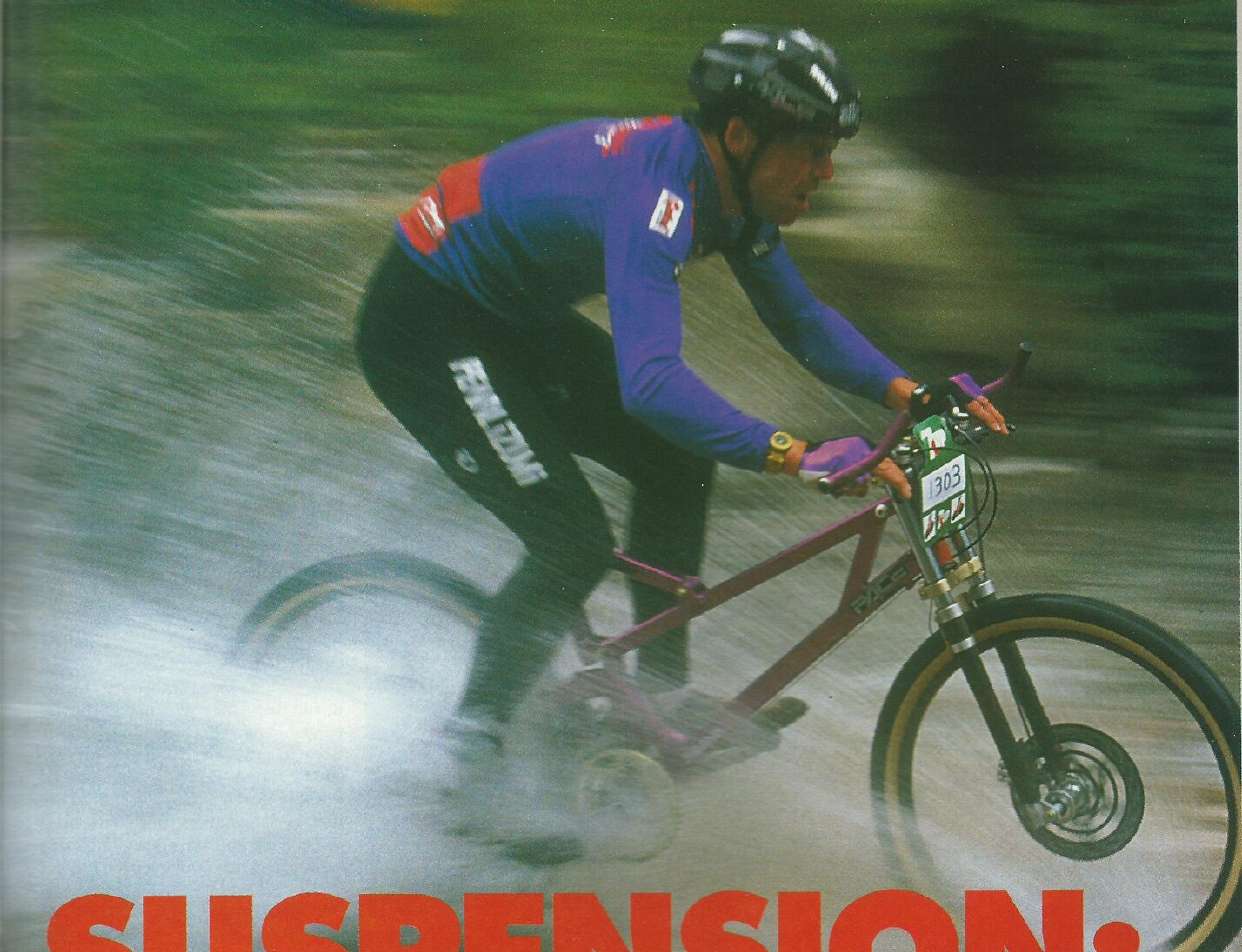


SUSPENSION: THE FULL LOW-DOWN

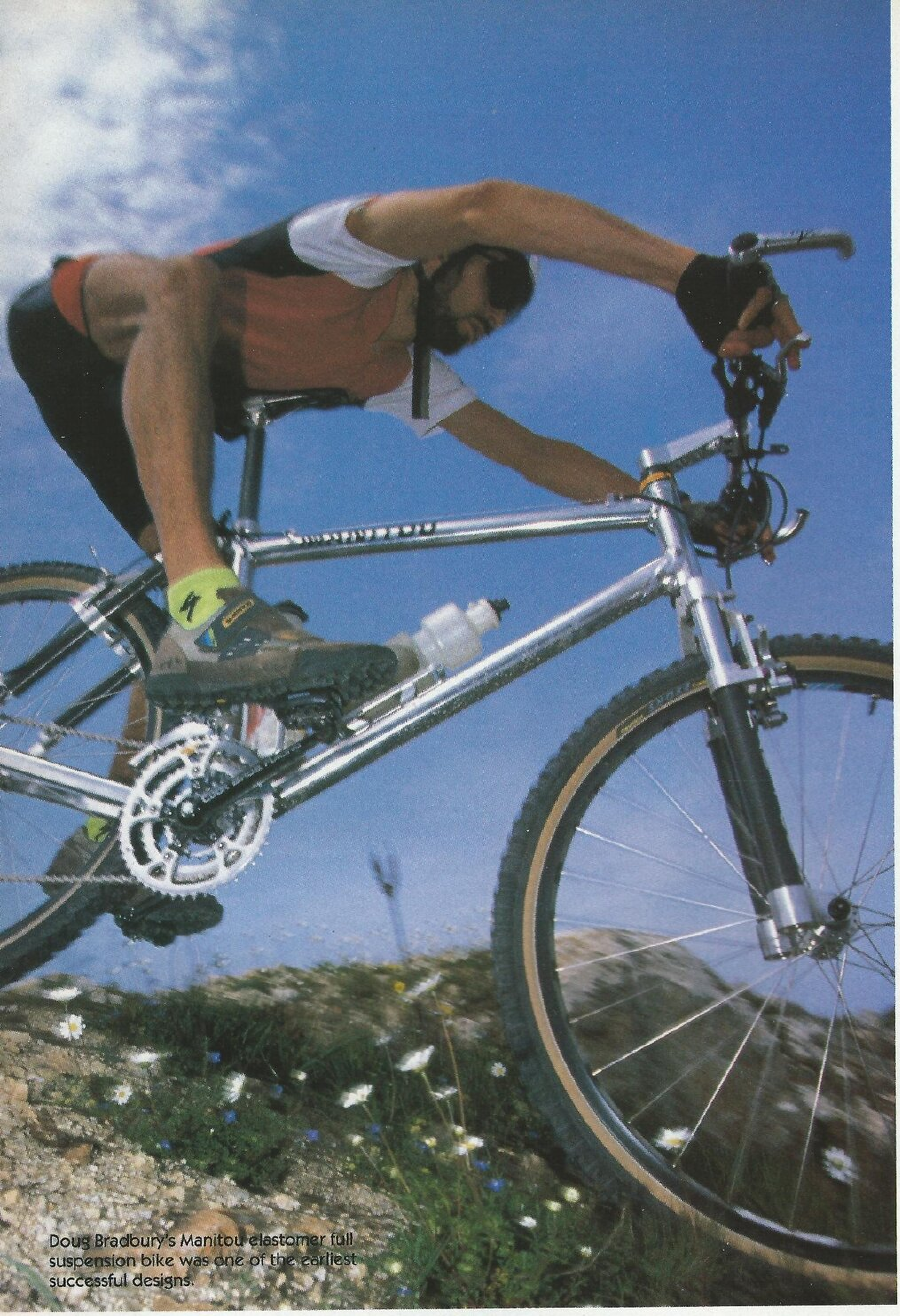
Full suspension bikes have finally graduated from bike show projects to workable, ridable, buyable off-road machines. But which systems are best? How do they work? What should you be looking for? 'Let me explain,' says BRANT RICHARDS...

Full suspension isn't that new on mountain bikes. It's been at the shows for several years, and there have been a couple of full suspension bikes available for most of that time. What is new this year is that the latest suspension bikes work a lot better than they did three years ago, because their designers are getting to grips with the real problems of a suspension bike that has to cope with an under-powered, oddly-behaving human engine.

Manufacturers are leaving behind the relatively easy task of building a 'downhill-only' bike and tackling the more complex, but more useful, problem of building a bike that anyone can ride on all gradients and that can help us ride faster, in more comfort and with an increase in the all-important fun factor.

Why be suspended?

On a bike that isolates trail vibration, the rider can traverse the terrain faster, safer and more comfortably. Faster, because the surface which you're crossing only affects the unsprung parts of the system, those 'below' the suspension, and therefore doesn't slow the whole bike; safer because the wheels will follow the ground more accurately, improving traction and therefore braking and handling; and more comfortably because trail shock and buzz are absorbed in the suspension, so they never reach the rider. Which of these features are the most important depends on who you talk to; a casual rider mightn't be that bothered about an increase in speed, but a racer will quite happily sell vital body parts if an increase in speed can be attained by simply bolting on



Doug Bradbury's Manitou elastomer full suspension bike was one of the earliest successful designs.

a new part. Early developments simply concentrated on increasing downhill speed, but the real deal is going to be improving comfort and handling for the vast majority of riders who just want to go play in the woods and have fun.

What's available?

Good designers engineer solutions to fit a brief, which lays out the needs of that design. Bad designers change the brief to suit the solution they've come up with. Be suspicious of anything you see tagged as a downhill bike. Is that what the designer intended? Why didn't they build an all-round bike?

The bottom line is that it's fairly easy to build a suspension bike that works downhill. It's harder to make a bike that excels downhill, and it's harder still to make a suspension bike that works for cross-country. Out in the marketplace are several suspension bikes that are highly unsuitable for XC use. They're tagged as downhill-only bikes because they're no good for all-round riding. Copying each other's designs doesn't improve things, we just get stagnation. Designers need to get a life and start designing bikes rather than just copying each other.

Suspension problems

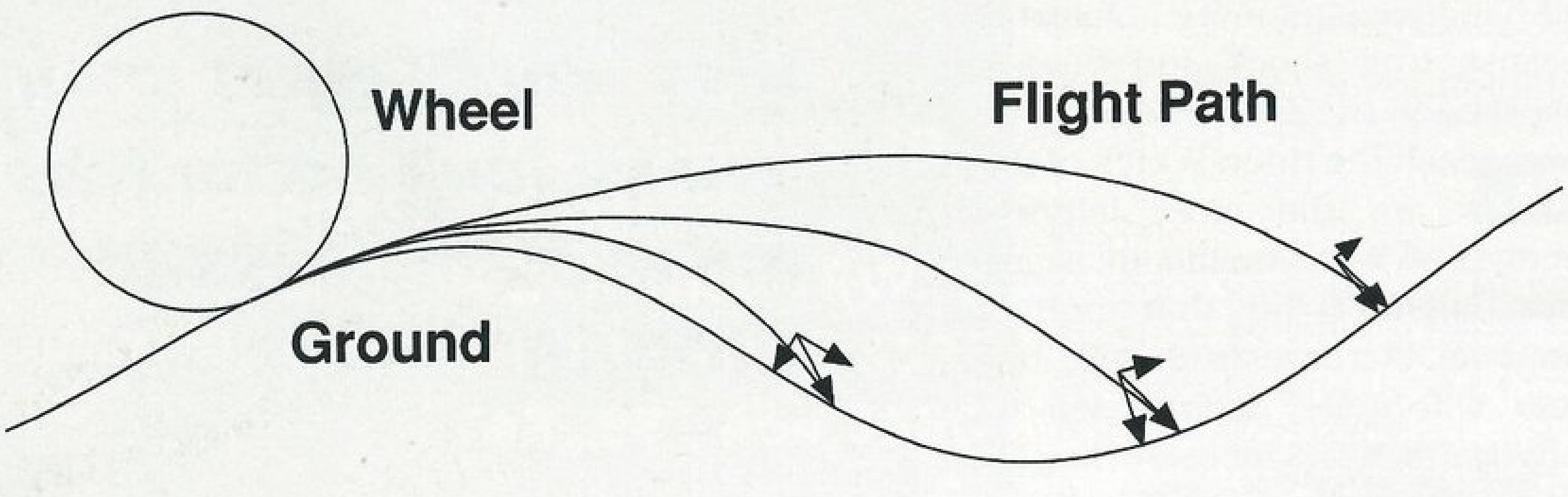
The problems these designers must overcome to produce a successful suspended XC race bike (the most difficult brief to fulfil – a good XC race bike will be usable for general riding as well), with bicycle suspension as opposed to motorcycle suspension, can be broken down into three parts:

1) A motorbike has lots of power. A twist of the wrist gives mucho power output, and so the suspension designer isn't too worried about the springs and dampers absorbing some of the power. With a bicycle, any system which absorbs any power from the rider is bad news. With only 0.5hp at the most to utilise, the system must not waste any energy compressing the suspension; excess weight will also lead to a reduced power-to-weight ratio, slowing the rider down. With the bicycle, this is of limited significance, the rider's weight dwarfing the bike's weight. However, light bikes are easier to ride, and weight must be kept to a minimum.

2) The power the rider is supplying is extremely non-linear. No matter how good you are at pedalling smoothly, your power output curve is still a very wavy line. During the pedalling cycle, the power peaks at

Energy loss through loss of ground contact

Every time your wheel leaves the ground you lose a little energy. This happens on large bumps (when you get air) and on little bumps (when your wheel is bounced off the trail). The amount of energy lost through going over this bump is shown by the arrow perpendicular to the surface at the point of impact.



around 1hp, averaging 0.3hp over the pedal stroke. This cyclical change in chain tension must be isolated from the suspension system. This power is being applied across the suspension system, from the suspended rider and bottom bracket to the unsuspended rear wheel, and the tension in the chain generates a torque reaction in the swingarm. The magnitude of this torque reaction depends upon the chainwheel and sprocket combinations used, and the position of the swingarm pivot.

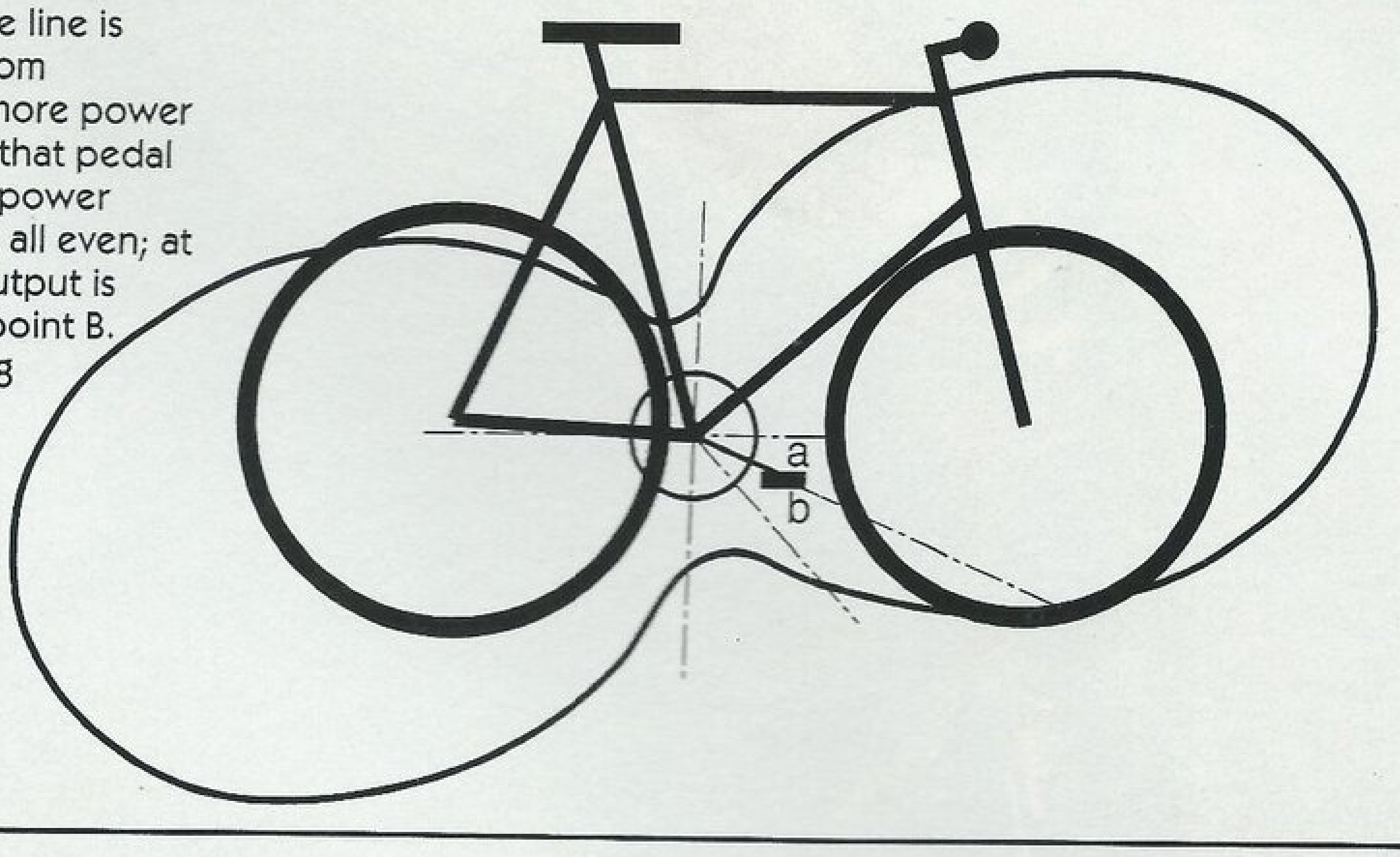
3) The rider's centre of gravity moves as the rider pedals, because your legs are constantly pumping up and down. This motion can feed through the frame and affect the suspension. It's much less of a problem with motorbikes because the moving parts are lighter in relation to the rest of the system, and moving much faster. It's an input that has the same frequency as the chain tension, but a different wave form. For effective suspension, this too needs to be isolated from the suspension.

To cap it all, the bicycle is a light vehicle and so must be lightly suspended, and because it's very short, it can't have lots of travel front and rear as it will pitch at the extremes messing up the geometry.

Most systems on the market use one method or another to isolate one or sometimes two forces from the problem. Chain-tension activated lockout, for example, means no 'bobbing' under load, but it also means no suspension when you're pushing on the pedals.

The cyclist's power output

The further the line is from the bottom bracket, the more power is available at that pedal position. Our power output isn't at all even; at point A the output is twice that at point B. This alternating power source causes badly designed suspension systems to bob about.



Shock absorbers

A shock absorber is made of two elements: a spring and a damper. The spring can be made from a variety of different elements: steel, air, nitrogen, rubber, titanium, concrete... The spring is in the shock to deflect under the load of the bump, and to then force the shock out again to absorb another hit.

The damper is also available from a variety of materials, depending on the type of damping needed. Friction can be used as a damper, but it is linear in performance, and isn't 'velocity sensitive'. On mountain bikes, damping is achieved with oil flowing through small holes in a piston, or by the internal squishing of an elastomer block. The damper slows the impact of the blow, dissipating the energy of the blow, allowing the spring to take the force by deflecting. Without the damper, the spring would return the same force as it was hit, but with the damper, the return is also controlled by rebound damping, stopping erratic shock handling.

In use on bikes today are three different types:

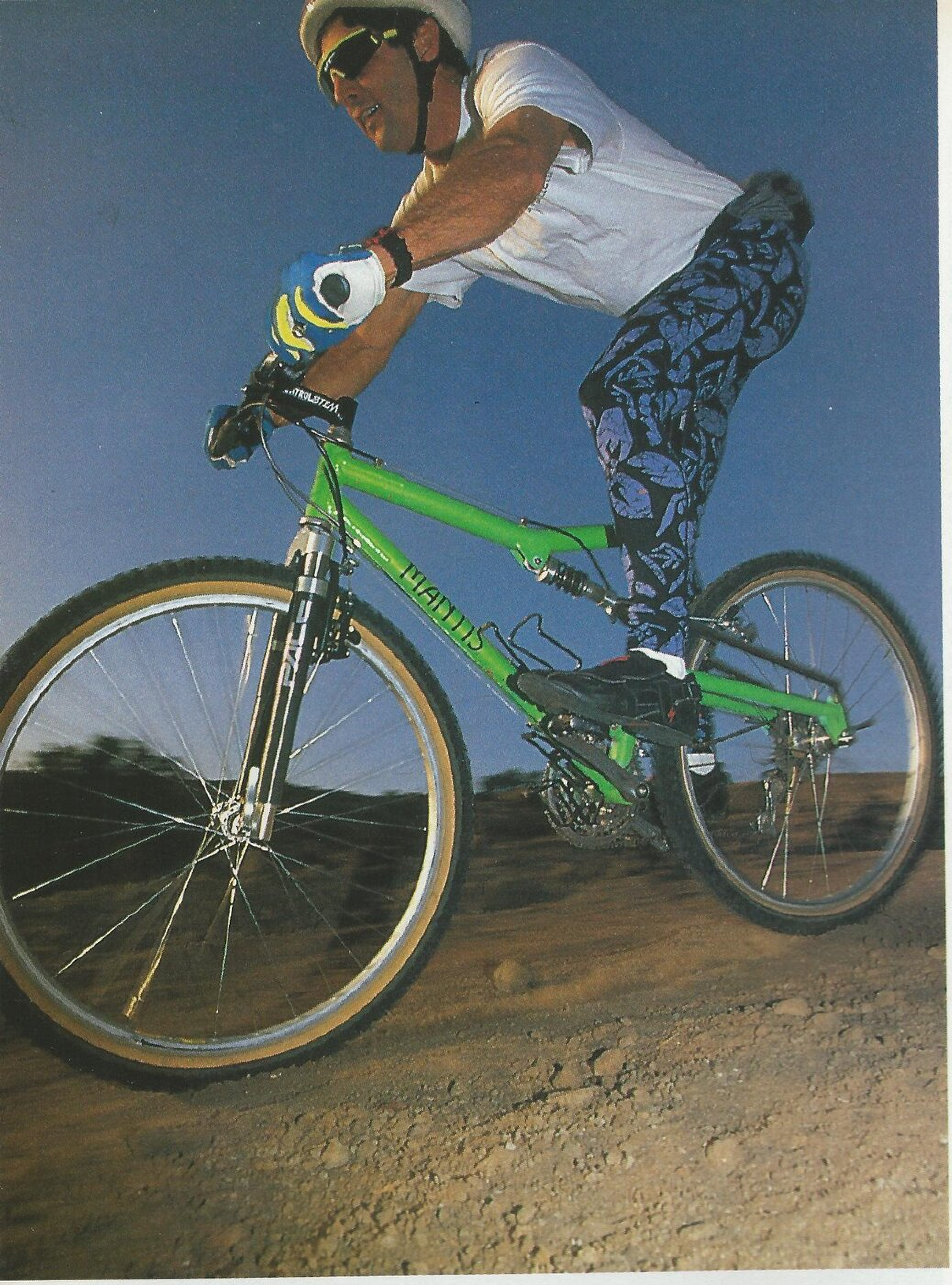
Oil-damped steel spring

This is the classic shock absorber, like those used on most modern vehicles. The steel spring isn't affected by heat or atmospheric pressure, and doesn't fade or break down in extended use. Oil damping is the most sophisticated way of controlling the compression and rebound speeds of the shock. Valves are employed to affect the compression and rebound speeds separately. The Nishiki bikes, Mantis Pro-Floater and GT RTS-1 use this type of shock.

Oil-damped air spring

Rock Shox are a front fork with this type of damping, and their use has got people into the idea of air providing an excellent suspension medium. The air is held in a space, and when compressed, it acts as a spring. The oil is held in a cavity as well, and is often separated from the air with a floating spacer. Like the spring

This is all we'll show of Stevenson – when we tested the RTS-1 he was too podgy for us to shoot the rest of him. Unfortunately, the plushness of a good suspension bike doesn't help fight the flab, but lots of riding does.



Mantis' Richard Cunningham is one of the gurus of full suspension bikes. His Pro-Floater is reputed to be one of the best-sorted bikes around.

shock, the valving can be adjusted to affect compression and rebound damping. Air is reasonable for this task, but nitrogen works much better, having more linear compression characteristics and less problems with seal stiction. However, nobody I know has a nitrogen tank in their back yard...

Elastomers

Gaining popularity in front forks, having gone from 'lumps of rubber' to 'elastomeric suspension cores', elastomer technology is pushed to its limit in rear suspension. The damping and spring rate are dependent on the mixture of chemicals poured into the mould. The industry standard is five per cent inaccuracy. This isn't too much of a problem with a fork, as the elastomer compresses on a 1:1 ratio, with the fork moving up and the elastomers compressing at the same rate. With rear suspension this usually isn't the case. Leverage ratios are employed with, say, a 3:1 mechanical advantage. The elastomers must be three times more accurately graded for the job in hand with the extra leverage, and this is very difficult to do in practice. Offroad and Manitou manage to avoid these problems by having lower leverage ratios and stiffer bumpers to be less affected by elastomer inaccuracies.

Stop that flex!

It might seem simple to just pivot a swingarm off a frame, connect a shock absorber and hey! A suspension bike! Unfortunately, it's a little more difficult than that. The big problem is flex in the system. A welded mountain bike will flex under cornering and pedalling loads, but this is nothing compared to a suspension bike. Badly engineered pivots and flexible materials used in the rear stays result in movement unheard of in rigid bikes. Whereas in rigid bikes a little flex is a good thing, in a suspension bike it's imperative to have the frame as rigid as possible and put all the travel in the suspension. For this reason, aluminium is the hot tip for main triangles, with either oversize aluminium or steel used for the swingarms.

Having an additional support for the swingarm limits flex too. According to Pace, having a rear axle which clamps in place like a motorcycle would seriously reduce flex in the rear triangle, but as long as people want to fit their own hubs, this isn't going to be possible.

Putting seat stays off the swingarm further stiffens the rear triangle by reducing the lateral flex. Manitou take this one step further by basically mounting a lightened fork in the place of the seat stays. The fork, with brace and twin sliders, does an excellent job in reducing the side flex from the pedalling load, but is incredibly time-consuming to build. It's some of the most intricate CNC work I've seen!

GT's rocker crank also adds a degree of side-to-side stiffness, but their system uses the rocker's variable mechanical advantage to affect the rate of the shock.

Where a swingarm pivots off the frame without any support, a clued-up designer uses a large pivot to support the load. Diamond Back's Dual Response bike uses a massive 50mm diameter pivot to keep everything snug and secure.

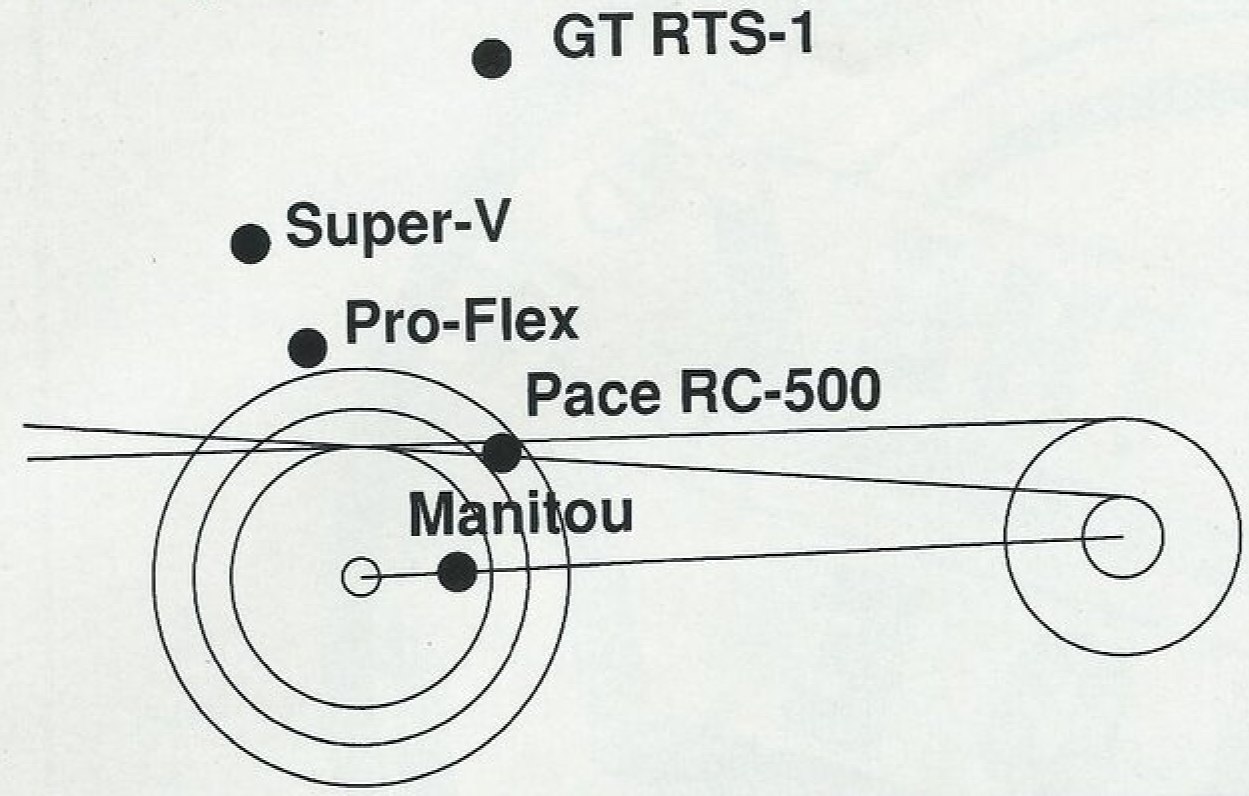
Have pivot will travel

The location of the pivot point in relation to the bottom bracket is essential in determining the nature of the travel, and the reaction of the suspension to pedalling input. Some designers complicate matters somewhat by putting the wheel several pivots away from the bottom bracket. This means that the movement isn't in an arc but a modified curve, with a variable rate of sensitivity to pedalling input.

Four basic pivot methods are used, depending on the location of the swingarm pivots.

Low swingarm pivot systems are led by the Manitou system, and the Yeti Arc FS. Here, the designers give

Pivot positions of common suspension bikes

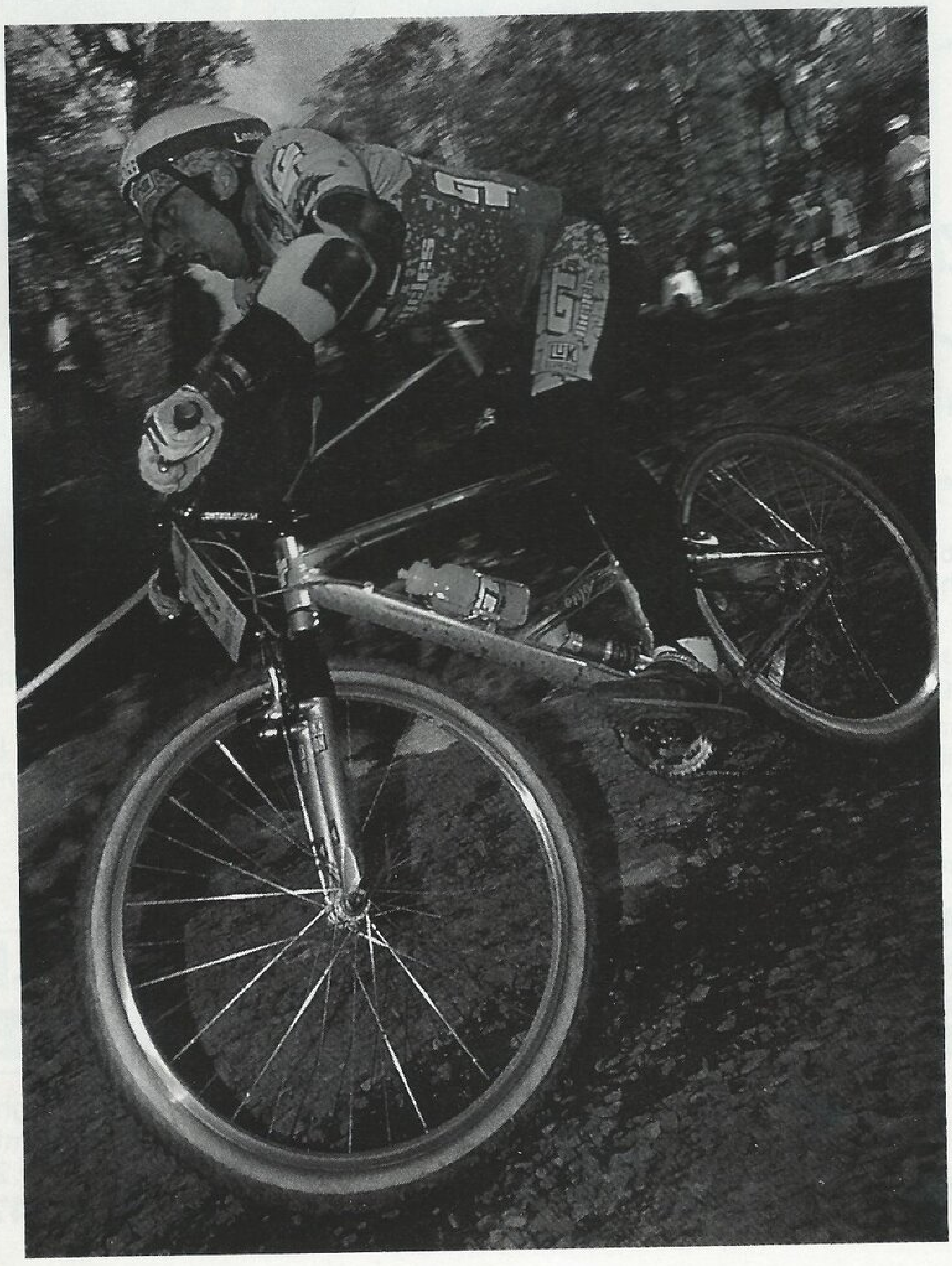


The top diagram shows the pivot point positions. The closer they are to the active zone, the better they work under pedalling.

The bottom table's figures were calculated on a CAD package. The smaller the number, the less 'lockout' the suspension has under load. Where the number is negative, the suspension absorbs some power. The Pro-Flex and RC-500 alter the chain length very little and work all the time, whereas the GT's chain length alters a lot, giving a suspension that only works under load, and needs a long chain to prevent it snapping under load in a big/big combo.

Change in chain length in mm for 2in of rear suspension movement

Chain/sprocket	48/28	36/20	24/28
Manitou	-10.5	-8.68	-8.5
Pace	0.07	0.32	2.14
Offroad	4	4.022	6.2
Cannondale	8.93	8.47	10.64
GT	20.5	19.86	22.01



Downhill racing is the obvious place where suspension comes into its own, but the real aim is to boost the fun factor for all-round XC riding.

up a little efficiency in the system to gain a simple answer to the works-all-the-time suspension angle. This works pretty well as long as travel doesn't get too great. With short travel and a high spring rate, the system doesn't tend to bounce too much under load. The torque reaction from the chain is greatest in the small ring, because of the gearing. Though the large chainring offers greater leverage over the pivot, the tension in the chain is less, and hence the torque less also.

High pivots are good for riders unwilling to learn new techniques for riding with suspension, or, to put it another way, make for bikes that feel like rigid bikes when you hammer and are therefore easier to sell. The chain tension pulls down the swingarm causing the suspension to lock out under hard pedalling loads. This phenomenon leads some manufacturers to claim increased traction on the really gnarly steep stuff. Opponents of this type of system claim that the suspension not working under load actually decreases traction, or at least reduces it to the level of a conventional rigid bike.

Problems can occur if any 'sag' is built into the system. The chain tension will extend the suspension on every stroke, causing the bike to bounce up and down like a rocking horse. Putting the pivot for the swingarm in line with the top of the middle chain ring, or at least close to this position, results in a system which reacts constantly to the terrain, the chain torque being largely isolated from the system. With little leverage over the swingarm, the chain tension remains roughly constant no matter where the swingarm is. Obviously, the torque cannot be completely isolated from the system, because different sized chain wheels are used, each necessitating a different ideal pivot position. With most off-road riding being done in the middle ring, this is the point where the pivot is located. This will result in a system which has a slight tendency to dig in the little ring and equally a slight pull up in the big ring. However, these torque reactions are small and the system is as close to 'free floating' as necessity allows.

Moving the rear wheel by means of a parallelogram or, correctly, a four bar link system, gives finer control over the travel. However, ideal motion programmes are one thing, low maintenance, high stress mountain biking is quite another. Placing the wheel one pivot away from the main triangle results in extra, unwanted movement. Additional pivots multiply the slop, so no matter how perfect the axle path in theory it's less than useful if you've got more flex than a Flymo.

Braking

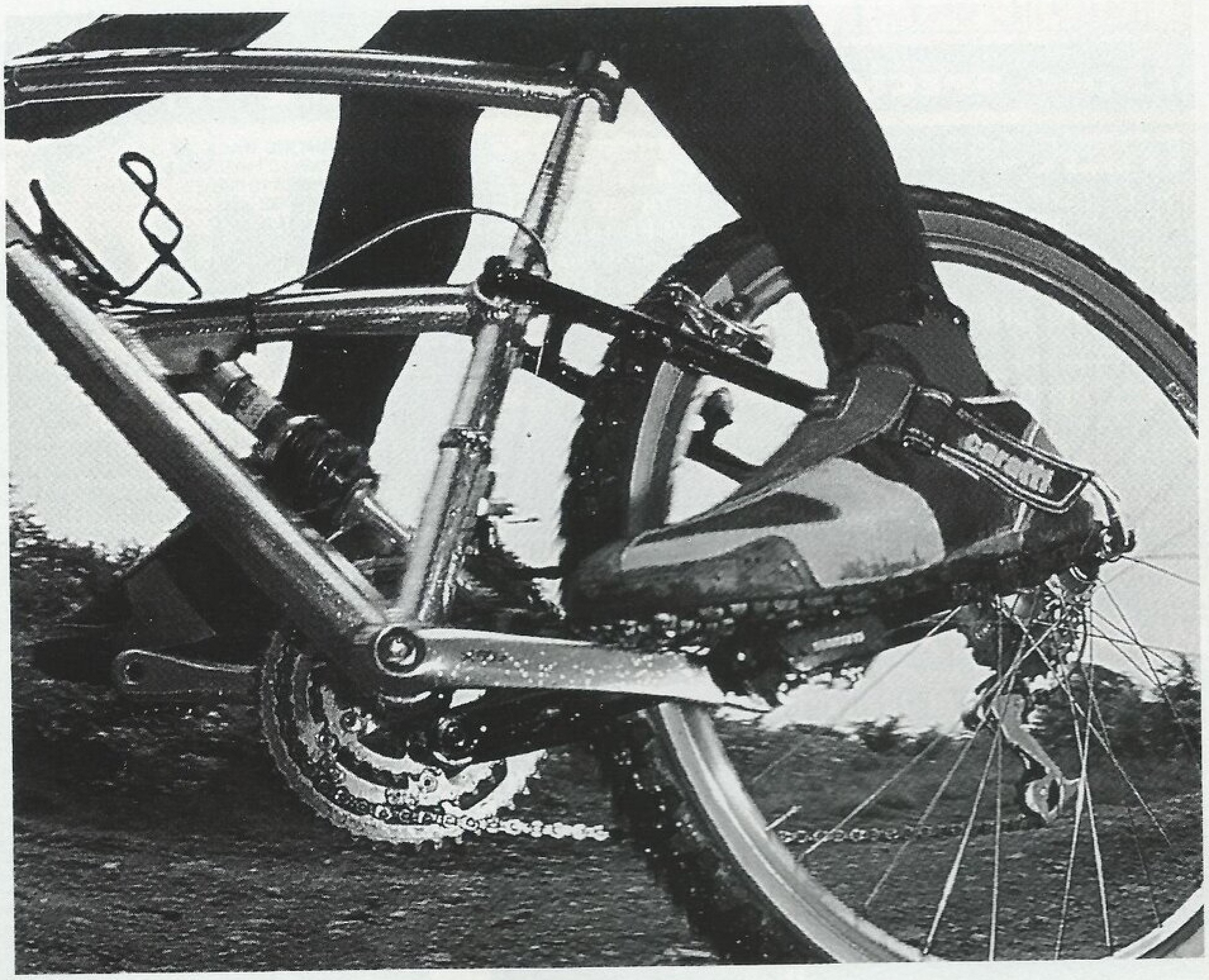
A lot is being said in other less than distinguished tomes about the negative effects of brake reaction on rear suspension systems. Pardon me if I sound stupid, but I've never found this to be too much of a problem. It reared its head in motorcycle suspension quite a few years ago, but all the fuss seems to have died down now. Compared to the major bugbear of chain torque reaction, it's a lot of fuss about nothing.

Compression damping

Whether it's in front or rear suspension, damping seeks to control the rates of movement of the system. When the system is compressing, compression damping slows the speed of the impact, lengthening the impact time and controlling the speed at which the force of the blow is absorbed. How this is actually achieved varies from system to system, either oil flowing through small holes, or the natural hysteresis of elastomer rubber. Without compression damping or with too little, the system would bottom out on every large bump, resulting in a bumpy ride, possibly bumpier even than a rigid bike on the same trail. Too much compression damping means that the system won't react to sharp blows and will only travel under high G load situations. It's a careful balancing act between compression damping and the spring strength to achieve the correct ride qualities.

Rebound damping

Just as compression damping seeks to control the speed of compression of the system, rebound damping controls the speed of the rebound stroke of the shock. Too little rebound damping results in a system which pushes back fast and hard from a compression. This can result in all sorts of nasty things happening. With a suspension fork, this can lead to the feeling of the handlebar being pushed up after an impact. Too much rebound damping leads to the suspension 'pumping down' under several successive impacts. Hit some big bumps in quick succession and each will compress the suspension a little more. If the damping is really wrong, successive bumps could turn your full suspension bike into a fully rigid bike. Too much compression damping on rear suspension leads to a wallowing sensation. Not nice.



Despite its high pivot, the RTS-1's suspension system works pretty well because of its well-controlled shock action and the way the rocker separates the frame's structure from the shock.

Spring rate

The stiffness of the spring used in the system is called the spring rate and depends upon the wants of the designer. The basic spring rate (how much the spring compresses for a given load, measured in inch-pounds – a 150inlb spring compresses 1in for a 150lb load) that is required is a function of the rider weight and the geometry of the system. However, as the suspension moves and the spring is compressed the designer can choose how the spring behaves, with either a rising rate, falling rate or straight rate. Rising rate means exactly what it says: the spring rate increases as the spring compresses. The actual spring rate is important, but the variable leverage that a swinging arm provides means that the spring stiffness isn't constant throughout the stroke.

For every spring rate there are certain windows of damping force (both compression and rebound) that will work. Problems with damping not matching spring rate can exist in the world of rear suspension bikes because, generally, the heavier you are the stiffer the spring needs to be. Several manufacturers simply fit stiffer springs, with the same dampers, which results in a shock with either too much or too little damping. Hopefully manufacturers will wise up to this, or else gentle 8st riders will continue to have to ride the same set-up as 18st lunatics. Does this make sense to you?

Unsprung weight ratio

On motorcycles, much is done to decrease the weight of the parts of the bike – the wheels and other bits 'below' the shock – whose job it is to follow the terrain. For optimum suspension movement, the inertia of these components should be as little as possible.

Light wheels make the suspension work better, but what's more important is the sprung:unsprung weight ratio. As the sprung weight is the bike plus rider, and the unsprung weight is just the wheels and other parts like the swingarm, aluminium nipples and titanium axles aren't going to improve your suspension performance that much. That said, light wheels do accelerate better than heavy ones, but if you've got a limited budget and have to make a choice, make sure it's the fast rotating big stuff (spokes, tyres, tubes, rim) you're saving the weight on, rather than the little stuff, close in (hub, axle, freewheel).

So what?

Read, study and understand this article, and we'll be asking questions next month. Right now, your intrepid Wrecking Crew are damaging bodies and minds on the best suspension bikes available. Bikes from GT, Offroad, Marin, Cannondale, AMP and SBike are being thrown down extreme mountain sides to bring you the ultimate suspension shootout, next month. ✪