dimensions and materials, depending on what the team can find.

3.2.3 Physical opportunities

- Special materials such as graphite, teflon, etc. can be counted toward the 0.5 Kg non-paper limit and used to reduce friction or increase durability.
- Special tools and spare parts (e.g. spare wheels or axles) can be brought to the match in case of failures.

4 Design Development

Background

In this section we describe the process that has lead to the current state of the design, including need-finding, brainstorming, concept selection, user and technical benchmarking, analysis, prototyping, etc. The emphasis is not on what your team did but on the results of the activities (i.e., the findings, conclusions, discoveries, prototypes, test results, etc.).

The goal of E310 design documentation is summarized in Figure 5 by G. Toye. In industry, a complex design process is rarely captured in enough detail to understand how the design evolved, and how it might evolve differently under other circumstances. In E310, we focus on capturing the design process as well as the design artifact. The findings of a team can influence teams in later years, even if they ultimately follow very different design paths.

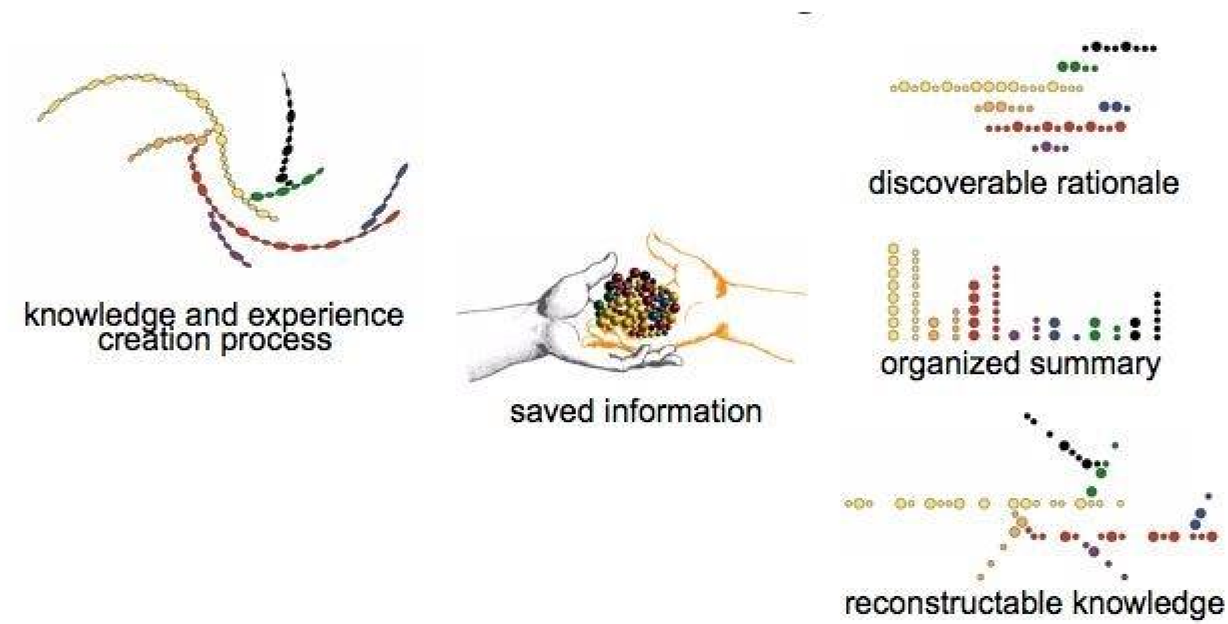


Figure 5: A typical design process and the role of design documentation in reconstructing it.

Advice

- The design is the protagonist of the story; the team is only a supporting character.
- Use lots of images and not just photographs: diagrams, schematics, flow charts, CAD renderings, etc. are often much more informative than a photo. In any case, use labels pointing to the features you want the reader to appreciate.
- Don't refrain from describing design ideas that were briefly pursued and dropped. Explain why they were abandoned. In other circumstances they might be worth picking up again.
- Lengthy details (e.g. detailed results of technical benchmarking) should go in an Appendix section, with an explicit forward reference from this section.
- Use tools such as concept selection and design decomposition (see examples later in this section) to clarify and communicate your understanding of how a design satisfies requirements.

The Design Development section does not have as strict a structure as some of the other sections (meaning you don't need to follow the section headings the example). Two common approaches are chronological (headings reflect stages in the design process as they occurred) and thematic (headings reflect components of the designs). If you choose a chronological exposition, as in the example sections 4.1-4.3 on the following pages, be sure that it is from the point of view of the design itself and is not a narrative about what you did.

Design process tools

Many tools exist for generating design alternatives, decomposing designs into their functional elements and choosing among alternatives. There are also some useful texts such as [UlrichEppinger95] and [OttoWood01]. In the remainder of this template we look at a couple of commonly used tools.

Pugh concept selection

Pugh concept selection [Pugh90] is a simple method that allows a team to compare alternatives and think about their advantages and disadvantages. Figure 6 shows a Pugh selection matrix for comparing different kinds of small actuators for a portable device. A distinguishing characteristic of the Pugh matrix is that the criteria are not weighted and are evaluated only in terms of whether they are equal, better or worse than a standard reference. The Pugh method should therefore be considered a qualitative tool whose principal value is to get the team thinking concretely about which criteria are useful for comparing designs.

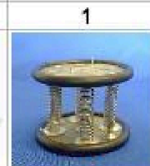
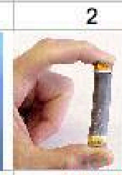
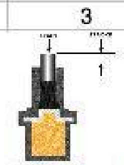
PROJECT	Actuator selection				
	DATUM	1	2	3	4
					
	DC motor	SMA	EPAM	Thermal	Piezo
Cost	0	0	0	0	-1
efficiency	0	-1	0	-1	0
max speed	0	-1	0	-1	-1
force/weight	0	1	0	1	1
power/weight	0	-1	0	-1	0
ease of control	0	-1	-1	-1	-1
noise	0	1	1	1	-1
compactness	0	1	0	0	1
reliability	0	-1	-1	0	0
Number better: Σ□	+0	+3	+1	+2	+2
Number worse: Σ□	0	-5	-2	-4	-4
Number same: Σ0	9	1	6	3	3

Figure 6: Example of Pugh concept matrix for comparing actuator types for a small mobile device. Table created using Excel template from [Otto07] (http://www.robuststrategy.com/).

More elaborate decision matrix methods exist [OttoWood01] with weighting factors for criteria and even explicit uncertainties in the values assigned to weights and criteria. Online Excel spreadsheet templates are also available [Otto07]. A note of caution with all these methods is that it is easy to adjust the weights and criteria to produce almost any outcome that a team desires. Use them as thinking tools and not to rationalize a subjective decision!

Function structure diagram

Decomposition trees can be used as part of benchmarking (to better understand and existing design) or as part of documenting a new prototype, to better understand the functional and physical requirements that a design corresponds to. Figure 7 shows a typical functional and physical decomposition for a two-axis force feedback joystick. The tree at left decomposes the top level function (display haptic feedback) into sub-functions that include measuring hand position, applying forces to the hand, etc. The tree at right shows the design elements and subsystems.

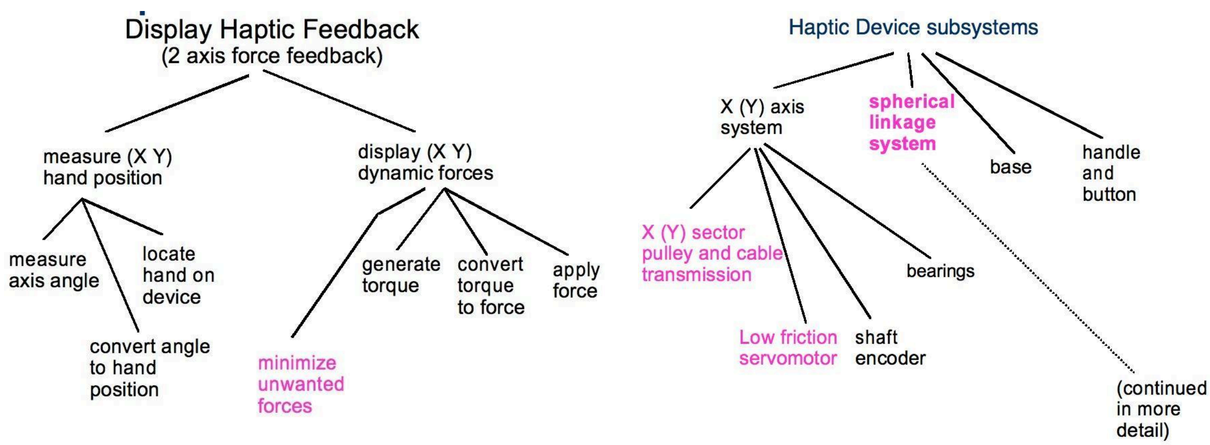


Figure 7: Example of a functional and physical (system/subsystem) decomposition of a 2-axis haptic force feedback device. The next step would be to draw links that map from elements or subsystems to the functions that they help to provide.

Sample Text

The remaining text is adapted loosely from [BuggyBumpers06]. For an example of a thematic organization see [Man o' Board06].

4.1 Vision

The guiding vision behind the Casterbike was to develop a vehicle that would be the envy of other players for its maneuverability, while also being stable and robust enough to survive the match. Consequently, the development of a paper caster set dominated the early design and testing.

4.1.1 Initial Testing and Design

Pretesting

The design process began with a tour of the environment of operation, Roble field. By testing some vehicles from previous years the team quickly discovered that rolling resistance would be unacceptably high for wheels less than 12 inches in diameter. It was also clear that collisions and the need to make quick stops and turns would impose much larger loads on the vehicle than the gravity load from the rider. Consequently, a simple analysis of the expected dynamic acceleration was performed (see Appendix 8.1).

The initial design incorporated a caster to address the functional requirement of maneuverability. The caster was placed at the front of the paper bike as a variation on the jogging stroller. This was done because most vehicles with casters at one end and fixed wheels at the other (e.g. shopping carts) tend to be unstable when pushed with the caster at the rear. Putting the caster in front allowed for an alternative if the caster proved too difficult or failed during testing. The caster could be replaced with a single fixed wheel in the front; in that case steering could still be accomplished by tilting the paper bike back and pivoting on the rear wheels.

Discoveries and failures

The decision to incorporate a caster, as well as the initial seating position, was derived from a test performed in the 310 loft. One teammate sat on a chair and swung a mallet at a ball while another frantically pushed him about the loft. Immediately the discovery was made that by placing one's feet behind the legs of the chair, one could reach out and hit the ball with much more extension than by simply sitting on the chair. Also, the casters on the chair allowed for extreme maneuverability further enforcing the decision to incorporate a caster design.

Figure 8: Testing different seating positions and reach using a chair. Notice the feet locked into position behind the rider. This gives the rider a high, upright posture. More detailed pictures of this test are located in Appendix 8.2

The first failure was due to a demonstration by the teaching team that mirrored the team's previous test. With multiple chairs rolling around, there were sudden stops, pile-ups, and rapid changes of direction. In a follow-up test when the passenger's feet were properly secured behind the chair legs, a sudden stop resulted in an immediate face plant. This was a design setback that temporarily put the seating concept on hold until a later date.

4.2 Critical Component

The caster was the immediate candidate for a Critical Function Prototype (CFP) for several reasons. First, it was the most technically challenging component of the initial design. Pursuing this design path could rapidly become an exercise in futility if the concept was not proved out early in the process flow. Second, failure of this component would require a redesign of the initial paper bike concept. Fortunately, a backup design of replacing the caster with a fixed wheel was put in place during the initial design phase of the process flow. Finally, and most significantly, the teaching team said it could not be done. In fact, it was discovered later that no paper bike caster has been successful in over 10 years of paper bike history. This led the team to a stubborn defiance of authority and a complete rejection of common sense in the pursuit of a functional paper bike caster.

4.2.1 Test Development

The caster was tested to examine several important issues: its ability to rotate while under load; rider location relative to the caster position; survivability during maneuvering; and general vehicle geometry. To facilitate this testing, the team built a wood frame with the expected wheel positioning and seating position in mind. To save time, previous paper bike wheels and entire components were recycled to make up the rest of the test bed.

Figure 9: Function Prototype testing. Note that in this figure the caster is located in the front of the vehicle. Upon further testing, it was found that the caster worked best when located at the rear of the paper bicycle.

4.2.2 Discoveries and failures

In an attempt to save time the caster design plan was not adhered to. The design called for a flat bearing surface between the caster and the frame cross member supporting the caster, however this was left out. The riser tube was left to ride on the Central Support (C1 in Figure XX) causing dimpling despite having doubled the tube. This was quickly solved by installing the Inner Support Tube (C4) and bonding a collar to the Vertical Caster Tube (C5). The bearing surface was then moved to the contact point between the collar and the riser tube which proved successful under load.

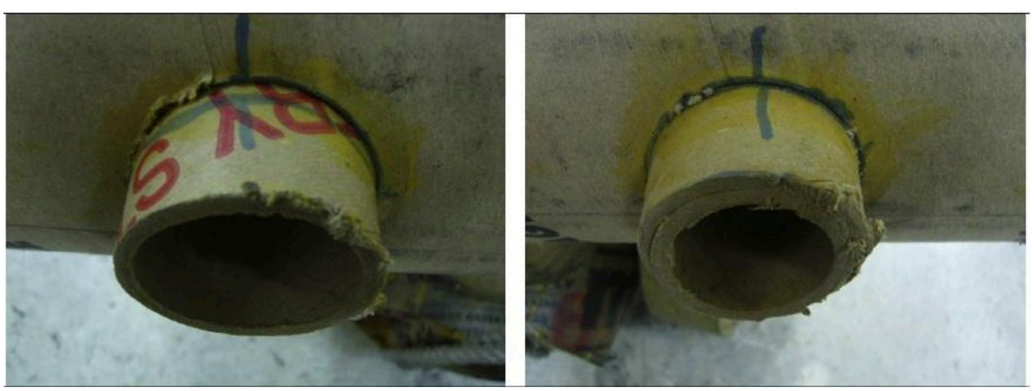


Figure 10: Testing revealed that the original tube connections (left) were vulnerable to crushing. Doubling the thickness of the inner tubes (right) solved this problem.

The next discovery was that the assumption of placing the caster in the front for stability was flawed. It was nearly impossibly to turn the test bed in the original design configuration. The team then tried pushing the test assembly backwards with the caster in the back. Miraculously the caster worked extremely well in the rear, and the bike was far easier to turn. The difference in the force required to turn the vehicle is a direct result of having a longer moment arm when the assembly is reversed. When the caster is used to turn as sharply as possible the pivot point is located between the non-caster wheels.

(If we were continuing this example, there should be another figure here with labels C1-C5 called out.)

Caster orientation	Advantages	Disadvantages
 Forward leaning post	caster rolls easily and tracks stably	requires more effort to turn
 Backward leaning post	can compenstate for frame wear (caster becomes nearly vertical)	more difficult to roll straight
 Vertical post	easiest to steer	difficult to maintain this geometry with frame wear or settling

Table 5: The effects of different caster rake angles.

When pushing the cart with the caster in front, the pusher is trying to apply torque with a small coupling moment arm. This orientation requires a large turning force. On the other hand, if the caster is at the back then the pusher has a moment arm the length of the vehicle. This large moment arm drastically reduces the force required to turn the bike and makes it possible for the pusher to do so.

Another potential cause for the pushing difficulties could be the caster geometry itself, or the angle of the riser tube in relation to the ground. Testing of this theory showed the results summarized in Table 5: The effects of different caster rake angles.Table 5.

5 Design Description

Background

Whereas the Requirements section defines what a valid solution to the problem must do (functionally) and be (physically) and the Development section documents the process by which the current state of the design has been arrived at, this section defines what the design is and does. It should be a concise description of the current state of the design. If you find yourself adding rationale for the design, or discussing design alternatives, you are writing text that should be moved into the Development section. A few teams find that this section fits more naturally if it comes before the Design Development section.

In the Fall quarter, the design will be in an early stage and this section is largely a proposal for what the design should be (you can call it that, explicitly). Even so, on the basis of preliminary need-finding, benchmarking and critical function evaluation, you have some idea of what is appropriate. Take a point of view and assert it. A CAD model or systems diagram of a concept is appropriate.

In the Winter quarter, this section becomes much more complete, describing the current (rough) state of the design. There should also be an explicit subsection describing what is projected for the Spring quarter. CAD models (with labels and key dimensions), systems diagrams and state-transition diagrams are all appropriate. It is often useful to have a table that compares design features or capabilities with the requirements they fulfill.

In the Spring quarter, this section defines the final state of the design, as well as future (post E310) recommendations for development. Materials and format will be similar to those of the Winter document. Good examples of Spring design description sections (also called specifications sections) include [Daimler-Chrysler06], [Toyota01] and [PanaSense07]. The teaching staff can suggest other good examples.

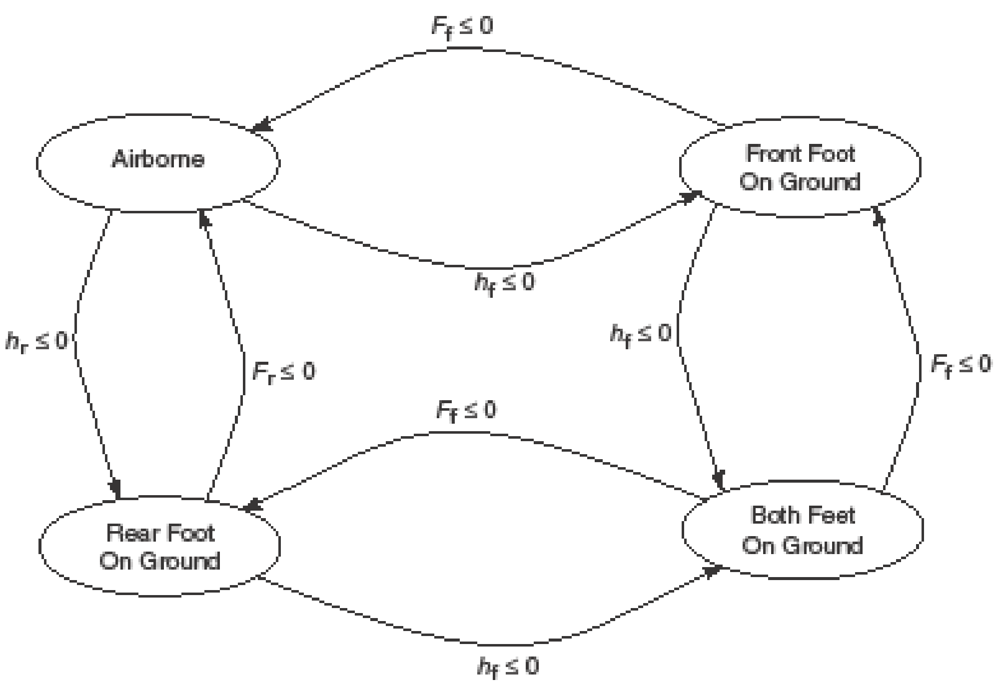


Figure 11: An example of a state-transition diagram (in this case for a two-legged hopping robot). Source: [Cham02].

Tips

As with the Requirements section, it can be useful to decompose the description into Functional and Physical attributes of the design. Ideally these should map in a clear way to the corresponding requirements to assure the reader that the design meets the requirements. Going a step further, the 3-column table format in Table 5 can be useful, especially for Winter and Spring, to make this correspondence explicit.

- Assume you will have separate subsections for the mechanical, electrical and software components of your design.
- In many cases photographs of hardware are difficult to interpret unless there are labels. Sometimes a CAD rendering is easier to interpret, especially if you can do cross-sections or cut-away views. Don't forget to add key dimensions.
- Often, photographs of electrical circuits are not instructive. They simply show the reader that some complicated electronics were developed. Show us a circuit diagram instead.
- Software should be described at a high level. Flow charts, state tables and state-transition (e.g., Figure 11) diagrams are all useful.

Requirement	Specification	Discussion
a brief listing of the requirement (ideally with cross-reference back into the Requirements section)	a brief listing of the corresponding specification achieved by the design	optional remarks on whether the requirements was met, exceed, not met but will be in future versions, etc.

Table 6: Three column table format suggested for comparing actual design specifications with requirements.

Examples of Paper Bike CAD and Tables

The examples on the following pages are taken from [SteamChariot06] to give a few ideas regarding CAD models and tables of specifications that are typically found in the Design Description section. The figures from the Executive Summary could also be repeated in this section for describing the design.

The headings should break down to the components of your designs. For an example of the entire section, see the rest of [SteamChariot06].

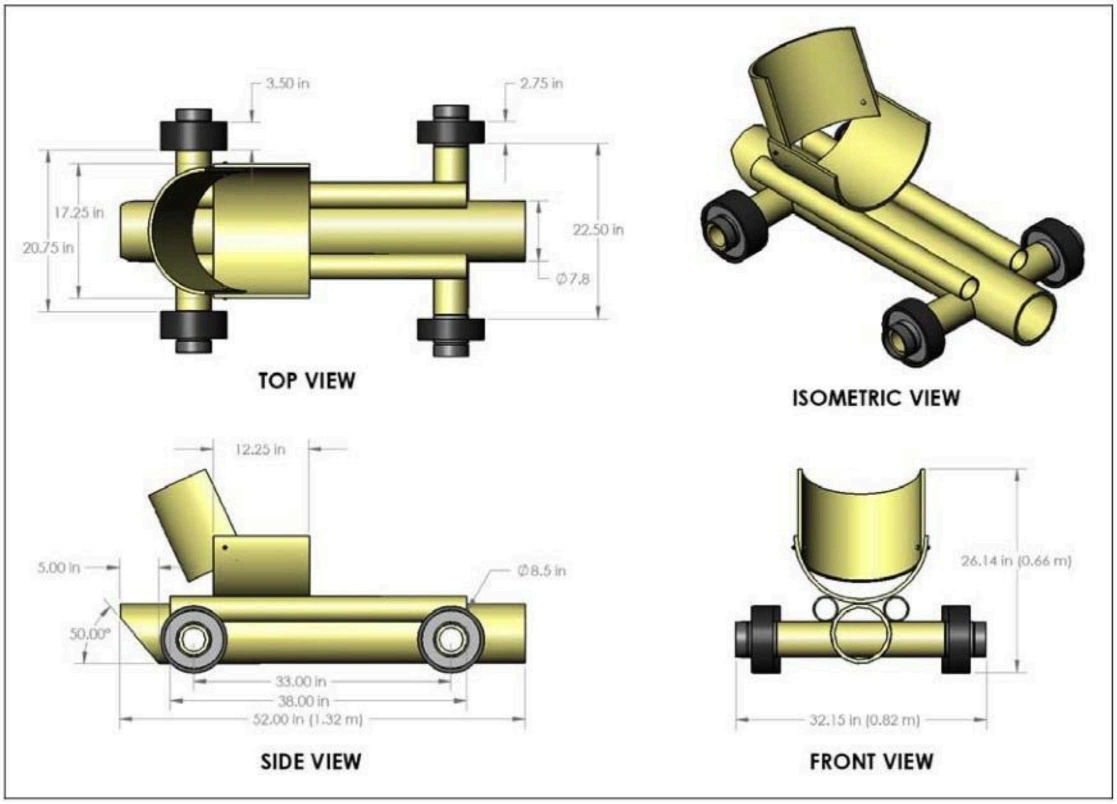


Figure 12: Steam Chariot [2006] CAD renderings (actual drawings could be larger and rotated landscape format to fill the page).

Table 3. Various Performance Metrics

Performance Metric	Measurement and Estimation
Rider space	32.75 in x 16.25 in (0.832 m x 0.0211 m)
Intended Rider weight	~170 lbs (77.1 kg)
Single strand rope load limit	20 lbs (89 N)
Max pulling speed	4.47 mi/hr (2 m/s)
Max pushing speed	3.36 mi/hr (1.5 m/s)
Expected life	~ 10 hours of continuous use
Average pulling force	~ 50 lbf

Figure 13: Steam Chariot [2006] performance specifications.

Table 1. Summary of Major Physical Dimensions and Weight

Physical Characteristic	Measurement	
	Metric Unit	English Unit
Vehicle width	0.82 m	32.2 in
Vehicle length	1.32 m	52.0 in
Vehicle height	0.66 m	26.1 in
Track (Front/Rear)	0.57 m / 0.53 m	22.5 in / 20.75 in
Wheelbase	0.84 m	33 in
Wheel diameter	0.22 m	8.5 in
Wheel width (Front/Rear)	0.070 m / 0.089 m	2.75 in / 3.5 in
Vehicle weight	16.51 kg	36.4 lbs

Table 2. Details on Non-paper Materials Used

Non-Paper Material	Quantity	Function	Total Weight	
			Metric Unit	English Unit
Bolt and nut	2 sets	To secure the back and bottom panel of bike seat together	24.5 g	0.054 lb
Zip-tie	6	To hold seat supporting tubes and main chassis tube together	12.0 g	0.0265 lb
Glue	-	To assemble various components	~300 g	0.551 lb
Rope	~300 in	To power the vehicle	81.8 g	0.180 lb
Total Non-Paper Material Weight			418.3 g	0.922 lb

Figure 14: Steam Chariot [2006] summary of physical specifications as examples of concise tables for the Design Description section.

5.1 Recommendations for Future Work

Even if your design satisfies 100% of the requirements, you should have recommendations for future development and refinement. For one good example of a future work discussion, see [DaimlerChrysler06].

6 Resources

6.1 Bibliography

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6.2 Human Resources

People, consultants and their contact info.

6.3 Vendors

Places where you purchased key components and their contact info.

7 The Design Team

Michael Scott
Status: M.E. Graduate Student
Contact: mscott@me310.stanford.edu

Born in Paris and raised in New Jersey, I attended Columbia University as an undergraduate. My interests include mechatronics, design (including medical devices), football, tennis, pick-up games, tail-gating, Entourage, South Park.

Skills: Mechatronics, CAD modeling (in both SolidWorks and Inventor), MATLAB scripting, and C programming. Comfortable with most machine shop processes, including milling, turning, and welding. Experience with LaserCAMMs and water-jet cutters.

Pamela Beesly
Status: M.E. Graduate Student
Contact: beesly@me310.stanford.edu

I grew up in Connecticut, moved to Santa Monica, went to boarding school in New Hampshire. A few things that interest me specifically in design are Human Computer Interaction, tangible interfaces, usability, and how people communicate with computers through interfaces. Outside activities I enjoy are being an editor for a design magazine, social dance, and traveling.

Skills: Oxy-acetylene welding, Lasercamm. Experience programming with Matlab, Java and then some elementary C, C++, html, Python. Mechatronics, basic electronics, and soldering skills, Familiar with Photoshop, InDesign, Solidworks.

Dwight Schrute
Status: M.E. Graduate Student
Contact: dwight@me310.stanford.edu

Born in San Diego and raised in Orange County, the ocean has never been far from me. I love all sorts of water activities including bodysurfing, surfing, swimming, and jumping off high objects. I love the outdoors too. I am a sheriff's deputy and expert marksman.

Skills: Experience using Assembler, C, C++, Java, Pro/E, IDEAS, MatLab, and Mathematica. I have machine shop experience. I am also pretty good at French and Spanish.

The Casterbike design team consists of three graduate engineers with a diversity of backgrounds and creative problem solving styles. The team was formed by the ME310 teaching team, using the

Wilde/Myers-Briggs methodology [Wilde97, Wilde07]. Table 1 shows the balance of creative engineering modes for the team.

Team/Types	Extroverted (E) / Introverted (I)	Intuition (N) / Sensing (S)	Feeling (F) / Thinking (T)	Perception (P) / Judging (J)	Overall
Scott	6	6	-6	12	ENTP
Pam	-18	30	-30	18	INTP
Dwight	6	18	-18	-6	ENTP

Table 6: Wilde/Myers-Briggs cognitive modes for team Casterbike

Coach

Put your team coach name and basic contact information here.

7.1 Design Reflections

Part of the purpose of a warm-up design exercise is to provide a context for shared reflection on what works and what doesn't. This process is more profound if we take some time to record our reflections. For the Paper Bicycle documents we therefore ask for a specific Reflections section with contributions from each team member. Reflections from the team as a whole are also welcome.

There are various ways that one could format this section. See paper bicycle documents from recent years for ideas.

8 Appendix

These sections are good places to put results of key brainstorming sessions, benchmarking or user survey results, test data, or detailed analyses. CAD images can also go here. Lengthy source code or emails should probably just be put onto a CDROM but key bits of code or critical messages should be reprinted in the Appendix.

8.1 Example analysis

Some useful analysis with respect to dynamic loads can be found in [PaperBike0304] at [http://wikibox.stanford.edu/twiki/bin/view/Main/PreciousAnalysis.html]. This was the year in which vehicles had to travel down a staircase while protecting a "precious cargo." In the current case, the cargo is perhaps the rider.

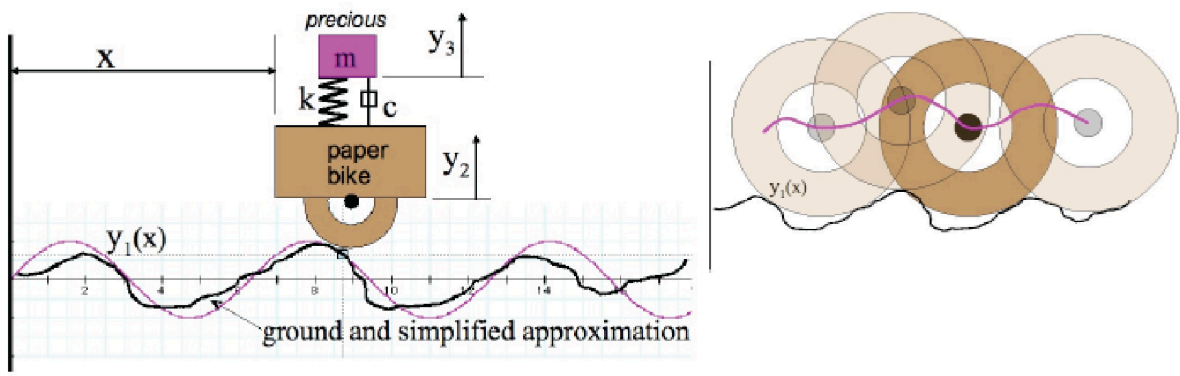

Figure 15:Diagram of simplified vehicle with precious payload traversing bumpy terrain (left) and detail of wheel tracking the ground (right).

If the wheel is large with respect to the bumps (likely in this case) then the axle follows a smoother path than the ground (formally, it creates a "traced surface" [Rossignac85] with respect to the ground). We can approximate the wheel motion with a harmonic function, following the equations in Figure 2. For a maximum speed of 0.75m/s, a bump height of 0.05m and a bump wavelength of 0.25m (which depends on both the ground and the wheel radius) we obtain an acceleration of 1.8G in addition to gravity. This result matches the rule of thumb that dynamic loading will easily double the estimated loads from gravity.

$$y = Y \sin(\omega t) \text{ where}$$
$$\omega = 2\pi v/\lambda, v = \dot{x},$$
$$\lambda = \text{bump\_wavelength, and}$$
$$Y = \text{vertical\_travel of axle}$$
$$\text{then: } \ddot{y}_{max} = (\tfrac{2\pi v}{\lambda})^2 Y$$

bump length, lambda	0.25	m
bump height, Y	0.05	m
fwd speed, v	0.75	m/s
frequency, f	3	cycles/sec
circ freq, omega	18.85	rad/sec
max accel,	17.77	m/s^2
max accel,	1.81	Gs

Figure 16: Equations and spreadsheet for model of axle acceleration as a function of bump height and speed.

9 Appendix B: This is Heading 1

This short appendix gives an example each style defined and used in the report. You can “Save-as” this file to the name of a new section that you'd like to start so that you automatically get all the styles.

9.1 Section: This is heading 2

Here is some more text in “Text body” paragraph style which refers to Figure 19 below using a cross reference (Insert Reference Cross-Reference) so it will update the number automatically if you select it and hit F9. Text body is the most common style in document for paragraphs.

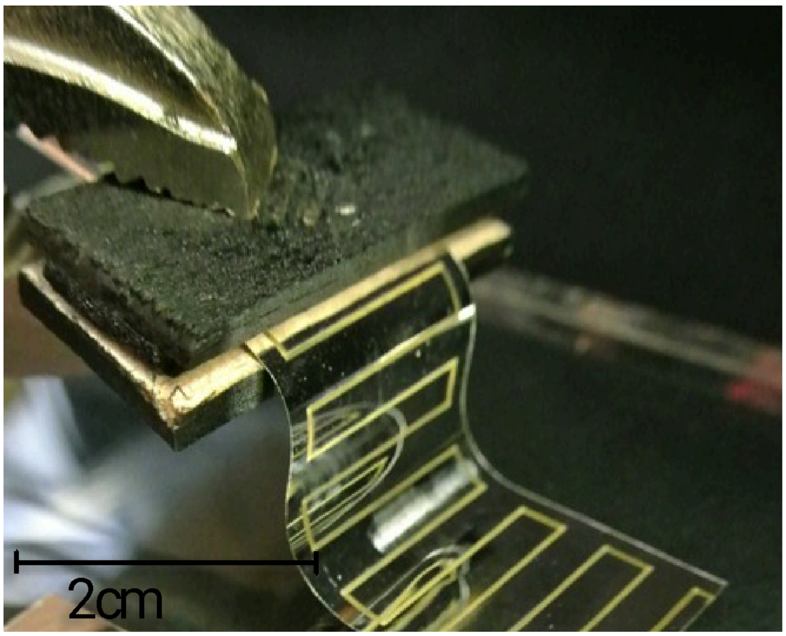

Figure 17: This is a figure consisting of a picture and its caption. The picture style is “310Figure” which puts a space above it. The caption style is “310Caption” and automatically increases numbers if you create it by going to Insert Reference Caption. “310Caption Short” is for short captions; They are centered instead of left aligned.

9.1.1 This is Heading 3

Here is more text in Text body paragraph style followed by a bullet list, which is in the “Text Body bulleted” style. Numbered list are in the “Text Body numbered” style.

- This is the first item in “Text Body bulleted” style.
- This is the second item.

“Table Heading” style	Metrics	Rationale
Text in “Table Contents” style	*Measurable quantities associated*	*Why this requirement is important or*

Table 7: Here is a table with a caption created by Insert Reference Table

Here is some more text with a reference to the table: Table 7. This text is a continuation of a paragraph so it is in the style "Text Body No Indent."

This is heading 4 (un-numbered minor headings)

The other styles used in the template are for the Bibliography, the TOC and List of Figure (which are automatically generated tables based on using the Heading styles and Captions from Inserting a Reference), and for the cover sheet.

This is the 310 Heading Example (indicates sample text follows)

Text in blue indicates that it is part of the guidelines included to help you write your document.