

1. INTRODUCTION

1.1. Background of Full-Suspension Bikes

Although mountain biking has only existed commercially since 1981 (when Specialized⁽¹⁾ produced the first mass-produced mountain bike: the \$750.00 Stump Jumper), it is now a very popular pastime and one of the fastest growing sports worldwide. The now multi-billion dollar industry caters to three main sectors of the market; ‘cross country’, ‘downhill racing’ and ‘freeriding’. Although full-suspension mountain bike designs exist for all three categories, this project will be focusing only on the ‘downhill racing’ and ‘extreme freeriding’ markets. To compete in these sectors a frame must have long travel rear suspension and be strong enough to withstand the rigors of the sport whilst not being too heavy, ideally 5-6Kg.

A purebred downhill race bike is designed to enable the rider to travel as fast as possible over rough terrain down mountainsides. The suspension design therefore focuses on bump absorption to give increased control and stability at speed. In order to travel at high speeds the bike must be light to increase manoeuvrability for braking, cornering and accelerating, whilst at all times offering a stable platform for ease of pedalling. An extreme freeride bike design focuses more on absorbing larger impacts and shocks such as landing from a large vertical drop. A bike designed for this style of riding must be very strong to withstand the forces, and weight is no longer of such high priority as it is with downhill racing frames.

Although there are other factors to consider (details given in section 2.2) the majority of the desired attributes of the frame and linkage design are shared by both disciplines of the sport. If a frame is well designed it is possible to attain the strength required of a freeride bike whilst optimising the design to use less material and hence reduce the weight allowing it to compete in both the downhill race and the freeride markets. This increases the potential market share. Since the first production full-suspension bike was introduced back in 1991 by Cannondale⁽²⁾ there have been a plethora of suspension designs introduced, ranging from the very basic single pivot designs, to much more complex multi-link designs.

1.2. History of Banshee Bikes

Banshee Bikes was established almost by accident as a result of one of mountain biking's most enterprising designers, Pippin Osborne, being asked to design a new bike for Canada's largest bike retailer, Bow Cycles from Calgary. This was for a bike that could withstand the rigours of modern aggressive riding better than the bikes commercially available at the time. Pippin had already founded a world famous mountain bike component company called Syncros Applied Technology back in the 1980's that is still in business today. From an engineering and business minded background Pippin designed a frame that was so 'bombproof' that it could be sold with a 10 year warranty, which was unheard of in the mountain biking industry at that time.

The frame that Pippin designed was exactly what the new generation of 'extreme freeriders' had been waiting for, and demand grew for the bike from both customers and dealers. One thing lead to another and within a year Banshee Bikes was established in Vancouver, Canada, in 2001, to capitalise on the dealer demand, and offer unrivalled products and support to customers.

Banshee bikes is now, officially, in its 4th year of operation and the product line up which started as one bike has now grown to eight frame models with future expansion planned into other market sectors. The company has distribution in over 30 countries on 5 continents, with new inquiries still coming from emerging markets. Sales are in the millions \$CAN with many more opportunities for continued growth.

2. OVERVIEW OF SUSPENSION LINKAGE DESIGNS

2.1. Types of Suspension Linkages

2.1.1. Single Pivot Design

A single pivot design is the simplest possible design for rear suspension system. Essentially this design consists of the rear axle being mounted into a swingarm which actuates a spring damper suspension unit (shock) via leverage on a single pivot. An example can be seen in Figure 1. This is the most basic and most commonly used suspension linkage available on the market and was directly modelled on the motorcycle industry's standard design.



Figure 1 Single Pivot Design (from Orange Bikes⁽³⁾)

Although the concept is essentially very simplistic, consideration must be given when deciding the location of the pivot and the shock mounting points. For example an apparently insignificant change in pivot position will alter the axle path, and therefore dramatically change how efficiently the bike pedals and reacts to bumps.

Mountain bikes will experience lateral forces on the wheels when cornering, landing slightly sideways, or going through very rough terrain. It is difficult to make single pivot bikes as laterally stiff as multi pivot bikes due to the moments all being transferred through just one pivot. As a result of these thrust loadings on the bearings they tend to wear out faster. However this is not a big problem due to the fact that the bearings used are normally standard sizes, hence affordable, and easily purchased when requiring replacement.

2.1.2. Four Bar Linkage

Four bar linkage suspension designs were developed to improve upon the downfalls of single pivot designs in terms of stiffness, as well as various other important factors. However these improvements often come with increased weight, and extra maintenance required due to the increased complexity.

2.1.2.1. ‘Horst Link’ Design

The ‘Horst Link’ was developed by Horst Leitner and Karl Nicolai and first patented^(a) in 1993. Several of the patented ideas were bought by one of the mountain biking industry giants, Specialized, between 1998-1999. The concept behind the ‘Horst Link’ was to reduce the change in effective chainstay length and hence chain growth. This is achieved by placing a pivot below and in front of the rear axle (as seen in Figure 2(a)). As a result of this pivot location, the rear axle is mounted on the effective seatstay of the linkage, and is no longer arcing around the mainframe pivot point like single pivot designs.

When calculated correctly this design can achieve a number of positive attributes, such as eliminating pedal kickback and any form of braking induced suspension reaction which are detrimental characteristics, as described in section 2.2. However to achieve this, the axle path becomes less desirable, and so a compromise has to be made to get an optimal design.

2.1.2.2. ‘Lawwill’ Design

A less commonly used four bar linkage design is the ‘Lawwill’ linkage developed by Mert Lawwill in Germany between 1992 and 1994 and patented in 1996^(b). The concept of this design is the most advantageous of the basic four bar linkage designs in terms of axle path manipulation and brake isolation. Once again the axle is mounted on the second bar of the linkage; however that link is now much shorter and actuates the shock via a long seat stay mounted rocker as seen in Figure 2(b). The problem with this design is that, in order to achieve

the desired strength, the linkage inherently uses a lot of material to get the desired stiffness characteristics from the extended rocker, and so the weight increases.

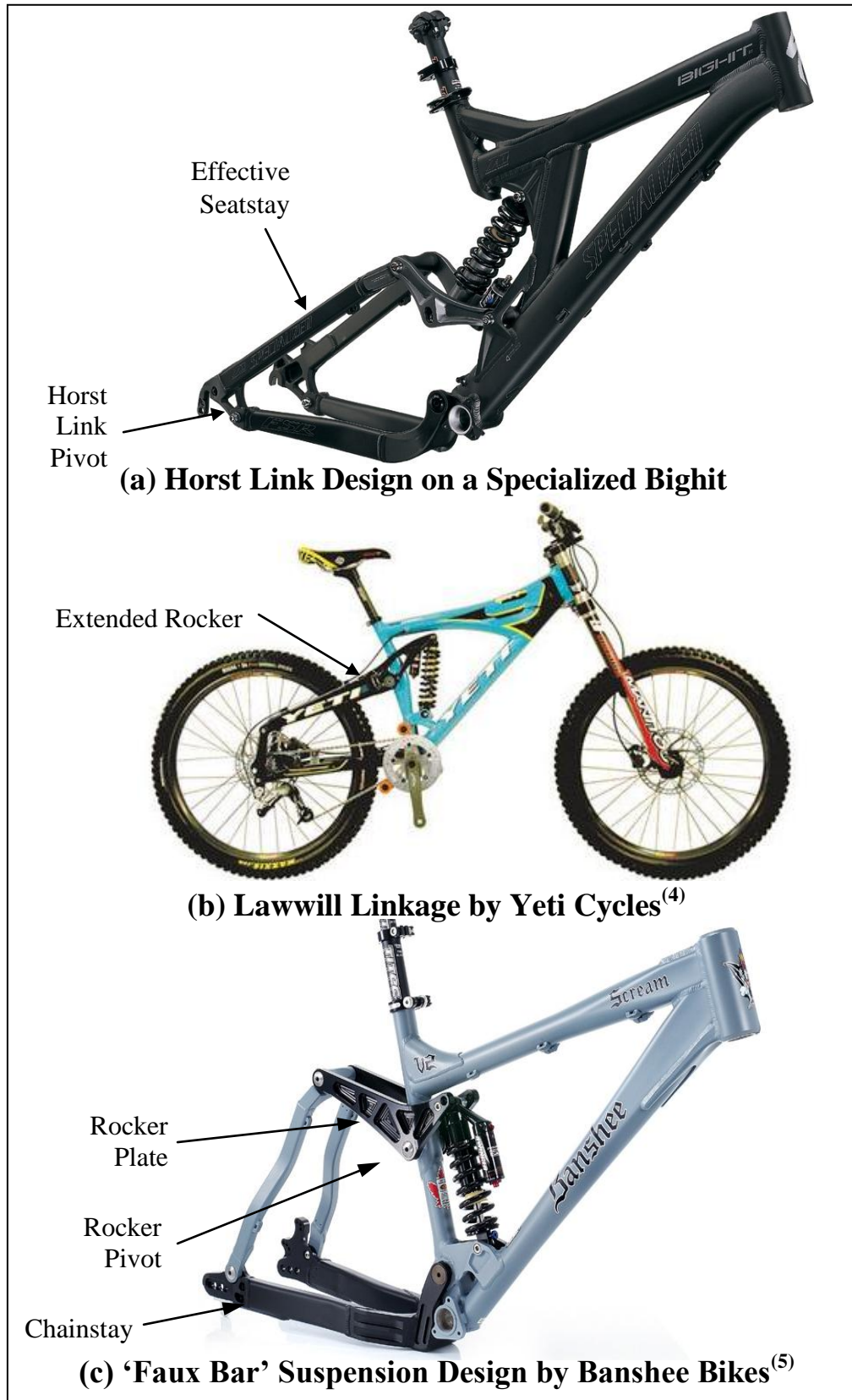


Figure 2 Examples of Different Four Bar Suspension Designs**2.1.2.3. ‘Faux Bar’ Design**

The most basic four bar linkage design is the ‘Faux Bar’ design as seen in Figure 2 (c). This is the suspension linkage design Banshee Bikes currently use for its large travel bikes. This linkage still has the axle mounted on a chainstay which is directly mounted to the mainframe via a pivot, exactly the same as a single pivot design, and so will have the same axle path characteristics. However the two extra links that act as an interface between the chainstay and the shock via the seat tube, in this example, make this design much more laterally stiff than a single pivot bike due to there being two frame mounted pivots as opposed to one. The rocker plates that actuate the suspension can be orientated in a variety of geometries and can actuate the shock in a number of different ways (as seen in Figure 3) and can offer more adjustability in terms of leverage ratios experienced by the shock.

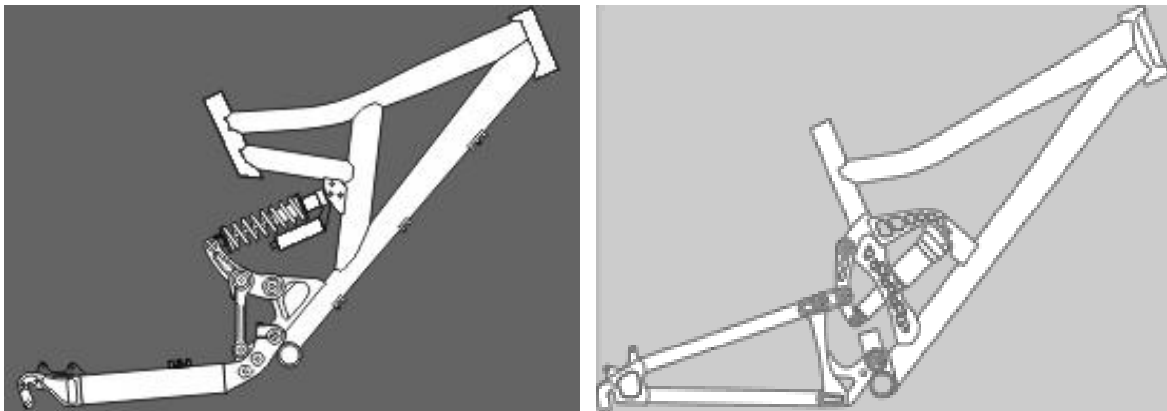


Figure 3 ‘Faux Bar’ Designs Showing Alternative Geometric Orientations from Rocky Mountain Bikes⁽⁶⁾

Although the increased number of pivots provides the linkage with a better lateral stiffness, as well as more options for geometrical optimisation of the linkage and frame design, there can be maintenance problems if the bearings are not designed to take the dynamic and static loads demanded of them. This can prove costly for the consumer as well requiring time off the bike for the customer to replace them. This is a potential problem that must be considered when designing all multi pivot bikes; will the benefits outweigh the potential reliability issues associated with more complex designs?

2.1.3. ‘Virtual Pivot Point’ (VPP)

The Virtual Pivot Point linkage design was developed by James Klassen of Outland Technologies and was patented^(c) in 1995. The VPP linkage is essentially achieved by mounting the axle on a triangulated second link (that encompasses the rear wheel) of a four bar linkage design, (as shown in Figure 4). The VPP linkage directs the rear axle along a predetermined S-shape path as the suspension compresses. A result of this concept is that the suspension will not compress much when pedalling due to the inherent chain stretch designed into the system (see section 2.2.5). This results in good acceleration characteristics without the loss of small bump absorption. The main drawback of current VPP, other than the potential maintenance problems that are apparent in all multi pivot bikes, is that there is no brake isolation. This means that the suspension will become less reactive under braking unless a floating brake⁽⁷⁾ (which will add weight and complexity) is used.

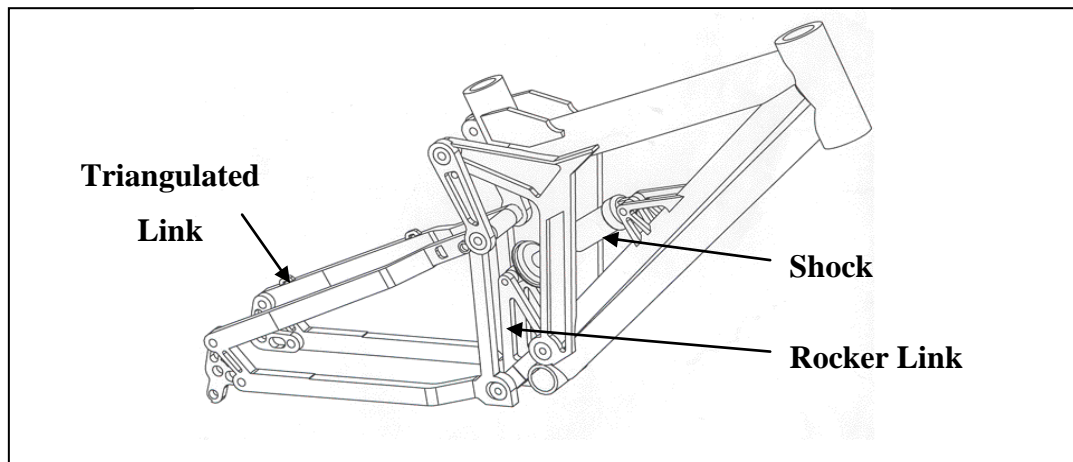


Figure 4 VPP Linkage on a Santa Cruz⁽⁸⁾, V10

This design has gained a very good reputation with mountain bikers worldwide, and so has become commonly used. Several variations of the design have been developed to make small improvements to the stiffness and suspension characteristics with care taken to avoid patent infringements.

2.2. Design Considerations

When designing any basic hardtail mountain bike there are several important geometric aspects to consider. As soon as a decision is made to design a bike with rear suspension, then a number of dynamic factors must also be considered. The relevance and importance of the dynamic constraints becomes even more crucial as the amount of rear wheel travel increases to the amount required to compete in the extreme-freeride and downhill race markets.

2.2.1. Frame Geometry

The most important parameters such as lengths and angles considered during basic frame design are shown in Figure 5.

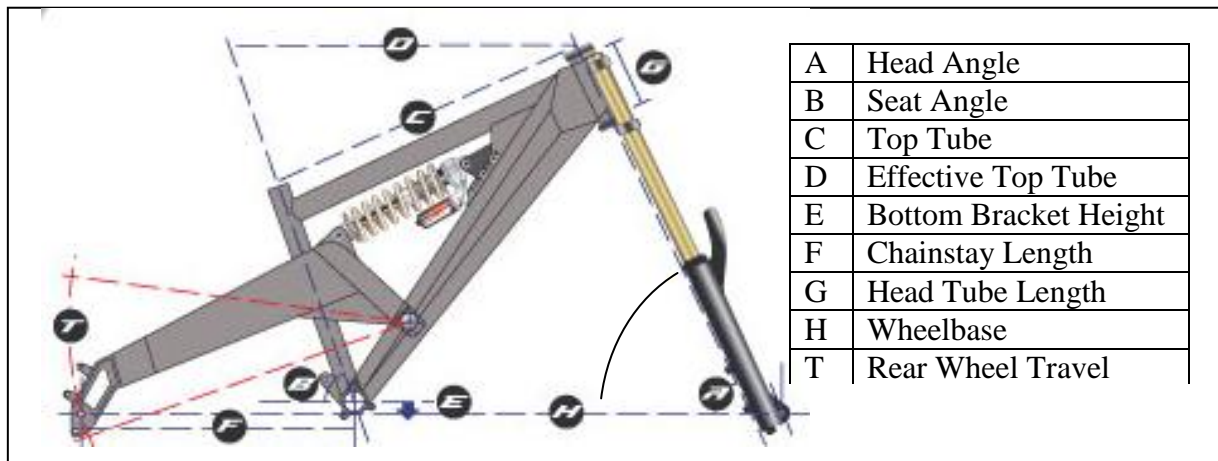


Figure 5 **Frame Geometry of Orange 224**

The dimensions of the front triangle on a well designed frame should be governed by the geometry of human bodies, and designed to be ergonomic in order to provide comfort and control. As a result most bikes are designed in three or more different sizes to suit people of all shapes and sizes.

2.2.1.1. Head Angle

The geometry of a bike frame also varies massively depending on the discipline of the sport it is designed for. For example the head tube angle will vary between about 72 degrees (steep) for cross country, and 64 degrees (slack) for purebred downhill race bikes. Although this might not seem like a big difference, the effect of changing the head angle by just a couple of degrees will have a massive effect on the way the bike handles. A slack head angle will make a bike less manoeuvrable at slow speeds, but will massively increase its stability at high speeds for two reasons. Firstly, by slackening the head angle the wheel base will generally be lengthened, which has the same stabilising effect as widening the legs of a tripod. Secondly, by reducing the angle between the ground being travelled over and the front suspension forks, means that the suspension is more in line with the direction in which the bumps will be applying forces to the front wheel; and so the suspension will react more effectively. Extreme freeride bikes will have slightly steeper head angles than downhill race bikes, generally ranging between 65 and 67 degrees. The steeper angles in this case are designed to give better slow speed control, as well as reducing the leverage forces experienced on the head tube by vertical drops.

2.2.1.2. Bottom Bracket Height

Another critical frame design factor that dramatically changes how a bike rides, is the bottom bracket height above the ground. Ideally a low bottom bracket is desired due to the lowered centre of gravity, which will provide greater stability. A low centre of gravity is a very much sought after attribute of a frame design, as described in section 2.2.2. However, having a low bottom bracket does mean that it will strike rocks and bumps when the bike is near the bottom-out position. This could cause ankle injuries to the rider, or cause him/her to fall off the bike altogether, as well as putting high shock loading forces on the frame in a direction for which it is not designed. Therefore an optimal bottom bracket height has to be chosen to offer a good trade off between ground clearance and low centre of gravity based on the type of riding and terrain the bike is designed for.

2.2.2. Centre of Gravity

A bike with a low centre of gravity will in general be much more stable both at low and high speeds over rough terrain. This stability will be especially noticeable when high speed cornering; additionally a lower centre of gravity will give the rider more control, and require less effort when leaning the bike into corners, and riding over off-camber ground.

The best way to lower the centre of gravity is to lower the bottom bracket height, as mentioned previously. By lowering the bottom bracket height, it effectively lowers the rider's height, and since the rider weighs considerably more than the bike, the centre of gravity for the rider and bike will lower significantly resulting in improved stability. Since there is a limit on how close to the ground the bottom bracket can be, it is important to design the frame so that the majority of the mass is as close to the bottom bracket as possible in order to achieve the lowest centre of gravity possible. Since the suspension unit is a relatively heavy part of the frame a lot of consideration must be taken to design the suspension around a low shock. By making the main body of the frame as low as possible the stand over height will also be reduced, which is beneficial to the rider due to the increased ease of shifting his/her weight relative to the bike while riding.

2.2.3. Leverage Ratio

On all full-suspension mountain bike designs, the rear suspension unit will be actuated by the force experienced by the rear wheel levering against a pivot. The overall leverage ratio can be easily calculated by dividing the total travel, by the stroke length of the suspension unit (the amount that the shock can compress). In order for a shock to have a longer stroke length, it must have a greater total length (known as eye to eye length). Therefore in order to increase the amount of travel a frame is capable of, either a longer shock must be used, or a greater leverage must be applied to the suspension unit.

Since bikes designed for the sectors of the sport covered in this project are required to be long travel bikes with excess of 200mm (8") (of vertical wheel travel, this is one of the biggest problems facing frame designers. By adding a longer stroke shock a lower leverage ratio can be achieved, which has beneficial factors mentioned later in this section. The only problem with using a larger shock is that it adds weight to the design. The other way to solve this problem in a geometric sense is to apply a greater leverage to the shock, and compensating for this by using a stiffer spring, so having a high leverage ratio. There are a number of problems with this solution. Modern suspension units have speed sensitive valve damping. Due to the fact that a large amount of wheel travel will be represented by a relatively small compression of the shock, the damper does not work very well as it is designed to work at higher speeds. This problem can be solved by having the suspension units custom valved. However, when a shock bottoms-out (fully compresses) under these criteria, the rear suspension unit effectively becomes a rigid strut, which when subject to a high leverage ratio will experience very high forces which will tend either to blow the oil and gas seals, or to buckle the whole unit.

The lower the leverage ratio, the better the suspension unit will dampen the ride, and the lower the force experienced by the shock. An overall leverage ratio of 3:1 or less has recently become a selling point of different bike designs. However the linkage will continually change the leverage ratio that acts on the shock due to changing the angle at which the shock is actuated by the lever and the effective length of lever arms of the dynamic system.

The dynamic leverage ratio has a huge effect on the 'feel' of the suspension and how it reacts to different scenarios. If the leverage ratio increases as the suspension moves through its travel, the design is a regressive one. Regressive designs are undesirable due to their tendency to bottom-out very easily and yet have poor small bump absorption characteristics. A linear design essentially means that the leverage remains constant throughout the travel, so that it is as easy to compress at the start of the compression as at the end. This design is favoured by a few downhill racers due to the predictable feel of the bike. In an ideal linkage design for this type of bike the linkage should be progressive, (become harder to compress as the suspension moves through its travel), in other words the apparent leverage ratio should gradually reduce as

the suspension compresses. There are several benefits of having leverage ratio characteristics that follow this pattern under normal riding conditions:

- Small bumps will actuate the shock with a relatively high ratio. This will result in a very plush ‘feel’ to the suspension, and will result in a smooth ride.
- The gradual reduction in leverage ratio will make the linkage act in a predictable and stable manner.
- Heavy landings will cause the bike to move through to near the end of the travel where the shock will experience a lower ratio of the force, and so will effectively stiffen up, resisting bottoming-out by firming up the suspension.
- Under bottom-out scenario, the forces acting on the suspension unit and thus the frame mountings will be relatively small due to the low leverage acting on the shock.

It must be remembered that the apparent leverage ratio takes into account the suspension unit characteristics, which are nearly always progressive. This means that linear linkage designs can react as if they are progressive, but purely rely on the shock to achieve this.

2.2.4. Pedalling Efficiency

The major problem that bike designers have been trying to solve since the first rear suspension bike was developed is a massive reduction in pedal efficiency. ‘Pedal-Bob’⁽⁹⁾ occurs when the suspension compresses under the vertical forces applied to the bottom bracket when the rider pedals. This compression of the suspension takes energy from the pedalling away from the chain which would otherwise apply a torque to accelerate the back wheel. It also causes the bike and rider to bounce up and down while pedalling, resulting in a loss of stability. Reducing pedal-bob is especially important for climbing up hills when the rider may be standing up on the pedals and exerting large downwards force on each pedal stroke. Reducing pedal bob can be achieved in a number of different ways. Modern suspension units have some sort of platform valving⁽¹⁰⁾ which is designed to recognize when the forces acting on the shock are applied due to the rider pedalling, and then stiffen the suspension so that it does not compress.

Unfortunately by making the pedal platform very stiff, the ‘feel’ of the suspension is affected in a negative manner, and so other methods for reducing pedal-bob by means of the linkage design need to be used.

2.2.5. Chain Extension (Chain “Stretch”)

Chain extension is an important design configuration which can be used to reduce pedal-bob. Chain extension is caused by the distance between the centre of the bottom bracket and the centre of the rear axle increasing as the suspension moves through its travel. If the linkage is designed so that under normal pedalling conditions this distance increases slightly, then this will be beneficial to pedalling efficiency. By the chain being effectively stretched every time the bike tries to compress under pedalling, it then applies a force opposing the compression of the suspension, and so reduces how much the suspension will compress. This design will have no effect on the suspension when the rider is not pedalling as the chain will no longer be in tension. This is an improvement over relying on a stable platform shock, as mentioned in section 2.2.4, as the ‘feel’ of the suspension is not sacrificed for the benefit of greater efficiency.

2.2.6. Pedal Kickback

When too much chain stretch (approximately $>30\text{mm}$) is inherent in a linkage, there can be very detrimental effects on the predictability and efficiency of the pedalling motion. The negative consequence of the effective chainstay length changing as the suspension is activated is known as pedal kickback. This is apparent on all bikes with chain stretch, but becomes more noticeable when the rate of change of chain stretch is higher. Essentially when the effective chainstay increases in length as the linkage compresses and the rear wheel comes into contact with a bump which compresses the suspension, a force will be experienced through the cranks that oppose the pedalling motion as a result of chain torque. This is the exact same feature in play to reduce pedal-bob, but working in the opposite and undesirable way. Another problem with a lot of pedal kickback is that the tension forces being experienced by the chain are in

proportion to the amount of chain extension, and so can result in chains snapping far more than they should. This tends to often result in injury to the rider. Hence, once again, an optimisation has to be made between getting good pedalling efficiency, and reducing the pedal kickback that can interrupt the pedalling motion.

2.2.7. Axle Path

The path which the rear wheel follows is a very important factor to consider, not just from the chain stretch and pedal kickback points of view, but because it will totally control how the bike reacts to different riding styles. If the rear wheel hits a small square edge obstacle it will react very differently depending on the direction that the axle path follows when reacting to the force exerted on the wheel by the obstruction.

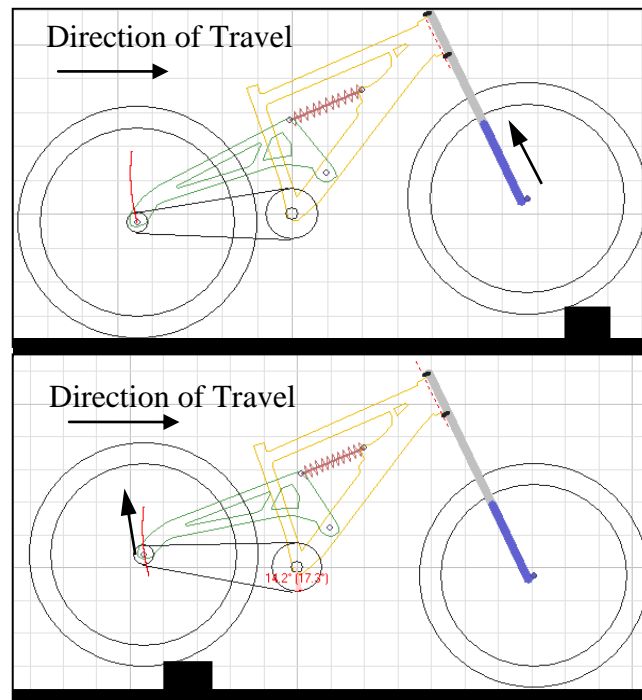


Figure 6 Backward Wheel Path Absorbing Small Square Edge Obstacle

The suspension will react best to this kind of obstacle if there is a backwards wheel path, as the travel will absorb the horizontal impact of the obstacle, due to the tangent of the wheel path, while compressing and allowing the rear wheel to get over it. Hence a backwards wheel path

results in a very smooth ride, and is desirable, as seen in Figure 6. However to make the whole axle path travel in a rearwards direction is unrealistic due to the high levels of chain stretch and pedal kickback that would be the result. Instead, giving the initial part of the wheel path this rearwards action results in a smooth ride over all but the roughest terrain. In order to keep the effective chainstay length within the desired boundaries, the axle path must become vertical, and even forwards towards the end of the travel. The end of the travel will normally be reached only when landing drops, and so a forwards wheel path is not considered detrimental, and in fact will give the bike a more ‘lively’ and manoeuvrable feel.

2.2.8. Brake Isolation

Most linkages are affected by brake induced suspension interference (BISI). This means that, under braking, a moment is created at the rear axle due to the braking forces applied to the rear wheel, which in turn creates a torque on the linkage which will cause either the shock to compress (brake-squat) or extend (brake-jack) depending on the geometry of the suspension. Both of these brake interference characteristics will affect how well the suspension will react to bumps.

Brake-jack is a very undesirable characteristic. Under heavy braking the front suspension forks of the bike will have already compressed to an extent, causing the front of the bike to ‘dive’. If the rear suspension then extends, the angle of the bike will pitch even further over the front wheel. The result of this is a loss of rear wheel traction under braking. This is obviously a very undesirable, and in extreme cases this could cause the rider to be ejected over the handlebars.

Brake-squat can, in moderate cases, be considered to be an advantageous feature. Since the rear suspension compresses slightly under braking it will match the front suspension characteristics and so keep the bike level and more predictable. This is especially advantageous with intense riding down steep, rough terrain when the rider will be trying to keep his/her weight as far back as possible for balance and control. However if a lot of compression is experienced under braking then the shock will not react as well to bumps in the terrain due to the position of the

axle on the axle path. The instantaneous leverage ratios and suspension unit characteristics, as mentioned previously, will also result in a linkage that is less reactive to bumps.

Yet again a compromise must be made between balancing the bike well under heavy braking, and having the suspension as active as possible to keep traction and improve the ride quality. Therefore a small amount of brake-squat is desirable in order to offer the rider a more stable riding platform whilst minimising the loss in suspension performance.

3. DESIGN OF NEW SUSPENSION LINKAGE

In order to achieve the best possible suspension characteristics without having to pay for use of a licensed patent, a new suspension linkage had to be developed. Firstly a new concept had to be conceived which would not infringe on current designs, hence the study of current design patents had to be carefully read and understood. The concept then had to be developed taking into account all the factors that can affect the suspension linkage performance as summarised in section 2.2.

3.1. Concepts of New Linkage Designs

It proved very difficult to design a new linkage that had desirable characteristics without infringing patents as there are a large number of both effective and redundant protected designs. However, after discussion with Banshee Bikes it was decided to explore concepts based on the virtual pivot point principle, due to the potential benefits offered by the polynomial axle path. The patent covering the VPP used by Santa Cruz and Intense cycles⁽¹¹⁾ is quite specific allowing for variation on the design without infringement, whilst still getting the beneficial suspension characteristics if designed correctly.

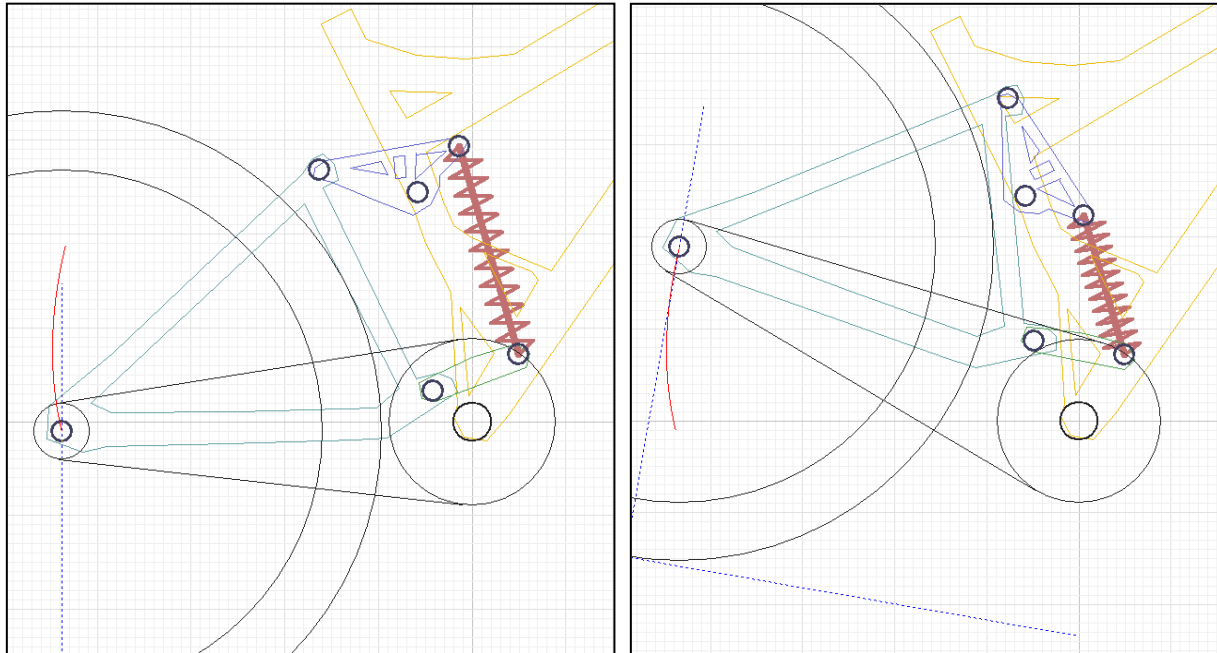


Figure 7 Diagram of Suspension Action of the Patented DW Link

The concept that was decided upon was an alternative geometrical arrangement of the linkages to give a virtual pivot point without copying the VPP design. A number of other designs have also attempted to achieve this without infringing the patent, such as the ‘DW link’⁽¹²⁾ (as seen in Figure 7). Therefore in order for a new design to compete with all the competition in the virtual pivot linkage market, the concept had to be developed to give better suspension and stiffness characteristics than the competitors. A greater competitive edge could be achieved by designing the new linkage for ease of maintenance and shock adjustment, as these are downfalls of the current designs.

3.2. Development of Concept

One of the initial concepts that was developed can be seen in Figure 8. After studying patents it was discovered that if the rear suspension unit was attached to the bottom link, and the links were arranged geometrically, as shown this design would not be infringing any other designs.

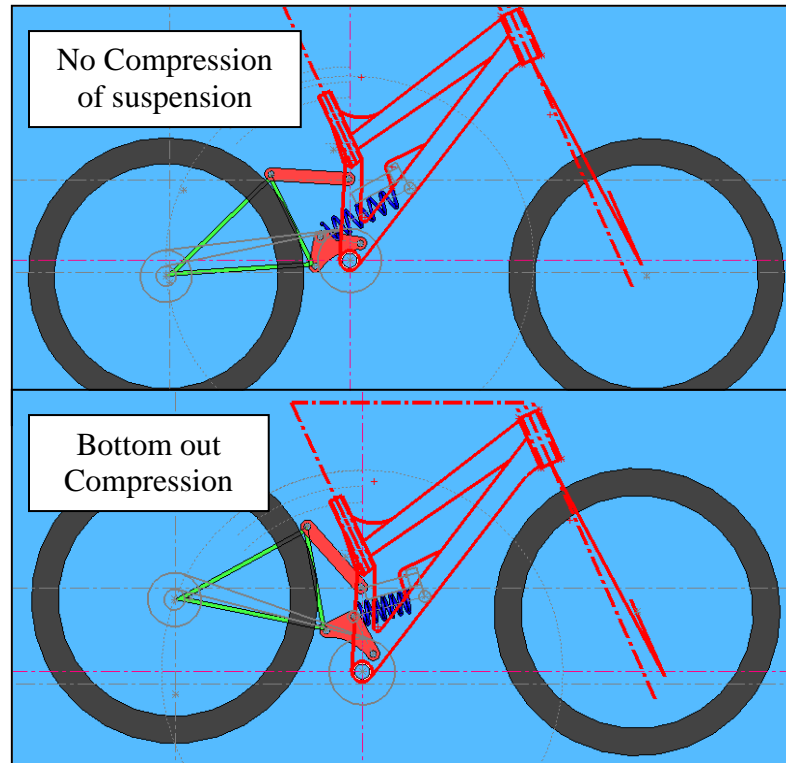


Figure 8 **Early Model of Developed Suspension Linkage**

This design was developed due to the lack of patent infringement problems, as well as the fact that it had several advantages over competitors designs. This will be discussed in section 3.4.

3.2.1. Compatibility with Components

Before the development of the concept properly began, decisions had to be made regarding components that the frame has to be compatible with. Firstly the type and size of the rear shock had to be decided. A new rear suspension unit from Manitou called the Revox⁽¹³⁾ has been developed using modern materials and manufacturing methods, as shown in Figure 9. When combined with the standard titanium spring, the weight of the shock is much less than that of their competitors for a given length shock. As a result of this, it was decided that improving the leverage ratio by using the largest suspension unit available in the Revox range was more beneficial than the weight saving that could otherwise be achieved by using a shorter stroke shock.

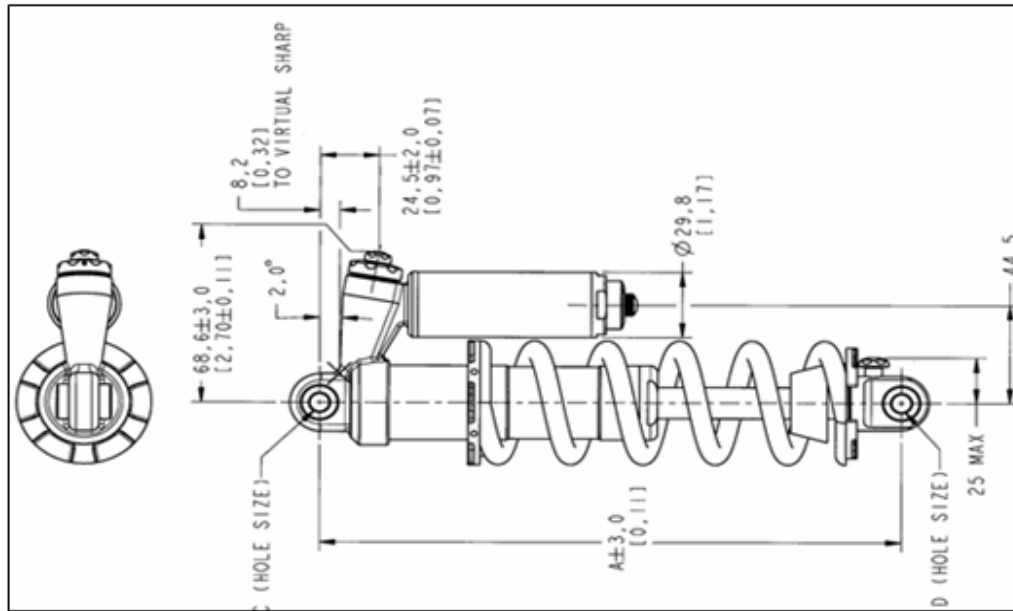


Figure 9 The New Revox Shock

Once the shock had been chosen it was possible to design, by reverse engineering, the rocker that will actuate it, based on the amount of travel desired of the frame, the shock mounting, and pivot positions, as well as stroke length of the shock. Other important compatibility issues that had to be considered throughout the design process include bottom bracket shell width and bearing dimensions, as there are industry standards for both of these.

3.2.2. Basic Geometrical Design of the Main Frame

The geometry of the front triangle, or mainframe, is very important in terms of both ride characteristics and ergonomics. By deciding factors such as desired head and seat angle, as well as stand over height and top tube length, the basic geometry of the mainframe can be developed. The geometry of the suspension linkage is complicated and was hard to develop. It is presented in detail in section 3.4. However the linkage must be considered when designing the front triangle to check compatibility with tyre clearance relative to the saddle and the seat tube. There is a well known example when tyre clearance of the saddle was overlooked: On the 2003 Santa Cruz V10 (as shown in Figure 10) if the saddle is positioned as low as it can go

(which is common for downhill riding), the rear tyre would hit the saddle when bottomed-out, resulting in sudden friction, causing braking, and potential injury.

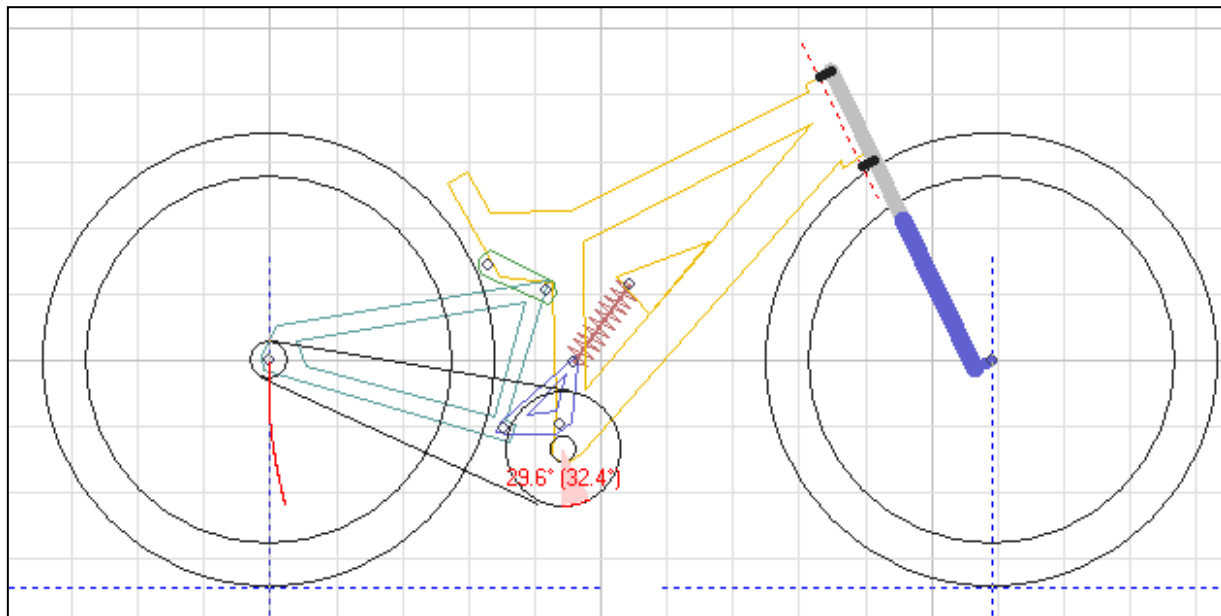


Figure 10 Santa Cruz 2003 V10 Bottoming-Out, Illustrating Tyre Clearance Issues

The mainframe concept also had to be designed around the positioning of the rear suspension unit and the linkage pivots to provide optimal strength to weight characteristics and compatibility with components, and offer clearance when considering the dimensions of the cranks and the predicted chain line.

3.3. CAD Modelling

Solidworks⁽¹⁴⁾ was used as a powerful computer-aided design tool to develop the whole frame including the linkage and geometry. The initial experimentation and optimisation to achieve the basics of a superior linkage were carried out with Solidworks using simple representations of linkages, as seen in Figure 11, before the geometry was imported into Linkage v2.5 for further optimisation and development as mentioned in section 3.4.

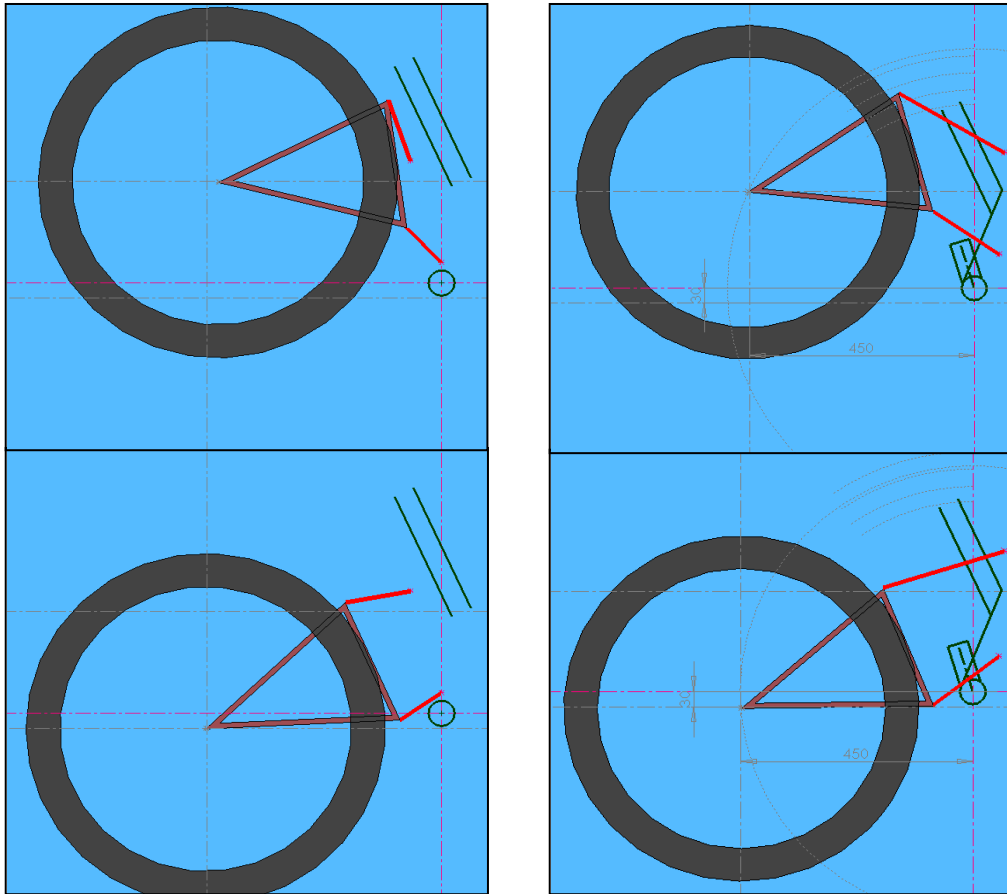


Figure 11 **Range of Movement of Early Concept Linkages**

Once the linkage had been finalised using Linkage v2.5, the geometry was exported back into Solidworks so that the compatibility, structural strength, and aesthetics of the design could be developed for the linkage plates and the mainframe.

3.4. Optimisation of Linkage Design

As previously mentioned, to optimise a suspension linkage a number of factors have to be considered before compromises have to be made to optimise the overall system. The nature of this new design made it possible to achieve superior characteristics over a more conventional design, whilst avoiding having to pay for use of patented designs. However compromises still had to be made.

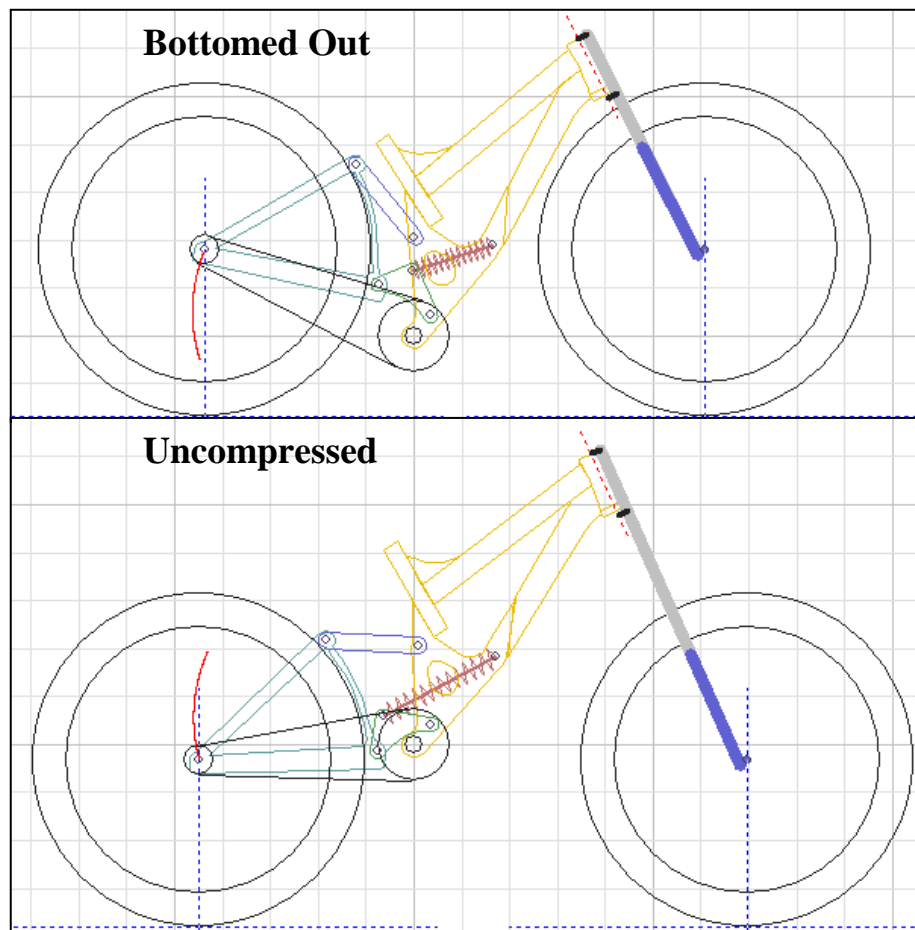


Figure 12 Final Frame Profile and Motion of Suspension Linkage

Linkage v2.5⁽¹⁵⁾ was used extensively for optimisation purposes after the initial development of the final linkage, as shown in Figure 12. This program allowed manipulation of pivot point positioning and linkage geometry whilst showing graphical analysis of eight performance factors such as axle path, chain extension and leverage ratio. A systematic iterative approach was applied by making changes to the linkage and studying how each characteristic was affected by the change. Although this was a time-consuming method, due to the large number of elements that could be altered, and the number of factors that would be effected by every minuscule change, no mathematical model could be developed for optimisation of the whole system in the time given. A system was developed by taking notes of how each characteristic was changed by every alteration made to the linkage. After a great deal of time and feedback from Banshee Bikes the geometry of the linkage was finalised with optimal suspension characteristics for the chosen market, as discussed in the following sections.

3.4.1. Centre of Gravity

When the initial linkage design was conceived, one of the key parameters was to have as low a centre of gravity as possible. This could be achieved by having the shock unit mounted low down in the frame. This was achieved by designing the mainframe of the bike to have a forged ‘shock basement’ which also doubled as a section of the downtube for the bike, as seen in Figure 13. This innovative design feature meant that it was possible to position the shock lower than any other virtual pivot linkage bike on the market. By lowering the mainframe shock mount to this low position not only lowered the centre of gravity, but also allowed for a more progressive leverage ratio.

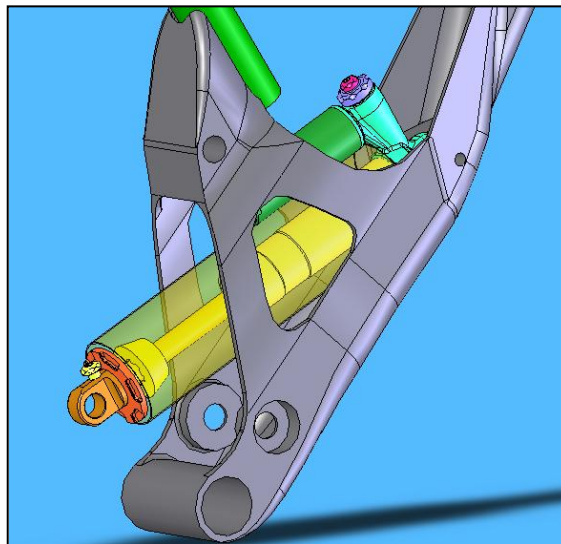


Figure 13 Model of Shock Basement with Revox Shock Mounted in Place

3.4.2. Leverage Ratio

The overall leverage ratio achieved in this design, due to the long stroke shock used, is lower than almost any other design on the market at 2.56:1, and so in turn puts less stress on the shock under bottom-out scenarios. Since having a low overall leverage ratio is one of the main concerns that customers have when buying frames, this very low ratio will help make the bike appeal to the market due to the improved suspension performance and the reduced risk of blowing shock seals.

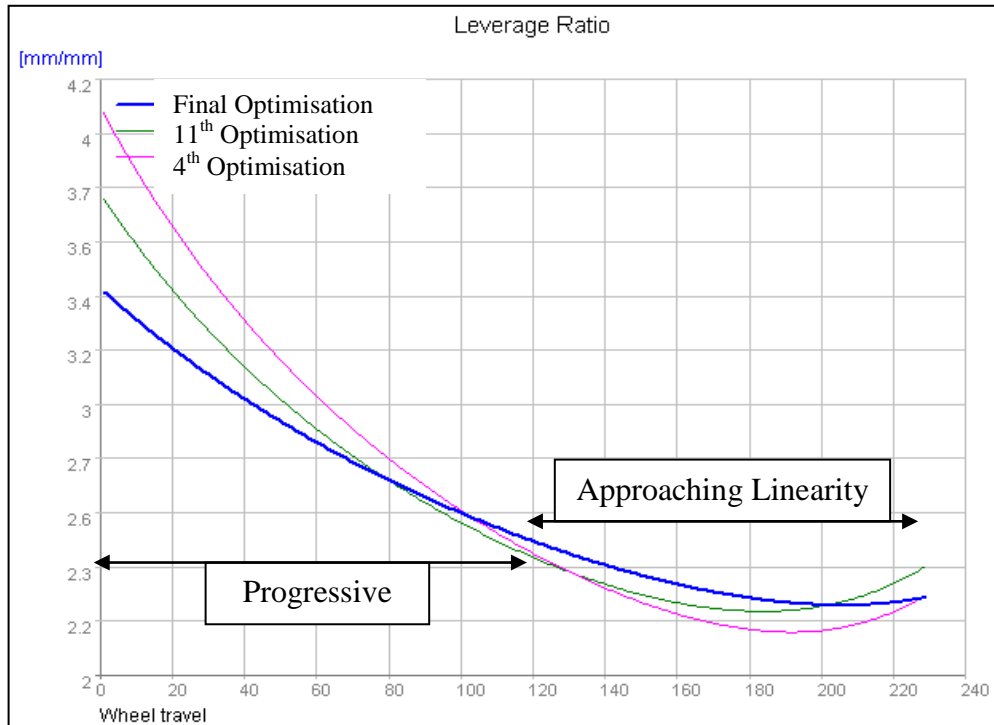


Figure 14 Graph Showing Leverage Ratios for 4th, 11th and Final Optimisation

The characteristics of the Revox shock were taken into account when the linkage was designed in order to create a smooth progressive nature to the travel. Since the Revox is designed to be progressive and to resist bottoming-out, the gradient of the leverage ratio was designed to start with a desirable progressive nature, but as the linkage moved through the travel the progressive nature of the shock would become more apparent, so the leverage ratio gradient no longer needed to be as steep. Hence the leverage ratio curves to a more linear shape at the end of the travel, as seen in Figure 14, in order to achieve a constant and gradual progressive nature to the suspension when taking into account the characteristics of the shock unit.

3.4.3. Chain Extension

Good pedalling efficiency was one of the priorities of the linkage design. Chain stretch was required in order to achieve this without relying heavily on platform valving of the suspension unit. A graph showing the chain extension of the designed frame as the suspension compresses compared with a market leader, the Santa Cruz V10 (as seen in Figure 4), is shown in Figure 15.

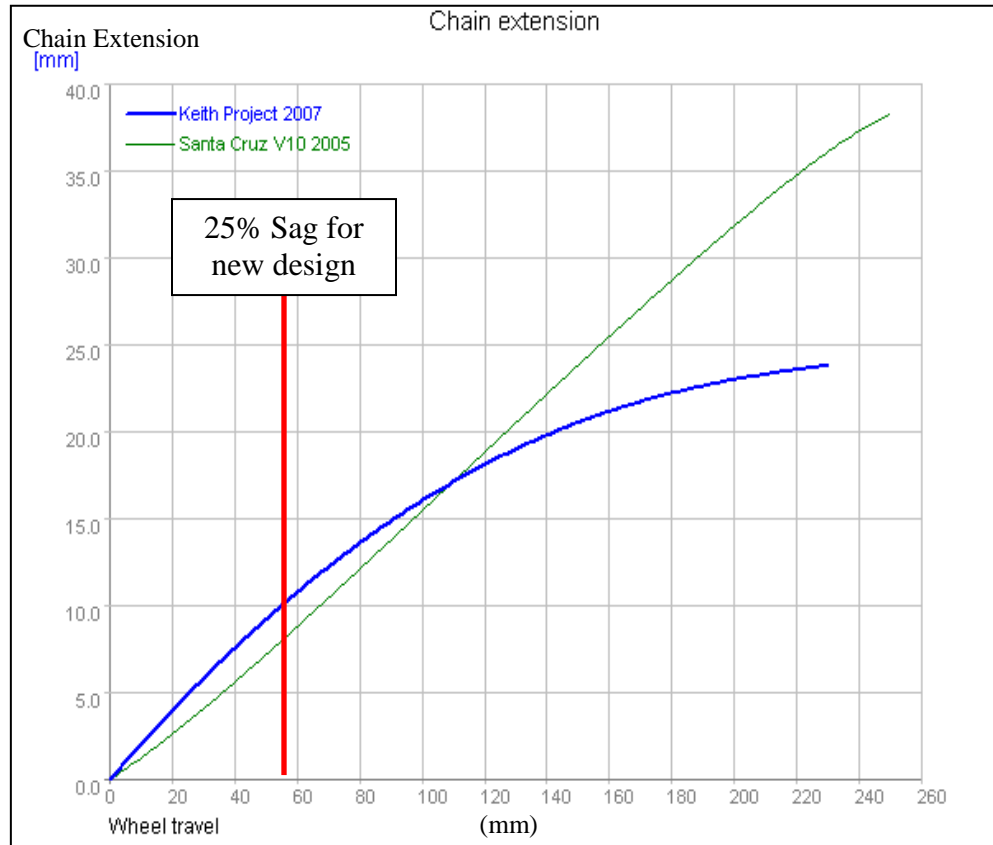


Figure 15 Chain Extension with Travel, Comparison of the New Linkage and V10

What must be considered is that the greater the maximum chainstay extension the more pedal kickback will be experienced over rough terrain. The linkage has been designed so that the maximum rate of chain stretch occurs at the start of the travel, and reduces as the suspension compresses. Under normal pedalling conditions the bike should be sitting at around 25% sag. It can be clearly seen in Figure 15, that at the sag point the gradient of chain extension with travel is steep, and so will counteract pedal-bob, resulting in more efficient pedalling and acceleration.

As the linkage moves towards the end of its travel the rate at which the chain stretches reduces. As it is not likely that the rider will be pedalling often when landing drops, or going over very rough terrain, the pedalling efficiency under these conditions is not considered important. Instead the focus changes to reducing the pedal kickback to maintain a smoother ride.

Therefore the linkage designed achieves optimal pedalling efficiency without having the negative effects on the ride quality due to a lot of pedal kickback.

3.4.4. Axle Path

The linkage has been designed to give an axle path with desirable characteristics as seen in Figure 16. For the first 40% of travel the wheel follows a backwards curve to give good small bump sensitivity and a smooth feel to the suspension. The path then curves into a forwards direction when small bump sensitivity is no longer as important to avoid excessive chain stretch issues that would result from maintaining the backwards path.

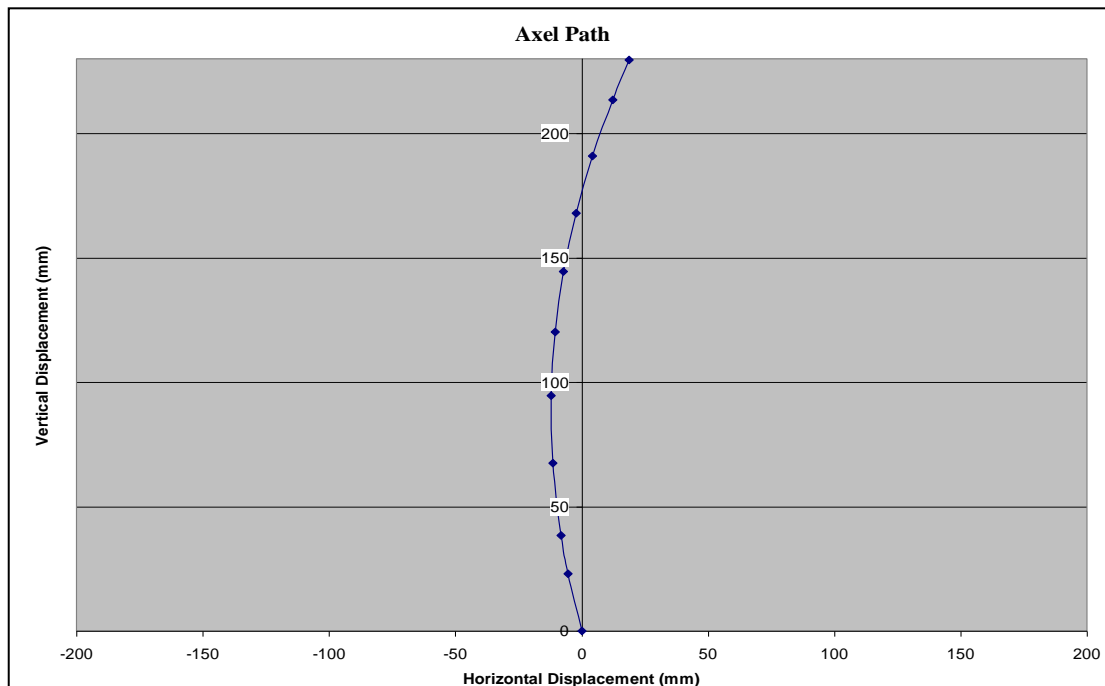


Figure 16 Graph Representing the Axle Path

This axle path represents an optimal compromise between that desired of a true downhill race bike and an extreme freeride bike and so will appeal to the majority of both markets.

3.4.5. Brake Isolation

The final linkage is designed so that when the rear brake is applied there will be a small amount of resultant brake-squat. This is done in order to balance the bike and reduce the likelihood of the rider being ejected over the handle bars as a result of the bike pitching forwards under heavy braking. However the brake-squat is minimal, and so the suspension will still remain very active and so offer more traction to the rear wheel under braking. This represents the optimal design for control, balance and braking power. The brake-squat apparent in this design is significantly less than other virtual pivot frame designs. This means that the suspension for the frame designed should be more active under braking, and as a result offer more traction to the rear wheel. This will enable the downhill racers riding this bike to brake later for obstacles which will in turn reduce the time taken to finish the course

3.4.6. Summary of Suspension Linkage

As can be seen in the previous sections, the suspension linkage designed during this project has resulted in a revolutionary concept. The linkage has desirable characteristics for all the factors that must be considered when designing a full-suspension mountain bike frame. Few, if any, other downhill race or extreme freeride bikes currently available in the worldwide market have overall suspension characteristics that can compete with the linkage design developed during this project, as discussed in section 6.1. When the linkage characteristics are combined with a long stroke, lightweight suspension unit placed low down in the frame, the result is a bike that will handle rough terrain, large jumps and vertical drops whilst being stable, lightweight and manoeuvrable. These characteristics are desirable in both the downhill race and extreme freeride markets.

4. MAINFRAME DETAILED DESIGN

Once the linkage had been designed to give the optimal suspension characteristics, the outline of the mainframe profile could be designed to have the ideal geometry for the rider as well as

giving the desired tyre clearance and compatibility of pivot and shock positions with mainframe features such as seat tube and bottom bracket.

4.1. Geometry

In order to give the final bike design desirable attributes such as wheel base, top tube and chainstay lengths for the three sizes, (as seen in Figure 17), the geometry of the rear linkage had to be considered since it had already been finalised. First and foremost the mainframe had to be designed so that there would be no contact between any part of the linkage or rear wheel and the frame. This was achieved by considering how the frame could be designed to be compatible with the shock and pivot locations. The seat tube had to be moved further forward than that of a conventional bike to avoid tyre clearance issues at bottom-out. To compensate for this positioning the angle of the seat tube was slackened to provide an ergonomic geometry for the rider when pedalling in a sitting position.

The table in Figure 17 shows the most important geometrical lengths and angles of the final frame design for the three sizes that will be manufactured. The dimensions have been chosen to give the rider the best comfort and performance in this sector of the sport by considering ergonomics, stability and manoeuvrability.

Frame Size	Small	Medium	Large
Effective Seat Tube	405mm	445mm	480mm
Effective Top Tube	564mm	578mm	598mm
Head Angle	66°	66°	66°
Seat Angle	60°	60°	60°
Bottom Bracket Height	380mm	380mm	380mm
Rear Wheel Travel	230mm	230mm	230mm
Chainstay Length	450mm	450mm	450mm
Wheelbase Length	1140mm	1165mm	1190mm
Stand Over Height	740mm	770mm	800mm

Figure 17 Table of Geometrical Lengths and Angles

4.2. Compatibility with Linkage

As mentioned in Section 3.4.1 the novel concept of creating a shock basement within the effective downtube of the bike. However, this cold-formed section of the frame also allows for

compatibility between the rear linkage and the front triangle by encompassing both the mainframe pivots and the shock mount as seen in Figure 18.

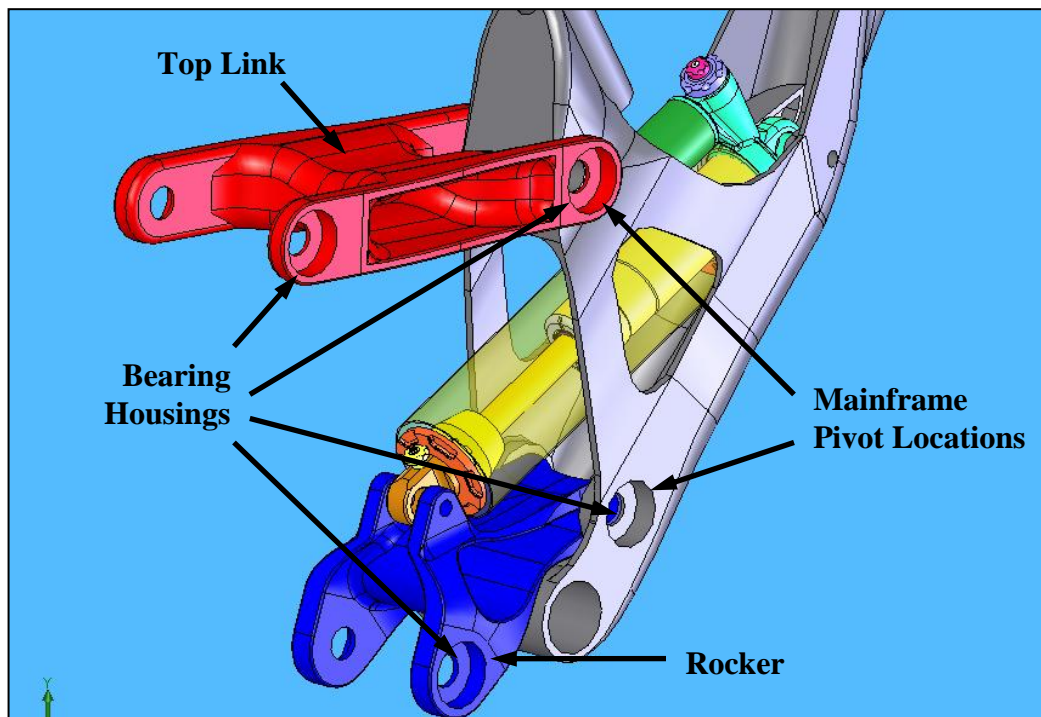


Figure 18 Shock Basement Incorporating Shock Mount and Mainframe Pivots

The clearance between the linkage plates, the suspension unit and the mainframe have been checked to ensure that there are no interference issues at any point in the rear wheel travel. The shock basement has also been designed for ease of removal of the suspension unit for maintenance and adjustability purposes, as seen in Figure 19. In many current designs the removal of at least one section of the linkage is necessary in order to remove the shock. The final design of this project permits the removal of the Revox without the need to dismantle the linkage. This aspect of the design will appeal to riders who like to tune their rear shock for different riding conditions and race courses.

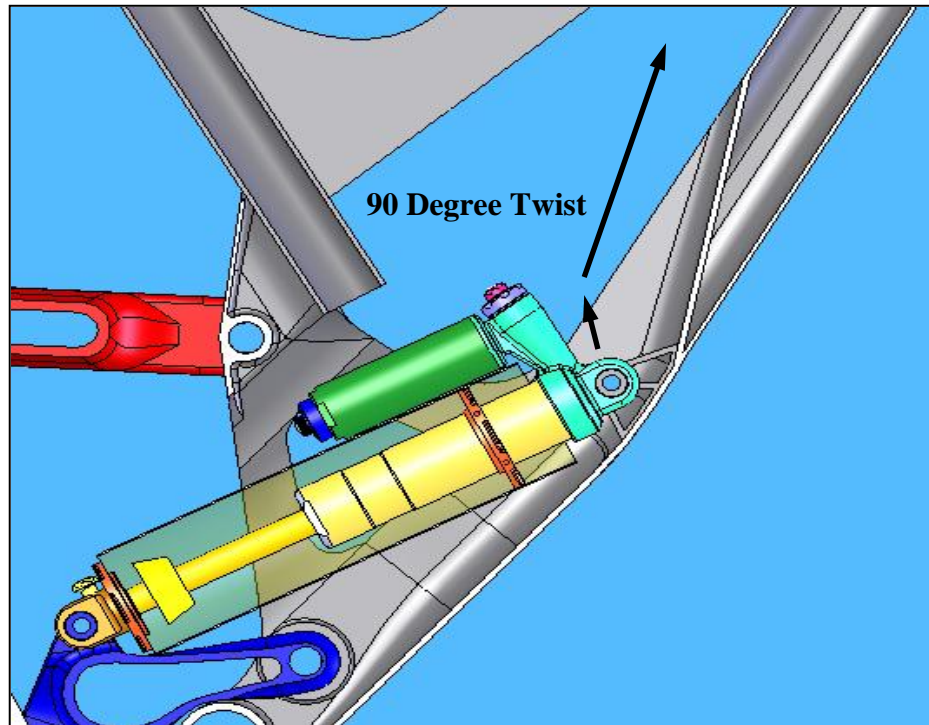


Figure 19 Cross Section Showing Path of Shock Removal

4.3. Bearing Compatibility

Using the same bearing type and size at every pivot simplifies maintenance and reduces costs as a result of bulk ordering. After much discussion with bearing experts from different bearing suppliers it was decided to use the 6002V-2RS full-complement deep groove bearing with labyrinth inner ring and dual-lip seal lubricated with Teflon grease. This choice was made after dimension, loading and maintenance considerations. At every pivot in the linkage the bearings are mounted as wide apart as possible, as seen in Figure 18. This reduces the potential axial loading on each bearing by increasing the distance between them, and increasing the lateral stiffness of the linkage for any sideways loading on the rear wheel. This should result in a longer bearing life and so requires less maintenance, and when the bearings do need replaced they will be easily accessible. The high lateral stiffness will result in a more responsive feel to the bike and will be most apparent when high speed cornering during which the sideways loadings are highest.

4.4. Increased Strength

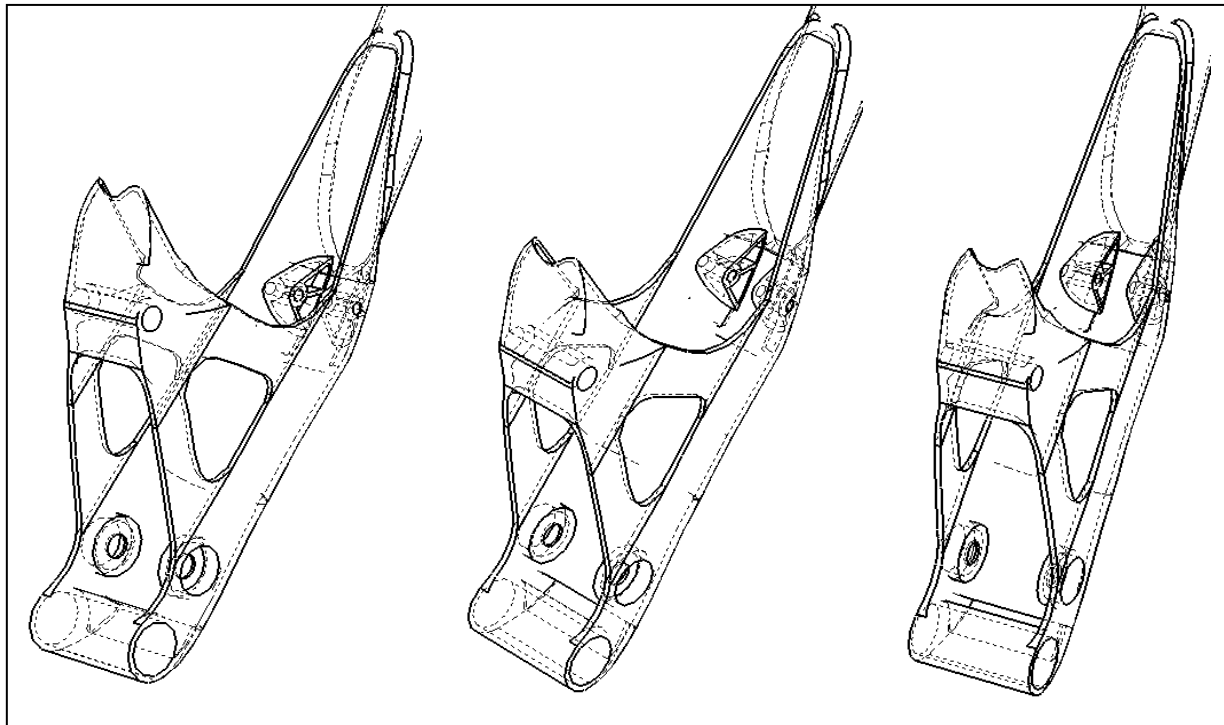


Figure 20 Different Drawing Views of the Shock Basement

The most common failure mode for full-suspension bikes tends to be cracking and eventual snapping of welds between rear suspension pivots. This is due to the very high forces transmitted through the pivots, (forces of 10kN are not uncommon between linkage pivots), and the fact that welds are not as strong as the material that is welded. As well as the high tensional or compressive forces that might be present, as the rider lands drops, or jumps slightly sideways, large torsional forces will be transmitted through the linkage. In order to combat this problem, all the linkage attachment points are connected to one section of the mainframe, the one piece cold-formed shock basement, as seen in Figure 20. This means that there are no welds present between any of the pivot points. This results in a stronger chassis with the desired stiffness characteristics.

4.5. Reduced Weight

Once again the shock basement concept results in reduced weight due to the increased stiffness and strength offered by this design. In order for another design to achieve the geometrical arrangement of the linkage interface it would have to consist of more than one part. For several smaller sections to attain the same strength and stiffness characteristics of the shock basement more material would have to be used in order to ensure that the weld interface areas were large enough to withstand the forces that would be transmitted through the structure. Since the shock basement requires less material it will have reduced the weight in comparison with alternative designs. This results in a lighter and more manoeuvrable bike.

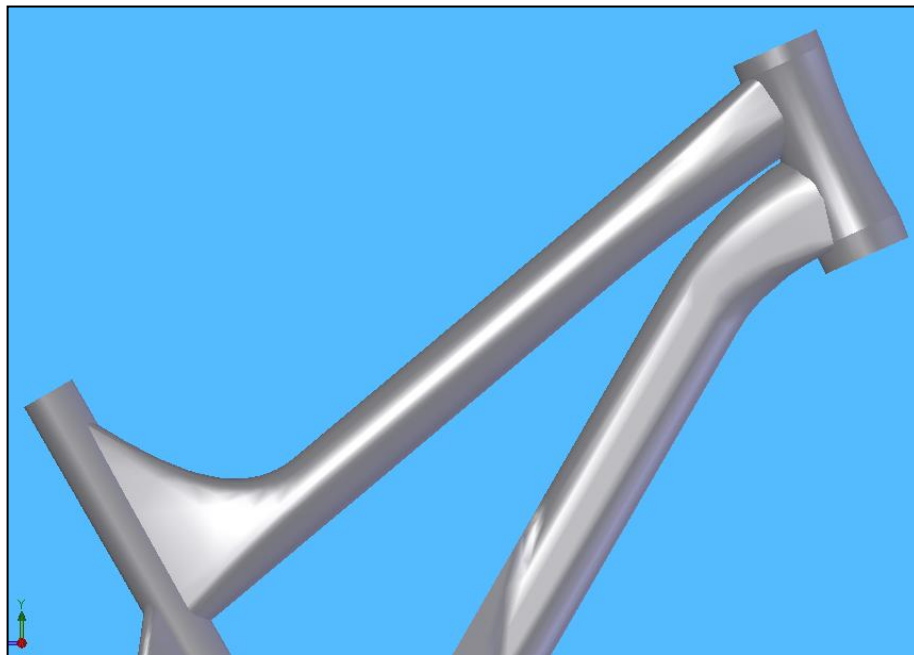


Figure 21 Hydroformed Top Tube and Downtube for Reduced Weight

The top tube and downtube of the design will be hydroformed, as seen in Figure 21, to achieve better interface strength characteristics with the head tube, seat tube and shock basement, whilst reducing the weight that would be incurred by having gussets to achieve the same performance. This process is already used by Banshee, and so will help the aesthetics of the design fit into the current Banshee product line up, as well as improving the performance of the design.

4.6. Aesthetics

The aesthetics of the mainframe design are very important to ensure the product appeals to customers. Consumers generally want smooth, flowing shapes and curves, combined with clean lines. This was achieved by using the desired geometry as a foundation for developing different profile design ideas and then combining the best looking designs to create the final mainframe profile as seen in Figure 22.

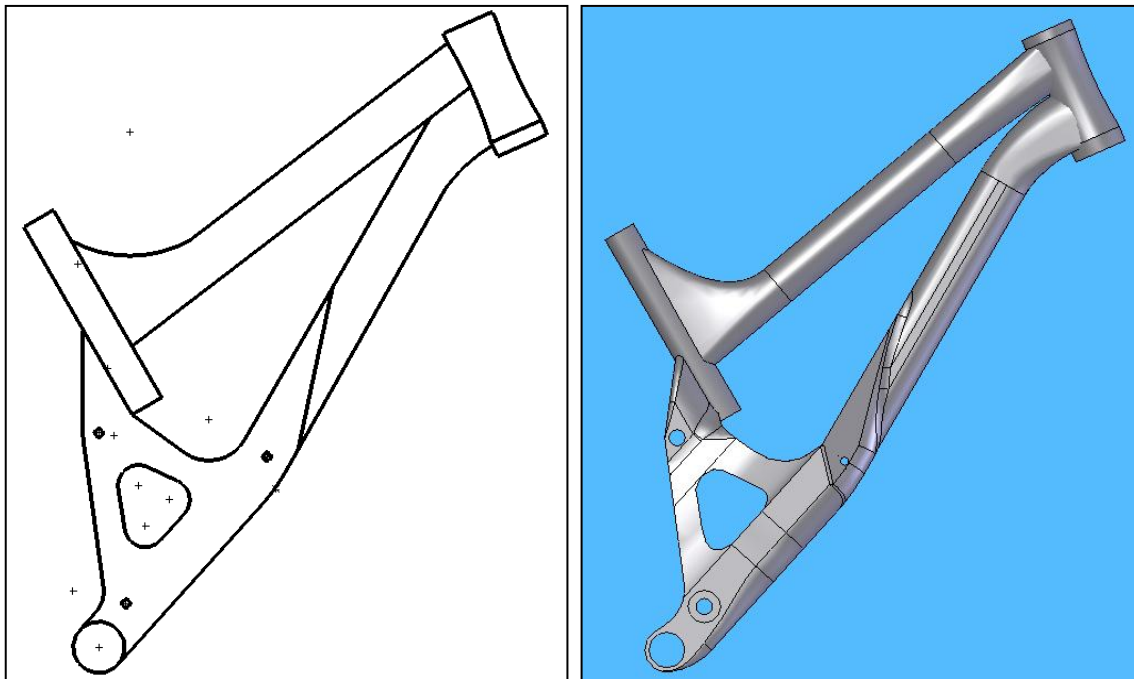


Figure 22 Profile of Concept Drawing and Profile of Final Model

5. DETAILED DESIGN

In order to ensure that the final model would have the strength characteristics necessary to withstand aggressive riding further testing had to be carried out on the frame. This testing was focused on the parts of the bike that would be subject to the highest loadings. The vicinity around which the top tube and down tube interface with the head tube is one such high loading area. However, as this bike will be using concepts very similar to existing designs in this region, it is not necessary to prove that the strength characteristics are acceptable. Extensive testing has already been carried out to ensure this.

To ensure the strength of the design, the substantial forces that the area around the interface between the mainframe and the rear suspension linkage are subjected to require the use of Finite Element Analysis (FEA). FEA is an invaluable tool to allow an increase in the rate, and reduce the costs of product development. This is due to the lack of time and resources used to build and test numerous prototypes. FEA also enables the designer to reduce the volume of material used by removing material from areas of low stress, and hence reduce the weight and material costs of the final products.

5.1. Forces Acting on Linkage

In order to test that the design will withstand the forces applied to it during aggressive riding, first the magnitudes and directions of the forces acting on the linkage had to be calculated. In order to carry out these calculations first a decision had to be made as to what magnitude the vertical loading acting upwards on the rear axle would be. Since Banshee believe in making some of the strongest bikes in the world and offer 10 year frame warranties on all their freeride bikes, instead of calculating the force that might be applied to the axle when landing a drop, it was decided that instead a biomechanical approach should be taken. The legs of an average human male ⁽¹⁶⁾ can withstand a force of approximately 4kN before either the bone breaks or there is a soft tissue failure. During extreme riding the forces experienced by the body are likely to be only about half the magnitude of the loading that may cause injury. Therefore the worst case loading scenario for the suspension linkage was taken to be a force of approximately 2kN acting purely through the back wheel. This produced the linkage and pivot loadings seen in Figure 23. These forces could then be used to carry out FEA on the linkage assembly.

A Von Mises factor of safety in excess of 4 is desirable for the frame components. This high factor of safety should ensure that the frame will not fail before the body of the rider. Although this might seem like overkill, it should ensure that failure of the frame will not occur and hence Banshee Bikes should not have to face very expensive law suites for catastrophic frame failure causing injury to the customer.

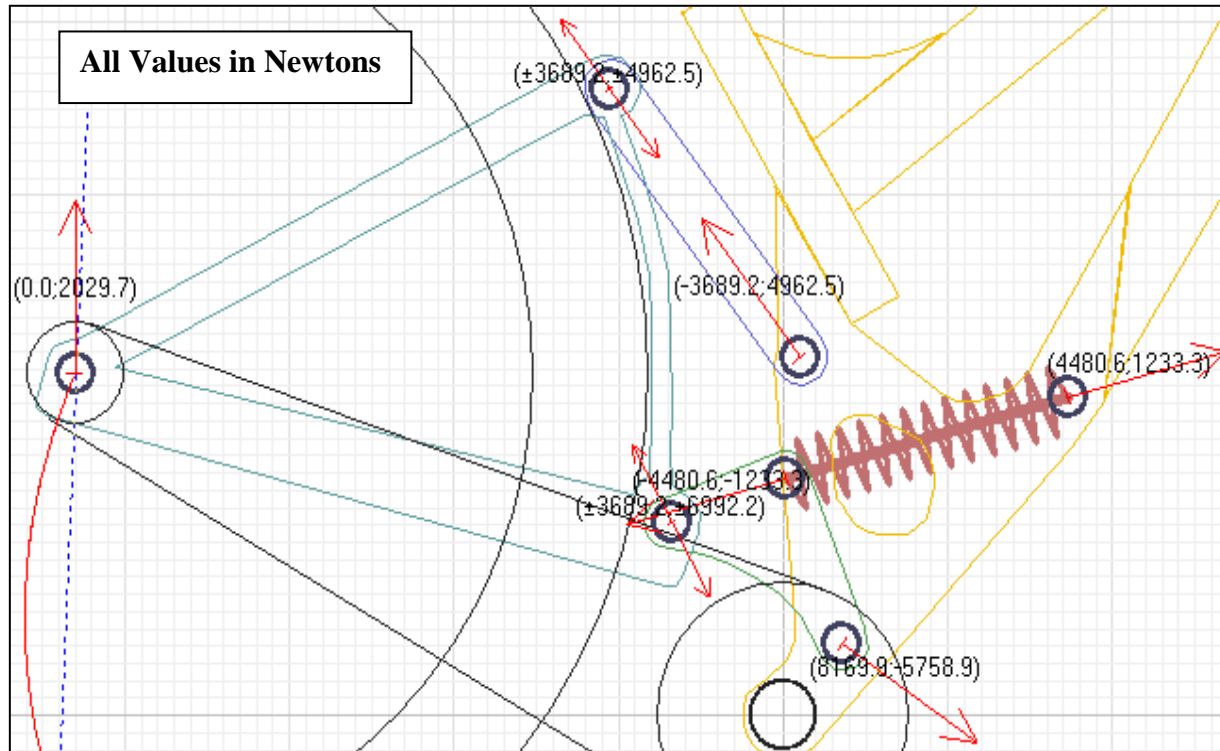


Figure 23 Forces Applied to Linkage under Worse Case Loading Scenario

5.2. Finite Element Method

In order to model the physical properties and reactions of a continuous body accurately, the body must be represented by a number of nodes that are linked to form an interlocking mesh of finite elements or cells. Individual cells can have different geometries in order to best replicate the continuous body that the mesh represents. A dense mesh will result in more accurate results than a mesh consisting of larger cells of the similar properties; however more computational time will be required to calculate the mesh attributes. Whereas a two-dimensional body can be represented by a number of triangular or quadrilateral cells (or plates), solid three-dimensional models can be represented by a solid mesh of tetrahedral or hexahedral bricks. Each finite element may also have nodes mid span between the corner nodes. These higher order elements will increase the accuracy of the results in much the same way as increasing the mesh density, and will also represent geometries with curvature more accurately than the same number of basic elements without mid span nodes. Typical arrangements of mesh plates and bricks can be seen in Figure 24.

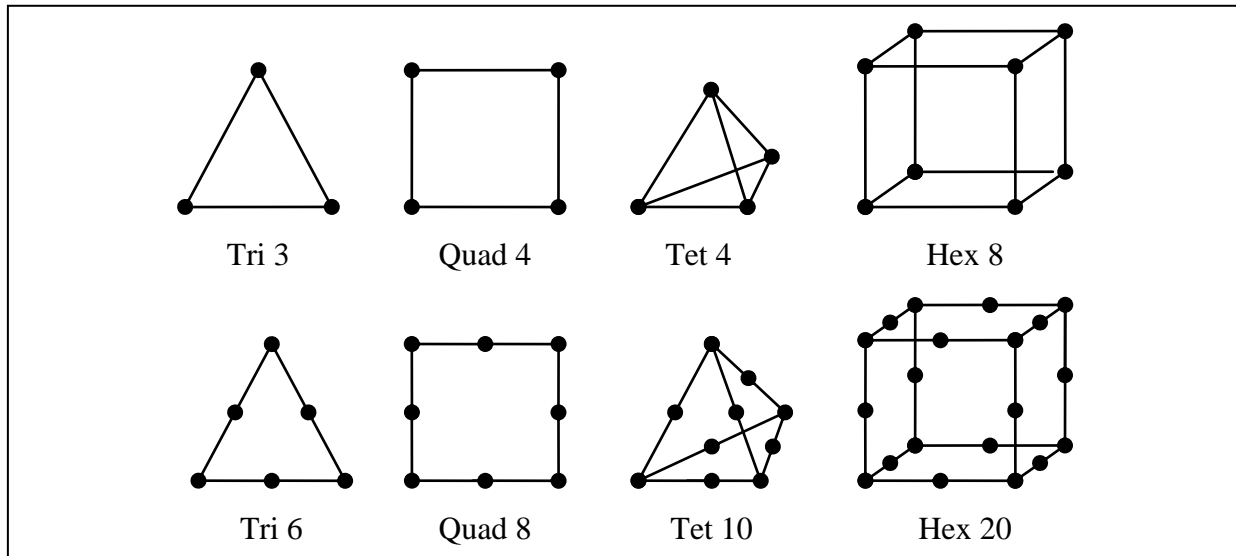


Figure 24 Common 2D Plate and 3D Brick Finite Element Geometries

A stiffness matrix can be calculated for every finite element due to the assumption that the elements react in a similar manner to forces for their given shape functions. The properties of the material (in this case aluminium, a homogeneous linear elastic material), are then taken into account to calculate the nodal displacement as a result of the equivalent force acting on each individual node. By performing these calculations on the mesh, the computer algorithm can accurately predict the reaction of the continuous body to the boundary conditions of applied forces and constraints.

5.3. Finite Element Analysis

The Solidworks® models were converted into the initial graphics exchange specification format (.igs), so they could be imported directly into Strand7⁽¹⁷⁾. This would ensure three-dimensional geometric consistency with the design and would, as a result, produce more accurate FEA results. The boundary conditions for the worst case loading scenario can then be applied. To restrain a face the vertices at the extents of that face would be either fixed, or restrained in a suitable way.

The model had to be altered slightly to represent the loading forces that would be applied through the pivot bearings and bottom bracket shell accurately. The volume that would be filled with each bearing was represented by a ring of solid material, and then a semi cylindrical section of material was added to the internal diameter. The orientation of this section of material meant that a face pressure could be applied normally to a flat surface resulting in a force on the bearing with the same magnitude and direction as seen previously in Figure 23. Similar alterations were made to the shock mounts and bottom bracket of the models, as seen in Figure 25. The value of the pressure that had to be applied at each loading point was calculated by dividing the force to be applied at each location by the area of the matching flat face. Loading the model in such a way resulted in a more realistic local distribution of stresses around the pivot, bottom bracket and shock mount locations.

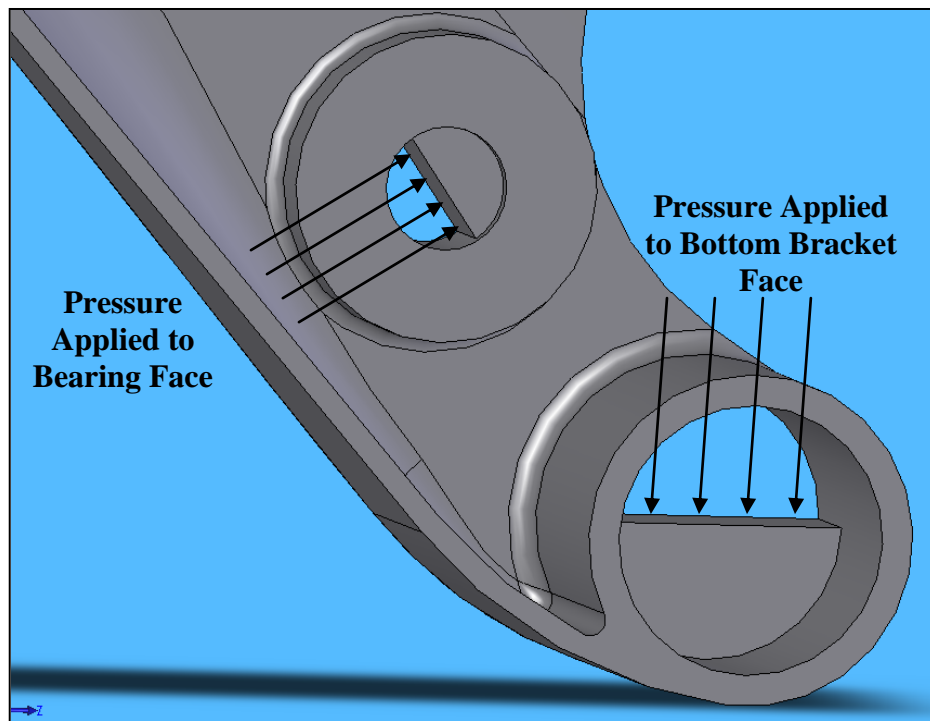


Figure 25 Representation of Pivot and Bottom Bracket Loadings by Face Pressure

Once the loads had been applied, the model a surface mesh had to be generated. For the surface mesh quad8 plates were used for increased accuracy of results and curvature profiles. Once the surface mesh was complete the models were then solid meshed. The solid mesh used the nodes of the surface mesh to generate a mesh of tet4 elements to complete the continuous body representation.

5.3.1. Accuracy

By increasing the number of nodes, and hence the density of the mesh, greater accuracy can be achieved. However the time taken to solve a finite element model is proportional to somewhere in the region of the number of elements cubed. Therefore very accurate results are possible, but at the expense of time. Since the main aim during the early stages was to attempt to reduce stress concentrations and make sure the basis of the structure was strong enough, very high accuracy is not as important. As the design became optimised to the point where it was considered to be potentially the final design, a denser, and hence more time-consuming, mesh was used to ensure the design was capable of withstanding the loads that would be applied to it.

The way in which the mesh density was controlled was by varying the maximum length of an element edge as a percentage length of the whole body, and choosing the ratio between maximum and minimum edge lengths for an individual element for the surface mesh. By manipulation of these values the number of nodes could be decreased significantly whilst still having a reasonably dense mesh at points of tight curvature where stress concentrations are expected to be located.

Initially the maximum length of an element edge as a percentage length of the whole body was set to 3% for concept development stages and reduced to 1% for the final models. For a 3% mesh the linear static solution for the shock basement took approximately 4 minutes to complete. This is an acceptable length of time to wait, and meant that the whole process including setting up the model with boundary conditions and carrying out the meshing could be done in approximately 20 minutes. The rate of analysis allowed for rapid development of the design to sufficiently withstand the loading. When the mesh density was increased to a 1% mesh the same solution took almost 9 hours to calculate. Although the calculated results were of higher accuracy, the time taken resulted in a massive reduction in the rate of progress.

5.4. Results

The properties of the material from which the frame is to be constructed must be known in order to calculate the linear static FEA solution. The table in Figure 26 shows the important material properties for 7005-T6 Aluminium alloy, the metal selected for the frame build. This material was selected due to the strength to weight properties and the ease by which it can be cold-formed and welded, and by the fact it is widely used already in the bike industry.

Physical Property	
Density	2780 Kg/m ³
Modulus of Elasticity	72 GPa
Tensile Strength, Ultimate	350 Mpa
Tensile Strength, Yield	290 Mpa
Fatigue Strength	350 Mpa
Poisson's Ratio	0.33

Figure 26 Properties of Aluminium 7005-T6

In reality, the property of the material in the final parts is likely to be slightly stronger than listed above due to the effect of the cold-forming processes that will be used to manufacture them. However to be cautious the values shown in Figure 26 will be used.

The results of the FEA showed the stress, strain and displacement characteristics of the tested structures, and showed the results in the form of colour contours. This means that the results could be easily interpreted. The lowest values of the desired reaction of the material are shown in a dark blue colour and the highest in bright pink, as seen in Figure 27. The FEA of the design is shown, and discussed in detail in section 6.2.

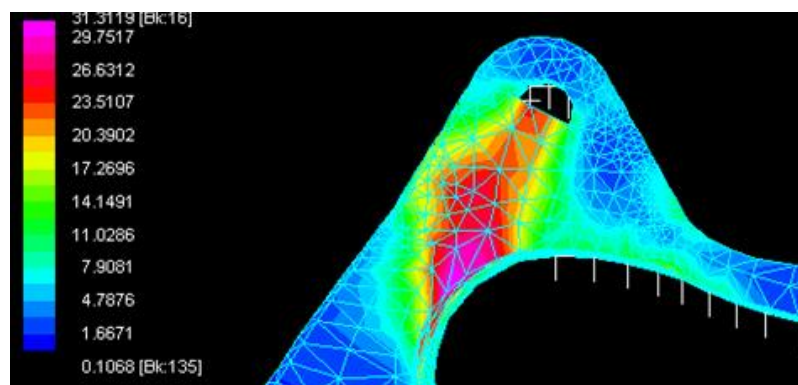


Figure 27 Colour Contours Representing Stress Concentration

6. DISCUSSION

6.1. Comparison of Linkage Design with Competitors

Making a comparison between specific factors of the final linkage design and the suspension linkages of competitors is simple, however this does not prove that one design is necessarily better than the other. The problem with making general evaluations of rear suspension linkages is that there is no one characteristic that is more important than any other. When a rider is buying a bike, his/her choice is generally governed by how the bike ‘feels’ when ridden. Every customer is an individual and so will have individual preferences. It is therefore impossible to make a bike that everyone will want to buy. Some people like single pivot designs, and some like multi-pivot designs; some choose to pay less for a more common bike; some are willing to pay more for a rare or specialist bike. However there are a few critical factors that are always considered beneficial to a rear suspension linkage design. This section will compare these linkage characteristics with three of the top selling, and most highly regarded frames, with similar amounts of travel currently available on the market. The three bikes that will be compared to the linkage developed in this project are:

- The Intense M3⁽¹¹⁾, top of the line downhill race bike with a VPP linkage
- Iron Horse Sunday⁽¹⁸⁾, leading downhill race bike using DW Link⁽¹²⁾.
- Specialized Demo 9⁽¹⁾, one of the most popular high end extreme freeride bikes using a 4 bar Horst Linkage.

6.1.1. Leverage Ratio

The leverage ratio of a frame is one of the first features that customers will look at. A comparison of the leverage ratios of the new linkage design against the three biggest competitors is shown in Figure 28. A low leverage ratio is always considered beneficial by the rider. The lower the leverage ratio is, the less likelihood of the shock seals failing under heavy bottom-out conditions. By reducing the leverage ratio the suspension will also feel smoother, and will have better damping due to the lower forces on the damping valves. However the

leverage ratio is always limited by the large rear suspension unit required, and the weight associated with the longer shock. These problems have been solved by using the new lightweight Revox shock with titanium spring, and designing the shock basement to fit the longer shock.

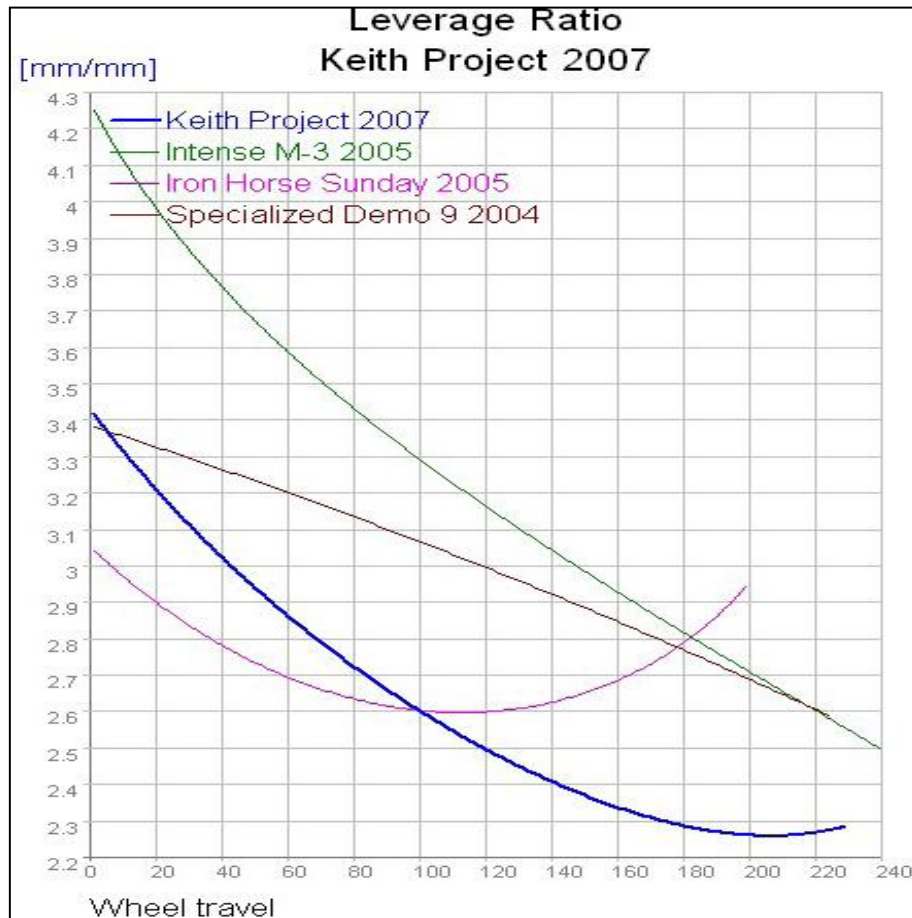


Figure 28 Leverage Ratio Comparison

As can be seen in Figure 28 the overall leverage ratio of the design is lower than all the competitors. It also shows that as the suspension compresses the leverage ratio reduces to give the suspension a progressive nature. This is unlike the Iron Horse Sunday, which becomes regressive towards the end of the travel, increasing the likelihood of bottoming-out. The higher leverage ratio at the start of the travel allows the suspension to have increased sensitivity over small bumps when cruising, and will result in better rear wheel traction and tracking as well as a smoother ride.

6.1.2. Chain Stretch

The shape of the axle path is apparent when comparing the amount of chain stretch and resulting pedal kickback as seen in Figure 29. Here the horst link of the Demo 9 becomes most apparent, as it experiences significantly less chain stretch than the other linkages. However the linkage designed during this project shows steep gradient of chain stretch roughly matching those of the two downhill race bikes. This will result in the bike's ability to accelerate faster than the demo 9 due to the increased pedalling efficiency by reduction of pedal-bob.

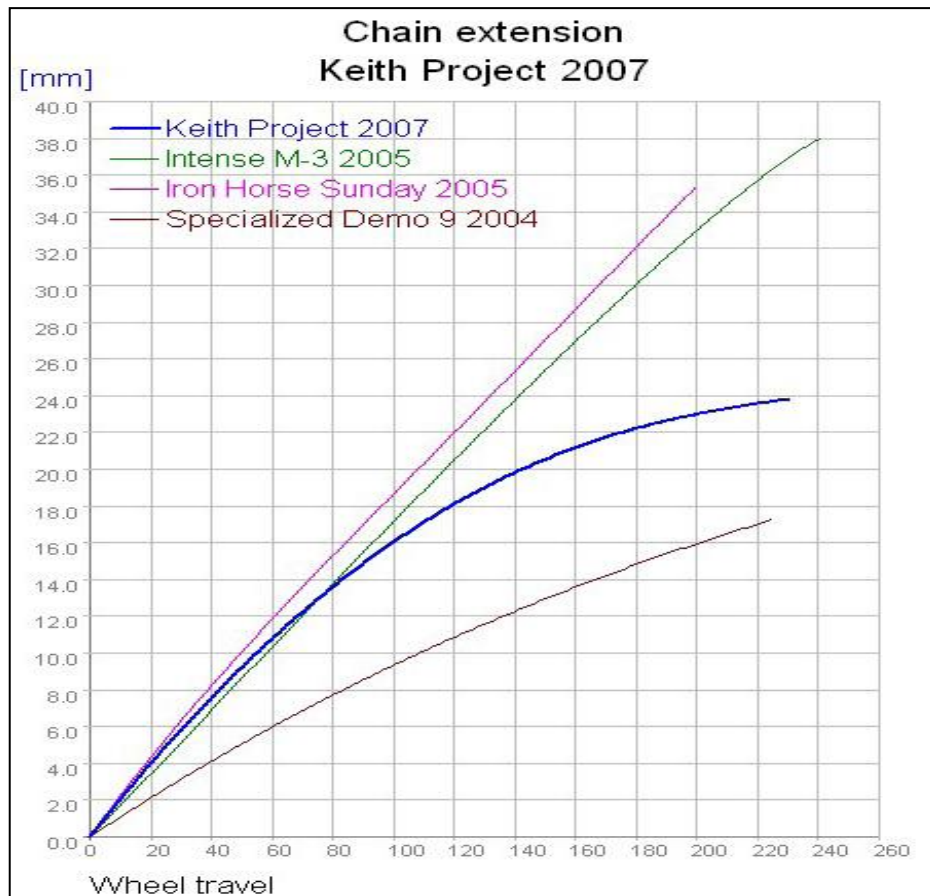


Figure 29 Comparison of Chain Stretch

Half way through the travel of the new linkage design the gradient of the graph starts to reduce. This results in the chain stretch at bottom-out being approximately 33% less than the two downhill race bikes. Since pedal kickback is proportional to chain stretch, a reduction in chain stretch not only puts less stress on the chain and gears, but also results in a smoother pedalling motion over large bumps due to a reduction of kickback.

6.1.3. Axle Path

Whereas downhill race bikes tend to have more rearward axle path than extreme freeride bikes, the difference between the two is not normally very great. Figure 30 shows that the linkage designed for this project has an axle path that lies between that of the Demo 9 and the M3. This means that the bike can compete strongly in both markets. The rearward wheel path at the start of the travel will result in very good small square edge bump sensitivity at high speeds, and give the bike a very stable feel.

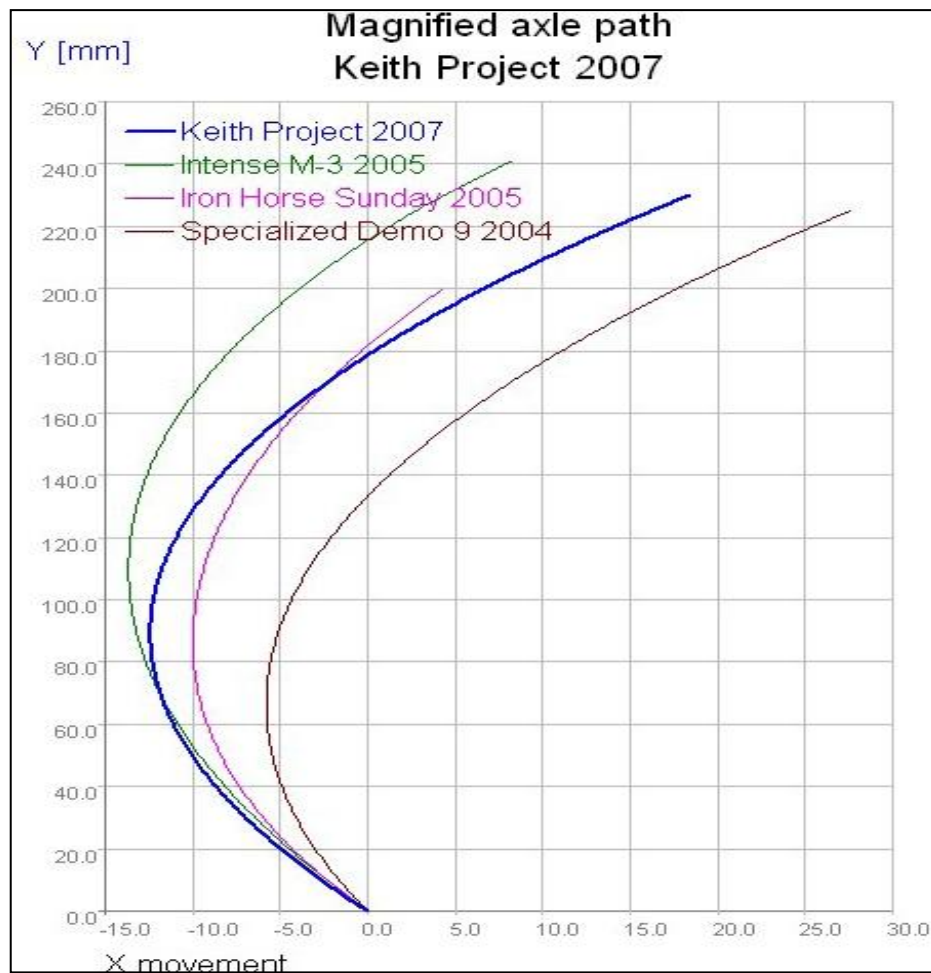


Figure 30 Comparison of Axle Paths

As the suspension linkage compresses towards the end of the travel, the axle path arcs to a forwards path. This forward path increases the manoeuvrability whilst reducing the chain stretch and pedal kickback for this sector of the travel.

6.2. Design Optimisation of Cold-Formed Parts

Finite element analysis was used extensively to optimise and develop the shock basement, rocker and top link models. The FEA helped ensure that the components were strong enough to withstand the loadings that they would be subject to during aggressive riding, as shown in Figure 23, whilst reducing the weight to make the design more competitive in the market.

6.2.1. Top Link

The most geometrically basic part to be tested was the top link of the suspension linkage. Boundary conditions, such as face pressures, vertex loading and restraints, were applied to the model in Strand7 as shown in Figure 31. These Boundary conditions represented the worst-case loading scenario for when the bike bottoms-out heavily with an extra lateral loading on the rear wheel.

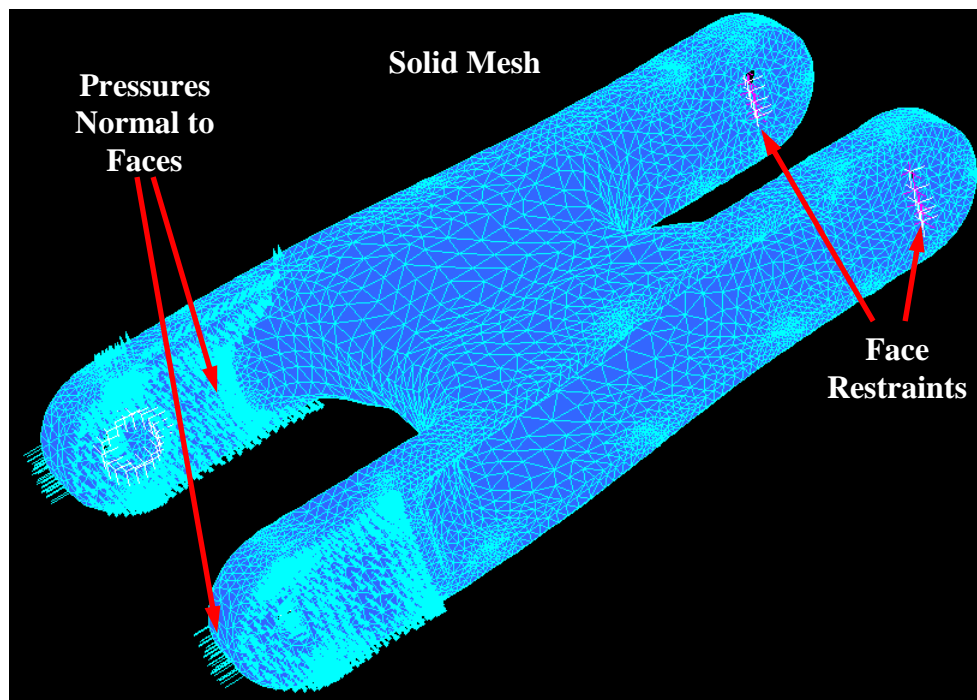


Figure 31 Solid Mesh of Top Link showing Applied Boundary Conditions

The stress concentrations under this loading scenario are clearly visible in Figure 32. The maximum stress apparent under these conditions was 57.5MPa which gives an acceptable Von

Mises factor of safety of 5. During the optimisation the weight of the part was reduced from 587g to 457g a weight saving of 22% from the initial concept.

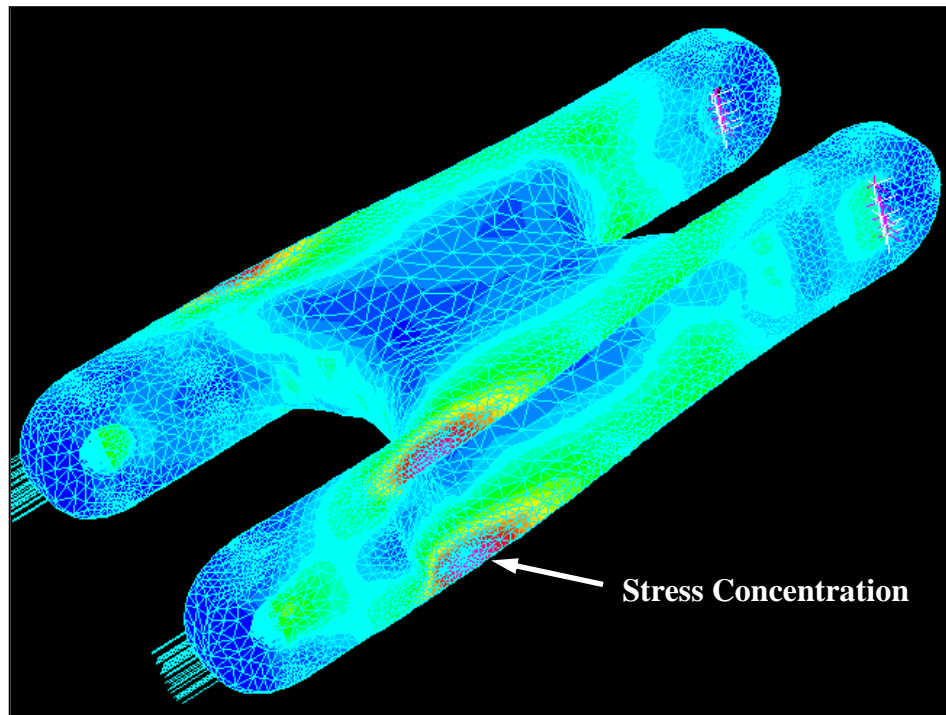


Figure 32 **Contours showing Stress Concentrations in Top Link**

6.2.2. Shock Basement

Since the concept of using a shock basement of this form is new to the industry, extensive FEA testing had to be carried out to ensure that the design would show the desired strength and stiffness characteristics when subjected to realistic worst-case loading scenarios.

Figure 33 shows that the maximum deflection expected from the model is acceptable at only 0.2mm. The maximum stress concentration shown was 106MPa, which is significantly less than the yield strength of the material (290MPa). However in order to get the desired factor of safety of at least 4 using this material, a redesign was required to reduce the maximum stress to below 72.5MPa.

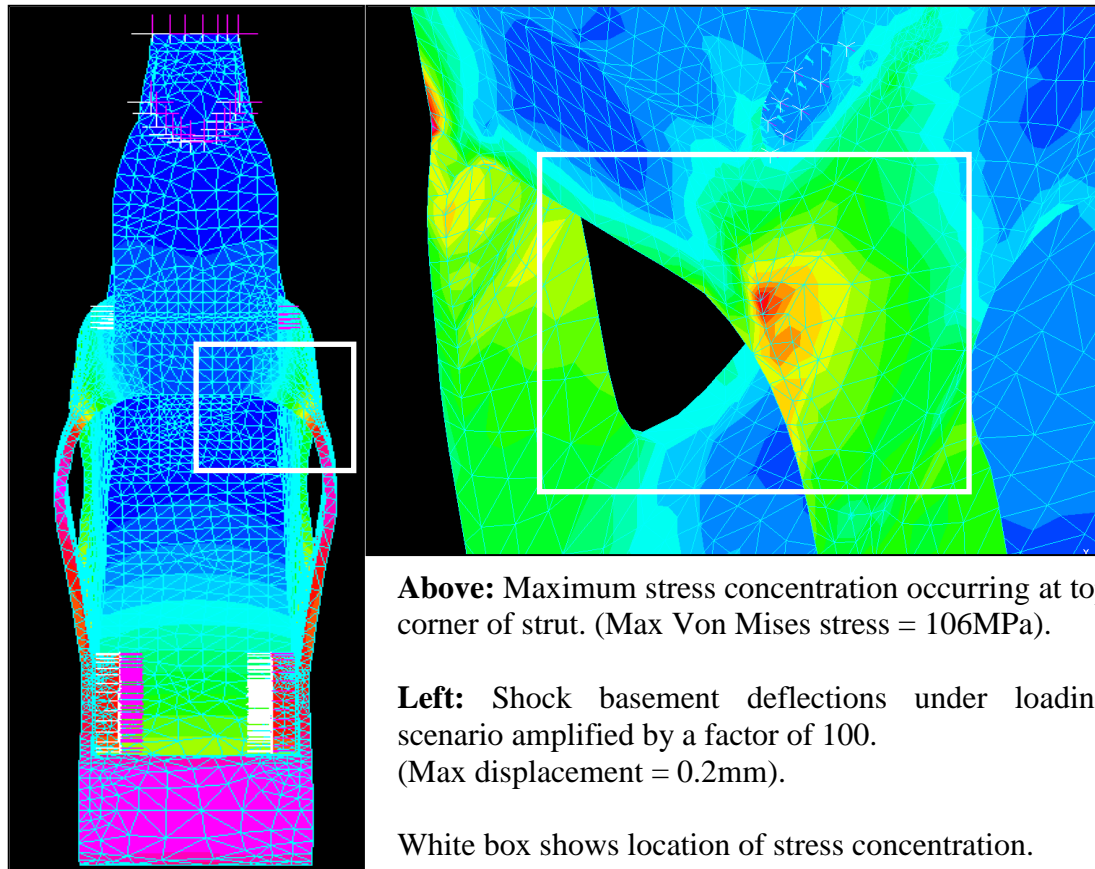


Figure 33 FEA Results for Early Model showing Need for Improvement

Since this was the only large stress concentration present in the model, the redesign was fairly simple. After a few iterations of remodelling and testing, the final design was established. This was achieved by widening the whole top link pivot interface and extending the shell, adding a large fillet to the model, as well as an increase in the radius of curvature to the area of maximum stress. The thickness of the material in areas of low stress was reduced to save weight to compensate for the increase of material volume elsewhere. The comparison of the initial design to the final design is shown in Figure 34

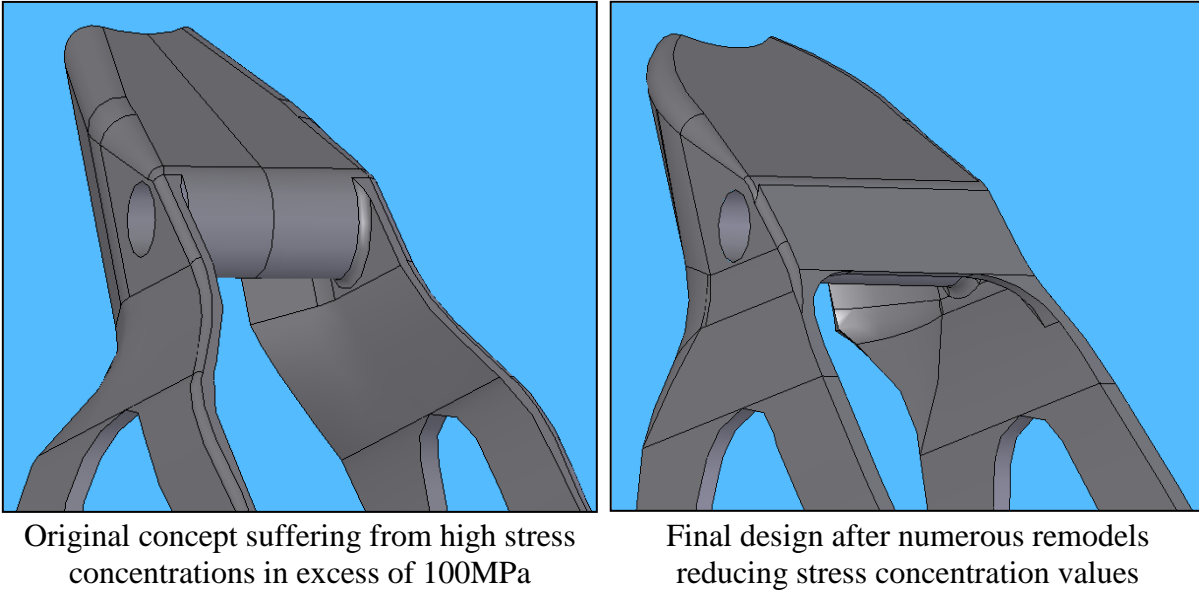


Figure 34 Improvements Made to Design to Increase Strength

As a result of these changes, the stress concentration was reduced to an acceptable level. Figure 35 shows that the area of maximum stress was still found in the same location as previous models; however the maximum stress is only 68MPa, which gives an acceptable factor of safety of 4.26 for the final design. The weight of the final shock basement design was reduced to 868g, a weight saving of 21% over the initial design concept.

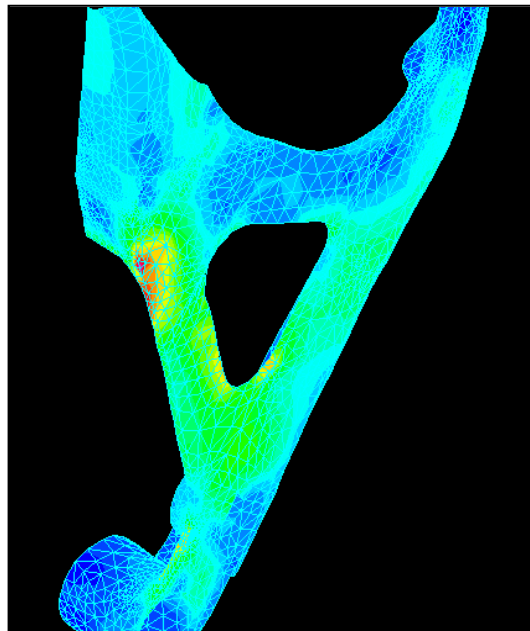


Figure 35 Restraints Allowing for Half Model Analysis of Final Design

6.2.3. Rocker

Similarly, the rocker was subject to the worst-case loading scenarios to optimise the design to achieve the desired strength characteristics and to reduce weight.

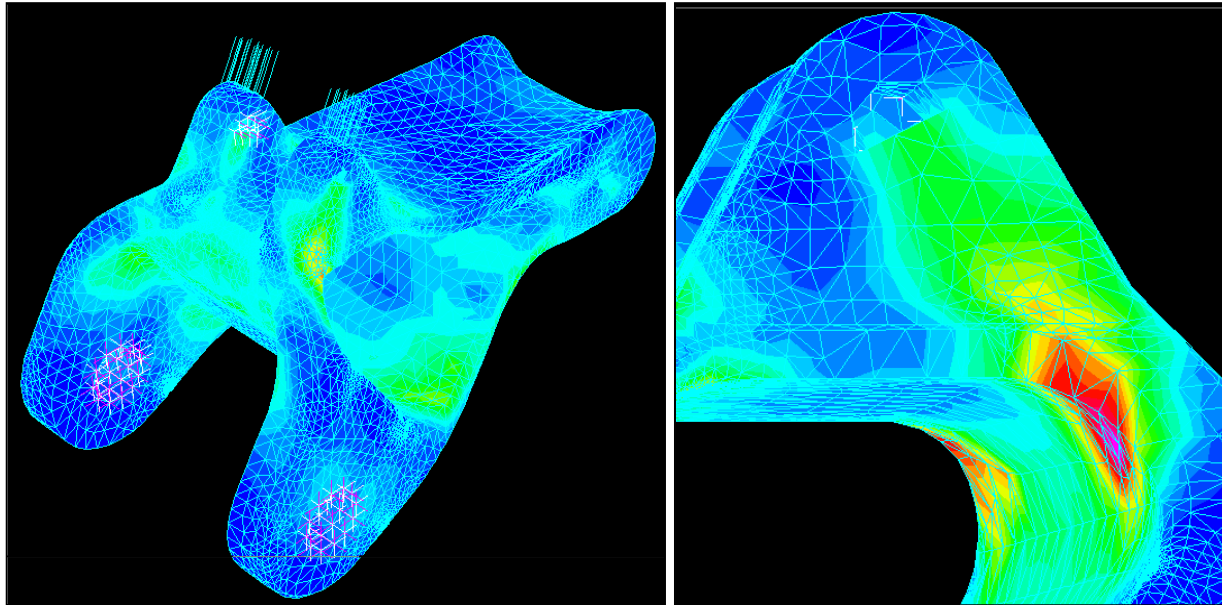


Figure 36 Stress Contours for Rocker under Worst Case Loading

During the development process of the rocker design the maximum stress was reduced from 96Mpa to 30Mpa, giving a factor of safety of 9.7. This very high factor of safety is important for this part as it will be subject to more torsional loading than the other parts. The weight was reduced from 507g down to 398g, a weight saving of 21.5%, achieved during the design optimisation.

7. CONCLUSIONS

The long travel full-suspension frame designed in this project meets or exceeds all the criteria requested by Banshee Bikes. Not only has an entirely new suspension linkage been developed that avoids infringing on any existing patents, but the mainframe was also designed to be compatible with the unique linkage geometry and shock placement. The innovative linkage will enable the frame to compete very strongly in both the downhill race and extreme freeride markets of the mountain biking industry. The multi-disciplined potential of the frame is achieved by taking the most desirable suspension and geometry characteristics from both of the target disciplines by optimisation using Linkage v2.5. This high level of optimisation carried out on the linkage design has resulted in a suspension system with maximum performance characteristics and minimal compromise.

The use of FEA throughout the design process has resulted in a frame that will not only be strong enough to withstand the abuse that accompanies the demanding and dangerous disciplines of the sport, but also achieve this at a very competitive weight. The bikes in Figure 37, are three of the biggest competitors in the market sectors with which this bike has been designed to compete. It has already been shown in section 6.1, that the linkage on the whole out-performs all three of these frames; however this frame must also be competitive in both weight and price to dominate the market.

Frame	Frame Only Price	Weight
Intense M3	£2549.99	4.9kg
Iron Horse Sunday	£1795.00	5.3kg
Specialized Demo 9	£1599.00	6.05kg

Figure 37 Table showing Prices and Weights of Biggest Competitors Frames

At a predicted total frame and shock weight of 4.95kg, this bike will compete very strongly as one of the lightest bikes in either the downhill or freeride sectors of the market. The strength characteristics are likely to be higher than those of the downhill race bikes and more similar to that of other extreme freeride frames. This has been achieved by designing the frame to

capitalise on modern cold-metal-forming techniques to reduce the number of welds and increase the stiffness properties of the structures.

The aesthetics of the frame are also thought to be desirable to the majority of customers, as shown in Figure 38. The shape of the hydroformed tubes results in a low stand over height, whilst also ensuring the desired strength of the design. The concept ensures good tyre clearance for both the front and rear wheel under bottom-out scenarios. The position of the rear shock unit results in a centre of gravity which is lower than competitor's designs which, when combined with the high performance suspension linkage, will result in a more stable and manoeuvrable bike.

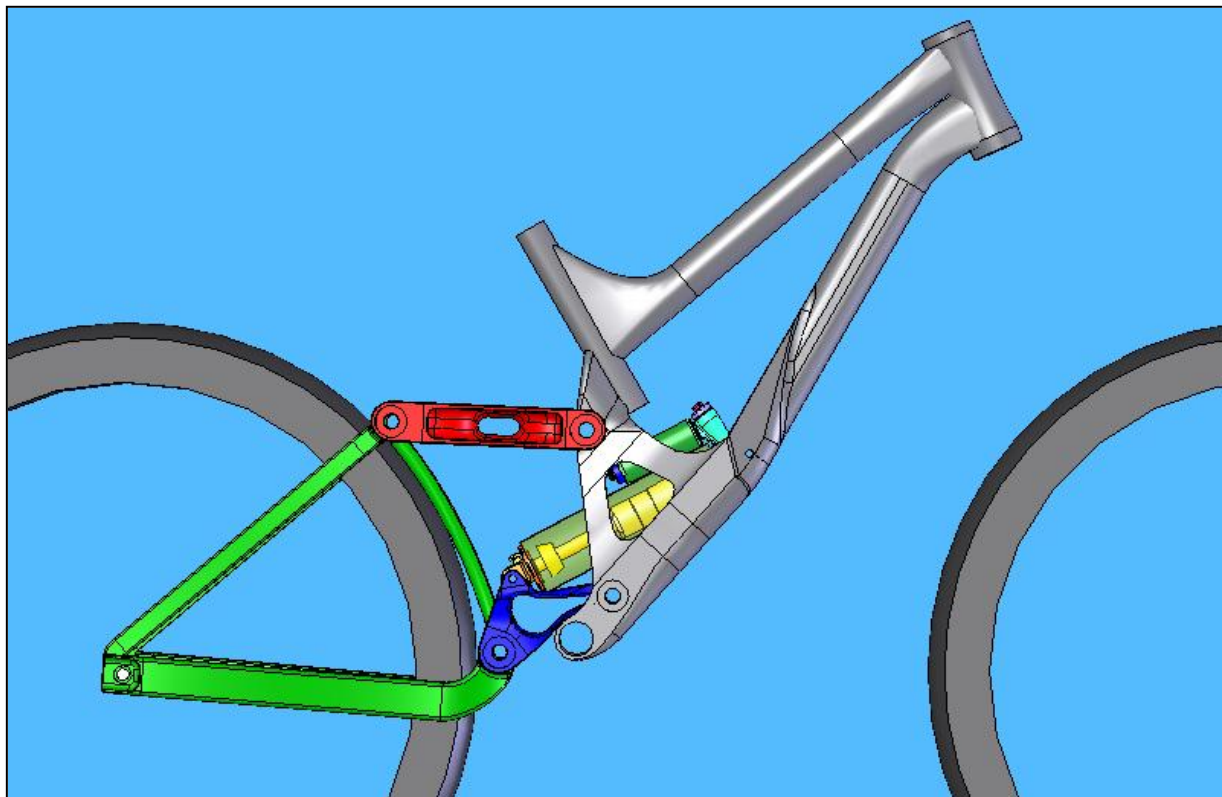


Figure 38 Model of Final Frame Design Complete with Rear Triangle

Although the price of the frame with shock is yet to be set, it is likely to be around £1750. This competitive price combined with good marketing could result in this high-performance frame potentially dominating sales for both the downhill race, and extreme freeride markets.

8. REFERENCES

- (1) www.specialized.com
- (2) www.cannondale.com
- (3) www.orangebikes.co.uk
- (4) www.yeticycles.com
- (5) www.bansheebikes.com
- (6) www.bikes.com
- (7) <http://www.therapycomponents.com/floaterfaq.htm>
- (8) www.santacruzmtb.com
- (9) <http://www.dw-link.com/physics.html>
- (10) <http://www.answerproducts.com/popup-tech.asp?techid=1>
- (11) www.intensecycles.com
- (12) www.dw-link.com
- (13) <http://www.answerproducts.com/items.asp?deptid=12&itemid=41>
- (14) Solidworks® 2005, Solidworks Corporation, 2005
- (15) Linkage, Version 2.5, Racooz Software, 2005
- (16) T.S.Keller & M.Liebschner, Tensile and Compressive Testing of Bone, CRC press, 1999, pp 175-206
- (17) Strand7, Version 4.4.5, G&D Computing, Australia, 2004
- (18) www.ironhorsebikes.com

9. PATENTS

- (a) “Rear Suspension for Bicycles”, LEITNER, Horst WO 93/13974 (21/01/93)
Followed up by: US005509679A on (23/04/96)
US005678837A on (21/10/97)
Assignee: Specialized Bicycles US005899480A on (04/05/99)
- (b) “Rear Suspension Bicycle”, LAWWILL, Mert DE19710697A1 (15/03/96)
- (c) “Bicycle Rear Suspension System”, Klassen, James US005553881A
Assignee: Outland Design Technologies (25/01/95)