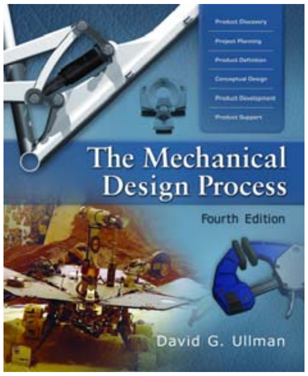
From Constraints to Components at Marin Bicycles



A Case Study for The *Mechanical Design Process*

Introduction

This case study details the development of the **Marin Mount Vision Pro** mountain bicycle rear suspension. Marin Bicycles is one of the earliest developers of the mountain bicycle as we know it today. Founded in 1986 by Bob Buckley (who still is active in the company) they are still leaders in mountain bicycle innovation.

The Mount Vision Pro was developed in 2006- 2007 by a team at Marin led by Jason Faircloth, a young mechanical design engineer. It was introduced in 2008 to good reviews and has sold well. The mountain bicycle market is highly competitive with industry leaders such as Marin pressured to develop new products each year in time for the annual bicycle shows. Within a year or two other manufacturers will copy and adopt new technologies developed by companies like Marin.

Additionally, Marin had been working for a number of years to make a breakthrough in rear suspension design as will be described. Thus, the development of the Vision Pro suspension was a combination of technology push and market pull for new products with better performance.

Figure 1 The Marin Mount Vision Pro

The Marin Mount Vision Pro bike was designed for the Cross Country mountain bike enthusiast. It is a quality and fairly expensive bicycle (over $3000USD). The primary demographic for this bicycle is male, 25-50 years old. But, because of its modern look and marketing it is also designed attract female and other age groups riders. It is intended for use on technical trails where there is a mix of uphill and downhill, where light weight and pedaling efficiency are of primary importance.

The Problem: Marin needed to design the rear suspension for their new Mount Vision Pro bicycle. This was a more complex suspension than they had designed before.
The Method: Marin used a structured method that progressed from Constraints to Configurations to Connections to Components. This methodology helped them ensure that the final configuration met the needs. Each of the four steps is described here.
Resources Used: Autodesk Inventor Dynamic Simulation and FEA, Microsoft Excel
Sources of information: *The Mechanical Design Process*, pages 246-260
Advantages/disadvantages: This method forces rigor and eliminates surprises. There is little down-side other than taking longer up front.

Constraints, *Configurations, Connections, Components*

The first step in this method is to understand the spatial constraints for the system. For the rear suspension of a mountain bicycle, the spatial constraints are shown in Figure 2. Beyond the obvious need to connect the wheel to the frame, the Marin engineers also wanted to control the path the wheel made relative to the frame as the suspension deflected, the stiffness of the suspension, and the chain length.

Figure 2 Physical constraints for the Mount Vision

Ideally, the wheel of the bicycle should move “nearly” straight up and down as it deflects. If the suspension was designed as a simple bar with a single pivot as on many bikes (see fig 3), then the wheel would make an arc with it moving closer to the front of the bike as it deflected. This would give the rider the feeling she was falling backward as the wheel deflected. The Marin engineers wanted to control the wheel path to manage the feel transmitted to the rider. As important as the wheel path, was the change in stiffness. The ideal suspension system for any vehicle is soft, has low stiffness, when it goes over small bumps and gets stiffer for large bumps. In other words, the larger the deflection, the stiffer the suspension system should become.

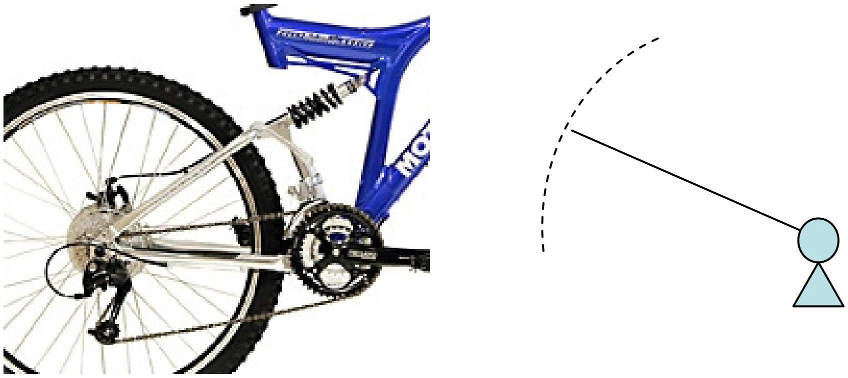


Fig 3 A simple, single pivot suspension

Finally, there was the desire to control the chain length. Consider a suspension that was designed so that when the pedals were pressed, the resulting tension in the chain pulled the suspension up (i.e. the frame down). The rider, when feeling the frame drop would then ease off the force and subsequently the frame would rise. Feeling the frame rise, the rider then reapplies the pedal force resulting in a ”pogo” motion and a very uncomfortable ride. Pogoing is often seen on poorly designed suspensions. Thus, an additional constraint is that the motions and accelerations felt by the rider will not lead to poor suspension performance.

Summarizing, the spatial constraints for the rear suspension are:

1. Wheel and chain must clear frame for all deflections
2. Wheel should move in a designed path
3. Low stiffness for small deflections, increasing with deflection
4. Chain length should not change during deflection

Constraints, ***Configurations****, Connections, Components*

The second step is to develop the configuration or architecture of a candidate system. The simplest type of suspension that can be put on a bicycle is a one with a single pivot as shown in Fig 3. On that bike, the pivot is near the center of the crank and every point on the rear triangular structure (called the rear “stay”) rotates around this point. As the wheel deflects, it makes a circular arc and the chain gets shorter, violating two of the spatial constraints. As the wheel moves up, the shock gets shorter. Shocks on bicycles generally have an air or oil damper with a mechanical, coil spring wrapped around it. This spring has a stiffness that remains essentially constant as the wheel deflects. Thus, it is clear that this type of suspension will not work for the Marin Mountain Vision Pro.

The technical advancement developed by Marin was to use a 4-bar linkage called the “Quadlink”. The Quadlink was not the first 4-bar suspension used on a mountain bicycle, bit it did bring this type of mechanism to a high level of refinement.

On the Quadlink the rear stay, the connection point for the rear wheel, rotates about the instant center and makes a nearly straight line. In order design the shape of the path followed the wheel Jason specified the lengths of links and the relative positions for the two fixed pivot points (the distance between them and angle of the line connecting them), for a total of 7 variables. There was a lot of design freedom.

To design the Quadlink Jason used the Autodesk Inventor Dynamic Simulation capability combined with an Excel Model that helped in parametrically studying the seven variables that determine the linkage to meet the spatial constraints. The final design is shown in Figure 4. Inventor helped Jason model and see the motion as the suspension deflected

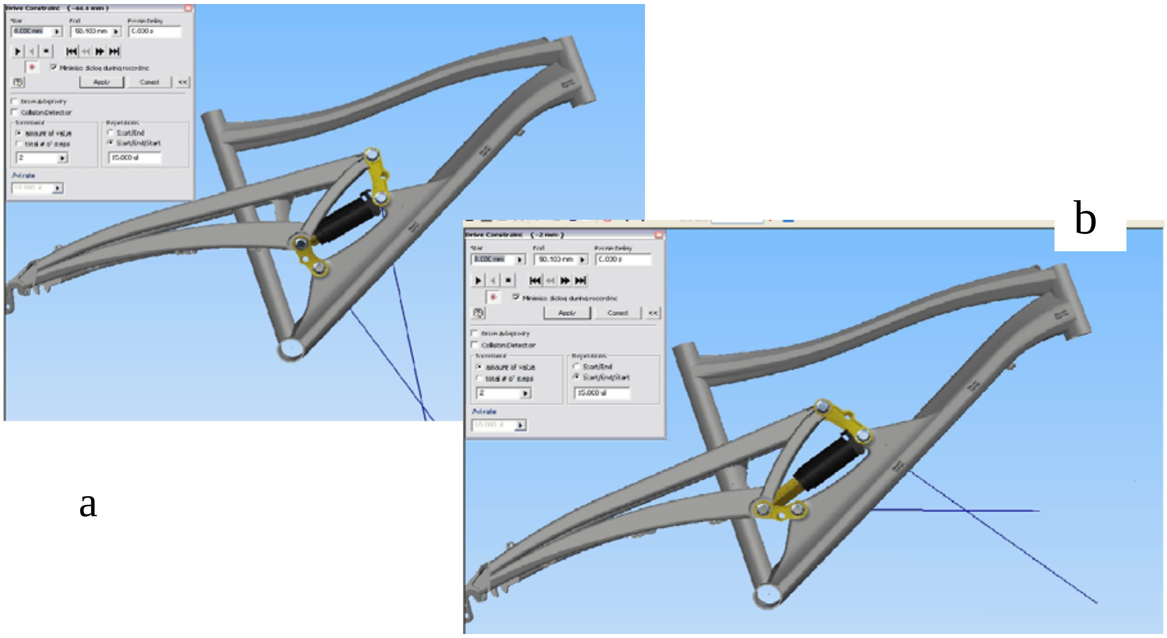


Figure 4 Simulation of the Quad link suspension, a) undeflected, b fully deflected.

The resulting linkage gives a fairly straight wheel path with near constant chain length. Further, by controlling the location of the virtual center and the positioning of the shock he was able to achieve low stiffness for small deflections, increasing with deflection. Specifically, when the virtual center is nearly under the crank (4a) the moment arm of the rear stay is much shorter than when the suspension is deflected (4b).

*Constraints, Configurations, **Connections**, Components*

The third step is to design the connections. On the Marin Mount Vision Pro, the connections are those between the links in the 4-bar linkage, those connecting the shock to the bike and those that connect the fixed parts together. Considering Fig 4, the shock could have been mounted in many different ways- between any two elements that move closer together as the system deflects. The addition of the shock adds two more pivots to the assembly making a total of 6 pivoting connections.

The Marin engineers reduced the number of pivots by mounting the shock on existing linkage pivots as shown in Figure 4.   As the suspension system deflects, the two pivots move toward each other. In fact, Jason, when determining the lengths of all the seven members, took the needed change in length of the shock as an additional constraint. The decision to mount the shock in this manner made the design of linkage more challenging and connections more complex, but the tradeoff for fewer pivots made this worthwhile.

The two pivots need to have the link and shock free to rotate about the axel (shown as a centerline in Figure 5). Note in Figure 4, the amount of rotation of these elements is small, only a few degrees in some cases. Bearings that operate primarily in one position and only move a small amount from that position present their own design problems as small deflections do not force the lubricant to flow to all the areas.

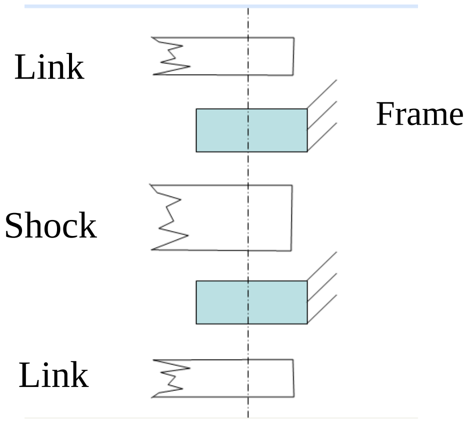


Figure 5 The components in shock pivots

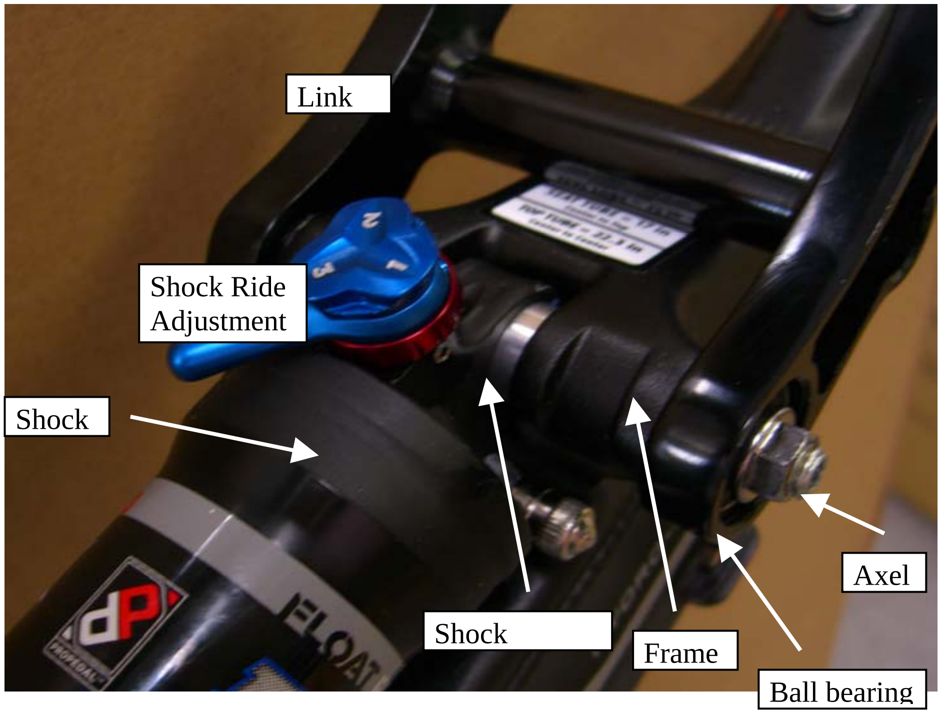


Figure 6 Final design of Pivot 2

The final connection at one pivot is shown in Fig 6. Connections between components that are moving relative to each other need to be addressed, as they are refined in the next section.

Constraints, Configurations, Connections, ***Components***

Finally, the actual components were developed. Vision Pro parts needed to be light in weight, manufacturable in volumes that matched the sales projections and had a look that would attract sales. Thus, these parts were a combination of structure and eye candy. .

The link is a very simple component that, like many on the bike, is forged aluminum with the bearing mounting surfaces machined. It is shown in two views in Figure 7.

Figure 7 Link A

The bearing between the axel and the link, shown pressed into the link in Figure 7, is a rolling element ball bearing. As mentioned earlier, this bearing does not rotate very much and thus requires special consideration. The final bearing chosen was one that was specially designed for aircraft control systems, another application with small, repetitive motions.

The link was modeled with Autodesk Inventor's FEA capability, so that the stresses in it could be seen during dynamic simulation. Since the loading signature on a mountain bike is not well modeled, FEA primarily served as visualization and learning tool with final decisions made based on physical fatigue testing.

The rear stay components could have been made out of round aluminum tubes welded together as with most aluminum bikes. However, to get a better "look", the designers wanted tubes that curved, and to save weight, the engineers wanted tubes that tapered. As shown in Figures 1 and 4 these two requirements were met. The manufacturing method used is called hydroforming. To hydroform, a round tube is put in a die and then the tube is filled with high-pressure liquid causing it to deform and be shaped by the die.

Summary

During the design of the rear stay a conscious effort was made to consider the Constraints, Configurations, Connections, and Components in a reasonable linear manner. This helped ensure that some details were not addressed too early in the process and that there was a clear path to follow.

Author

This case study was written by David G. Ullman, Emeritus Professor of Mechanical Design from Oregon State University and author of The Mechanical Engineering Process, 4th edition, McGraw Hill. He has been a designer of transportation and medical systems and hold five patents. More details on David can be found at www.davidullman.com. David was assisted by Stephen Salazar of Syncromatics Corp of Los Angles, California.

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