Re-design of an In-line Speed Skate Clap Frame

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Abstract

The purpose of this project was to redesign an In-line Speed Skate Clap Frame, according to the expectations of Bont Speed Skates, the sponsoring company, and their potential customers. The basis for the re-design was Bont current product, called the 'Slingshot'

To achieve this objective, a systematic design process was utilised, as well as Computer Aided Engineering techniques, such as Solid Modelling and Finite Element Analysis.

To find out what the customer wanted, a survey was conducted over the Internet, as well as by asking the Bont marketing department about their expectations. The main concerns identified were weight, strength, durability and clap noise abatement.

A range of concepts were brainstormed to satisfy the requirements, and a concept was selected to take care of the issues. The preferred concept was developed into a final design, and detailed drawings completed.

The final design weighed 8.9% less than the current product, but stiffness and strength were requirements which were partially sacrificed.

Acknowledgment

I would like to acknowledge the following people in helping me with my project and related issues:

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- Alex and Sarah Bont and Bont Speed Skates for the opportunity to do this project with them.
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- My parents and family for their continued support.
- My superiors and colleagues at Toll Automotive Logistics for their support and understanding.

Declaration

I, Corey Gibson, certify that the following document does not contain any material previously submitted for a degree or diploma.

To the best of my knowledge, this thesis contains no material previously published or written by person/s where due reference is not given, and is solely my own work.

Corey Gibson

29th October 2001

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1. Introduction

1.1 History of In-line Speed Skating

In-line skating has its roots in ice skating and is a form of roller skating. The first known roller skate was invented by Joseph Merlino, a Belgian, in 1760 (Van Zandt, 1978; www.rollerskatingmuseum.com, 2001). The skate invented by Merlino had its wheels in an in-line configuration.

In 1819, the first roller skate was patented in Paris by M. Petitbled, which also had an in-line configuration for its wheels. The in-line trend for roller skates continued until 1863, when James Plimpton introduced the quad skate, which had two pairs of wheels side by side (www.rollerskatingmuseum.com, 2001). The quad skate had better control and subsequently dominated the industry for many years.

Figure 1. A Quad Style Roller Skate

Whilst the quad roller skate was dominating the industry, many companies continued to invent and patent in-line skates. A commercially viable skate did not come about until the 1980's, when two ice hockey players from Minnesota developed a skate that resembled an ice hockey skate. It was invented by the Olsen brothers, who went on to form Rollerblade Inc. (www.rollerblade.com, 2001; www.skatingmuseum.com, 2001). This skate had four wheels in a row, made of polyurethane, which had been used for quad skate wheels for many years by then.

The skate was a great success, causing a new sensation in the roller skating world. In-line skating grew over the years, to a point where in 1997 there were almost 30 million participants in the USA (American Sports Data, 1998 at www.rollerblade.com, 2001). In the year 2000, it was estimated that there was fifty thousand regular participants in roller sports (roller sports includes quad and in-line skating) in Australia (ABS, 2000).

Figure 2 – A selection of in-line roller skates through the ages (www.rollerskatingmuseum.com, 2001). Clockwise from top: A 1994 Rollerblabe Inc. skate, 1930's Best-Ever-Built Skate Company clamp on skate, an 1819 Petitbled skate, a skate of unknown origin circa 1860.

Inline speed skates were developed based on the success of the 'Rollerblade'. It was seen as a chance for long track ice speed skaters to have an off-season training tool. The in-line speed skates were based on long track ice skates, having a long frame, with five wheels, instead of the four wheels used for a conventional in-line skate. The use of an in-line roller skate, was proved to be acceptable as a training tool for ice speed skaters, where the technique and physiological responses were found to be the same for both sports (de Boer et. Al, 1987).

Inline speed skating was not accepted as part of the speed roller skating championships until 1992, and even then only on a limited basis, where they could only be used in three events (Begg, 2001; www.rollerskatingmuseum.com, 2001). For the rest of the events, skaters had to use quad roller skates. The roller skating world was sceptical of the in-line revolution, but eventually they were fully accepted to the speed roller skating world championships in 1994. Since then, in-line speed skating has dominated the sport.

1.2 In-line Speed Skating Equipment and Developments

When purchasing an in-line speed skate, it is generally purchased as separate components, as opposed to a recreational in-line skate, which is usually a complete unit. The diagram below shows the components that go into speed skates.

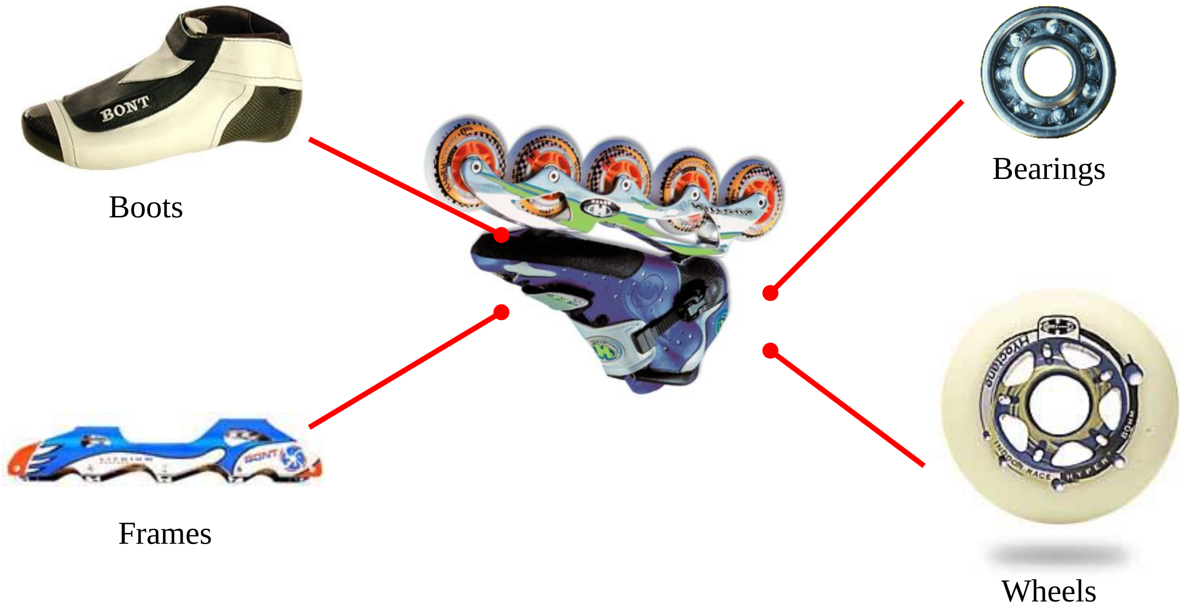


Figure 3 – The components of an In-line Speed Skate (pictures courtesy www.bont.com & www.hyperskate.com)

In-line speed skating boots are usually the same as ice speed skating boots. They have a moulded composite fibre boot base, which provides most of the support for the foot. The polymer for the composite boot base can either be thermoplastic, allowing the base to be moulded to the foot by heating it, or it can be made of a thermosetting polymer, for which the boot is custom moulded to the skater's foot. The upper is generally a leather construction and the boot laces up, with some having straps to provide extra support.

Frames are generally a one piece aluminium extrusion, machined to shape. They normally accommodate five wheels, but some have four wheels typically for smaller skaters. They are measured from the centre of the front axle to the centre of the rear axle, with a typical frame being 326 millimetres or 12.8 inches.

In-line speed skates usually have five wheels that are 80 millimetres in diameter. They are made of polyurethane, ranging in durometer from 75A to 95A, and typically, in-line speed skate wheels have a moulded nylon hub.

There are two bearings per wheel, which by standard are 608 type bearings, but there has been an increase in the use of 688 bearings for in-line skating applications.

1.2.1 Developments and variations of the standard In-line Speed Skate

Over the years of in-line speed skating, there have been some different ideas tried for in-line speed skates. The following section outlines some of those variation.

1.2.1.1 Clap Frames

Clap frames were developed for ice speed skating, with their introduction to competition in that sport being quite successful. Houdijk et. Al. (2000) highlighted the physiological advantages that are provided by the use of clap skates in ice skating. Clap skates allow the skater to use plantar flexions, which are suppressed with a conventional frame, to improve the efficiency and speed of the skater. That is that the skater can point their toe using their calf muscles to gain extra length in their push off stroke. This technique of skating is also considered more natural, and is likened to the motion of the foot in running (van Ingen Schenau et. al. 1996).

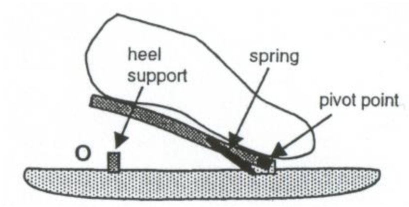


Figure 4 – Schematic of an ice clap skate (Allinger & Motl, 2000)

Clap frames have only really been introduced to in-line skating during 2001, but have not really been tested in international competition as yet. There have been indications of in-line clap skates providing better results by Bont (2001), where during testing of their clap frame. During training the skaters pace behind a motorbike at a maximal speed. The skaters were able to achieve a top speed of 45 km/h on clap skates, where they would normally only skate at 40 km/h on fixed frames during such an exercise. This indicates that a 12.5% increase in top speed may be possible using an in-line clap skate. Other evidence of the advantages of clap frames will be discussed later in this report.

Figure 5 – The action of Bont's In-line Clap Skate (www.bont.com, 2001)

1.2.1.2 Monocoque Chassis

The monocoque chassis in in-line speed skating is relatively new. This skate incorporates the boot base and frame as one composite section. No real evidence of any significant advantages has been found.

Figure 6 – Xenan Monocoque Skate (www.xenan.com, 2001)

1.2.1.3 Large Wheels

Wheels larger than the standard 80 millimetres have been tried on and off over the years. Currently, Xenan have options that allow for larger wheels, including the skate showed in figure 5. A frame that can be bolted to standard boots is also available. This configuration has four wheels, the second wheel from the front being a standard 80 millimetre wheel, and the other three wheel being 100 millimetres. It has been shown by Nett (2001) that this set up actually faired worse than fixed and some clap frame skates in a five mile test.

Wheels that were 82 millimetres in diameter were also tried in standard frames and were popular around 1996. During this season, their popularity slowly declined, as skaters found that while they were fine for pack racing, they would be beaten in a sprint by skaters using 80 millimetre wheels (Bont, 2001).

1.3 The Sponsor Company: Bont Speed Skates

This project was sponsored by Bont Speed Skates. Bont is an Australian company, based in Sydney, that design, manufacture and supply a range of in-line and ice speed skating equipment around the world (www.bont.com, 2001). Whilst Bont's core business is making speed skating boots, they also design and supply skate frames and resell a range of bearings under their own brand name.

Mr. Inze Bont, who was a recreational and speed ice skater at the time, started the company. Initially, Mr. Bont started by adding fibre glass to the ankle area of his leather boots for extra support. His friends liked the idea and requested that he do the same for them, hence Bont Skates was started.

The company grew from there, and started using new materials, including advanced composites, velcro and neoprene in making their boots better. They are the leaders in the speed skating boot market.

They also started with in-line skating in around 1983, making cross training skates for ice skaters to use in summer. Since in-line speed skating boomed in 1993 with the acceptance of the format into the world roller skating championship, Bont Skates' boots were the benchmark other manufacturers strived to achieve.

Bont has looked to expand their range into other areas of in-line and ice speed skating equipment in recent years. They started to concentrate some of their efforts on designing and producing frames and blades for speed skates. Whilst they are not currently the leaders in the market, they hope to be up there with the best is the future. (Bont, 2001; www.bont.com, 2001)

1.4 Aim and Approach

The objective of this project is to redesign Bont's in-line speed skate clap frame, the 'Slingshot', according to the expectations of Bont and their potential customers. The importance of listening to the concerns of the customer and Bont is stressed in conducting the design process.

It should be noted that it the purpose of this project **was not** to prove that in-line clap skates provide better performance than fixed frame skates. Nor was the project to change the design parameters that Bont's marketing group considered important or alter the view of their marketing group.

To achieve this aim, the product design approach described by Dieter (2000) was employed to provide the best possible results. This includes exactly defining the problem, gathering relevant information, generating concepts to satisfy the problem, evaluating those concepts, and finally designing the product. The design process would also rely heavily on the use of Solid Modelling for designing the frame and Finite Element Analysis in both the design and validation phases. Where applicable, standard calculations were applied for design and validation purposes.

1.5 Design Methodology

As it has been previously stated, the product design methodology that was employed in this project are largely described by Dieter (2000), but was adapted to suit this situation. This process is outlined in the following diagram.

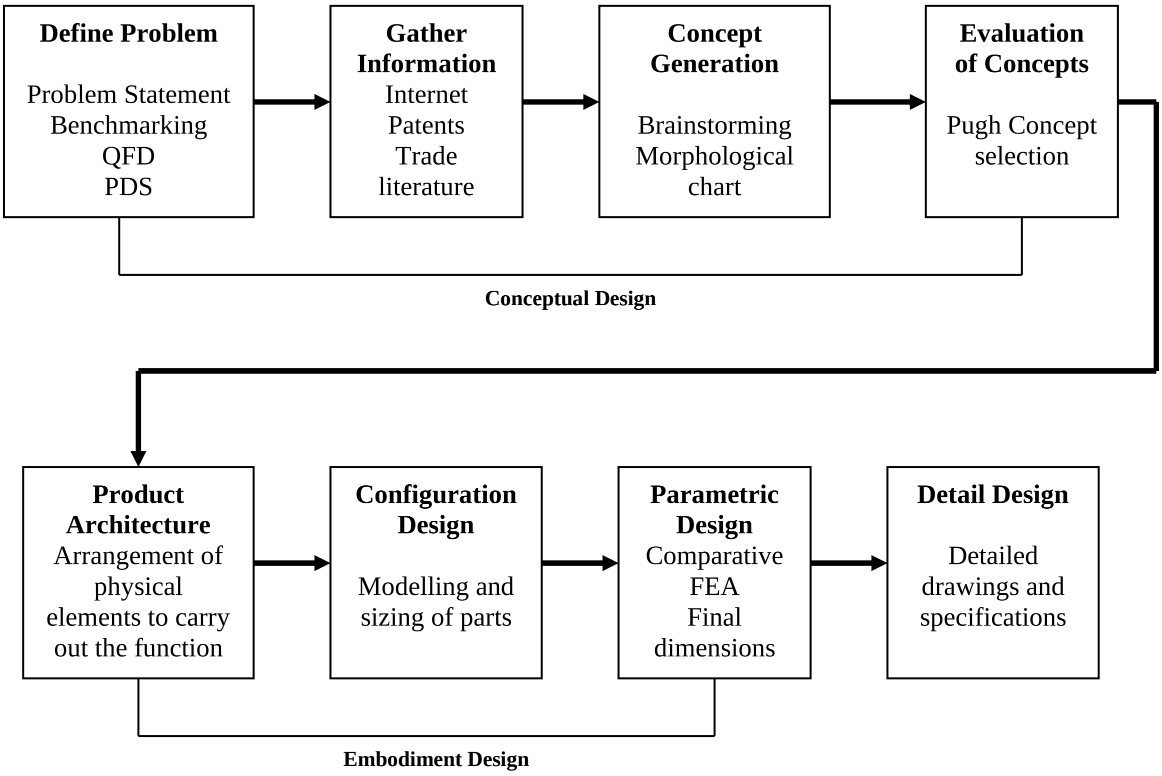


Figure 7 – The Design Process for this project adapted from Dieter (2000)

1.5.1 Problem Definition

The problem definition incorporates the problem statement, benchmarking, Quality Function Deployment (QFD) and the Product Design Specification (PDS).

The problem statement is essentially the aim of the project, which has already been defined.

Benchmarking involves looking at the key characteristics of the current and competitive product to outline key performance metrics and targets for the new product.

Quality Function Deployment (QFD) is used as a tool for planning and problem solving. It links the customer's requirements with engineering characteristics and helps focus the rest of the design process on the most important of the engineering characteristics.

Finally, the Product Design Statement (PDS) is a document that will control and define the rest of the design and manufacturing process. It includes the definition of; the product's purpose and market; the functional requirements of the product; all the considerations that have to be made in the design; corporate constraints; and the social, political and legal requirements.

1.5.2 Gathering Information

In this phase of the project, information relevant to the project was sought to assist the design process. This information may be technical information that could be used in the design phase such as materials information, or information check for copyright or patent infringements. It could also be information to assist in the generating concepts or to compare other concepts that are not accounted for in the benchmarking study.

1.5.3 Concept Generation

During concept generation, concepts are generated through a number of brainstorming techniques. The concepts that are thought of are arrange into a morphological chart for easier understanding and assessment. The concepts in the morphological chart are also 'assembled' into a series of overall concepts for the product.

1.5.4 Evaluation of Concepts

The evaluation of concepts for this project utilised Pugh’s method for evaluating concepts. This method used the concept assemblies from the previous process and comparatively assessed them.

1.5.5 Embodiment Design

Embodiment design groups the processes of Product Architecture layout, Configuration Design and Parametric Design. Computer Aided Design (CAD) is paramount in this section of the project, as it helps assembly modelling and aids visualisation.

1.5.5.1 Product Architecture

Product Architecture is the first stage in the putting the design on paper. It defines the interactions of all of the components, either fundamental or incidental. It also aid sin the layout of the process and groups together any sections of the design that should be considered together.

1.5.5.2 Configuration Design

Configuration design is when the basic dimensions and physical layout of the product are defined. It relies on an accurate Product Architecture to ensure that the interactions are considered.

The best form for each component is determined in this phase, which includes Design for Assembly (DFA) considerations. The initial solid model of the components and assembly are the end results of this segment of the design process.

1.5.5.3 Parametric Design

Parametric Design takes the solid model from the previous step, and looks at what variables in the design could be changed to enhance the design. Enhancing the design includes weight reduction and improvements in strength and robustness. The result of Parametric Design is a design with its final dimensions and tolerances, which is ready for the detailed design.

One of the main reasons for parametric design in this project is to look at weight reduction and it effects on the frame's strength and deflection characteristics. Using Cosmos/Works Finite Element Analysis (FEA), the parametric design analysis for the afore mentioned characteristics was quickly and easily carried out. The cost and risk is also minimised using this method.

1.5.5.4 Computer Aided Design

Computer Aided Design was used intensely during the design phase of the project. Solid Modelling was used for visualisation, assembly modelling and interference detection.

The choice of platform for CAD solid modelling was SolidWorks, for it ease of use in solid modelling, as it can be run on the Windows 98 operating system, and a simple port to Finite Element Analysis software was available in Cosmos/Works.

CAD was also used for path analysis problems, where the location of points of more complex geometries were sought to during at different times of the mechanism's position. The problem could be simplified by only considering the key points of the mechanism and using simply geometric relations to determine a solution for the problem. The choice of software for this function was AutoCAD R14.

1.5.6 Detailed Design

Detailed Design is the final portion of the design process. The result is a set of drawings that can be used, the Bill of Material (BOM) of the final product and a final design review. It also forms the basis for any costing and analysis that needs to be done.

The use of SolidWorks greatly reduces the amount of time required in this phase, as all of the data from the solid models at the end of the parametric design phase can be used to generate the detailed drawing and BOM.

1.5.7 Validation

The purpose of validation of the design is to ensure that the product is safe and reliable before it goes to the consumer. There are a variety of methods for validation including theoretical, computational, field testing and by surveying prior research. As much validation as possible should be done prior to field validation, as this is the most expensive type of validation, because it requires prototypes to be made to test. It is, however, considered more reliable than other forms of validation, because it can account for issues that can't be tested or considered using other methods.

1.5.7.1 Theoretical Validation Methods

Theoretical validation includes method of analysis that are included in most standards and text books. Examples are stress calculations in spring design and the use of standard calculations for deflection of beams. Theoretical validation is relatively inexpensive in most cases, but can sometimes be drawn out and labour intensive if iterative or large calculations are required.

1.5.7.2 Computational Validation Methods

Using computational methods of analysis reduces the time and cost in a lot of validation processes. It is still usually more expensive than using a theoretical approach due to the computer hardware requirements, but can be applied in more complex situations where complex geometries are too hard to analyse theoretically. Also, its reliability can sometimes come into doubt, as the engineer usually had to make some assumptions in the input of loads and boundary conditions, which would cause some errors when compared to the actual results. The size of the mesh also determines the accuracy of the result. A finer mesh can make the results more accurate, but also costs more in computational time and therefore costs more money. The choice of platform for computational analysis in this project is Cosmos/Works, which is also utilised in the Parametric Design phase. The computer being used for the FEA was a PentiumII 450 MHz with 196 Mb of RAM and a 10 Gb hard disk. Cosmos/Works is a simple port from SolidWorks, which can use the solid model geometries generated to mesh. It also provides a simple post processing interface. There are drawbacks in using Cosmos/Works. It can only be used for linear analysis. While contact analysis is possible, it requires huge amounts of memory and is subsequently unreliable because a coarse mesh has to be used to get a result without the computer crashing. Dynamic and large deformation analysis is also not possible, however, the model can be ported to Cosmos/M for these types of higher end analysis (www.srac.com, 2001).

1.6 Literature Review

Literature on the sport of in-line speed skating is quite scarce. Most of the literature that is available is on the Internet and quite informal and potentially unreliable. There is a vast array of literature relating to ice speed skating available, and it is quite relevant to this project.

1.6.1 General Literature Review

This portion of the literature review will look at the general literature that is available on both in-line and ice speed skating.

De Boer, Vos, Hutter, de Groot, and van Ingen Schenau (1987) found that the relationship between the bio-mechanical and physiological aspects of in-line and ice speed skating on conventional fixed frame skates was almost the same. This indicated that in-line speed skating could be used as a training tool for ice speed skaters during non-ice periods. It also allowed for cornering techniques to be worked on during the off season, which was not possible with other off season training techniques.

De Boer, Cabri, Vaes, Clarijs, Hollander, de Groot and van Ingen Schenau (1997) discussed the suppression of the plantar flexion in the push off technique in ice speed skating. They found that when an ice speed skater pushes off, the suppression of the plantar flexion in ice speed skating on fixed frame skate limited the knee extension and the overall stroke length. This indicated that the impediment of the knee extension caused the push off to be more explosive than it would be if a plantar flexion was available during the stroke.

Gorant (1998) highlighted the resistance of many top skaters to use ice clap skates early in their introduction. Blaire (cited in Gorant, 1998), five time Olympic gold medallist, stated that she did not like the skate because it was a mechanical device. German skating star Neiman (cited in Gorant, 1998) called for the clap skate to be banned from international ice speed skating. De Koning (cited in Gorant, 1998), stated that despite ice clap skates providing more work per stroke, the skater still has to have the additional physical capacity to achieve the increase. This indicates that it is not simply a case of bolting on a pair of clap frames to some boots, skaters still must condition themselves to achieve the greater output.

1.6.2 Advantages and Disadvantages of In-line Clap Skates

The following table is a summary of the literature found that indicates the advantages and disadvantages of in-line clap skates. Some of the evidence relates to ice clap speed skates, but as it has been proved that in-line speed skating with fixed frame skates is an acceptable cross training for ice speed skaters on fixed frame ice skates, it has been assumed that the same will be true for the relationship between clap in-line and ice skates. The magnitude of the error in this assumption is presumed to be almost negligible.

Advantage	Disadvantage	Source	Evidence
✓ Ice clap skates improved the performance junior Dutch skaters.		van Ingen Schenau,G.J., De Groot, G., Scheurs, A.W., Meester, H., de Koning, J.J. (1996). A new skate allowing powerful plantar flexions improves performance. *Medicine and Science in Sport and Exercise.*28(4) 531-535.	Conventional, fixed blade ice skates suppress the use of plantar flexors (ie. pointing of the toe with calf muscle) from contributing to external work. A hinge between the blade and the boot (clap skate) was introduced to the skates of 11 Dutch junior ice skaters and their progression was tracked against a control group of 72 other Dutch junior skaters on conventional ice skates. The improvement in personal best times for the ‘clap skaters’ was, on average, 6.2% compared to 2.5% for the conventional skaters.

✓ Clap skates provide an improvement in physiological responses for ice speed skaters.		Houdijk, H., Heijnsdijk, E.A.M., de Koning, J.J., de Groot, G., Bobbert, M.F. (2000). Physiological responses that account for an increased power output in speed skating using klapskates. *European Journal of Applied Physiology.* 83:283-288.	Six skaters performed maximal and sub-maximal 1600m skating tests on conventional and clap ice skates. The subjects were able to skate 4.1% faster for the maximal test using clap skates. It was shown that using clap skates, they could sustain a higher power output for the same oxygen uptake when compared with skating on conventional ice skates. Also, blood lactate concentrations were higher when using clap skates, indicating higher anaerobic power. For the sub-maximal test, it was shown that gross efficiency (mechanical power out vs. aerobic power) was better when using a clap skate rather than a conventional skate. This indicated that the advantage of ice clap skates were in efficiency gains.

✓ A change in the push off mechanics in ice speed skaters using clap skates accounted for an increased power output.		Houdijk, H., de Koning, J.J., de Groot, G., Bobbert, M.F., van Ingen Schenau,G.J. (2000). Push-off mechanics in speed skating with conventional skates and klapskates. *Medicine and Science in Sports and Exercise.* 32(3) 635-641	This paper investigated the differences in skating technique for ice skaters using clap and conventional skates. When using the clap skate, the skaters showed a 6% increase in velocity as a result of an increase of 25 Watts in mean power output. This was achieved by an 11 Joules (6%) increase in work per stroke and an increase stroke rate from 1.30 to 1.36 strokes per second. The extra work per stroke came from the plantar flexion (extension of the foot about the ankle using the calf muscle) which occurs in the last 50ms of the stroke.

✓ Ice speed skating records that had stood for a significant period of time fell well the clap skate was introduced to international ice speed skating. The records continue to be broken.		International Skating Union (2001). Complete list of historical speed skating records. [www] Available: http://www.isu.org	From 1991 to 1994, 6 seconds were taken off the 5000m men's ice speed skating world record. The record was then stagnant until 1997 when the clap skate was introduced to international competition, when Dutch skater Romme broke the record by 4 seconds. Since then, Romme has taken another 12 seconds off the world record, totalling 16 second off the record since clap skates were introduced. This represents a 4% decrease since the clap skate was introduced. Skaters using clap skates now hold records in all other distances for both males and females.

	▯ Clap skates are noisy and not suited to the in-line speed skating race formats where sneak attacks are required.	Bont, A. (2001). [e-mail] Discussion on in-line clap skate design.	Clap skates originate from long track ice skating where there are two skaters on the track each racing against the clock. Inline speed skating races are more closely related to cycling, where there is a pack of athletes using tactics such as a sneak attack to gain advantage. The 'clapping' of in-line clap skate can be heard by the pack, so that when a skater increases their stroke rate for an attack from behind, the skaters in front will know they are coming.

	▯ So far, all in-line clap skates are significantly heavier than fixed frame in-line speed skates	Nett, R. (2001). Clap frame time trials. [www] Available: http://www.nettracing.com/clap-rev.htm	The weight of clap frames is between 1.5 to 2 times greater than a standard fixed frame. The current Bont frame is 17% heavier than one of its major competitors, the Mogema Clap frame.

✓ In testing their in-line clap frame prior to release, Bont found that the maximum speed that could be achieved in pacing during training was increased.		Bont Skates (2001). Inline Clap Skate. Available: http://www.bont.com/news/featurearticles/clapinline/inlineclap.htm Bont, A. (2001). Clap skates in general, the Slingshot in particular. [Usenet newsgroup] Posted to *rec.sports.skating.inline*. 8 April 2001.	In testing the Bont Slingshot frames prior to release, skaters were able to be paced (skating behind a motorcycle for training) at 5km/h faster on the clap skates than on conventional fixed frames. This represented an increase of 13% in maximum speed for such a trial.
	☐ Clap frames may be cost prohibitive to the consumer.	Nett Racing. (2001). Inline Speed Skating Equipment. [www] Available: http://www.nettracing.com/frames.htm	The Bont clap frame is over twice as expensive as most high end fixed frames. It is also 19% more expensive than one of its main competitors, the Mogema clap frame.
✓ In-line clap frames were independently tested against other frame configurations, and the Bont and Mogema Clap frames were better than fixed frame skates.		Nett, R. (2001). Clap frame time trials.[www] Available: http://www.nettracing.com/clap-rev.htm	5 different frames were tested by doing an 8km (5 mile) skate on a winding circuit course. The frames trialed were; Bont Clap, Mogema Clap, Verducci Clap, Boen conventional (fixed), Xenan fixed w/ big wheels(100mm). The fastest time was achieved on the Bont clap frame, and it was 2.8% quicker than the fixed frame tested.

From the negative issues raised above, three of the disadvantages indicated could be designed out or minimised. These are the noise, weight and cost issues.

Specifically on the issue of cost, if you consider that clap frames for ice speed skates were also more expensive than conventional frame, yet have now come down in price and are now the standard for long track and marathon skating, in-line clap frames are likely to follow the same path. Analogies in other sports can also be considered such as the decrease in cost of suspension for mountain bikes and its increase in volume being bought as its acceptance grew.

2. Identification of the Product Design Specification

2.1 Introduction

The purpose of this portion of the project identifying the what the problem is and determining the specification for the product that will be the solution. Overall, this section is the most important part of the project as it defines what course the rest of the project will take.

It starts with the problem statement, which defines what the objective is of the design process. This needs to be absolutely clear, as if the statement is slightly wrong, the project could take the wrong path.

The next phase is to determine the benchmarks, which will form the basis for the specification of best practice, and indicate the targets to strive for in the project. Also, for the case of this project, surveys were conducted to find out what the customer's expectations are.

The customer's expectations form the basis of the Quality Function Deployment (QFD) where they fall into the customer requirements field. The customer requirements (CR's) are then linked with a series engineering characteristics (EC's), which are essentially what can be controlled in the design. The relationship between the each engineering characteristics is also considered. The result of the QFD is to provide a focus of what to focus on in the design of the product.

The result of this section of the project is the Product Design Specification (PDS). The PDS forms the governing document for the design process, and should account for all of the requirements and considerations that are required to complete the project.

2.2 Problem Statement

The purpose of this project, as previously discussed in section 1.4, is to redesign Bont's in-line speed skate clap frame, the 'Slingshot', according to the expectations of Bont and their potential customers.

The scope is to basically improve the existing design but is **not** to prove that in-line clap speed skates are advantageous in comparison to conventional fixed frame skates, nor was it is alter the key design parameters set out by Bont in their current product.

2.3 Benchmarking: Comparative Analysis of Existing Designs

Benchmarking provides an insight into best practice in the industry, and provides a basis for targets to be aimed for. It is a process of gathering information about what other products are in the market place that satisfy most or all of the design problem. In discussing the benchmarking issue with Alex Bont (2001), he suggested that the Bont Slingshot would be the benchmark for all the other manufacturers. Despite this, it is still recommended that the top competitive frames be considered in the benchmarking phase, as the competitor's product may have one or two feature that may feature prominently in the customer’s selection process. If your product is considered the best in the marketplace, it will also provide a chance for you to keep ahead of what your competitors are doing.
The products that are benchmarked in this project Bont’s Slingshot, which the redesign is based on, the Mogema M41 and the Maple Reaction Clap.

2.3.1 Bont Slingshot

The Slingshot is the first model of frame for Bont in a clap configuration (www.bont.com, 2001). It is different from other manufactures attempts at clap frames, in that it has only the front three wheels pivoting, while the rear two travel with the boot. This design is has been labelled a ‘split system’, because it uses two separate extrusions and the wheels are split into the two groups when the mechanism opens.

Figure 8 - The Bont Slingshot In-line Speed Skate Clap Frame (www.cheapskater.com, 2001)

Figure 9 - The Bont Slingshot Clap Mechanism (www.bont.com, 2001)

The mass of one frame assembly with out axles was measured and found to be 389g. This was measured on an AND FC-10K Electronic Scale at Toll Automotive Logistics in Campbellfield, Victoria. The scales have a regular maintenance and calibration schedule.

The spring to return the mechanism is a torsional spring. The recommended retail price when released was US$520.

2.3.1.1 Bill of Materials for the Bont Slingshot

The following is the bill of materials for the Bont Slingshot, with the estimated time to assemble the component and the weight of each component from the solid models. The mass properties for all of the materials were taken from Askeland (1996).

Description of Part	Qty	Mass of Part (gms)	Total	Time to Assemble (s)	Total
Lower Frame	1	104.7	104.7	0	0
Upper Frame	1	211.2	211.2	3	3
Pivot Washer	4	0.4	1.6	4	16
Pivot Screw	2	5.1	10.2	12	24
Pivot Nut	2	5.0	10	10	20
Spring	2	13.3	26.6	30	60
Spring Rod	1	1.0	1	30	30
Spring Rod Screw	2	0.4	0.8	12	24
Clap Block	1	7.0	7	5	5
Clap Block Screw	2	0.1	0.2	5	10
Dampers	2	0.4	0.8	5	10
Totals:	20		374.1		202

It was noted that the value of total mass was different to the mass measured. This may be because of errors drawing the parts in SolidWorks, some discrepancies in manufacturing tolerances and the material properties entered into the computer for each solid model may have differed to the actual materials.

2.3.1.2 Benchmarking the Slingshot using FEA

As drawings and a physical example were available for the Slingshot, Finite Element Analysis (FEA) was utilised to determine the maximum stress and displacement under various loading conditions. FEA was also used to view the shape of the deflection under these loading conditions. The drawings for the current Slingshot can be found in Appendix A.

The front and rear frames were analysed separately. As previously discussed, Cosmos/Works was the platform for the FEA. The SolidWorks solid models of the Slingshot were created from detailed drawings supplied by Bont. As some of the dimensions that were required to define the model fully were missing from the detailed drawings, a Mitutoyo dial calliper was used to find the required dimensions.

2.3.1.3 Loading Conditions Used

The loading conditions considered in for benchmarking the front frame were under weight load straight down on the frame and under a pushing load where the frame was leaning at a 45 degree angle. The rear frame was loaded with a weight load straight down and under turning conditions where the skate was leaned over 45 degrees and the skater was travelling at 11.1 m/s (40 km/h) around a turn 5m in radius. Much more complex conditions could be considered for the various load cases, however it was assumed that with a reasonable factor of safety, these loading conditions would be acceptable.

The coefficient of friction between the skate’s wheel and the ground was assumed to be 0.6 as the data for such an interaction was unavailable.

Skating takes place on reasonably smooth surfaces and the wheels used are made of relatively soft elastomers. Therefore it was also assumed that there were no significant impeding forces in the direction of the movement of the skater, that is the ‘x’ direction shown in the diagrams in this section.

In all cases, the skater’s centre of gravity is assumed to be directly in line with the middle wheel of the skate for simplicity. The mass of the skater will be taken as

100kg, which is probably above the average for a typical skater. Higher forces could be considered due to dynamic loading considerations, but speed skating has a smooth flow where landing a jump on skates is an anomaly. Therefore the dynamic forces would not be too significant, and any moderate factor of safety would accommodate them.

The following sections show the free-body diagrams and the calculations used to determine the magnitude and direction of the loads for each of the loading conditions described above.

2.3.1.3.1 Free Body Diagram of a Skater and Calculation of Forces

The following free body diagram describes the forces in a where the skater's centre of gravity (COG_{skater}) is directed over the middle wheel of the skate. Also, the force acting on each wheel from the ground is considered were F_{W1}, F_{W2}, F_{W3}, F_{W4}, and F_{W5} are the forces acting on wheel 1, 2, 3, 4 and 5 respectively.

From the assumption that COG_{skater} is acting directly over wheel 3, the following can be stated:

$$F_{W1} = F_{W2} = F_{W3} = F_{W4} = F_{W5} = F_W \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2.1)$$

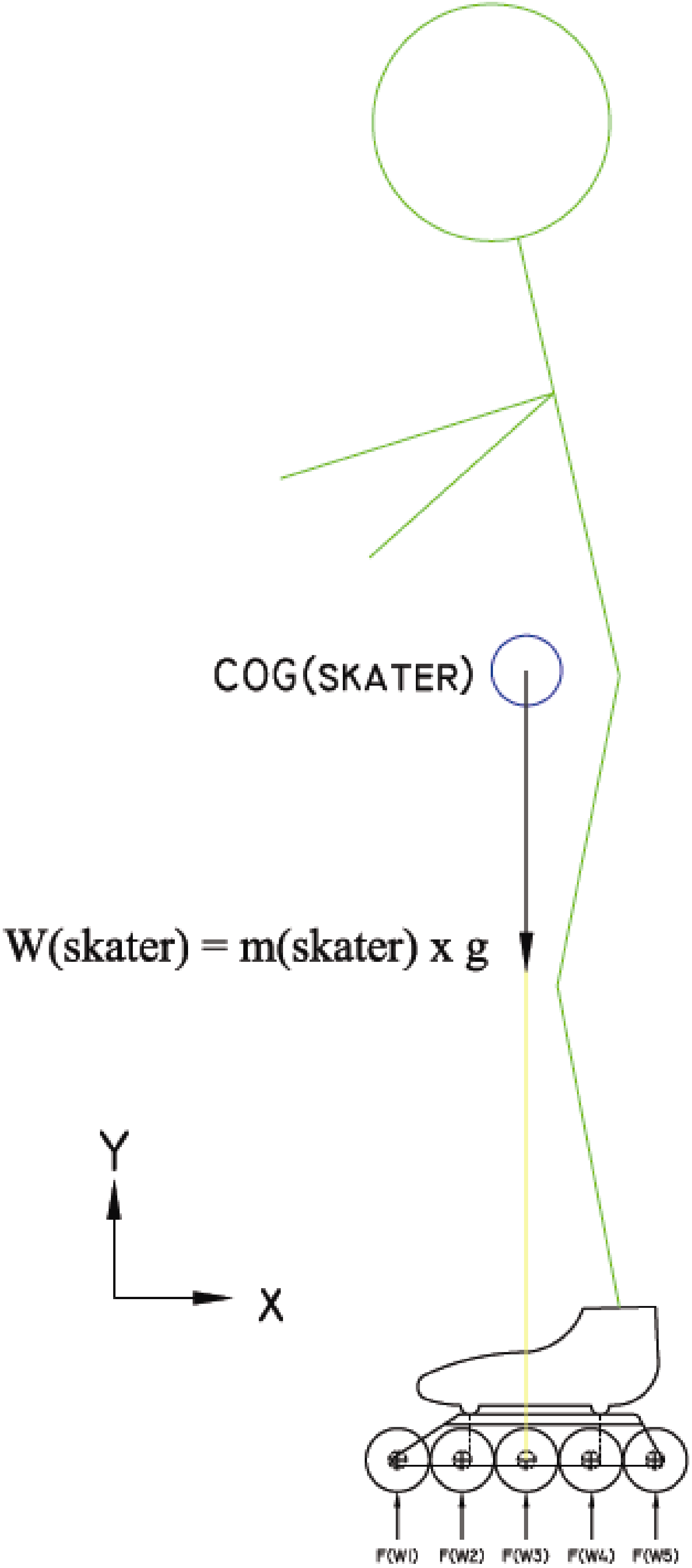
Therefore, if the forces are summed in the Y direction, we find:

$$\Sigma F_y = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2.2)$$

$$\therefore\ 5 \text{ x } F_W = W_{skater} = m_{skater} \text{ x } g \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2.3)$$

$$\therefore\ 5\ F_W = 100 \text{ x } 9.81 \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2.4)$$

$$\therefore\ F_W = 196.2 \text{ N} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2.5)$$


COG(SKATER)
W(skater) = m(skater) x g
Y
X
F(W1)
F(W2)
F(W3)
F(W4)
F(W5)

2.3.1.3.2 Calculating the Reaction Forces in the Front (lower) Frame when under Weight Loading

The following is the free body diagram for the front frame under weight load conditions. No forces are considered in the 'x' direction as it was assumed there were no impeding forces in the direction of the skater's motion as discussed in section 2.3.1.3.

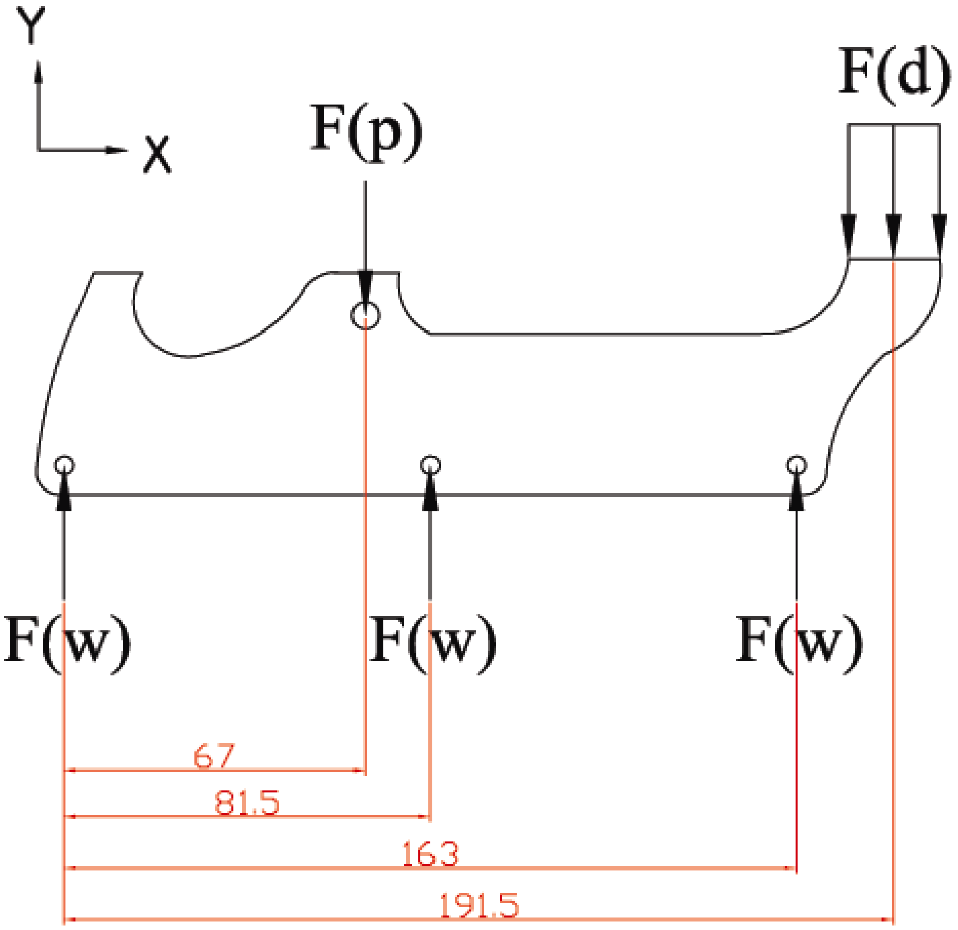


Figure 10 - Front weight load free body diagram

F_w is the force from the wheels acting on the from which was calculated at (2.5) as being 196.2 N. F_p is the force at the pivot joint and F_d is the distributed force at the damper (clap block), which can be assumed is operating at the centroid of the damper. To find F_d, sum of moments about F_p can be calculated as follows:

$$\Sigma M (F_p) = 0 \qquad \text{………………(2.6)}$$

$\therefore\ 67\,(F_w) + 124.5\,(F_d) = 14.5\,(F_w) + 96\,(F_w)$ ………………(2.7)

$\therefore\ 124.5\,(F_d) = 14.5\,(196.2) + 96\,(196.2) - 67\,(196.2)$ …………(2.8)

$\therefore\ F_d = 68.5\text{ N}$ ………………(2.8)

From this, the forces can be summed in the Y direction to find F_p:

$\Sigma\ F_y = 0$ ………………(2.9)

$\therefore\ 3\,(F_w) = F_p + F_d$ ………………(2.10)

$\therefore\ 3\,(196.2) = F_p + 68.5$ ………………(2.11)

$\therefore\ F_p = 520.1\text{ N}$ ………………(2.12)

2.3.1.3.3 Calculating the Reaction Forces in the Rear (upper) Frame when under Weight Loading

The following is a free body diagram for the rear frame under weight load conditions:

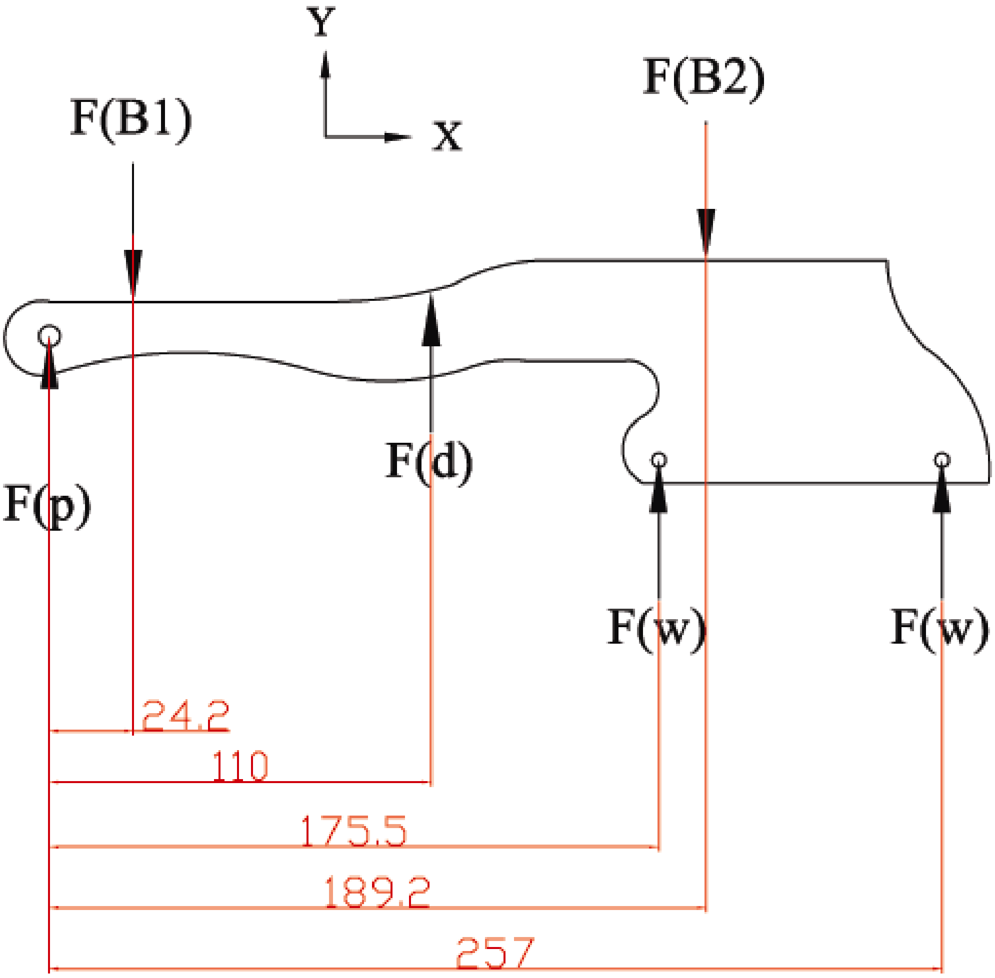


Figure 11 – Rear weight load free body diagram

F_{B1} is the reaction force at the front boot mount, and F_{B2} is the reaction force at the rear boot mount. It is know that; from (2.5), F_w is 196.2 N; from (2.8), F_d is 68.5 N; and from (2.12), F_p is 520.1 N. By summing moment about F_{B1}, F_{B2} can be determined as follows:

$$\Sigma M (F_{B1}) = 0 \qquad \text{………………}(2.13)$$

$$\therefore\ 24.2 (F_p) + 165 (F_{B2}) = 85.8 (F_d) + 151.3 (F_w) + 232.8 (F_w) \qquad ..(2.14)$$

$\therefore F_{B2} = 416 \text{ N}$ ………………(2.15)

The forces can now be summed in the Y direction to find F_{B1}:

$\Sigma F_Y = 0$ ………………(2.16)

$\therefore F_p + F_d + 2 (F_w) = F_{B1} + F_{B2}$ ………………(2.17)

$\therefore F_{B1} = 565 \text{ N}$ ………………(2.18)

2.3.1.3.4 Calculating the Reaction Forces in the Front (lower) Frame when under Push-off Loading

One case of a push off loading will be considered for the front frame FEA. This will be when the angle of the frame is such that it is tilted at a 45 degree angle from being straight up. The load at the wheels will not be calculated, as the axles will be restrained, and the reaction force is not required to be input into the FEA model.

The following is a free body diagram that represents the condition:

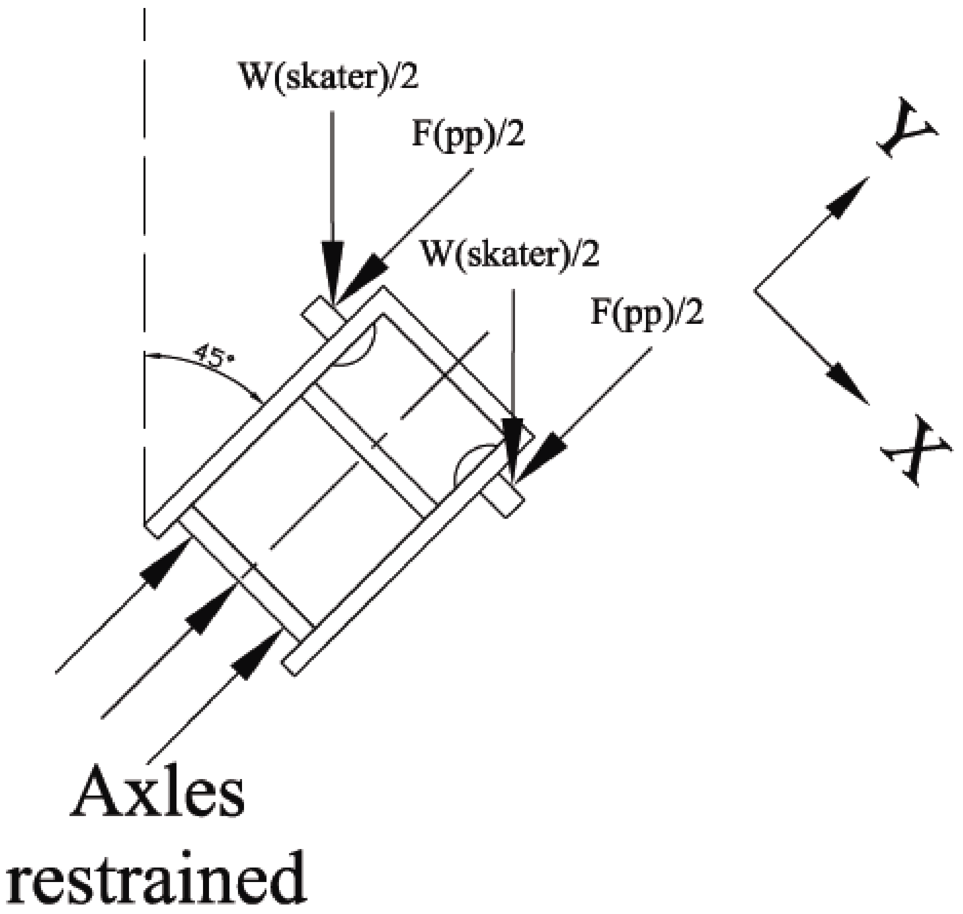


Figure 12 - Free body diagram of forces to consider during pushing on the front frame

W_{skater} is the weight of the skater that was highlighted previously at (2.3). F_{pp} is the reaction force during pushing at the clap pivot pin. W_{skater} is calculated as:

$$W_{skater} = m_{skater} \times g \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2.19)$$

$$\therefore\ W_{skater} = 100 \times 9.81 = 981 \text{ N} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2.20)$$

F_{pp} may be estimated based on the maximum normal force on the skate, that would be governed by the coefficient of friction between the wheel and the ground, μ. It has been assumed that the value for μ would be 0.6. Subsequently, F_{pp} is given by:

$$F_{pp} = \mu\, N \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2.21)$$

And N is the normal force at this point, which would be equal to the weight force, W_{skater}. Therefore, the maximum pushing force is:

$$F_{pp} = \mu W_{skater} \qquad \text{.................}(2.22)$$

$$\therefore F_{pp} = 0.6 \text{ x } 981 = 588.6 \text{ N} \qquad \text{.................}(2.23)$$

These values can be applied to the FEA model using Cosmos/Works.

2.3.1.3.5 Calculating the Reaction Forces in the Rear (upper) Frame when under Turning Load

For the worst case for the rear frame, it was decided that the loading to be considered would be while turning. The conditions were where the skate was angled at 45 degrees, and the skater was turning a corner of 5 meter radius at 11.1 m/s (40 km/h). For loading the FEA model, the pivot pin and axles would be restrained, so determining the forces at the boot mounts was required.

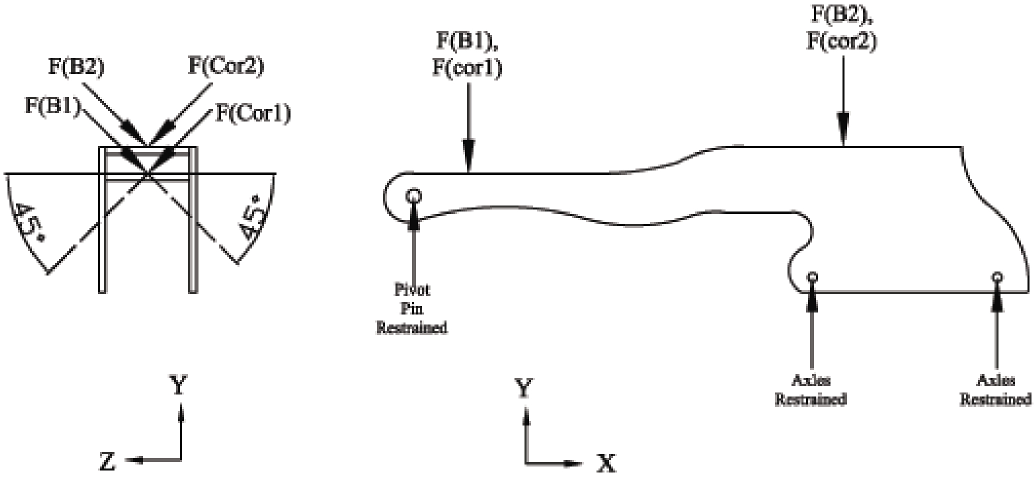


Figure 13 - Free body diagram for rear frame loading condition during turning

F_{B1} and F_{B2} are the same as the boot reaction forces calculated in (2.18) and (2.15) respectively. F_{Cor1} and F_{Cor2} are the reaction forces at the boots caused by normal acceleration while turning an arc. Since it has been assumed that the skater COG acts through the middle wheel, it can be said that the ratio of the distribution of cornering forces between the front and the back boot mount is the same as the ratio of the distribution between the reaction forces at the boot. That is:

$(F_{Cor1} / F_{Cor2}) = (F_{B1} / F_{B2})$ ………………(2.24)

and $F_{B1} = C\ (F_{B2})$ ………………(2.25)

It is known that F_{B1} is 565N and F_{B2} is 416N, therefore solving for C yields:

$565 = C\ (416)$ ………………(2.26)

$\therefore\ C = 1.36$ ………………(2.27)

$\therefore\ F_{Cor1} = 1.36\ F_{Cor2}$ ………………(2.28)

It can be said that the sum of the individual cornering reaction forces at the boot, F_{Cor1} and F_{Cor2}, come to the total centripetal cornering force, calculated from the normal acceleration for an object travelling in an arc. This is given by:

$F_{Cor1} + F_{Cor2} = F_{Cor}$ ………………(2.29)

$\therefore\ 1.36\ F_{Cor2} + F_{Cor2} = F_{Cor}$ ………………(2.30)

$\therefore\ F_{Cor} = 2.36\ F_{Cor}$ ………………(2.31)

The acceleration normal to the direction of the skater's motion can be found by:

$a_{Cor} = (v^2 / r)$ ………………(2.32)

$\therefore\ a_{Cor} = (11.1^2 / 5) = 24.6\ m/s^2$ ………………(2.33)

The cornering force, F_{Cor} can now be determined by using the relation F=ma. Subsequently, F_{Cor1} and F_{Cor2} can be determined:

$F_{Cor} = 100 \times 24.6 = 2460\ N$ ………………(2.34)

$\therefore\ F_{Cor2} = 2460/2.36 = 1040\ N$ ………………(2.35)

$\therefore\ F_{Cor1} = 2460 - 1040 = 1420\ N$ ………………(2.36)

The forces for F_{B1}, F_{B2}, F_{Cor1} and F_{Cor1} can now be applied to the FEA model in Cosmos/Works.

2.3.1.4 Boundary Conditions

Boundary conditions were applied to the axles in all load cases. There were no translations allowed, but the axles were allowed to rotate, as they would be able to on a skate.

An additional boundary condition was applied on the models of the rear frame. The holes where the pivot pin was located were also held by a boundary condition that allowed rotation but not translation.

2.3.1.5 Material Applied to the FEA Model

The material used for all parts of the FEA models (frame section, axles) was aluminium with a Young's Modulus of 69GPa and Poisson's ratio of 0.33 (Askeland, 1996).

2.3.1.6 Meshing the FEA models

All models were meshed automatically by Cosmos/Works, at a mesh size of 3.5mm.

2.3.1.7 Results of the Benchmarking FEA

Plots of the post processing results can be seen in Appendix B.

The following table summarises the FEA benchmarking results of the Bont Slingshot.

Frame Section	**Load Case**	**Max. Stress**	**Max. Displacement**
Front	Weight Load	9.7 MPa	0.0163mm
	Pushing Load	178 MPa	0.374mm
Rear	Weight Load	28.4 MPa	0.020 mm
	Cornering Load	82.1 MPa	0.178 mm

2.3.1.8 Discussion of Slingshot Benchmarking FEA

The results set out above are simply an indication of the maximum displacement and stress that can be compared to the final design. The post processing of the benchmarking can also allow for point on the surface of the model to be probed. This method will be discussed later, when the benchmark results will be compared to the parametric and final design.

However, as Cosmos/Works does not allow for any control on the output of results of specific nodes and elements, it is hard to hone in on any specific node results or to find where a specific node number is on the model. This means that when the list of the highest stressed nodes is requested, you do not know the location of those nodes on the model.

2.3.2 Mogema M41 Clap Frame

Figure 14 - Mogema M41 Clap Frame (www.cheapskater.com, 2001)

The Mogema M41 is a clap frame where all 5 wheels are on the pivot (www.mogemasports.com, 2001). The spring used to close the mechanism is a helical extension spring. The frame weighs 312 grams without axles and has a retail price of US$499.

One of the interesting features of this frame is that the top clap pivot section can be taken off and attachments can be added to the frame to make it a fixed frame.

Actual examples of this frame were not available for testing and assessment nor were drawings. FEA benchmarking was subsequently not possible.

2.3.3 Maple Reaction Clap Frame

Figure 15 - Maple Reaction Clap (Bennink, 2001)

Figure 16 - Maple Reaction Clap in use (Bennink, 2001)

The Maple Reaction In-line Clap frame has the two front wheels on the pivoting section of the frame (Bennink, 2001). The frame uses a helical extension spring to return the mechanism. The frame’s retail price is around US$250 and it weighs 300 grams.

Actual sample of this frame were not available for testing and neither were drawings, therefor FEA benchmarking was not possible.

Alex Bont (2001) has looked at these frames and feels that their quality is far inferior to the Bont Slingshot.

2.3.4 Discussion of Benchmarking Study

A summary of what was found in the benchmarking study is shown in the following table.

	Bont Slingshot	**Mogema M41**	**Maple Reaction**
Wheels Pivoting	3	5	2
Spring Type	Torsion	Helical	Helical
Retail Price (US)	$520	$499	$250
Weight (gms)	389	312	300
Other	Pivot stopper stops the mechanism opening too much and the boot hitting the wheels.	Optional hardware converts the frame to a fixed frame.	

Benchmarking using Finite Element Analysis was undertaken for the Bont Slingshot frame, but none of the others were able to be benchmarked in this way. Using FEA would have provided extra insight into the competitors' frames, as would having actual sample of the frames to trial and test. Without this, the benchmarking is not truly complete.

2.4 Surveys

To gain insight into what was required in the redesign of the product, and as was specified in the problem statement, both Bont and Bont’s potential customers were surveyed.

2.4.1 Survey of Bont

To provide extra insight into what the expectations of the redesign were, Bont's marketing manager, Alexander Bont was surveyed by e-mail. Bont (2001) suggested that the redesign should address the following areas:

- Bont are looking for ways to decrease the weight, but maintain the frame's strength.
- When the clap mechanism closes, the clap sound is quite loud. It makes sneak attacks hard in the pack. Bont are hoping to find a way to reduce this sound.

Also, Bont would said the key features of the frame retained. These are the 3 wheels on the clap pivot, and a device that stops the frame from opening too much and the boot hitting the front wheel.

2.4.2 Customer Survey

As per the problem statement, the potential customers of Bont were also surveyed to find out what they wanted in a speed skate frame. This information was used for assessment in the Quality Function Deployment (QFD).

2.4.2.1 Design of the Customer Survey

The questions in customer survey were based around the following categories;

- Strength
- Durability
- Performance
- Aesthetics
- Functionality

The following statements were put to the customer and they were asked to respond on a scale with 5 options from strongly agree to strongly disagree:

- The color scheme of the frame is important.
- The shape of the frame is important.
- The texture of the frame (how it feels to touch) is important.
- The ease of wheel change over is important.

- Ease of attachment of the boot to the frame is important.
- Low rolling resistance of the skate is important.
- Overall, the strength of the frame is important.
- Durability of the components (eg. axles, bolts etc) is important.
- Strength of material used for the frame is important.
- Strength of materials used for the components is important.

The customers were also asked ‘Do you prefer your skate to be:’ with a 5 option scale from very light weight to very heavy to be checked.

The following questions were also included with the responses available listed after them:

- Do you prefer: 5 wheel frames; 4 wheel frames; Either.
- Which of the following do you think would provide the greatest advantage to your skating? Clap Frames; Monocoque Chassis; Big wheels.
- Which style of frames do you prefer? Fixed Frame; Clap Frame; Monocoque Chassis; Any; Other (with written response).
- Which continent are you from? North America; South America; Australia/Oceania; Europe; Asia; Africa.
- How many days per week do you skate? 1 or less; 2-3; 4-5; 6 or more.
- At what level of competition do you skate? International; National; State; Other; Don’t compete.
- Where do you skate? Indoor; Outdoor; Banked Track; Other (with written response). (Respondents could choose more than one answer to this question).
- What is your preferred race distance? Sprint (0-1km); Middle distance (1-5km); Long distance (5-20km); Very long distance/Marathon (20-75km); Ultra marathon or longer (75km+).
- What is your age? 0-15; 16-25; 26-35; 36-45; 46-55; 56-65; 66-75; 75+

The following questions were asked where the customer was required to provide a short written answer:

- What boots are you currently skating on?
- What frames are you currently skating on (including length)?

- What wheels do you prefer to skate on (including size and durometer)?

Finally, a section at the end of the survey was included where the customer could make any comment they wanted on in-line speed skate frames.

2.4.2.2 Delivery of the customer survey

The customer survey was delivered over the Internet, using ‘Surveywire’ (www.surveywire.com, 2001). This provided the opportunity to survey customers on other continents, particularly North America were much of Bont’s in-line skating customer base is. Traffic was brought to the survey by requesting that speed skaters fill out the survey on the rec.sport.skating.inline and the rec.sport.skating.racing newsgroups and by posting to the message boards of www.speedskating.com. Bont also provided a link to the survey from their home page ate www.bont.com.

2.4.2.3 Results of the customer survey

The results of the customer survey can be seen in Appendix C.

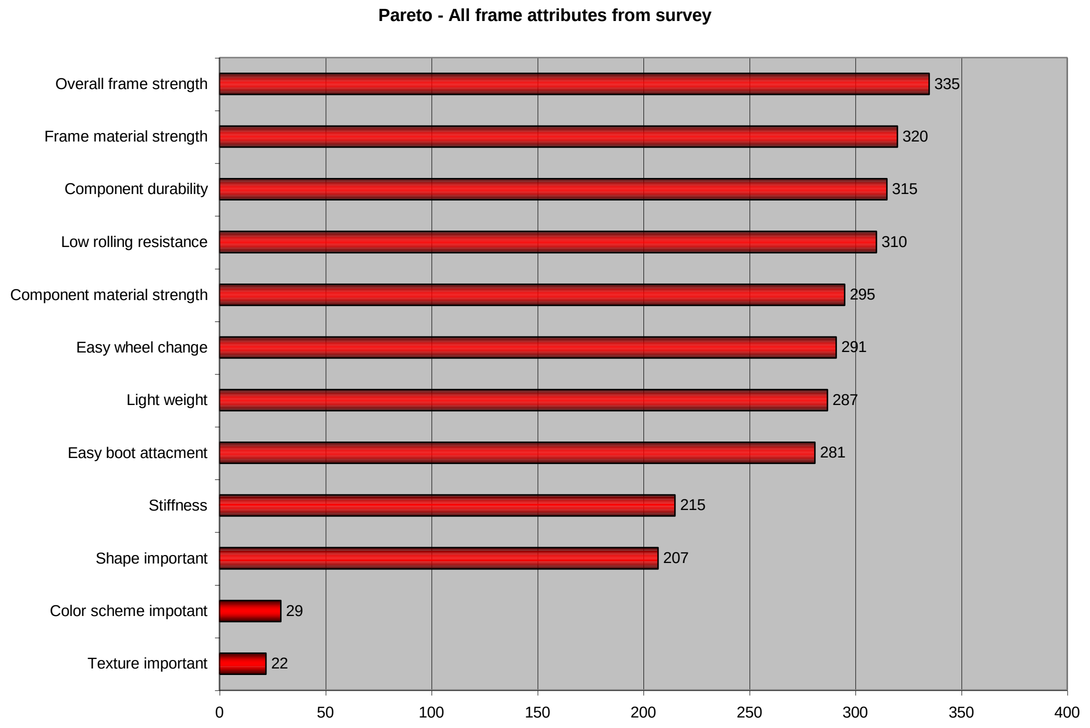
2.4.2.4 Discussion of the results of the customer survey

The first 12 questions were the main ones considered for this project, as they were based on the five categories that were to be focused on. Using the results from these questions, a system of determining the results was developed.

Each response to the question that was strongly agree scored a 2, an agree was worth 1, neither agree nor disagree was worth 0, disagree was worth –1, and strongly disagree was worth –2. Each of these questions were scored using this method, and the following scores were obtained:

Question	Brief Description	Result
1	Color scheme important	29
2	Shape important	207
3	Texture important	22
4	Easy wheel change	291
5	Easy boot attachment	281
6	Low rolling resistance	310
7	Overall frame strength	335
8	Component durability	315
9	Frame material strength	320
10	Component material strength	295
11	Stiff	215
12	Light weight	287

This was then arranged into a Pareto chart. A Pareto chart is a bar chart that orders the results to show the highest result at the top of the chart through to the lowest at the bottom. It then provides a very easy to understand picture of the results.
The following is a Pareto chart of the above results.



This chart highlights that frame and component strength and durability are of paramount importance to the customer. Surprisingly, a light weight frame is rated quite low.

2.5 Quality Function Deployment

Quality Function Deployment (QFD) is a tool for planning and problem solving that translates the Customer Requirements (CR's) into Engineering Characteristics (EC's) (Dieter, 2000). The CR's are taken from the surveys that were performed, while the EC's are generated by asking what can be controlled to help meet the customer's need. A set of EC's are brainstormed based on asking this question of each CR. The diagram that is formed during QFD is often referred to as the 'House of Quality', as it was developed to provide a better quality end product.

In the case of this project, the CR's are generated from the customer survey and the survey of Bont. The CR's are;

- Texture
- Color Scheme
- Shape
- Noise

- Increased stiffness
- Light weight
- Lower rolling resistance
- Component strength and durability
- Component material
- Frame strength and durability
- Frame material
- Cost
- Easy boot attachment
- Accommodation of big wheels
- Low frame profile

These CR's were also groups into the following groups, as can be seen in the QFD chart;

- Aesthetics
- Performance
- Strength & Durability
- Cost
- Design Attributes

The following EC's were determined for the QFD;

- Extrusion Profile
- Frame Design (Profile)
- Frame Material Type
- Component/Hardware Design
- Component Material
- Clap Block Design
- Clap Block Material
- Axle Design
- Frame Color
- Frame Decal Scheme
- Weight of Frame

- Component Material Strength:Weight Ratio
- Frame Material Strength:Weight Ratio
- Number of Components
- Stiffness of Frame
- Roughness of Extrusion Texture
- Manufacturing Quality
- Cost to Manufacture
- Manufacturing Tolerances

Where the EC what quantitative, a plus (+) or minus (-) sign was placed next to it to indicate the direction that the characteristic should take.

At the top of the QFD diagram is what can be referred to as the ‘roof’ of the house of quality. In this section, the relationship between each of the EC’s is considered. This is done to highlight that by changing one EC, it will affect the other. This affect could be positive or negative.

The Customer Importance rating is taken from the surveys and is a scale from 1 to 5, 1 being the lowest importance, 5 the highest. For example, the customer did not rate the color scheme of the frame very important, therefore it got a 1. Alternatively, the customer survey suggested the frame strength and durability was very important, and therefore it scored a 5. The noise CR scored a 5 as Bont considered it an important issue.

A rating for each of the CR’s for the benchmark products was also assigned, on a 1 to 5 scale. Where it was not possible to give it a score because it was unknown, a dash was put in that box. A rating, again from 1 to 5, was assigned for the expectations of the planned product. The planned improvement ratio was then determined by dividing the planned product rating by the current product rating.

Sales points were also assigned to each CR, where it was given a rating in terms of its marketability. The possible ratings, with the score assigned in brackets, for this were high (1.5), moderate (1.3) and low (1.0). For example, cost scored as high (1.5) because the cheaper a frame is, the easier it will be to market.

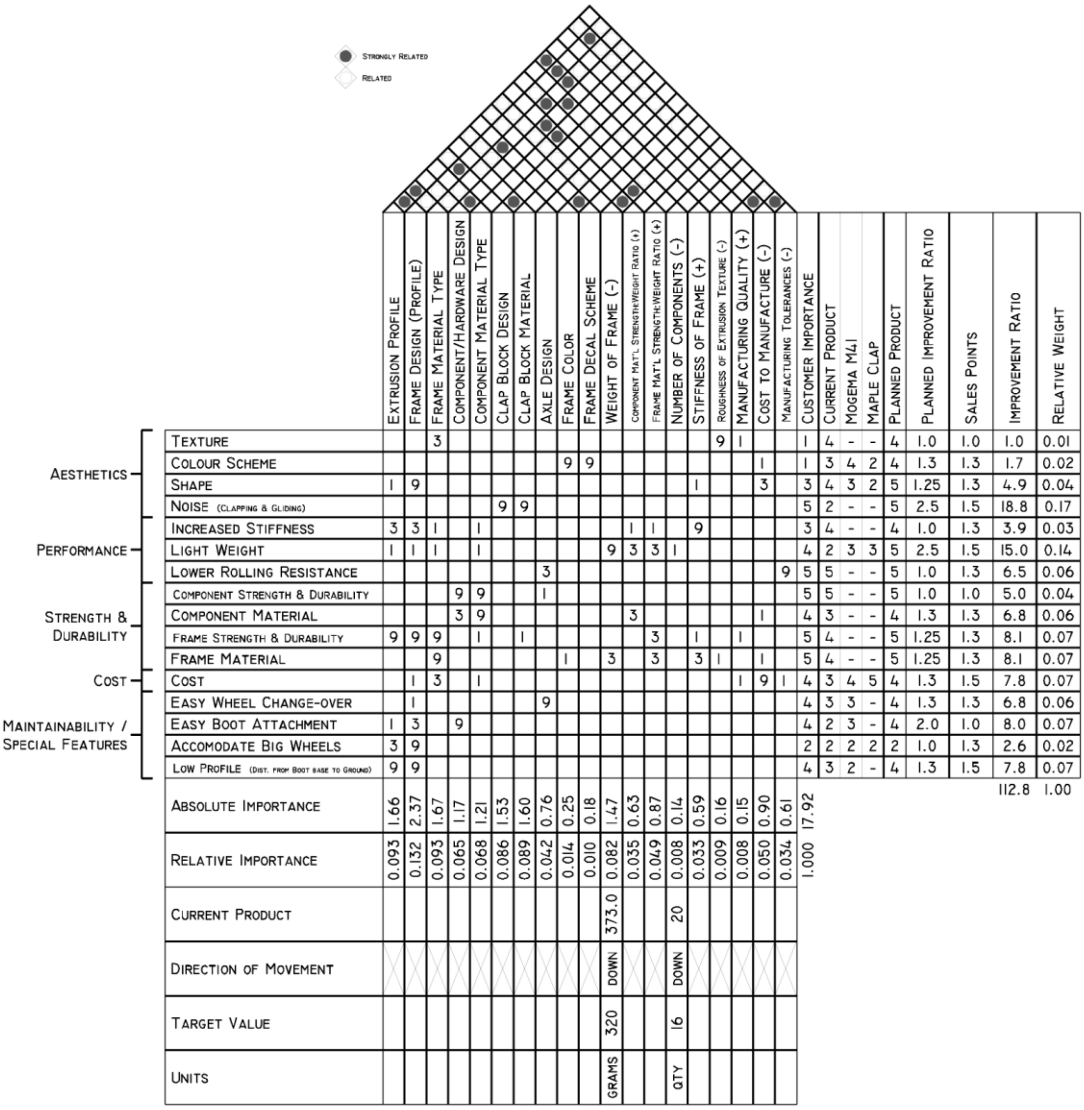
The Improvement Ratio could then be determined by multiplying the Customer Importance by the Planned Improvement Ratio by the Sales Points. The sum of the Improvement Ratio values was calculated for all so that the relative importance for each CR could be determined. This was done by dividing the Improvement Ratio for the CR by the sum of all of the Improvement Ratios.

The next step in the QFD was to complete the correlation matrix, which is the main section of the QFD chart. This required rating the relationship between the CR's and the EC's with a 9/3/1/0 (blank), where 9 is a high correlation between the CR and the EC and 0 means there is no correlation between the CR and the EC. For example, the noise and the clap block material scored a 9 because there is a strong relationship between the two, where as noise and the frame color scored a 0 because there is no relationship between the two.

One the correlation matrix had been completed, the absolute importance of each EC was determined by summing the score for a CR multiplied by its Relative Improvement Ratio score. For example, the absolute importance of the manufacturing tolerances is (9 x 0.06) + (1 x 0.07) which gives 0.61. All of the values of Absolute Importance were summed, so that the normalised scale of Relative Importance could be reached for each EC.

Were the EC was quantitative and known, the actual value of the EC for the current product was added to the QFD chart. The preferred direction of movement was stated and a target value was also determined. The units that the EC were measured in were also assigned.

The following is the QFD chart that was developed for the project. It can also be seen in A3 format in Appendix D.

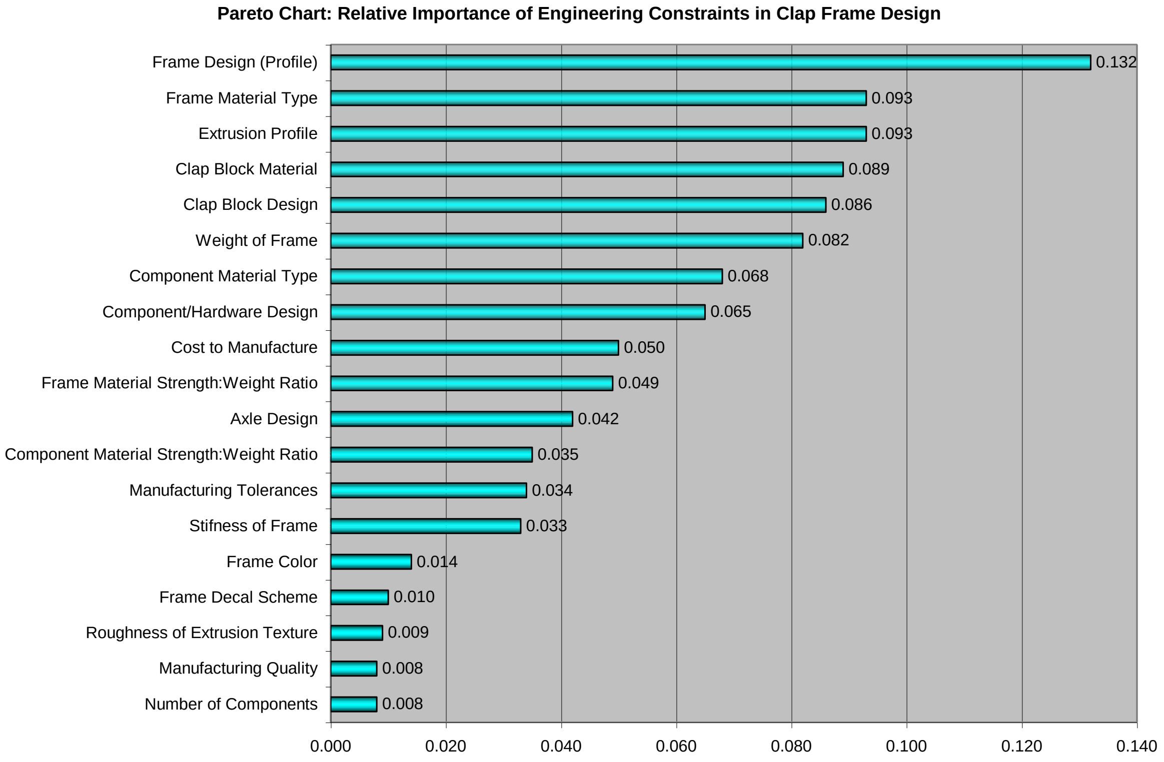


		Extrusion Profile	Frame Design (Profile)	Frame Material Type	Component/Hardware Design	Component Material Type	Clap Block Design	Clap Block Material	Axle Design	Frame Color	Frame Decal Scheme	Weight of Frame (-)	Component Mat'l Strength:Weight Ratio (+)	Frame Mat'l Strength:Weight Ratio (+)	Number of Components (-)	Stiffness of Frame (+)	Roughness of Extrusion Texture (-)	Manufacturing Quality (+)	Cost to Manufacture (-)	Manufacturing Tolerances (-)	Customer Importance	Current Product	Mogema M41	Maple Clap	Planned Product	Planned Improvement Ratio	Sales Points	Improvement Ratio	Relative Weight
Aesthetics	Texture			3													9	1			1	4	-	-	4	1.0	1.0	1.0	0.01
	Colour Scheme									9	9								1		1	3	4	2	4	1.3	1.3	1.7	0.02
	Shape	1	9													1			3		3	4	3	2	5	1.25	1.3	4.9	0.04
	Noise (Clapping & Gliding)						9	9													5	2	-	-	5	2.5	1.5	18.8	0.17
Performance	Increased Stiffness	3	3	1		1							1	1		9					3	4	-	-	4	1.0	1.3	3.9	0.03
	Light Weight	1	1	1		1						9	3	3	1						4	2	3	3	5	2.5	1.5	15.0	0.14
	Lower Rolling Resistance								3											9	5	5	-	-	5	1.0	1.3	6.5	0.06
Strength & Durability	Component Strength & Durability				9	9			1												5	5	-	-	5	1.0	1.0	5.0	0.04
	Component Material				3	9							3						1		4	3	-	-	4	1.3	1.3	6.8	0.06
	Frame Strength & Durability	9	9	9		1		1						3		1		1			5	4	-	-	5	1.25	1.3	8.1	0.07
	Frame Material			9						1		3		3		3	1		1		5	4	-	-	5	1.25	1.3	8.1	0.07
Cost	Cost		1	3		1												1	9	1	4	3	4	5	4	1.3	1.5	7.8	0.07
Maintainability / Special Features	Easy Wheel Change-over		1						9												4	3	3	-	4	1.3	1.3	6.8	0.06
	Easy Boot Attachment	1	3		9																4	2	3	-	4	2.0	1.0	8.0	0.07
	Accomodate Big Wheels	3	9																		2	2	2	2	2	1.0	1.3	2.6	0.02
	Low Profile (Dist. from Boot base to Ground)	9	9																		4	3	2	-	4	1.3	1.5	7.8	0.07
																												112.8	1.00
	Absolute Importance	1.66	2.37	1.67	1.17	1.21	1.53	1.60	0.76	0.25	0.18	1.47	0.63	0.87	0.14	0.59	0.16	0.15	0.90	0.61	17.92								
	Relative Importance	0.093	0.132	0.093	0.065	0.068	0.086	0.089	0.042	0.014	0.010	0.082	0.035	0.049	0.008	0.033	0.009	0.008	0.050	0.034	1.000								
	Current Product											373.0			20														
	Direction of Movement											DOWN			DOWN														
	Target Value											320			16														
	Units											GRAMS			QTY														

Figure 17 - The QFD chart

2.6 Discussion of the QFD

By looking at the QFD diagram, it is hard to determine which of the EC's are the most important. By putting them onto a Pareto chart, the top rating EC's can be easily determined, as is shown in the following.



From this chart, it was decided that everything with a relative importance over 0.060 would be considered as the most important for the rest of the project. This gave some focus on where to head.

2.7 Product Design Specification (PDS)

As has been previously stated, the Product Design Statement (PDS) is a document that will control and define the rest of the design and manufacturing process. It includes the definition of; the product's purpose and market; the functional requirements of the product; all the considerations that have to be made in the design; corporate constraints; and the social, political and legal requirements.
The following is the PDS that was determined for this project:

Product Design Specification

Product Title

Inline Speed Skate Frame

Purpose

To provide an in-line speed skate frame with improved performance characteristics for in-line speed skaters. To provide a redesigned in-line speed skate clap frame with better performance characteristics.

Special Features

- Clap mechanism similar to that used in ice speed skating
- Only 3 wheels move with the clap mechanism
- Lighter weight with better strength and stiffness characteristics
- Minimal noise when the clap mechanism closes

Competition

The main competitive in-line clap skate frames are (manufacturer underlined);

- Mogema M-41
- Verducci V-Drive
- Maple Clap

Competition from the conventional (fixed) frame market also should be considered. Many manufacturers, including those listed above, make fixed frames.

Intended Market

The intended market is intermediate to advanced in-line speed skaters who compete in the sport. A secondary market is long track ice speed skater looking for an off season training device.

Need for the product

A survey was conducted over the Internet that indicated 67% of speed skaters thought that a clap frame would be advantageous to their skating over monocoque chassis and larger wheels.

Also, as part of their business strategy, Bont wants to become on of the top 5 in-line speed skates frame manufacturers (Bont, 2001). As the in-line clap frame market emerges, Bont will need to be a part of the phenomenon when clap frames gain more market share.

Relationship to existing product lines

The product will be considered the second generation of in-line clap frame for Bont, the first generation being the current ‘Slingshot’ frame.

Also related is Bont’s fixed frame selection, including the Lithium and Inferno.

Anticipated market demand

The targets have not yet been set. The target set will depend on the sales of the current product, which has had slow uptake possibly due to high price (Bont, 2001).

It should be noted that this years target for the Slingshot was 1000 units. The selling price has been decreased to try to achieve the target.

Target selling price and estimated retail price

This has not been set, but as indicated by the current market, the retail price should not go beyond US$520 and a target of US$500 could be considered.

Functional performance

The product should;

- allow the skater to achieve maximum efficiency and power output for their given input
- allow the wheels and bearings to roll freely
- provides the connection between the wheels and the boot
- allow for easy wheel attachment/detachment

Physical requirements

The product should;

- have the same wheelbase as the current Slingshot frame – 328mm
- accommodate wheels up to 80mm with the existing hub/bearing standardised design
- have a profile height that is as minimal as possible
- be as light weight as possible with whilst being as strong and stiff as possible

Service environment

The environment the product will operate in will require;

- the product be able the operate in temperatures from 0 to 75 degrees Celsius
- the materials used be resistant to corrosion caused by water splashes and potentially some salt spray
- the product should withstand loading conditions with mild vibrations
- dirt and dust should not affect the product’s performance

Life-cycle

The product must not fail for at least 500,000 cycles (ie. strokes)

Human factors

- The product should not have any sharp edges capable of cutting a skin in the event of a fall.
- The product should be aesthetically pleasing. It should ‘look fast’.

Time to market

There is a view to have a new product on the market in time for the northern hemisphere 2002 summer (Bont,2001). Therefore, it is suggested that the target be set for 1st April 2002.

Manufacturing requirements

Typically, Bont chooses to source manufacture and assembly of their frames offshore. The current Slingshot frame is made in Taiwan. The manufacture and assembly process has been sourced by a third party, essentially making manufacture a ‘black box’ operation. This approach is preferred, however other options may be considered depending on feasibility.

Safety, standards and liability

There are no specific standards for design of in-line skate frames. It was noted that a competitor’s frame developed stress fractures and broke. This prompted Bont to keep the thickness of aluminium to at least 12mm as a standard (Bont, 2001). However, it is suggested that with the appropriate validation methods, this limit may be lowered.

3. Concept Generation

3.1 Introduction

In this section, concepts are generated that may satisfy the problem that has been outlined in the previous section. The method for generating these concepts is brainstorming. As an idea was thought of it was sketched up assessed for positives and negatives.

This section is focused on generating concepts for the following main areas that were identified by the QFD as being most important;

- Frame Material
- Extrusion Profile
- Frame Profile
- Clap Pivot Hardware
- Spring Design
- Wheel Axles
- The Pivot Stopper
- Clap Block Design
- Clap Block Material

3.2 Concepts for the Frame Sections

3.2.1 Frame Material Concepts

Potential materials that could be used for the frame sections include:

- Aluminium Alloys– The current choice of most in-line speed skate frames, as it can be easily extruded to custom sections, is relatively inexpensive and has good strength to weight characteristics.
- Steel Alloys– It is probably one of the cheapest, most well known and easiest to work with metals available.
- Magnesium Alloys– It displays quite good strength to weight qualities and is used in many alloys.

- Titanium Alloys– Possibly the best alloys in terms of strength to weight ratio.
- Carbon Fibre Reinforced Polymer – This type of composite shows quite good strength to weight ratios and could be in either a moulded form such as the Xenan monocoque skates (www.xenan.com, 2001) or a pultruded profile (www.atp-pultrusion.com, 2001).

3.2.2 Extrusion Profile Concepts

The following diagram shows some CAD sketches of potential extrusion profiles for the frame sections.

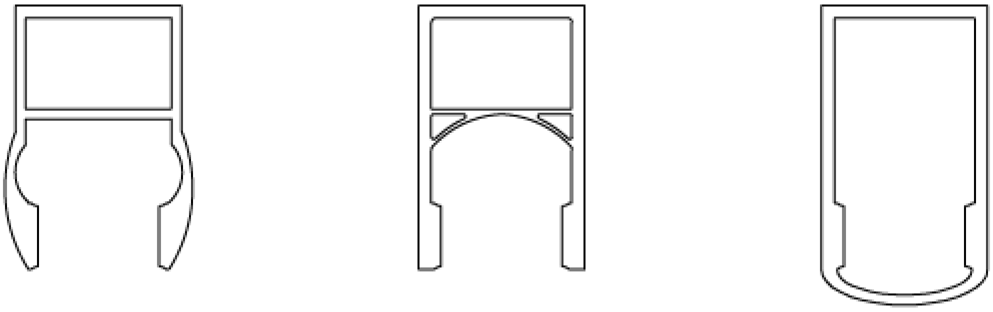


Figure 18 - Potential Extrusion Profiles

These profiles are an attempt to increase and exploit that second moment of area properties of the profile, while decreasing the cross-sectional area and hence the weight in the frame.

The first profile has curved vertical members that put more material out further to increase the second moment of area. The second is a multi-void section that spreads the available material around to move the centroid of the section to attempt to make the second moment of area bigger. The third tries to move material to the extreme edges to try to make the second moment of area bigger.

The materials these sections could be made of is all the metals discussed in 3.2.1 as well as pultruded carbon fibre reinforced polymer (www.atp-pultrusion.com, 2001).

3.2.2.1 Quantitative Comparison of the Extrusion Profile Concepts

The aforementioned concepts for the extrusion profile can be assessed quantitatively for their deflection and torsional characteristics. By using standard equations for beam deflection and torsion, a quantitative comparison can quickly and easily be built up.

The equation for deflection that is defined in Mott (1992) for a beam with a point load in the middle is:

$$d = Wl^3/48EI \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3.1)$$

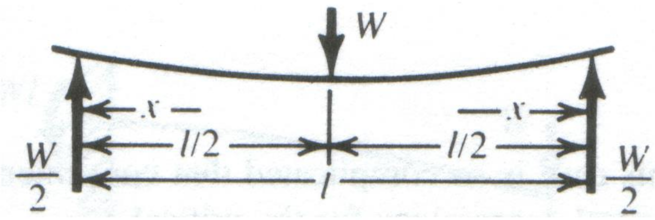


Figure 19 - Diagram defining the deflection of a beam under a point load (Mott, 1992)

Where:

- d is the beam deflection at the centre (m)
- W is the load on the beam (n)
- L is the length of the beam (m)
- E is the Young’s modulus of the material (Pa)
- I is the second moment of area for the section of the beam (m^4)

The equation for torsion that is defined in Mott (1992) for a beam loaded with a moment at its end is:

$$\theta = TL/GK \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3.2)$$

Where:

- θ is the angle the beams rotates at L
- T is the torque applied (Nm)
- L is the length of the beam (m)
- G is the Shear Modulus of Elasticity (Pa)
- K is the polar moment of inertia (m^4)

G can be calculated from the equation:

$$G = E/2(1+\nu) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3.3)$$

Where:

- E is the Young’s modulus of the material (Pa)
- ν is the Poisson’s Ratio for the material

Assuming the material is aluminium, E is 69GPa and ν is 0.33 (Askeland, 1996). For all beams, the length, L or l, will be taken as 1m. For the deflection of the beam, the force applied, W, will be 1000N, and for the torsion of the beam, the moment applied will be 1000Nm. The shear modulus can be found using (3.3):

$$G = E/2(1+\nu) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3.4)$$

$$\therefore G = 69 \times 10^9 / (2 (1 + 0.33)) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3.5)$$

$$\therefore G = 25.9 \text{ GPa} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3.6)$$

To find the second moment of area about both the X-X and Y-Y axis and the polar moment of inertia about the centroid, the sections were sketch in SolidWorks. The moment of area properties could then be called up using the ‘Section Properties’ tool. The output for each of the concepts can be seen in Appendix E.

From this, the deflections can be calculated. For example, the section of the current Slingshot has a second moment of area of 94604.75mm^4 about the X axis and 70458.93mm^4 about the Y axis. The polar moment of inertia is 165063.68mm^4 about the centroid for this section.

From this, the deflection about the X axis is:

$$d_{xx} = Wl^3/48EI_{xx} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3.7)$$

$$\therefore d_{xx} = 1000 \times (1000)^3 / (48 \times 69 \times 10^3 \times 94604.75) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3.8)$$

$\therefore d_{xx} = 3.19\text{mm}$ ………………(3.9)

The deflection about the Y axis is;

$D_{yy} = Wl^3/48EI_{yy}$ ………………(3.10)

$\therefore d_{yy} = 1000 \times (1000)^3 / (48 \times 69 \times 10^3 \times 70458.93)$ ………………(3.11)

$\therefore d_{xx} = 4.29\text{mm}$ ………………(3.12)

Finally, the torsion about the centroid is;

$\theta = TL/GK$ ………………(3.13)

$\therefore \theta = 1000 \times 1000/(25.9 \times 10^3 \times 165063.68)$ ………………(3.14)

$\therefore \theta = 0.234 \times 10^{-3}$ Radians ………………(3.15)

Utilising Excel, the values for the deflection of the concept sections can be calculated quickly and easily. The following table shows these values:

Description	**Bend abt X (mm)**	**Bend abt Y (mm)**	**Torsion (radians)**	**X-sec area**
Current Front	3.19E-06	4.29E-06	2.34E-04	403.29
Front Concept 1	2.68E-06	4.16E-06	2.08E-04	400.93
Front Concept 2	2.56E-06	4.23E-06	2.04E-04	400.93
Front Concept 3	1.88E-06	4.16E-06	1.65E-04	396.28
Current Rear	1.45E-06	1.84E-06	1.04E-04	634.75

The cross sectional area is also shown in the end column. This table shows that all of the concepts have better deflection and torsion characteristics than the front frame section. The area figure indicates that they achieve this with lower mass per length. It also shows that the deflection characteristics of the rear frame are far better than the front frame, but it also uses over twice as much material to do this.

3.2.3 Frame profile concepts

The frame profile concepts are basically three possibilities, cut-outs from the edge of the frame, holes cut in the frame profile, or a combination of both. The effect that each of these has on strength and deflection can not be fully determined with out uses FEA on each individual case. However, the trend from the benchmarks is to either have only cut-outs from the edge of the frame, or to have a combination of both cut-outs from the edge and holes.

3.3 Concepts for Hardware and Components

3.3.1 Clap pivot concepts

Only one concept was developed for the clap pivot, it was a pin and cir-clip arrangement as outlines in the following sketch.

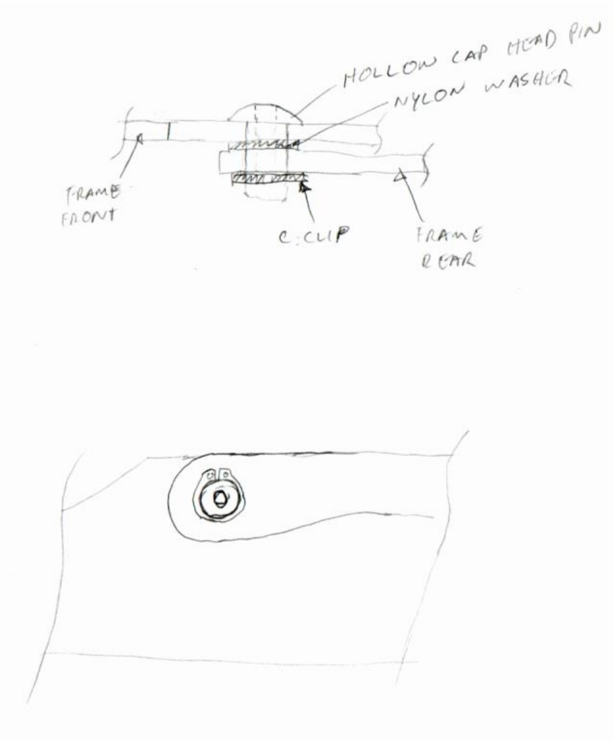


Figure 20 - Pin and cir-clip concept for the clap pivot

The advantages of this design include the possible weight saving over the current method, less assembly time with no threaded connectors. A possible disadvantage is the requirement of tighter tolerances.

3.3.2 Spring Design Concepts

The first spring design concept considered is a helical extension spring mounted to the outside of the frame, similar to the set-up used on the Maple Reaction Clap.

The second concept for the spring design is the use of a torsional spring that is directly connected to the upper and lower frames. It would be a double wound spring. A sketch of this is shown below.

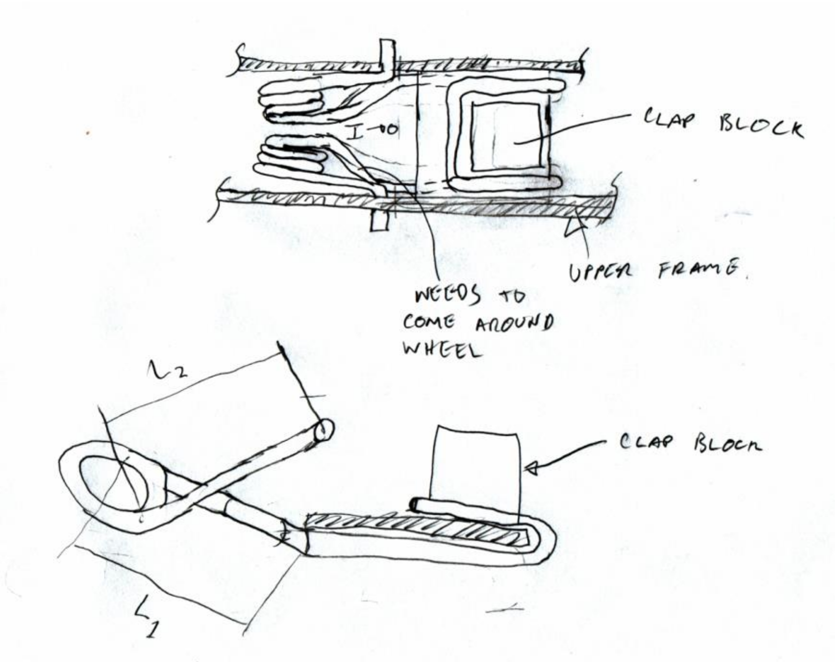


Figure 21 - Concept for a 'direct connect' torsion spring

The advantages of this are that less parts are required and the spring can be used also as a pivot stopper. Possible disadvantages are the complexity of the design and manufacture of the spring.

3.3.3 Spring Mount Concepts

One of the spring mount concepts is described in the spring concept section above. It is the direct connect system where the spring is attached to the upper and lower frame directly with no additional hardware.

Another concept in this area is reliant on using the current design of torsion spring, which is mounted on a rod. The rod could be a simple hollow rod and it could be held in place with cir-clips at either end. Advantages of this are a potential weight saving and simplicity in manufacture and assembly. A concepts sketch follows.

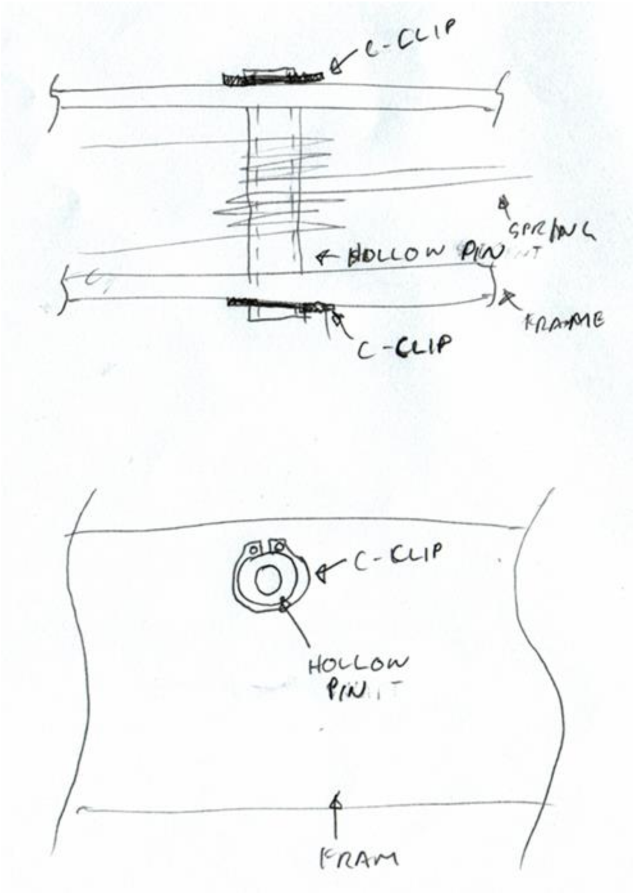


Figure 22 - Concept for a hollow rod and cir-clip fro the torsion spring mount

3.3.4 Wheel Axle Concepts

The first concept explored for the wheel axles is a quick release type axle system. This utilises a cam leaver mechanism to hold the axle in place, much like a quick release bicycle axle. It is expected that this system would be quicker for changing over axles and the frame would be cheaper to manufacture as no threads need to be tapped. The disadvantages are the weight would probably increase, tight manufacturing tolerances would be required and the custom cam lever and axle would be quite expensive. Concept sketches are shown as follows:

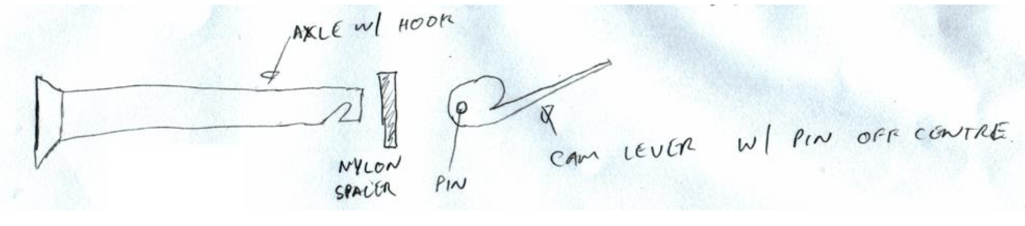


Figure 23 - Exploded concept sketch for a quick release axle

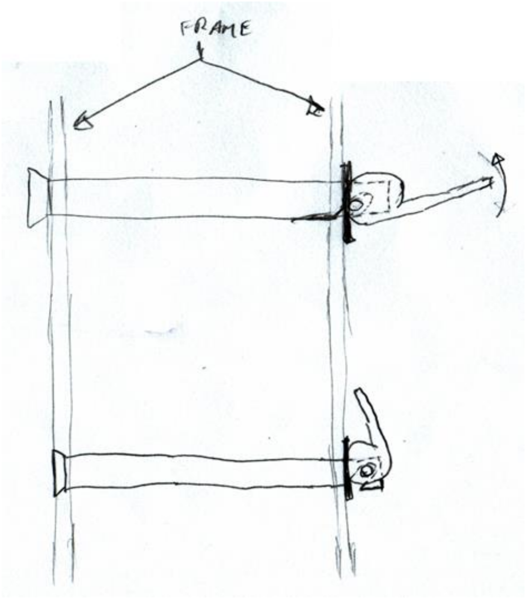


Figure 24 - How the quick release axle would function

A two piece axle system was also to be considered. These axles are quite common on in-line hockey skates. They do take longer to take on and off, as they are in two pieces.

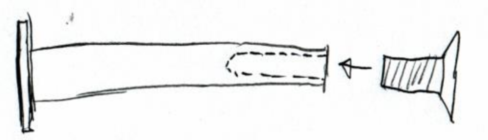


Figure 25 - Two piece axle system

Also, a three piece axle system was considered, which are quite common on recreational skates. This system takes even longer to work with than a two piece system, as there are two threaded connections and three pieces.

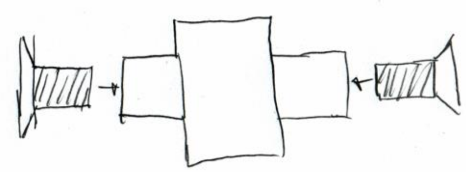


Figure 26 - Three piece axle system

3.3.5 Pivot Stopper Concepts

One form of a pivot stopper considered was a retaining system that used a cable attached to the upper and lower frame. When the pivot got as far as it should go, the cable would become taut, stopping the mechanism opening any further. Another variation on this theme was to have the cable looped around the spring rod. The end of the cable could then be joined as a sub-assembly using less hardware to mount it. It is envisaged that either system would weigh less than the pivot stopper as part of the frame profile.

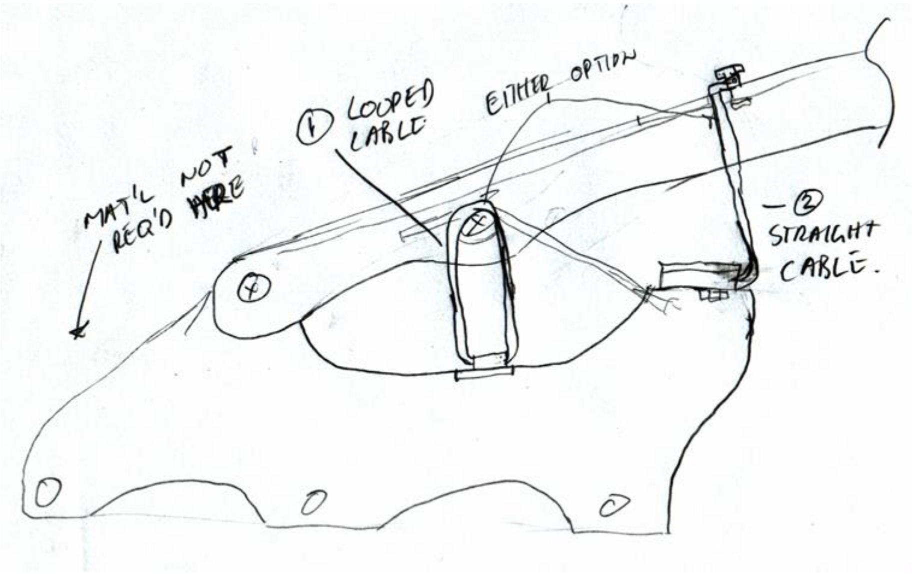


Figure 27 - A concept sketch that shows the options of (1) a looped cable retainer and (2) a straight cable retainer

The other possible concept for a pivot stopper is to use the direct mount torsion spring concept in 3.3.2, and design it so that the spring can only open to a certain angle, where the boot wont touch the front wheel.

3.4 Concepts for clap block design

The following section highlights some of the concepts that have been developed for the clap block. This includes the material selection, design of the main section of the clap block, and the possible options for damping elements for noise abatement.

3.4.1 Design Concepts for the Main section of the Clap Block

The first concept for the clap block is to simply have a flat block. This would simplify the mould and potentially be cheaper than the current block.

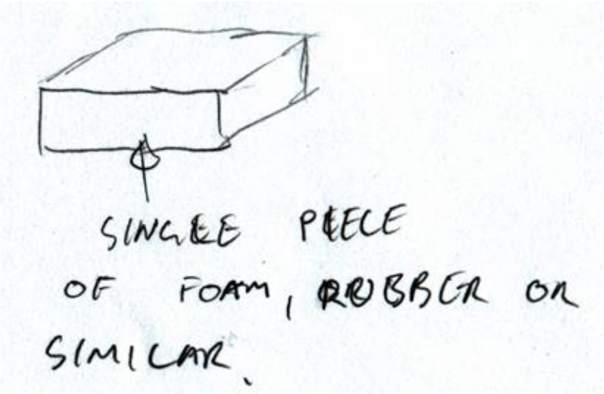


Figure 28 - Concept for Flat clap block

The next concept is a lateral convex along the mating surface of the clap block. It is hoped that by reducing the amount of material that comes in contact with the frame on impact, the noise will be reduced too.

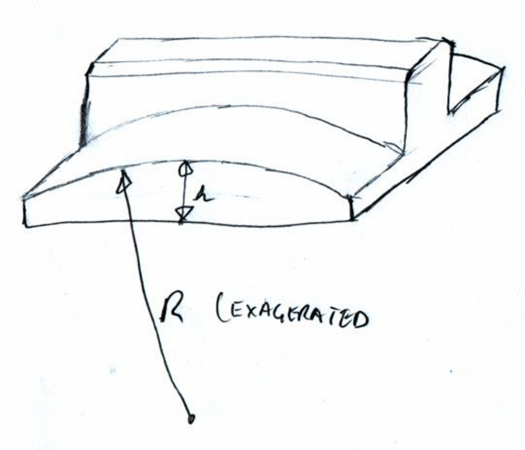


Figure 29 – Concept of a Clap Block with a lateral convex

Another concept explored was based along the same theory as the last. With this concept though, the convex is in the longitudinal direction. As well as that, other shapes are considered for the this design.

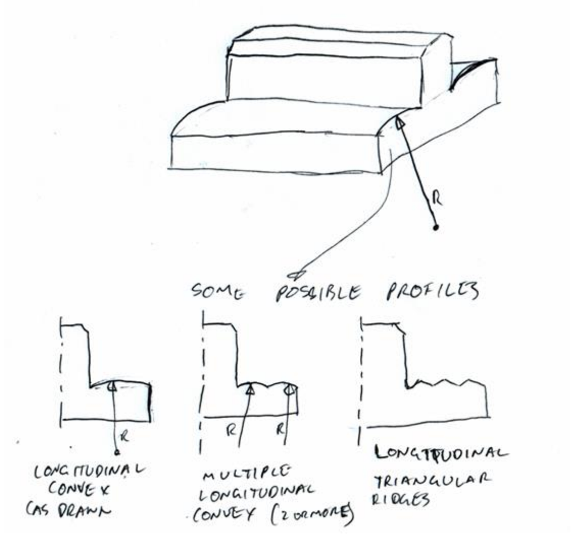


Figure 30 - Concept of a Clap Block with a longitudinal convex with other shape considered

3.4.2 Concepts for a Damping Element

The following section defines the concepts that were generated for a damping element in the clap block. The concept for damping out the noise come from the impulse equation; I = F ∆t (Fahy, 2001). The over all impulse, I, for the interaction will always be the same, and the higher value of the impacting force, F, the greater the noise emitted. If the change in time, ∆t, portion of the function is increased, then the peak of F will decrease, resulting in lower noise.

The first concept is that the main section of the clap block uses a softer material such as an elastomer or elastomeric foam. This will increase the ∆t part of the function in which the force acts, and decrease the noise in theory.

The second concept relies on a soft block of foam being screwed into the back of the current clap block. It is hoped that this method would help minimise the noise. It should be noted that this method would result in a higher part count and more assembly time.

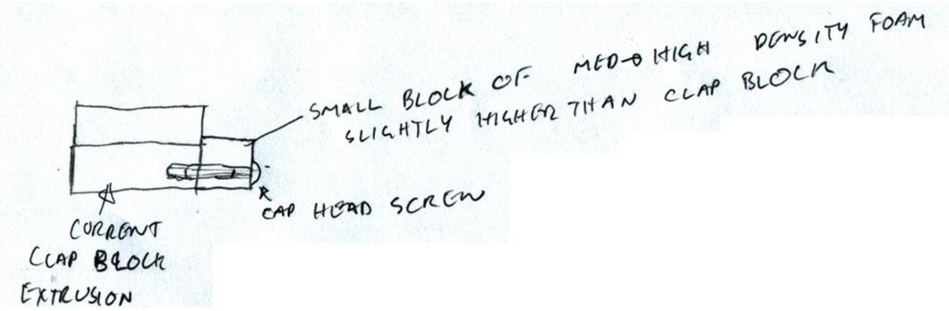


Figure 31 - Concept of a Clap Block with a soft foam block for noise abatement

The third concept involves inserting a longitudinal soft foam extrusion into the clap block. This would make the main body of the clap block more complex to mould and the assembly method would need to be developed.

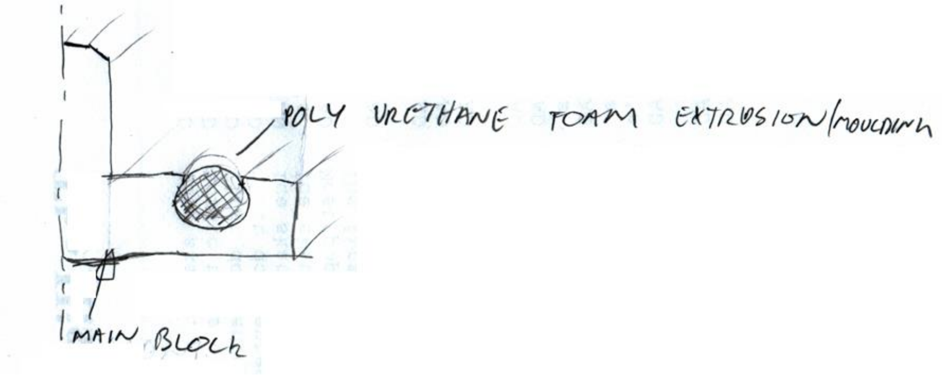


Figure 32 - Clap Block with a soft foam extrusion embedded

The fourth concept is to have a tab on the main clap block that would have to be made of some kind of a flexible elastomer. The skate would impact with the tab first to slow it down before coming to rest.

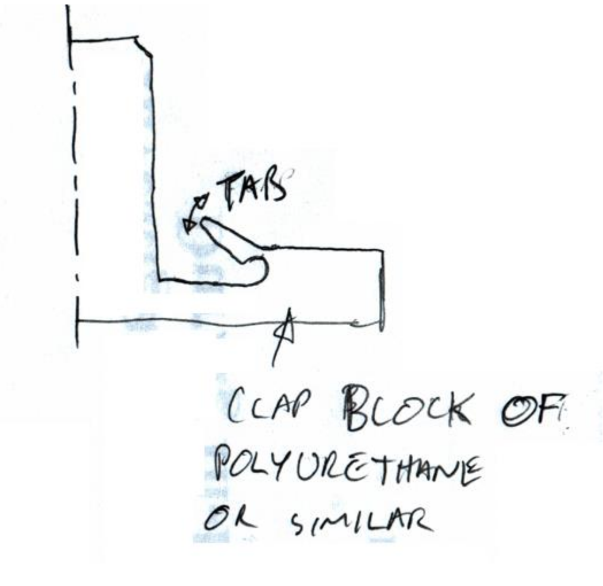


Figure 33 - Clap block with a tab for damping

The fifth concept is a separate soft block that would side under the spring rod. When the mechanism closes, the spring rod, and even the spring, would hit the soft block before that skate came to rest on the main clap block.

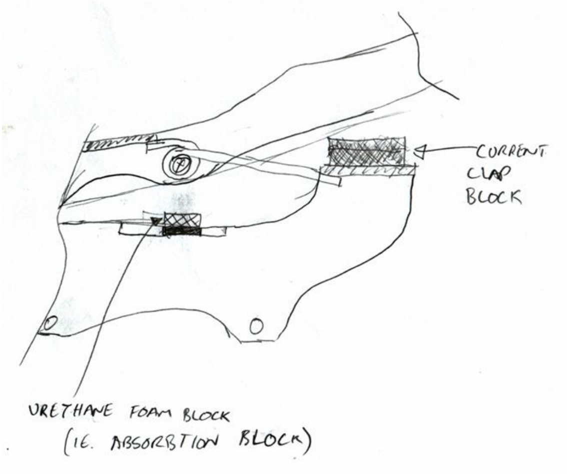


Figure 34 - Concept with a soft block under the spring rod

The sixth and final concept for a damping element is a soft elastomer block underneath the current clap block. This block would be attached with the regular screws underneath the main clap block.

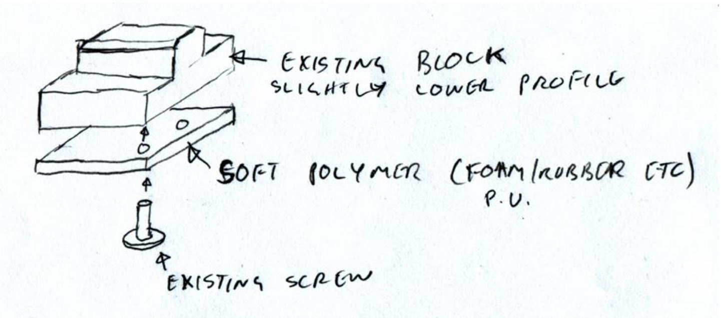


Figure 35 - Concept where a soft block is mounted under the main clap block

3.4.3 Concepts for Clap Block and Damper Material

Throughout the concept generation, materials for the clap block and damper have been discussed. These potential materials will be collated in this section and discussed.

The material requirements for the clap block or damper should help minimise the noise that it emitted when the mechanism closes. This, as discussed previously, is related to the impulse equation, $I = F \Delta t$. To minimise the noise, the force, F, must be minimised. This means increasing the time step for the impact, Δt, and material can aid this are of paramount importance.

The materials considered to do this are:

- Polybutadine (Askeland, 1996) – This is an elastomer that is used in tyres and bushes which can help dampen out the noise.
- Polyurethane (www.erapol.com.au, 2001) – There are a range of polyurethanes that are available for impact loads and noise abatement. Polyurethanes exhibit good strength properties when in impact loading situations.
- Flexible Polyurethane Foam (www.erapol.com.au, 2001) – Certain Polyurethane foams are designed to be used in applications where parts are impacting. They rebound from compression well.
- Silicone (Askeland, 1996) – Silicone may be used in impact situations to dampen the load.

It should also be noted that nylon is also to be considered for the main section of the clap block.

3.5 Collating and combining concepts

Now that concepts have been developed, they must be collated to get an overview of what is available, and then they can be selected one by one to form an overall concept for the product. In the selection process, a number of options are put together from the concepts available that could satisfy the PDS. These ‘concept assemblies’ can then be later assessed as a whole to find a preferred concept.

3.5.1 Morphological Chart of Concepts

The morphological chart is an overview of all the concepts available to the designer. It helps by putting the concepts in a logical order and for each sub-function, it shows the possibilities of how the problem could be satisfied (Dieter, 2000).

The following shows the morphological chart for the concepts that have been generated in the previous sections. Included in the chart are the concepts that make up the current product, the Slingshot.

Insert morph chart here.

3.5.2 Assembly Concepts Developed by Combining Concepts.

By selecting one concept from each sub-function group on the morphological chart, a series of overall concepts that could satisfy the design problem. These concept assemblies can be later assessed to find the best one, or to generate more concept assemblies that would exhibit a better solution to the problem.

The following are ten concepts developed using this method, as well as the current product assembled using this method as an example.

Current Frame

Cut out from edge on upper and lower frames (1.1.1 &1.2.1) where both are single void A-sections (1.3.1 &1.4.1) and made of aluminium (1.5.1 & 1.6.1).

The clap pivot is a nut and bolt arrangement (2.1.1) with a pinned internal torsional spring (2.2.1) where the pin is a two piece axle type arrangement (2.3.1). The axles are one piece (2.4.1) and the pivot stopper is part of the frame design (2.5.1).

The clap block is a nylon (3.3.1) extrusion with a locating boss (3.1.1) but there is no dampening element (3.2.1 & 3.4.1).

Concept 1

The lower frame profile should consist of internal and ‘from edge’ cut-outs (1.1.3) while the upper frame would be monocoque (1.2.4 & 1.4.6). The lower frame would have curved vertical members (1.3.3) and be made of titanium (1.5.4). The upper frame would be carbon fibre reinforced polymer (1.6.5).

The clap pivot would be held by a pin and c-clip arrangement (2.1.2). The spring would be a torsional type directly connect to the upper and lower frame at the ends of the spring (2.2.3 & 2.3.4). The wheel axles would be one piece as per the current design (2.4.1) and the pivot stopper should be inherent in the design of the spring (2.5.4).

The clap block should have a longitudinal convex (3.1.4) and be made of urethane (3.3.4) whilst the dampening element would be inherent in the main section’s material selection (3.2.2). No dampening element material needs to be selected (3.4.1).

Concept 2

The upper and lower frame would have cut-outs internal to the frame (1.1.2 & 1.2.2). The lower frame section profile would be multi-void (1.3.2) and the upper frame's section would be a 'C'-section (1.4.5). The lower frame would be made of steel (1.5.2) and the upper section would be made of magnesium (1.6.3).

The clap pivot would be a nut and bolt (2.1.1). The spring would be an externally mounted helical spring (2.2.2) and mounted directly to the upper and lower frames directly (2.3.4). The axle system would be three piece type (2.4.4) and the pivot stopper would be a straight cable retainer (2.5.3).

The clap block would be a flat section (3.1.2) made of nylon (3.3.1) with a soft polymer block under it (3.2.7) made of polybutadine (3.4.3).

Concept 3

The cut-outs in the lower frame would be from the edges (1.1.1) while the cut-outs in the upper frame would be a combination of internal and 'from edge' cuts (1.2.3). The lower frame would have a fully enclosed section (1.3.4) made of carbon fibre reinforced polymer (1.5.5) while the upper frame would be a multi void section (1.4.2) made of titanium (1.6.4).

The clap pivot would be a pin & c-clip arrangement (2.1.2) with a torsion spring mounted on a hollow shaft with two c-clips (2.2.1 & 2.3.2). The axle would be quick release type (2.4.2) and the pivot stopper will be looped cable retainer (2.5.5).

The clap block will have a lateral convex on the mating surface (3.1.3) and the dampening will be inherent in the clap block material (3.2.2) which will be polybutadine (3.3.3 & 3.4.3).

Concept 4

The lower frame will have cut-outs 'from the edge' (1.1.1) and the upper frame will have a combination of internal and 'from edge' cut-outs (1.2.3). The lower frame would be made of a channel section (1.3.5) and the upper a fully enclosed section (1.4.4). The lower frame would be magnesium (1.5.3) and the upper steel (1.6.2).

The clap pivot would be a nut & bolt (2.1.1), the spring an internally mounted torsion type (2.2.3) mounted directly to the upper and lower frame (2.3.4) and the axle a two piece arrangement (2.4.3). The pivot stopper would be inherent in the design of the spring (2.5.4).

There would be no clap block (3.1.5) or dampening element (3.2.1) and hence no material needs to be selected for either (3.3.6 & 3.4.1).

Concept 5

The lower frame would have a combination of internal and ‘from edge’ cut-outs (1.1.3) and the upper frame would have internal cut-outs (1.2.2). The lower and frame sections would have curved type vertical members (1.3.3 & 1.4.3) and be made of aluminium (1.5.2 & 1.6.1).

The clap pivot would be a pin & c-clip arrangement (2.1.2) and the spring an internally mounted torsion spring on a hollow shaft with two c-clips (2.2.1 & 2.3.2). The wheel axles would be a quick release type (2.4.2) and the pivot stopper a looped cable retainer (2.5.2).

The clap block would be an extruded block with a locater (3.1.1) and a longitudinal poly-urethane foam extrusion inserted (3.2.4 & 3.4.5). The main block would be made of nylon (3.3.1)

Concept 6

The lower frame would have cut-outs internal to the profile (1.1.2) and the upper would have the cut-outs from the edge (1.2.1). The lower frame profile would be a multi-void extrusion (1.3.2) and the lower frame profile would be a fully enclosed section (1.4.4). Both upper and lower would be titanium (1.6.4 & 1.5.4).

The clap pivot would be a nut & bolt (2.1.1). The spring would be an internal mounted torsional spring mounted on a two piece shaft (2.2.1 & 2.3.1). The wheel axles would be a two piece system (2.4.3) and the pivot stopper a part of the frame profile (2.5.1).

The main section of the clap block would be flat piece of nylon (3.1.2 & 3.3.1). The dampening element would be a soft block of urethane foam screwed to the clap block (3.2.3 & 3.4.5).

Concept 7

The lower frame has cut-outs internal to the profile (1.1.2), has a single-void ‘A’-section profile (1.3.1) and is made of aluminium (1.5.1). The upper frame is monocoque type (1.2.4 & 1.4.6) made of carbon fibre reinforced polymer (1.6.5).

The clap pivot is a nut & bolt assembly (2.1.1). The spring is an externally mounted helical spring (2.2.2) mounted at its end directly to the upper and lower frame (2.3.4). The axles are a three piece assembly (2.4.4) and the pivot stopper is a straight cable retainer (2.5.3).

The clap block is an extrusion with locater (3.1.1) and has a tab for a dampening element (3.2.5). The whole extrusion is made of silicone (3.3.2 & 3.4.2).

Concept 8

The lower frame cut-outs are from the edge of the frame (1.1.1) and the upper frame has cut-outs combined of from edge and internal types (1.2.3). The lower and upper frame are fully enclosed type sections (1.3.4 & 1.4.4). They are also both made of aluminium (1.5.1 & 1.6.1).

The pivot is a pin and c-clip arrangement (2.1.2). The spring is an internally mounted torsional spring on a hollow shaft held on by two c-clips (2.2.1 & 2.3.2). The wheel axles are one piece (2.4.1) and the pivot stopper is part of the frame profile (2.5.1).

The clap block is a nylon extrusion with a locater (3.1.1 & 3.3.1). A separate dampening element is mounted under the spring axle (3.2.6) and made of urethane (3.4.4).

Concept 9

The lower section of the frame has cut-outs made up of a combination of internal and from edge cuts (1.1.3) and the upper frame has internal type cut-outs only (1.2.2). The lower frame has a multi-void type section (1.3.2) and the upper frame has a fully closed type section (1.4.4). Both the upper and lower frame sections are made of aluminium (1.5.1 & 1.6.1).

The clap pivot is a pin and c-clip arrangement (2.1.2). The spring is an internally mounted torsion spring (2.2.3) directly mounted to the upper and lower frame (2.3.4) and is designed to be the pivot stopper also (2.5.4). The axles are one piece (2.4.1).

The clap block is a flat section (3.1.2) made of urethane foam (3.3.4) which also forms the dampening element (3.2.2 & 3.4.5).

Concept 10

The lower section of the frame has cut-outs from the edge (1.1.1) and the upper has internal type cut-outs (1.2.2). The lower frame section has curved vertical members (1.3.3) and the upper frame section is a fully enclosed type (1.4.4). Both upper and lower are made of aluminium (1.5.1 & 1.6.1).

The clap pivot is a pin & c-clip arrangement (2.1.2). The spring is an internally mounted torsion spring mounted on a hollow shaft held in place with c-clips (2.2.1 & 2.3.2). The axles would be quick release type (2.4.2) and the pivot stopper would be a looped cable retainer (2.5.2).

The clap block would be a have a longitudinal convex on the mating surface (3.1.4) and be made of urethane (3.3.4). The dampening characteristics could be inherent in main block (3.2.2 & 3.4.4).

The Following table is a count of how many times each concept was used in the concept assembly process.

Final concept usage count from excel

	1	**2**	**3**	**4**	**5**	**6**	**7**	Total
1.1	5	3	3					11
1.2	2	4	3	2				11
1.3	2	3	4	1	1			11
1.4	1	1	2	4	1	2		11
1.5	6	1	1	2	1			11
1.6	5	1	1	2	2			11
2.1	5	6						11
2.2	6	2	3					11
2.3	2	4		5				11
2.4	4	3	2	2				11
2.5	3	3	2	3				11
3.1	4	3	1	2	1			11
3.2	2	4	1	1	1	1	1	11
3.3	5	1	1	2	1	1		11
3.4	3	1	2	2	3			11

4. Evaluation and Selection of the Preferred Design Concept

4.1 Introduction

The purpose of this section of the project is to select the best concepts from the concept generation and find the best solution to the design problem. To achieve this, a range of concept selection tools are offered by Dieter (2000), but only some need to be used.

The first filter in this selection method is a series of go-no-go screenings. First it is based on the judgement of the feasibility of the design of each concept, then on the readiness of technology, and finally it is based on the customer requirements from the QFD (Dieter, 2000).

After this initial screening is performed, a more complex method of assessing the concept assemblies is used. This approach is Pugh's Concept Selection Method and is well documented by Dieter (2000).

4.2 Basic Concept Evaluation

4.2.1 Concept Evaluation Based on Judgement of Feasibility of Design

This first step in the design process is assess whether the design is feasible. This means that if a concept is judged as absolutely not feasible, that is that the design will **never** work, then it immediately gets screened out in this phase as a NO-GO. If a concept is borderline, then it is kept in.

A table for showing this assessment of all concepts in this phase can be seen in Appendix F.

4.2.2 Concept Evaluation based on an Assessment of Technology Readiness

This section determines whether or not there is technology available to achieve the concept. Because product design is an inappropriate place to be doing research and

development, any concepts that require R&D input are excluded from the design process.
A table for showing this assessment of all concepts in this phase can be seen in Appendix F.

4.2.3 Concept Evaluation based on Screening the Customer Requirements

This section of the concept screening uses the Customer Requirments (CR's) from the QFD to screen out any concepts that don't meet the CR's. A question is formed around each CR to assess the concepts. For example, the CR of cost would lead to the question being asked, will the cost impact of this concept be minimal.
A series of tables for this assessment comparing all CR's to all of the concepts in this phase can be seen in Appendix F.

4.2.4 Concepts Screened out during the Basic Evaluation Phase

The following is a list of concepts that did not make it through the initial go-no-go screening described in the previous three sections along with a justification of why the concept was ruled out:

1.3.5 – The design of the section needs some reinforcement lower down to stiffen up the frame.

1.4.5 – As for 1.3.5.

1.5.2 – The strength to weight ratio for steel is not as good as aluminium. The frame would need to be heavier to get adequate strength. (Askeland, 1996)

1.5.3 – Cost of Magnesium is over twice that per kg than Aluminium. It also would cost more to machine as special machining practices need to be used to stop it from becoming unstable in the machining process. (Askeland, 1996)

1.5.4 – The cost of Titanium is 9.3 times more than Aluminium per kg whilst the strength to weight ratio is only 1.4 times better than Aluminium. This therefore would not be cost effective. (Askeland, 1996)

1.6.2 – As for 1.5.2.

1.6.3 – As for 1.5.3.

1.6.4 – As for 1.5.4.

2.3.3 – Suggested that no spring mounting was to be included. Eliminated in design feasibility evaluation as the spring must mount in at least 3 places. (Mott, 1992)

2.4.3 – 2 piece wheels axles were common and speed skates in the past, but take longer than the 1 piece design in use.

2.4.4 – 3 piece wheel axles are commonly used on recreational and aggressive skates but take much longer to attach the wheel assembly to the frame. They tend to be used because the frame are plastic and cannot accommodate a load bearing threaded attachment. (www.rollerblade.com, 2001. www.k2skates.com, 2001. www.roces.it, 2001, www.kryptonics.com, 2001)

Notes:

3.2.1 and 3.4.1 would have been eliminated from the concept selection on the basis that Bont considers them unacceptable, however, with some extra design considerations, they may be considered OK.

3.2.1 – This is the current design and is deemed not acceptable to the customer for noise issues (Bont, 2001). The noise can be attributed to not having sufficient dampening in the current design. This design may work with a different approach to material selection.

3.4.1 – As for 3.2.1.

4.3 Advanced Concept Evaluation and Selection

In this segment of the project, the concepts that have passed through from the basic concept evaluation are considered as parts of product assemblies. It should be noted that as the original concept assemblies from section 3.5.2 have concepts in them that have since been ruled out, the concept assembly process must be done again. Once the second concept assembly has been completed, the advanced method of Pugh's Concept Selection can be used.

4.3.1 Changes to the Concepts Developed from Combining Concepts

Since some of the concepts in the prior concept assemblies are no longer valid, a new set of concepts needs to be developed. The method will be the same as before, but only eight concepts will be developed as the are fewer individual concepts left.

Current Frame

Cut outs are from the edge on the upper and lower frames (1.1.1 &1.2.1) where both are single void A-sections (1.3.1 &1.4.1) and made of aluminium (1.5.1 & 1.6.1).
The clap pivot is a nut and bolt arrangement (2.1.1) with a pinned internal torsional spring (2.2.1) where the pin is a three piece rod type arrangement (2.3.1). The axles are one piece (2.4.1) and the pivot stopper is part of the frame design (2.5.1).
The clap block is a nylon (3.3.1) moulding with a locating boss (3.1.1). The damping element is an axially compressed cylinder (3.2.1) and is made of urethane (3.4.1).

Concept 1

Cut outs would be internal to the frame for both the upper and lower frames (1.1.2 & 1.2.2) and both sections would use multi-void cross sections (1.3.2 & 1.4.2). The material used would be aluminium for both sections of the frame (1.5.1 & 1.6.1).
The clap pivot would use a pin and cir-clip (2.1.2). The spring used would be an external helical spring with the ends mounted directly to the upper and lower frame (2.2.2 & 2.3.4). The wheel axles would be quick release type (2.4.2). The pivot stopper would be a straight cable retainer (2.5.3).

The Clap Block would have a longitudinal convex (3.1.4) where the damping element would be inherent in the main sections material selection (3.2.2) and the material would be silicone (3.3.2 & 3.4.2).

Concept 2

The upper and lower frame would have cut outs both internal and from edge (1.1.3 & 1.2.3). The lower frame would be aluminium (1.5.1) while the upper frame would be carbon fibre reinforced polymer (1.6.5). The lower frame would have curved vertical members (1.3.3) and the upper frame a fully enclosed type cross member (1.4.4).

The clap pivot would be a pin and cir-clip arrangement (2.1.2) and the pivot stopper would be a looped cable retainer (2.5.2). The spring would be an internally mounted torsion spring mounted on hollow rod retained by cir-clips (2.2.1 & 2.3.2). The wheel axles would be one piece (2.4.1).

The main section of the clap lock would be flat (3.1.2) with a longitudinal poly-urethane foam extrusion inserted into it (3.2.4 & 3.4.4). The main section of the clap block would be polybutadine (3.3.3).

Concept 3

The lower frame would have a combination of internal and from edge cut outs (1.1.3) while the upper frame would be monocoque style (1.2.4). The lower frame would be a fully enclosed cross section (1.3.4) and the upper frame would of course be monocoque (1.4.6). The lower and upper frame would be made of carbon fibre reinforced polymer (1.5.5 & 1.6.5).

The clap pivot would be a pin and cir-clip (2.1.2). The spring would be an internally mounted torsional spring with the ends mounted directly to the upper and lower frame (2.2.3 & 2.3.4) while the pivot stopper would be inherent in the spring design (2.5.4). The wheel axles would be quick release type (2.4.2).

There would be no significant clap block (3.1.5 & 3.3.6) while instead a small soft damping block (3.2.7) made of urethane foam (3.4.4) would be place in there as a ‘de-bounce’.

Concept 4

The lower frame would have cut outs internal to the frame (1.1.2) and the upper frame would have cut outs from the edge (1.2.1). The lower frame would be a multi-void section (1.3.2) and the upper frame would have a section with curved vertical members (1.4.3). The lower and upper frame would both be made of aluminium (1.5.1 & 1.6.1).

The clap pivot would be a nut and bolt assembly (2.1.1). The spring would be an externally mounted helical spring (2.2.2) with the ends mounted directly to the upper and lower frames (2.3.4) with a straight cable retainer (2.5.3) through the centre of the spring. The axles would be one piece (2.4.1).

The clap block would have a lateral convex (3.1.3) with the damping element being inherent in the main section (3.2.2). The main section, and hence damping element would be made of polybutadine (3.3.3 & 3.4.3).

Concept 5

The lower frame would have cut outs from the edge (1.1.1) and the upper frame would be monocoque (1.2.4 & 1.4.6). The lower frame would be made of aluminium (1.5.1) and be a single void ‘A’ section (1.3.1). The upper frame would be carbon fibre reinforced polymer (1.6.5).

The clap pivot would be a nut & bolt assembly (2.1.1). The spring would be an internally mounted torsion spring directly mounted to the upper and lower frames at its ends (2.2.3 & 2.3.4). The wheel axles would be quick release (2.4.2) and the pivot stopper would be inherent in the spring design (2.5.4).

The main section of the clap block would have a longitudinal convex (3.1.4) and be made of urethane (3.3.4). The damping element would be a soft block of urethane foam (3.4.4) under the main section of the clap block (3.2.7).

Concept 6

The lower and upper frame would both have cut outs internal to and from the edge of the frame (1.1.3 & 1.2.3). The lower and upper frames would both have curved vertical members in their sections (1.3.3 & 1.4.3) and they would be made of aluminium (1.5.1 & 1.6.1).

The clap pivot would be a cir-clip and pin (2.1.2). The spring being an internally mounted torsion spring on a hollow rod held by cir-clips (2.2.1 & 2.3.2). The wheel axles would be one piece type axles (2.4.1) and the pivot stopper would be part of the frame profile (2.5.1).

The clap block would have a longitudinal convex (3.1.4) and be made of nylon (3.3.1). The damping element would be a soft block of urethane foam mounted under the spring axle (3.2.6 & 3.4.4).

Concept 7

The upper and lower frame would have cut outs internal to the frame section (1.1.2 & 1.2.2). The upper and lower frame would have a fully enclosed type section (1.3.4 & 1.4.4) and be made of aluminium (1.5.1 & 1.6.1).

The clap pivot would be a nut and bolt arrangement (2.1.1) and the pivot stopper would be a looped cable retainer (2.5.2). The spring would be an internally mounted torsion spring mounted on a three piece rod system (2.2.1 & 2.3.1). The wheel axles would be one piece (2.4.1).

The main section of the clap block would be an extrusion with locater tab (3.1.1) made of nylon (3.3.1). The damping element would be a polybutadine block (3.4.3) screwed to the back of the main clap block (3.2.3).

Concept 8

The lower frame would have cut outs from the edge of the frame (1.1.1) while the upper frame would have a combination of internal and from edge cuts (1.2.3). The lower frame would be of a section with curved vertical members (1.3.3) and the upper frame would be an single void ‘A’ section (1.4.1). Both lower and upper frames would be aluminium. (1.5.1 & 1.6.1).

The clap pivot would be a pin and cir-clip (2.1.2). The spring would be an internally mounted torsional spring which is directly connected to the upper and lower frame (2.2.3 & 2.3.4). The wheel axles would be one piece (2.4.1) and the pivot stopper would be inherent in the spring design (2.5.4).

The clap block would be a moulding with locater (3.1.1) and have a tab as part of the main section for the damping element (3.2.5). The material would be silicone (3.3.2 & 3.4.2).

The Following table is a count of how many times each concept was used in the concept assembly process.

Final concept usage count from Excel Spreadsheet

	1	**2**	**3**	**4**	**5**	**6**	**7**
1.1	3	3	3	■	■	■	■
1.2	2	2	3	2	■	■	■
1.3	2	2	3	2	░	■	■
1.4	2	1	2	2	░	2	■
1.5	8	░	░	░	1	■	■
1.6	6	░	░	░	3	■	■
2.1	4	5	■	■	■	■	■
2.2	4	2	3	■	■	■	■
2.3	2	2	░	5	■	■	■
2.4	6	3	░	░	■	■	■
2.5	2	2	2	3	■	■	■
3.1	3	1	1	3	1	■	■
3.2	1	2	1	1	1	1	2
3.3	3	2	2	1		1	■
3.4	1	2	2	4	■	■	■

4.3.2 Selection of Concepts using Pugh's Method

Pugh's Method for Concept Selection is well documented in Dieter (2000).
The first step in this approach is to determine the criteria by which the concepts will be evaluated. These criteria are largely based on the Engineering Characteristics (EC's) from the QFD. Other factors outside the EC's such as technical risk and marketability can also be considered. The criteria used in the Pugh's analysis for this project are:

- Marketability of shape – this is how well the shape of the frame will be to sell to the customer.

- Marketability of materials used – how marketable the materials used in the frame are.
- Technical risk – the chance that the technical aspects of the concept will cause problems
- Clap noise abatement – how well the clap noise will be minimised
- Increased stiffness overall – whether the frame is expected to be stiffer overall
- Less lower frame weight – whether the weight of the lower (front) frame is expected to be any lower
- Less upper frame weight – whether the weight of the upper (rear) frame is expected to be any lower
- Lower component weight – wether the component weight is expected to be any lower
- Component strength & durability – wether the components are likely to be any stronger or more durable
- Lower frame strength & durability – whether the lower (front) frame is expected to be any stronger or more durable
- Upper frame strength & durability – whether the upper (rear) frame is expected to be any stronger or more durable
- Cost of lower frame (material & manuf.) – whether the lower (front) frame is expected to be any cheaper to produce
- Cost of upper frame (material & manuf.) – whether the upper (rear) frame is expected to be any cheaper to produce
- Cost of axles – wether the axles are expected to be any cheaper
- Cost of clap block – whether the clap block is expected to be any cheaper
- Cost of other components –whether the cost of other components is expected to be any cheaper
- Cost to assemble – whether the cost to assemble the frame is likely to be any cheaper

A matrix is then formed with the criteria forming the row heading and the concepts forming the column heading. Once it is ensured that the design concepts are clearly understood, the datum concept is chosen. In the case of this assignment, the first datum concept to be considered will be the current product, the Slingshot.

The matrix is then run, comparing each of the concepts to the datum, based on the criteria. The completed matrix for the first run can be seen in Appendix G.

The results of this first run are quite interesting. By summing the +ves and subtracting the –ves, it is shown that all of the concepts could be considered better than the datum. From this, it can also be seen that concept 8 is the strongest concept, and will carry over as the datum for the next run of the matrix.

For the second run, the current product was removed from the matrix, as it does not need to be considered any longer. He matrix is run again, comparing all of the concepts to concept 8. The completed matrix for the second run can be found in Appendix G also.

On the second run of the matrix, with concept 8 as the datum, Concept 3 has essentially equalled the datum (Concept 8). However, on a qualitative assessment of the analysis, the negatives would more often than not outweigh the positives for concept 3. The technical risk and cost of developing and making a monocoque chassis at this point in time would not be viable. Further down that track, perhaps this could be explored, as a monocoque chassis combined with a clap frame would satisfy many of the desires of skaters as the survey suggested and would be a very marketable concept.

The significant positive of concept 3 is the clap noise abatement and clap block cost. Using a simple foam urethane block as a de-bounce would be cheap, easy and more effective than a custom silicone block.

I would not suggest that any of the other positives are significant from the other concepts. Hence, by putting the concept 3 clap block into concept 8, the dominant solution is found.

Final Concept

Therefore, the final concept is as follows.

The lower frame would have cut outs from the edge of the frame (1.1.1) while the upper frame would have a combination of internal and from edge cuts (1.2.3). The lower frame would be of a section with curved vertical members (1.3.3) and the upper frame would be an single void ‘A’ section (1.4.1). Both lower and upper frames would be aluminium. (1.5.1 & 1.6.1).

The clap pivot would be a pin and cir-clip (2.1.2). The spring would be an internally mounted torsional spring which is directly connected to the upper and lower frame (2.2.3 & 2.3.4). The wheel axles would be one piece (2.4.1) and the pivot stopper would be inherent in the spring design (2.5.4).

There would be no significant clap block (3.1.5 & 3.3.6) while instead a small soft damping block (3.2.7) made of urethane foam (3.4.4) would be place in there as a 'de-bounce'.

4.4 Discussion of the Concept Selection and Evaluation

Dieter (2001) suggests that while the conceptualisation phase can be done on an individual basis, the concept selection process should be done as a team. This is a very good point, as it was found that doing the concept selection and making these decisions was hard as an individual, as you had no one to refer to or discuss the issues with.

The result of the of the concept selection process was a key point in the project, as this was one of the major points of undertaking the project, to find a concept that would improve on the existing design.

Aside from this, I believe that the concept selection process was quite successful, with a good concept coming of it.

5. Embodiment Design

5.1 Introduction

The embodiment design phase (Dieter, 2000) takes the preferred concept from the concept selection, and turns it into a model that is ready to be put down on detail drawings. It starts off by defining the interactions in the product architecture, then moves on to layout out the model in the configuration design, and finishes with the parametric design, where the design variables are considered to try and achieve a better design.

The result is a solid model that is ready to be put down on paper in the detailed design phase.

5.2 Product Architecture

The product architecture defines the interactions that need to be considered in the design. A well layed out product architecture will ensure that all the fundamental and incidental interactions are sorted out and considered before the product takes shape. The product architecture for this project takes into account;

- The boot
- The clap block
- The torsion spring
- The pivot hardware
- The upper (rear) frame
- The lower (front) frame
- The wheel axles
- The bearing spacers
- The wheels
- The bearings

Some of these components, such as the boots, are external to the design, but the interactions still has to be considered. From this list of components, the product architecture was laid out in AutoCAD.

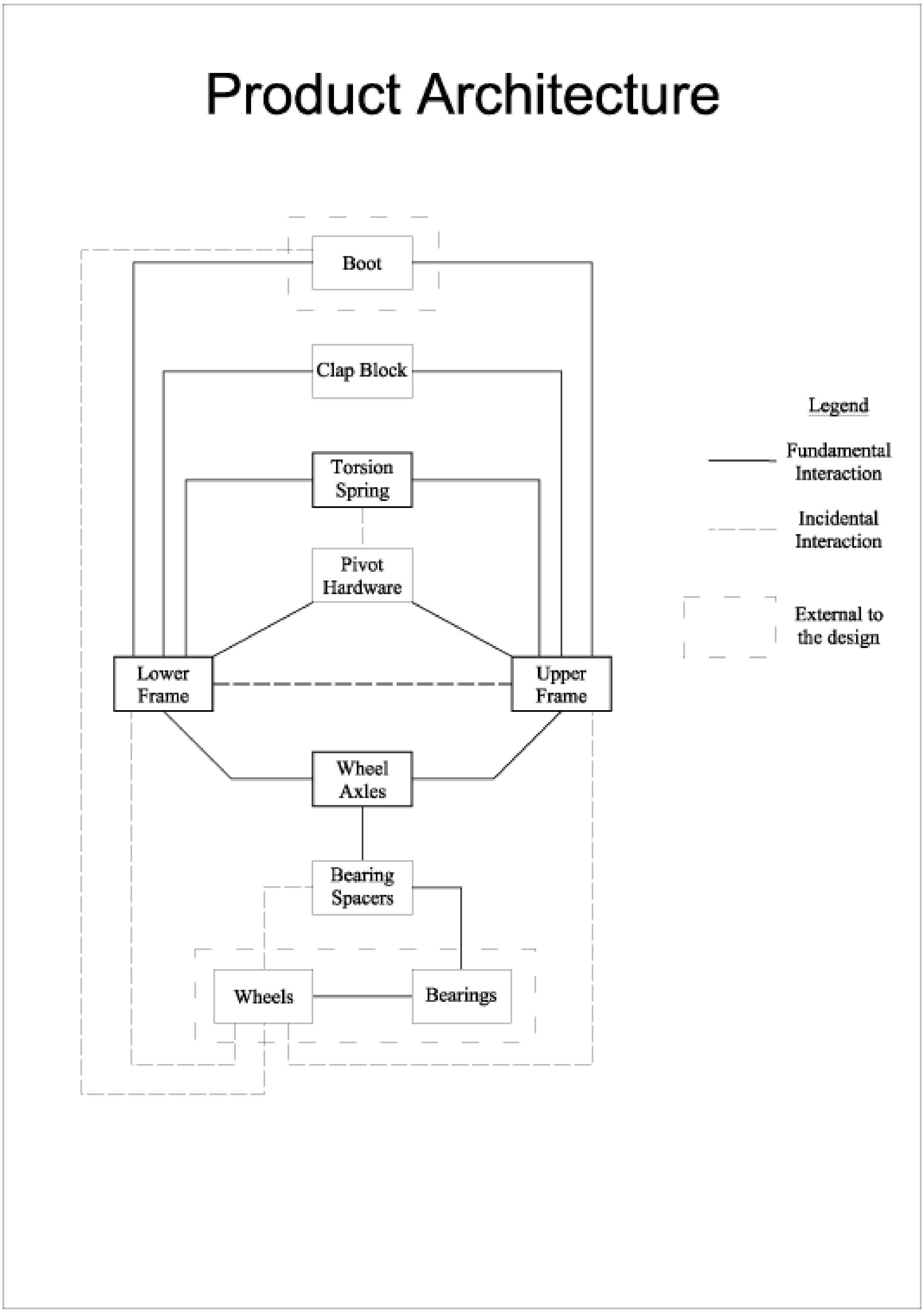


Figure 36 - The Product Architecture

5.3 Configuration Design

The purpose of the configuration design it to develop the basic layout and dimensions of the design. The main dimensions of wheel placement, clap pivot point and boot mounting holes were carried over from the current product. Also, the designs of the wheel axles and bearing spacers were carried over, as they are a standard components for Bont and they fit into the final concept without the need for validation.

A sketch was layed out for the configuration design to assist in turning the design into a solid model. The drawing of the current product in Appendix A were also used to make the solid model.

The result of the configuration design process was a solid model ready to be considered for parametric design.

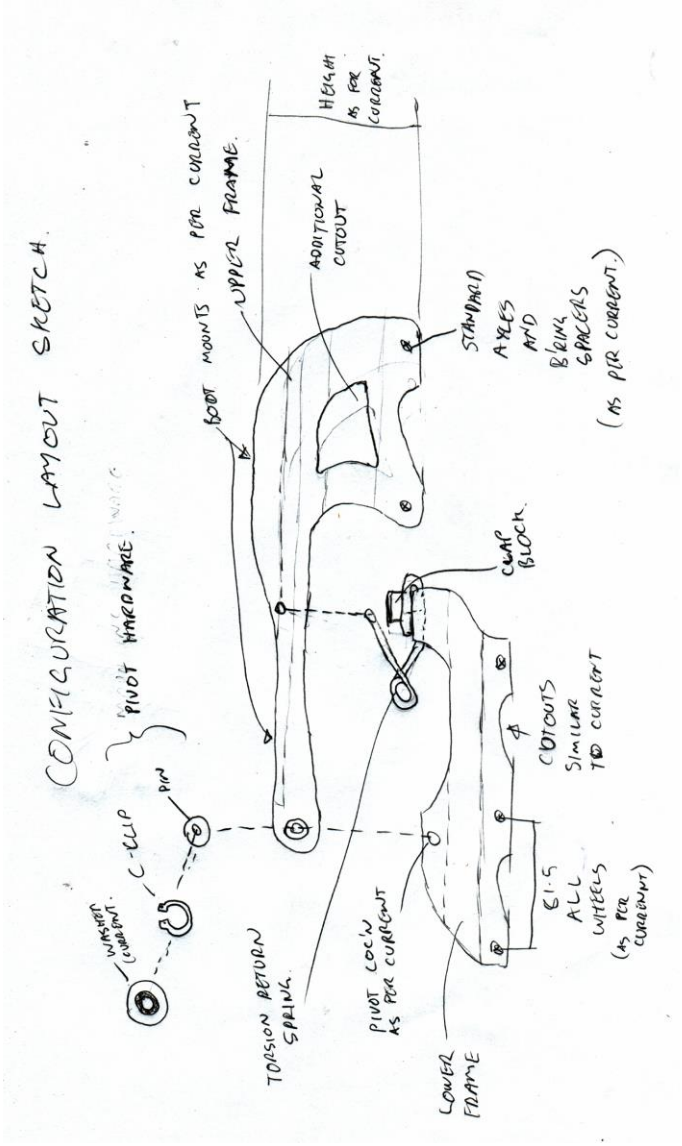


Figure 37 - The Configuration Design Layout used in the design process

5.3.1 Configuration of the spring and upper frame slot

The spring design and the slot in the upper frame were very important in the configuration design process. An acceptable spring configuration design had to be determined and the slot in the upper frame had be considered as this formed the basis of the pivot stopper. A sketch for the configuration design of the spring is shown below.

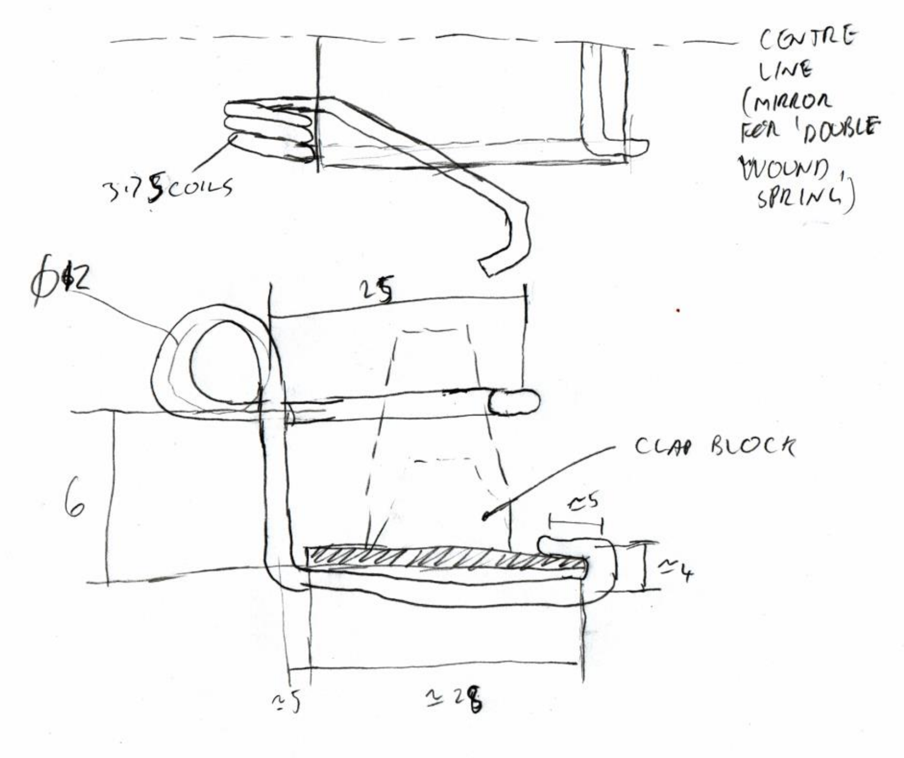


Figure 38 - Configuration Design Sketch for the Spring

Based on these figures, the spring was solid modelled, and added to the assembly. When the spring was added to the assembly, there was some interference in place, therefore, some changes had to be. These changes did not affect the doing a path analysis to determine where the end of the slot would go.

The configuration design sketch had specified where the start of the spring slide slot would need to be, and it also had also specified where the spring's path arc would be. The angle allowable by the current product was measured by tracing the open and closed positions on paper and measuring it with a protractor. From this a path analysis could be done to determine where the end of the spring slot should be located.

The path analysis was drawn in AutoCAD to scale.

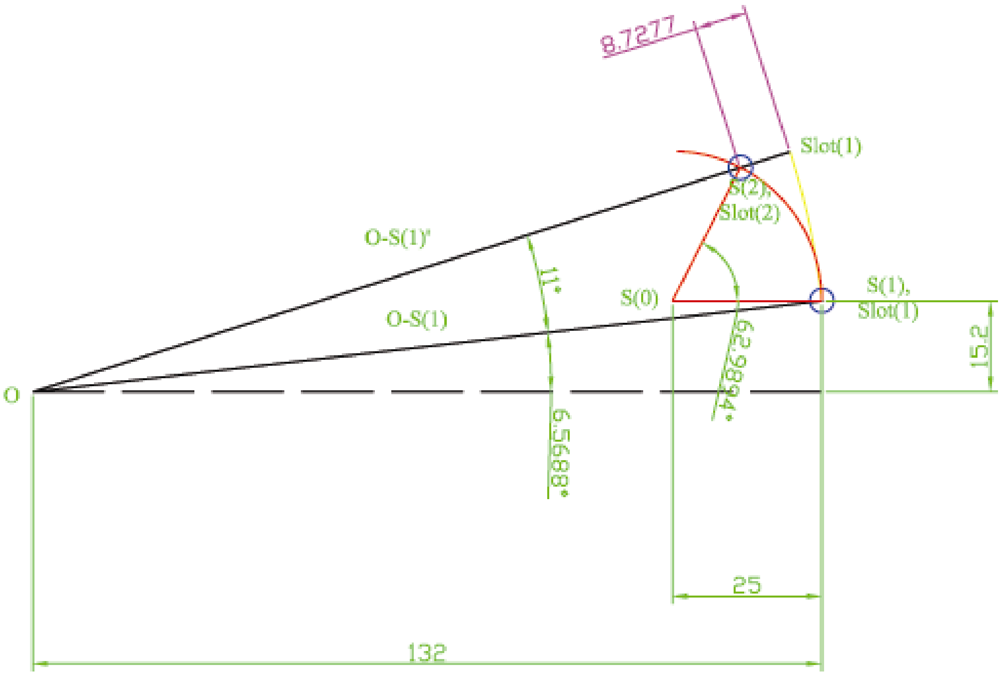


Figure 39-Spring Path diagram from AutoCAD

The point O is the clap pivot point, S(1) is the home position of the spring and Slot(1) is the start of the slot. As you can see from the diagram, Slot(1) and S(1) are the same Point. S(0) is the centre of the spring's arc, 25mm back from the start of the slot.
Line O-S(1) is rotated 11 degrees to that maximum point the frame will be allowed to open to create line O-S(1)'. An arc is drawn 25mm radius about S(0), which is the arc which the end of the spring will travel. The point at which the arc intersects O-S(1)' is the second point of the spring slot which is required to stop the frame over pivoting. This point is 8.7mm from Slot(1) towards O. The slot with therefore be designed to be 8.7mm long. The angle between lines S(0)-S(1) and S(0)-S(2) provides us with the maximum angle the spring opens, which is 63 degrees.
To determine if the spring design is OK, the standard equations in Mott were used. We must start by defining the knowns. The diameter of the wire (D_w) is 3mm and the Mean Coil Diameter (D_M) is 12mm. The ends of the springs, L_1 and L_2 are 6mm and 25mm respectively. The spring index, C, can be determined by:

$$C = D_M / D_w \qquad \ldots\ldots\ldots\ldots\ldots(5.1)$$

$\therefore C = 12 / 3 = 4$ ……………(5.2)

The effective number of spring coils needs to be determined, this is given by:

$N_a = N_b + N_e$ ……………(5.3)

and

$N_e = (L_1 + L_2)/(3 \Pi D_M)$ ……………(5.4)

$\therefore N_e = (25 + 6)/(3 \Pi \times 12) = 0.27$ ……………(5.5)

$\therefore N_a = 0.27 + 3.75 = 4.02$ ……………(5.6)

The spring rate is given by:

$k_\theta = (E D_w^4)/(10.2 D_M N_e)$ ……………(5.7)

where

$E = 77.2 \times 10^3$ MPa for Chromium-Vanadium Spring Wire (Mott, 1992)

$\therefore k_\theta = (77.2 \times 10^3 \times 3^4)/(10.2 \times 12 \times 4.02) = 12.7 \times 10^3$ Nmm/Rev
……………(5.8)

The moment at the maximum opening of the spring of 63 degrees is given by:

$M = k_\theta \times \theta$ ……………(5.9)

$\therefore M = 12.7 \times 10^3 \times (63/360) = 2220$ Nmm ……………(5.10)

The maximum stress is given by:

$\sigma = (32 M k_b) / (\Pi D_w^3)$ ……………(5.11)

and

$k_b = (4C^2 – C – 1)/(4C (C-1))$ ……………(5.12)

$\therefore k_b = 59/48 = 1.23$ ……………(5.13)

$$\therefore \sigma = (32 \times 2220 \times 1.23) / (\Pi \times 3^3) = 1030 \text{ MPa} \qquad \ldots\ldots\ldots\ldots\ldots(5.14)$$

This stress is considered to be acceptable for medium service duty (Mott, 1992), which a clap skate could be considered to be.

5.3.2 Configuration Design of the Pivot Hardware

To determine an adequate cir-clip selection for the loading during pushing, the Arcon Ring Catalogue was consulted (www.arcon.com, 2001). It was envisaged that a 6mm pin would be used, because it also suits the current frame design and could be validated in the current frame easily.

The cir-clip selected was an Arcon D1400-6. The maximum thrust load allowable on the clip is 4100N. From the benchmarking study, the maximum load axially is 693N, which is spread over the two pins. Therefore, one pin takes 346.8N. The clip is therefore adequate in taking the thrust load of the skater pushing.

The thrust capacity on the groove in the pin must be considered too. The thrust groove capacity is 330N for a pin made of mild steel. This is not enough for the thrust outlined above. However, if a better material for the pin is used, the thrust groove capacity of the pin is increased. The modified thrust groove capacity is given by:

$$T(g)' = T(g) \times Y' / Y \qquad \ldots\ldots\ldots\ldots\ldots(5.15)$$

Where

$T(g)'$ is the modified thrust groove capacity

$T(g)$ is the thrust groove capacity for mild steel

Y' is the Yield strength for the pin material chosen

Y is the Yield strength that Arcon suggests for Mild Steel. The value of this is 300MPa

It is suggested that the steel chosen for the pin is 4340 Alloy steel. Mott (1992) suggests this is a good steel for parts that require good through hardening. The yield strength for this material is 469MPa (Mott, 1992). Therefore, the modified groove capacity using 4340 Alloy steel for the pin is:

T(g)’ = 330 x 469 / 300 = 515.9N ……………(5.15)

This means the groove can take 515.9N, which is more than the required 346.8N for the pushing load. Therefore, using a 6mm Arcon D1400-6 cir-clip with a pin made of 4340 Alloy steel would hold the pivot together adequately.

5.4 Parametric Design

The parametric design phase was mainly performed to try and reduce the weight of the frame. Dimensions on front and rear frames were chosen to be altered. FEA was used to assess what the changes did to the frame and the loading conditions that were used were carried over from the benchmarking study.

5.4.1 Parametric Design Study of the Front Frame

The following diagram shows the dimensions chosen to be altered in the parametric design of the front frame.

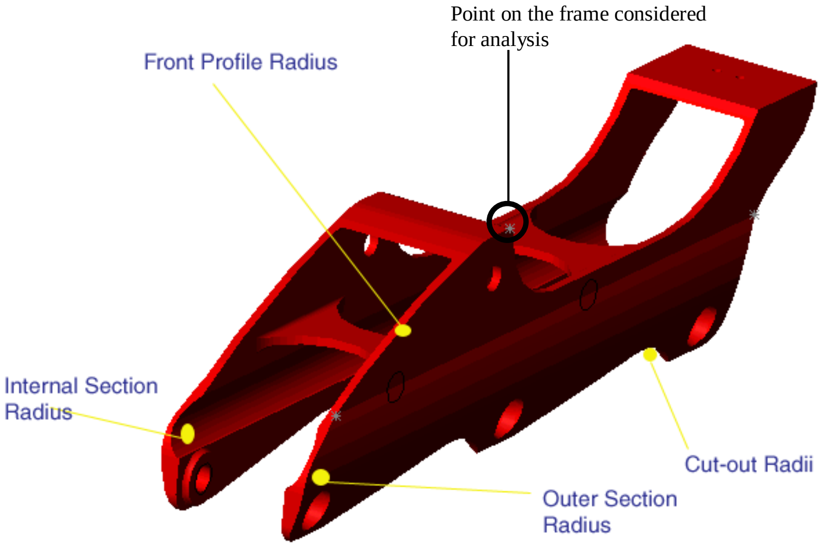


Figure 40 - Dimensions of the front frame altered for the parametric design study

The four parameters altered in the parametric design study were;

- the radii of the cu-out between the wheels – they were both kept the same magnitude as each other for each trial, and changing this dimension altered the depth of the cut-out
- the radius of the front sweeping section of the profile – changing this dimension altered the amount of material on the front of the frame
- the internal radius on the extrusion profile – changing this altered the amount of material along the extrusion
- the outer radius on the extrusion profile – changing this altered the amount of material along the extrusion

The point indicated on the diagram above was probed during post processing as a consistent point to gauge the deflection of the frame. The benchmark was also probed at this point to provide a baseline figure for the deflection.

The FEA technique used for this study was that same as described in the benchmarking FEA studies. The pushing load case was used in the study.

5.4.1.1 Results of the Front Frame Parametric Design study

A table of results of the front frame parametric design study using FEA can be seen in Appendix H.

From these results, the final magnitude of each of the dimensions was chosen. They were;

- Cut out radii – 22mm
- Radius of the front sweeping section of the profile – 200mm
- Internal radius of the extrusion profile – 8mm
- External radius of the extrusion profile – 36mm

The resultant mass of the front frame was 98.6 grams as calculated by SolidWorks. It was noted that the values of maximum stress and displacement were also significantly greater than for the benchmark frame.

5.4.2 Parametric Design Study of the Rear Frame

The following diagram shows the dimensions chosen to be altered in the parametric design of the rear frame.

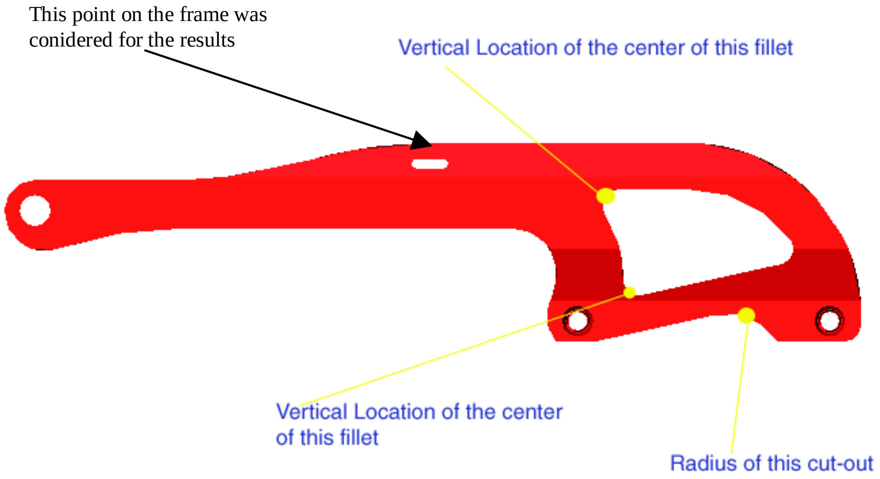


Figure 41 - Dimensions considered in the rear frame parametric design study

The three parameters considered in the rear frame parametric design study were;

- the vertical location of the top fillet on the rear frame hole – this altered the size of the hole
- the vertical location of the bottom fillet on the rear frame hole – this altered the size of the hole
- the radius of the cut-out between the rear wheels, this altered the depth of the cut out

The point indicated as being considered for the results, was where the arc met the top flat section of the frame. This point was probed for values of deflection.

The FEA method used was the same as described in the benchmarking of the current product rear frame. The turning load case was used for the study.

5.4.2.1 Results of the Rear Frame Parametric Design Study

A table of results of the rear frame parametric design study using FEA can be seen in Appendix H.

From these results, the magnitude of each of the dimensions was determined. The dimensions chosen were;

- vertical location of the top fillet – 49mm

- vertical location of the bottom fillet – 20mm
- the radius of the cut-out between the wheels – 19mm

The resultant mass of the rear frame was 194.7 grams as calculated by SolidWorks. It should also be noted this design displayed values of displacement and maximum stress that were larger than those set the benchmark.

5.4.3 Discussion of the Parametric Design

The parametric design phase of the project had a huge number of potential parameters that could have been considered. A parametric study of a frame could be a whole project in itself, looking at the optimisation of a particular frames parameters for weight and deflection characteristics.

The results of the FEA for the rear frame showed that, despite the large hole added to the frame profile, the displacement and maximum stress were only slightly higher than the benchmark. On the other hand, the front frame showed values of stress and displacement far greater than the benchmark.

6. Detailed Design

6.1 Introduction

In this final stage of the design process, the detailed drawings will be produced, any validation not already covered will be performed and the design will be reviewed against the governing documents.

The result of this final step in the process is a design that is ready for field validation.

6.2 The Final Design

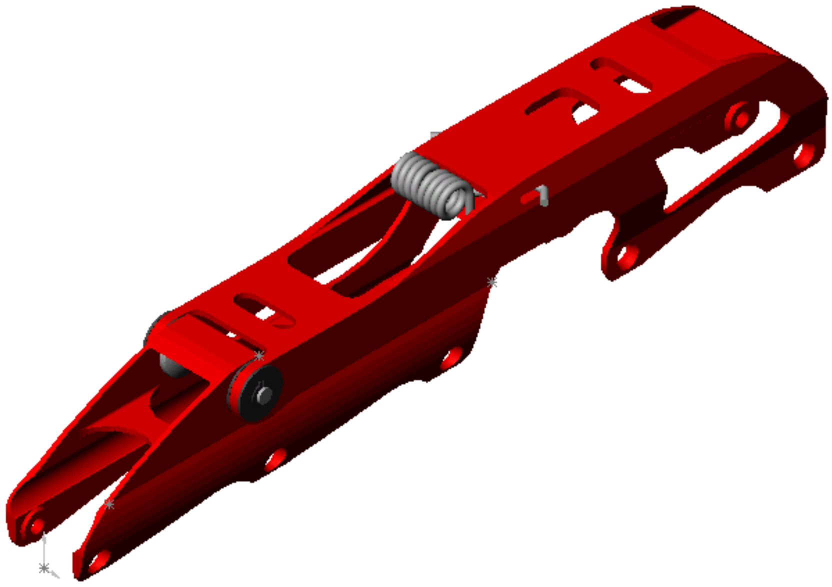


Figure 42 - 3D Isometric View of the final design

6.2.1 Detailed Drawings

The final detailed drawings are in Appendix I. This includes details for all components that are unique and the assembly.

6.2.2 Final Validation of the Frame Sections

The only parts that have not as yet been validated are the front and rear frame sections. Since they are quite complex and available as a solid model, they can be easily validated using Cosmos/Works.

6.2.2.1 Validation of the Final Front Frame Design.

The validation of the front frame will be done by using the pushing load case developed in the benchmarking section of the project. The same materials and boundary conditions are applied, but the mesh is made finer to attempt to get a more accurate results. The mesh was specified to be 1mm.

6.2.2.2 Results of the Validation of the Front Frame

The FEA validation of the front frame showed the following maximums for von-Mises stress and resultant displacement:

Max. stress	273MPa
Max. displacement	0.411mm

The stress value is under the yield strength for 7005-T53 Aluminium Alloy Extrusion which is 300Mpa (www.capral-aluminium.com.au, 2001) which is the only extruded aluminium alloy in Capral’s list that will take this load without yielding. This only a factor of safety of 1.1, however, the accuracy of the loading model leaves a lot to be desired.

6.2.2.3 Validation of the Final Rear Frame Design

The validation of the rear frame will be done using the cornering load case developed in the benchmarking phase of the project. The same materials and boundary conditions are also used, but a more accurate result was sought by refining the mesh. The mesh was specified to be 1mm.

6.2.2.4 Results of the Validation of the Rear Frame

The FEA validation of the rear frame showed the following maximums for von-Mises stress and resultant displacement:

Max. stress	94.7MPa
Max. displacement	0.189mm

This would indicate that the 6005A-T4 Aluminium extrusion would be adequate, but the factor of safety would be only 1.2 for it yield strength of 110MPa (www.capral-aluminium.com.au, 2001). I would suggest the use of 6005A-T5 would be a better option with a yield strength of 240Mpa and a subsequent factor of safety of 2.5.

6.2.2.5 Comparison of FEA results to the Benchmark

The following is a comparison of the results from the benchmarking FEA studies for the current product to the results from the validation FEA for the proposed product.

	Current		**Re-design**		**Change**	
Section	Stress (MPa)	Max Disp. (mm)	Stress (MPa)	Max Disp. (mm)	Stress	Disp
Front	178	0.374	273	0.411	53.4%	9.9%
Rear	82.1	0.178	94.7	0.189	15.3%	6.2%

This indicates that the both the strength, while not compromised, does not have as high a safety factor with the proposed design, particularly the re-design of the front frame. The stiffness of the frame has also decreased, with the maximum displacement increasing for both the front and rear frame sections.

6.2.3 Bill of Material, Mass and Estimated Assembly Time

The following table shows the Bill of Material (BOM) and estimated time to assemble the re-designed frame.

Description of Part	**Qty**	**Mass of Part (gms)**	**Total**	**Time to Assemble (s)**	**Total**
Lower Frame	1	98.6	98.6	0	0
Upper Frame	1	194.7	194.7	3	3
Pivot Washer	4	0.4	1.6	4	16
Spring	1	23.6	23.6	40	40
Pivot Pin	2	10.7	21.4	8	16
Cir-clip	2	0.2	0.4	10	20
Clap/Damper Block	1	0.4	0.4	8	8
Clap/Damper Block Screw	2	0.1	0.2	5	10
Totals:	14		340.9		113

6.2.3.1 Comparison of the BOM and assembly time to the Benchmark

The following table compares the results of the Bill of Material, final mass of the frame assembly and estimated assembly time of the re-designed frame to the benchmark, the original Bont Slingshot.

	Current	**Proposed**	**Change**	**Direction**
Quantity of Components	20	14	30%	Down
Time to assemble (est)	202	113	44%	Down
Assembly Weight (grams, excluding axles)	374.1	340.9	8.9%	Down

This comparison shows some of the advantages of the re-designed frame as a reduced part count, a lower assembly time and a lower frame assembly weight.

6.2.4 Cost to Manufacture

The cost to manufacture the front and rear frame sections as well as the current product’s front and rear frame sections was sought from an engineering work shop. However the results were not available at the time of publishing this report.

6.2.5 Review of the Design

The problem statement for this design was to re-design the Bont Slingshot In-line Clap Speed Skate Frame in accordance with Bont’s and their potential customers’ expectations.

To find out what those expectations were, Bont and their potential customers were surveyed. Bont were concerned with decreasing the weight of the frame while maintaining a strong, stiff assembly. They were also concerned with the noise of the clap mechanism when it returns to the home position.

From a survey conducted over the Internet, the potential customers of Bont wanted a frame that they knew was strong and durable. It would also be acceptable to sacrifice some stiffness to decrease the weight.

The resulting proposed frame was 8.9% lighter than current product. The weight reduction did come at a cost, the maximum stress and deflection have increased in the frame. The stress in to front frame was of particular concern, where the factor of safety was reduced to 1.1 as indicated by the static FEA. This may be of concern as when dynamic effects are considered, the frame may plastically deform in places leading to a failure. However, the load cases were only estimates, so there could be a significant amount of error in them, and I would suggest that they are on the over loaded side rather than under loaded.

In all, the proposed product fits as a solution to the problem as defined, but is not perfect.

7. Discussion

This project took on a very systematical approach to the problem of re-designing the product. The result was a concept that fits what the customers and the project sponsor require.

The undertaking of such a project was far too great for one person to do alone thoroughly, a group of at least two people need to be part of such an activity. The most significant problem in working alone on such a project came into effect in the concept evaluation and selection phase. A it is a process that requires opinions to make decisions is going to have a far better result if a small group is putting forward a range of opinions rather than the opinions of one person.

With the scope that is available in a project such as this, especially in brainstorming the concepts, a larger group would have also provided more options to be considered. There was, and still is, a huge range of potential in a venture such as this, and one person cannot possibly consider it all. Examples of where more depth could be considered is in generating concepts for extrusion profiles and considering the vast number of parameters that could be altered in the parametric design.

The accuracy of the Finite Element Analysis load cases possibly leaves a lot to be desired. While there is some data on the push off mechanics of ice speed skating, it is not necessarily relevant to in-line speed skating, particularly on clap skates. Subsequently, the values that were obtained in the FEA sections of the project may not be totally applicable to the actual situation. The FEA results were good enough to make comparisons between the proposed design and the benchmark.

The other consideration that needs to be made is for dynamic effects. All of the load cases were only for static loading, and dynamic vibrations may paly an important roll in the way the strength of the frame is affected.

One of the important notes that should be made is that some of the concepts could be added to the current frame design to enhance it. For example, one of the clap block designs could be easily fitted to the current product.

8. Conclusion and Recommendations

Using the design methodology described by Dieter (2000) and a range of Computer Aided Engineering techniques, it was possible to re-design the Bont In-line Clap Speed Skate Frame to satisfy most of the requirements Bont and their potential customers.

The main conditions that were outlined by Bont and met were to reduce the weight improve on the noise abatement in the design. The requirement to ensure that strength wasn't compromised, that was considered important by both Bont and their customers, was met. However, the factor of safety was reduced significantly, too a point where the dynamic nature of skating could cause the front frame to fail. However, the validity of the load cases that were used in the computational analysis is in doubt, and the result may not be realistic.

The following recommendations are made in relation the this and future projects in the field:

- The concepts should be validated in the field. This includes proving the design concept for the spring and clap block/damper.
- Suitable load cases need to be established for computational analysis model to provide valid an realistic results.
- Concepts in the areas outlined in the project should continue to be developed, particularly in the area of the profile of the extrusions.
- Further parametric design studies taking into account a wider range of variables should be performed to gain insight into what affects the strength, mass and stiffness of the frame.
- Frames with different, quantifiable stiffness characteristics should be independently by a variety of skaters to find if there is a relationship between the qualitative user rating of stiffness an the actual stiffness of the frame.

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