Abstract

The subject of this project is the design of a recumbent bicycle prototype. A recumbent bike is a type of bicycle in which the rider mounts in a reclined position. In order to do this, we will learn about these bicycles by showing the different types there are, its evolution over the years, and so on. After that, it is shown the recumbent bicycle design and all its components. It has been invented the frame and so, it is explained the material choice, a brief anthropometric study and FEM (finite element method). Moreover, after analyzing this type of bike, it has been decided to propose an improvement in the transmission mechanism for front-wheel bikes. Then, all the components of it will be described. It is also explained from where the standard components used are taken. The program used to create the 3D model is SolidWorks.

Finally, a budget of the total cost of the project will be made.
# Index

<table>
<thead>
<tr>
<th>ABSTRACT</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>INDEX</td>
<td>3</td>
</tr>
<tr>
<td>1. PREFACE</td>
<td>5</td>
</tr>
<tr>
<td>2. INTRODUCTION</td>
<td>7</td>
</tr>
<tr>
<td>2.1. Purpose</td>
<td>7</td>
</tr>
<tr>
<td>2.2. Scope</td>
<td>7</td>
</tr>
<tr>
<td>2.3. Motivation</td>
<td>8</td>
</tr>
<tr>
<td>3. INFORMATION ABOUT RECUMBENT BICYCLES</td>
<td>9</td>
</tr>
<tr>
<td>3.1. Description</td>
<td>9</td>
</tr>
<tr>
<td>3.1.1. Classification</td>
<td>9</td>
</tr>
<tr>
<td>3.1.2. Types and brands</td>
<td>14</td>
</tr>
<tr>
<td>3.2. Recumbent bicycles history</td>
<td>16</td>
</tr>
<tr>
<td>3.3. Comparison between recumbents and uprights</td>
<td>18</td>
</tr>
<tr>
<td>4. RECUMBENT DESIGN</td>
<td>22</td>
</tr>
<tr>
<td>4.1. Previous requirements</td>
<td>22</td>
</tr>
<tr>
<td>4.2. Frame</td>
<td>24</td>
</tr>
<tr>
<td>4.2.1. Material selection</td>
<td>24</td>
</tr>
<tr>
<td>4.2.2. Anthropometric study</td>
<td>27</td>
</tr>
<tr>
<td>4.2.3. Finite Element Method (FEM)</td>
<td>29</td>
</tr>
<tr>
<td>4.3. Transmission</td>
<td>34</td>
</tr>
<tr>
<td>4.3.1. Cardan or Universal joint</td>
<td>34</td>
</tr>
<tr>
<td>4.3.1.1. Study of maximum torque</td>
<td>36</td>
</tr>
<tr>
<td>4.3.1.2. Double cardan joint selection</td>
<td>38</td>
</tr>
<tr>
<td>4.3.2. Assembly</td>
<td>40</td>
</tr>
<tr>
<td>4.3.3. Axis</td>
<td>42</td>
</tr>
<tr>
<td>4.3.4. Sprockets</td>
<td>43</td>
</tr>
<tr>
<td>4.3.5. System supports</td>
<td>44</td>
</tr>
<tr>
<td>4.3.6. Bearings</td>
<td>46</td>
</tr>
<tr>
<td>4.3.7. Spacer rings</td>
<td>48</td>
</tr>
<tr>
<td>4.3.8. Bottom bracket</td>
<td>49</td>
</tr>
<tr>
<td>4.3.9. Crankset</td>
<td>49</td>
</tr>
</tbody>
</table>
4.3.10. Chainwheel .................................................................................. 50
4.3.11. Cassette ....................................................................................... 51
4.3.12. Gear ratio study ........................................................................... 53
4.3.13. Derailleur gears .......................................................................... 54
4.3.14. Pedals .......................................................................................... 55
4.3.15. Chain ........................................................................................... 56
4.3.16. Safety features ............................................................................ 57
4.4. Seat ................................................................................................. 57
4.5. Fork ................................................................................................. 60
  4.5.1. Headset ......................................................................................... 61
    4.5.1.1. Bearings .................................................................................. 62
    4.5.1.2. Star nut ................................................................................... 62
    4.5.1.3. Top cover ................................................................................ 63
    4.5.1.4. Top cap ................................................................................... 63
4.6. Handlebar ......................................................................................... 64
4.7. Wheels ............................................................................................. 66
4.8. Tires ................................................................................................. 67
4.9. Brakes .............................................................................................. 69

5. REGULATIONS .................................................................................... 72

6. BUDGET .............................................................................................. 73

7. ENVIRONMENTAL IMPACT ............................................................. 76

8. PLANNING .......................................................................................... 77

CONCLUSIONS ..................................................................................... 78

BIBLIOGRAPHY .................................................................................... 79

Bibliographic references ............................................................................ 79
Complementary bibliography ...................................................................... 79
1. Preface

I have chosen as the subject for this project to design a bike to go to wonderful places as the port, the urban coast of the “villa Olímpica”... well restored for citizenship. I said urban coast because the features of this bicycle are ideal for this type of displacements; flat and urbanized. There is where it has the best performance.

I have always been interested in bikes as transportation, but especially for sports riding, I practiced “Biketrial” years ago. I come from a family that has practiced trial in motorcycle, lover of motor world associated with the sport, so the bike seems like a good way to make a tribute updated of that sport. I said updated because the bike is clean and non-polluting as a way of transport. It is a leap forward for me and not vice versa as some think, in the future of humanity. We can think of emerging countries with overcrowded cities in which is selling the impossible idea of a car for all. The disaster is already visible in cities like China, India and so on. They are late, the actual and contemporary is the bicycle and so with this project I do homage to this simple invention.

Doing this project has also meant a challenge for me since it has been presented difficult technical moments which have tested my skill and above all my patience; for instance, the invention of new components that did not exist. This project has required to me to be constantly aware of technical aspects but I think I like the technical side of engineering. For that reason doing this project has left me things clearer about what I want to do in the future.
2. Introduction

2.1. Purpose

The aim of this project is to design an entire recumbent bicycle adapted to use it in Catalonia. In order to make the project more realistic, it has been assumed that a local company of bikes, as it could be Monty, has asked us the realization of a study on these bikes and the design of a first prototype for a hypothetical future industrialization. For me this dissertation represents my first important and realistic project done by me. Moreover, I will learn to work and improve on complex programs as SolidWorks.

2.2. Scope

First of all, it is important to clarify that this project consists of a design of a first recumbent bicycle prototype. Obviously, if we would like to carry on, some modifications might appear.

Due to the short time given to perform this TFG, it is an entirely theoretical project. We are going to do the following points:

- Little description and classification of these kind of bicycles.
- Review of the origin and evolution of this bicycle to the present.
- Brief explanation about the differences between recumbents and uprights.
- Design of the most important mechanical element in a bicycle: the frame.
- Choice of the frame material and justification.
- Anthropometric study to adapt the bicycle frame 90% percentile of inhabitants in civilized countries.
- A simple finite element study to see the solicitations of the frame.
- A 2D plane of the frame to see the basic measures.
- Invention and detailed design of a new transmission concept.
- A basic calculation of the transmission torques.
- Creation of all components of the bike in SolidWorks.
- Assembly of the bike in SolidWorks.
- A budget of the bike costs and its hypothetical sale price.
- Planning.
- Environmental impact.
The following points are not going to be developed in this project:

- Construction process. Monty is a specialized company manufacturing bicycles, so it has better qualified people to develop this point.
- Specific regulations about these bicycles.
- A scale model of the final bike.
- FMEA (Failure Mode Effects Analysis) of the bicycle or any of its components.
- Hand calculations of the resistance of the frame or components.
- 2D plane and breakdown of each component.
- A business plan.

### 2.3. Motivation

From the industrial point of view, it would be to see whether this kind of bikes can grab market share in Spain or Europe. And academically, consider the realization of a complete project.
3. Information about recumbent bicycles

3.1. Description

A recumbent bicycle is a bicycle which you ride in a laying down position. Unlike conventional bikes, the recumbent ones the weight is distributed over a larger area. Moreover, they are more ergonomic and comfortable and that is the reason why most recumbent riders choose this kind of bikes (see Figure 1).

![Figure 1: Recumbent bicycle. www.whycycle.co.uk](https://www.whycycle.co.uk)

The main feature of recumbents is the aerodynamic geometry. The reclining position of the body permits to have less resistance to the air. As a result, the world speed record for a bicycle is held by a recumbent.

As we are going to see, recumbents present a wide range of configurations depending on its components and geometry. The main ones are: regarding the wheels, large, small, or a mix of sizes; about the frame, from a long to a short wheelbase; regarding the steering, underseat, overseat or no-hands; and finally, front-wheel or rear-wheel drive.

3.1.1. Classification

Recumbent bicycles can be classified according to their wheel sizes, wheelbase, steering system, front-wheel or rear-wheel drive and faired or unfaired.

**Wheel sizes**

The rear wheel has no restrictions on its size; it can be from around 410 mm (16 inches) to 622 mm (most commonly called 700C, only used on race or urban bikes). Even though, the
most common are 660,4 mm (26 inches).

The front wheel is frequently smaller than rear, although many bikes carry dual 26 inches (ISO 559) and ISO 622 (700C). An advantage of both wheels being the same size is that the bicycle uses only one size of inner tube and tire. Moreover, wheels with a larger diameter generally have lower rolling resistance. Nevertheless, a higher profile involves higher aerodynamic drag. The rotation of the front wheel involves a problem called the “heel strike” which occurs when the rider’s heel touches the front wheel in tight turns. So, front wheels are constrained by the geometry of the frame. In order to overcome this problem there are three solutions: putting a small front wheel (e.g. 20 inch), a frame design which places the bottom bracket far enough to not touch the wheel with the pedals or setting a pivoting-boom front-wheel drive in which pedals and front wheel turn together.

Figure 2: Dual 700C recumbent. www.ab-bike.com

Wheelbase

There are three types of recumbent bikes regarding the distance between their wheels.

Firstly, there are compact long-wheelbase (CLWB) models which have the pedals very close to the front wheel or they even are above it.

Figure 3: Compact long-wheelbase (CLWB) recumbent. www.hpvelotechnik.com
Secondly, short-wheelbase (SWB) models which place the pedals in front of the front wheel.

![Short-wheelbase (SWB) recumbent](www.bentupcycles.com)

Finally, long-wheelbase (LWB) which have the pedals placed between the front and rear wheels. Obviously, within these categories there exist variations, intermediate models and so on.

![Long-wheelbase (LWB) recumbent](www.bikeroute.com)

**Steering system**

Regarding recumbent bicycles’ steering, it can be generally grouped in three types: center steering or pivot steering, over-seat (OSS) or above seat steering (ASS) and under-seat steering (USS).

Center steering or pivot steering recumbents, may have no handlebar at all as Flevobikes or Pythons recumbents.
OSS or ASS is generally direct, i.e. the recumbent uses a steerer like a conventional bicycle handlebar.

USS is habitually indirect; the handlebar connects to the fork through a system of cables or rods.

Drive

Unlike conventional bicycles, which always have rear wheel drive, recumbents may have either a front or a rear wheel drive. In recumbents, front wheel drive is admitted because of the proximity of the crankset to the front wheel. Until the moment all the figures have shown rear wheel drive, where the sprockets of the wheel and the chainwheel rotate in a parallel plane. The problem with the front wheel drive is that the plane of the sprockets turns with the fork.

As mentioned in Wheel sizes section, there is the Pivoting-boom Front Wheel Drive (PBFWD). This system has the crankset connected to and moving with the fork. Moreover, it has two important advantages; the chain can be shorter and it permits to use a big size
wheel and so have less rolling resistance. Nevertheless, one disadvantage of PBFWD for some riders is a slightly longer "learning curve" because of the adaptation to the pedal-steer effect (forces applied to the pedal can actually steer the bike). Beginner riders tend to swerve along a serpentine path until they adapt a balanced pedal motion. After adaptation, a PBFWD recumbent can be ridden in a straight line as any other bike, and can even be steered accurately with the feet only (as it is said in “steering” point). Examples of PBFWD recumbents include Cruzbike, Flevobike, and Python Lowracer. Finally, it is important to mention the main disadvantage of the front wheel drive (FWD) which is "wheelspin" when climbing steep hills covered with loose gravel, wet grass, and so on.

![Recumbent with front wheel drive](www.buybuybicycles.com)

**Figure 8: Recumbent with front wheel drive. www.buybuybicycles.com**

**Fairings**

It’s much more common in recumbent bikes than upright equip them with a fairing. The aim of these fairings is to reduce aerodynamic drag and furthermore to keep the rider drier and warmer in wet and cold weather.

![Recumbent bike with fairing](www.zzipper.com)

**Figure 9: Recumbent bike with fairing. www.zzipper.com**
3.1.2. Types and brands

In our rapidly changing society, people like to try new things and that is the reason why recumbent bikes are becoming much more popular. Therefore, there are a lot of brands and each one with different models. In the next figures some of them are shown:

Figure 10: Azub recumbent. www.azub.eu

Figure 11: Raptobike recumbent. www.raptobike.nl
As it can be seen, there are infinity of different geometries and configurations of these bicycles. Each brand has its own design and its own characteristics; in this project it will be made a mix of them. There are some special components for this type of bikes, so some of them will be used for our bicycle.

The average price of these bikes is about 2000 €, they are fairly expensive due to the components used. Recumbents are becoming more popular in Europe in countries like Holland since these bikes are ideal for going around the city and flat places.

Now, knowing all these types it is possible to choose the specifications that we want for our design. The recumbent bike of this project has been based on the Raptobike model.
3.2. Recumbent bicycles history

After the drive chain was invented in the bicycles construction in 1880, some inventors performed variations of this concept. Among them are the first ancestors of the recumbent bike: Fautenil the French model (1893) and the Swiss Challand (1895). One of the first popular bikes was the Brown-Recumbent U.S. in 1900, which came to be exported to Europe and it is the prototype of the called chopper bike with a less inclined position. All these designs were based on the long-wheelbase.

In 1914, Peugeot was the first important enterprise which built a recumbent bicycle model; it was based on the Brown-Recumbent. In the 20’s stands the German model J-Rad built by aeronautical engineer Paul Jaray, one of the builders of the popular Zeppelin airship. In early 30, Charles Mochet built the Velocar, the first recumbent bike used successfully in sporting events. In 1933, this model set the hour record (45,056 km), which is the record for the longest distance cycled in one hour on a bicycle.

![Figure 14: Francis Faure riding Charles Mochet's recumbent bike. www.uh.edu](Figure 14: Francis Faure riding Charles Mochet's recumbent bike. www.uh.edu)

In 1934 the International Cyclist’s Union or UCI banned recumbent bikes in official competitions, which was a blow to their development. Even though, Mochet carried on developing new models, like the first reclining coated aerodynamically, which reached 50 km/h in an hour in 1939, an achievement that meant a new record but it was not recognized by the UCI because of the new rules.
Meanwhile, the first short recumbent were built, the first commercial model was *The Cycloratio*, 1935. German engineer Paul Rinkowski contributed, from 1947, that short recumbent is the type most popular among recumbents nowadays.

In the post-war years, recumbents had short boom since many people in the war-torn Europe, as they did not have the money to buy a car, they turned to recumbent bikes more comfortable than conventional. But from the 50's this kind of bike was a rapid decline in popularity.

In the 70's, recumbents rebirth began when some professional cyclists appealed to them to set new records, even if they were not recognized by the UCI. In 1976 the International Human Powered Vehicle Association (IHPVA), an association dedicated to the development of all human-powered vehicles, was created. Recumbent bikes are central in their activities, as they are currently the fastest vehicles in this category.

In the last years of the 70s and 80s, the interest focused on short distances, which allowed getting speeds previously unthinkable. In 1977 it reached 75 km/h and finally in 1986 the 100
km/h. In those years prevailed the tricycle with fairing like the Vector, which set some records in the 80s (see Figure 17).

However, thanks to its lower weight than tricycles, bicycles returned to dominate the competitions since 1990, when it became popular the construction of bikes with very low seats. They are called Low Racer, for instance the Cutting Edge which inspired many builders today.

3.3. Comparison between recumbents and uprights

There are remarkable differences between recumbents and upright bikes. In the list below it has been quoted some advantages and disadvantages over traditional upright bicycles:

Advantages

- **Health.** Many riders switch to recumbents to alleviate the chronic back from riding upright bicycles. In addition, the fact that recumbent riders are not bent over as are conventional bike riders, makes breathing easier. Also, recumbents, in which the rider has the legs nearly at the same height as the heart, reduce the rider’s hydrostatic pressure, thus allowing venous blood to more easily return to the heart. This physiological effect of improved circulation suggests an increase in rider endurance and it increased power output on long rides.

- **Comfort.** The recumbent riding position reduces strain on the body, making it particularly suitable for long rides and touring. As we said, for those people who suffer back pain it is a perfect way of making rides without pain.

- **The low center of mass** significantly increases braking and stopping capabilities, since the recumbent design avoids the problem of flying over the handlebars when the rider nails the front wheel brake. This may, nonetheless, increase the risk of a
front wheel slip. Likewise, losing a front wheel or fracturing a front fork will also be far less injurious than in a traditional upright bike. Moreover, especially in the city, the recumbent design makes it possible to ride very close to the curb without risking a pedal-curb collision.

- **Safety.** The recumbent bicycle's low center of mass and short distance from the ground notably reduce the consequences of a fall for the cyclist. In particular, the recumbent rider's head is about half a meter (and in some recumbents, up to 1 meter) lower than in a conventional bike. The worries of head injuries are therefore reduced.

- **Turns.** Unlike the upright bikes, recumbents allow the rider to continue pedaling even during tight turns without the pedals coming into contact with the ground.

- **Speed.** Thanks to its horizontal design, recumbent bicycles are in general faster than upright bicycles for the same level of effort. This is because the aerodynamic profile of the rider reduces air resistance. It is this feature which led to the UCI banning them in the 1930s (as it is explained in *Recumbent bicycles history*). The world speed record for human-powered vehicles was set by Dutch cyclist Sebastiaan Bowier pedaled a streamliner (a fully faired recumbent) for 200 meters at 133.78 km/h.

![Figure 18: Sebastiaan Bowier breaks world speed record. article.wn.com](image)

**Disadvantages**

- **Uphill.** The main disadvantage of these bicycles is the effort required to ride up hills due to recumbent position. On an upright bicycle, the rider can stand on the pedals and pull against the handlebars, although on a recumbent the rider can push against the seat. The most important difference is probably the additional weight of the
recumbent layout combined with the difficulty of balancing a bike with a low center of mass at speeds below about 8 km/h.

- **Balance.** In comparison to riders of upright bikes, two-wheeled recumbent riders have less capacity for displacing their body in order to help balance the bicycle or to steer. Consequently, tight turns and riding at low speed it is more difficult on a recumbent.

- **Length of the frame.** Due to recumbent bike geometry, the length of the frame usually is rather long and this can be a nuisance for its transport. Moreover, on rear wheel drive bikes, the chain is two or three times as long as a conventional bike and usually requires some guiding sprockets (Google definition: "a pulley that transmits no power but guides or tensions a belt or rope"). Although it is diminutive, in these pulleys there is an amount of friction which also reduces power slightly.

- **Maneuverability.** Because of its geometry too, most recumbents have a larger turning radius and combined with the greater difficulties of balance, tight and low-speed maneuvers can be hard.

- **Bad visibility of the road.** On recumbents, the distance from the eyes to the front end is somewhat larger than an upright, and also the rider cannot lean forward. Due to the backward position of the head, in an intersection, the rider has to stop nearly in the middle of it to have visibility.

- **Safety, visibility of the bicycle.** Particularly in the city, there is the problem that many recumbent bikes are below the eye level of many automobile drivers and it can cause serious accidents. Some recumbent riders add flags and reflecting materials to their bikes in order to increase visibility.

- **Constant position.** On a recumbent, the riding position is comfortable and removes stress from the arms, even though; it cannot easily be varied during a ride (as upright riders might stand for a hill). Sometimes this can cause the so called "recumbent butt," a pain in the gluteal muscles caused by their increased effort while being compressed. This can usually be addressed by adjusting the seat angle and pedal position. In a more reclined position, the weight is spread uniformly between the back and buttocks. In addition, the rider of an upright bike can stand up on the pedals to allow his legs to absorb the shock of a severe bump in the road. The recumbent rider cannot (although many models include suspension to alleviate this).
• **Starting.** Due to the recumbent position, starting is not as easy as a conventional bike. The way to start in an upright bicycle is by pushing off with one foot on the ground, and one foot on a high pedal. However, recumbents cannot be started with this technique. Starting a recumbent does not require big strength; it is a matter of balance and a skill which must be learned. It is recommended to learn from an experienced rider.

• **Nonstandard design.** The different geometries and designs of recumbents make it impossible to follow a standard. So it can be a problem when shipping the bike or putting it on racks on automobiles. In addition, some bicycle mechanics may be reluctant to work on "nonstandard" bicycle designs because of the difficulty of mounting in traditional bike work stands.

• **Price.** Recumbent bikes are generally more expensive than uprights of equivalent quality. Practically all are hand-built in relatively small runs by independent manufacturers, require at least a few specialized parts, and sell in far fewer numbers as compared to traditional bicycles.
4. Recumbent design

In this section it is shown the final design of the recumbent bike and its different components. Some of them are standard components which can be bought on the internet or in a shop and others are invented and adapted for our bicycle. In the Figure 19 it can be seen the final bicycle.

![Final bicycle. Render SolidWorks](image)

**Figure 19:** Final bicycle. Render SolidWorks

4.1. Previous requirements

Thanks to the learned experience about these bikes it has been listed some requirements which the final bicycle should meet:

- Weight: up to 15 kg.
- Maximum load: 120 kg (rider + luggage).
- Wheelbase: up to 1,30 m.
- Bottom bracket height: up to 0,70 m.
- Seat height: up to 0,70 m (seat higher than the bottom bracket).
- Both statically and dynamically stable.
- Normal operation under rain, snow and / or mud conditions.
- Temperature range from -10 °C to 40 °C.
• Must have no dangerous sharp edges.

• High resistance to corrosion and scratches.

• Should not need maintenance except periodical greasing.

• Must be suitable for 90% of the adult population.

• Average cost of all the components between 500 and 700 Euros, which will drive us a price about 1500 to 2000 € when the bike will be manufactured in series.

• Front wheel drive. As explained previously, in this kind of bikes having a rear wheel drive involves an enormous chain and sometimes some idler pulleys. So, it has been chosen this type of drive in order to avoid this extra components and because such a long chain is not aesthetic. As it has been explained before, it will be important to note the main disadvantage; having wheelspin when climbing steep hills. Nonetheless our bike is focused on cities and flat places.

• Seat angle: 30 to 50 degrees (bigger angle than in most recumbents). With an almost horizontal position you have to stretch your neck and it can cause serious damage to cervical.

• Above seat steering (ASS). It is the most similar system to the upright bikes and so, it will be the easiest one to use.

• Short-wheelbase (SWB). As it is wanted an easy-transported bicycle, it has been chosen the minimum distance between wheels. Consequently, the bottom bracket will be in front of the front wheel. As it is wanted to market here in Spain and in the future in the all Europe, it is important to think in this point; here the space is limited whereas, for instance in USA, this would not be a problem.

• 660,4 mm (26 inches) both rear and front wheels. The aim of this project is to create a useful bicycle which you can ride both in the city and on the mountain. So, to having an off-road bike it will use the two wheels of 26 inches, which raises the center of gravity of the bike. Thereby, it permits to ride down a curb without worrying about the frame touching the curb.

• Hydraulic disc brakes. In these bicycles, which get a lot of speed when going downhill, it is very important to have a good brake system. Therefore, it has been decided to implement a hydraulic disc brake, the best system nowadays.
4.2. Frame

The frame is the main structure of a bicycle. It is the responsible for holding all the other components of the bike as the wheels, steering, seat, and so on. This is a component that it has been designed in this project. So, this section is longer than the standard components; it is going to select the best material, to do a brief anthropometric study and finally a study of finite elements (FEM).

The idea is to make a frame design combining simplicity with aesthetics. In the Figure 20 it is shown the final frame.

![Frame Design](image)

Figure 20: Isometric view of the frame design. Render SolidWorks

4.2.1. Material selection

The first step to create a design is choosing the material most convenient and suitable. The choice of material depends on a number of factors:

- Weight
- Fatigue
- Material cost
- Weldability

Nowadays what people want is a lightweight bike and satisfying the above conditions. From all materials that meet these conditions we have chosen three candidates: aluminium, titanium and carbon fiber. In order to choose the ideal material we have done a chart with different factors to consider.
The most suitable material for our frame is aluminium. This verifies why most of the bike frames are built of this material nowadays. The most important characteristics are:

- It is bright white, with good optical properties and high reflectivity and thermal radiation.
- Easy and cheap to recycle.
- Its metal production from ore is expensive and requires big electric power amount.
- It is abundant in nature. It is the third most common element in the crust Earth, after oxygen and silicon.
- Resistant to corrosion, chemicals, weathering and seawater, thanks to the layer of Al₂O₃ formed.
- It has a high electrical conductivity; between 34 and 38 m / (Ω·mm²) and a high thermal conductivity (80-230 W / (m·K)).
- The atomic weight of aluminium is 26.9815 u.
- It is a light metal, with a density of 2700 kg/m³ (2.7 times the density of water) one third of the steel.
- It has a low melting point: 660 °C (933 K).
There are a lot of types and alloys of aluminium, each one for a particular application. After searching information about what kind of aluminium it is used for bike frames, we choose the alloy 7005-T6 (see the Bibliography).

The main alloying of aluminium 7005-T6 are copper, zinc and magnesium. T6 heat treatment confers an approximate tensile strength of 350 MPa. In the Table 2 we can see the mechanic properties which we are going to use for the numerical simulations and finite element method (FEM).

<table>
<thead>
<tr>
<th>Aluminium 7005 T6</th>
<th>Base material</th>
<th>Weld region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate tensile strength [MPa]</td>
<td>372</td>
<td>315</td>
</tr>
<tr>
<td>Yield strength [MPa]</td>
<td>315</td>
<td>261</td>
</tr>
<tr>
<td>Young’s modulus [MPa]</td>
<td>71000</td>
<td></td>
</tr>
<tr>
<td>Density [g/cm³]</td>
<td>2.6 - 2.8</td>
<td></td>
</tr>
</tbody>
</table>

*Table 2: Aluminium 7005-T6 properties.*
4.2.2. Anthropometric study

A bicycle is a machine driven by human being and many of its dimensions are conditioned by the morphology of the human body. So it is important to see what the standard dimensions of the human beings are. However, it has been difficult to find information about that. The aim is that the bicycle could be used by the 90% of the adult population.

Finally the information has been taken from “Anthropometry and Biomechanics (NASA)” whose website is in the bibliography for further information [1]. Moreover, in the annex is attached the whole document.

Five sizes of the human body are enough to consider when designing a bicycle. In the Figure 21 it can be seen these five sizes. On the left it is shown the body size of the 40-year-old American male for year 2000 which covers 95% percentile of the population, whereas on the right it is shown the body size of the 40-year-old Japanese female for year 2000 covering 5% of the population.

It is practically impossible that only one bike frame could be functional and satisfy 90% of the population without creating from a certain discomfort to severe difficulty in management for those people which are in the limits. To solve this problem our frame will be equipped with an
adjustable moving tube which permits the displacement of the bottom bracket (see Figure 22). The tube is fixed by tightening two M5 screws.

We interpolate both measures in order to get intermediate sizes, which will consider in our bicycle design (see Figure 23).

In the annex the 2D planes are attached, which show the frame sizes according to the
anthropometric sizes. In Figure 24 it can be seen my own anthropometric sizes (which are within the range studied) when riding the bike.

![Figure 24: Sketch of my own sizes when riding the bike (in mm). Scale 1:150.](image)

4.2.3. Finite Element Method (FEM)

It is important to do a numerical simulation in order to find out how the bicycle can react when the rider is seated on it. Initially, it was going to use the program ANSYS to do this analysis but due to some difficulties and not having the license, it has been decided to do it with SolidWorks Simulation. Although it is known that ANSYS is much more appropriate because SolidWorks is very limited in this field.

It is going to show how the frame is deformed when a person of 70kg weight is sitting on the bike. The aim is to see if 5mm thickness tube is enough.

In order to do this, a force of 1000 N is applied where the rider sits. The force is 1000 N since it is the value that corresponds to a rider of 70kg with a safety factor of 1.5. This force is distributed in the four seat supports.

For the simulation it has been added a solid tube representing the fork. It is a clump tube in order to be deformed as little as possible, since it is the deformation of the frame which is being studied in this point.

Regarding the fixations, the most realistic would be:
1. To fix all displacements of the rear wheel axis and allow free rotation in the Z-axis.
2. To fix all the displacements of the end of the fork except for the X-axis and allow free rotation in the Z-axis too.

*Figure 25* shows the allowed movement for each fixture.

Nevertheless, the SolidWorks Simulation program does not allow us to impose these movements; only allows us to impose fixations in all displacements and all rotations (see *Figure 26*).

*Figure 26: Forces and fixations. SolidWorks Simulation*

By fixing all the directions and all the rotations, it is known that the results of this analysis will not be very similar to reality. Therefore, it has been decided to take these results as a
reference for future essays with the prototype built.

When selecting the material for the analysis, it was necessary to create it by introducing the properties of the Aluminum 7005-T6 described above. This alloy does not appear in the list of materials and aluminium alloys that the program offers.

Regarding the mesh, all the information is shown in the *Table 3*.

<table>
<thead>
<tr>
<th>Mesh type</th>
<th>Solid Mesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesher Used:</td>
<td>Standard mesh</td>
</tr>
<tr>
<td>Automatic Transition:</td>
<td>Off</td>
</tr>
<tr>
<td>Include Mesh Auto Loops:</td>
<td>Off</td>
</tr>
<tr>
<td>Jacobian points</td>
<td>4 Points</td>
</tr>
<tr>
<td>Element Size</td>
<td>10.6706 mm</td>
</tr>
<tr>
<td>Tolerance</td>
<td>0.533531 mm</td>
</tr>
<tr>
<td>Mesh Quality</td>
<td>High</td>
</tr>
<tr>
<td>Total Nodes</td>
<td>43925</td>
</tr>
<tr>
<td>Total Elements</td>
<td>22664</td>
</tr>
<tr>
<td>Maximum Aspect Ratio</td>
<td>29.414</td>
</tr>
<tr>
<td>% of elements with Aspect Ratio &lt; 3</td>
<td>86.9</td>
</tr>
<tr>
<td>% of elements with Aspect Ratio &gt; 10</td>
<td>4.06</td>
</tr>
<tr>
<td>% of distorted elements(Jacobian)</td>
<td>0</td>
</tr>
<tr>
<td>Time to complete mesh(hh:mm:ss):</td>
<td>00:00:32</td>
</tr>
<tr>
<td>Computer name:</td>
<td>BASSO</td>
</tr>
</tbody>
</table>

In *Figure 27* it can be seen the meshed frame with the mesh described before.
Figure 27: Meshed frame. SolidWorks Simulation

The plot of the displacement shows that the maximum displacement is 4,705 mm (see Figure 28).

Figure 28: Displacement plot. SolidWorks Simulation
It is wanted that the frame has a good rigidity when passing a curb and when we are generally riding but this is not possible to study it with FEM. So, the idea is to take these values as a reference and build a prototype, tested it and if it is necessary change the tube thickness based on these values.
4.3. Transmission

As we had seen in the Classification point, there are a lot of configurations of these bicycles. In the Previous requirements section it is said that our bike should have front wheel drive. Even though, we do not like so much the existing systems.

The chainwheel of the bottom bracket (fixed to the frame) and the sprockets should be in the same plane, whereas having the second fixed to the fork (which rotates) this is impossible. So, in this project it is wanted to invent and improve a transmission system between the bottom bracket and sprockets.

The aim is to transmit rotational motion in two non-collinear axes. The straightforward solution that we have is a Cardan joint, also called Universal joint.

4.3.1. Cardan or Universal joint

The Cardan joint is a mechanical component, invented by Girolamo Cardano, which allows joining two non-collinear axes (see Figure 29). The concept of this joint is based on the design of gimbals, which have been in use since antiquity. To quote Wikipedia: “A gimbal is a pivoted support that allows the rotation of an object about a single axis”.

![Figure 29: Simple Cardan joint. es.wikipedia.org](es.wikipedia.org)
The main problem is that the axis to which the movement is transmitted does not rotate at a constant angular velocity due to the configuration of the gimbal. However, these differences of angular velocity can be annulled putting two gimbals, provided that the angle between the input shaft and center yoke is equal to the angle between the center yoke and the output shaft. So, in order to obtain the same angular velocity at the inlet and outlet it will use a "Double Cardan Joint". Nevertheless, it is essential to know how to assemble to have a constant velocity (see Figure 31).

In our bicycle the second configuration is used.
4.3.1.1. Study of maximum torque

In order to choose the correct model of cardan joint it is necessary to do a study of the torque.

Assuming that the maximum acceleration that a cyclist can do is 3 m/s, the mass of the cyclist, on average, is 70 kg and 15 kg for the bicycle it is easy to calculate the force that the wheel does against the floor:

From the equation:

\[ F = m \cdot a \]

Where:

\[ m = m_c + m_b \]

The force is:

\[ F = (70 + 15) \cdot 3 = 255 \ N \]

By knowing this force it is possible to calculate the maximum torque in the cardan axis \( (T_c) \) in a few steps.
So, the wheel torque \( T_w \) will be:

\[
T_w = F \cdot R_w
\]

Where \( R_w \) is the wheel radius: 26 inches / 2 (330, 2 mm)

\[
T_w = 255N \cdot 0,3302m = 84,2 \text{ Nm}
\]

The force on the chain \( F_c \) is easy to calculate with the wheel torque and the sprocket radius \( R_s \):

\[
F_c = \frac{T_w}{R_s}
\]

The chain force is inversely proportional to the sprocket radius so, a smaller sprocket will generate a bigger force through the chain. As the aim is to calculate the extreme case it has been taken the smaller sprocket, with a radius of 21,12mm. The selection of these sprockets is explained later.

\[
F_c = \frac{84,2}{0,02112} = 3.986,74 \text{ N}
\]

Finally, to calculate the maximum torque of the cardan joint \( T_c \):

\[
T_c = F_c \cdot R_s \,'
\]

Where \( R_s \,' \) is the radius of the sprocket which is in the same axis that the cardan joint and its value is 29,24mm.

So:

\[
T_c = 3.986,74 \text{ N} \cdot 0,02924 \text{ m} = 116,57 \text{ Nm}
\]
4.3.1.2. Double cardan joint selection

It has been quite difficult to find a double cardan joint that meets the required dimensions and that withstands the maximum torque. Finally, after an exhaustive research it has been found the adequate joint which is from Huco Dynatork brand.

Huco Dynatork is a manufacturer of precision couplings with 44 years of experience. In the double cardan joints section of its website [2] there are a lot of different models. The joint that best meets our requirements is the model 146.321.4242 from the Table 4.

![Double cardan joint parameters. www.huco.com](image)

<table>
<thead>
<tr>
<th>Joint Ref</th>
<th>Bores B h7</th>
<th>D1</th>
<th>L2</th>
<th>L4</th>
<th>L5</th>
<th>Static Torque at Break</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td>Nm</td>
</tr>
<tr>
<td>146.161.2828</td>
<td>8</td>
<td>16</td>
<td>11</td>
<td>62</td>
<td>22</td>
<td>40</td>
</tr>
<tr>
<td>146.162.3232</td>
<td>10</td>
<td>16</td>
<td>15</td>
<td>74</td>
<td>22</td>
<td>40</td>
</tr>
<tr>
<td>146.201.3232</td>
<td>10</td>
<td>20</td>
<td>13</td>
<td>74</td>
<td>26</td>
<td>120</td>
</tr>
<tr>
<td>146.202.3535</td>
<td>12</td>
<td>20</td>
<td>18</td>
<td>88</td>
<td>26</td>
<td>120</td>
</tr>
<tr>
<td>146.251.3535</td>
<td>12</td>
<td>25</td>
<td>15</td>
<td>86</td>
<td>30</td>
<td>220</td>
</tr>
<tr>
<td>146.252.4242</td>
<td>16</td>
<td>25</td>
<td>22</td>
<td>104</td>
<td>30</td>
<td>220</td>
</tr>
<tr>
<td>146.321.4242</td>
<td><strong>16</strong></td>
<td><strong>32</strong></td>
<td><strong>16</strong></td>
<td><strong>104</strong></td>
<td><strong>37</strong></td>
<td><strong>380</strong></td>
</tr>
<tr>
<td>146.322.4848</td>
<td>20</td>
<td>32</td>
<td>25</td>
<td>124</td>
<td>37</td>
<td>380</td>
</tr>
<tr>
<td>146.401.4848</td>
<td>20</td>
<td>40</td>
<td>23</td>
<td>128</td>
<td>47</td>
<td>800</td>
</tr>
<tr>
<td>146.402.5252</td>
<td>25</td>
<td>40</td>
<td>32</td>
<td>156</td>
<td>47</td>
<td>800</td>
</tr>
<tr>
<td>146.501.5252</td>
<td>25</td>
<td>50</td>
<td>29</td>
<td>160</td>
<td>56</td>
<td>1550</td>
</tr>
<tr>
<td>146.502.5858</td>
<td>32</td>
<td>50</td>
<td>40</td>
<td>188</td>
<td>56</td>
<td>1550</td>
</tr>
<tr>
<td>146.631.5858</td>
<td>32</td>
<td>63</td>
<td>33</td>
<td>198</td>
<td>68</td>
<td>2800</td>
</tr>
<tr>
<td>146.632.6363</td>
<td>40</td>
<td>63</td>
<td>48</td>
<td>238</td>
<td>72</td>
<td>2800</td>
</tr>
</tbody>
</table>

*Table 4: Dimensions and order codes*
However, it would be necessary to request the seller to modify bores B; they must be hexagonal instead of cylindrical.

With the selected joint the factor of safety is about 3.26 as it is shown in the equation below:

\[ FS = \frac{380 \, Nm}{116.57 \, Nm} = 3.26 \]

It has been considered that is a sufficient factor of safety for a first prototype.

In order to isolate the joint from small stones, branches, sand, mud, etc, it has been put a cover. These covers are called “Universal Joint Boot Covers”. It can be bought from Belden brand since they provide a wide range of this product. As it is build of an elastic material, we must choose a diameter shorter than the joint to ensure that it does not move. So, the boot cover selected for our joint is the model **1250 Boot** (see page 15 of the Belden catalog in the annex). We can appreciate that this model has a diameter of 31.8 mm whereas the outer diameter of the joint is 32 mm. The material of this boot cover is Nitrile. We can see in boot material information, below the list of different models that it is the standard material and it will be sufficient to protect the joint from weather conditions. The other advantage of this boots is that they keep the joint fully lubricated.

![Universal Joint Boot Covers](beldenuniversal.com)

Searching on the internet, it has been found a model in SolidWorks of a double cardan joint but it has been necessary to modify the sizes. In **Figure 34** the final joint model in SolidWorks is shown.
4.3.2. Assembly

The main idea is to put a sprocket on each side of the joint; one fixed to the frame and the other fixed to the fork. So, in this recumbent we have two chains: one which links the bottom bracket with the sprocket fixed to the frame, and a second which links the sprocket fixed to the fork with the cassettes and derailleur.

At first, it had been decided on the configuration shown in Figure 35. But after mounting all the components it has been noticed that this configuration has an important error: the chain wheel and the sprocket were not aligned (see Figure 36). A bicycle chain allows a little gap between the two gearwheels but not 4 cm.
In order to solve this significant problem, it has been decided not to modify the fixations of the frame nor fork but to put the two sprockets in contact with the double cardan joint. The definitive configuration is shown in Figure 37.

With this new design of the transmission we solve indirectly another point. It is now more comfortable for the legs because the system is shorter and so it is more difficult to touch it with the knees. Moreover, the sprockets are now better protected thanks to being inside. However, the only disadvantage is that now it will be a bit harder to change the chain; you will have to disassembly the all system.

In order to learn about mechanic components and to design the transmission system it has been used an excellent book of industrial design [3].

In Figure 38 all the components are shown.
4.3.3. Axis

In this transmission system there are two axes. They are identical for ease of manufacture. However, one (which is fixed to the frame) is totally fixed to the universal joint shaft too, whereas the other (which is fixed to the fork) slides along the shaft. That is the reason why one shaft has a pin which blocks the movement between them.

The diameter of the axis is 10 mm but one end is hexagonal, which penetrates the shaft of the joint. At the opposite end couples a circlip which is responsible for closing the transmission system assembly. The datasheet of this circlip is attached in the annex (order no. 07330-101000). It also has a hole where the cotter for the sprocket goes and another for the pin (but only the axis fixed to the frame will use the pin).

As a pin I used a Hexagon Socket Screw with flat tip. In the annex we can find the specifications: order no. 07165-103X12. Of two possible materials we choose the stainless steel one.
4.3.4. Sprockets

The two sprockets are identical. The sprocket selected is a 15 tooth sprocket for bicycle chain. The inner diameter is 10 mm, as the axis. It has a keyway slot to be fixed to the axis and rotate together. In Figure 40 it can be seen the sprocket model in SolidWorks.

![Figure 40: 15 tooth sprocket model. SolidWorks](image-url)

The key used in order to transmit rotation between the sprocket and the axis is a parallel key and “A” type (rounded corners). In Figure 41 it is shown the parallel key whereas in Figure 42 the “A” type.

![Figure 41: Cross-section of a parallel keyed joint. en.wikipedia.org](image-url)
4.3.5. **System supports**

As it has been shown previously, this transmission system is formed by two brackets: one from the frame and the other from the fork. It has been designed a “box” in which within there are the bearings for the axis. This “box” is the same for both brackets. In *Figure 43* it can be seen the support which comes from the frame.

---

**Table 5: Our key dimensions**

<table>
<thead>
<tr>
<th>h (mm)</th>
<th>3,2</th>
</tr>
</thead>
<tbody>
<tr>
<td>b (mm)</td>
<td>3</td>
</tr>
<tr>
<td>l (mm)</td>
<td>8</td>
</tr>
</tbody>
</table>

*Figure 42: “A” key type parameters. sparkfix.com.br*
So that the bracket will not deform, it has been put a rib. Moreover the thickness of the tube is 2 mm thus giving stiffness.

For the other bracket it has been applied the same idea. It has been necessary to modify an existing fork adding the support. It has been put a rib and the thickness is 2 mm too (see Figure 44).
4.3.6. Bearings

In order to have a good rotation, there are four bearings, two in each “box”. The bearings chosen are from INA brand. The technical specifications of these bearings are:

![Diagram of bearing parameters]

Figure 45: Bearing parameters. www.kramp.com

<table>
<thead>
<tr>
<th>Part number</th>
<th>618002RS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Properties</td>
<td>Single-row roller bearing</td>
</tr>
<tr>
<td></td>
<td>Lip seal on both sides</td>
</tr>
<tr>
<td>d (mm)</td>
<td>10</td>
</tr>
<tr>
<td>D (mm)</td>
<td>19</td>
</tr>
<tr>
<td>B (mm)</td>
<td>5</td>
</tr>
<tr>
<td>Basic load ratings dyn. Cr (kN)</td>
<td>1.72</td>
</tr>
<tr>
<td>Basic load ratings (kN) Stat. Cor</td>
<td>0.73</td>
</tr>
<tr>
<td>Limiting speeds (rpm) Grease lub.</td>
<td>22000</td>
</tr>
</tbody>
</table>

Table 6: Bearing specifications
These bearings are fixed within the “box” by an inner circlips. The technical specifications about these circlips are shown below (DIN 472 INOX).

![Figure 47: Inner circlip parameters. www.tracepartsonline.net](image)

**Table 7:** Circlip specifications

<table>
<thead>
<tr>
<th>Reference</th>
<th>6276110</th>
</tr>
</thead>
<tbody>
<tr>
<td>d1 (mm)</td>
<td>10</td>
</tr>
<tr>
<td>e (mm)</td>
<td>1</td>
</tr>
<tr>
<td>d3 (mm)</td>
<td>10,8</td>
</tr>
<tr>
<td>a (max) (mm)</td>
<td>3,2</td>
</tr>
<tr>
<td>b (mm)</td>
<td>1,4</td>
</tr>
</tbody>
</table>
4.3.7. **Spacer rings**

In the all system there are four spacer rings, two in each “box” next to the bearings. There are two different sizes: the outer have an outside diameter of 14 mm and 3 mm width; and the inner 14 mm inside diameter too and 4,6 width. The material of these spacer rings is a carbon steel making them highly resistant.

![Figure 48: Outer spacer ring. SolidWorks](image)

![Figure 49: Inner spacer ring. SolidWorks](image)
4.3.8. Bottom bracket

Nowadays there are several types of bottom brackets. For the bottom bracket it has been selected the Truvativ Square LE (113 x 73) model.

The Truvativ Square LE Bottom Bracket Features:

- Sealed cartridge bearings
- Square taper spindle
- BB Shell Width: 73 mm
- Weight: 327 g
- BB Thread Type: English
- Spindle Interface Type: Square Taper JIS

![Bottom bracket chosen. www.raptobike.nl](image)

4.3.9. Crankset

The crankset for our recumbent has been taken from an important brand of recumbent bicycles: Raptobike. It is fitted to the bottom bracket so they are related (as the bottom bracket has a square taper spindle, the crankset hole must be square too). Regarding the crank arm length there are several different sizes, from shortest to largest: 140mm, 155mm, 165mm, and 175mm. It has been selected a medium size considering anthropometric measures study. It has to be long for having more push on the pedal but it is also important to consider that a too long crank arm could touch the front wheel when turning.
Features:

- 155 mm crank arm length
- BCD 130 mm
- 5 arm spider
- Square bottom brackets

4.3.10. Chainwheel

There are also different chainwheel sizes depending on the number of teeth they have; for this type of bicycles there exist from 39T (the smallest) to 70T (the biggest). However, this big difference between chainwheels sizes is for being used by bikes which have a front derailleur. There are recumbent bicycles with a chainwheel derailleur but it represents an additional component. Moreover, it is necessary to have a noseboom (derailleur mount, see Figure 52).

Figure 51: Crankset 155mm. www.raptobike.nl

Figure 52: Noseboom, derailleur mount. www.raptobike.nl
Depending on the number of teeth, it would be more or less easy to ride up hills. In our case, as our bicycle is designed to go through relatively flat places and not steep slopes, with an only one chainwheel it will be sufficient. The BTT bikes, which can climb steep slopes, generally use a small chainwheel of 28 teeth. Although our bike is not designed to climb steep slopes, it must be able to climb and so it has been chosen the 39T model. This chainwheel size allows both run on the downhill and climb small slopes (it will be shown in Gear ratio study section). This component is also has been taken from Raptobike brand.

![Figure 53: Chainwheel 39T + ring. www.raptobike.nl](image)

**Description:**

The center hole is 115 mm diameter and the pitch for the 5 fixation points is 130 mm diameter. This means the holes are 65 mm from central bottom bracket axis. Blade thickness 2 mm. Fixation points are 11 mm diameter. It includes a fixed protection ring on the outside of the chainwheel.

### 4.3.11. Cassette

In order to choose the most appropriated gear ratio, it is important to consider that our bike uses only one chainwheel and so, the cassette should have a wide range. Even thought, the gear ratio is very personal and depends on the preferences of the rider. The cassette selected for our recumbent is Shimano Deore XT CS-M770 9-Speed (it will be also shown in Gear ratio study).
Figure 54: Shimano Deore XT CS-M770 9-Speed. www.nashbar.com

Features:

- Designed with a cog "spyder" carrier to keep the weight low at 267 grams (11-32T)
- Chrome plated
- For use with super narrow HG chain

Specifications:

- Weight: 267g (11-32T)
- Material: Steel, Chrome-plated
- Compatibility: Shimano freehub; 9-speed Shimano chain
- Size: 11-12-14-16-18-21-24-28-32 (number of teeth of each sprocket).

Figure 55: Shimano Deore XT CS-M770 9-Speed model. SolidWorks
4.3.12. Gear ratio study

In order to corroborate that the chainwheel and cassette are correct for our bike, it has made a gear ratio study. It is the relation between the rate at which the rider pedals and the rate at which the drive wheel turns. It is calculated by the number of teeth of the chainwheel and the number of teeth of the sprocket. As our bicycle has 9 sprockets in the cassette and one chainwheel, there are 9 (9 x 1) different gear ratios. However, it is only necessary to calculate two gear ratios: the first, between the chainwheel and the smallest sprocket; and the second one, between the chainwheel and the biggest sprocket. The rest will be within this range.

- Gear ratio between the chainwheel and the smallest sprocket. This combination of speeds will be used to descend a slope. As mentioned before, the smallest sprocket has 11 teeth and the chainwheel 39, so the gear ratio between them is:

\[
\frac{39}{11} = 3.55
\]

This means that for each turn of the chainwheel (one pedaling), the sprocket (and so the drive wheel) does 3.55 turns.

With one turn of a 660.4 mm (26 inches) diameter wheel, the bicycle moves 2.074 mm (perimeter of a circumference, \(P\)).

\[
P = \pi \cdot D = \pi \cdot 660.4 \text{ mm} = 2.074 \text{ mm}
\]

So, with this configuration for each pedaling the bike moves 7.365 m (2.074 m x 3.55 turns).

- Gear ratio between the chainwheel and the biggest sprocket. This combination of speeds will be used to up a slight slope. It has been used the same process; the biggest sprocket has 32 teeth and the chainwheel is always the same so:

\[
\frac{39}{32} = 1.22
\]

Therefore, for each turn of the chainwheel, the sprocket does 1.22 turns. With this configuration for each pedaling the bikes moves 2.530 m (2.074 m x 1.22 turns).
4.3.13. Derailleur gears

The derailleur is a mechanism to shift the chain from one sprocket to another. There are two pulleys: the guide pulley and the tension pulley. Guide pulley pushes chain from one sprocket to the other. The tension pulley maintains tension in the chain. In our recumbent this component is placed in the front wheel. It has been selected the Shimano Deore XT RD-M772-SGS Shadow derailleur (see ¡Error! No se encuentra el origen de la referencia.).

![Shimano Deore XT derailleur](www.performancebike.com)

**Figure 56: Shimano Deore XT derailleur. www.performancebike.com**

**Description:**

- Top-normal design offers crisp, clean, derailleur-controlled shifts to hard gears, allowing excellent shifting under heavy load and acceleration.
- In high gear, the derailleur has a profile that is a full 15mm less than a traditional rear derailleur and hardly protrudes past the quick release nut to give you extra protection.
- Direct cable routing uses less cable, so it is lighter, shifts faster and reduces the chance of getting caught up on roots and rocks.
- Derailleur body with a stronger spring provides snappy shifting, more stability and less bounce in rough terrain.
- Redesigned bracket axle prevents the derailleur body from contacting the chainstay for smooth, silent performance.
- 11T sealed bearing pulleys run quieter and spin smoother for long-lasting performance.
• Four fluorine coated link pivot pins minimize friction and increase shifting response.
• Aluminium construction for lightweight strength.
• Long cage design gives you a wider gear range.

Specifications:

• Capacity: 45T
• Compatibility: 9-speed
• Material: Aluminium
• Max. Cog: 34T
• Max. Front Difference: 22T
• Min. Cog: 11T
• Spring Type: Top-Normal/Traditional
• Weight: 235g
• Rating: 5

4.3.14. Pedals

The pedals are an important element of the transmission since they are in direct contact with our feet and they permit you to control pedaling power. As it is said that we want a lightweight bicycle it has been chosen a magnesium pedals which only weighing 188 g (whereas conventional 300 g) from the brand Wellgo.

![Wellgo magnesium pedals. www.bi-cycles.net](www.bi-cycles.net)
Features:

- Size: 118.3 x 112.6 mm
- Weight: 376 g/pair
- Thread: 9/16"

4.3.15. Chain

As it has seen, this transmission uses two independent chains. They are identical except for their length. It has been selected the Shimano XT HG93 9 speed chain. In Figure 58 it can be clearly seen the two chains.

![Figure 58: Independent chains. SolidWorks](image)

Precision construction maintains strength, dependability and shifting performance on narrower 9-speed sprockets.

Shimano HG93 9 speed chain features:

- Mega9 - Super Narrow Hyperglide (HG) chain
- Recommended for current Ultegra, Deore XT and Nexave C900/C600 drivetrains
- Zinc-alloy plated pin link plates for superior corrosion resistance
- Grey roller link plate
- Chromising treatment link pin
- Average weight 304 g (114 links)
4.3.16. Safety features

In order to avoid accidents with the transmission system, in the cardan sprockets it will be put a fixed protection ring. These rings prevent the pants can snag on the sprockets.

4.4. Seat

Like the frame and the transmission system, the seat has been designed by me. For this recumbent I want a lightweight and comfortable seating where you could rest your head. Nowadays most of these seats are built by carbon fiber and so I have chosen this resistant material. In my opinion it is very important that the seats allow you to rest the head in order to avoid neck pain. Therefore, this seat is longer than typical; I designed it myself considering anthropometric parameters studied previously (see Figure 60).

As people have different ways of cycling, the seat has multiple positions. To get an idea, it is like a gym bench.
The seat has two support points: one under the bottom and the other behind the back. The first one plays as articulation and the second one allows you to regulate the inclination you prefer.

![Figure 61: Support that articulates the seat. SolidWorks](image)

This second holder attaches to the frame via a bar to which it has been called “T” bar (see Figure 63). This component is articulated in the frame and the head has a 10 mm diameter cylinder that fits into the support. In order to avoid the escape of the “T” bar from the holder when passing a bump, it has been designed the holder with an interference. In the sketch of Figure 64 it can be seen that the entry is 0.5mm (10 – 9.5) smaller than the cylinder which fits into the support.

![Figure 62: Support that permits to regulate inclination. SolidWorks](image)
It has been used the same system to attach the “T” bar and the articulation-support to the frame: a pin, washers and circlips. The assembly of these components is shown in Figure 65.
4.5. Fork

The fork plays an important role in this bicycle. Due to the transmission system invented, the fork has an extra arm which is responsible for holding the cardan joint together with the frame. In addition, because of having front wheel drive it is necessary a special fork (must fit the cassette) and to have a derailleur hanger. We could order the construction of the entire fork but there is a cheaper alternative: to buy a fork to Raptobike Company, since at being a company specializing in these bikes have forks for front wheel drive, and welding the additional arm in it.

As our recumbent uses disc brakes the fork must have the caliper support. Therefore, it has been chosen the model fork: ERTRO 559 (see Figure 66).

Figure 65: Pin, washers and circlips assembly. Render SolidWorks

Figure 66: Raptobike’s fork. www.raptobike.nl
Features:

- 660.4 mm (26 inches) wheel
- Tubing 28.6 mm (1 1/8 inches)
- 135 mm spacing
- Quick release
- Derailleur hanger
- Disc brake
- Black

![Figure 67: Additional arm welded. SolidWorks](image)

4.5.1. Headset

To quote Wikipedia: "The headset is the set of components on a bicycle that provides a rotatable interface between the bicycle fork and the head tube of the bicycle frame itself". For our headset it has been used the following components.
4.5.1.1. Bearings

It is used the 1 1/8 inch ball bearing with the following sizes:

- 30.15mm x 39mm x 6.5mm (inner diameter, outer diameter, height)
- 45deg x 45deg (chamfer)

![Figure 68: Headset bearing. www.downhillspecific.com](image)

4.5.1.2. Star nut

The star nut is an important component of the headset because is where the bolt cap is screwed, which is responsible for maintain all the components joined.

![Figure 69: Star nut ahead claw with aluminium screw. www.bike24.com](image)

**Features:**

- Weight: approx. 10g
- Ø Bar Clamp: 1 1/8 inches
- Color: black
- Aluminium screw (1 1/8 inches - M6x35)
4.5.1.3. Top cover

The top cover selected is the Orbit 28,6 mm (1 1/8 inches) x 10 mm black alloy (see Figure 71).

4.5.1.4. Top cap

The top cap chosen is of Chris King brand (see Figure 72).

**Key Features:**

- Designed for a 28,6 mm (1 1/8 inches) steerer.
- Aluminium.
- Black
4.6. Handlebar

The handlebar of our recumbent bicycle is composed of two components: the stem and the tiller. These two parts permit that the handlebar is adjustable. As is not a conventional handlebar, also it has been taken from RaptoBike brand.

The stem, which links the fork to the tiller, has a 300mm length and it is suited for 1 1/8” fork tubes.
Regarding the tiller, this brand offers two types:

- 90 degrees: default and most straight positioning of the wrists.
- 110 degrees: suited for taller people or people who prefer their handlebars to be a bit wider.

Figure 74: Different types of tillers. www.raptobike.nl

For our bike it has been selected the 90 degrees tiller. To quote Raptobike’s website: “Comfortable and fast! This tiller was designed to offer maximum comfort. Your wrists, hands and shoulders will be completely relaxed”. Therefore it is thought that it would be the most appropriate tiller.

Figure 75: Stem for the recumbent bike. SolidWorks
4.7. Wheels

The wheels taken for our recumbent bicycle are 660,4 mm (26 inches) wheels. There are different types of wheels, depending on the category of the bike (mountain bike, racing, etc). Our bicycle has no defined clearly its category, so it is chosen a conventional wheel with a wide range of uses.

The wheels selected are of Taurus brand.

Features:

- For XC, All Mountain and Marathon
- GURPIL hub sealed bearings:
  - Front hub for through shafts of 9 mm (conventional) of 15 mm and 20 mm
  - Rear hub 9mm quick closing or 12 x 135 and 12 x 150
  - 6 screws
  - 8/9 and 10 speed (in our case 9 speed)
- Front 9mm (red) weight: 1.000gr
- Rear 9x135 (red) weight: 1.150gr
It is necessary to mention an important detail. At being front wheel drive, in this bicycle the conventional rear wheel is the front one and vice versa. It is logical since in this case the cassette is in the front wheel.

### 4.8. Tires

As wheels, there are a big variety of tires depending on the cycling style (see Figure 78). With the idea of creating a versatile recumbent bike that allows you to ride both at the parks as urban ways, it has been selected a mountain bike tire. They are made for riding on mountains or similar areas and they are designed to provide maximum grip on the loosest surfaces to make your journey pleasurable. For our recumbent bike it has been chosen Maxxis Ikon 26 x 2.2 tires.
Description:

- Product Number: 5028-250
- Made in Taiwan
- Rubber compound is 3C Maxx Speed
- High-volume casing and fast-rolling tread design for performance in all conditions
- 120 threads per inch

Specifications:

- Weight: 480g
- Intended use: mountain
- Bead: folding
- Wheel position: front or rear
- Tire size: 26 x 2.2 inches
- Recommended PSI: 65psi

*Figure 79: Maxxis tire chosen. biketires.eu*
4.9. Brakes

As it has been explained before, recumbent bikes get high speeds above all in downhill and so it is crucial they have good brakes. Therefore, it has been chosen disc hydraulic brakes for our bicycle. Monty uses these brakes with its trial bikes so it is selected the brakes that the brand Hope manufactures for them. These brakes are used by bikes which require heavy braking so it can be ensured that they will be appropriated for our bicycle.

![Hope brakes](www.trial-bikes.com)

*Figure 80: Hope brakes used for our recumbent. www.trial-bikes.com*

![Right lever](www.trial-bikes.com)

*Figure 81: Right lever. www.trial-bikes.com*

**Description and materials**

- New Hope Trial Zone disc brake, with a fashionable anodized red finish, made exclusively for the Spanish brand Monty.
- CNC machined from a solid billet of 2014 T6 aircraft spec aluminium alloy.
- Split bar clamp allows a fast set up, with 2 aluminium bolts which also save some good few grams.
- New lever, stiffer and more comfortable than before, improves braking performance by over 15%.
- PVC hose reduces 107g (40g for the front brake and 67g for the rear) compared to the metallic hose version.
- Post Mount caliper, with two 25mm magnetized pistons (as seen in the IS version), which
avoid any noises and improve overall performance.
- Stunning anodized red finish with silver laser etched graphics.
- Supplied with all necessary parts to simply fit on your brake, it also comes bled.
- Front (left lever) and rear (right lever) versions available.

**Includes**

- 650mm (front) and 1240mm (rear) long PVC hose.
- Caliper adjustment washers.
- Hope rotor, 160mm.
- Post Mount Hope caliper, suitable for both front and rear brakes.

**Finishes**

- Anodized red.
- Silver laser etched Hope graphics.

**Weight**

- 226g (front) and 238g (rear), without bolts included (+11.9g).

**Additional information**

When bleeding, use only Dot 4 or Dot 5.1.

All this information has been taken from a biketrial website [4].

![Rear caliper of our recumbent. Render SolidWorks](image)

Regarding the discs it has been selected Hope Mono Mini-M4 Saw Disc Brake Rotor.
Specifications

- Fits Mono Mini and Mono M4 brakes
- Fixing bolts included
- Floating rotor or standard one piece.
- Diameter: 180 mm

Figure 83: Hope disc brake. www.chainreactioncycles.com
5. Regulations

The rules most considered in making this project are listed below:

- EN 14764: City and trekking bicycles – Safety requirements and test methods
- ISO 3452-1984: Non-destructive testing
- ISO 1101:1983: Geometrical tolerancing
- ISO 6344:1998: Coated abrasives, sizes and tests
- ISO 5775-1:1997: Bicycle tyres and rims (1)
- ISO 5775-2:1996: Bicycle tyres and rims (2)
- ISO 9633:2001: Cycle chains – Characteristics and test methods
6. Budget

This chapter is divided into two parts. First of all, it has been made a budget of the project itself, considering the number of hours spent on its realization. Secondly, it has been made a budget of how much the bike costs.

For the realization of this project it has been spent about 300 hours. Nevertheless, the tasks have been very varied and not all have the same price. From the 300 hours, it has been billed 250 since the remaining 50 have been devoted to my own learning. So it has been made a classification of these different tasks with its prices (see Table 8).

<table>
<thead>
<tr>
<th>Task</th>
<th>Cost / hour (€/h)</th>
<th>Hours spent (h)</th>
<th>Cost (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawing 3D CAD</td>
<td>25</td>
<td>75</td>
<td>1.875</td>
</tr>
<tr>
<td>Searching components</td>
<td>35</td>
<td>45</td>
<td>1.575</td>
</tr>
<tr>
<td>FEM</td>
<td>35</td>
<td>35</td>
<td>1.225</td>
</tr>
<tr>
<td>Invention</td>
<td>45</td>
<td>30</td>
<td>1.350</td>
</tr>
<tr>
<td>Report</td>
<td>25</td>
<td>65</td>
<td>1.625</td>
</tr>
</tbody>
</table>

**TOTAL COST** 7.650

*Table 8: Project cost considering the hours spent on it*

So, the total cost of the project is 7.650 €. It is important to note that it has not been considered the software licenses costs; it has been used student versions. If it was a real project it would be considered. Regarding the cost/hour of each task, they have been agreed with the tutor of the project. The invention is the most expensive because it is the most difficult task, while the CAD drawing is the cheapest since can be made by a scholar without much knowledge about bicycles. However, is in this last task in which it has been invested more hours.

Regarding the bicycle cost it has been made two different budgets. The first one is about how much the bike costs as a prototype. The second one is about how much it costs producing it in series.

In order to calculate the cost of the prototype, it has been taken the prices of each component from the internet and it has been added up (see Table 9).
<table>
<thead>
<tr>
<th>Component</th>
<th>Market price</th>
<th>Units</th>
<th>Final price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission bearings</td>
<td>4,2</td>
<td>4</td>
<td>16,8</td>
</tr>
<tr>
<td>Universal joint</td>
<td>82,75</td>
<td>1</td>
<td>82,75</td>
</tr>
<tr>
<td>Chain sprocket wheel</td>
<td>3</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Carbon seat</td>
<td>265</td>
<td>1</td>
<td>265</td>
</tr>
<tr>
<td>Chain</td>
<td>19,9</td>
<td>2</td>
<td>39,8</td>
</tr>
<tr>
<td>Bottom bracket</td>
<td>15</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Front wheel</td>
<td>88</td>
<td>1</td>
<td>88</td>
</tr>
<tr>
<td>Rear wheel</td>
<td>76</td>
<td>1</td>
<td>76</td>
</tr>
<tr>
<td>Brakes</td>
<td>179</td>
<td>2</td>
<td>358</td>
</tr>
<tr>
<td>Discs</td>
<td>35</td>
<td>2</td>
<td>70</td>
</tr>
<tr>
<td>Stem</td>
<td>45</td>
<td>1</td>
<td>45</td>
</tr>
<tr>
<td>Tiller</td>
<td>45</td>
<td>1</td>
<td>45</td>
</tr>
<tr>
<td>Pedals</td>
<td>21,99</td>
<td>2</td>
<td>43,98</td>
</tr>
<tr>
<td>Crankset</td>
<td>50</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>Chainwheel</td>
<td>90</td>
<td>1</td>
<td>90</td>
</tr>
<tr>
<td>Cassette</td>
<td>39</td>
<td>1</td>
<td>39</td>
</tr>
<tr>
<td>Tires</td>
<td>70</td>
<td>2</td>
<td>140</td>
</tr>
<tr>
<td>Derailleur</td>
<td>79,9</td>
<td>1</td>
<td>79,9</td>
</tr>
<tr>
<td>Fork</td>
<td>87,5</td>
<td>1</td>
<td>87,5</td>
</tr>
<tr>
<td>Headset bearings set</td>
<td>17</td>
<td>1</td>
<td>17</td>
</tr>
<tr>
<td>Star nut + Alu screw</td>
<td>3,5</td>
<td>1</td>
<td>3,5</td>
</tr>
<tr>
<td>Top cover</td>
<td>13,25</td>
<td>1</td>
<td>13,25</td>
</tr>
<tr>
<td>Top cap</td>
<td>7,99</td>
<td>1</td>
<td>7,99</td>
</tr>
<tr>
<td>Frame</td>
<td>400</td>
<td>1</td>
<td>400</td>
</tr>
<tr>
<td>Extra (welding tubes, seat bars, screws...)</td>
<td>400</td>
<td>1</td>
<td>400</td>
</tr>
</tbody>
</table>

**TOTAL COST**  2479,47

*Table 9: Cost of a recumbent prototype*

The cost of a recumbent prototype is **2479,47 €**.

To calculate the cost of this bicycle produced in series the best way would be to ask the manufacturers of each component for a quotation. However, I cannot do this option because at being a student, the manufacturers would not give me the quotation. So, thanks to our experience in this field and knowing the cost of the prototype, it can be done the approximation of divide this cost by 4 (see *Table 10*).
Recumbent bicycle design

<table>
<thead>
<tr>
<th>Component</th>
<th>Market price</th>
<th>Reducing factor</th>
<th>Units</th>
<th>Final price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission bearings</td>
<td>4.2</td>
<td>0.25</td>
<td>4</td>
<td>4.2</td>
</tr>
<tr>
<td>Universal joint</td>
<td>82.75</td>
<td>0.25</td>
<td>1</td>
<td>20.69</td>
</tr>
<tr>
<td>Chain sprocket wheel</td>
<td>3</td>
<td>0.25</td>
<td>2</td>
<td>1.50</td>
</tr>
<tr>
<td>Carbon seat</td>
<td>265</td>
<td>0.25</td>
<td>1</td>
<td>66.25</td>
</tr>
<tr>
<td>Chain</td>
<td>19.9</td>
<td>0.25</td>
<td>2</td>
<td>9.95</td>
</tr>
<tr>
<td>Bottom bracket</td>
<td>15</td>
<td>0.25</td>
<td>1</td>
<td>3.75</td>
</tr>
<tr>
<td>Front wheel</td>
<td>88</td>
<td>0.25</td>
<td>1</td>
<td>22.00</td>
</tr>
<tr>
<td>Rear wheel</td>
<td>76</td>
<td>0.25</td>
<td>1</td>
<td>19.00</td>
</tr>
<tr>
<td>Brakes</td>
<td>179</td>
<td>0.25</td>
<td>2</td>
<td>89.50</td>
</tr>
<tr>
<td>Discs</td>
<td>35</td>
<td>0.25</td>
<td>2</td>
<td>17.50</td>
</tr>
<tr>
<td>Stem</td>
<td>45</td>
<td>0.25</td>
<td>1</td>
<td>11.25</td>
</tr>
<tr>
<td>Tiller</td>
<td>45</td>
<td>0.25</td>
<td>1</td>
<td>11.25</td>
</tr>
<tr>
<td>Pedals</td>
<td>21.99</td>
<td>0.25</td>
<td>2</td>
<td>11.00</td>
</tr>
<tr>
<td>Crankset</td>
<td>50</td>
<td>0.25</td>
<td>1</td>
<td>12.50</td>
</tr>
<tr>
<td>Chainwheel</td>
<td>90</td>
<td>0.25</td>
<td>1</td>
<td>22.50</td>
</tr>
<tr>
<td>Cassette</td>
<td>39</td>
<td>0.25</td>
<td>1</td>
<td>9.75</td>
</tr>
<tr>
<td>Tires</td>
<td>70</td>
<td>0.25</td>
<td>2</td>
<td>35.00</td>
</tr>
<tr>
<td>Derailleur</td>
<td>79.9</td>
<td>0.25</td>
<td>1</td>
<td>19.98</td>
</tr>
<tr>
<td>Fork</td>
<td>87.5</td>
<td>0.25</td>
<td>1</td>
<td>21.88</td>
</tr>
<tr>
<td>Headset bearings set</td>
<td>17</td>
<td>0.25</td>
<td>1</td>
<td>4.25</td>
</tr>
<tr>
<td>Star nut + Alu screw</td>
<td>3.5</td>
<td>0.25</td>
<td>1</td>
<td>0.88</td>
</tr>
<tr>
<td>Top cover</td>
<td>13.25</td>
<td>0.25</td>
<td>1</td>
<td>3.31</td>
</tr>
<tr>
<td>Top cap</td>
<td>7.99</td>
<td>0.25</td>
<td>1</td>
<td>2.00</td>
</tr>
<tr>
<td>Frame</td>
<td>400</td>
<td>0.25</td>
<td>1</td>
<td>100.00</td>
</tr>
<tr>
<td>Extra (welding tubes, seat bars, screws...)</td>
<td>400</td>
<td>0.25</td>
<td>1</td>
<td>100.00</td>
</tr>
</tbody>
</table>

**TOTAL COST** 619.87

*Table 10: Cost of a recumbent bike manufactured in series*

The final cost for each recumbent bicycle produced in series is 619.87€. This is the cost that Monty would pay if it decided to carry it on.

Finally, the RRP is calculated by multiplying the cost of manufactured in series per 3. So, the price is 1.857 €, a price very competitive in comparison with another brands of recumbent bikes.
7. Environmental impact

In general, this bicycle has little environmental impact.

Regarding the production, recycled materials and easily recyclable plastics will be used. Moreover, we will try to avoid PVC since it is a hard recyclable material.

This bicycle does not pollute and does not need fossil fuels. Also, it does no pollute with motor oils (toxic waste). So it is a clean means of transport and healthy because creates a habit of exercise. It helps you to do sport while doing a displacement. In addition, the bike not spoils the landscape nor modifies it (motorways for cars). Even parked, it does not need large areas of parking as cars need.

So we can say that it is favorable to the environment.
8. Planning

As any project, it has followed a planning. The project started in February 2014 learning about this type of bicycles called recumbent bikes. The first step was to know all about these bikes and after that I was able to start the own design. After doing different calculations, designs and so on, the final step was to write the report. When writing the report it has been devoted many hours to change and modify different points.

In order to see more clearly the planning a Gantt chart is done (see Table 11).

Table 11: Gantt chart for the planning.
Conclusions

Nowadays, we live in a world where more and more people go to work by bike or just go for a bike ride. Therefore, companies that manufacture bicycles are constantly searching and looking for new concepts. So, the idea of investing in a bicycle is current since it is an ecological vehicle which does not use fossil fuel and so it is the future.

Throughout the project there have been many difficulties, especially techniques. I have had to spend more than fifty hours in self-learning complex programs like SolidWorks and Ansys (finally not used) using tutorials and YouTube videos. Even though, it has been very difficult to model in 3D elements; much of the time for the project has been invested in doing this.

Technically, I am proud for the final results because it has achieved to design an entirely recumbent bike. The final design meets all the previous requirements except for one (the seat was higher than the bottom bracket). This does not represent any problem because it was an aesthetic requirement. As it has said, it is a first prototype design and we know that if we want to carry on this project, some modifications would have to be done. Nevertheless, we have achieved the first step, which is for Monty to consider whether producing this kind of bikes or not. It would be interesting to continue the project to build the first prototype and verify calculations and hypotheses analyzed.

To sum up, for me carrying out this project has taught me to be patient, learn how to solve technical issues and learn how to manage a technical project of this type. I have definitely learned how to use the software SolidWorks, which will clearly help me in the future. I have also seen that I consider myself a more technical than business engineer.
Bibliography

Bibliographic references

[1] Anthropometry and biomechanics (NASA)
   http://msis.jsc.nasa.gov/

[2] Universal Joints


   www.trial-bikes.com

Complementary bibliography

The following websites have been visited between the months February and September 2014.

- Wikipedia: history of recumbent bicycles
  http://en.wikipedia.org/wiki/Recumbent_bicycle

- Aluminium alloys properties
  http://www.lumetalplastic.com/dural_carac_mec.html

- Aluminium 7005 T6 properties
  http://www.makeitfrom.com/material-data/?for=7005-T6-Aluminum

- Aluminium 7005 T6 properties
5&show_prop=uts&Page_Title=Aluminum%20Alloy%20AA%207005

- Cardan joints

- Cardan joints

- Transmission torque
  http://www.imac.unavarra.es/web_imac/documentation/Bicicleta_con_pedales_de_movimiento_rectilineo.pdf

- Cyclist acceleration simulator
  http://www.analyticcycling.com/PowerMeasAnalyAcceleration_Page.html