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DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

CDIO WORLDWIDE CHALLENGE

ME519 GROUP PROJECT

DATE: 18/03/2016

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ACKNOWLEDGEMENTS

SynopTech would like to recognise a number of people without whom this project would not have reached successful completion. Firstly, the authors would like to thank Professor James Boyle who acted as advisor for the project and provided critical guidance when needed. Moreover, the support and advice provided by Mr Chris Cameron and his team of technicians, was gratefully appreciated throughout both the design and manufacturing phases of this project. Their experience and assistance were paramount to the creation of the fully operational prototype bicycle The Commuter. In addition, the authors would also like to thank the team at Bike Station Glasgow for their sponsorship of parts and workshop use without which the power train would not have been assembled. The head of the Mechanical and Aerospace Engineering Department at the University of Strathclyde, Professor Andrew Heyes, is also recognised for agreeing to sponsor SynopTech in their participation at the CDIO regional competition in Belfast. Finally, special thanks go to Reynolds Tubing for their kind help when purchasing tubing and Mrs L. Lang for supplying the personalised decals for the bicycle.

EXECUTIVE SUMMARY

The aim of the project undertaken was to conceive, design, implement and operate a prototype folding bicycle in accordance with the CDIO Initiative. A number of design considerations were to be made including fold up volume and speed, mass, and safety. This project was split into three different work packages - research, design and manufacture. Within the team of six, individuals were given the lead on each work package whilst the remaining three took up the roles of chief executive officer, chief financial officer and administrative officer. The first work package, research, was undertaken alongside the planning phase at the beginning of the project. This was immediately followed by the design phase where Pugh's Total Design methodology was employed. The first semester concluded with the finalisation of design and the procurement of necessary parts and materials. Having completed the first two work packages in semester one and procured materials, semester two was focussed on manufacture. In addition to, and concurrently with manufacture, both a detailed business plan and website were created. The project concluded with the successful manufacture of a folding bicycle as specified within the original customer contract. The final product, named "The Commuter", was built to a mass of 9.9kg, a folded capacity of 136.8cm^3, and a folding time of approximately 30 seconds. It is intended for this prototype to be assessed and raced at the regional CDIO competition at Queen's University Belfast in June 2016.

CONTENTS

1. INTRODUCTION

1.1 SYNOPTECH – THE COMMUTER

SynopTech is an innovative and contemporary manufacturing company, founded on the principals of design simplicity and efficiency. It fundamentally specialises in delivering compact products that succinctly meet the user requirements without over-complicating or over-engineering. SynopTech's flagship product, The Commuter, embodies this attitude, by delivering an ergonomic, lightweight, single-speed, folding bicycle, designed specifically for commuters. This report aims to outline the process of designing and manufacturing the prototype folding bicycle for use in an urban environment, and on public transport. Both the technical and commercial aspects of the project will be discussed, as well as an evaluation of SynopTech's management structure and organisation. In particular SynopTech was tasked with creating a prototype bicycle that minimised weight, folded volume, and folding time, while still allowing a reasonable speed to be obtained within a city environment. In addition to meeting these product specifications, a secondary requirement was introduced to compete at the UK CDIO Competition at Queen's University Belfast, where the prototype version of The Commuter will be raced and judged on the aforementioned criteria. The CDIO initiative is an international engineering teaching framework, intended as a design methodology for both system and product design [1]. It is comprised of Conception, Design, Implementation, and Operation stages, all of which were employed by SynopTech in the production of the folding bicycle. Similarly, this report will follow the general outline of the CDIO initiative, while also proposing a three-year manufacturing business plan, and marketing strategy through the SynopTech website. Ultimately, the performance and effectiveness of the bicycle will be critically evaluated, and the extent of The Commuter's success will be discussed.

1.2 BACKGROUND

As global urbanisation levels continue to grow, the resulting high population densities are producing greater congestion and increasingly stressful journeys for commuters. By far the most common method of commuting within the UK, as recorded by the national census in 2011, was by car [2]. It is estimated that of the 57.3% who take the car to work, the majority are only driving short distances and often with no passengers. Understandably there is an increasing demand, both domestically and internationally, for Governments to take effective action in tackling the adverse effects of this over-crowded culture, not least to reduce the carbon emissions and associated poor air quality in urban areas.

Certain European countries have identified the solution to this problem in a traditional technology that has been in existence for the last two centuries – the bicycle. By creating designated lanes, storage, and public transport facilities, a number of cities have encouraged the uptake of cycling as a form of commuting. Notable schemes include the 'NextBike' project, which has a rent-and-ride policy, allowing those who commute by public transport to use bicycles between stations and work places once in the urban environment [3]. While this approach can serve as an encouragement to commuters, it is also greatly limited by the availability of bicycles at commuter-specific locations, and the daily cost at the point of use. These disadvantages, suggest that personal bicycles remain the ideal solution; though the challenge now facing transport authorities, is how to improve this mode of transport for widespread public use. The concept favoured by the international community, due to its minimal impact on existing city infrastructures, is the folding bicycle. A machine capable of transporting a commuter easily across short city commutes, while remaining portable and simple to store.

Folding bicycles have a number of intrinsic advantages over the standard safety bicycle, and this is largely due to their adaptability. One of the principal ways that commuters are discouraged from cycling to work, is the lack of storage space on buses or trains. Specific bicycle bays on trains are often limited to six bicycles across three carriages, and throughout Scotland these are only available on a first-come-first-served basis during rush hour [4]. In these circumstances, the compact nature of a folding bicycle enables greater portability and use within other storage facilities on board public transport. This is also true for those who commute via park and ride schemes, as a folding bicycle can be easily contained within a car boot, precluding the need for bicycle mounts or roof-racks. The additional implication of greater portability is the reduced risk of theft, as the bicycle no longer needs to be stored outside. The National Cycling Charity estimates that as many as 381,000 bicycles were stolen in England and Wales from April 2014 to March 2015 [5], and therefore bicycle owners can have a greater sense of security knowing that the folded bicycle is stored inside, both in the office and at home. Furthermore the folding bicycle is, by nature, more convenient than traditional models, and this enables the owner to use it more frequently. This is a common argument used by the British Cycling Federation to qualify its environmental benefits, as owners are more likely to find opportunities to cycle than using fossil-fuel powered modes of transport [6]. Finally, the folding bicycle is a machine that has been designed for purpose, and so users will find it more lightweight and efficient in city traffic, than larger models, such as mountain bikes.

For these reasons, the folding bicycle has become a popular alternative for many commuters, and several bicycle manufacturers have made significant investments in this technology. Therefore the efficient design of a folding bicycle that minimises both complication and weight, is a relevant and challenging undertaking for the UK CDIO Initiative.

1.3 CDIO WORLDWIDE CHALLENGE

The CDIO Initiative is a framework which stresses engineering fundamentals within the context of Conceiving, Designing, Implementing and Operating industry-relevant systems and products [1]. From its roots as a teaching concept at Massachusetts Institute of Technology in the late Twentieth Century, CDIO has grown worldwide, and has now been adopted by over 120 educational institutions, including 11 in the UK. Fundamentally, it aims to replicate practical, real-world challenges, and therefore its introduction at an educational level intends to better prepare students for their future careers in engineering. In particular this involves equipping students to work as part of a group, and develop effective team-working skills while collaborating on a technical engineering project. Ultimately, the principal CDIO component of the folding bicycle project is to compete in the UK CDIO Competition against several other universities, including Queen’s University Belfast, and the University of Liverpool.

2. STATEMENT OF WORK

At the inception of the CDIO Challenge, SynopTech's first task was to create a contract that outlined the key project deliverables, as well as the fundamental customer requirements. While the entire contract cannot be included within this report due to its length, the following sections provide an overview of the material that it discussed.

2.1 WORK PACKAGES

The project was split into three discrete work packages in order to better define the requirements of the project, and to create distinct deliverables. In addition to defining these work packages, one group member was also assigned to lead each package.

Work Package 1: Research of current products, markets, and designs, including a survey into consumer interests and expectations.

Work Package 2: Detailed technical engineering design of a fully functional folding bicycle with a view to manufacture.

Work Package 3: Manufacturing and fabrication of a prototype model in accordance with the design developed in Work Package 2

2.2 DELIVERABLES AND MILESTONES

In addition to the work packages mentioned above, a number of deliverables and milestones were defined in order to measure progress of the project.

Deliverable	Title	Deadline
D1	Semester 1 Interim Report	20/11/2015
D2	CDIO Competition	04/06/2016
D3	Final Report Submission	18/03/2016

Table 1: Project Deliverables

Milestone	Title	Deadline
M1	Research Complete (WP1)	30/10/2015
M2	Design Complete (WP2)	11/12/2015
M3	Manufacture and Test Complete (WP3)	29/02/2016

Table 2: Project Milestones

2.3 GOAL STATEMENT

The principal objective of this project was to design a fully functioning prototype folding bicycle, in accordance with BS EN ISO 4210-2:2014, which was able to complete an urban commute from home to workplace. The bicycle must be suitable for a journey that includes the use of public transport, such as buses or trains, either by being carried or wheeled along.

The client requires that an emphasis be placed on the following design considerations. These comprise the project Goal Statement, and must be satisfied in the final product created.

1) The product mass must be minimised and is acceptable within the range of 10 to 20kg. If possible, it is desirable to keep the product weight below 10kg, and the upper limit of 20kg is set allowing for the inclusion of an electric motor.
2) The product must have a minimal folded volume that should not exceed 300 litres.
3) The product must be able to fold within a minimal time that should not exceed 60 seconds.
4) The product must be scalable to a maximum production cost of £500 per unit.
5) The product must be designed with consideration to environmental production.
6) The product must be designed to have a widespread aesthetical appeal.
7) The product must comply with the British Safety Standards contained within BS EN ISO 4210-2:2014. Many of the standards contained within BS EN ISO 4210-2:2014 require adherence to complex testing methods, a large number of which may not be practical within the scope of this project.

3. SYNOPTECH MANAGEMENT STRUCTURE

3.1 GROUP ROLE ASSIGNMENT

On completion of the initial research phase and an introductory meeting with the project supervisor, a better understanding of the required deliverables and group tasks was obtained. In order to proceed both efficiently and effectively, it was decided that the group should be divided into six clearly defined roles. The responsibilities of each role, and the associated group member are described in Table 3 below:

Title	Role Definition / Responsibilities	Group Member
Chief Executive Officer	Ensures deadlines are met and group is collaborating effectively. Makes key design decisions and organises assets. Oversees all work packages and is principal contact to project supervisor.	Christopher Barrick
Chief Financial Officer	Responsible for all financial aspects of the project including procurement of sponsorship, purchase of materials and expenses for travel to competition.	Reuben Penny
Administrative Officer	Arranges meetings, and sets appropriate timescales for the project. Organises all data storage both electronic and physical and collates all documentation for project deadlines. Provides support to design and manufacturing leads.	Paul Lang
R&D and Marketing Officer	Oversees all aspects of Research Phase and is in charge of marketing and web development.	Gloria Arcilla
Lead Design Engineer	Oversees all aspects of Detailed Design Phase	Tom McCubbin
Manufacturing Engineer	Oversees all aspects of Manufacturing Phase	Caio Dias

Table 3: Group Role Assignment

The roles were assigned at the earliest convenience and each candidate was selected by analysing their strengths and weaknesses, as well as interests. In addition, each group member completed Belbin's Self Perception Inventory (SPI), in order to identify the roles to which they would be best suited [7]. In the event that a role was sought by more than one person, each candidate was to prepare a one minute pitch, to provide evidence as to their suitability and experience for the role. A secret ballot was then conducted to decide who would undertake the position. The assignment of roles created a clear structure within the team and allowed personal responsibilities and workloads to be managed more appropriately.

3.2 RESOURCE AVAILABILITY

One of the key factors in effectively managing the group dynamic, was to assess and exploit the availability of the team's collective resources. Arguably the most important of these was the time that each group member could offer to the project. Given the diversity of courses and timetables, a poll was created to identify opportunities throughout the working week where all six members were available to meet. This produced two clearly defined weekly sessions that were ideal for meeting and ensuring that all members were updated on design decisions. In addition to these slots, it was clear from the outset that meetings would be required during weekends and evenings, so once again a diary was created to coordinate and facilitate these sessions. Another important resource that was vital to the design stage, and in particular to those responsible for the frame and steering structures, was the computational simulation software ANSYS Workbench 16.0. Due to the limited availability of university computer laboratories, it was decided that each group member should download and install the software to ensure that it was more readily accessible. This also allowed the finite element analyses to be conducted out with the University campus.

In addition, given the practical design nature of the CDIO challenge, the resources required to successfully manufacture and construct a fully-functioning prototype had to be carefully managed. One of the first tasks undertaken by the group was to ensure the availability of the mechanical labs for use between the project conception and completion. After the availability of a suitable location was agreed with the project supervisor, a storage locker was secured, which allowed the tools, materials, and parts to be properly stored throughout all stages of construction.

It was also imperative that the group was aware of the requirements and availability of the technicians and workshop mechanics, so as to make full use of their experience and expertise. To this end, a meeting was arranged with the Senior Lab Technician Chris Cameron to discuss the scope of the project and the resources available to guarantee its completion. This was a particularly useful discussion as it set deadlines for submitting technical drawings to the workshop, as well as providing a better understanding of what level of detail was required. Ultimately, the meeting helped the group to understand the availability of the technician support, and how best to make use of this valuable resource. Furthermore, the group was made aware of the capabilities and limitations of external technicians should the concept have to be outsourced for manufacture. Indeed, throughout the manufacturing phase, Mechanical Engineering technicians were consulted for advice on how to proceed with technical setbacks.

Local support was also sought from a Glasgow bicycle repair shop called Bike Station, who sponsored SynopTech throughout the project. Their key resources included an understanding of the technical and historical aspects of folding bicycles, but most importantly a skilled team of bicycle maintenance technicians who were available to provide assistance with the drive train installation and discounted part procurement.

Finally, the personal skills and resources associated with each individual group member were carefully considered when assigning roles and responsibilities. For example, one group member who studied Mechanical Engineering with Finance and had less classes during the first semester was given the position of Chief Financial Officer. This role required fiscal and financial decisions to be made, predominantly near the start of the project, such as procurement of materials and sponsorship. Conversely, one of the more practical group members, who was also largely available during the second semester, was tasked with leading the manufacturing work package. This decision was made as the manufacturing role required a larger time commitment over the second half of the project by someone with proficient hands-on skills. In this way, the availability of resources to the group was carefully considered and managed in order to optimise and exploit the available assets.

4. PROJECT TIME SCALE AND MANAGEMENT

4.1 PROJECT GANTT CHART AND TIMELINE

This project was conducted over a period of six months from the 1/10/2015 to the 18/03/2016, and so a Gantt chart was created during the planning phase in order to define clear deadlines within the project and a realistic timescale. A copy of this chart is included for reference in Appendix A. To create the Gantt chart, the project management software package Microsoft Project was used. This purpose built package allows the easy definition of predecessors whilst simultaneously defining a network flow diagram for the user. This allowed a critical path to be identified which helped structure the project. The project Gantt chart covered both semesters, though more detailed time-plans were created for individual work packages, such as Manufacturing.

By considering the different milestones, deliverables and work packages alongside the risk management document, a detailed timeline was created for the Gantt chart. One of the major considerations was the academic deadlines for project submission, by which the project had to be completed. This was the driving deadline for the second semester, around which all other tasks were organised. Likewise, it was understood that risks of part delivery delays or any problems with technician availability would put pressure on second semester work, and so the driving deadline for the first semester was to procure the majority of parts and submit technical drawings to technicians by the end of the Christmas break. This not only reduced the risks mentioned but also a number of others which are included within the following risk management analysis.

It was also understood that the Gantt chart could only approximately estimate the time required for each task, and so a degree of flexibility was also built into the timeline to allow for delays. As with any manufacturing-based project, issues and technical difficulties are inevitable when developing prototype models. Indeed, the likelihood of delays with this project were increased by the dependence on technicians and welders, as the individual group members were unable to use workshop and welding facilities independently.

4.2 SEQUENTIAL AND CONCURRENT ENGINEERING

The nature of the project and the small team size meant that the project plan was largely sequential with very few opportunities to implement concurrent engineering. This was reflected within the network flow diagram which showed a critical path that included a large number of tasks.

Though there was little opportunity to implement concurrent engineering across the broad task groups, it was possible to do so within the categories themselves. For example, within the detailed design stage the team was split into three distinct groups to simultaneously focus their efforts on different aspects of the bicycle design. The only other opportunity to implement concurrent engineering on a larger scale was during the research and planning stages with initial market research being conducted alongside project planning.

5. RISK MANAGEMENT

A thorough risk assessment was conducted prior to the commencement of the project in an attempt to identify both major and minor risks. Identification of risks allowed mitigation steps to be implemented to minimise their likelihood or consequence.

5.1 RISK ASSESSMENT FORMAT

The risks were subdivided into a number of categories for organisational purposes but also to help with identifying as many risks as possible. These categories aligned with the major stages in the project and included Research Risks, Design Risks, Procurement Risks and Manufacturing Risks. For each risk identified, the following steps were taken:

Step 1: A group member was allocated responsibility for managing the risk.

Step 2: The likelihood and consequence of the risk was rated from 1-3 in accordance with Table 4.

Step 3: The consequence rating was multiplied by the likelihood to give the overall risk score.

Step 4: Steps for mitigation were identified for each risk.

Step 5: The new likelihood and consequence were identified.

Step 6: The new likelihood was multiplied by the new consequence to give the residual risk score.

Rating	Likelihood	Consequence
1	Unlikely	Little to no impact on the project
2	Moderately Likely	Risk of causing delays to the project
3	Highly Likely	Risk of project failing

Table 4 - Risk Rating Definitions

An example row from the risk management table is illustrated in Figures 1 and 2 as a visual representation of the format. In total 25 risks were identified using this method across all categories.

Risk	Responsible	Likelihood (1-3)	Impact (1-3)	Overall Risk score
Design				
Lack of detail in initial concepts resulting in inadequate decision making	Tom	2	2	4

Figure 1 - Initial Risk Rating

Mitigation	New Likelihood (1-3)	New Impact (1-3)	Residual Risk score
Only one concept to be created by each individual to promote detail in the concept. Detailed concept generation to be encouraged including folding mechanisms and drawings of the concept before and after folding. Pros and cons of concept to be identified by individual to ensure further thought	1	2	2

Figure 2 - Mitigation Steps and Residual Risk Rating

5.2 MAJOR RISKS IDENTIFIED

The risk analysis found a wealth of risks both small and large. The larger of these risks are outlined within this section:

a) Conception of Designs beyond Manufacturing Capabilities

With a risk rating of 9, this was one of the two identified risks to reach the maximum possible rating. A number of mitigation steps including detailed research before concept generation and two feasibility studies both before and after concept generation reduced the likelihood of this occurring from a three to a one, as this would provide a practical reminder of the workshop restrictions. The consequence remained as a three, but this was deemed acceptable due to the low likelihood rating.

b) Lack of Technician Availability and Technician Delays

This was the second risk reaching the maximum of nine on the risk rating scale. It was identified as being somewhat out of the groups control; however a number of mitigation factors were identified in an attempt to reduce the risk. For example, minimising the number of parts that had to be submitted to the technicians for manufacture, and the outsourcing of any complex jobs to specialists both helped. Finally, a feasibility study with the Senior Technician Chris Cameron helped confirm whether or not the demand on technicians was acceptable or if it was likely to cause any problems.

c) Additional Large Risks

Two other risks that, even after mitigation steps, rated at 4 on the risk scale, were a lack of manufacturing experience within the group and unforeseen difficulties during manufacture resulting in a change in the design being required. Both of these were unavoidable but mitigation steps were added where possible to minimise the likelihood and/or consequence.

6. COST PROJECTION AND SPONSORSHIP

6.1 COST PROJECTION

The initial budget that was set for this design project came to a total of £600. As this was the maximum funding available from the Mechanical and Aerospace Engineering Department, it was critical that this budget was managed carefully. This task was one of the key responsibilities of the Financial Officer. A cost projection was performed after the design stage to identify which parts were to be purchased, manufactured, or procured for free from the project sponsor Bike Station as described below. Different cost projections were created as there were multiple combinations of acquisition methods that were applicable. A shared cloud-based spreadsheet was created to enable all group members to stay up to date on what purchases were made, and what the remaining available budget was at each stage.

6.2 SPONSORSHIP

The limitation of funds provided by the university added another challenge to the project, as designing and manufacturing a fully functioning bicycle prototype can be an expensive task. On top of the bicycle, funding for a trip to Northern Ireland for the competition at the end of the year also had to be taken into account. Several methods were considered, specifically looking into the use of crowdfunding or sponsorship to raise the capital that is required to complete the project. Hubbub, a student crowdfunding website, was researched in some depth while possible sponsors were also investigated.

The Bike Station, a bicycle shop in the west end of Glasgow that repairs and sells unwanted bikes, was identified as a possible sponsor. A visit was set up and after a successful meeting with the operations manager of the branch, it was agreed that they would sponsor the project by supplying the group with parts for the bicycle free of charge. In return, the group was to paint the logo of the Bike Station onto the side of the bike, and post on Bike Station's Facebook page during the official competition. For this reason, sponsorship in the form of the Bike Station supplying parts was chosen over the crowdfunding option, as it would save time and additionally they have expertise in the subject of bicycles.

Financing for the trip to the competition was also a consideration within the group. The expense of getting to and from Belfast, coupled with accommodation costs, was identified as being almost as much as the £600 budget, if not more. A meeting was therefore set up with the Head of Department, Professor Andrew Heyes, to identify if the Department of Mechanical and Aerospace Engineering would consider funding the trip, as the group would be representing the university in a competition. After a successful meeting with Professor Heyes, in which SynopTech's Executive and Financial Officers presented the case for funding, financial assistance was granted. This lifted pressure for funding the trip from the group budget and allowed higher specification parts to be sought.

7. RESEARCH AND BICYCLE BASICS

The first major component of the CDIO procedure, is to conceptualise the product, and identify spaces in the market that a unique and original design could fill. In order for SynopTech to generate relevant and practical concepts, a concentrated review into the fundamental principles of bicycle design and the current bicycle market had to be conducted. This was especially important as none of the team members had a background in bicycle mechanics. To this end a period of dedicated research was pursued by each member, and a number of books, such as Wilson's 'Bicycling Science' were studied [8]. This section outlines the key discoveries learned and outlines the basic components that comprise the traditional safety bicycle. While this information is not entirely specific to folding bicycles, many of the concepts are transferrable, and it ultimately provided a firm basic understanding upon which to build.

7.1 BRAKES

Bicycle brakes are available in two broad categories – disc and rim. The more traditional and cheaper rim breaks clamp around the forks or brake mount, thus allowing the brake pad to apply friction to the wheel rim just beneath the tyres. Disc brakes comprise a small metal disc that spins in tandem with the hub, and is capable of applying pressure to the spokes when braking [9]. Both methods of braking are operated using fixed levers on the handlebars, which in turn pull the brake cable and activates the relevant braking system. Particular care must be taken to ensure that brake cables remain tensioned and are not subject to any sharp corners during folding which may result in damage. The inner cable is generally manufactured from stainless steel, but it is a legal requirement for this to be covered by an outer coating.

7.2 GEARING

Ease of pedalling, speed and acceleration are all directly affected by the gearing system, also known as drive train. The gear ratio is a key factor when determining bicycle performance in a particular chain arrangement. This is determined using the number of teeth on both the front and back sprocket and can be expressed as a dimensionless ratio. In order to obtain the most efficient design for any bicycle the gearing ratios and attributes must be the last design constraint to be set as they are highly dependent on the overall performance requirements, such as the shape, and structure of the bicycle frame [10].

7.3 FRAME – COMPOSITION

Before the initial conception of the modern safety bicycle, the design and shape of the frame was varied dramatically and frequently in an attempt to construct the most efficient structure for the two wheeled vehicle. It is clear that the shape has seen only minimal development over the last two centuries, [8], where a triangular main frame consisting of the top tube, down tube and seat tube, is followed by a rear triangle connected by seat and chain stays. The key nomenclature of the frame components are described in Figure 3 [11] , and careful consideration was given to the stresses experienced in these members, when the frame was designed. Notably, a number of leading folding bicycle manufacturers have abandoned the down tube, and instead apply more effort to designing a structurally rigid top tube. This was an important factor considered in the development of The Commuter.

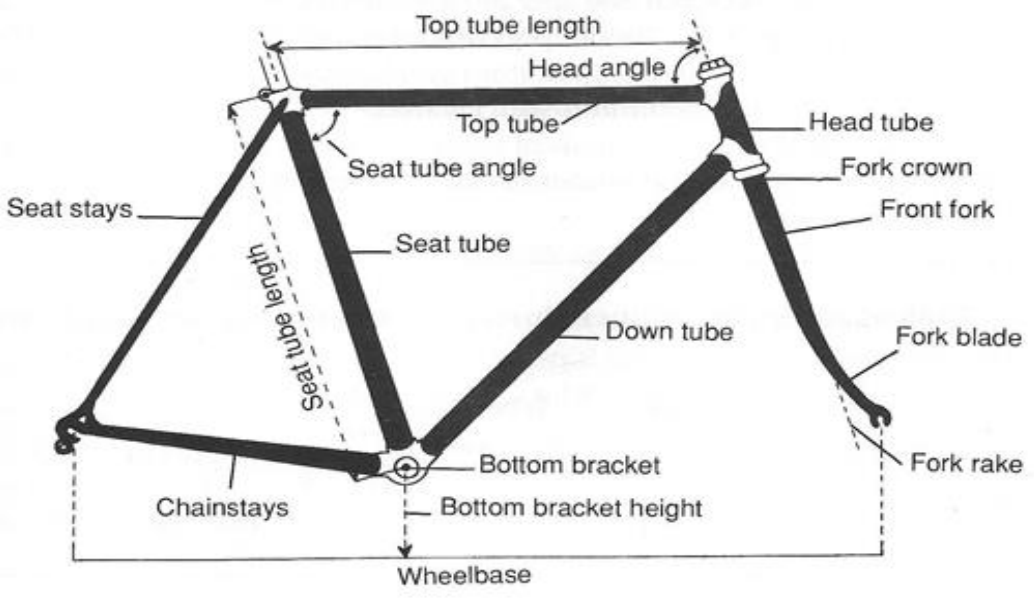

Figure 3 - Key Components of a Bicycle Frame

7.4 FRAME – MATERIALS

Carbon fibre reinforced polymer is one of the highest grade materials used in bicycle manufacturing in terms of strength-to-weight ratio; however the specialised fabrication process required, and exceptionally high cost eliminated it from likely materials to be used in The Commuter. As weight is such an important factor in the folding bicycle sector, aluminium alloys are also very popular, and in particular the alloy 6061. Although this is more expensive than steel, it is still readily available at a cost within the project budget. It is recognised however, that a thicker cross-section of tube would likely be required to provide a stiffness competitive to steel, and so this added weight could counter balance its use. The major disadvantage of aluminium is its low fatigue strength in relation to other materials. Other common bicycle frame materials, include Chromalloy, a 41xx steel alloy composed of chromium and molybdenum that has an excellent strength-to-weight ratio. When butted, and shaped to remove excess weight, it can deliver a relatively light frame that will endure through years of hard use. This concept of butting tubes to reduce weight was ultimately one pursued by the team during the design phase of the project. Another material that commonly features in high value bicycles is the expensive, though durable, Titanium. Its high tensile strength makes it suitable for use in high-quality bicycles and has been used directly in shock absorbers [12]. Once again the principal limitation to this product is its expensive cost.

7.5 FRAME – FABRICATION PROCESSES

As expected, the manufacturing process by which the bicycle frame is fabricated, depends highly on the material. For the most part, either steel or an aluminium alloy is used, and both materials require similar manufacturing processes. In fundamental terms, there are two possible ways to produce the tubes used in bicycle frames – seamless or seamed. The seamed tubes refer to pipes that have been formed by welding a single plate; whereas seamless frame tubes are constructed from solid blocks of steel that are worked in several stages, such as piercing and machining, before arriving at the final product. As previously mentioned, the process of butting is a common technique used in bicycle tubes. This involves increasing the thickness of the tube walls at the joints or ends of the tube, as this is where most of the stresses are transferred. Conversely the centre of the tube is thinned to reduce the amount of material in the section that bears little load. Notably, the tubes used in the construction of bicycles are often tapered, and as such have varying cross sectional shapes. This is most common and single spar bicycles that only have a top tube and no down tube, though it is also commonplace among seat and chain stays too. The most common methods for altering the blank bicycle tubes are hydroforming and mitring. After mitring they must be joined together and the three most common joining processes are welding, adhesive bonding and mechanical fastening [13]. In particular, the process of brazing is the most frequently used method of connecting the various tubular components. When performed professionally, brazing results in a smooth seem of filler material between adjoining tubes, and this can be especially effective for thin-walled tubes. The use of adhesives and mechanical connectors are most often reserved for carbon fibre and composite materials that cannot be readily welded due to their relatively low temperature tolerances.

7.6 HINGE MECHANISMS

A hinge is a mechanical joint that connects two solid objects, typically allowing only a limited angle of rotation between them. In terms of folding bicycles, the type of hinge can be categorised largely by their position on the frame and their locking mechanism. Hinges can be found at a number of locations on a folding bike; however only common main folds are explained in the following list:

Mid-Fold:	The traditional triangular frame often employs a hinge in the middle of the top tube which allows the bike to be folded in half.
Vertical Fold:	This style of bicycle has one or two hinges along the top tube which allow the rear wheel to fold vertically under the frame.
Triangle Hinge:	Similar to the vertical fold but involves the entire rear triangle and wheel. A hinge in the frame allows the rear triangle to be flipped forward under the main tube.
Breakaway:	Not only do these bikes fold, but they also disassemble in order to fit into an accompanying bag.

7.7 CURRENT MARKET PRODUCTS

On Tuesday 3rd November 2015, a Brompton bicycle was hired from Evans Cycles for an initial analysis of the workings of a folding bike. As well as being ridden to study ride comfort, ease of gear changing and the maximum speed that the bike could achieve, an in-depth analysis of how the bicycle folds and unfolds was completed. This examination highlighted a number of different design considerations, such as the potential use of a hub gear; reducing folded volume by compactly folding the handlebars; and minimising the thicknesses of the mainframe to optimise mass. It also served as inspiration of what could be achieved with a folding bike, as the Brompton has one of the smallest folding volumes on the market.

7.8 BICYCLE SAFETY STANDARDS

The safety standards used for this project are BS EN ISO 4210-2:2014. These standards apply to bicycles with a saddle height above 635mm and specifies both “safety and performance requirements for the design, assembly, and testing” of bicycles. [14] While a large proportion of the rules and regulations discussed in this standard could not be diligently followed, as they required specific test rigs and exhaustive experimental assessments, a condensed version of the standards was created that highlighted only the most important sections. These pertained to the generic rules of avoiding sharp edges, ensuring tightness of screws and secure folding mechanism. It also prohibited dangerous protrusions and set a standard for braking systems. The steering and handlebar requirements were also studied, alongside the rules for wheels and seat post insertion depths.

8. Market Research

8.1 MARKET ANALYSIS

Market research was conducted on over 100 individuals to obtain current market information on how the public view bicycles and transport.

The market that SynopTech is targeting with the release of The Commuter is the portion of the population that commutes to and from work, university or school through an inner city built environment. As seen in Figure 4 below, 10% of commuters consider biking to be a viable option for commuting, implying that this is the immediate market to target. However, the segments that selected 'Walking' and 'Car' as their preferred option, as much as 60% of the market, are the future markets that will emerge when cycling becomes ever more prominent.

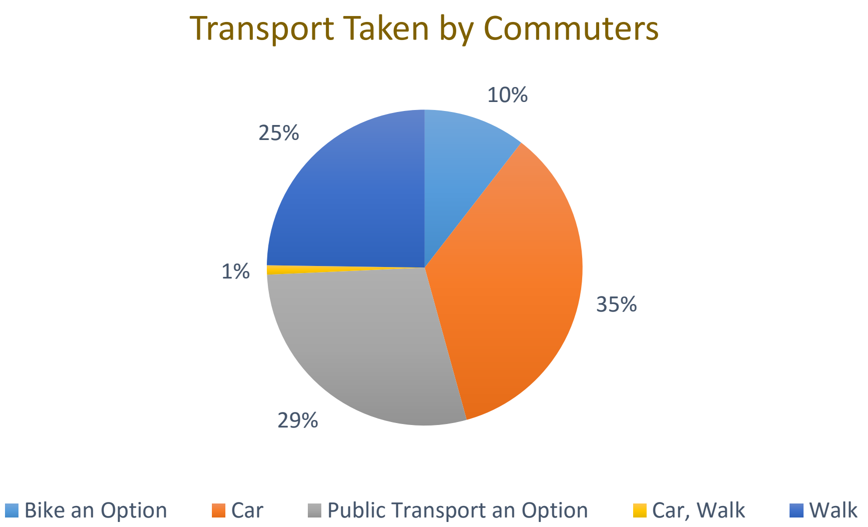

Figure 4 – Commuter's preferred transport methods

As of 2011, the current number of commuters is estimated at 26.6 million in England and Wales [15]. This means the current market for people commuting by bicycle is approximately 2.7 million people, suggesting that it is a significant and potentially growing market. SynopTech's market research also indicated the buying preferences of those who would buy a bicycle for commuting. As many as 93% of those surveyed preferred to purchase a bicycle from a chain shop rather than over any other platform (Figure 5). This gives important information for how SynopTech will go about selling The Commuter to the general public, and storefront locations will need to be considered within the business plan.

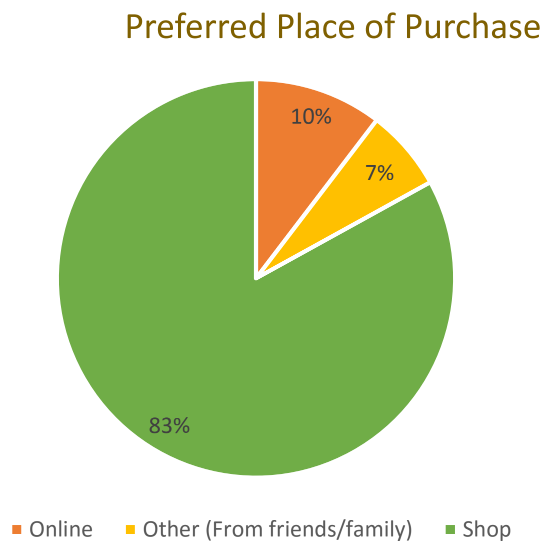

Figure 5 - Preferred Place of Purchase

8.2 COMPETITION

The folding bicycle market is busy and highly competitive, and therefore breaking into it will require excellent pricing and advertising strategies. It is largely dominated by companies such as Brompton Bicycles, Raleigh and Dahon, with the former gaining ever growing popularity due to its excellent folding mechanism and experienced design. However, it is an unexpected market dominator as the price of the bicycles range from £800 to £1200, on the upper end of the folding bicycle prices.

A lot can be learned from the way these companies advertise and set pricing models, and their mistakes can be avoided when building up the SynopTech business. A very competitive pricing strategy will ensure that the company is not forced out of the market in the early stages of the start-up, but will allow re-investment of capital to sustain growth. SynopTech will also rely on greater customer care and experience, as this has been identified as a gap in the market. Therefore, a unique selling point would involve comprehensive service and maintenance offers, and also a greater extent of personalisation of the product. This will include having numerous optional extras for customers to choose, including handlebar style, colour-scheme, and personalised decals, allowing their bicycle to be very unique.

Strong branding that enables the bicycle to be highly identifiable will also aid in separating The Commuter from the competitors in the market, and will be continued throughout all of SynopTech's future products.

8.3 PRICING

The pricing of the product is based around the market research conducted, which asked the public what they would be willing to pay for a folding bicycle to be used every day for commuting. A cost estimation graph was then generated to visualise the spread of prices that people would pay for the bicycle (Figure 6).

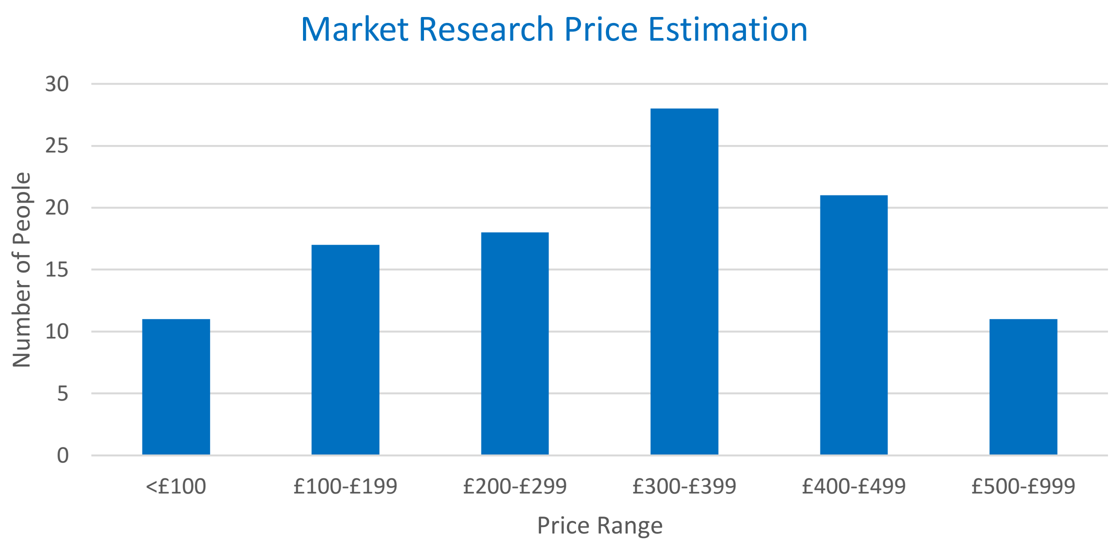

Figure 6 - Bicycle Price Estimation

Pricing The Commuter between £300 and £399 would be an ideal figure, as this would allow for profits to be generated while also offering a cheaper alternative to what is currently on the market. If the bicycle takes this pricing strategy, those willing to pay that price, and the prices higher than that will be the ones buying the bicycle. The total number of people who did responded to the survey was 106, and the number of people who would pay in excess of £300 for the bicycle was 60, meaning the percentage of the population who would be willing to pay the price of The Commuter would be 56.6%. Assuming the survey is representative, this is a considerable initial percentage of the market. Thus, compounded with the expectation that this number will expand as the brand grows in strength and recognition, a considerable market is foreseeable.

Accounting for this, an initial ball-park figure for the price of The Commuter was set at £380, though it is understood that this will be altered on final evaluation of the prototype and completion of the business plan. This price will be the initial market price, but continuous monitoring will ensure that the business can continue to operate at a profitable level.

8.4 FULL MARKET ANALYSIS

The full results of the questionnaire and a comprehensive review of the market analysis can be found in Appendix B, at the end of this report.

9. PRODUCT DESIGN METHODOLOGY

Stuart Pugh’s Total Design model was identified for use throughout the design phase. It was hoped that identification and use of a specific methodology would add structure and direction to the team’s effort during the design phase. Pugh’s Total Design was selected as it has been used before by a number of group members and has also gained a reputation as an extremely successful procedure within the design discipline. The following list illustrates a high level overview of the methodology adopted in the design of The Commuter.

9.1 STEPS FOR CONCEPT GENERATION AND SELECTION

Step 1: Generation of a Product Design Specification (PDS).

Step 2: Each group member was to create a concept for the frame design and folding mechanism, listing the advantages and disadvantages of each concept.

Step 3: A controlled convergence matrix was to be formed and used to identify the best concept.

Step 4: All disregarded concepts were to be analysed to identify advantages, and all relevant transferrable attributes to be incorporated into the final chosen concept.

9.2 STEPS FOR DETAILED DESIGN

Step 1: The group was to be split into specific areas of design to try and improve the chosen concept with ideas from other concepts and previous research. These areas include the drive-train, frame, and steering sections.

Step 2: Useful features from unsuccessful concept were to be identified.

Step 3: The scope of the group and how it integrates with other groups using the Design Connectivity Map was to be defined.

Step 4: Detailed analysis was to be performed as appropriate such as FEA/Optimisation.

Step 5: Construction materials to be specified.

Step 6: An approximate cost analysis, including delivery prices was to be performed.

Step 7: Each sub team was then to complete and sign off the final part design and safety analysis with the Design Lead; the manufacturing process with the Manufacture Lead; and the costing analysis with the Financial Officer; before finally getting the Executive Officer to sign it off.

9.3 STEPS FOR DESIGN HAND OVER

Step 1: Once the design was signed off, each part was to be drawn within the CAD software PTC Creo, and all technical drawings were to be produced by the sub-team responsible.

Step 2: Once all of the above steps had been performed the Project Manager was to sign-off and the group could proceed to procurement and booking technician time.

10. CONCEPT GENERATION AND SELECTION

10.1 PRODUCT DESIGN SPECIFICATION

In order to progress the project from the research phase into the design phase a product design specification (PDS) was required. The PDS includes several constraints and aims initially identified by the group through individual research, the CDIO competition brief, and the contract agreed with the project supervisor. This PDS was then used to aid concept generation and start the design phase of the project. Notably, the Convergence Matrices used in later selection processes, made use of this PDS to rate the concepts on how well they met the project criteria. The full PDS for the folding bicycle is included at the end of this report in Appendix C.

10.2 CONCEPT GENERATION

Once the PDS and research had been compiled and read by each member of the team, the conception phase, which represents the first step of the CDIO process, gathered momentum. In order to begin Work Package 2 and identify the best basic frame design and folding mechanism, each group member was asked to produce a concept of what they thought to be the best approach to the project. In order to get several different design proposals this task was done individually with only the PDS shared between the team. This left each group member free to design anything from an adaption of an existing folding bicycle to a completely new innovative design. Due to the groups even spread of personalities this approach worked extremely well with seven separate concepts being produced as can be seen in Appendix D.

In the initial concept briefing meeting, it was decided that a group hybrid concept should be produced. This decision was made as it was thought that there was an opportunity to exploit the groups combined knowledge and ideas alongside a folding method which was not addressed by any concept created individually. This hybrid design was included as Concept Number 8. The advantages and disadvantages of each concept, as identified by the team member responsible for that concept, can be seen in Table 5.

Concept Number	Advantages	Disadvantages
1	Simple, Fast Fold	Fold-up Volume
2	Fold-up Volume	Manufacture, Safety
3	Originality, Aesthetics	Safety, Manufacture
4	Performance, Safety	Fold-up Volume, Heavy
5	Fold-up Volume, Safety	Originality, Manufacturing
6	Fold-up Volume, Simple	No. Hinges, Safety
7	Manufacture, Cost	Fold-up Volume, Weight
8 – Group Hybrid	Fold-up Volume, Weight, Safety	Manufacture

Table 5 - Advantages and Disadvantages of each Concept

10.3 CONCEPT SELECTION

In order to determine which concept would provide the basis for the detailed design, a concept convergence matrix (CCM) was used as can be seen in Figure 7. The screenshot shows the initial CCM performed using the eight attributes from the product design specification as scoring criteria. Each criteria was weighted from 1 to 3 depending on the perceived importance that each would have on the final design decision. For each attribute the concepts were rated from 1 to 8 with the best concept being given a score of 1 and the worst a score of 8. In order to get the total score for each concept the rating was multiplied by the weighting of the relevant criteria and all 8 scores summed.

Attribute	Weighting (1-3)	Concept Generator							
		1	2	3	4	5	6	7	Group Hybrid
Cost	3	7	4	2	6	1	8	5	3
Weight	2	5	1	6	3	7	4	8	2
Performance	2	3	5	8	6	2	7	1	4
Aesthetics	1	6	2	7	3	5	4	8	1
Safety	2	8	2	7	6	5	3	4	1
Fold up time	2	4	5	2	6	7	8	1	3
Ease of manufacture	3	6	1	3	5	2	8	7	4
Fold up Volume	2	5	7	4	3	8	2	6	1
	Total	95	57	76	84	72	100	84	44

Figure 7 - Concept Convergence Matrix, Round 1 Scoring

Once the round had been scored the two highest scoring concepts were eliminated from proceedings and the process was reinitialized with the remaining concepts. This eliminated any scoring anomalies produced by the weaker and now disregarded concepts. A total of three rounds were performed and after the analysis, it was found that the group hybrid concept, Figure 8, was the winner to be taken forward into the concept development stage. Although the CCM was used to determine which concept had the best overall design it also highlighted some flaws with the chosen concept. From the final round three matrix it was found that the chosen concept especially required attention within cost and ease of manufacture sectors. Several ideas could be found on how to improve these flaws within the concepts that scored lowly in these categories.

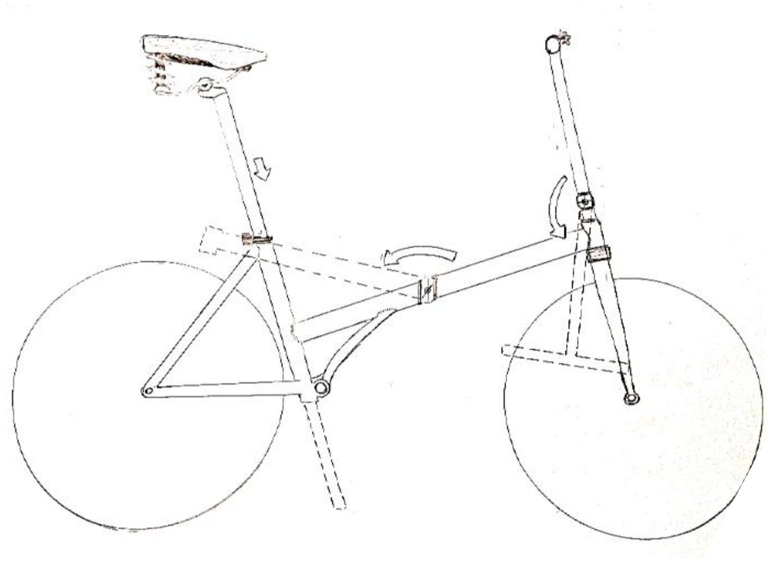

Figure 8 - Final Chosen Concept

The final concept was comprised of a total of three distinct folds. The first involved a rotation of the handlebars and steering column to align with the front wheel; the second was a pivot around a hinge in the top tube that would align the axles of the wheels; and finally the seat-post was intended to drop through the seat tube and act as a stand when in the folded position. Although this was an arguably unoriginal design, it was understood that a unique latching mechanism and handlebar rotation would provide a novel ad attractive product. Furthermore, there was a need to balance originality with competitive effectiveness, and the majority of bicycles with a mid-fold along the top tube were proven to have the smaller folded volumes.

10.4 DESIGN CONNECTIVITY MAP

After concept selection and prior to commencing the detailed design stage, a design connectivity map was created. The aim of this map was to help gain an understanding of the highly interconnected relationships between different parts of the bicycle and to create a visual representation which could be quickly and easily used for reference. Undertaking this activity encouraged the design team to think about the concept in much greater detail and to identify potential problems that had not been realised in the concept generation and selection phases of the design. The key structure of any bicycle, fixed or folding, is the frame which acts as a link between all the systems. For the purpose of this design project, the frame was split into a number of sub-parts which formed the centre of the map as can be seen in the design connectivity map found in Appendix E. The frame can therefore be seen as the core system from which a number of sub-systems branch off. To date, the design connectivity map has proven very useful and has been used regularly by the team to check what other components would be influenced by a design change. It provided an easy reference during the detailed design phase to see where dependencies lie within the design. The connectivity map also encourages collaboration in a meaningful way as each member can easily identify which other members they must communicate with when working on each part.

11. DETAILED DESIGN – FRAME

11.1 DETAILED DESIGN APPROACH

Due to the tight timescale of the project, the concept selection process needed to be performed as soon as possible in order to start progressing with the detailed design. The main characteristics of the chosen bicycle concept include a single member directly connecting the front steering column and the seat tube. The hinge is centrally located in the aforementioned member so as to fold the bike in half, with both wheels to be axially aligned after folding. The bottom bracket through which the pedals and forward gear hub connect, was moved forwards in order to allow the seat tube to drop all the way through the frame. In terms of sizing, the final vertical frame height between the ground and top tube is approximately 0.5m. Some simple trigonometry revealed a required bottom bracket height of 0.25m so that the safety standard regarding pedal-ground-clearance was adequately met. This frame design took into account many different qualities such as folding time, ease of fold, ease of manufacture, rider comfort and critically the final folded capacity.

In order to deal with such a large design, the bicycle was subdivided into three distinct sections; namely the frame, the drive train, and the steering column. Under the direction of the Lead Design Engineer, SynopTech was split into these three factions to concurrently design all aspects of the bicycle within a short timescale. To further improve productivity, the Frame Sub-team was then sub-divided again into three principal sections involving the Rear Triangle, Main Frame, and Hinge Mechanism.

11.2 MAIN FRAME

This is the largest section of the bicycle and is usually also the heaviest. It was important to design the shape and the size of the top tube and seat tube in order to make the bicycle not only aesthetically appealing but also sufficiently stiff and light weight. A finite element analysis was used to identify optimal shapes, materials and thicknesses. The top tube was created in Autodesk Inventor 2016, as shown in

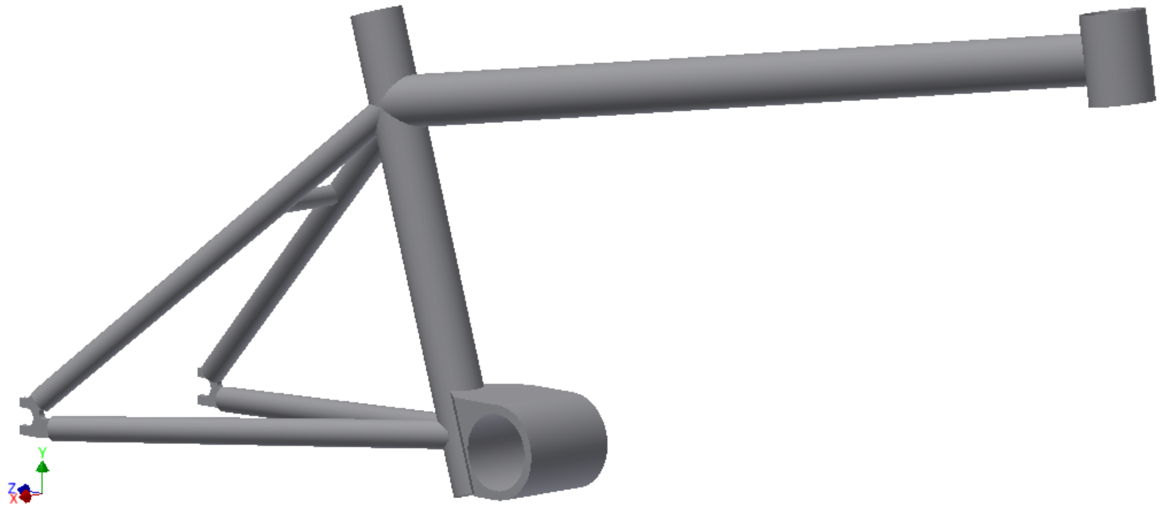

Figure 9 – Final Frame Design

Figure 9. However it was necessary to assume an average rider size before it could be fully dimensioned. To accommodate a rider of medium height, 1.65m to 1.75m, the length of the tube was set to 0.54m based on sizing tables within D. G. Wilson's Bicycling Science Textbook [5]. In addition, the angle formed by the seat tube and the horizontal was to be varied between 71 and 74° to ensure an adequate and comfortable handlebar-reach. Furthermore, the initial models included a head tube angle that was perpendicular to the ground, as this fixed the position of the steering column and handlebars and by extension it set the distance between the front and rear wheel. Initial dimensions for the tubular cross-section of the frame were set based on measurements of the Brompton bicycle during the research phase. These include, an outer diameter of 33.8 mm, an inner diameter of 28.8 mm and therefore a thickness of 2.5mm. These values provided an initial estimate for the ANSYS model, and were altered after the analysis and optimisation processes were complete.

In the majority of traditional bicycles, the crankshaft is attached via a circular tube welded directly across the bottom of the seat tube. However, as the chosen concept required the seat post to drop entirely through the seat tube, attaching the crank shaft in this location was not possible. Instead, the tubular section through which it was to be connected, had to be offset from the seat tube, and this demanded a cantilevered housing for support and to attach it to the rest of the frame. For this reason the bottom bracket housing was one of the key components of the bike that enabled the seat post insertion to minimise folded volume. However, it did require detailed design due to its cantilevered nature, as it was therefore a likely location for stress concentrations to develop. While initial sketches had included a supporting spar connecting the bottom bracket to the top tube, this was omitted from the ANSYS analysis in an attempt to save weight.

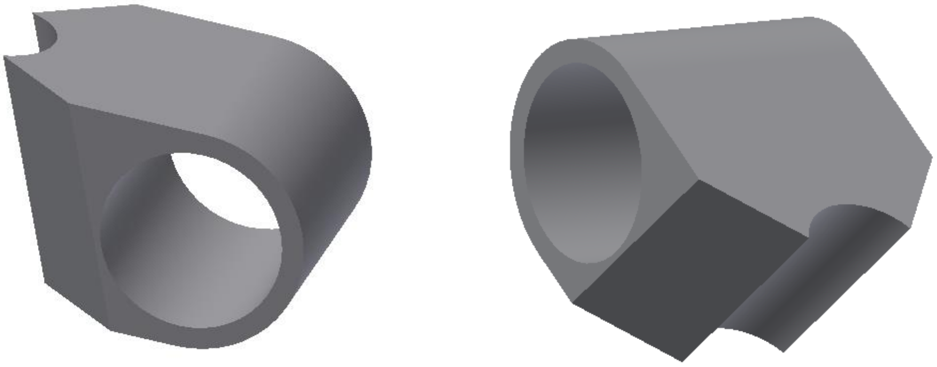

Figure 10 - Bottom Bracket Housing

To this end, the smallest available crankshaft hub was sourced and a bottom bracket shell was purchased. This shell was machined to include the specific threads required by the crankshaft, and the intention was to punch the shell directly into the bracket, to avoid issues with the commercially specific thread. The shell had an external diameter of 42mm and a width of 60 mm. These were the driving dimensions use to set the size and shape of the bracket. Given the offset angle of the seat tube to the horizontal, the curved surface that was to be mated on the bottom bracket had to be machined at a precise angle. Therefore it was understood from an early stage that this component would have to be manufactured by one of the laboratory technicians.

The key advantage of the curved design was that it would allow a large surface area for welding the bracket into place. This was a critical consideration as the bracket had to be securely attached to the frame. Despite the best efforts to reduce the size of the bracket, the fixed shell dimensions ensured that the bracket was a heavy and substantial structure, which introduced difficulty when attempting to reduce the weight. Another setback in this respect was with the material and chosen manufacture process, as this component had to be machined from a solid block of mild steel. Ideally, a shell structure would have been designed from steel plates;

however, given the requirement to be accurate with the angles and the limited resources within the labs, it was decided to proceed with the single block approach. It was for this reason that more angled sections were removed from the bracket to minimise as much mass as possible.

11.3 REAR TRIANGLE

This section connects the rear wheel to the seat tube and has to withstand some of the largest loads as it supports the rider's weight. As is customary for most small framed bicycles, it was decided that this would be formed of thin tubes, using finite element analysis in order to reach ideal sizes, and thicknesses.

The rear triangle design was created in PTC Creo Parametric 3.0 with dimensions set in accordance with the main frame and assuming a 16in rear wheel. As can be seen from the overhead perspective in Figure 11, the bottom tubes (chain stays) are straight while the upper tubes (seat stays) have a more curved design to ensure that the attached dropouts are parallel to the rear wheel axle. This has also been sized with the consideration that the chain will have to pass in between the seat and chain stays and so an adequate clearance has been allowed. The side-on view highlights that the traditional bicycle triangular design is kept, as this is proven to maintain

Figure 11 – Rear Triangle Design

stiffness within the structure. It is understood that all angles used in the design have an associated accuracy that may not be replicable in the manufacture phase, particularly for welded members. In order to initially identify how the chosen concept frame design would act under loading, a simple ANSYS model was produced. Initially a very rough estimate of dimensions was sketched and transferred into the Design Modeller component of Workbench. Once the model had been assembled a basic mesh was created and the standard mesh sensitivity analysis performed before the boundary conditions were applied. Specifically these were to constrain the back wheel with a pin joint, the front wheel with a roller joint and to load the saddle appropriately with typical loads as suggested by Max Glaskin, in his book Cycling Science [16]. This involved the average mass of a 70kg rider exerting 35 % of their weight through the handlebars, with 45% on the seat tube and 20% on the bottom bracket, as an approximation for the pedals. Once the analysis had been run a number of times to accurately refine the mesh the following deformation plot was obtained, as illustrated in Figure 12.

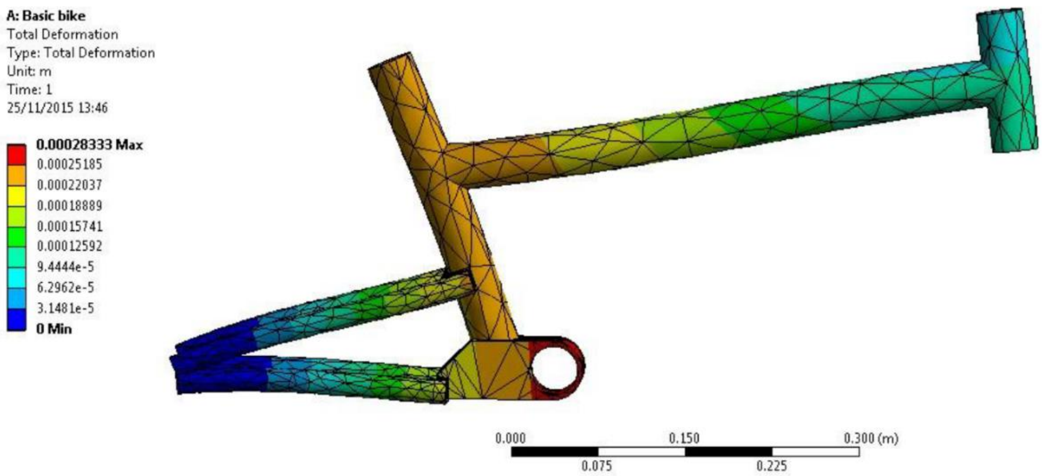

Figure 12 – Preliminary Simplified ANSYS Analysis

This simple analysis indicates that the fundamental design was acceptable to take forward albeit with more refined shapes, dimensions and alterations, as admittedly this simplified model included generous wall thicknesses. The main consideration identified from this analysis was the potential need to limit displacement around the bottom bracket through the use of an additional spar that linked up to the top tube. A more rigorous and comprehensive ANSYS analysis was performed on the final design, as described later in this section.

11.4 HINGE MECHANISM

This is one of the most important components of any folding bicycle and can often provide a distinguishing characteristic to the model. Within the bicycle, two hinges were required, one on the steering column and another on the top tube. In the interests of consistency, it was decided that both of these fixtures should be identical in their operation. Market research had identified that there were many different types of latches used in folding bicycles, however in the majority of cases these involved specifically cast components that screwed tight or had built in spring elements.

Ultimately, what was desired from the hinge assembly was a component capable of effectively transferring the loads, with an easy and simple to use mechanism. For this reason a simple pivot levered latch was investigated, as it was understood that these could be purchased to withstand heavy duty loads. In terms of mounting the latch, it was decided to make use of angled mild steel sections on either side of the hinge. On one face, only a small section of the angle would be welded, allowing the catch to be fixed perpendicular to the hinge. Likewise, on the other face, a larger section of the angle would be positioned to accommodate the lever. Heavy duty hinges were also sourced that could withstand loads up to 300kg. The full CAD assembly model is illustrated in Figure 13.

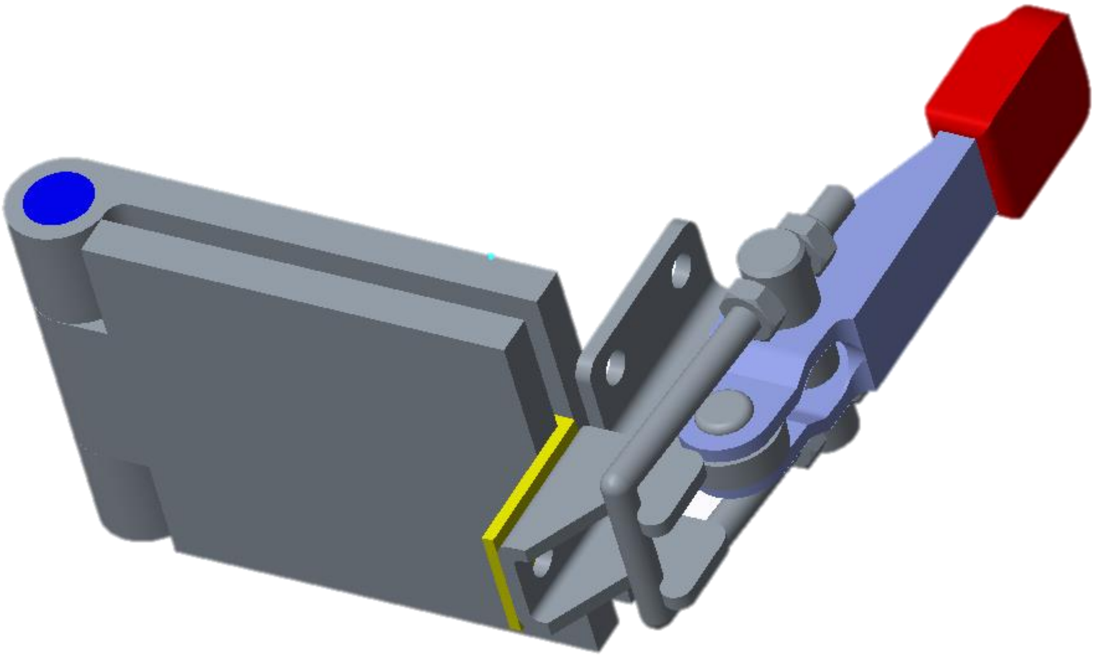

Figure 13 - Hinge and Latch Assembly

11.5 DETAILED FINITE ELEMENT ANALYSIS

A detailed Finite Element Analysis of the bicycle structure was then completed to ascertain the stresses that the bike frame would be under, and to use as a decision tool for choosing grades of steel tubing. A simplified bicycle frame model was used in the analysis, as the number of elements available was limited due to limited licencing. The analysis completed was a simplified static structural analysis to simulate the effect of a person sitting on the bicycle.

ANSYS Workbench 16.0 was used to complete the FEA of the bicycle frame under these conditions. Before any simulations were run, the properties of several grades of steel tubes, available from sourced suppliers, were imported into the Engineering Data Tables. This was done so that the different steel grades could be assigned in different simulations. The material used in the rear dropouts and bottom bracket was different from the tubes, so mild steel properties were assigned to these parts.

a) The Model

There were element limitations imposed on the frame due to licences having a set number of elements available for analysis, and so the model was slightly simplified. One benefit to this was the reduced running time of the program, due to the smaller number of elements, which saves on computational time spent in laboratories. It was also for this reason that the FEA model was simplified so it did not include the

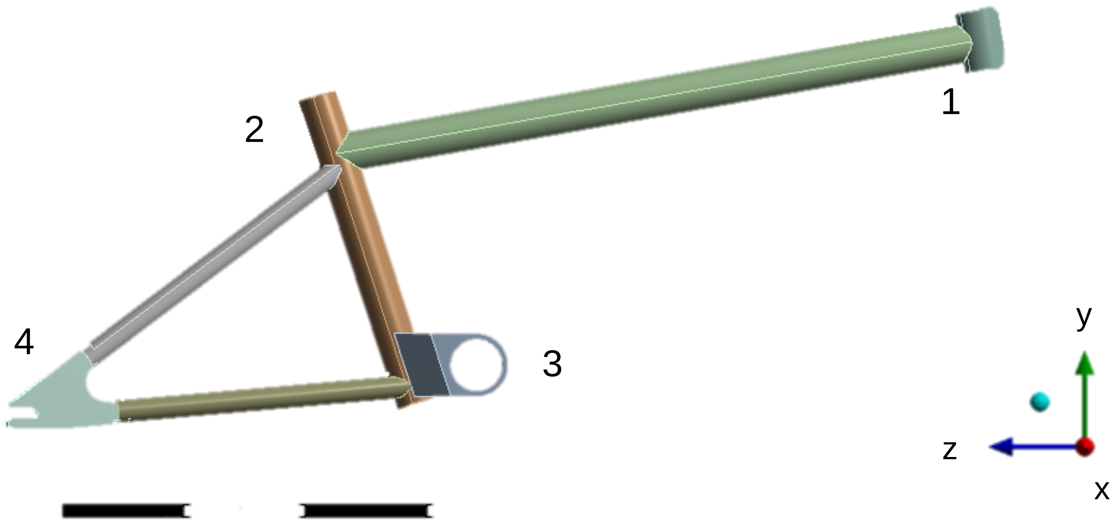

Figure 14 - Simplified FEA Model

handlebars or front fork. However, careful placement of forces and supports on the model mitigates the errors produced by not including those parts in the model.

There were four key areas of the bicycle frame to consider. The first (1) is the attachment of the handlebar to the mainframe through the headset, which is assumed to be the inside area of the head tube. This area will either be under forces from the moment arm of the handlebars or will be a constraint from the wheel and front fork. The second (2) is the area of the frame in the inner area of the seat tube which holds the seat post. This area was used to simulate the forces created by a person sitting on the seat, and having their weight transferred through the seat post, onto the seat tube. The third (3) is the area where the crank arm of the bicycle will go through, which is the circular inner area of the bottom bracket. This area was used to apply forces which occur due to the pedalling motion of the person riding the bike. The final area of interest when setting up the model (4) was the connection from the rear dropout to the frame. This was used as a fixed support area as there should be no movement of that part with respect to the frame due to it being directly connected to the ground through the wheel.

b) Sitting Scenario – Static Structural Analysis

The analysis consisted of simulating a person of weight 910N, sitting on the bicycle seat with their hands on the handlebars and feet on the pedals. The distribution of the forces and supports was as described in Table 6.

Part Name (Number)	Support/Force	Value (N)
Head Tube (1)	Z-direction Support / Downward Force	315
Seat Tube (2)	Force in direction of seat tube	405
Bottom Bracket (3)	Downward (Y-direction) Force	180
Rear Dropouts (4)	Fixed Support	-
	Total Force	900 (91.8 kg)

Table 6 - Force Distribution and Supports

The directions in the middle column refer to the co-ordinate system shown in Figure 14. Just under half the weight is situated on the seat, with a third on the handlebars and the remaining on the pedals of the bike. Using these forces the analysis was run, and parameters such as displacement and stress were set as outputs.

c) Results

The results from the analysis showed the greatest stress concentration was in the connections between tubing. This is understandable, as it is the point where the material is at its smallest thickness and the change in direction acts as a stress raiser. It was initially thought the greatest stress would occur in the connection between the stays and the dropouts, but due to the dropouts being of a higher grade steel than the tubing, they experienced smaller stresses.

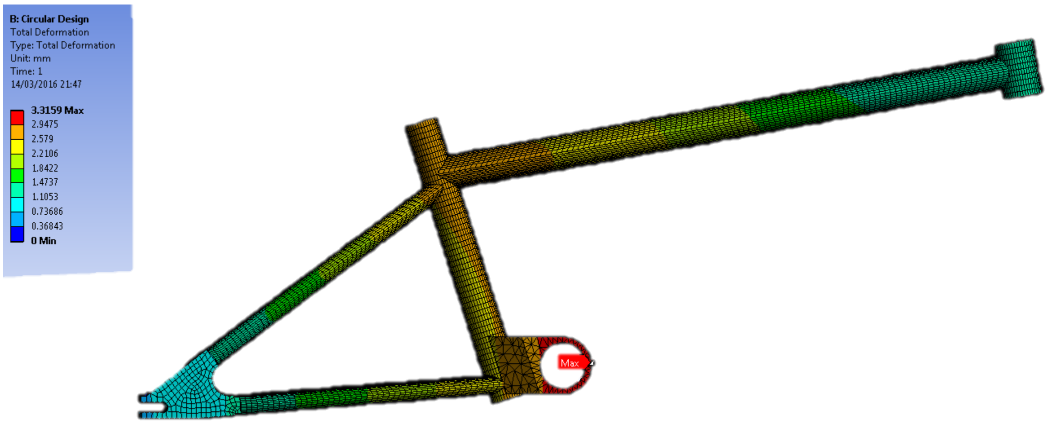

Figure 15 - Total Model Deformation

In Figure 15, the total deformation of the model is shown. What can be seen is that the highest amount of deformation occurs in the bottom bracket. This could be because of the flex in the bicycle rather than the bottom bracket itself bending.

One area of concern is the bending that occurs in the top tube, as this is the longest tube with a constant cross section. As can be seen from Figure 16, the deformation in the Top Tube is around 2.7mm, at the end that connects to the seat tube. This is not a great amount of deflection in the bike, but considering the addition of a hinge in the final prototype, it might necessitate an additional supporting spar between the bottom bracket and top tube.

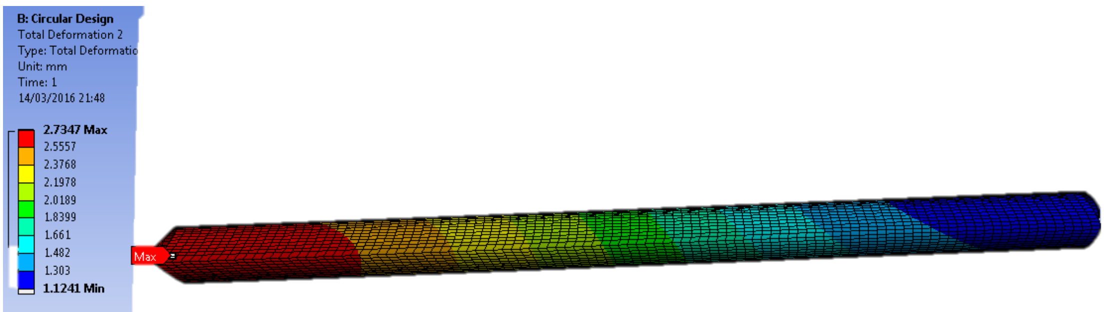

Figure 16 - Top Tube Deformation

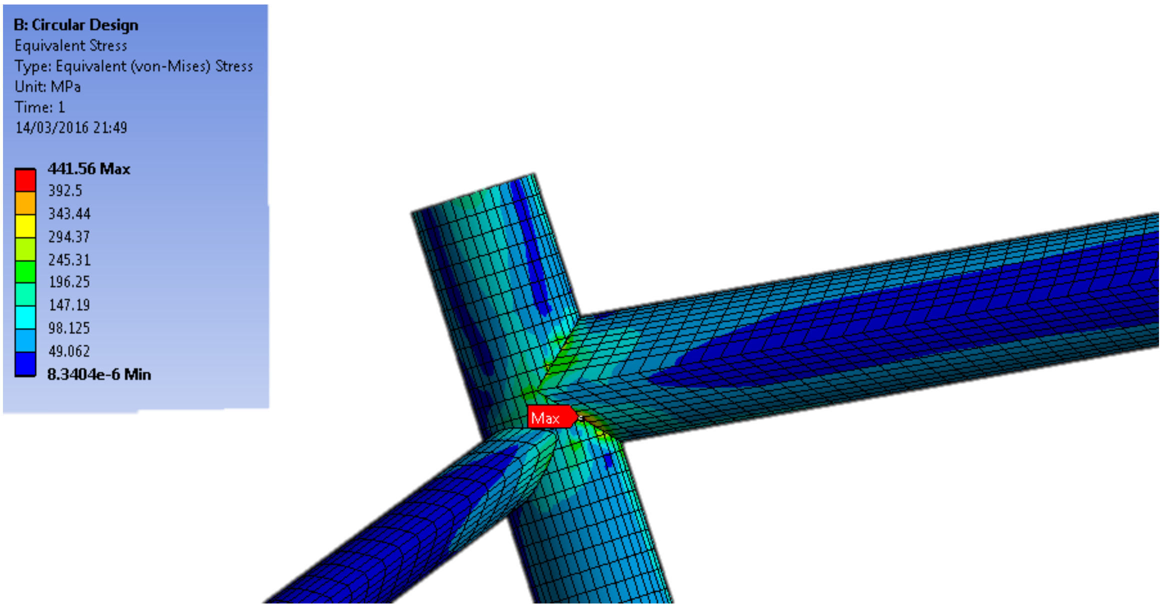

Figure 17 - Location of Highest Stress

The final point of note, is the location of highest stress in the system, as this will give information as to whether the bicycle can withstand these forces, and if it fits into the chosen factor of safety. The highest stress in the model is approximately 440MPa, which is lower than the Ultimate Yield Strength of Reynold's Tube Supplier's weakest steel (Grade 525) with a value of 600MPa [17]. This would leave a Factor of Safety of 0.73 for the model, on the basis that the lowest grade steel tubing is bought and used in the bicycle, and this was deemed acceptable.

12. DEATAILED DESIGN – DRIVETRAIN

Although this project was open to designing a bicycle entirely from procured materials, the initial decision was to purchase the complex drivetrain components such as gearing and braking systems. There were many reasons for this, including the complexity, tight tolerances and manufacturing requirements of these specific parts which could be considered a project in their own right. Furthermore, the securement of sponsorship from Bike Station meant that these normally expensive parts could potentially be acquired free of charge. The final reason for using parts from major bicycle manufacturers' was the associated simplification in the manufacturing process due to the use of standardised components and fitting procedures.

The key additional challenges and drivetrain considerations include the management of cables at hinge mechanisms and ability to maintain chain tension during folding. Each of these design challenges has been considered in depth to relieve any potential issues during the manufacturing phase.

12.1 GEAR RATIOS

Once the detailed design phase was nearing completion, a gear ratio analysis was done. The main alternating factors relating to the ratio were wheel size and performance requirements. The prototype was designed specifically for the regional CDIO competition where a speed test was assessed; however for the purposes of the business model, the design was required for a city commuter that required less top speed but an easier pedal motion. Therefore, two gearing ratios were discussed, both of which contained one main chain ring and 3 sprockets on the rear wheel, changed by either a hub gear or derailleur system, thus creating a 3-speed bike.

$$Gear\ Ratio = \frac{Total\ Teeth\ on\ Chainring}{Total\ Teeth\ on\ Sprocket}$$

Equation 1

The following data contained within Table 6 shows the amount of teeth that each ring/sprocket would have and the relevant gearing ratio.

Configuration	Teeth				Gear Ratio		
	Chain Ring	Sprocket 1	Sprocket 2	Sprocket 3	Sprocket 1	Sprocket 2	Sprocket 3
Commuter	38	15	20	28	2.5	1.9	1.4
Prototype	38	12	17	24	3.2	2.2	1.6

Table 7 - Gear Ratios for Selected Configurations

12.2 ADDITIONAL CONSIDERATIONS

Furthermore, the possibility of buying optional extras was investigated in order to improve performance, safety, and minimise weight after purchasing the prioritised frame components. Although the decision was made to go with the second-hand drive train components, due to the reasons listed above, should the budget, time and manufacture process allow there were further ideas that would be beneficial to be incorporated into the design as listed below.

a) Hub Gears

Using a hub gear system where the gearing system is incorporated within the wheel hub has many benefits for a folding bicycle used for a general commuter. Initially hub gears use significantly smaller space than a derailleur system which is key when trying to minimise fold-up volume. They also eliminate several chain crossing and maintenance issues as there are no combinations and derailleurs to consider, therefore making the system more reliable. Due to the lack of crossing between sprockets and chain-rings there is the possibility of using a Kevlar belt and plastic cogs which could potentially minimise the ‘dirty’ components of a traditional system such as oil, and this ‘clean’ product is ideal for The Commuter. Although these advantages are extremely relevant to the project, there are several drawbacks to hub gears. The most important is that these gears can be of a similar weight to a standard, much cheaper, derailleur systems. These gears are also built into the wheel hub and are very complex so in order to have success the correct gearing ratio and wheel size would have to be purchased.

b) Carbon Components

Carbon-fibre drive train components could be extremely beneficial for the prototype bicycle as minimising mass is a key element of the product design specification.

These components do the exact same job as traditional aluminium or steel components; however they provide a significant weight reduction from the total bicycle mass for an equivalent strength. Although this concept appears to be extremely beneficial, it is extremely expensive, and therefore regarded as an optional extra, reserved for some potential components after a full budget analysis for the cost of essential components is complete.

c) KERS / Electric Motor

Although the option of an electric motor was explored in initial research, it is another component that is regarded as an optional extra. An electric motor or a Kinetic Energy Recovery System (KERS) would give instant performance improvement, consistency and safety for commuters in heavy traffic on an uphill street. However a KERS or electrical motor has similar downfalls to the other considered extras in that they are very expensive, heavy, and cause severe difficulties during manufacture due to the additional components.

d) Disc Brakes

The least significant extra option to be discussed in this section is the possibility of using disc brakes. These would maximise user control during braking, which is essential during commuting in a busy urban environment however due to the use of small wheels in our design this advantage over traditional hub braking systems is negligible. Also traditional braking systems are less expensive and easier to manufacture whilst having similar weight to a disc brake.

13. DETAILED DESIGN – STEERING AND WHEELS

The steering column and wheels present a unique challenge for the design of a folding bicycle. In many ways, the size of the wheels limits the folded capacity of the bicycle, while the handlebars and steering post represent the largest volume held at the furthest distance from the frame. When considered both together, the choice of components and folding mechanism is critical to minimising the overall folded volume.

13.1 WHEELS

Before either the frame or steering column could be accurately sized, the dimensions of the wheels had to be confirmed, as this would allow other aspects of the design to progress. Market research identified the predominant wheel diameters on commercially available folding bicycles were within the range of 16in to 20in. Therefore the trade-off lay between the smallest folded volume; the improved handling and turning circle; and the relatively high power and speed delivered by a bicycle with larger wheels. After researching and testing the 16in Brompton from Evans Cycles, one of the leading folding bicycles on the market, it was agreed that reducing the folded capacity was not only in line with the requirements of the CDIO initiative, but also met the increased portability standard which was a key selling point in the group’s commercial model. Therefore, the decision was made to design the bicycle with 16in wheels.

13.2 HANDLEBARS AND UPPER STEERING COLUMN

Within the forward steering section of the bicycle, two important objectives were considered; namely the ability to compactly and simply fold the handlebars within the span of the wheels, and secondly to design an innovative means of reducing the volume. A number of different concepts were considered that were capable of achieving the first outcome, though the process of a controlled convergence matrix was successful in identifying the definitive folding mechanism. The chosen concept, involved a set of handlebars that were free to rotate 90^o about the top of the steering column, and could be locked into the steering position with a spring-loaded bolt. After a translation of 90^o, so that the handlebars were aligned with the top tube, a standard locking hinge, located just above the headset, will enable the entire top section to drop down in front of the wheel. This fold can be made prior to splitting the main frame, and therefore the handlebars would be contained between the front and rear wheels when fully folded. The detailed analyses required for this design include the forces translated through the steering column and hinge via the handlebars, and identifying suitable materials and thicknesses for the appropriate members. It was assumed that the pivot hinge used in the top tube of the main frame would also be used to fold the steering column and for this reason, the ability to rotate the handlebars to align with the wheel was predominantly considered. This mechanism was key to the compact folding volume of the bicycle, but foremost had to be designed for safety, as a failure in the locking mechanism could result in the rider's loss of steering control. Moreover, the component that is used to lock the rotation of the handlebars, must also be responsible for transmitting the turning motion to the steering column, and so the design has to be significantly robust. The conceived solution involved the use of a spring loaded bolt attached to the underside of the handlebars as indicated in Figure 14.

The handlebar tube was to be directly welded to a small diameter tube intersecting perpendicularly at the centre of the bars to form a T-section. This smaller tube would then be inserted concentrically, inside the larger tube that is the upper portion of the steering column. The tolerance between the upper steering column and insertion tube will be maintained tightly to ensure a smooth rotation of the handlebar T-section within the steering column. A series of holes would then be drilled within both concentric tubes to accommodate a spring loaded bolt. The bolt which can be as thick as 10mm in diameter would then lock the T-section and steering column in place and transmit any turning force. When the handlebars are to be folded, the spring bolt lever will be pulled back, thus allowing the T-Section to be rotated 90$_o$, before the bolt is released locking the section in line with the wheels.

In order to attach the spring loaded bolt to the handlebars, a deviation from traditional bicycle shapes is required. The spring loaded bolt has a flat surface with

Figure 18 - Assembly of Upper Steering Column and Handlebars

pre-cut bolt holes, however this requires another flat surface in order for the fasteners to be secure. As traditional circular handlebars cannot provide this surface, a hollow tube of ovular cross-section was sourced that had a flat section with two round edges. This enabled the spring loaded bolt to be mounted directly to the handlebars, but also maintained the curved surfaces that are important ergonomic features when gripping the bars. Ultimately, this bolting method should satisfy the prototype fold; however it is likely that the spring loaded bolt would be contained and concealed within the handlebar tube for aesthetic reasons when preparing the business plan and a commercially available model.

There were a number of complications that arose due to the choice of handlebars, such as the compatibility of handlebar mounted components such as brake levers and gear shifters, which are ordinarily designed for circular handlebars. However, a more serious consequence of the ovular handlebar was the additional weight. The ovular tube section was only available in the required diameter from one supplier who stocked it in 1.5mm thick mild steel. Over the length of the 0.5m handlebar this becomes a significant weight and so an ANSYS analysis was performed to investigate the effect of removing material from the underside of the handlebars. This involved removing two oblong holes along the flat section of the tube as illustrated in Figure 14. It was important to monitor the variation in both deformation and stresses under Glaskin's assumed loading, with the length of these holes [16]. The results are indicated in Figures 15 and 16 below, and the minimal increase in stresses and deflection were permissible for the associated 20% weight reduction.

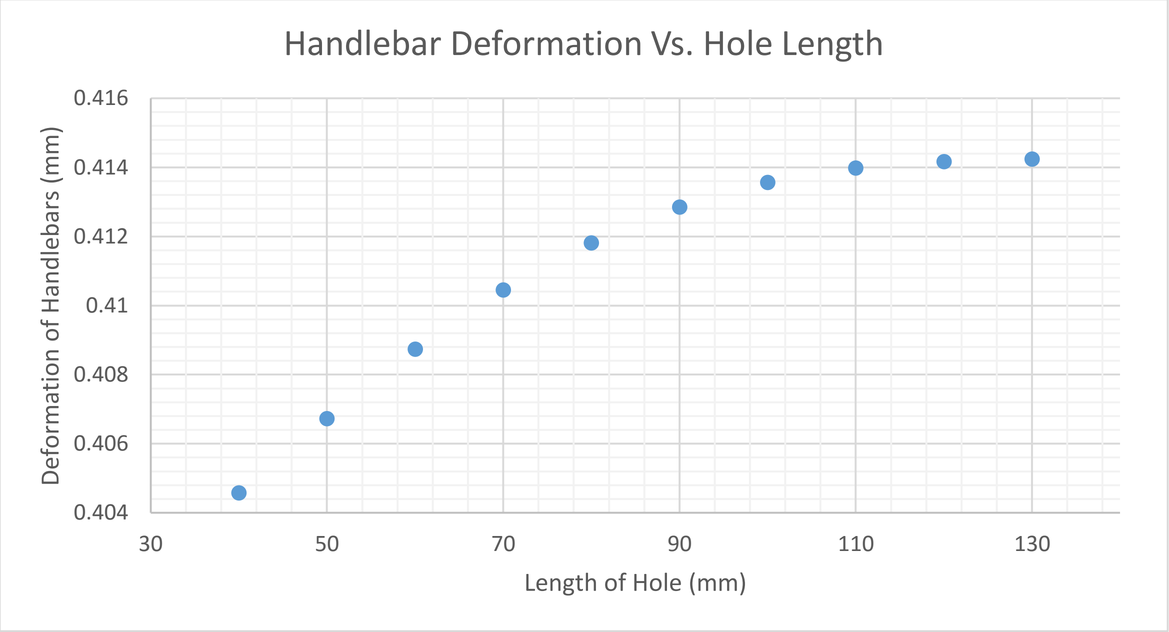

Figure 19 - Handlebar Deformation Variation

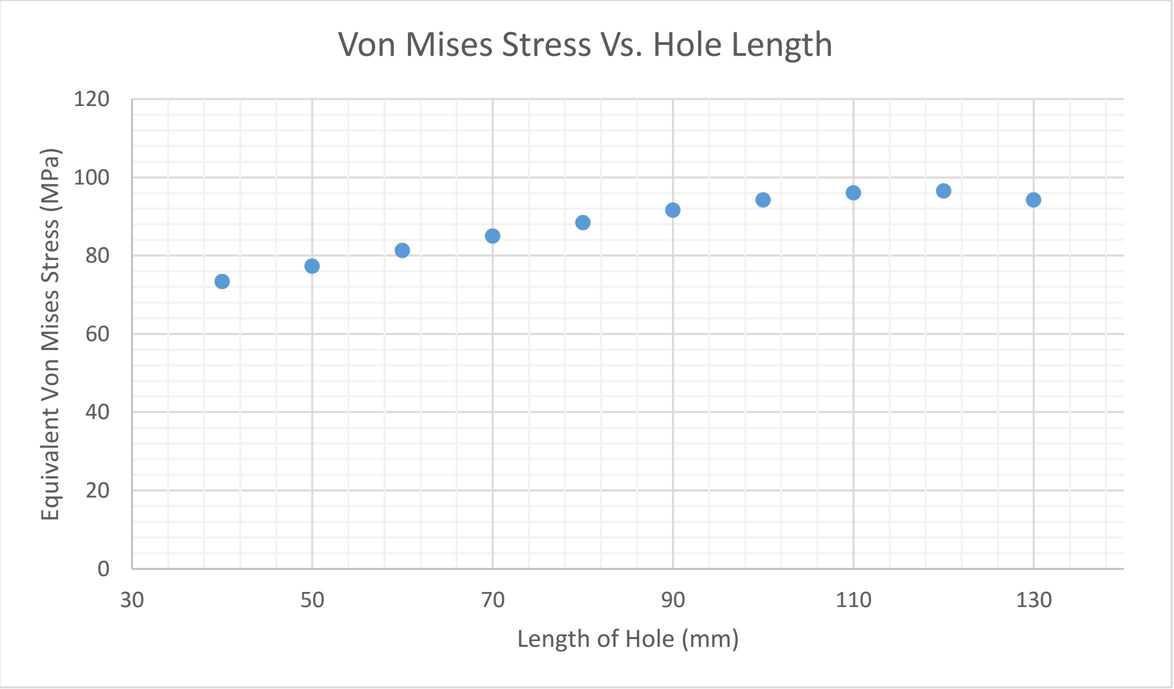

Figure 20 - Handlebar Stress Deformation

Figure 21 - ANSYS Stress Analysis of Handlebars

After the decision to remove handlebar material had been finalised, a full ANSYS analysis was performed on the upper steering assembly to determine the thickness requirements for the steering column tube. It was discovered that this member had to have a greater thickness than any of the main frame components as it was bearing a significant compressive load. The maximum equivalent stress was measured just below 50MPa at the intersection of the bolt and the upper steering column. This can be readily explained as the bolt is transmitting all moments from the horizontal handlebars to the vertical column, in addition to rotational loads when turning. While this stress is well below the yield stress of mild steel at 370MPa, it was still decided to use as large a bolt as possible in the spring loaded mechanism.

13.3 FRONT FORK

The second objective of the steering design, focused largely on the fork that holds the front wheel in position; and once again a controlled convergence matrix was generated to narrow the number of options considered. This originally resulted in the most creative concept being taken forward, which involved a single bladed fork supporting the front wheel. Only a select number of bicycles on the market offer this type of connection, and it is also in the interest of minimising mass and folded volume, as it essentially removes an entire spar. However, in order to ensure that the single blade is structurally and safely able to transmit the wheel and rider loading, it is necessary to perform a detailed analysis and use strong materials.

Initial enquiries were made with Burrows Engineering, a company that specialises in the construction of monoblade forks [18]. Given the time constraints of the project, two recommendations were offered. Firstly, to identify a local manufacturer of prepreg carbon fibre and attempt to secure time and material to model a specific monoblade for the prototype, or secondly to deconstruct a standard mountain bike fork, by removing one of the blades, as the engineers assured that these have been designed for extreme use and therefore would provide ample support for a small 16in wheel used for short commuter journeys. While both options were considered, these discussions did not take place until the latter end of Semester 1, and so time constraints lead to the latter option being adopted. However, when the dismantling of the mountain bike fork was discussed with Senior Technician Chris Cameron at the feasibility study, he raised issues regarding the weight and excess volume occupied by the suspension systems on those type of forks. Instead, for simplicity it was decided to procure a standard 16in fork as a complete component, and then modify the length and type of lower steering column to suit the handlebar fold. The standardisation of lower steering column would also allow for an easier assembly of the bearings within the headset, as these are specifically designed to fit over industry sizes. Finally, the steering hinge assembly was to be mounted on top of the lower steering column as shown in Figure 18. This was connected using another insertion tube welded to the lower face of the hinge that would slot inside the lower steering column. A bolt would then be inserted to secure the orientation of the hinge. The upper steering column would then be directly welded to the top face of the hinge, thus completing the steering assembly.

Figure 22 - Front Fork and Lower Steering Column

14. FINAL DESIGN AND PART PROCUREMENT

14.1 FINAL DESIGN MODEL

By the final week of the first semester, the folding bicycle had been fully designed and tested in ANSYS and so a full assembly model was created in PTC Creo, as illustrated in Figure 23.

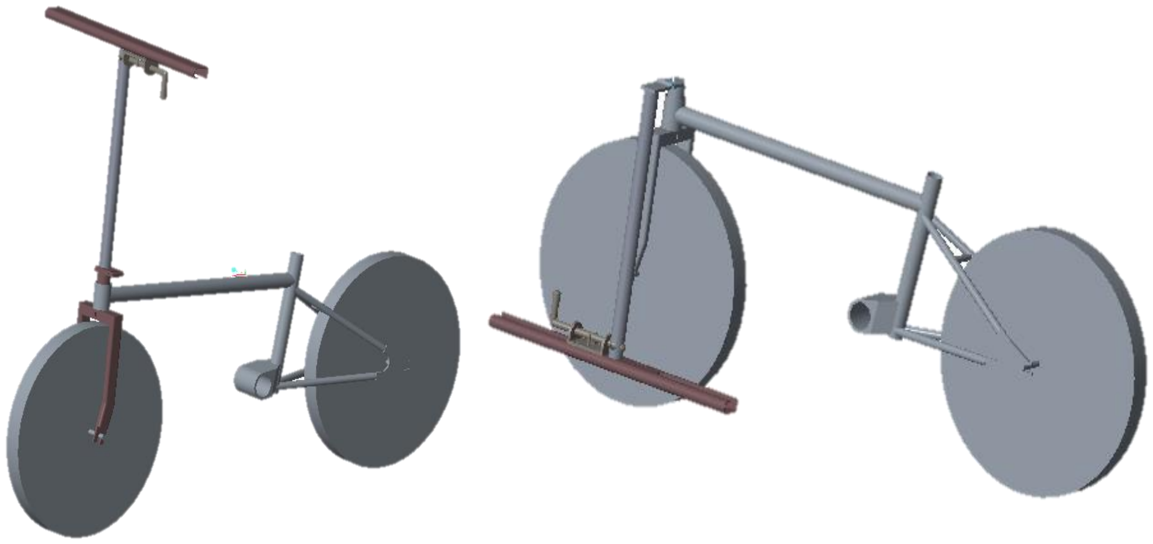

Figure 23 - Fully Assembled CAD Model

The model to the right demonstrates a partially folded model where the upper steering column has been lowered across the front wheel. This model is lacking the top tube hinge fold due to difficulties in estimating the size of cranks and pedals within the CAD sotware which would have allowed correct placement to be specified. This was the first time that the group developed a perception of the final product and how it was intended to look after construction. Once the complete assembly was finalised and the Lead Design Engineer and Chief Executive had signed off their approval, the technical drawings then had to be created for each part. These were drawn to assist with the maufacturing phase and provide a set of clear instructions for the lab technicians when submitting component parts to the workshop. These covered the dimensions and sizes of all of the tubes and mounts, but importantly, a number of tracing drawings were also produced of the end profiles of tubes to allow the ends to be correctly shaped before welding. A full collection of these drawings are attahed at the end of this report in Appendix E.

14.2 PART PROCUREMENT

One of the crucial aspects of the design phase was to ensure that the components that were designed could be readily maufactured from available material. To this end, a number of suppliers were sourced at the early stages of design, as this allowed the final model to be accurately dimensioned to parts that were available on the market. A key example of this ivolves the project tubing supplier Reynolds. Reynolds Tubing specialise in producing bicycle spars and sections from high grade steel. In particular they are renowned for their precise fabrication practices that allow the tubes to be precisely butted at either end and tapered in the middle, providing an inherently stiff member. Contact was made with Reynolds to secure dimensions and material properties of the tubes of interest, and these were in turn used to verify structural stability in the FEA analysis. This procedure was also followed for other components such as the front fork, handlebars and spring-loaded bolt.

Throughout this process of secruing suitable suppliers, a careful watch was placed on SynopTech's financial resources. The Financial Officer remained in control of the budget and ensured that all parts were sourced to minimise both cost and delivery time. A final list of all components to be purchased was submitted to the client Prof. Boyle who approved the request. A complete list of the procured parts, and their associated cost is included in the following section of the financial evaluation. Given the specificity and spread of parts required, the procurement was sourced from a wide range of suppliers. In order to maintain progress and remain in pace with the Gantt Chart, all of the parts required for early manufacture were ordered at the end of the first semester, to allow a reasonable delivery period over the Christmas Break. This ensured that all of the required components were delivered by the start of the second semester, and allowed the manufacturing phase to begin immediately.

14.3 BRANDING

At this stage in the design process, the Research and Development Officer, chaired a meeting to develop the company brand and a marketable name for the product. After discussion and several pitches as to the company name, SynopTech was eventually agreed. By definition, the word 'synoptic' refers to something that is succint, to-the-point, and provides a simple solution. It was felt that this ethos was in line with the group and also in terms of the product that had been designed. The folding bicycle was a simple and easy to use machine, that was neither over-engineered, nor over-complicated. It was designed specifically for commuters, and as a marketing campaign strategy was formed, synoptic thinking would also prevent the product from being over priced. The “Tech” section was added retrospectively as it was thought prudent to emphasise the technological nature of the company.

By extension of this company name, the product name was chosen to be simply The Commuter. Once again, this was a simple and minimimalistic approach, which makes clear the purpose of the product and also the target market. A wheel has been included in place of the ‘o’ in Commuter to reinforce this companies identity as a bicycle manufacturer. The logos for both SynopTech and The Commuter are illustrated below in Figure 24.

Figure 24 - SynopTech and The Commuter Logos

15. MANUFACTURING AND IMPLEMENTATION

15.1 MANUFACTURING PHASE OVERVIEW

Following the completion of the Conception and Design phases of the CDIO Initiative, the third and most practical work package was initiated. Implementation of the detailed design, by practically manufacturing the folding bicycle in the workshop, proved a challenging though rewarding task. Before work was started in the labs an updated Gantt chart was created specifically for the manufacturing process. This kept all group members appraised of the anticipated build stage and manage their time in the lab accordingly. A total of 50 tasks were identified between the start of the second semester and the final project deadline. These were organised accounting for initial time estimates given by the lab technicians, and collated in the Gantt chart. A copy of this document is included for reference in Appendix G at the end of this report. The first practical step towards manufacturing the bicycle was to submit both the bottom bracket and hinge angles to the technicians, and this was done at the start of the second semester. The majority of the main frame components relied on these parts being completed by the technicians, however it was initially stated that these components would only be ready in two weeks. As such, at the outset of Semester 2, a more pronounced focus was directed towards manufacturing the steering column.

15.2 MANUFACTURE OF STEERING AND HANDLEBARS

The steering system of The Commuter includes the handlebars, steering column, fork and front wheel. The first job required for manufacture was to cut the relevant tubes to their appropriate length, and to mark out the locations for mounting the spring bolt and insertion tube. All the welds necessary for this section were directly onto a flat surface and the insertion tube could be welded to the underside of the handlebars at an early stage. Conserving the precise handlebar design according to technical drawings took longer than expected, due to the restricted access of equipment, such as the milling machine. To overcome this the group removed the excess material from the bottom of the handlebars by drilling and sawing at narrow angles. While this was a time consuming process, the end effect proved worthwhile as all of the material indicated on the technical drawing was successfully removed. This task was not only effective in reducing the weight of the handlebars, but it also enabled greater access to the inside of the ovular tube. This was particularly beneficial when attaching and tightening the spring-loaded bolt with mechanical fasteners. Once this was positioned, both the spring and the bolt were removed to align the holes through the insertion tube, and prepare the surface for drilling. After the holes were drilled, the bolt was reattached and the upper handlebar assembly was completed, as indicated in Figure 25.

Figure 25 - Handlebar Assembly

The upper steering column was then cut to size, and the four holes at the top of this section were aligned and cut using the pillar drill. This fit closely over the insertion column and only some minor filing was required to enable full penetration of the spring bolt. At this stage the upper steering column was welded to the upper face of the hinge. On the underside of the hinge a second insertion tube, similar to the one on the handlebars was also welded, completing the upper steering sections.

The front fork also required some modification as its lower steering column had to be shortened. This was to allow the handlebars to be at a reasonable height for a comfortable riding position, while also clearing the ground when folded under. Additional complications arose when attempting to insert the front wheel in the fork, as the fork had been built for a thinner model of wheel. This created some minor setbacks as a new wheel and tyre had to be acquired. Finally another hole was drilled through the top of the fork steering column, and this allowed the insertion tube on the underside of the hinge to be bolted to the fork. In this way, both the upper and lower steering sections were connected.

15.3 MANUFACTURE OF FRAME

After completion of the handlebars, the group proceeded to cut the various main frame tubes to the correct sizes. To join these now correctly sized tubes, small sections on the edges had to be shaped into profiles according to templates developed on CREO. This meant cutting and filling down to shapes that would improve the contact area of the tubes to be welded. This was done to both the seat and chain stays and also to the top tube, since these were going to be welded onto the seat and head tubes respectively. Preparing the tubes for welding took a considerable period of time, as it involved a lot of filing to get the shape as perfect as possible.

The next step was to spot-weld the tubes, this was done to make sure that all the parts were correctly aligned, the angles were right, and it was a way to see the how it would look in the case anything went wrong. The advantage of spot welds was that they could be removed without much effort and without doing a lot of damage to the tubes. At this stage, further progress depended on receiving the bottom bracket from the technicians, though unfortunately this overran by over two weeks on their initial estimate. Having completed the steering column in the meantime, all stays and tubes were ready for welding by the technicians as shown in Figure 26.

Figure 26 - Welding of Main Frame

Having completed the welds, only two principal tasks were left to finish the frame, namely creating the rear dropouts and cutting the main tube to insert the hinge. The rear dropouts could not be manufactured before the seat and chain stays were welded in place, as they were highly dependent on the angles between them. Once the angles were measured and dimensions finalised, they were water jet cut from an 8mm steel plate, crimped and brazed onto the stays. At this point they were bent until they were parallel. The design of the dropouts is illustrated in Figure 27.

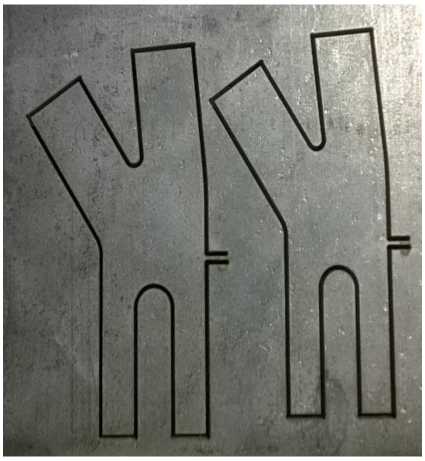

Figure 27 - Dropouts

With the dropouts attached, both wheels could be mounted to the frame, which allowed for the fitting and inflating of the inner tubes and tyres. The steering column was connected to the main frame via the headset, however, due to the non-standardised nature of the fork, this also proved difficult. Ultimately a hybrid of two headsets were used to apply adequate friction and hold the steering column in place. This successfully allowed the handlebars to rotate freely inside the head tube. Unfortunately, the welding of the main frame had not been performed satisfactorily, and resulted in slag on the inside of the seat post. Practically, this had significant ramifications to the folding design, as the seat tube could no longer be inserted into the seat post, and therefore it was unable to drop-through as initially intended. This necessitated a design change, and so separate seat clamps were purchased and were mounted to the frame. This introduced another step into the folding process, as the seat post had to be fully removed from the seat tube and inserted into these additional seat clamp to reduce the folded volume.

15.4 MANUFACTURE OF HINGE

After the angled sections had been returned by the technicians and the hinges had been cut to size, a final welding job was submitted to attach the latches and angles together. The position for the mid-frame cut was then decided by measuring the distance between the two wheels and cutting the frame at the middle distance. This way, when the bicycle was folded it would have both wheels side by side. The incision was made perpendicular to the ground and the hinge welded to the two ends of the top tube afterwards. Another factor that had not been considered was that the non-standard front wheel was slightly larger than the rear wheel, although both were quoted as 16in. The result of two mismatched wheels, was that the rear wheel was raised off the ground in the fold, and so a solution had to be conceived that would hold the two sections of the frame together when folded. A set of two neodymium magnets with 8.3kg pulling force were ordered and superglued in place at the left rear dropout. This had the effect of efficiently holding the frame together when folded as desired. The latches on the hinges were then adjusted and tightened to ensure that the hinges were being held securely closed when in riding position. An adhesive foam was then inserted inside the hinge to maintain a closed gap when the hinges were closed.

15.5 MANUFACTURE OF DRIVETRAIN

The manufacture of the drivetrain was left to the end of the manufacture phase. After the entire frame was made and steering mechanism was set up the bicycle was ready for the installation of a drivetrain. This was done by making use of Bike Station's offer of technical assistance, near the end of the project and taking the nearly complete bicycle there and fitting the majority of items with the specialised tools and personnel they had available. Going to Bike Station also allowed the inexperienced team to get advice and any parts which had been neglected within procurement. This approach proved to be successful, to a great extent, however several problems were encountered. A major one being the limited time within their laboratory with this risk being limited by doing all the jobs that required the specialised tools such as the gearing system.

The initial drivetrain concern, was during frame construction when the bottom bracket shell, due to be punched into bottom bracket, was too small and a loose fit. However this was overcome by the use of a strong adhesive and this allowed the group to utilise the overhang of the shell in order to avoid the pedals hitting any of the seat stays. At this point, the crank arms and pedals were then professionally fitted and the rear wheel gearing system was then considered.

A further problem was established by this stage, due to the misalignment of the stays during welding and the low tolerances taken by the technicians. The result was that the stays were welded at the wrong angles. Practically, this meant that the rear wheel and chain ring were misaligned longitudinally and laterally, and that the chain could not pass between the two without rubbing over the right seat stay. This resulted in another change of design, as the group conceded to go for a single speed bicycle due a lack of space for any additional gears by the rear wheel, let alone a derailleur. This was combatted by mounting the nylon covered keeper from the neodymium magnets onto the seat tube at a calculated height. This keeper provided a slight pressure on the chain to keep it aligned with the chain ring, and enable the bicycle to function properly.

Brake levers had to be modified to fit over the ovular handlebars, and two side-pull calliper v-brakes were fitted to the front fork and rear brake mount using standard fittings. Inner brake cables were inserted into an outer casing and fed through the brake system and tightened accordingly, thus completing the drivetrain of the bicycle.

15.6 AESTHETICS

The final step in manufacturing the bicycle was to consider the aesthetic appeal of the product. Primarily, this was achieved through its paintwork. The entire frame was rubbed down with sand paper to increase adherence of the primer, before multiple layers of grey primer were applied and dried out for one day. The following day the bicycle was sanded down again to remove any imperfections before several coats of paint were applied as in Figure 28. The paint also took 24 hours to dry at which point two layers of clear lacquer were applied to the whole frame for a more glossy finish and to protect the paint. The colour chosen for the paint work was BMW Topaz Blue as it was felt that this was in keeping with the University of Strathclyde colour scheme, and it was appropriate as the bicycle would be representing the department at the CDIO regional competition in Belfast.

Figure 28 - Priming and Painting of Bicycle

A final aesthetic consideration, was the inclusion of stickers and decals on the finished prototype. Part of the contract with Bike Station, involved an obligation to print the Bike Station Logo on the bicycle, and this raised the notion of creating SynopTech's own branded decals. Using a Silhouette cutting software with adhesive vinyl card, a series of stickers featuring the SynopTech logo and The Commuter name were produced. These were applied to the frame, as in Figure 29, before one final coat of clear lacquer was applied, as this would seal the stickers in place.

Figure 29 - Personalised Stickers and Decals

Finally, a seat clamp, reflectors, handlebar tape and a saddle were all added to the bicycle, and the prototype Commuter was complete.

16. FINAL PROTOTYPE REVIEW

After completion of the first three phases of the CDIO Initiative, the final stage involved the operation of the prototype design. It was at this point that the product could be compared to the original specification and goal statement to determine the success of the project. In terms of the original aims, which were to minimise, mass, folding time and folded volume; The Commuter surpassed all of the maximum restrictions set at the project conception. The final mass of the prototype was measured at 9.9kg, and this could be reduced to fit within a 136.8cm^3 volume after folding. While the time required to fold is highly dependent on the user and their familiarity with the mechanisms, the average recorded time was 30 seconds. The final folded version of The Commuter can be seen below in Figure 30, where the bicycle rests on the two hinges and seat clamp.

Figure 30 - Final Prototype Folded Orientation

Figure 31 - Final Prototype Riding Orientation

When in the riding orientation, as illustrated in Figure 31, the bicycle was tested by performing trial runs along a test track. Some minor concerns were raised regarding the flexibility around the top tube hinge when the bicycle was mounted, however this did not impair riding conditions and the structural integrity of the bicycle was maintained. A slight vibration was also noticed in the upper steering column, but again this was minimal, and the rider was in full control of the bicycle handling throughout tests. Overall, the bicycle handled well, could be folded up with minimal effort and was easily carried when folded. The testing and operation of the bicycle proved that the concept was based on an effective design that could be successfully manufactured within a limited time and workspace. For this reason, SynopTech began considering the commercial viability of The Commuter and the possibility of introducing it to the market.

17. SYNOPTECH WEBSITE

17.1 PURPOSE OF WEBSITE

Another requirement set out by the client was to create and publish a website detailing the process by which The Commuter had been conceived, designed, and manufactured. The website was to contain key project details but also acts as a marketing tool for SynopTech that is in line with the overall business plan. The website was designed and hosted using the free website builder "Wix". This is a cloud based website development tool that allows users with little knowledge of coding to create a HTML5 web site through the use of its innovative and user friendly graphics user interface.

17.2 PLANNING AND STRUCTURE

The website was treated as a project within itself. The Marketing Officer was tasked with its completion and given a deadline similar to that of the final report. In order to ensure this deadline was met, a Gantt chart was created and weekly updates were given to the project manager at the team's weekly meeting. This Gantt chart, created using Microsoft Project, can be seen in Appendix H. In addition to providing a schedule, the Gantt chart allowed for a flow diagram to be viewed with ease and this aided in planning the development of the website.

During the planning stage, a structure was established for the website. This process included the identification of what was to be included within the website alongside how the different pages would link together. Multiple pages were implemented to avoid the congestion and confusion associated with having all of the information on one page. It was believed that the separation of information onto logical pages would also create better flow and a more appealing website. The different pages and the content within them are outlined below in Table 8:

Page	Description of Content
Home	Name of the company, slogan and pictures of the product.
About	Background information and CDIO competition information.
Who We Are	Picture, description and project role of each member.
Project Management	Schedules, organization of the group, Gantt chart, etc.
Design	Initial concepts and detailed information regarding the final folding bicycle.
Manufacture	Process used to manufacture each component and final prototype assembly.
The Commuter	Outline of final product and achievements
Sponsors	Details and acknowledgement of thanks to those providing sponsorship.

Table 8 - Structure of Website

17.3 CONSTRUCTION

Having completed the planning stage and identified a suitable structure, construction of the website began. This was initiated by revising and summarizing all of the research that had previously been undertaken and by compiling an initial draft of information to be included. It was important that this information was concise and of a level which could be understood by a lay reader. As the website was constructed, a number of pictures were uploaded, including pictures of the design, manufacture and the team members. In addition to this, a brand meeting was held where a company name, product name and company slogan were brainstormed and selected. Following these decisions, both the company and product logo were developed. Both of these are included within the website.

Another important inclusion within the website was the sponsor's page. This space allowed for an official and public recognition of thanks to be given to those that have supported the development of The Commuter financially. This was particularly relevant to Bike Station who, as already discussed, provided parts sponsorship alongside free workshop usage. To this end, the company logo, opening times and a direct link were included.

17.4 THE COMPLETED WEBSITE

Upon completion of the website, it was published so that it could be viewed within the public domain. The website in its entirety can be viewed via the URL found on the cover page of this report. The following images included in Figure 32 show various screenshots of the website in its final state:

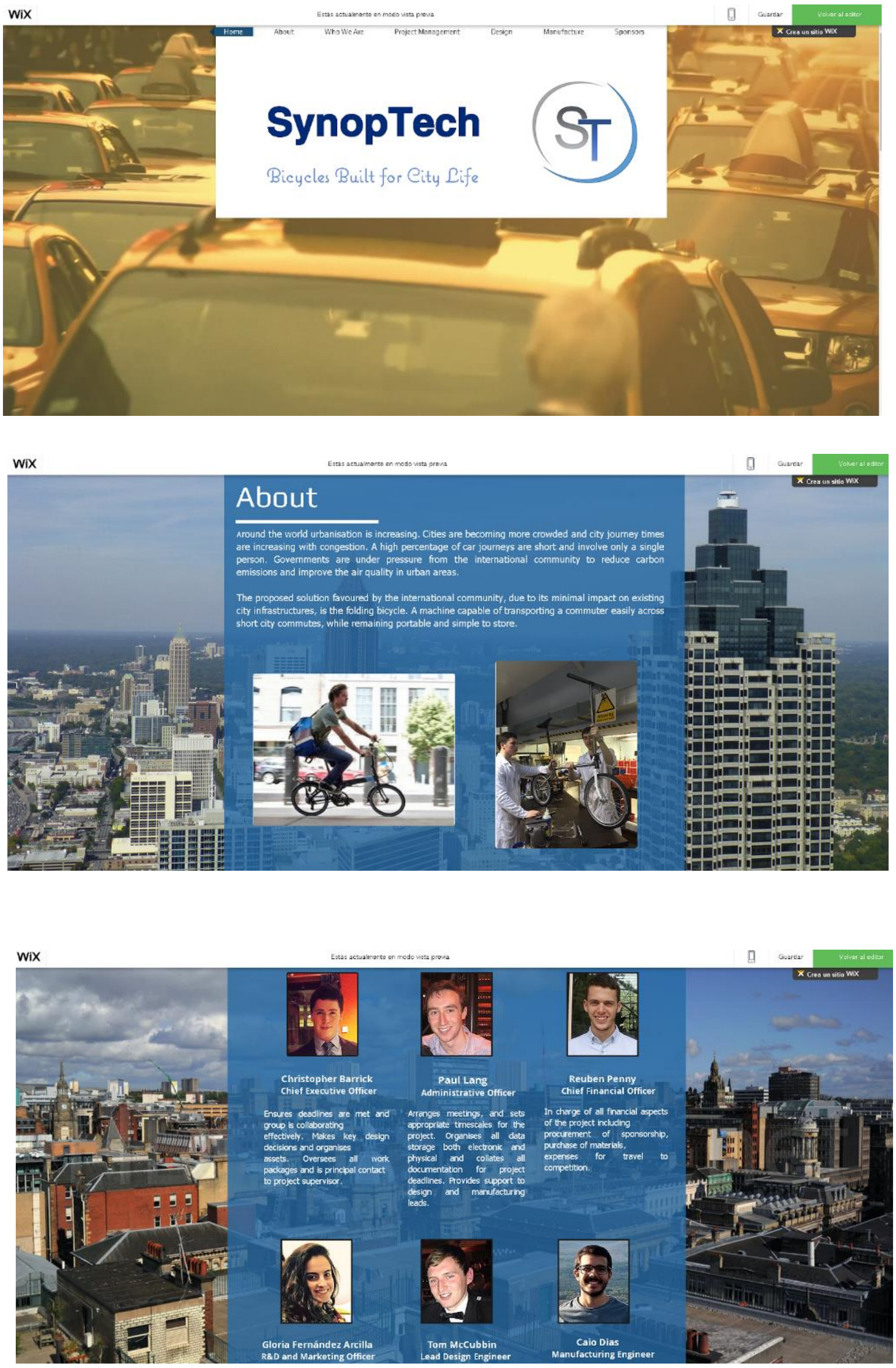

Figure 32 - Website Screen Shots

17.SYNOPTECH BUSINESS PLAN

18.1 OVERVIEW

A three year business plan was created to determine the financial viability of introducing The Commuter into the market. A target bike production of 2000 units in the third year is the aim of the business plan. The following is a financial overview that was put together to see the growth of SynopTech over the three year period, and provides a good sense as to what will cost the most for the business in term of percentage of revenue.

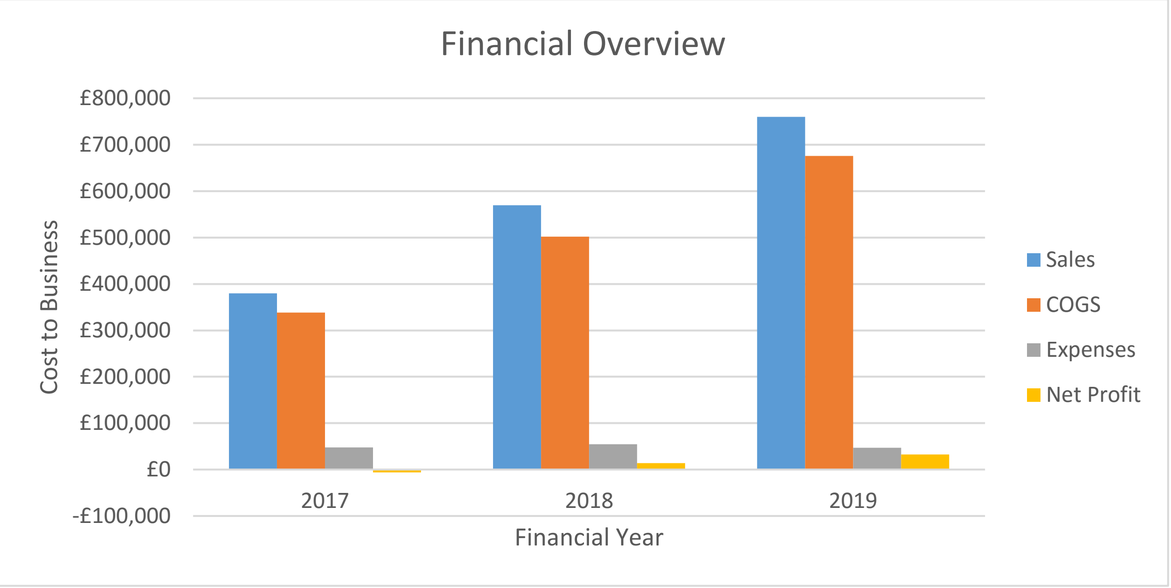

Figure 33 - Financial Overview of SynopTech

Figure 33 shows that the Cost of Goods Sold (COGS) is by far the largest cost to the business. This includes the wages paid to all employees in the business and the six founding members of SynopTech. It also includes all the material costs associated with manufacturing the amount of required bicycles. As can be seen, a small loss is made in the first year, but this loss can be offset against the capital investment required for the start-up. However by the third year, a profit is generated which sums to 4.26% of total revenue for that year.

18.2 MISSION STATEMENT

The mission statement provides an indication as to the amount of capital required to start the business and to begin manufacturing which, in turn, will start generating revenue. It is estimated that SynopTech will require approximately £250,000, which will cover all legal costs (patents, trademarking etc.), initial material ordering costs, labour, and insurance expenses.

Following this plan, production would start in the last quarter of 2016, and The Commuter would go on sale at the start of 2017 or just before Christmas to gain the extra sales that go in hand with the festive period.

Appendix I shows the full Business Plan, with Profit/Loss statement and sales projection included. This Business Plan will be used to pitch to venture capitalists to try and obtain investment. It will also be attached onto a crowdfunding page to raise the capital required.

18. SYNOPTECH FINANCIAL EVALUATION

19.1 SPONSORSHIP

The Bike Station, a bike shop in the West End of Glasgow that repairs and sells unwanted bikes, was identified as a possible sponsor at the beginning of the project. A visit was set up and after a successful meeting with the operations manager of the branch, it was agreed that they would sponsor the project by supplying parts for the bicycle for no cost. In return, the group was to attach the logo of the Bike Station onto the side of The Commuter, and post on their Facebook page during the competition. This allowed SynopTech to save capital for other parts of the bike that needed bought in, and permitted a safety net of cash to be upheld. In Table 9 below is a list of parts that were acquired through the Bike Station and the estimated saved costs of the sponsorship.

Component	Cost Saved (£)
Brake Cables	3.00
Rear Derailleur	20.00
Rear Sprocket	20.00
Front and Rear Brakes	22.00
Brake Handles	9.00
Front Chain Ring	8.00
Crank Arms	16.00
Gear Shifter	6.00
Gear Cables	4.00
Pedals	9.50
Reflectors	4.50
Total Capital Saved	**£123.00**

Table 9 – Capital Saved through Sponsorship

Not only was an estimated total of £122 saved due to the sponsorship, but The Bike Station also arranged for the building and attachment of the drive train, braking and gearing components to be done in their workshop. The appropriate tools were made available, saving both time and money for the project which allowed the product to be delivered to the client in a timely manner.

Financing for the trip to the competition was also a consideration made by SynopTech. The expense of getting to and from Belfast, coupled with staying there, was identified as being almost as much as the £600 budget, if not more. A meeting was then set up with the Head of Department, Professor Andrew Heyes, to identify if the Mechanical and Aerospace Engineering Department would consider funding the trip, as SynopTech are representing the university in a competition. After a successful meeting with Professor Heyes, financing was granted, so pressure to fund the trip with the company budget was lifted.

19.2 COST PROJECTION

A cost projection was completed to determine the estimated cost of purchasing the required materials, and to manufacture the bicycle. The cost projection took into account the availability of funds from the University for the Trip to Belfast, but not the parts supplied from The Bike Station.

Bicycle Part	Estimated Cost (£)
Tubing	170.00
Hinges	30.00
Braking System	34.00
Pedalling System	25.50
Saddle	5.00
Gear System	58.00
Steering System	40.00
Aesthetics (Paints etc)	55.00
Wheels	82.00
Ireland Trip	0.00
Admin and Delivery	50.00
Total Cost	**£539.50**

Table 10 - Cost Estimations

As can be seen in Table 10, the estimated cost at the start of the year was lower than the actual cost of the manufacturing of the prototype, as seen in Table 11 in the following section. This can be explained by parts of the bicycle costing more than originally predicted. A good example of this is the wheels, in which a second front wheel had to be bought for extra cost so it could fit into the non-standard front fork. The projected cost was below the overall budget of £600, which is why no additional funding was sought.

19.3 BUDGET MANAGEMENT

As the budget of £600 was set from the project initiation, very careful management of how much money was spent was required. This was to prevent the project going over budget or potentially being abandoned due to lack of funds. Going over budget is an industry wide problem, as miscalculating the overall cost of a project can be severely detrimental to the business.

To keep track of the amount of capital spent on an up to date basis, a Google Sheet was created on the group Google Drive and this required constant updating whenever any cost arose. Additionally, before any procurement began, the total cost of ordering all the materials required to complete the project was found, and a safety net of money was kept aside (this was 10% of the total budget) leaving £540 spending money. It was important to do this as not all the ordering was completed at once, with half the procurement occurring before Christmas and half done after. All procurement was done through only one person, with each part bought being signed off by the group leader and added to the Google Sheet. During procurement, the remaining budget was continuously monitored, and this allowed decisions to be made regarding the quality of product bought. The allocation of capital to different parts of the bicycle also allowed for late decisions to be made. If one section was predicted to be too expensive, then different options were explored.

19.4 FINANCIAL PROBLEMS ENCOUNTERED

There were a number of issues that were encountered during the procurement and manufacturing process. During procurement, it was sometimes difficult to keep up with which parts needed ordered, where it was ordered from and how much it cost. This was due to 6 different people working on differing parts of the bike, and constant part updates were required.

In addition, technical issues with manufacturing put a strain on resources available, as each problem needed some capital to be fixed. These posed issues which could often only be fixed by the purchase of extra parts. An example of this is the brazing of the bottom bracket to the seat tube, which drastically deformed the seat tube. This meant that the original idea to have the seat post drop all the way through was therefore not possible. This solution was fixed by the purchasing of clamps that attach onto the tubes of the bike, which hold the seat post and saddle while the bike is folded. While this resolves the technical difficulty, it also impinges an added cost of £17.93.

A number of these issues were costly, and needed a large amount of the remaining budget to try and solve.

19.5 FINAL COST REPORT

The final prototype cost of the bike is shown in Table 11 over the page, and includes the administration and delivery fees separately. The total amount spent was higher than originally calculated, and this is due to faults in design and procurement creating extra costs. It is however within budget, and therefore meets the specifications set out at the start of the project, that the bicycle must be built for under £600. The initial idea of having a safety net of £60 to be able to deal with problems that arose late on in the manufacturing phase, proved invaluable, and enabled the successful completion of The Commuter. The £60 safety net was used to deal with several manufacturing problems, allowing the project to be delivered under budget and on time.

<table>
<tr><th>Part Name</th><th>Part Cost (£)</th></tr>
<tr><td>Bottom Bracket Shell</td><td>14.99</td></tr>
<tr><td>Tubing</td><td>125.22</td></tr>
<tr><td>Seat Post</td><td>22.24</td></tr>
<tr><td>Rear Dropouts</td><td>5.95</td></tr>
<tr><td>Hinges</td><td>10.80</td></tr>
<tr><td>Latches</td><td>3.18</td></tr>
<tr><td>Angle (Mounting Plates)</td><td rowspan="2">12.57</td></tr>
<tr><td>Upper Steering Column</td></tr>
<tr><td>Front and Rear Tyres</td><td rowspan="2">55.29</td></tr>
<tr><td>Headset</td></tr>
<tr><td>Front Wheel</td><td>25.00</td></tr>
<tr><td>Rear Wheel</td><td>14.24</td></tr>
<tr><td>Handlebars</td><td>9.25</td></tr>
<tr><td>Front Fork</td><td>52.00</td></tr>
<tr><td>Spring Bolt</td><td>4.43</td></tr>
<tr><td>Saddle</td><td>5.00</td></tr>
<tr><td>Brompton Tyre</td><td>24.50</td></tr>
<tr><td>Inner Tubes</td><td>11.24</td></tr>
<tr><td>Seat Clamp</td><td rowspan="5">61.90</td></tr>
<tr><td>Grey Primer</td></tr>
<tr><td>Topaz Blue Paint</td></tr>
<tr><td>Clear Lacquer</td></tr>
<tr><td>Project Kit</td></tr>
<tr><td>Handlebar Tape</td><td>5.00</td></tr>
<tr><td>Front Mech Band on Clamp</td><td>13.98</td></tr>
<tr><td>Front Fork</td><td>10</td></tr>
<tr><td>Single Speed Gear</td><td>14.99</td></tr>
<tr><td>2x Brake Pads</td><td rowspan="2">13.35</td></tr>
<tr><td>Chain</td></tr>
<tr><td>Neodymium Magnets</td><td>6.13</td></tr>
<tr><td>Brake Callipers</td><td>26.99</td></tr>
<tr><td>Admin and Delivery</td><td>38.90</td></tr>
<tr><td>Cost of Refunds</td><td>4.60</td></tr>
<tr><td>Total</td><td>£591.74</td></tr>
</table>

Table 11 - Final Budget of Project

19. PROTOTYPE MANUFACTURING EVALUATION

The majority of problems associated with the manufacturing phase can be traced back to the design stage and the team's lack of practical bicycle knowledge when developing a working design for the folding bicycle. Should the project be repeated, manufacture would be considered as the key aspect of design process and be weighted extremely heavily during the product design specification (PDS).

One aspect of the design that has been extremely difficult to maintain during manufacture was the extremely high tolerances that were unreasonable to work to, especially due to a high usage of hand tools. SynopTech's margin for error was extremely small going into phase 3 of the project and this caused several problems with maintaining clearances and rigidity in the final framework structure.

A further area where the design process could have been improved, involved sourcing more technical information of components and tubes prior to purchasing. This would have minimised the tolerance issues as parts would be designed to fit together instead of attempting to use the ideal properties from our in-depth FEA analysis. This problem was especially noticed during procurement where having several different suppliers, as well as parts that relied on welding accuracy, mechanically fastened joints would have been preferable.

Another part of manufacture that caused several problems was the welding. For example, allowing a bigger margin for weld material on the inside of the hinge where the angled plate sits would have resulted in a stiffer hinge with less flex. Another lesson learned was with regard to the small thickness of the seat tube which had been chosen in order to save weight. Due to this being the primary tube that all the welding is attached to, it should have been thicker in order to avoid deformation in the future and give a greater surface to mount all the other tubes onto.

Moreover, another improvement that the group felt would have benefited the project would have been more consultation with experts on the bicycle specific areas of a bicycle, such as gearing. Locating several experts of different areas of the bicycle from frame design to hinge mechanisms instead of online research, would have greatly benefited the manufacture process in terms of efficiency and effectiveness.

This was particularly noticeably in the manufacture of the headset and remainder of the steering column.

One major manufacturing problem was the speed of technicians getting back with the machining of parts. In particular, the bottom bracket block took nearly a month to complete. Next time, SynopTech would aim to get all the part drawings requiring machining completed and submitted for the end of week 12 to allow these parts to be completed whilst the group were on exam break.

As the tolerances had been lowered during the manufacturing phase, certain problems arose, such as a reduced understanding of the folded dimensions before cutting the bicycle in half. This had to be done roughly and has since caused alignment issues. This could be combatted by getting the half cut prepared by technicians or building the bicycle in two halves.

There was also the case when a part that was delivered was different from what was expected. Specifically, this happened with the wheels. SynopTech purchased two different 16 inch wheels for the front and back of the bicycle so they would fit specifically for the fork and the rear drop outs. After trying to put them together, it was clear that the rims needed different tyres, and thus one of the original tyres that were bought became obsolete. The solution was simple: buying new ones online, and within one week the new tyre arrived, albeit at an additional cost.

Manufacturing involved a lot of hands-on work, but the fact that the group was limited in terms of equipment they could use without the supervision of technicians was a problem in and of itself. Simple tasks like cutting tubes, metal plates and drilling holes took longer and the results were inferior in terms of precision, but with patience and persistence, results were achieved.

One of the biggest problems came when the tubes needed to welded together. To make sure that everything with the frame was correctly aligned and the correct size, the parts were spot-welded at first. Because the tubes used were thin in order to cut on weight the welds melted trough them and created bumps on the inside of the tubes. On the case of the seat tube on the frame, this was an enormous problem because the seat tube fitted perfectly inside. To remove these simple bumps took hours of work filing. That is why it was desired to braze instead of welding when permanently joining the tubes. Unfortunately, the level of precision required for bicycle brazing was not available, and after welding the design had to change.

A final issue with the manufacturing phase, involved the headset, which was too large for the non-standard front fork. This meant that the whole handle bar tube was loose and it was uncomfortable to ride the bicycle. At first, the group tried to fill the excess space with tape but this alone was not working well enough, so additional foam was added to dampen the vibrations.

In spite of these numerous setbacks, SynopTech's manufacturing team pulled together effectively, sacrificing time and effort to achieve a fully functional prototype by the final deadline.

21. RISK MITIGATION EVALUATION

21.1 HOW THE THREE MAJOR RISKS OCCURRED

Having now completed the project, it is possible to look back on the risks identified and to analyse whether the steps taken to mitigate them were sufficient and whether they were appropriately rated.

a) Conceiving Designs beyond Manufacturing Capabilities

Following the manufacturing stage, it can be concluded that this risk was mitigated effectively. The SynopTech design team created parts that were potentially out with manufacturing capability; however a number of meetings with the universities Senior Technician, Chris Cameron, during the design phase allowed us to make the necessary changes before committing to procurement. These feasibility studies with an experienced member of staff were critical to the success of the project.

b) Lack of Technician Availability and Technician Delays

This was identified as one of the two major risks at the beginning of the project and so the group implemented a combination of outsourcing and minimisation of technician tasks to avoid delays. Based on this principal, only two parts were submitted to be manufactured by the technicians. Despite this, delays in excess of two weeks on top of the estimated part completion date were exhibited. These delays were a result of a number of unforeseeable delays such as technician illness and holidays leading to a generally under-staffed workshop. The full extent of the setback could arguably have been avoided, had the group not submitted the two parts together as one job lot. Doing this meant that both of our parts were tied to the same technician and this essentially formed a “queue” which might have otherwise been avoided had they been submitted separately.

c) Additional Large Risks

The first of the additional large risks identified was a lack of manufacturing experience within the group. This did not prove to be a problem and the mitigating factors implemented worked well. A particularly useful tool in this area was the availability of experienced technicians from our sponsor, Bikestation, who were willing and able to help when needed. The other large risk identified was the possibility of unforeseen problems arising, requiring design changes. However the flexible manufacturing Gantt chart and close working relationship with the Senior Technician, allowed the manufacturing team to progress to new solutions quickly.

21.2 UNIDENTIFIED RISKS

Though a number of risks were associated to procurement, part compatibility was not one of them. The team assumed, perhaps due to a lack of experience in the field, that all parts for a 16” bicycle would be compatible. An example of this was when a 16” fork and 16” wheel were purchased from separate manufacturers. These parts did not fit together. This resulted in wasted time and expense from a scenario which arose almost entirely due to budget restrictions.

Furthermore, the team failed to identify risks associated with welding, which was likely due to a lack of experience with this manufacturing process. As a result, what was a highly accurate design at the start of manufacture, lost a lot of precision when connecting the tubes around the rear triangle, and this resulted in further problems. Additionally, the group failed to recognise that welding of the seat tube would produce slag on the inner diameter and cause problems with the “drop-through” nature of the seat post. These problems are outlined in further detail in the manufacturing section of this report.

21.3 PROCESS REFLECTION

As with the majority of prototype development, and given the benefit of hindsight, it is possible to see how this process could have been greatly improved. Though the process of the risk analysis was sound, and the mitigating factors essential, there were holes which proved costly. The most evident of this is the lack of detail in the manufacturing risk analysis. This process was conducted at the beginning of the project and worked very well throughout the research and design work packages. At the manufacturing stage though, it was not possible to predict risks at a detailed level. It would therefore have been more beneficial to perform a detailed manufacture risk assessment at the end of the design phase and before procurement. It is possible that doing this would have avoided weld and compatibility problems in the manufacturing phase.

21.4 TIME MANAGEMENT

Time management was another elemental risk, and proved critical to the ultimate success of the project. The majority of the responsibility for time management was placed upon the project leader and a number of implementations were made at this level to ensure adherence to targets. One of the most useful tools in achieving this was the Gantt chart. A Gantt chart was created at the beginning of the project and served as a very useful guide for Semester 1. As the project evolved, so too did time constraints and the initial Gantt chart became outdated. A review was therefore conducted at the beginning of Semester 2 and a new Gantt chart created which also incorporated a detailed view of manufacture. The project leader ensured that deadlines were met and encouraged work package leads to adhere to the Gantt chart.

To further ensure deadlines were met, additional targets were implemented by the project lead and work package leads to ensure tasks were completed on time. An example of this was when writing both the interim and final reports. Individuals were required to complete their sections a week in advance of the deadline to allow time for collating and proof reading. Another example of good time management is shown when the weeks for manufacture and final report writing had to be switched as described in the section on “Project Management Reflection”.

22. MANAGEMENT STRUCTURE EVALUATION

22.1 TEAM WORK AND REFLECTION – SEMESTER 1

Throughout all of the planning, researching and design phases, the team dynamic and organisation was highly effective. Setting up a clear leadership structure for the project was key to progress made during the first semester. Indeed, the constant vigilance of the project manager in confirming that deadlines had been met and that the aims were being adhered to, significantly contributed to this progress. In addition, the project management structure based on work packages ensured that all members were contributing in equal measure and that no one member was overwhelmed. The personalised role assignment successfully maximised each member's unique skillset which varied from computer based or numerical competency, to research, financial or practical attributes. Despite this effective group set-up, there were some initial issues that required attention. It was recognised early on, that each of the Work Package Leads (Research, Design and Manufacturing) would be extremely busy for a third of the year as their project phase was undertaken. This disadvantage was significantly reduced by involving all other group members within these project phases. This also had the advantage of avoiding a highly compartmentalised group from forming in which members felt isolated. Isolation was further combatted by having regular group meetings. Several methods of communication were also implemented so that all members were able to collaborate effectively and keep up to date with the work of other sub-teams.

22.2 TEAM WORK AND REFLECTION – SEMESTER 2

The team structure and much of the successful aspects of team work from semester one were carried through into the second semester of the project. This once again began with identifying a weekly slot when all members were free to meet. This meeting was increased in duration from one to two hours, which meant that work could be completed as a group, while also keeping all members appraised of recent developments. Due to the large quantity of work that had to be completed in the second semester, and the potential difficulties associated with having all six members involved in manufacture, the construction responsibilities were divided within the team. Firstly, the lead manufacturing engineer was given command of a sub-team entirely responsible for the manufacture of the bicycle, and this comprised of three group members. Meanwhile, the two remaining members were assigned responsibility for the website and business plan respectively, as each had experience pertaining to these fields. Indeed, this organisational structure was very effective and ensured that no one person was overloaded with work. Another positive aspect of SynopTech's team dynamic was each individual's willingness to remain versatile and to assist with other areas when required. This was particularly evident during the manufacturing stage as there were often tasks that needed several members to be available at short notice, to complete various components within a tight timescale. Both the flexibility and perseverance of the team, were critical to achieving an operational prototype by the set deadline.

The most significant issue that the team experienced during the second semester was when the Lead Manufacturing Engineer became suddenly unavailable for ten days due to personal circumstances at the height of the busy manufacturing phase. This problem was overcome by the implementation of a temporary lead to fill the position, as the Administrative Officer assumed responsibility for manufacturing during this time. This decision was made as this group member had a strong understanding of the design, and was capable of devoting significant time in the labs. The collective engagement of all group members, drove this phase to completion and ensured that excellent progress was made, despite this minor setback.

22.3 PROJECT MANAGEMENT REFLECTION

Due to the size of the team it was important that a structured and well organised approach was taken from a project management perspective. Both the size of the team and the large workload to be undertaken, necessitated a division of responsibility within the group in the form of work package leads. This decision required the project manager to step back and allow work package leads to do their job with minimal interference. Most of the project meetings followed a general structure, whereby the meeting began with broad, overall updates from the Executive Officer before the relevant work package lead directed a more in depth discussion of progress and new tasks. This worked well, and, for the most part, avoided “over management” by the Executive Officer. The only occasion on which this was unavoidable was when the Lead Manufacturing Engineer was unavailable, but this was combatted as outlined in the previous section. As mentioned, communication was an essential for the group structure to work. In addition to weekly meetings being scheduled, a group chat was made alongside a group forum which allowed for continuous and quick communication. The final implementation was a shared cloud storage space which greatly aided organisations.

Other difficulties from the project management included a considerable delay in the manufacturing phase. This was unavoidable and occurred due to issues with the mechanical technicians who over-ran by two weeks. While this halted the construction phase, the decision was made to rearrange the project schedule to complete work that was independent of manufacturing. Specifically, the final two weeks of manufacture were swapped with the weeks allocated for writing the final report. This decision by the Executive Officer helped to mitigate the problem, though inevitably, further unforeseen delays occurred which are discussed in full detail in the manufacture section of this report. Another potential issue identified by the Executive Officer was the unclear assignment of responsibility between the Financial and Administrative Officers. The Administrative Officer ultimately oversaw and was responsible for the procurement process, which meant they were in the best position to finalise SynopTech’s budget, whereas this was originally a task for the Financial Officer. On balance, this did not cause any problems and, if anything, was beneficial to the team as the Financial Officer had a high workload in creating the business plan.

Overall, it can be concluded that the success of this project was entirely down to the effective collaboration of individual team members who were all willing and motivated to maintain a consistent work ethic. This, combined with the team’s adaptability and the willingness of a number of individuals to take on additional tasks in spite of other work pressures, resulted in a strong group performance.

23. ADHERENCE TO CONTRACT

A number of requirements were outlined within the Statement of Work which was defined at the beginning of the project. Within a broad scope, it was indicated to the client that the team would undertake three work packages and meet with the client on a monthly basis to report progress. All work packages were successfully achieved and regular meetings with the project supervisor were maintained throughout. Only one deliverable has not yet been achieved by the time of writing, and that is the participation of the team in the CDIO competition. This competition is scheduled for early June and it is hoped that the team will attend with the fully functioning prototype Commuter. All milestones were completed on schedule with the exception of Milestone 3 – the building and testing of the bicycle. The delays experienced here were due to technician delays out-with SynopTech's control and every effort was made to complete this milestone as close as possible to the original intended date. Accounting for the two week technician set-back the third milestone was eventually completed by 14/03/2016, and all deliverables were submitted.

A detailed set of requirements for the final product were outlined in the Goal Statement which established firm criteria which the prototype had to meet. The British Standards were read thoroughly and the team endeavoured to adhere to the stringent requirements where possible. The ability to fully comply with these was, however, limited by the nature of the project and the equipment and manufacturing techniques available to the team. The product mass fell in the lower end of the target value at a weigh of 9.9kg and the fold up time was well under the 60 seconds specified at approximately 30 seconds. The folding volume was also within the specified tolerance as this was estimated at 136.8cm^3**.** Moreover, although aesthetics are largely subjective, the efforts of painting, decorating and marketing The Commuter as a high quality product resulted in a visually appealing model. On review, it was agreed by the group and most importantly the client supervisor, Professor James Boyle, that the bike was aesthetically pleasing. Finally, the business plan indicated that scalable mass production of the bike to a cost of £592.74 per unit is possible, which is also below the £600 limit imposed. Therefore, SynopTech successfully adhered to the stringent requirements set by the client at the project's inception.

24. CONCLUSION

The CDIO Initiative is a framework which stresses engineering fundamentals and aims to replicate real-world challenges. There can be no doubt that this project in the technical and commercial development of The Commuter, has adhered to the aims of the initiative. The real-world problems of urbanisation and the associated congestion were tackled through the approach of this folding bicycle. None of the team members had any previous experience designing or building bicycles and so the use of engineering fundamentals was essential. In-depth research was undertaken and Pugh's Total Design Methodology used. This methodology encourages the use of first principles and ensures that a rational and well detailed design is formed. This design process culminated with procurement of materials for manufacture at the end of Semester 1. The following semester the prototype bicycle was manufactured. A number of problems were encountered and overcome during this stage including, perhaps the most notable problem, a slight lack of chain alignment. Despite testing the resolve and initiative of the group, all of these challenges were overcome without straying from the specified goal statement. This resulted in a folding bicycle that met the customer requirements and adhered to the contract outlined at the beginning of the project.

On the whole, the team worked very well together and overcame many unexpected challenges. Perhaps one of the most important traits exhibited by each individual member to achieve this was communication. The varying lines of communication that were employed meant that team members were contactable whenever they might be required to provide information. Although the team worked well it was challenged by the tight timescale and imminent deadlines that required compromise on the design. Therefore it was due to the resilient perseverance and collaboration of all individuals that can be attributed to the final prototype.

Should the project be undertaken again there are, naturally, a number of things that the team would have done differently. The most notable of these would have been a mid-project risk assessment. This review may have allowed some developing risks to be identified and tackled before they caused problems. It should also be considered an essential step as risks are dynamic and this is something that was not fully realised as the project progressed.

On balance, SynopTech, has worked effectively and cohesively as a professional team. Throughout both technical and commercial aspects of the project, the team has been driven to produce a robust design that will enable it to perform to a high standard at the regional CDIO competition. This resilient motivation coupled with a firm understanding of engineering principles has resulted in the development of a dynamic and compact product in The Commuter. The product met all of the clients' requirements, as established in the goal statement, at a weight of 9.9kg, folded capacity of 136.8cm^3, and a folding time of 30seconds. Therefore, despite the setbacks and lessons learned throughout the project, SynopTech's successful development of The Commuter was ultimately realised. The final assessment of the prototype will be conducted at Queens' University Belfast, where SynopTech are looking forward to testing the performance of the bicycle under official conditions.

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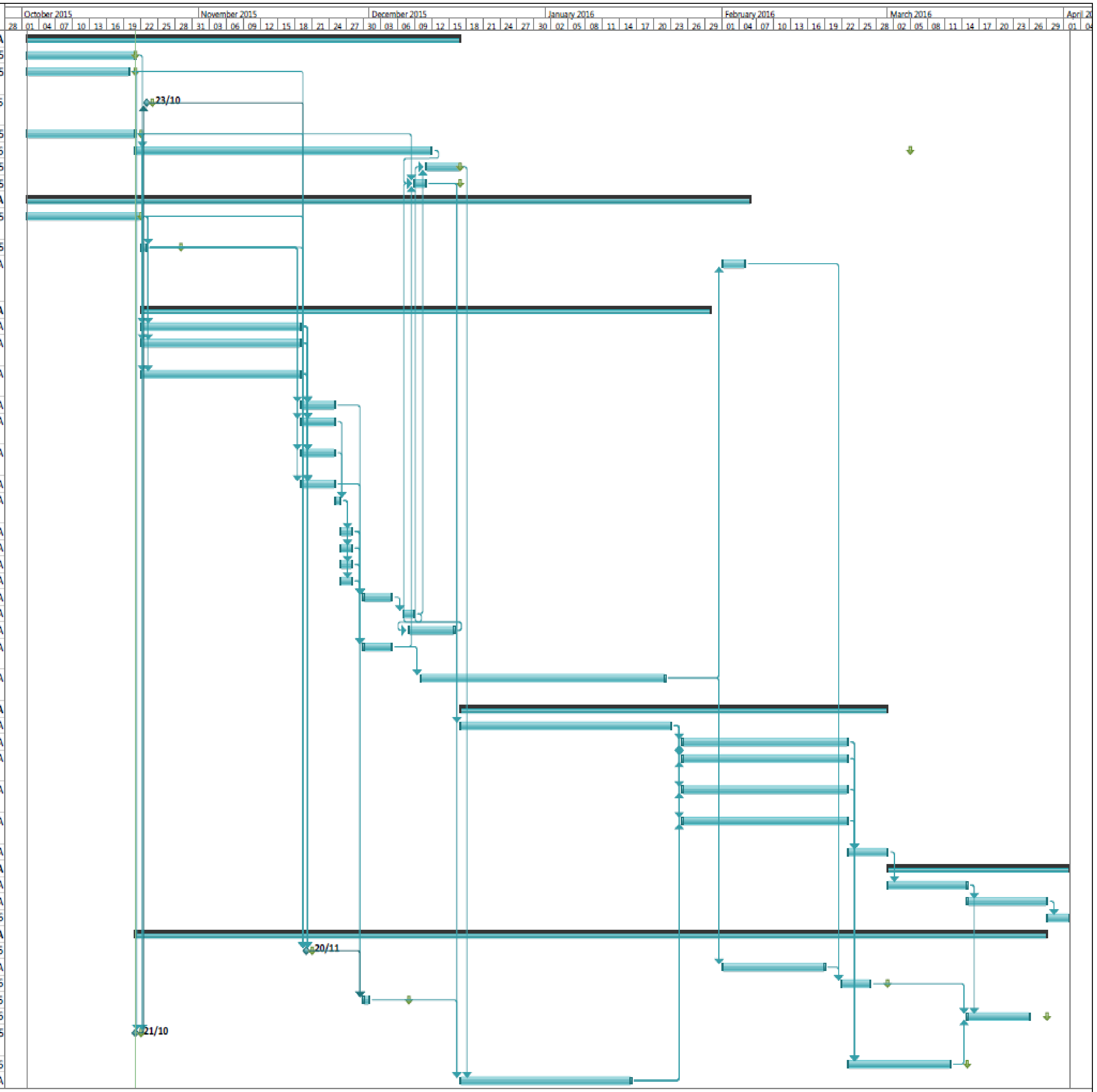
[21] "Wix," [Online]. Available: http://es.wix.com/. [Accessed 2015].

APPENDIX A – PROJECT GANTT CHART

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names	Deadline
1			**Planning**	**54 days**	**Fri 02/10/15**	**Wed 16/12/15**			**NA**
2			Create Contract	13 days	Fri 02/10/15	Tue 20/10/15			Tue 20/10/15
3			Create Gantt Chart	12 days	Fri 02/10/15	Mon 19/10/15			Tue 20/10/15
4			Revision and Submission of Contract	0 days	Fri 23/10/15	Fri 23/10/15	48		Fri 23/10/15
5			Group Role Assignment	13 days	Fri 02/10/15	Tue 20/10/15			Wed 21/10/15
6			Procuring Sponsorship	38 days	Wed 21/10/15	Fri 11/12/15	5		Fri 04/03/16
7			Submit Technical Drawings	4 days	Fri 11/12/15	Wed 16/12/15	28,27		Wed 16/12/15
8			Procurement (Jim Docherty)	2 days	Wed 09/12/15	Thu 10/12/15	28,29,5,6		Wed 16/12/15
9			**Research**	**91 days**	**Fri 02/10/15**	**Fri 05/02/16**			**NA**
10			Initial Market Research	14 days	Fri 02/10/15	Wed 21/10/15			Wed 21/10/15
11			Hire Folding Bike	1 day	Thu 22/10/15	Thu 22/10/15	10		Wed 28/10/15
12			Website information gathering	4 days	Mon 01/02/16	Thu 04/02/16	30		NA
13			**Design**	**72 days**	**Thu 22/10/15**	**Fri 29/01/16**			**NA**
14			Power Train Research + Design	20 days	Thu 22/10/15	Wed 18/11/15	5,10		NA
15			Steering and Wheels Research + Design	20 days	Thu 22/10/15	Wed 18/11/15	10,5		NA
16			Frame and Hinge Research + Design	20 days	Thu 22/10/15	Wed 18/11/15	10,5		NA
17			Safety R+D	4 days	Thu 19/11/15	Tue 24/11/15	14,15,16,11		NA
18			Materials + Manufacturing R+D	4 days	Thu 19/11/15	Tue 24/11/15	14,15,16,11		NA
19			Enviromental considerations R+D	4 days	Thu 19/11/15	Tue 24/11/15	14,15,16,11		NA
20			Intellectual Property R+D	4 days	Thu 19/11/15	Tue 24/11/15	14,15,16,11		NA
21			Chris Cameron Feasability Study	1 day	Wed 25/11/15	Wed 25/11/15	18,19		NA
22			Finalise Design - Chassis	2 days	Thu 26/11/15	Fri 27/11/15	21		NA
23			Finalise Design - Hinge	2 days	Thu 26/11/15	Fri 27/11/15	21		NA
24			Finalise Design - Powertrain	2 days	Thu 26/11/15	Fri 27/11/15	21		NA
25			Finalise Design - Steering	2 days	Thu 26/11/15	Fri 27/11/15	21		NA
26			Finalise Design Assembly	5 days	Mon 30/11/15	Fri 04/12/15	22,23,24,25,20,17		NA
27			CAD Assembly	2 days	Mon 07/12/15	Tue 08/12/15	26		NA
28			Technician Drawings	6 days	Tue 08/12/15	Tue 15/12/15	27		NA
29			Cost (prototype) R+D	5 days	Mon 30/11/15	Fri 04/12/15	22,23,24,25		NA
30			Cost (series production) R+D	31 days	Thu 10/12/15	Thu 21/01/16	29		NA
31			**Construction**	**53 days**	**Thu 17/12/15**	**Mon 29/02/16**			**NA**
32			Material Procurement	27 days	Thu 17/12/15	Fri 22/01/16	8		NA
33			Build chassis	21 days	Mon 25/01/16	Mon 22/02/16	50,32		NA
34			Build hinge mechanism	21 days	Mon 25/01/16	Mon 22/02/16	50,32		NA
35			Build brakes, gears and chains	21 days	Mon 25/01/16	Mon 22/02/16	50,32		NA
36			Build seat and handlebars	21 days	Mon 25/01/16	Mon 22/02/16	50,32		NA
37			Assemble bike	5 days	Tue 23/02/16	Mon 29/02/16	33,34,35,36		NA
38			**Testing**	**24 days**	**Tue 01/03/16**	**Fri 01/04/16**			**NA**
39			Final Safety checks	10 days	Tue 01/03/16	Mon 14/03/16	37		NA
40			Testing	10 days	Tue 15/03/16	Mon 28/03/16	39		NA
41			Competition	4 days	Tue 29/03/16	Fri 01/04/16	40		Fri 29/04/16
42			**Academic Deadlines**	**114 days**	**Wed 21/10/15**	**Mon 28/03/16**			**NA**
43			Interim Report Submission	0 days	Fri 20/11/15	Fri 20/11/15	3,4,5,10,11,14,15,		Fri 20/11/15
44			Website design	14 days	Mon 01/02/16	Thu 18/02/16	30		NA
45			Website creation	5 days	Mon 22/02/16	Fri 26/02/16	44,12		Mon 29/02/16
46			Semester 1 Presentation	1 day	Mon 30/11/15	Mon 30/11/15	22,25,43		Mon 07/12/15
47			Final Assessment (28 March)	9 days	Tue 15/03/16	Fri 25/03/16	45,49,39		Mon 28/03/16
48			One-to-one Group Meetings (21st October)	0 days	Wed 21/10/15	Wed 21/10/15	2,3,5		Wed 21/10/15
49			Final Report (14th March)	14 days	Tue 23/02/16	Fri 11/03/16	33,34,35,36		Mon 14/03/16
50			Exam Leave	22 days	Thu 17/12/15	Fri 15/01/16	7,8,46		NA



APPENDIX B – FULL MARKET ANALYSIS

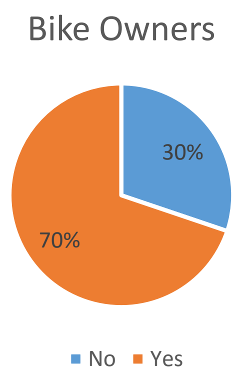
Market Research was conducted by means of a questionnaire on 106 people, ranging from 20 to 60 years old, asking multiple questions that revealed certain trends in the market. This type of research is important for determining how the product can appeal to the mass market, and how certain aspects of the product should be pushed more than others.

To start with, 70% of the sample market owned a bicycle (Graph 1). They were then asked why they own one and how often it is used, to which, many admitted to using it infrequently, for recreation or for transport. All three of these options held similar market portions (Graph 2). Of the 30% that don't own a bicycle, half said it was because of no need for one (Graph 3), though 13% replied that it was due to lack of storage space at home. Having a folding bicycle could potentially eliminate this 13% due to its small storage space requirements. The data in Graph 4 explains the ways in which people commute. As shown, 10% of people consider the bicycle as a form of transportation for commuting purposes. The use of public transportation as an option is also useful, as the folding bike can be used in conjunction with public transport. A further 29% of people use public transport which makes it the second biggest market, and therefore a large market to try and sell to.

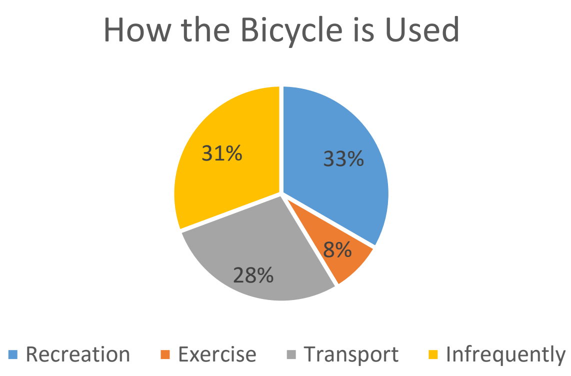
The market research also revealed that the vast majority of those surveyed (83%) would prefer to purchase a bicycle from a shop (Graph 5), as they would like to test ride it before purchasing. This reveals that bicycle shops must be targeted to get The Commuter as widely distributed as possible when it goes on general sale. A costing analysis was then completed to show what prices people are willing to pay for folding bicycles (Graph 6). This highlighted that most people are unwilling to pay high prices, with the majority electing to pay £300-£400. Moreover, only 55% of people also said that they were willing to buy a fold-up bike, while 45% wouldn't (Graph 7). The 55% were then asked what they would use the bike for, and commuting came out as the largest response (Graph 8). This is relevant as the CDIO Worldwide Challenge is attempting to tackle increasing urban populations and increasing congestion. The 45% who said they were not interested were mainly split between having no need for a folding bicycle, or disliking the design and having a preference for the standard design (Graph 9). Notably, 18% revealed that their reservations arose from a belief that there were design or safety issues with a folding bicycle, and this could be something to focus on when advertising The Commuter.

This idea was expanded upon (Graph 10) and the research went on to ask about the safety of a folding bicycle relative to traditional models. When asked if they felt that a folding bicycle was as safe as a fixed traditional model, the majority answered that they did not know enough about the safety to say so or not. This again reinforces the needs to focus on safety when advertising. The penultimate question was regarding how the bicycle should be powered (Graph 11) and this illustrated the swing in the market towards conventional human-powered methods, with a hybrid human-electric coming in second place. Finally, Graph 12 details whether or not those surveyed would prefer to buy a fixed or a folding bicycle, and unfortunately fixed won by a significant margin of 77%. This suggests that the advertising campaign will also need to strongly emphasise the advantages of folding bicycles over traditional models.

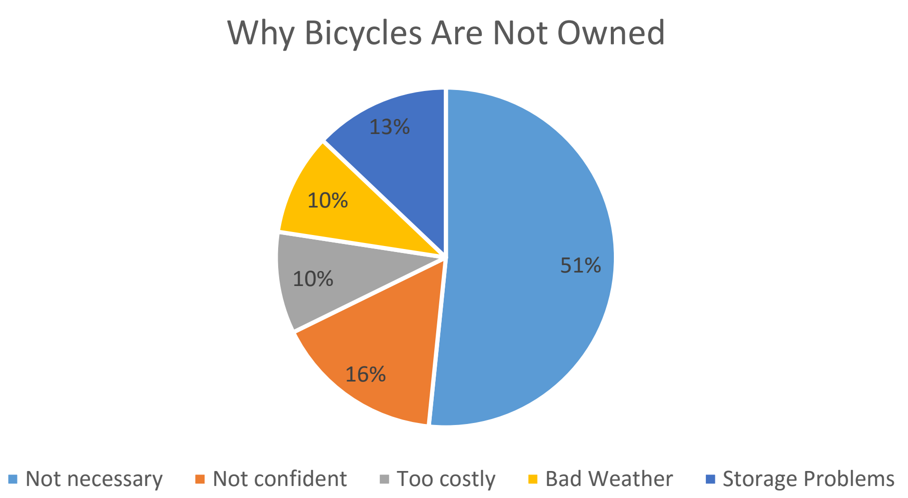
Graph 1



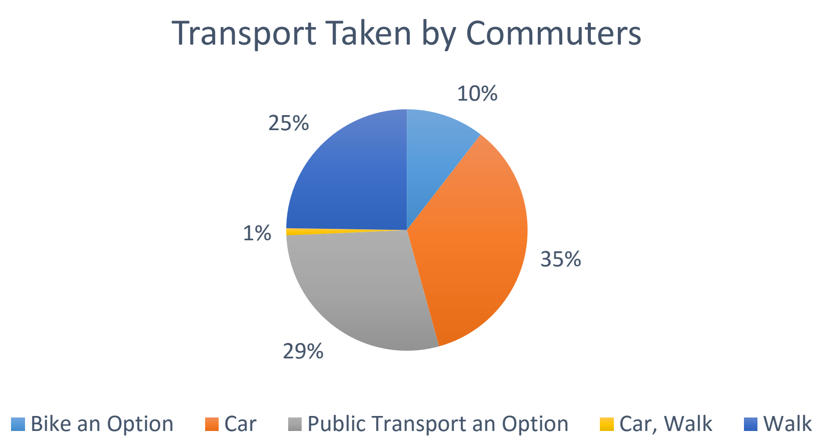
Graph 2



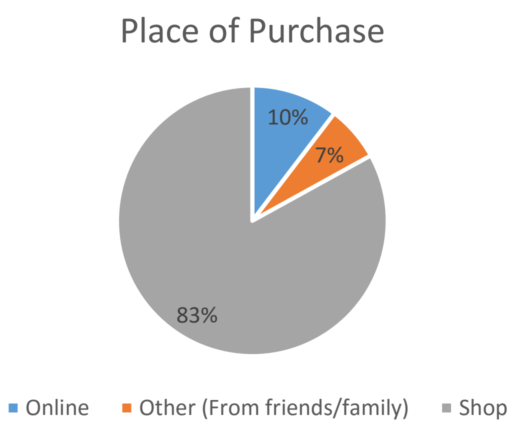
Graph 3



Graph 4

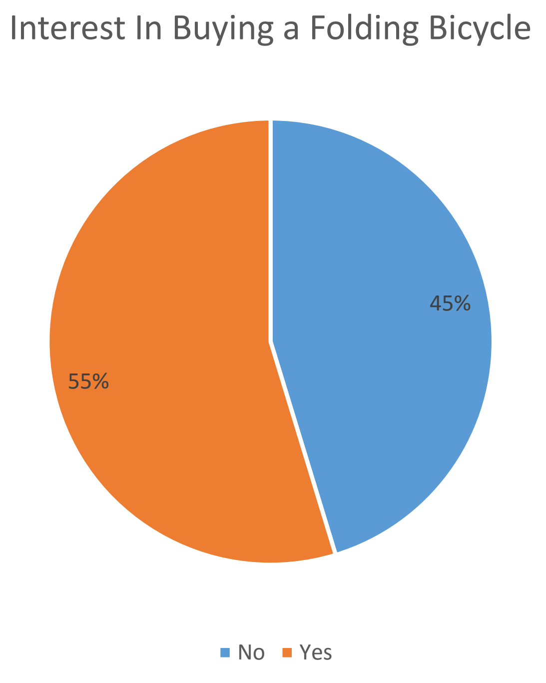


Graph 5

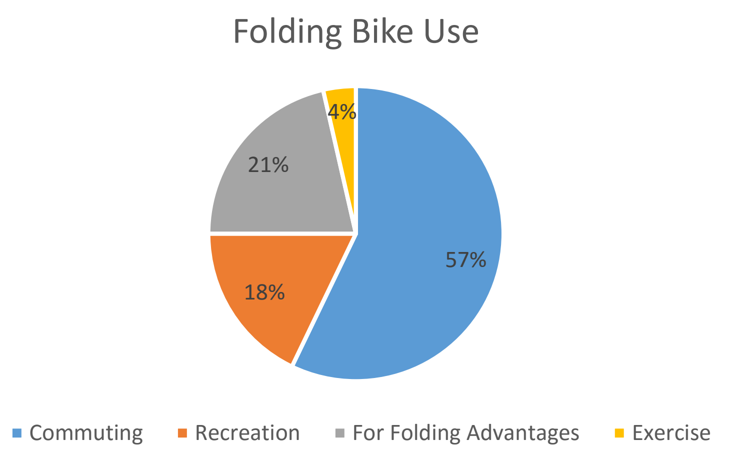


Graph 6

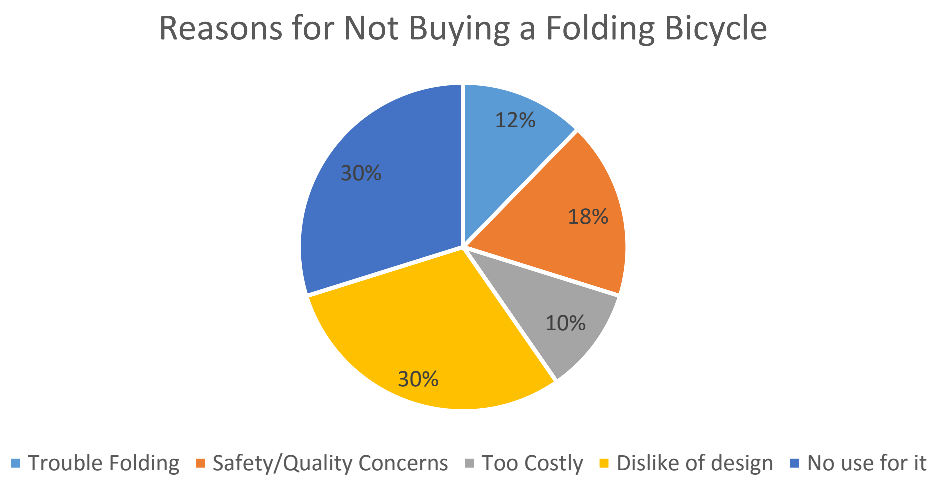
Graph 7



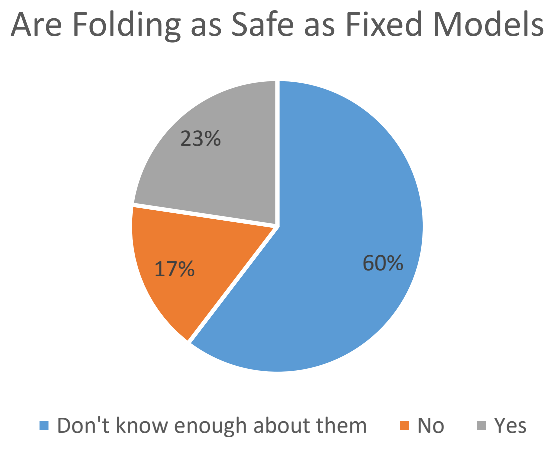
Graph 8



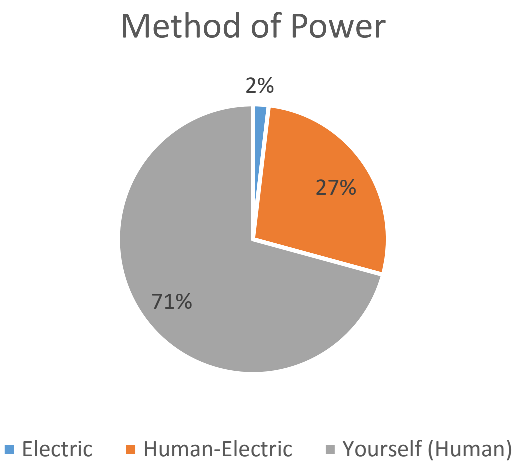
Graph 9



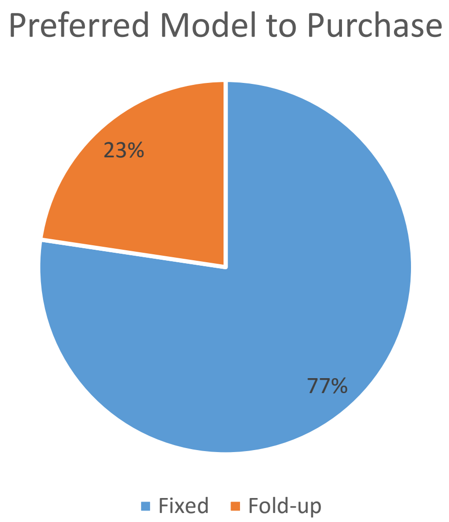
Graph 10



Graph 11



Graph 12



APPENDIX C – PRODUCT DESIGN SPECIFICATION

1. Cost

a. Prototype should be able to be built within £600 budget

b. Should be minimised in order to maximise budget on optional components

c. Be able to be mass-produced at £500 per unit and be sold for a profit

2. Weight

a. Should be kept below 20kg

b. Should be minimised without affecting other factors

3. Performance

a. Should be able to perform well in competition events

b. Be comfortable to ride

c. Should reach a maximum speed and be agile through corner sections

4. Aesthetics

a. Look like designs that the market research dictates people will buy

5. Safety

a. Should adhere to all safety standards as in BS EN ISO 4210-2:2014

6. Fold-up Time

a. Should have a maximum fold-up time of 60 seconds

b. Be minimised by making the process as simple as possible

7. Ease of Manufacture

a. Must be capable of being manufactured within university facilities

b. Manufacturing costs should be minimised by using simple methods

8. Fold-up Volume

a. Should have a maximum folded volume of 300 litres

b. Be minimised by making the fold-up shape as cubic as possible

APPENDIX D – INDIVIDUAL CONCEPT GENERATION

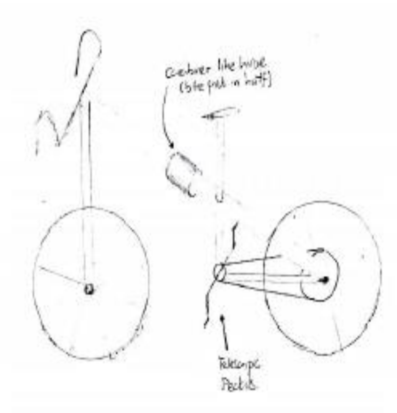


Figure C1 – Concept 1

Figure C7 - Concept 2

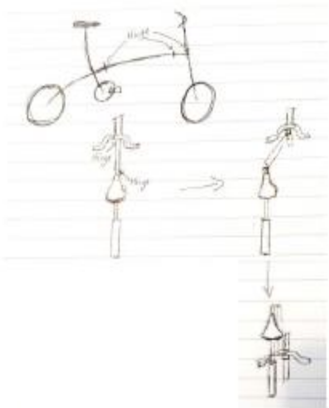


Figure C3 – Concept 3

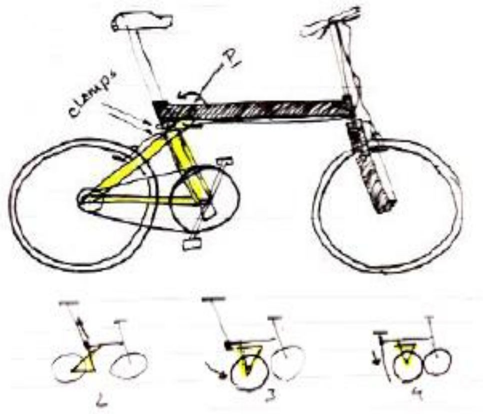


Figure C4 – Concept 4

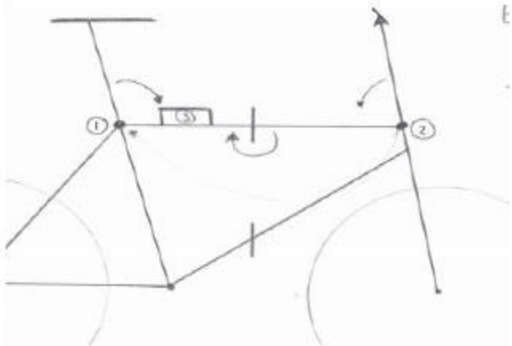


Figure C5 – Concept 5

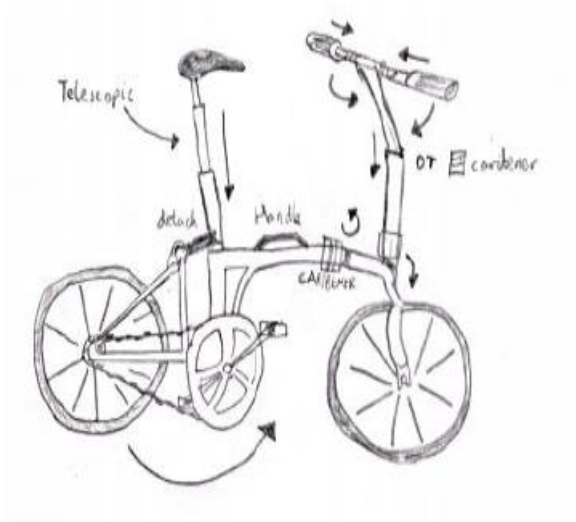


Figure C6 – Concept 6

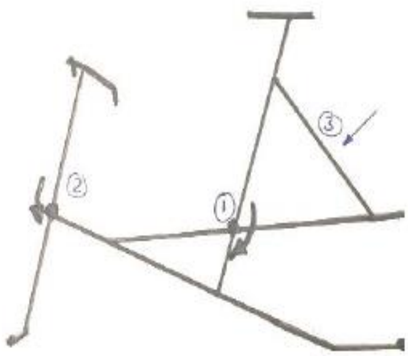
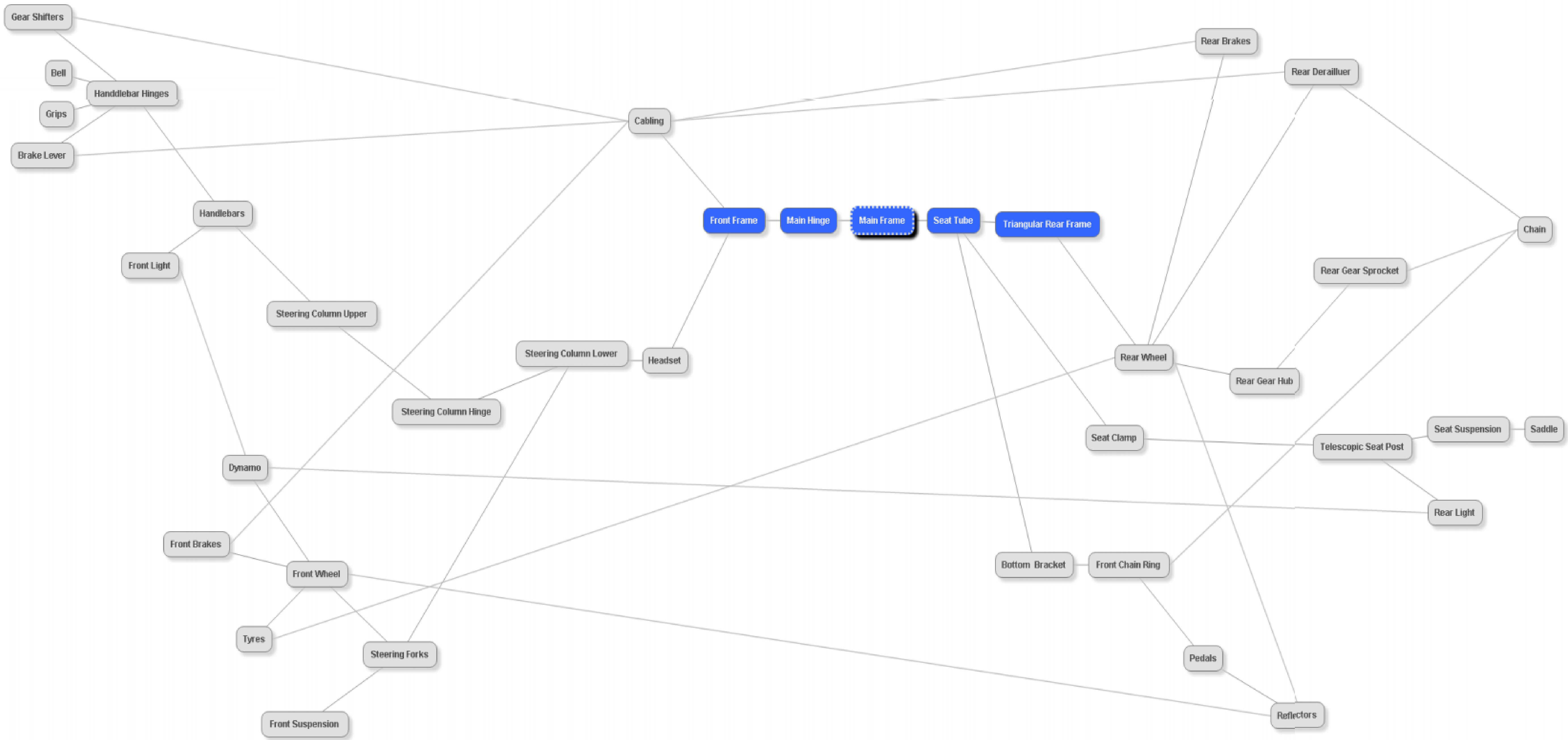
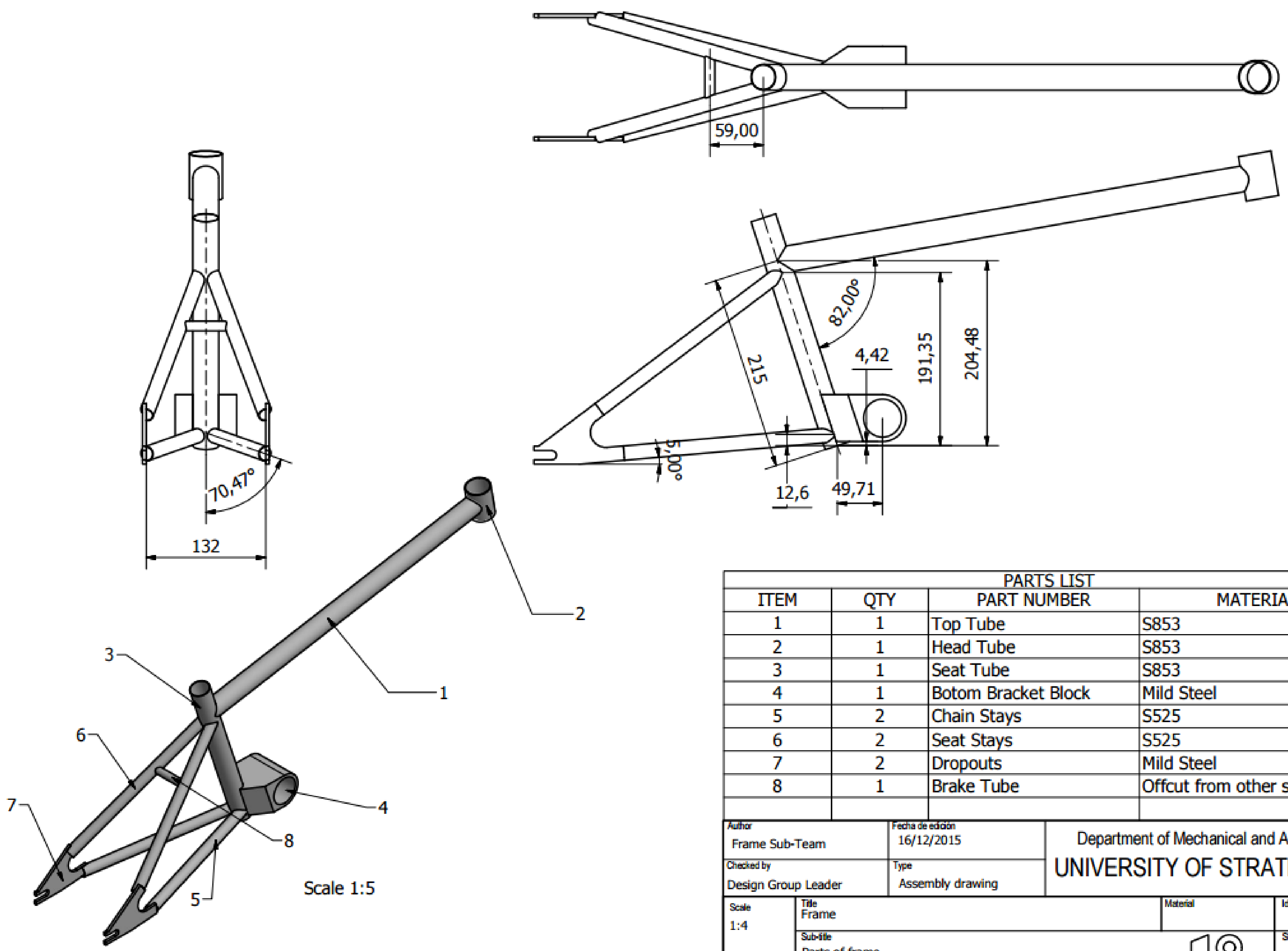


Figure C8 – Concept 7

APPENDIX E – DESIGN CONNECTIVITY MAP


Gear Shifters
Bell
Handdlebar Hinges
Grips
Brake Lever
Cabling
Rear Brakes
Rear Derailluer
Handlebars
Front Light
Front Frame
Main Hinge
Main Frame
Seat Tube
Triangular Rear Frame
Chain
Rear Gear Sprocket
Steering Column Upper
Steering Column Lower
Headset
Rear Wheel
Rear Gear Hub
Steering Column Hinge
Seat Clamp
Seat Suspension
Saddle
Telescopic Seat Post
Dynamo
Rear Light
Front Brakes
Front Wheel
Bottom Bracket
Front Chain Ring
Tyres
Steering Forks
Pedals
Reflectors
Front Suspension

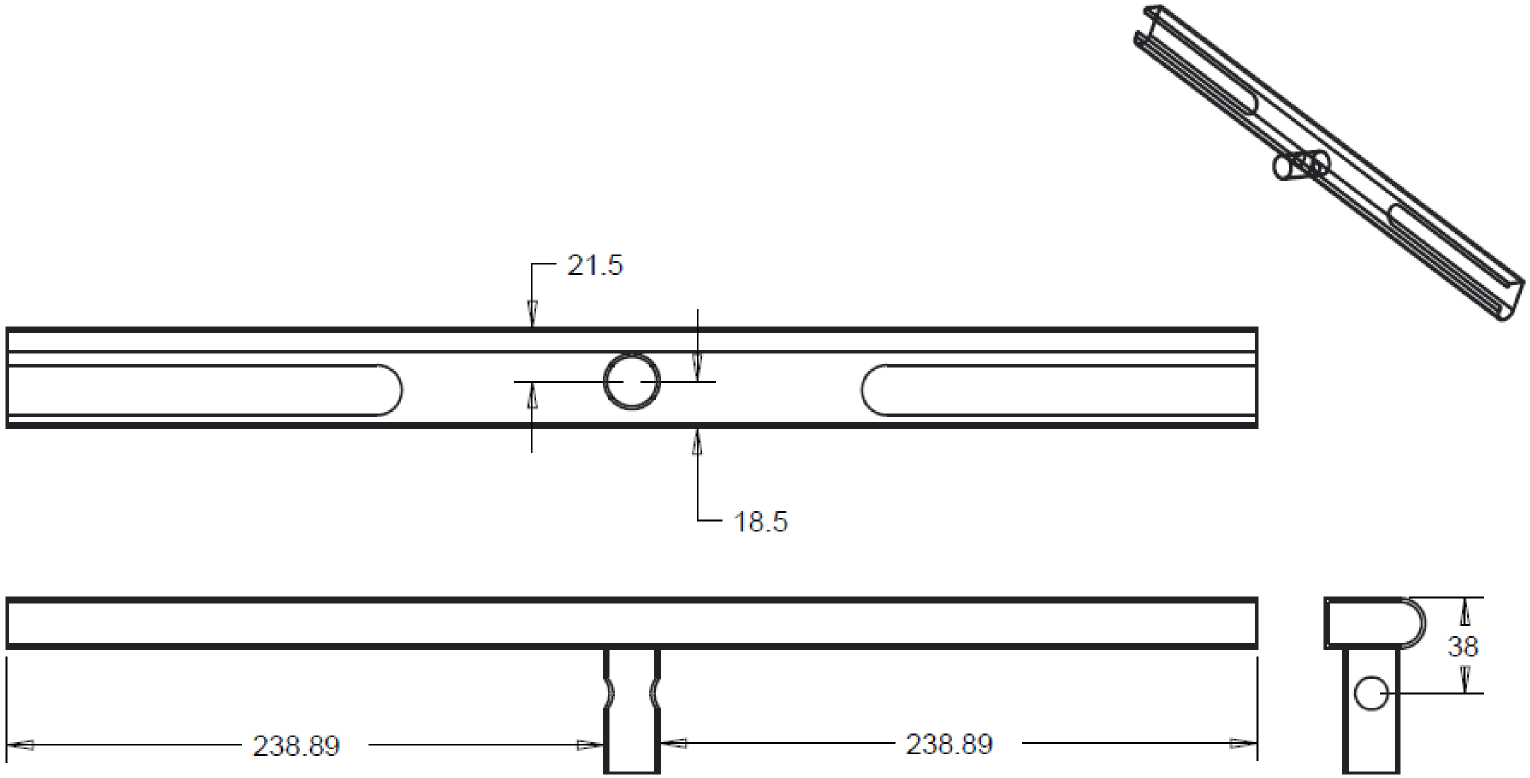
APPENDIX F – TECHNICAL DRAWINGS



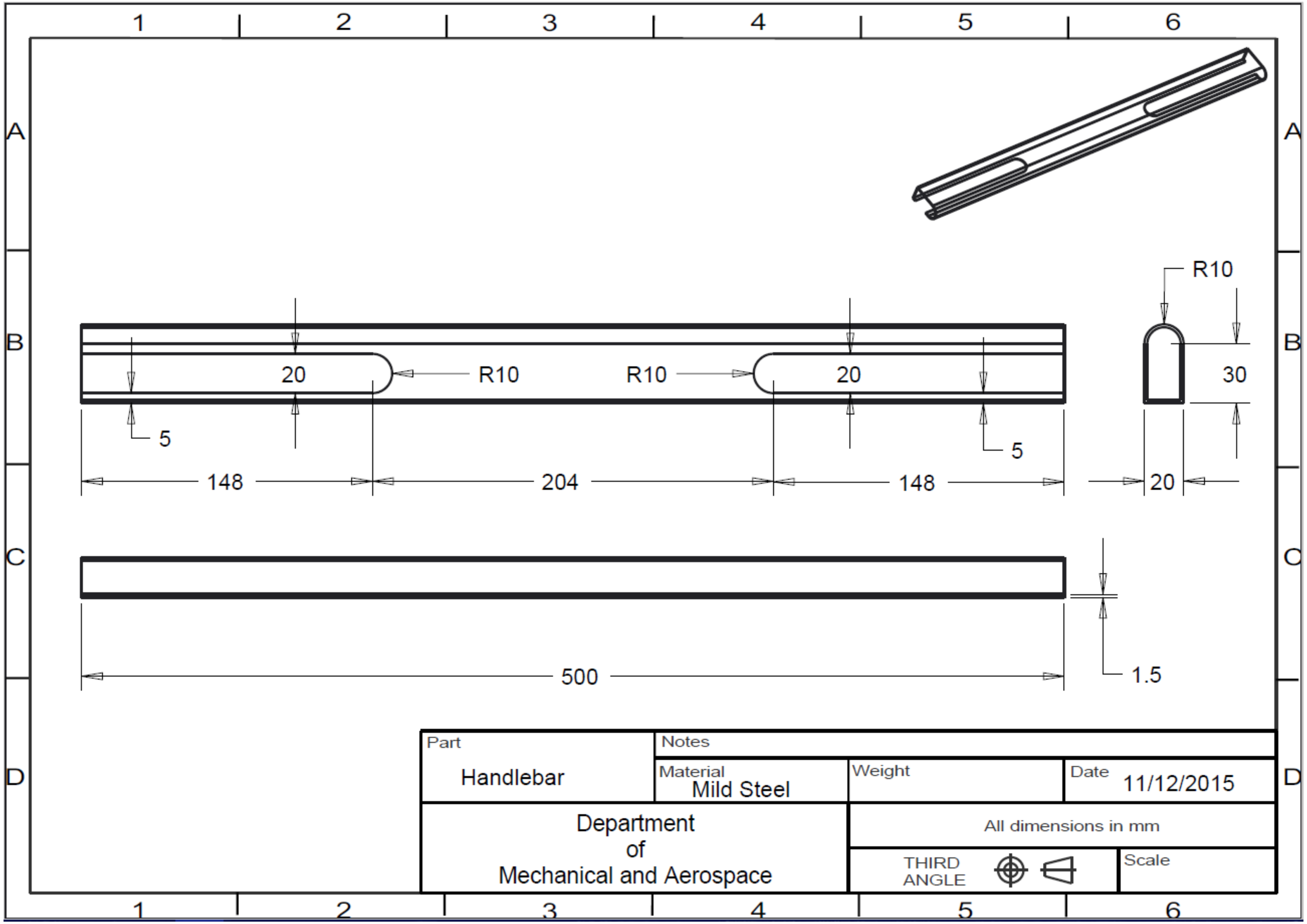
PARTS LIST			
ITEM	QTY	PART NUMBER	MATERIAL
1	1	Top Tube	S853
2	1	Head Tube	S853
3	1	Seat Tube	S853
4	1	Botom Bracket Block	Mild Steel
5	2	Chain Stays	S525
6	2	Seat Stays	S525
7	2	Dropouts	Mild Steel
8	1	Brake Tube	Offcut from other stuff

Author: Frame Sub-Team	Fecha de edición: 16/12/2015	Department of Mechanical and Aerospace UNIVERSITY OF STRATHCLYDE
Checked by: Design Group Leader	Type: Assembly drawing	

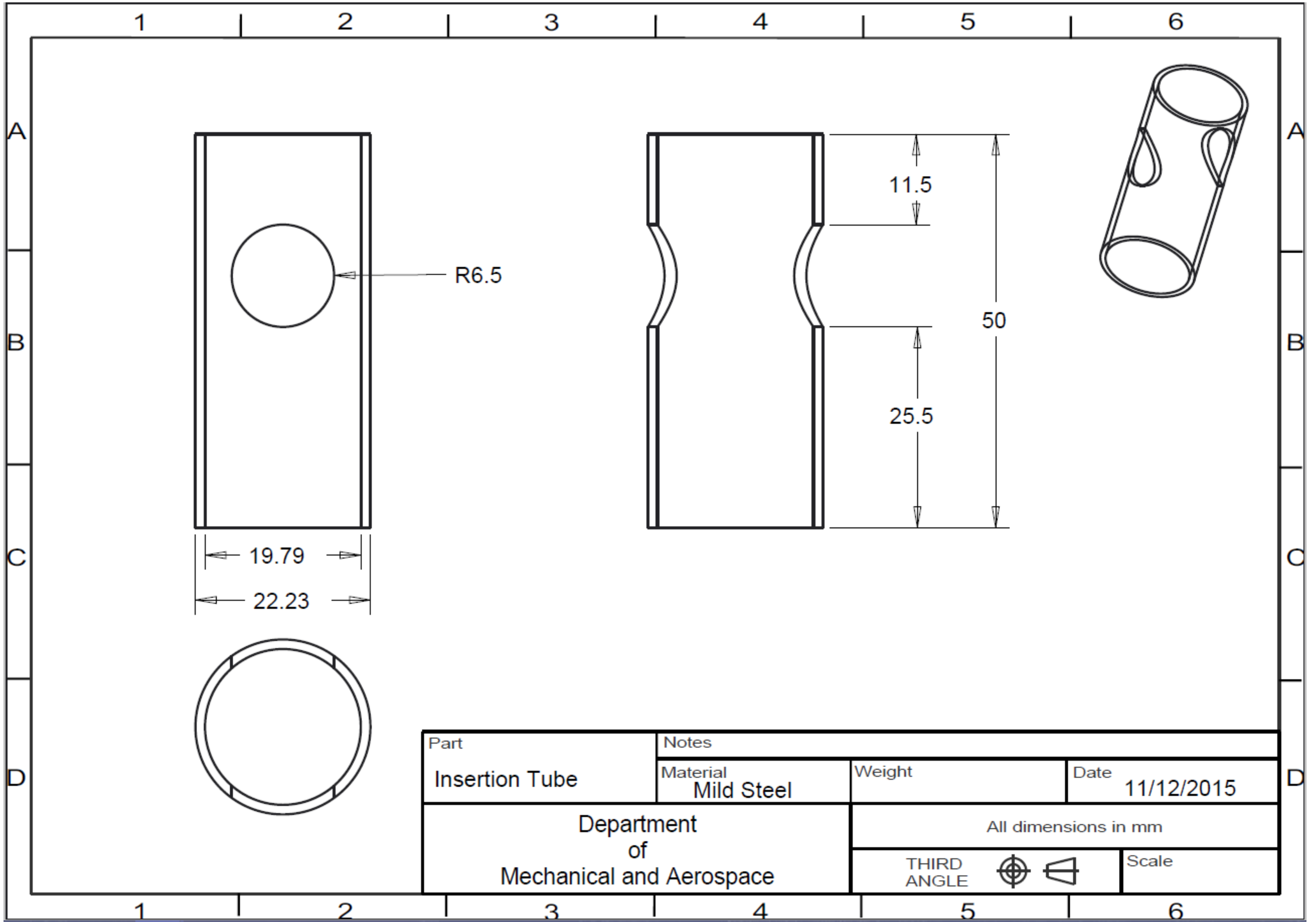
Scale: 1:4	Title: Frame	Material:	Identification:
	Sub-title: Parts of frame		Sheet Num.

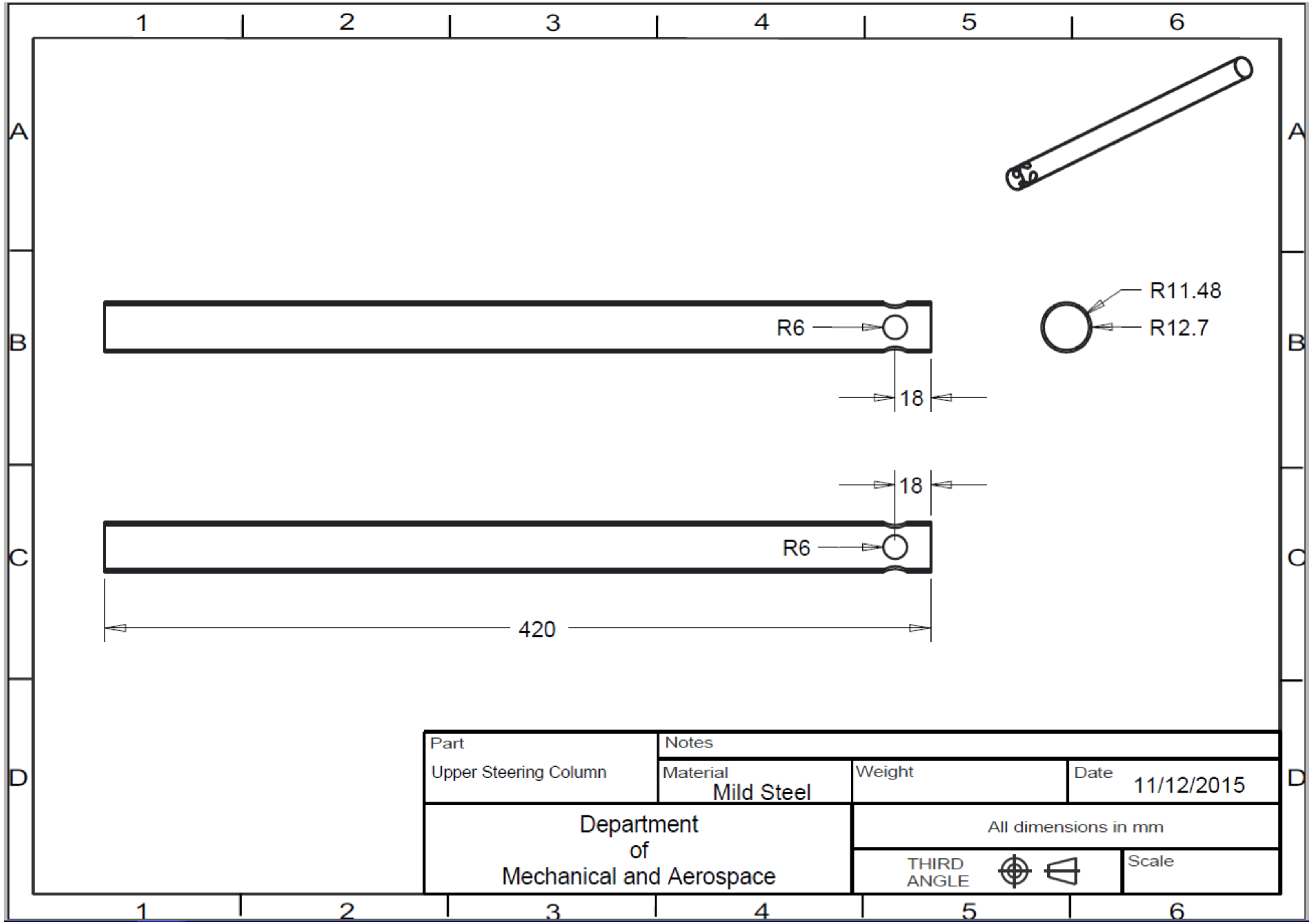


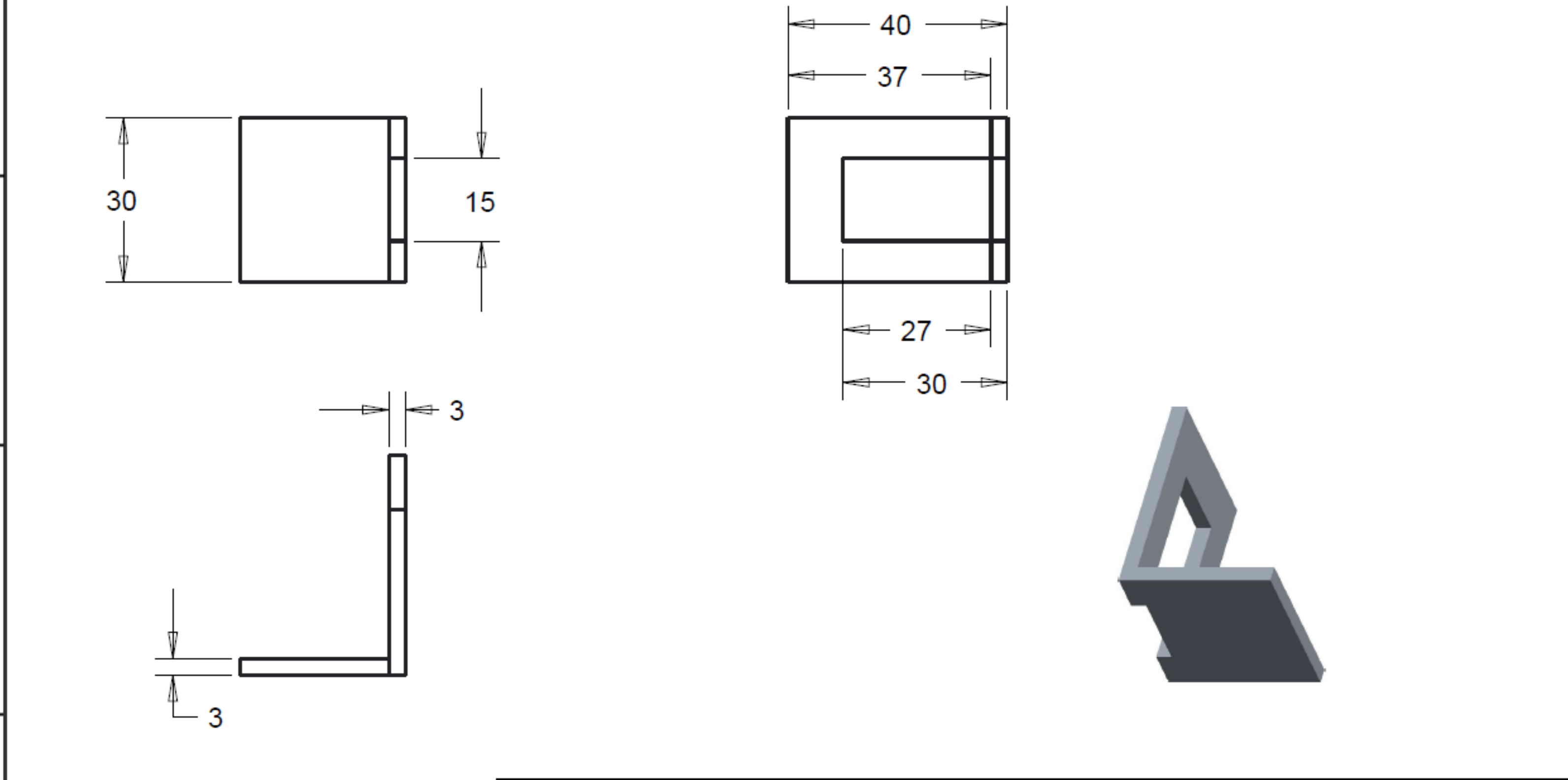
Part Handlebar Assembly	Notes		
	Material	Weight	Date 11/12/2015
Department of Mechanical and Aerospace	All dimensions in mm		
	THIRD ANGLE		Scale



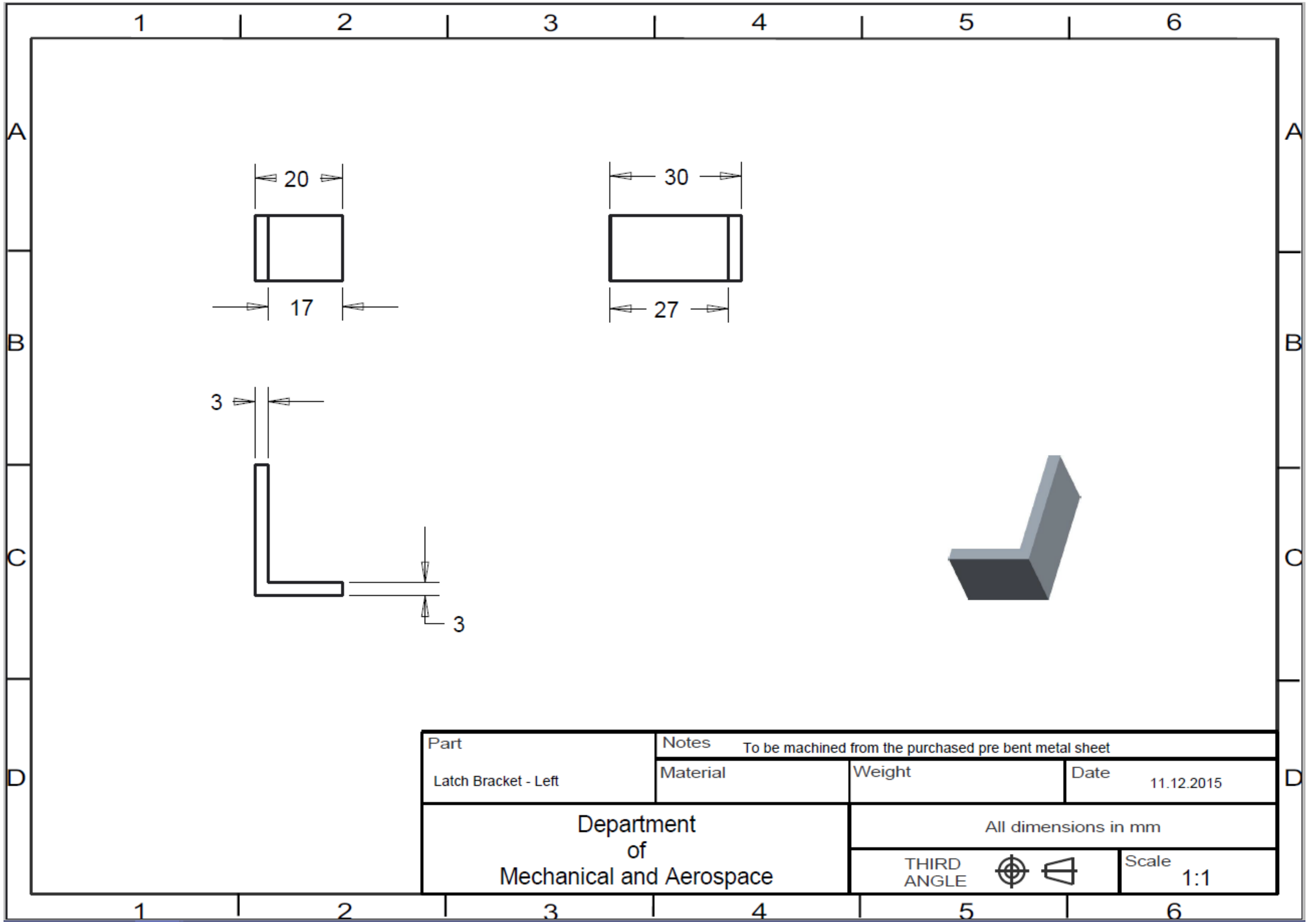
R10
20
R10
R10
20
5
5
30
148
204
148
20
500
1.5
Part
Handlebar
Notes
Material
Mild Steel
Weight
Date
11/12/2015
Department
of
Mechanical and Aerospace
All dimensions in mm
THIRD ANGLE
Scale

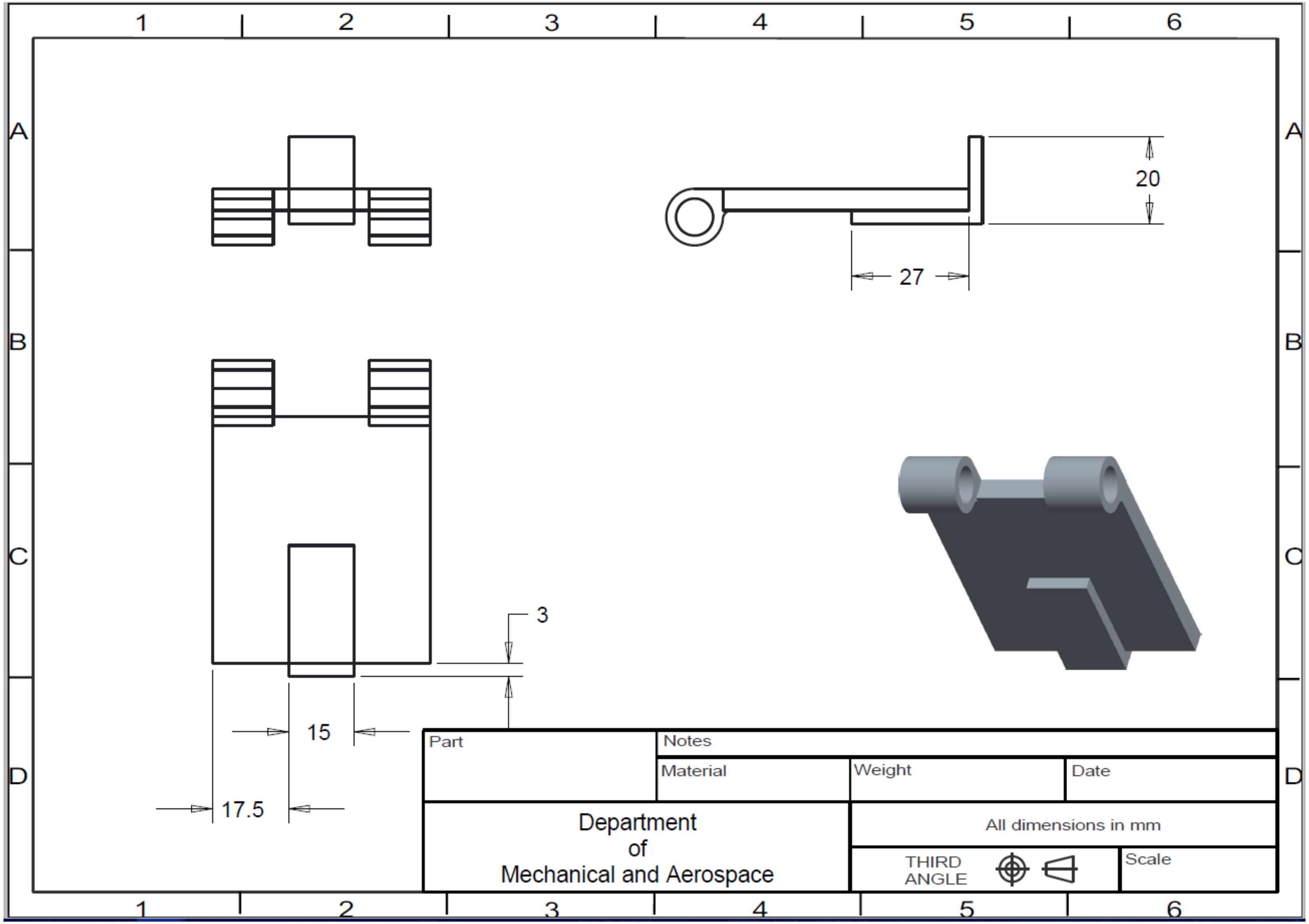

R6.5
19.79
22.23
11.5
50
25.5
Part
Insertion Tube
Notes
Material
Mild Steel
Weight
Date
11/12/2015
Department
of
Mechanical and Aerospace
All dimensions in mm
THIRD
ANGLE
Scale

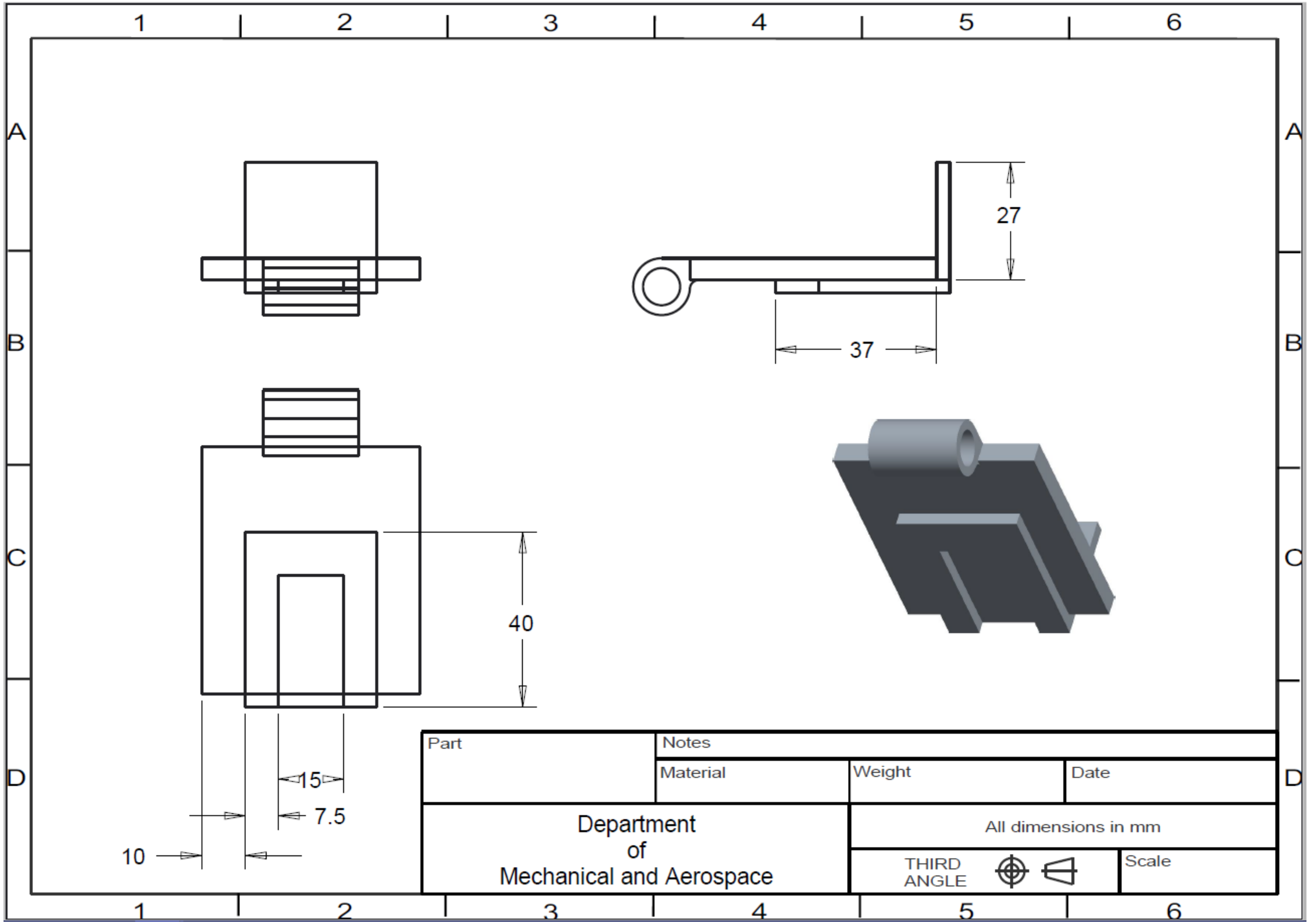

1
2
3
4
5
6
A
B
C
D
R11.48
R12.7
R6
18
18
R6
420
Part
Upper Steering Column
Notes
Material
Mild Steel
Weight
Date
11/12/2015
Department
of
Mechanical and Aerospace
All dimensions in mm
THIRD ANGLE
Scale

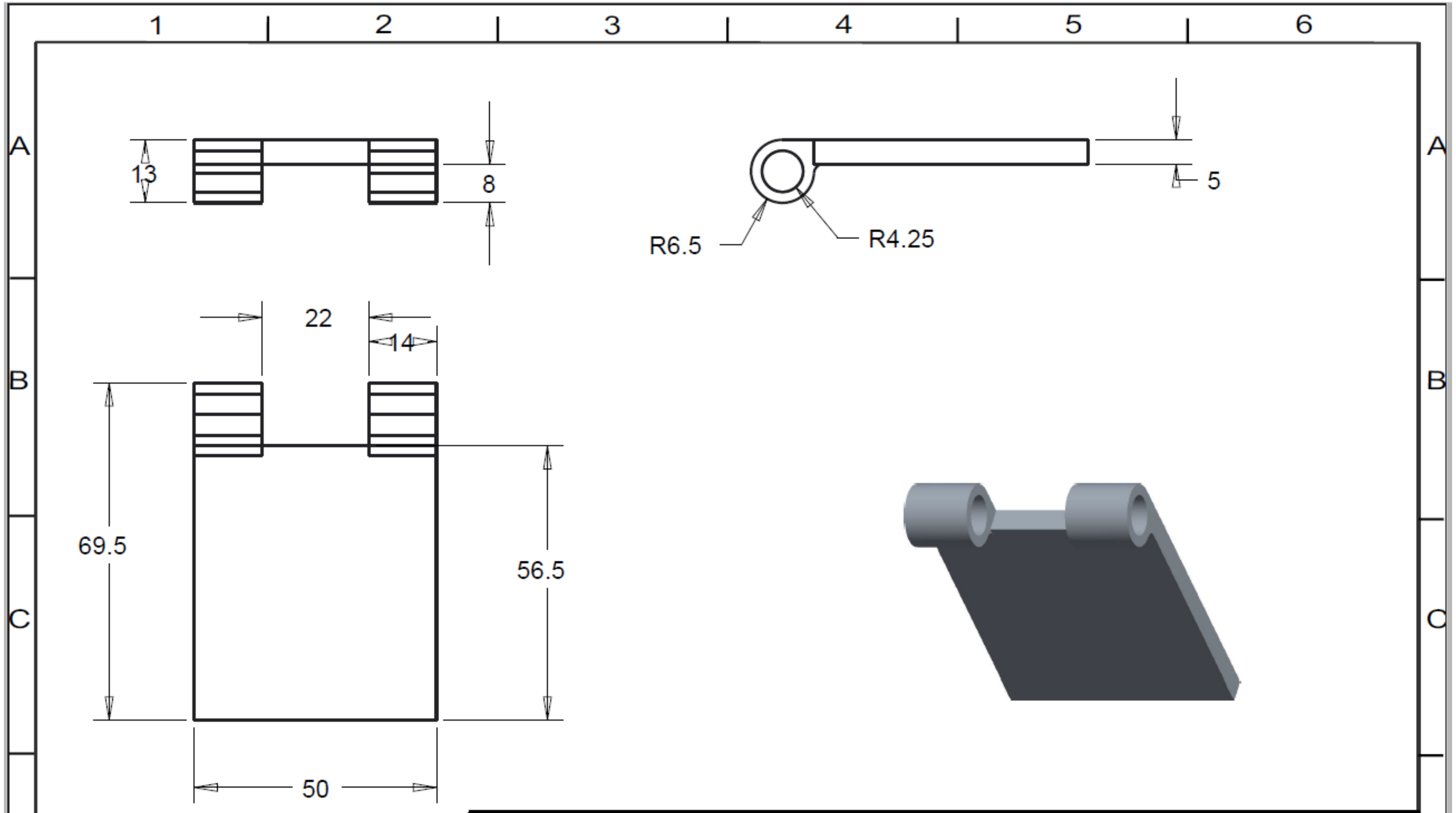


Part: Latch Bracket - Rught	Notes: To be machined from the purchased pre bent metal sheet		
	Material	Weight	Date: 11.12.2015
Department of Mechanical and Aerospace	All dimensions in mm		
	THIRD ANGLE		Scale: 1:1

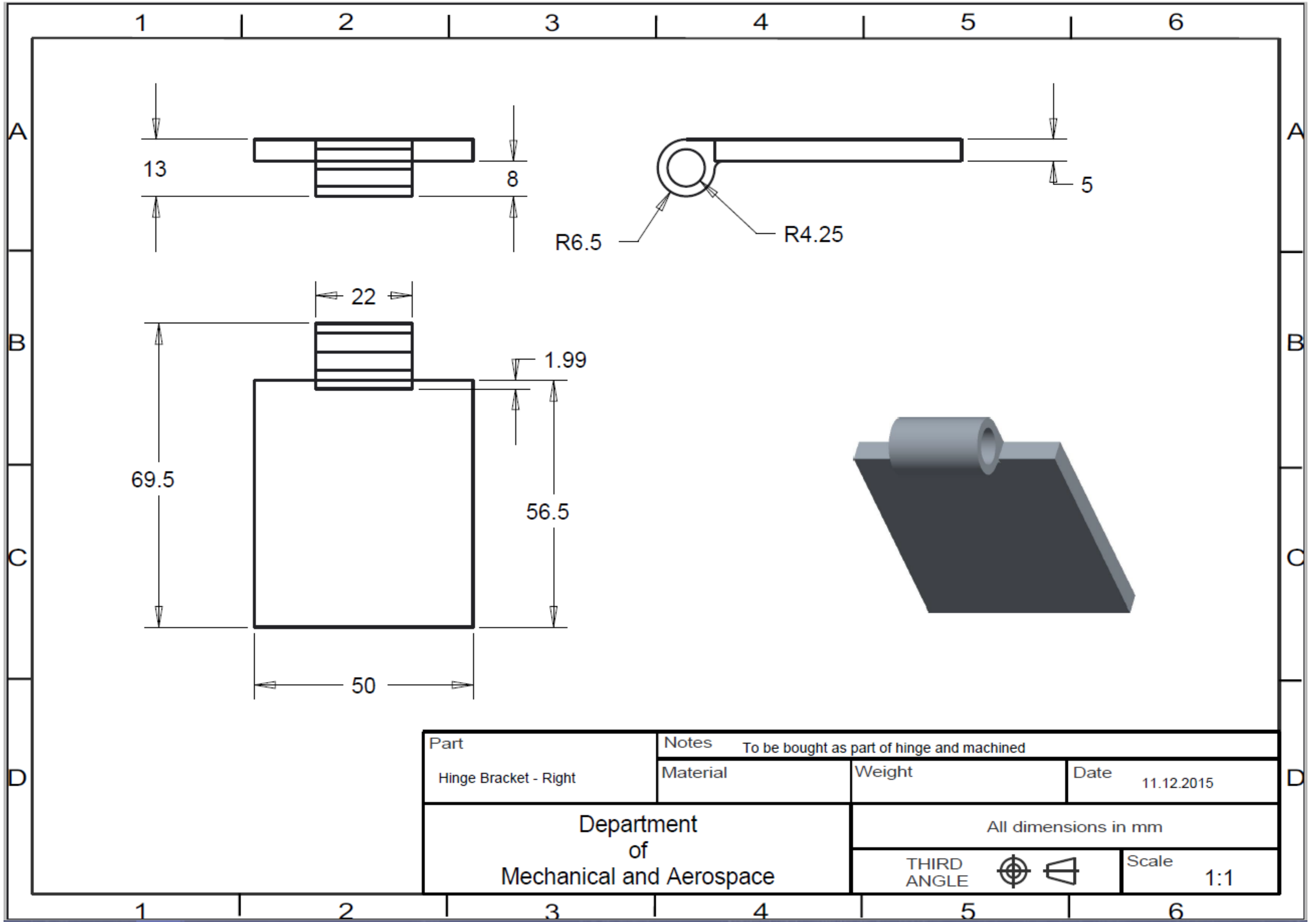

20
17
30
27
3
3
Part
Latch Bracket - Left
Notes
To be machined from the purchased pre bent metal sheet
Material
Weight
Date
11.12.2015
Department of Mechanical and Aerospace
All dimensions in mm
THIRD ANGLE
Scale
1:1


1
2
3
4
5
6
A
B
C
D
20
27
3
15
17.5
Part
Notes
Material
Weight
Date
Department
of
Mechanical and Aerospace
All dimensions in mm
THIRD
ANGLE
Scale

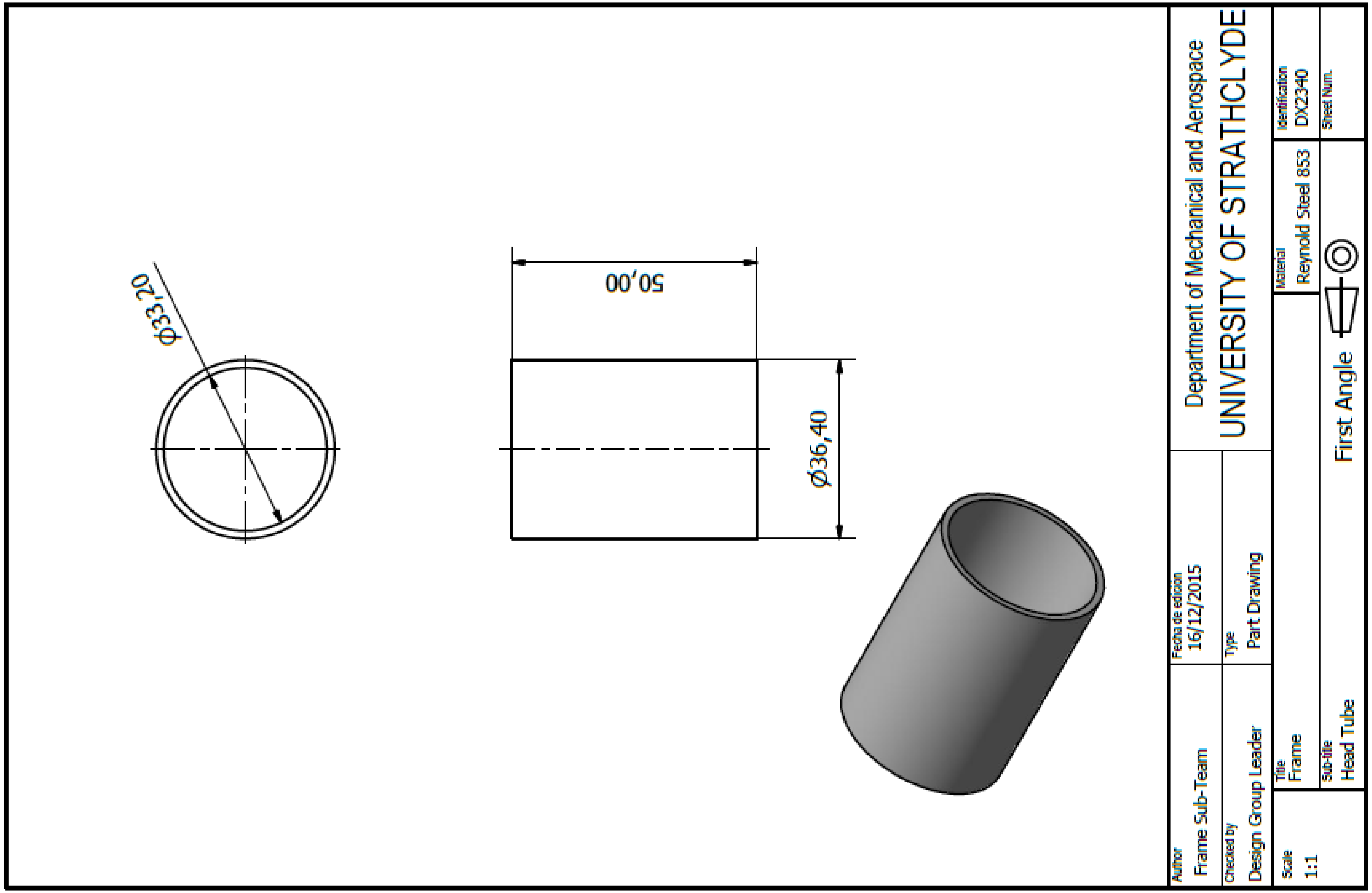

1
2
3
4
5
6
A
B
C
D
27
37
40
15
7.5
10
Part
Notes
Material
Weight
Date
Department
of
Mechanical and Aerospace
All dimensions in mm
THIRD
ANGLE
Scale



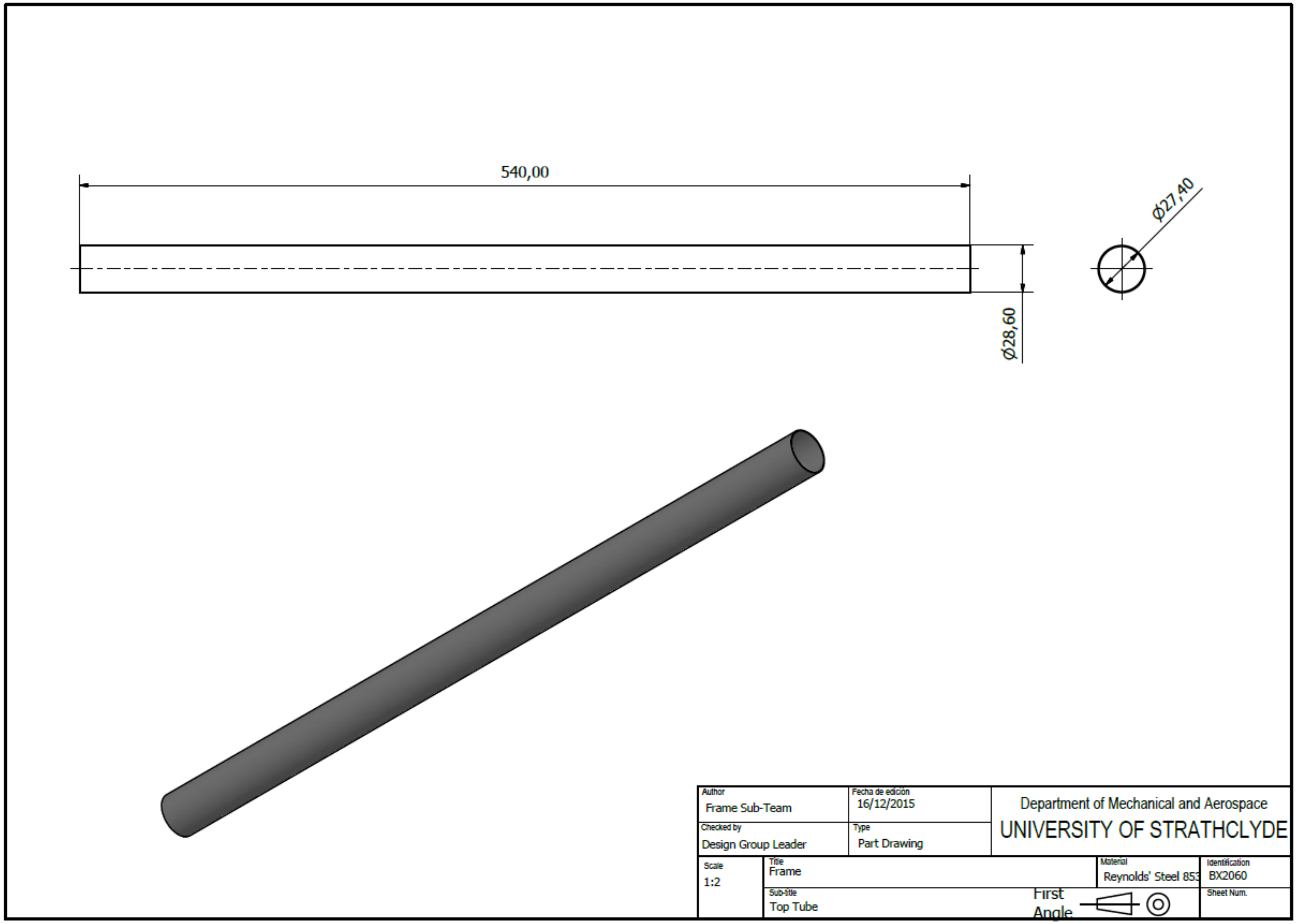
Part: Hinge Bracket - Left	Notes: To be bought as part of the hinge and machined		
	Material	Weight	Date: 11.12.2015
Department of Mechanical and Aerospace	All dimensions in mm		
	THIRD ANGLE		Scale: 1:1

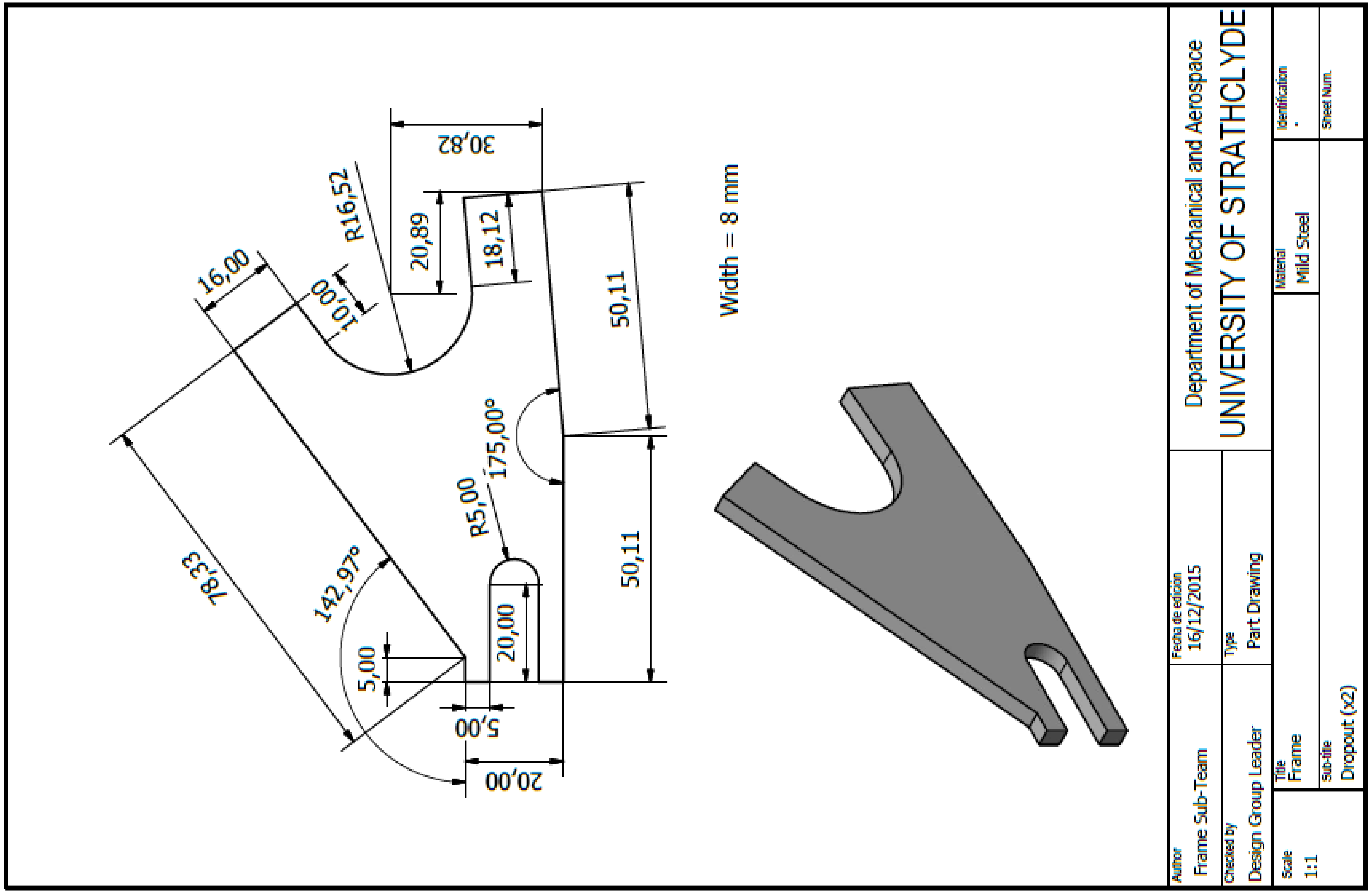


13
8
R6.5
R4.25
5
22
1.99
69.5
56.5
50
Part
Hinge Bracket - Right
Notes
To be bought as part of hinge and machined
Material
Weight
Date
11.12.2015
Department
of
Mechanical and Aerospace
All dimensions in mm
THIRD
ANGLE
Scale
1:1



ϕ33,20
50,00
ϕ36,40
Department of Mechanical and Aerospace
UNIVERSITY OF STRATHCLYDE
Author
Frame Sub-Team
Checked by
Design Group Leader
Fecha de edición
16/12/2015
Type
Part Drawing
Scale
1:1
Title
Frame
Sub-title
Head Tube
First Angle
Material
Reynold Steel 853
Identification
DX2340
Sheet Num.


540,00
Ø27,40
Ø28,60
Author
Frame Sub-Team
Fecha de edición
16/12/2015
Department of Mechanical and Aerospace
UNIVERSITY OF STRATHCLYDE
Checked by
Design Group Leader
Type
Part Drawing
Scale
1:2
Title
Frame
Material
Reynolds' Steel 853
Identification
BX2060
Sub-title
Top Tube
First Angle
Sheet Num.


30,82
R16,52
16,00
10,00
20,89
18,12
50,11
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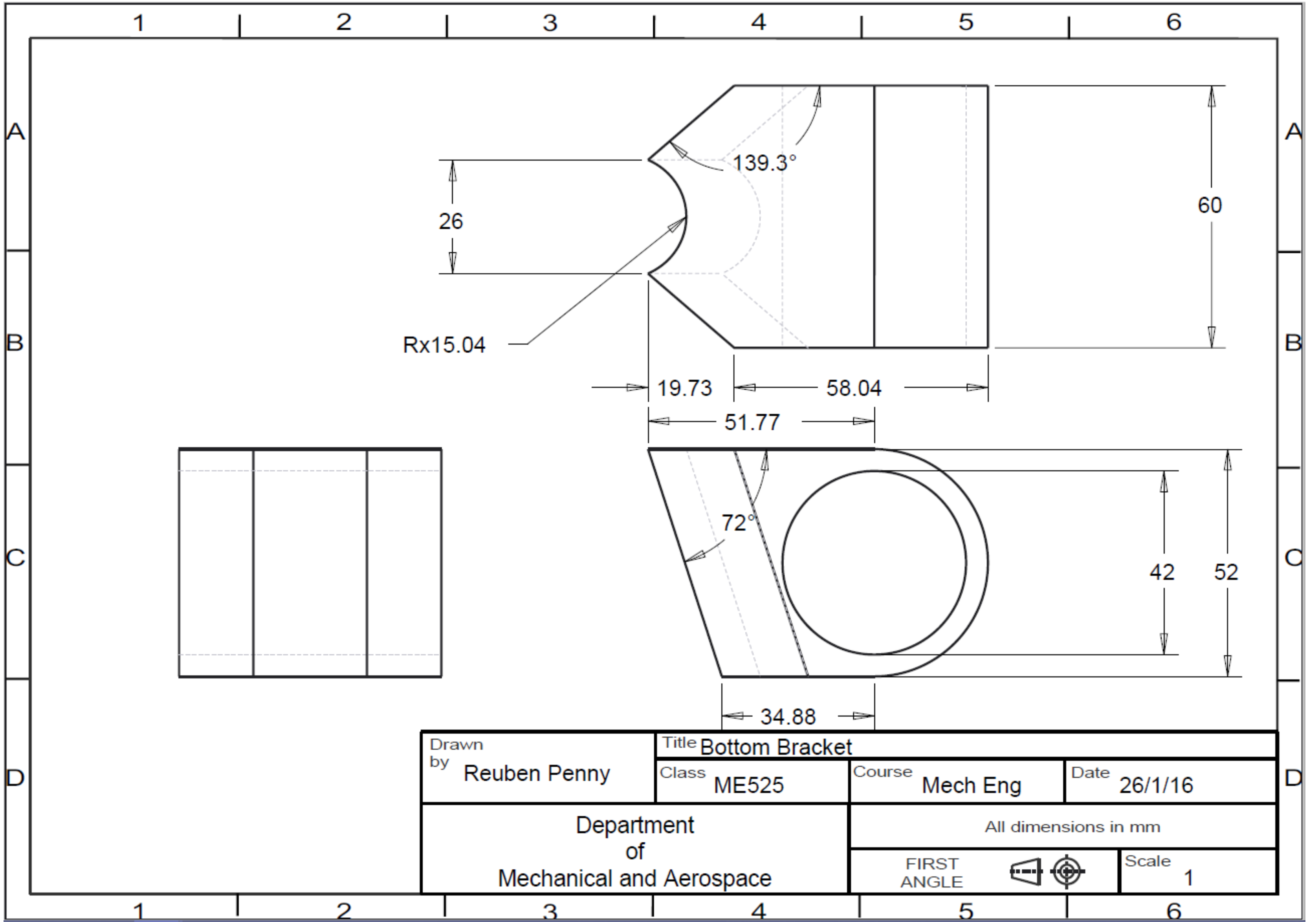
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Reuben Penny
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Mechanical and Aerospace
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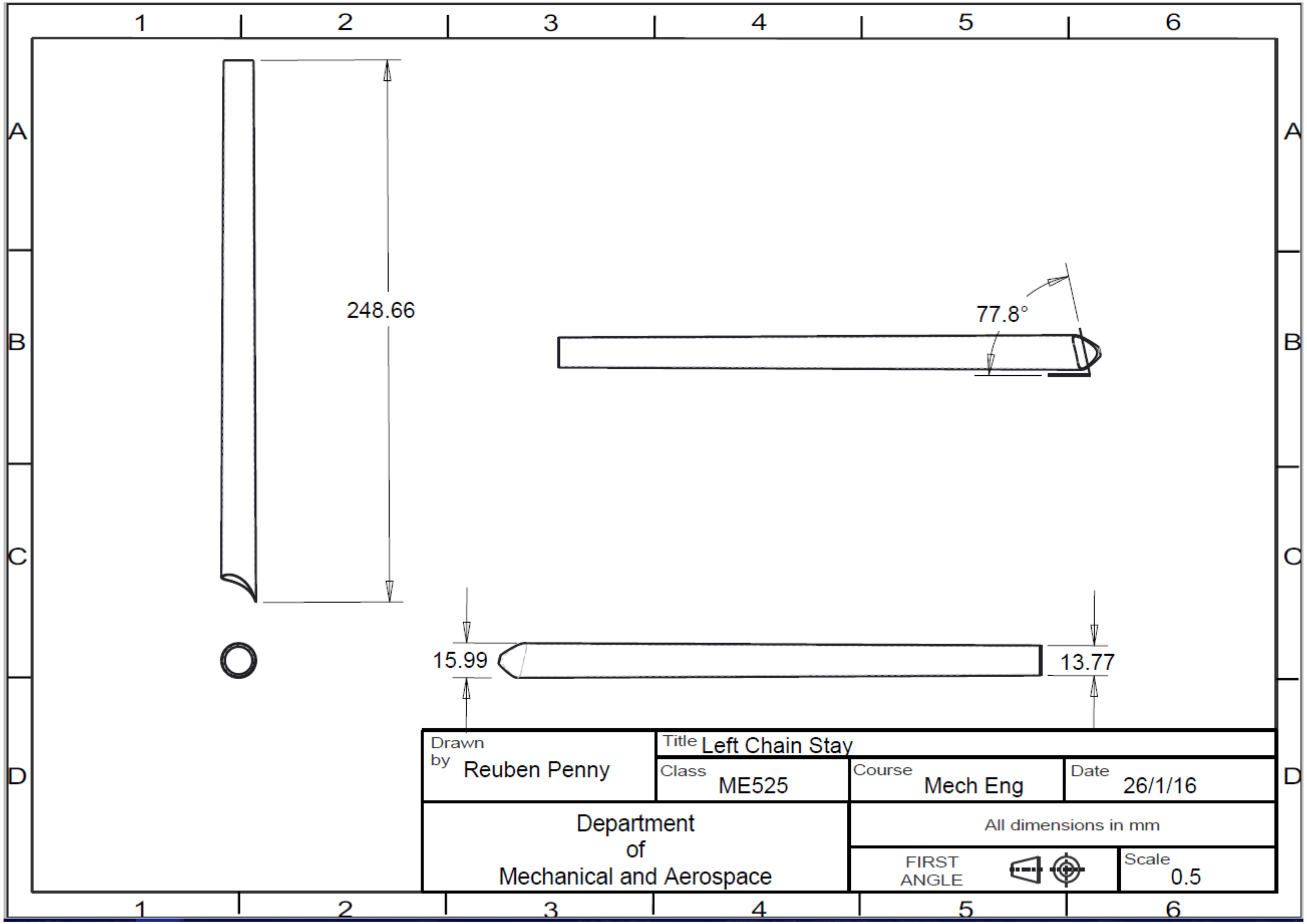
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Course
Mech Eng
Date
26/1/16
Department of Mechanical and Aerospace
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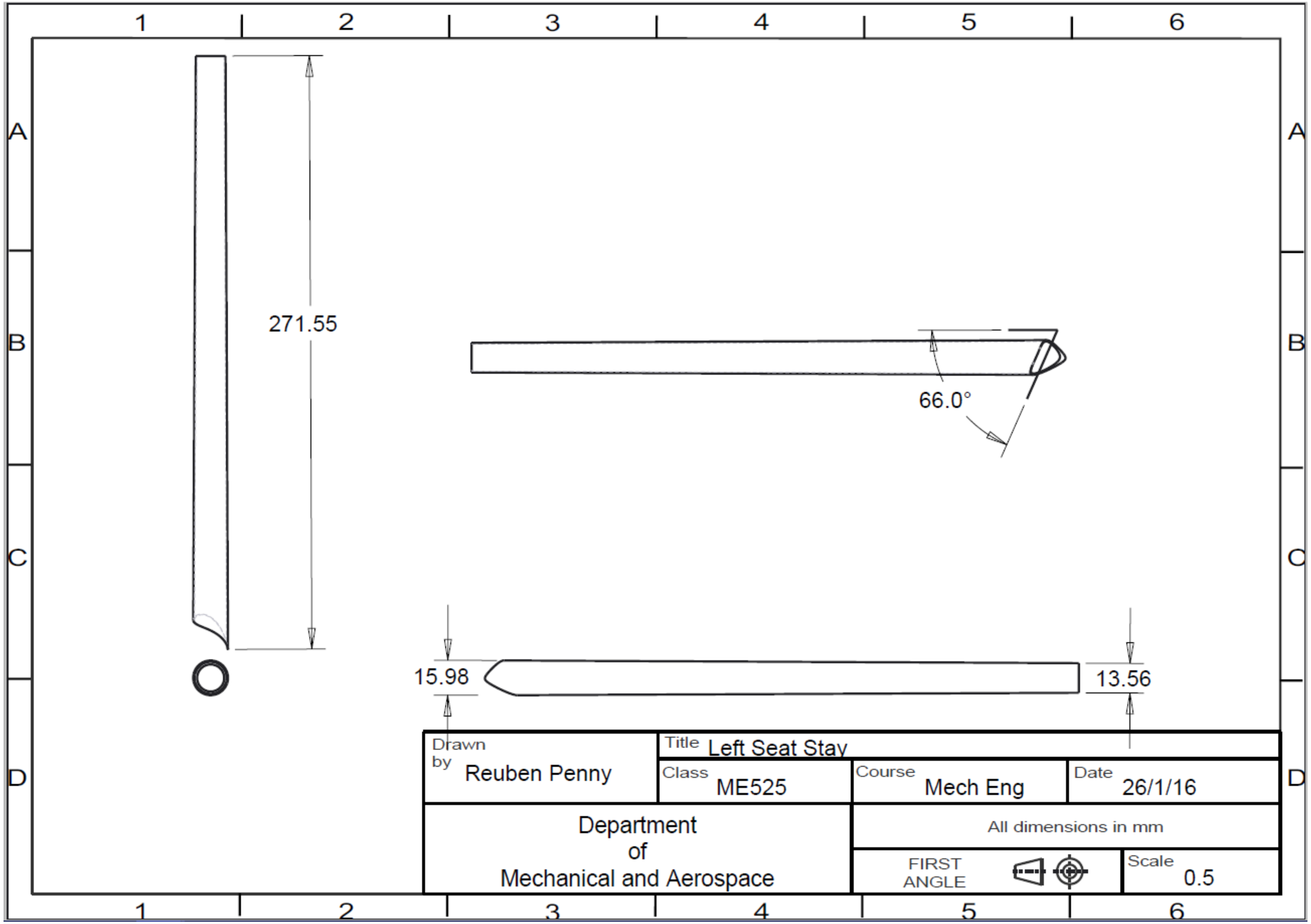

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Course Mech Eng
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Department of Mechanical and Aerospace
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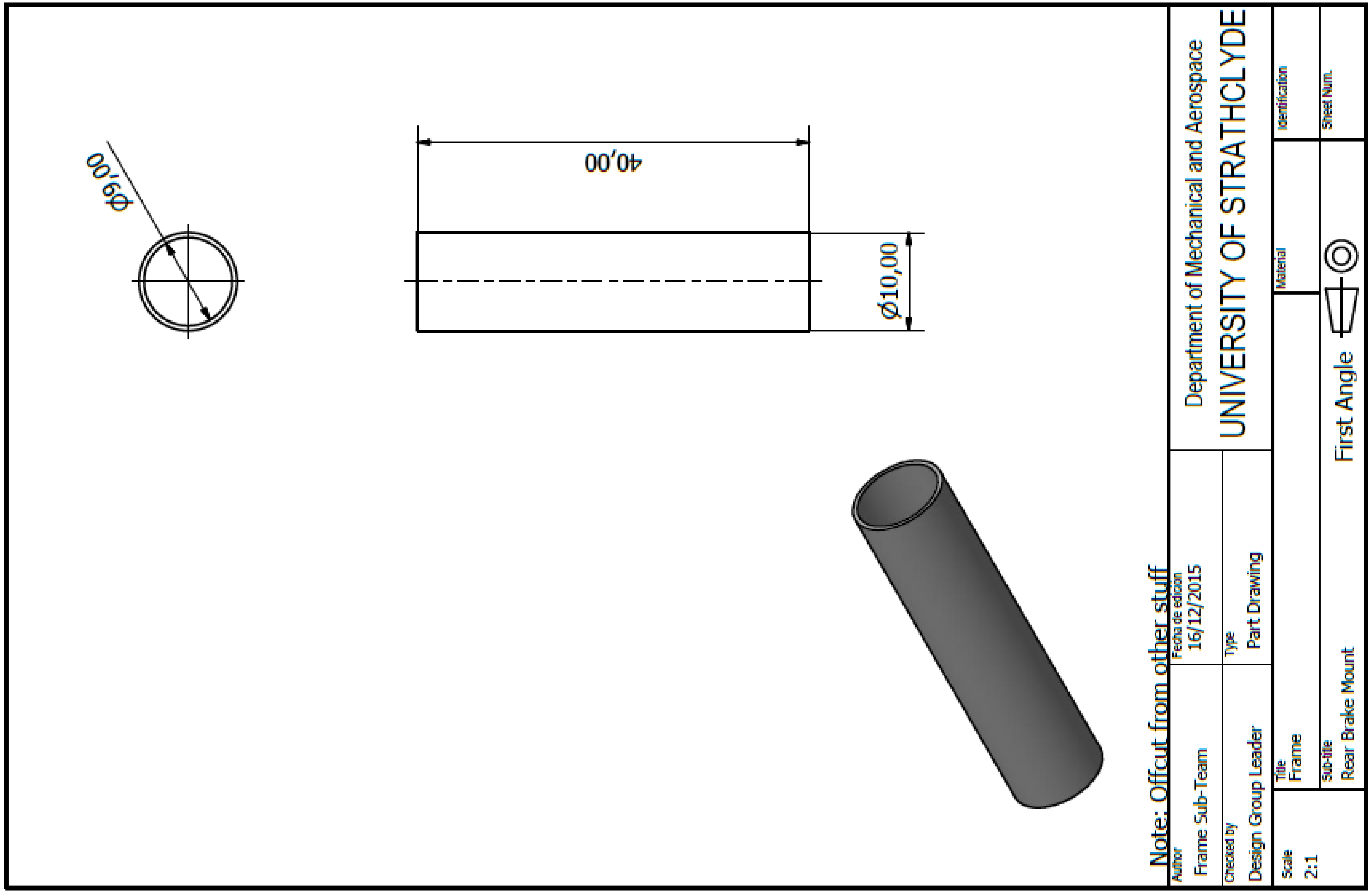
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Identification
Material
Sheet Num.
Title
Frame
Sub-title
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Scale
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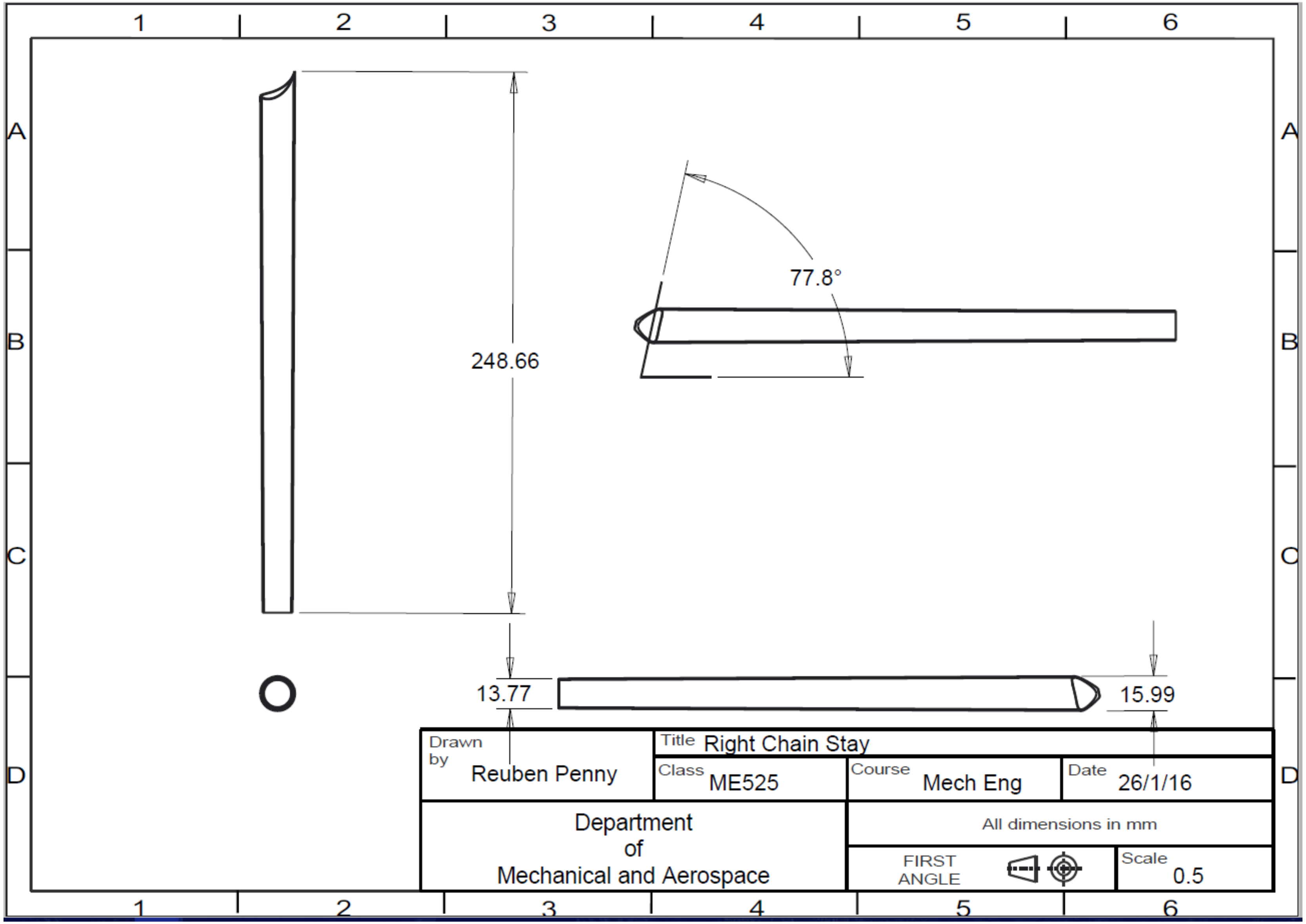
First Angle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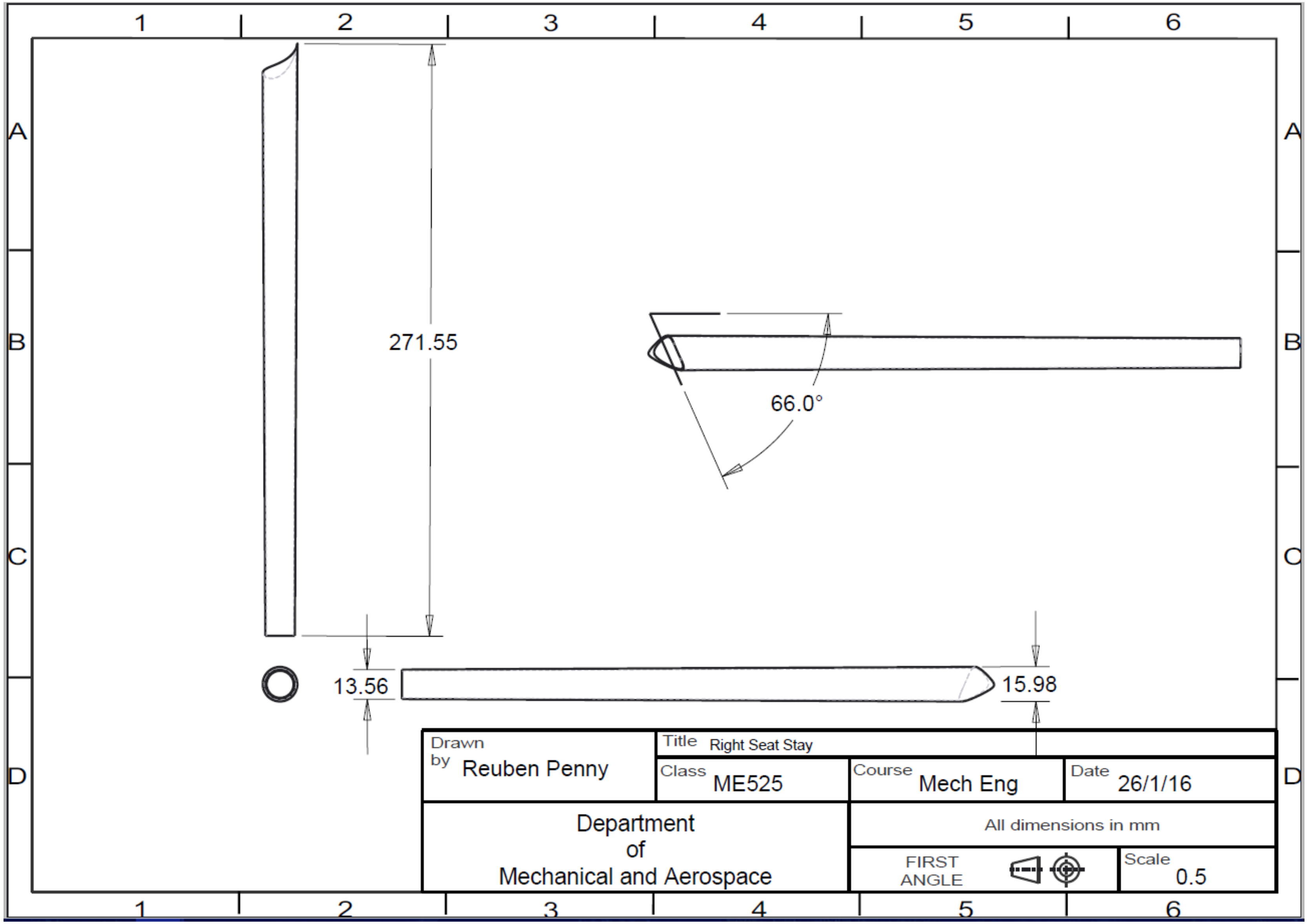
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Course Mech Eng
Date 26/1/16
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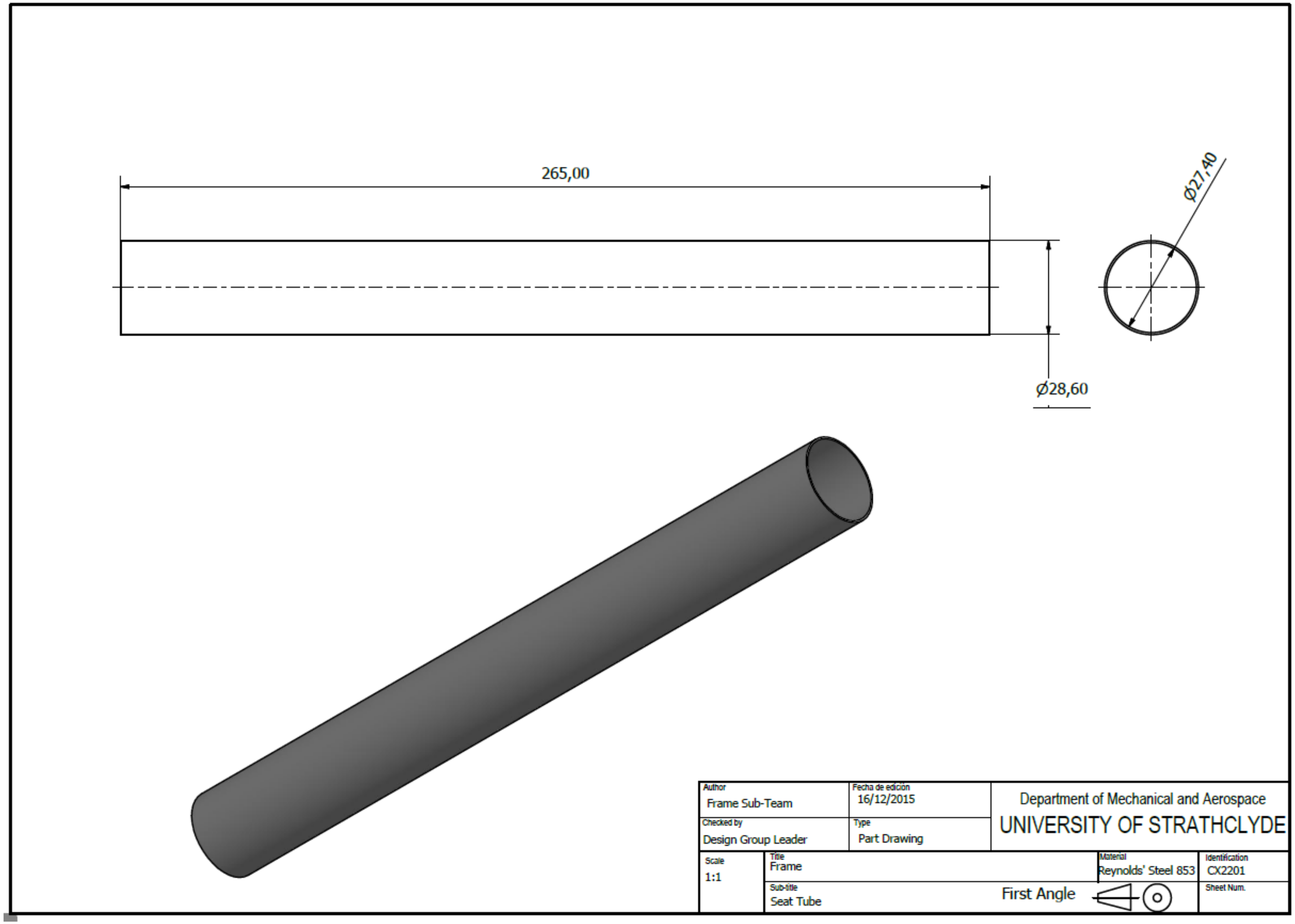
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Department of Mechanical and Aerospace
UNIVERSITY OF STRATHCLYDE
Checked by
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Type
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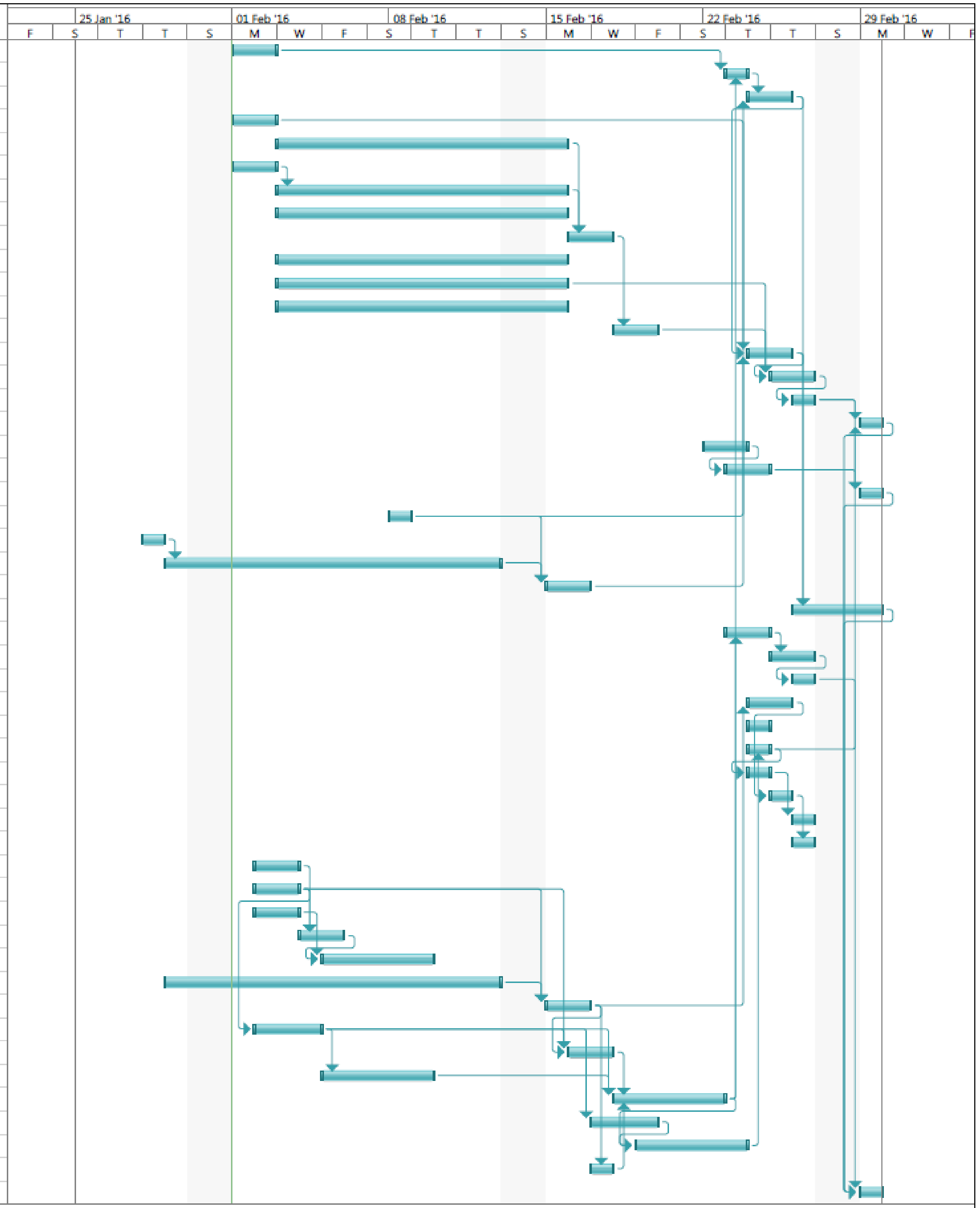
Reynolds' Steel 853
Identification
CX2201
Sub-title
Seat Tube
First Angle
Sheet Num.

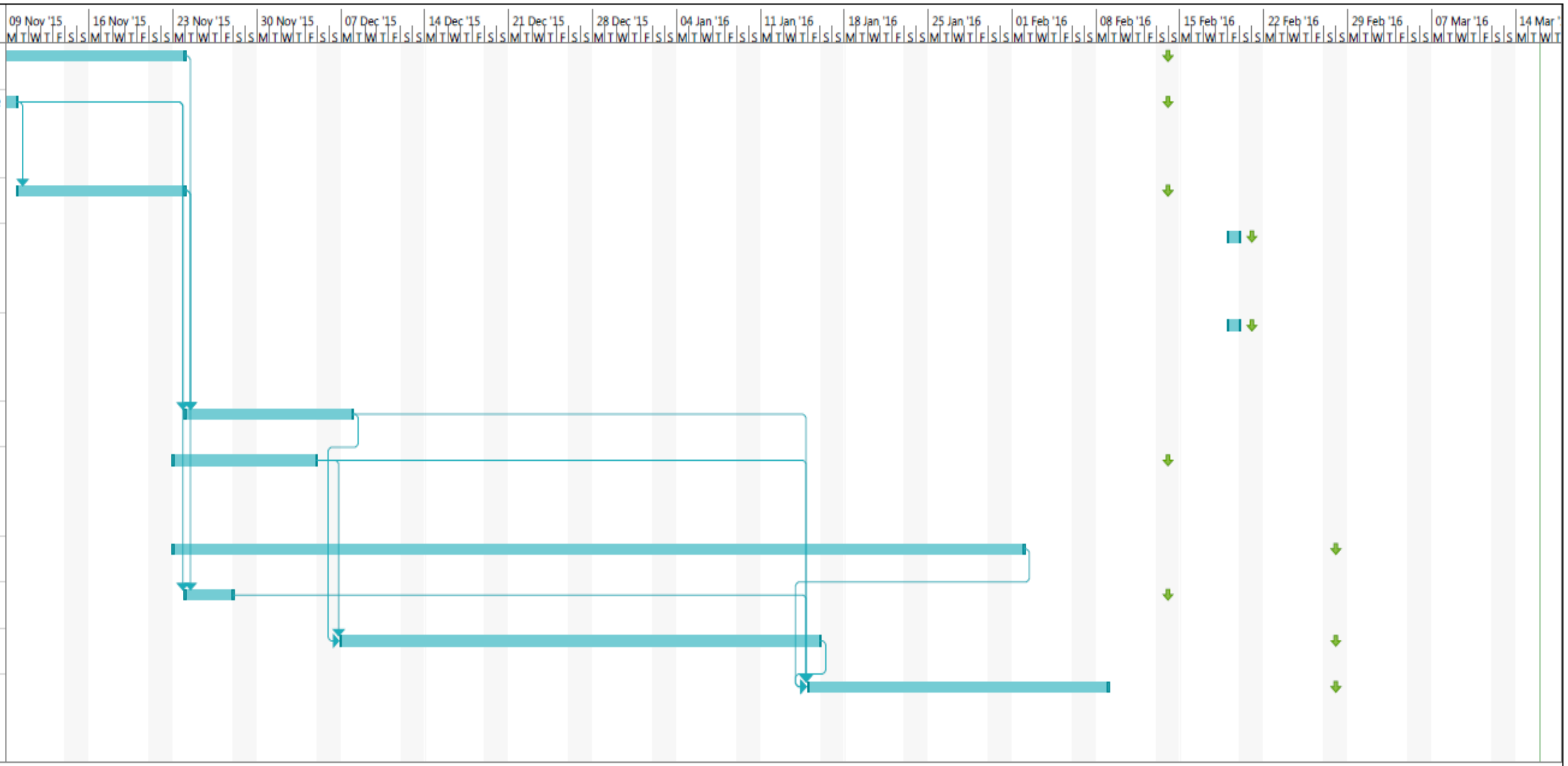
APPENDIX G – MANUFACTURING GANTT CHART

ID		Task Mode	Task Name	Duration	Start	Finish
1			Size fork steering tube – cut to appropriate length	2 days	Mon 01/02/16	Tue 02/02/16
2			Connect fork steering tube to head tube via head set at appropriate height	1 day	Tue 23/02/16	Tue 23/02/16
3			**Weld hinge to top of fork steering tube**	2 days	Wed 24/02/16	Thu 25/02/16
4			Cut upper steering column to appropriate length	2 days	Mon 01/02/16	Tue 02/02/16
5			Cut insertion tube to appropriate length	9 days	Wed 03/02/16	Mon 15/02/16
6			Cut handlebars to appropriate length	2 days	Mon 01/02/16	Tue 02/02/16
7			Remove excess material from indicated areas on handlebars	9 days	Wed 03/02/16	Mon 15/02/16
8			Mark out locations of insertion column and spring bolt	9 days	Wed 03/02/16	Mon 15/02/16
9			**Weld insertion column to handlebars**	2 days	Tue 16/02/16	Wed 17/02/16
10			Mark out holes in insertion column at appropriate level and tolerances	9 days	Wed 03/02/16	Mon 15/02/16
11			Drill holes in the insertion tube	9 days	Wed 03/02/16	Mon 15/02/16
12			Make necessary modifications to the spring bolt	9 days	Wed 03/02/16	Mon 15/02/16
13			Attach spring bolt to the handlebars	2 days	Thu 18/02/16	Fri 19/02/16
14			**Weld upper steering column to hinge**	2 days	Wed 24/02/16	Thu 25/02/16
15			Mark out holes on upper steering column at appropriate level and tolerances	2 days	Thu 25/02/16	Fri 26/02/16
16			Drill holes in the upper steering column	1 day	Fri 26/02/16	Fri 26/02/16
17			Augment additional components – reflectors, brakes, shifters, handlebar tape etc.	1 day	Mon 29/02/16	Mon 29/02/16
18			Fit inner tubes over front wheel rim	2 days	Mon 22/02/16	Tue 23/02/16
19			Fit tyre over front wheel	2 days	Tue 23/02/16	Wed 24/02/16
20			Inflate tyre and mount in fork drop outs	1 day	Mon 29/02/16	Mon 29/02/16
21			Cut hinges to appropriate size	1 day	Mon 08/02/16	Mon 08/02/16
22			Cut angle to appropriate length	1 day	Thu 28/01/16	Thu 28/01/16
23			**Cut puzzle sections**	11 days	Fri 29/01/16	Fri 12/02/16
24			**Weld angle to both steering and top tube hinges**	2 days	Mon 15/02/16	Tue 16/02/16
25			Mount latch to steering hinge angle	2 days	Fri 26/02/16	Mon 29/02/16
26			Cut bicycle frame at appropriate location	2 days	Tue 23/02/16	Wed 24/02/16
27			**Weld hinge to top tube**	2 days	Thu 25/02/16	Fri 26/02/16
28			Mount latch to top tube hinge angle	1 day	Fri 26/02/16	Fri 26/02/16
29			**Punch the bottom bracket shell into block**	2 days	Wed 24/02/16	Thu 25/02/16
30			Hub gear and rear sprocket to rear wheel	1 day	Wed 24/02/16	Wed 24/02/16
31			Mount side pull caliper rear brakes	1 day	Wed 24/02/16	Wed 24/02/16
32			Brake levers and gear shifter onto handlebar	1 day	Wed 24/02/16	Wed 24/02/16
33			Insert Threaded Bottom bracket, chainring(with 1 crank arm and axle), and other crank arm	1 day	Thu 25/02/16	Thu 25/02/16
34			Mount cabling	1 day	Fri 26/02/16	Fri 26/02/16
35			Add chain and pedals	1 day	Fri 26/02/16	Fri 26/02/16
36			Cutting the top tube with a length of 540 mm	2 days	Tue 02/02/16	Wed 03/02/16
37			Cutting the seat tube with a length of 265 mm	2 days	Tue 02/02/16	Wed 03/02/16
38			Cutting the head tube from seat tube with a length of 50 mm	2 days	Tue 02/02/16	Wed 03/02/16
39			**Welding seat tube and top tube according to the technical drawing**	2 days	Thu 04/02/16	Fri 05/02/16
40			**Welding the Head Tube to the Top Tube with an angle og 90°**	3 days	Fri 05/02/16	Tue 09/02/16
41			**Shape bottom bracket block to appropriate size**	11 days	Fri 29/01/16	Fri 12/02/16
42			**Welding the bottom bracket block to the Seat Tube**	2 days	Mon 15/02/16	Tue 16/02/16
43			Seat/chain stays cut to size	3 days	Tue 02/02/16	Thu 04/02/16
44			**Weld stays to seat tube and shape**	2 days	Tue 16/02/16	Wed 17/02/16
45			**Dropouts cut to size and bent**	3 days	Fri 05/02/16	Tue 09/02/16
46			**Dropouts crimped/welded to stays**	**3 days**	Thu 18/02/16	Mon 22/02/16
47			Brake mount cut to size and shape	3 days	Wed 17/02/16	Fri 19/02/16
48			**Brake mount welded to seat stays**	3 days	Fri 19/02/16	Tue 23/02/16
49			Cut threaded bar for technicians drop out mounting bits	1 day	Wed 17/02/16	Wed 17/02/16
50			Final Design Completion	1 day	Mon 29/02/16	Mon 29/02/16



APPENDIX H – WEBSITE GANTT CHART

ID	Task Name
1	**Planning**
2	Discuss the contents of the website
3	Create a Gantt Chart
4	Create a name for the company
5	Create a name for the bike
6	**Research**
7	Collect information for the website
8	**Website**
9	Create the structure
10	Contents
11	Review and upload new contents



APPENDIX I – BUSINESS PLAN

CDIO Worldwide Challenge

ME519 GROUP PROJECT

1. Executive Summary

1.1 Highlights

SynopTech is built around six founding members, each with a Masters of Engineering degree, but each with unique skills and qualities. Inspired by the CDIO worldwide project to tackle increasing global urbanization, a folding bicycle prototype was designed and built, and named The Commuter. The result is the product being presented here, and the plan to introduce The Commuter to the UK market is set out.

A three year profit/loss statement was created to estimate the viability and growth of the business. Below is a brief overview of the growth of the business over the next three years, and the projected profit that will be generated.

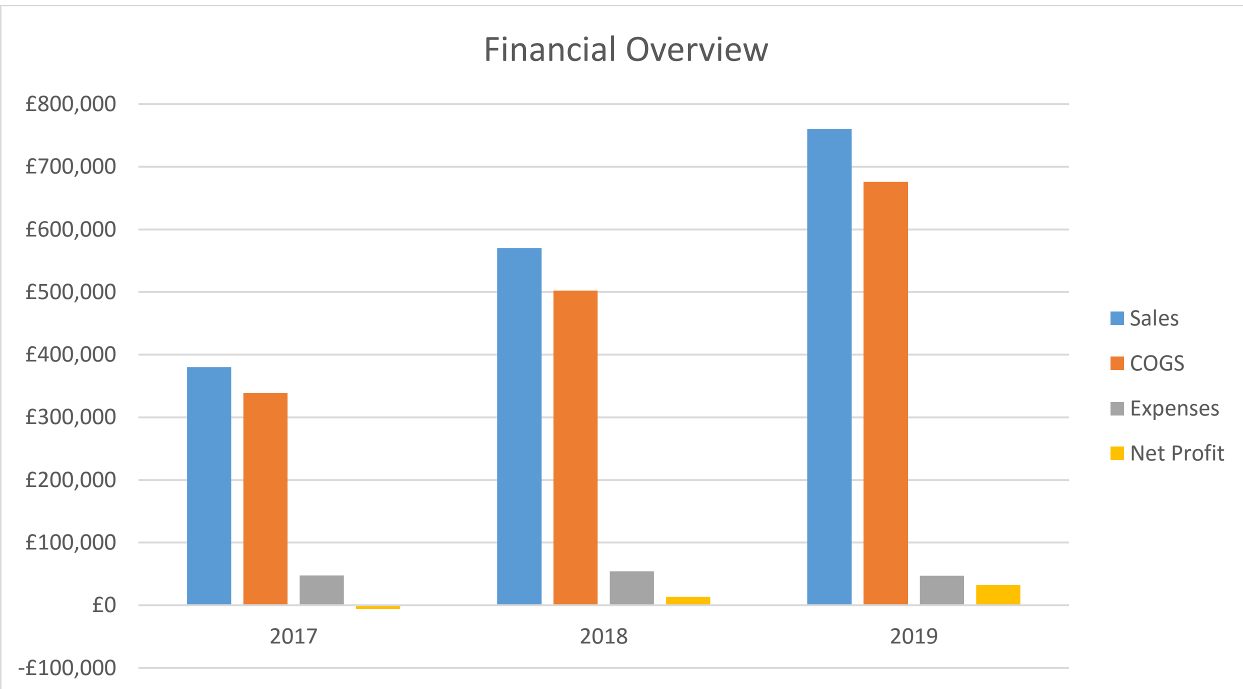


Figure 1 – SynopTech's Financial Overview

A small loss is made in the first year, but this is offset against the starting capital of the business. By the end of 2019, the profit accounts to 4.26% of the total yearly revenue. This figure will be expected to rise further into the future as the business gains more momentum, and a greater understanding of business and the market is gained.

1.2 Objectives

It is SynopTech's goal to sell 2000 bikes in the year 2019. The demand and relative success of The Commuter will dictate how fast the company grows, and in what time-frame expansion into different products will be available. It is the company's expectation to manufacture multiple different folding bicycles in different markets, creating a portfolio of different products on sale.

1.3 Mission Statement

An initial capital investment of £250,000 is required to get the business up and running. Included in this is the cost of the bicycles initially manufactured in 2016, ready for sale at the start of 2017, or potentially just before Christmas to try and generate early sales of the product. Additionally, this accounts for the early costs incurred in the business, and this will be used to offset against the loss made in year 1, meaning the asset/liability balance sheets will be balanced.

1.4 Keys to Success

The key to SynopTech's success will be the six founding members of the company, as these will be the brains and engine of the company. It will be a unique company setup that allows for greater productivity and decision-making capabilities. Together, SynopTech will be driven to success.

2. Description of the Business

The business is built around the idea put forward during the CDIO Worldwide project, which is that there is ever increasing urbanization, and therefore growing pollution and congestion. The idea is to bring a folding bicycle to the market that is user friendly, price competitive and intuitive to use. What makes the business unique is that it is built in its foundation from a group of 6 mechanical engineers, each with unique backgrounds and experiences. This allows adaption to manufacturing and design techniques quickly and effectively, keeping SynopTech competitive and successful in the market.

The Unique Selling Point (USP) of The Commuter will be its simplicity, as it has no unnecessary complexity or hassle. It is not under or over-engineered, it is designed to do precisely what it sets out to do, and no less. The distinctive customer care and product quality will attract customers and build a good consumer loyalty and base. This will be done by having purchasable add-ons when buying the bicycle to allow for in-depth customization, giving a very personal feel to the bike and therefore the company. There is also a future plan in place to have portable bike repair workers that customers can call when needing repairs or replacements done, and this will work on a subscription basis and will act simultaneously as insurance.

The primary goal as a business is to break quickly into the folding bike market and to try and grow using a unique business model. A longer term objective of the business would be to break into different bicycle markets like mountain bikes and road bikes, creating a portfolio of assets that will reduce risk and increase profit. These will follow the same naming system as the folding bike (The Mountaineer, The Roadster, and The Trackster).

2.1 Company Ownership/Legal Entity

The business will start-off being a partnership, evenly split between the 6 founding individuals of the concept. Having a partnership instead of a corporation type structure will reduce start-up costs as there are no administrative fees associated with the setup of the business and there will be minimal lawyer fees due to the simple legal requirements of a partnership business. It will also ease the running of the company from the get go as the 6 partners will decide how it is run with no interference from shareholders. There will therefore be no disparity between management and shareholders as there so often is in large corporations.

2.2 Products and Services

The product will be hitting the markets at a crucial time for the transport industry, a time in which the traffic and pollution in cities are reaching all-time highs and real action is needed to tackle this problem. The bicycle and public transport services working hand-in-hand is the answer that the transport industry is looking for and there will therefore be increasing demand for folding bicycles.

Customers benefit from the expertly engineered folding mechanism and from the multiple optional extras that they can choose from, making the purchasing of the bike feel very personal as it is customizable to meet the customer's wants and needs. This will include adjustments in frame size for taller or shorter people, a range of colours to select from and a choice of traditional or hub gearing.

What will be implemented in the future is an insurance that is optional to purchase when buying the bicycle. What this will include is an emergency breakdown service that will provide repairs to anyone who has broken down. This will be provided by engineers with the necessary tools to carry out repairs and they will be mobile around the city on bicycles. This is a unique service that will separate the product from the many others that are present in the market at the moment.

2.3 Location

When considering the location of the warehouse where manufacturing will take place, it would preferably be near to London, as this would be the best place for the bicycle to be introduced into the market. This is due to the large population and high number of commuters in the city, and the higher levels of investment in bike lanes in London comparative to other cities (Laker, 2016). This would also fit into the long term expansion plan of the company to break into the Netherlands as London is close to mainland Europe. The Netherlands is a great country to sell bikes in due to the large number of cyclists in the country and the emphasis on cycling as a mode of transport.

The location may also be important because not only will the warehouse serve to manufacture the bikes, but it could also be a store front for customers to buy bicycles from, allowing a low cost method of distributing bikes to customers, making the business both a wholesaler and a retailer.

2.4 Manufacturing

The advantage of building a bicycle is that the manufacturing process is relatively simple, due to the easy access to all parts of the bike and the light weight nature of the vehicle. There are however some specific specialist tools that are needed to build a bicycle, which is an unavoidable cost of manufacturing a bike.

Further in the future as the business grows, it would be desirable to introduce automated manufacturing (for welding etc.) in an effort to minimise manufacturing costs.

2.5 Management

Main control and management of the business will remain with the 6 founding members of SynopTech. The management setup will be similar to that created during the design and build of the prototype, in which roles will be assigned in the following way:

- CEO – Chris Barrick MEng
- CFO – Reuben Penny MEng
- Lead Research and Development – Gloria Arcilla MEng
- Lead Design Engineer – Tom McCubbin MEng
- Lead Manufacturing Engineer – Caio Dias MEng
- Administrative Officer **–** Paul Lang MEng

This management setup has proven a success as was shown during the whole research, design and manufacturing of the prototype. Each person showed their own strength in their area of expertise, and has experience in these roles.

This will remain applicable throughout the 3 year cost projection of this business plan.

2.6 Financial Management

The management of the finances is most crucial over the first 3 years, as this can be the difference between successfully building a company up from nothing, and going bankrupt. The company will not be profit driven for the first two years, as in fact a loss is made in the first year, and all profits for the second year are re-invested to support growth. The third year will show the first profits that SynopTech will generate, when 2000 bikes are produced in that year.

An initial cash inflow will be needed to get SynopTech off the ground, as expenses such as rent, utilities, patenting and insurance will cost considerable amounts of money so having a large initial investment is a necessity. An operating budget will be setup at the start of the operation to try and prioritize certain costs over others, as they will have differing degrees of importance to the business.

2.7 Start-Up Capital

There are a number of possibilities to obtain the start-up capital required to bring The Commuter into production and to the market. These include:

- Crowdfunding

Crowdfunding serves as a relatively easy and inexpensive way to raise the capital that SynopTech will require in its start-up. There are now many different sites, each with its own advantages and disadvantages to raising capital. Kickstarter remains a very popular and ever growing crowdfunding website, and is a definite possibility.

One advantage that crowdfunding has is that it serves as a sort of advertising for the product, helping hype the product up before it is even in mass production. This helps to increase initial sales as there will be more expectation on the release of the bicycle to the market. It could also help to predict sales forecasting as following the interest in the product is easy.

A disadvantage is that each donator expects something in return, and this is dependent on the amount of cash invested. This will mean that capital is needed before the start-up capital is raised, which might potentially pose a problem.

- Venture Capitalists

Using venture capitalists to fund the company, or a specific product, is another popular way of raising initial capital for the business to start from. It consists of pitching the company and product to a group of wealthy individuals in the hopes that some will see the opportunity to invest in you.

Advantages include the ability to raise large sums of money quickly, and having the business expertise that comes along with that venture capitalist.

Disadvantages include the fact that there is no prior exposure of the product to the market before release, unless there is significant investment in advertising. Also, it involves handing over a significant size of the company to an outside party, which may not be desirable.

3. Marketing

3.1 Market Analysis

Market research was conducted on over 100 individuals to obtain current market information on how the public view bicycles and transport.

The market that SynopTech is targeting with the release of The Commuter is the portion of the population that make commutes to/from work, university or school that involves inner city travel. As seen in Figure 2 below, 10% of commuters consider biking to be a real option for commuting, meaning they are the immediate market to sell to. However, the segments with walking and car as their preferred option (60% of the market) are the future markets that will emerge when cycling becomes ever more prominent.

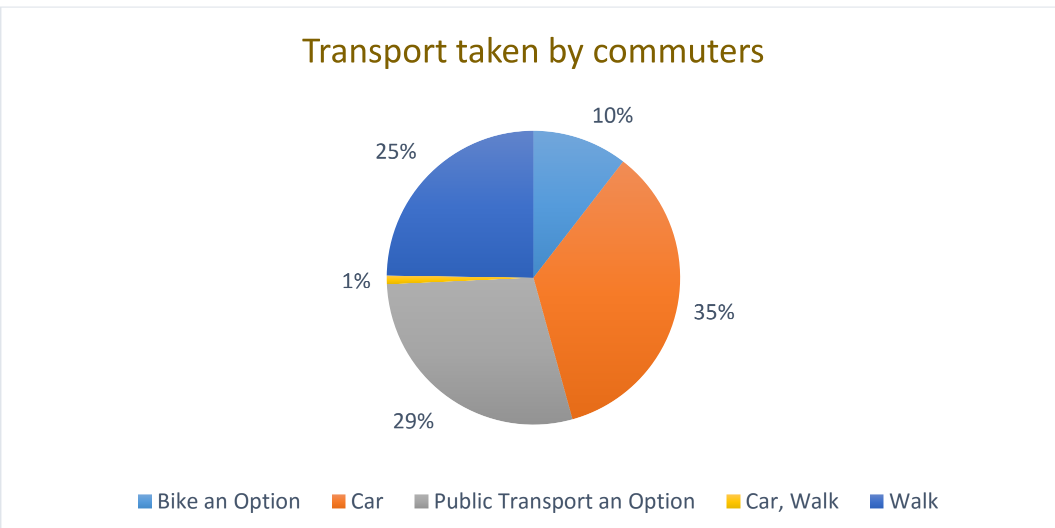


Figure 2 – Commuter's preferred transport methods

As of 2011, the current number of commuters is estimated as 26.6 million in England and Wales (Office for National Statistics, 2013). This means the current market for people commuting by bicycle is approximately 2.7 million people big, making it a large and ever growing market.

The market research also indicated the buying patterns of people who would buy a bike, with 93% of people preferring to buy a bike in a shop rather than over any other platform (Figure 3). This gives important information for how SynopTech will go about selling The Commuter to the general public.

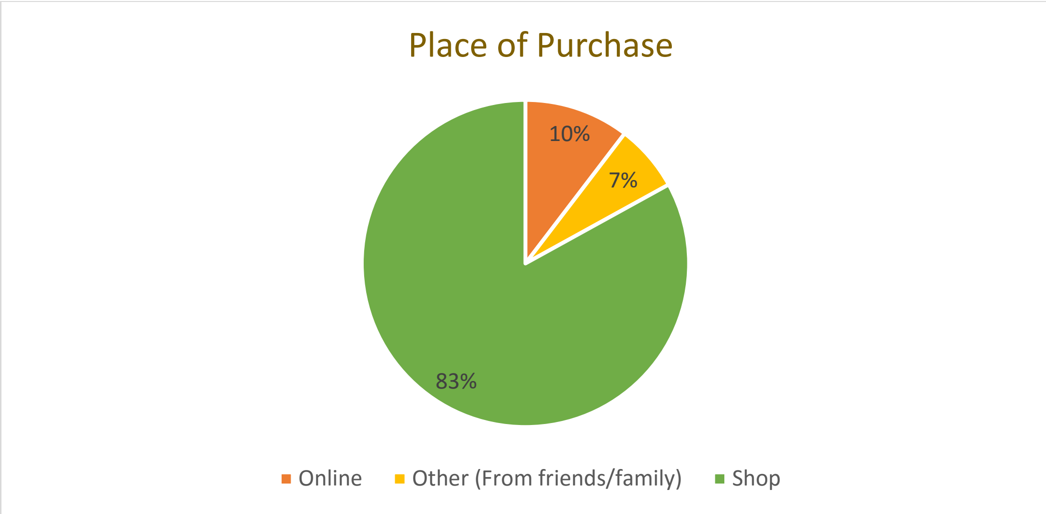


Figure 3 – Place of Purchase

3.2 Competition

The folding bicycle market is a busy and highly competitive market, and breaking into it will require excellent pricing and advertising strategies. It is largely dominated by companies such as Brompton Bicycles, Raleigh and Dahon, with the former gaining ever growing popularity due to its excellent folding mechanism. However, it is an unexpected market dominator as the price of the bikes range from £800 to £1200, on the upper end of the folding bicycle prices.

A lot can be learnt from the way these companies advertise and set pricing models, and their mistakes can be avoided when building up the SynopTech business. A very competitive pricing strategy will ensure that the company is not forced out of the market in the early stages of the start-up, but will allow re-investment of capital to sustain growth. SynopTech will also rely on greater customer care and experience, as this has been identified as a gap in the market. This will include having numerous optional extras for customers to choose, meaning their bike can be very unique.

Strong branding and being highly identifiable will also aid in separating The Commuter from the competitors in the market, and will be continued throughout all of SynopTech's future products.

3.3 Pricing

The pricing of the product is based around the market research conducted, which asked the public what they would be willing to pay for a folding bicycle. A cost estimation graph could then be built to visualize the spread of prices that people would pay for the bicycle (Figure 4).

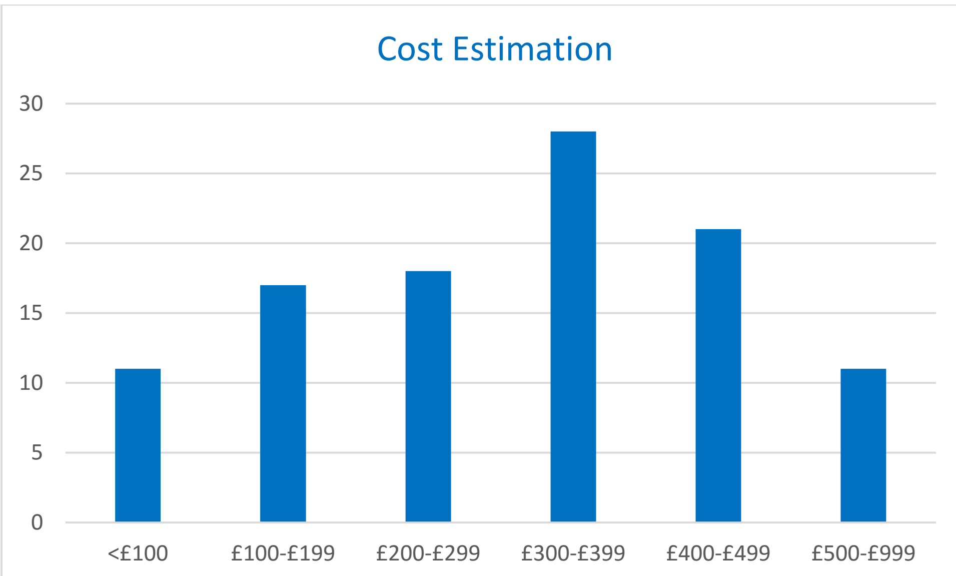


Figure 4 – Cost Estimation

Pricing The Commuter between £300 and £399 would be an ideal figure, as this would allow for profits to be generated while also offering a cheaper alternative to what is currently on the market. If the bike takes this pricing strategy, those willing to pay that price, and the prices higher than that will be the ones buying the bicycle. The total number of people who did the research was 106, and the number of people who would pay £300-£399 or greater comes up to 60, meaning the percentage of the population who would be willing to pay the price of The Commuter would not be a factor is 56.6%. This is a considerable initial percentage of the market, and this will grow as the brand grows in strength and recognition, meaning people will pay more for the bike.

Considering this, the price of The Commuter has been set as £380. This price will be the initial market price, but continuous monitoring will ensure that the business can continue to operate at a profit making level.

3.4 Advertising and Promotion

Initial advertising will consist of having an internet presence (website, Facebook/YouTube page) and try and create a following online. This will go on for a minimum of one year, to ascertain how the bicycle is performing in the market and to customize advertising dependant on customer feedback.

During the second year advertising will begin, which will consist of billboard adverts in large cities, specifically London where the location of the build factory and shop will be. This has been reflected in the Profit/Loss statement in the Appendix, where it is clear to see the allocation of capital to advertising. The adverts will be thought up and designed in-house, saving money on hiring advertising companies.

4. Appendix

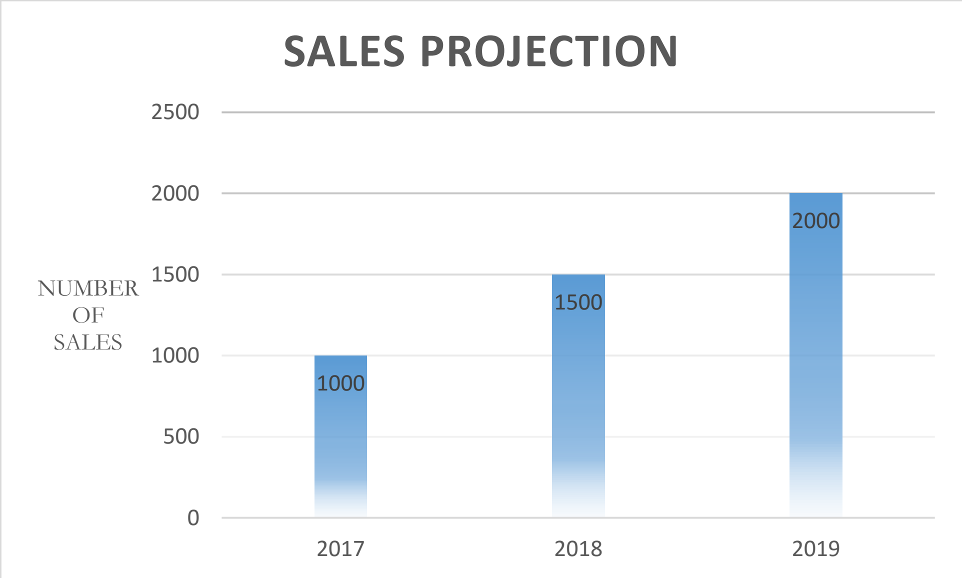
4.1 Determining Pre-product Launch Expenses

	Oct '16	Nov '16	Dec '16
Cash Out:			
Labour	14083	14083	14083
Materials	81620	-	-
Insurance	1333	1333	1333
Warehouse Rent	640	640	640
Utilities	227	227	227
Telephone	65	15	15
Patenting	1400	-	-
Legal & Professional fees	4000	-	-
Total Cash Out	21748	16348	16348
CAPITAL REQUIRED	*£136,064*		

4.2 Profit & Loss Statement (£000's)

		2017				2018				2019			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Income													
	Revenue	95.00	95.00	95.00	95.00	142.50	142.50	142.50	142.50	190.00	190.00	190.00	190.00
COGS													
	Total Labour Costs	42.25	42.25	42.25	42.25	62.00	62.00	62.00	62.00	81.75	81.75	81.75	81.75
	Total Material Costs	81.62	0.00	81.62	0.00	122.43	0.00	122.43	0.00	163.24	0.00	163.24	0.00
	Total Vehicle Expenses	1.56	1.56	1.56	1.56	2.34	2.34	2.34	2.34	20.60	0.60	0.60	0.80
	Total COGS	125.43	43.81	125.43	43.81	186.77	64.34	186.77	64.34	265.59	82.35	245.59	82.55
Gross Profit		-30.43	51.19	-30.43	51.19	-44.27	78.16	-44.27	78.16	-75.59	107.65	-55.59	107.45
Total Expenses		6.89	6.89	6.89	26.89	7.65	8.87	8.87	28.87	11.99	11.71	11.71	11.71
Net Income		-37.32	44.30	-37.32	24.30	-51.92	69.29	-53.14	49.29	-87.58	95.94	-67.30	95.74
Tax paid on NI			0.00				0.00				4.42		
Profits					**-6.02**				**13.54**				**32.40**

4.3 Sales Forecast



5. References

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