

Front-End Geometry for Different Speeds, Loads and Tire Sizes

by Jan Heine

Summary

Current thinking is that "laid-back" geometries, with ample geometric trail, result in "stable" bikes. Contrasting this, old French cyclotouring bikes rely on relatively wide, low-pressure tires for stability. They use very little geometric trail, minimizing the wheel flop that makes current "high-trail" bikes difficult to control for a tired rider and/or heavy load. However, "low-trail" bikes require a minimum tire size to be stable.

Introduction

The steering and balancing of bicycles are so complex that they remain poorly understood.¹ While it is possible to model a rider-less bicycle, this is not very useful, because rider input determines a bike's handling and feel.² In the end, geometries usually are derived empirically (through trial and error). There are many bicycles, with very different geometries, that handle quite pleasantly.

In North America and many other places, racing bicycles have received the lion's share of the attention. Geometries for cyclotouring bikes – whether they are called sport-touring, touring or randonneur bikes – usually are derived from racing designs.

Cyclotourists' demands on bicycle handling often are fundamentally different from those of racers. During a race, riders rarely go slower than 30 km/h (18.8 mph), while cyclotourists spend most of their time below that speed. Many feel that a racing bike should react to very small inputs immediately, especially during criterium races, where quick and almost intuitive maneuvers are essential to avoid crashes. Contrasting this, a cyclotouring bike needs to be able to tolerate a certain sloppiness of a tired rider. Add to that a handlebar bag or even loaded panniers, and you introduce an entirely new set of variables.

Handlebar bags have an especially bad reputation in many quarters: They are said to affect the bicycle's steering in a negative way.³ Much of this problem can be traced to poorly designed bags that sit too high and/or swing from side to side because they are not supported by a rack.⁴ But even with bags that are mounted correctly, some bikes are more affected by a full bag than others. A bicycle's front end geometry also determines how well the bike will carry a front bag.

Almost any bicycle can be ridden after its rider has become accustomed to its handling. However, riding no-hands, the rider's input is reduced. No-hands riding, especially at low speeds and around corners, is a good test for bicycle handling.

More geometric trail equals more stable handling?

Geometric trail – often simply called "trail" – has received much attention in the discussion of bicycle handling. Geometric trail (Fig. 1) results from the combination of head angle (the inclination of the steerer axis) and fork offset (also called "rake"): A "slacker" head angle increases geometric trail, while more fork offset puts the wheel further forward, decreasing geometric trail. Wheel size also comes into the equation, with larger wheels increasing geometric trail.⁵

Because the front wheel contacts the ground behind the steerer axis, many believe geometric trail exerts a self-straightening force on the handlebars once the bike is moving. This is not entirely true because a bicycle can lean. Still, many believe that geometric trail alone will determine the handling of a bicycle, with more geometric trail resulting

in a more "stable" bike.⁶ Some even have postulated optimum geometric trail figures, usually between 50 and 65 mm.⁷

Experience with a number of bikes contradicts this assertion: Many old French cyclotouring bikes have extremely large fork offsets (rakes) – much more than what currently is considered appropriate for their head angles – and thus little geometric trail (43 mm or less). The predominant current thinking is that such a geometry would result in an unstable bicycle, almost impossible to ride.^{8,9} Yet these bicycles are perfectly stable and pleasant to ride for long distances, whether loaded with a bag or "empty." They corner with ease and precision, allowing even minute adjustments to the line in mid-corner, to the point where cornering no-hands does not pose a problem. At the same time, they are unlikely to "wander" off course under a tired rider.

On the other hand, the Co-Motion Nor'Wester (Fig. 13, see also test on p. 22), a Mercian King of Mercia for loaded touring (Fig. 14) and other bikes with significantly more geometric trail, corner almost as easily as the old French bikes, showing that a moderate increase in geometric trail does not affect on the cornering capabilities of a bicycle. But these bikes are not as easy to ride in a straight line without hands, especially with a loaded handlebar bag. They also are more likely to wander off course under a tired rider. This behavior indicates that these bicycles "overreact" to small inputs caused by weight shifts.

Despite more geometric trail, these bikes feel less "stable" at typical cyclotouring speeds (20-30 km/h; 13-19 mph). In fact, two different parameters must be distinguished here, which I define as follows:

- **Stability** is the ability of a bicycle to hold a given line. An unstable bike will be hard to ride around a corner on a given radius. On the other hand, a bike that is too stable will resist cornering altogether and tend to "run wide."

- **Oversensitivity to small inputs:** Small shifts of body weight or hand pressure, even crosswinds or pedaling forces, cause relatively large steering deviations on bikes that overamplify small inputs. Such a bike may appear "unstable" or "twitchy," because it is difficult to ride in a straight line. The same bike may be quite stable at high speeds.

The old French cyclotouring bikes are neither unstable nor overly

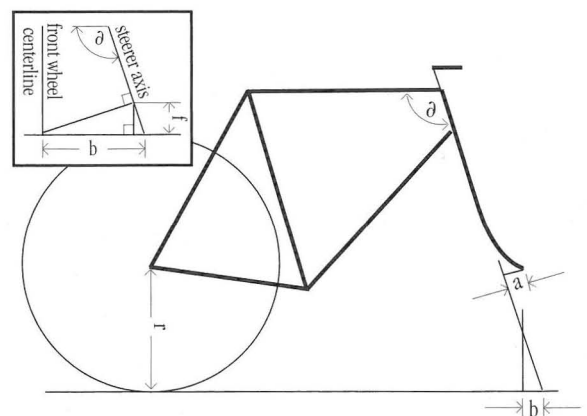


Fig. 1: Geometric trail "b" is determined by the head angle "δ," the fork offset (rake) "a," and the radius of the wheel "r." Inset: Wheel flop is directly proportional to "f" ($f = b \sin a \cos a$).

sensitive to small inputs, despite their "insufficient" geometric trail. This illustrates that a bicycle's steering is affected by numerous factors other than geometric trail (see sidebars for more detailed explanations).¹⁰ These include:

Wheel Flop: Oversensitivity to small inputs

As you turn the handlebars, the front of the bike goes down. This means that gravity tries to turn the handlebars further once they have begun to turn – wheel flop is taking over. In Figure 1, imagine the bike's top tube being held in a clamp so it stays level. As you turn the handlebars, the front wheel will lift off the ground.

Wheel flop is proportional to the weight and to the vertical segment "f" in Fig. 1.¹¹ More geometric trail and a shallower head angle both result in more wheel flop. Most people think of wheel flop as something that occurs only at very low speeds. But the forces persist at higher speeds and can result in a bike that is overly sensitive to small, involuntary inputs: Small inputs (even involuntary ones) result in a significant change in direction, and the bike is difficult to ride in a straight line.

Gyroscopic Forces

Gyroscopic forces are very complex. For practical purposes, they stabilize the bike, because as the handlebars are turned, the front wheel automatically counters the resulting lean of the bike. These forces are more pronounced with larger and heavier wheels, and at higher speeds. Gyroscopic forces apparently cancel wheel flop at higher speeds.

Pneumatic trail: Wider, softer tires are more stable

The bigger the contact patch of the tire, the more it stabilizes the bike. Pneumatic trail works very similar to geometric trail in this respect. Thus, a bike with wider tires run at lower pressure will be more stable. Pneumatic trail also increases with heavy riders and loads.

Weight on the front slows steering

Weight on the fork slows the steering of most bikes, making them more stable with a handlebar bag or panniers than when "empty."

The French approach to front end geometry

In France, much of the theory on cycling was based on the writings of Carlo Bourlet,¹² who saw geometric trail as a necessary evil: Necessary to stabilize the bike, but evil because it causes wheel flop. He postulated that geometric trail should be minimized to the point where the bike still is stable enough, yet the effects of wheel flop are minimized. One of the foremost thinkers of the French cyclotouring movement in the 1930s, Etienne Bernadet, recommended geometric trail values between 10 and 30 mm, and in no case more than 50 mm (with wide 650B tires). He reasoned that with improving roads, bikes did not need to be as stable as before, and geometric trail could be reduced.¹³

Evolution of French Cyclotouring Bikes Since 1945

With one exception, the bikes shown here are ones that I have ridden, some more than others, over familiar courses, with the same loads in the handlebar bag. Because I require relatively large frames, these bikes display few of the compromises that often are inherent in smaller frames (for example, to avoid toeclip overlap). These frames can be seen as the "ideal" expression of each framebuilder's theory.¹⁴

Early 650B Machines: Extremely little geometric trail

The early machines with wide 650B tires took the "low geometric trail" approach to an extreme. The 1947 Alex Singer (Fig. 2) has only 11 mm of geometric trail; the 1952 René Herse (Fig. 3) has 26 mm. With their

A Look at the Physics

with contributions by Jim Papadopoulos

Gyroscopic Forces

Some have suspected that gyroscopic forces keep a bicycle upright. This is not true: Constantly moving the wheels sideways, to keep them directly under the center of gravity, counters each developing lean and keeps a two-wheeler upright.

Even so, gyroscopic forces do stabilize a bicycle: Moving the handlebars to one side causes the bike to lean to the other side (countersteering) and initiates a turn. The gyroscopic force of this lean helps move the front wheel toward the side to which the bike leans. In effect, the gyroscopic force counters the initial "counter-steering," righting the bike after a steering input. This means a bicycle will become more stable at higher speeds, when the gyroscopic forces are greater. And a bicycle with larger and/or heavier wheels will be more stable.

Pneumatic trail

Where a tire contacts the ground, it creates a 'contact patch' that can be up to 10 cm (4") long. If you try to slide it sideways when it is at rest, the rubber of the tire deforms symmetrically, and the tangential reaction (friction force of the road) is pretty uniform along the patch. This leads to a net force that is centered. For example, if the wheel were mounted in vertical straight forks (90° head angle, no offset), pushing the bike to one side while it is at rest would not tend to turn the wheels.

When a wheel rolls, tire tread is laid down at the front of the contact patch without any lateral deformation. But to generate side force, for example, when initiating a turn, there must be deformation after that point. That deformation occurs because the wheel moves at a slight angle to its ultimate direction, which means that the sideways deformation of the tire grows to a maximum near the back of the contact patch. Therefore the net sideforce presses at a point BEHIND the center of the wheel. A vehicle moving forward, when subjected to sideforce, gets a reaction tending to turn the wheel, in effect trying to 'escape' the push. The wheel acts like a caster wheel, self-aligning even though there is no geometric trail. This pneumatic trail is effective forwards or backwards, without flipping the wheel!

Henry James

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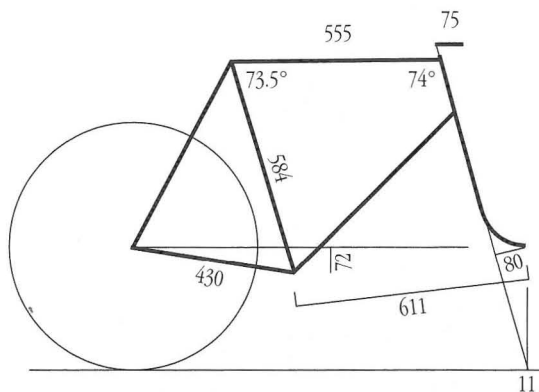
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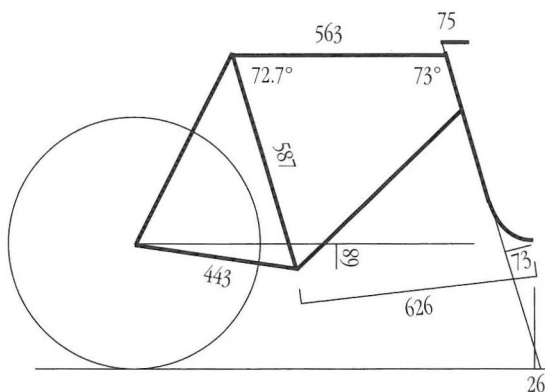
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wide tires (36 mm and wider) and the resulting pneumatic trail, these bikes are perfectly stable and corner with precision at all speeds.

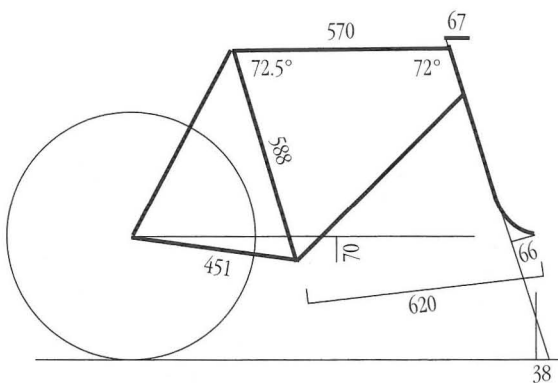
Mid-ride, I switched bikes with Mark Vande Kamp: Even after his "high geometric trail" bike, he found the Singer's handling pleasant and pre-



2. Alex Singer Randonneur No. 613, 1947.²⁶ Mitsubishi 650B x 38 mm tires (width: 36 mm, diameter: 660 mm). Wheelbase 1034 mm. $f = 3.0$ mm. Ridden 115 km (72 miles), longest ride 95 km (60 miles): Stable, but lacking sensitivity to weight shifts.



3. René Herse Randonneur No. 252, 1952.²⁷ Michelin 650B Semi-Con fort tires (width 39 mm, diameter: 669 mm). Wheelbase: 1060 mm. $f = 7.2$ mm. Ridden 450 km (280 miles), longest ride 165 km (103 miles): Stable, does not overreact.



4. Jo Routens, ca. 1952.²⁸ Mitsubishi 650B x 38 mm tires (width: 36 mm, diameter: 660 mm). Wheelbase 1065 mm. $f = 11.1$ mm. Ridden 550 km (345 miles), longest ride: 190 km (120 miles): Too stable on pavement, great on loose surfaces.

dictable. The Singer is extremely easy to ride straight no-hands at very low speeds, but to steer around corners no-hands, it requires significant weight shifts. At low speeds (<10 km/h/6 mph), it takes a lot more input to change its line than most bikes. At moderate or high speeds, the Singer corners with ease and precision. More than most bikes, it reacts to small inputs even in mid-corner. A rider used to "modern" bicycles will "overreact" at first, but it is easy to get used to this trait.¹⁵

The Herse (Fig. 3) displays none of these concerns. It handles very pleasantly at all speeds. However, switching to narrow 29 mm tires resulted in an unstable bike. While the bike still was easy to ride, the predictability of its trajectory around bends was lost: The radius decreased or increased unintentionally. And riding next to a friend on the straight, we suddenly touched handlebars, because I inadvertently had moved to his side. While the smaller wheel diameter decreases the geometric trail by 2.6 mm, this alone cannot explain the instability. It appears that the reduced pneumatic trail made the bike unstable.¹⁶

With 36 mm tires run at low pressures of 2.8 bar (40 psi) or less, the 1952 Routens (Fig. 4; 38 mm trail) is perfectly stable on gravel roads. It requires no special skills even at low speeds – a friend riding a mountain bike switched bikes with me and felt comfortable right away. The bike also is stable at high speeds and corners with ease.

However, unlike the Herse and Singer, the Routens appears "slow-witted" on pavement. While it can be made to turn just fine, the bike tends to run wide until the rider has become accustomed to the need to "force" the bike into the turn. It appears that pneumatic trail is more effective with the increased friction between tire and road. While one eventually gets used to this behavior (and increasing the tire pressure reduces the effect), cornering on pavement never feels as intuitive with this bike as it does with the 1947 Singer (Fig. 2) or 1952 Herse (Fig. 3).

Therefore, for a 650B bike with wide tires (and ample pneumatic trail), a "low geometric trail" geometry with ample fork offset (rake) appears preferable for general use. On loose surfaces, a moderate increase in geometric trail is useful, to counter the reduction in pneumatic trail due to the reduction in friction.

Narrower tires require more geometric trail

The early 700C bikes from Singer (Fig. 7, 8) and Herse (Fig. 9) have significantly less fork offset (and more geometric trail) than the 650B bikes. With narrower, higher-pressure tires, they require more geometric trail to be stable – which is achieved by reducing the fork offset. Today, the geometric trail figures of 38 to 44 mm for these bikes still would be considered low. Compared to more "modern" geometries (Rivendell, Fig. 12; Co-Motion, Fig. 13), these bikes handle better under a tired rider and/or with a fully loaded handlebar bag. Even placing two heavy phone books (4 kg/9 lbs.) in the handlebar bag¹⁷ has few negative effects on the steering, while the more "modern" machines (Fig. 12-14) become difficult to ride no-hands with this load.

Like their 650B counterparts, the old 700C randonneur bikes also depend on pneumatic trail to stabilize them. After replacing the 26 mm front tire (at 5.9 bar/85 psi) of the 1954 Singer (Fig. 7) with a 21 mm tire (at 7.9 bar/115 psi), the bike exhibited the same instability as the 650B Herse (Fig. 3) did with narrow 29 mm tires.

Modernity takes it toll

Since the 1970s, many French cyclotouring bikes with 700C wheels have been built with more "standard" geometries: less fork offset and more geometric trail. For example, the dimensions of the 2000 Alex

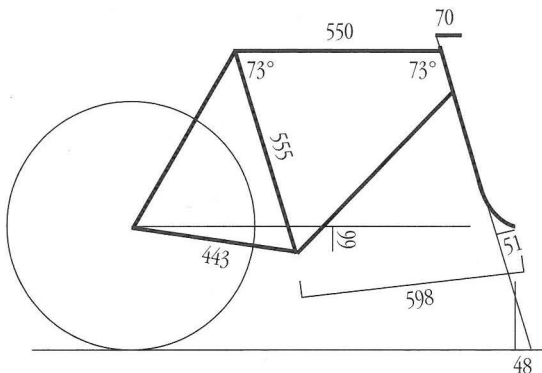
Measuring Geometry

by Jan Heine and Mark Vande Kamp

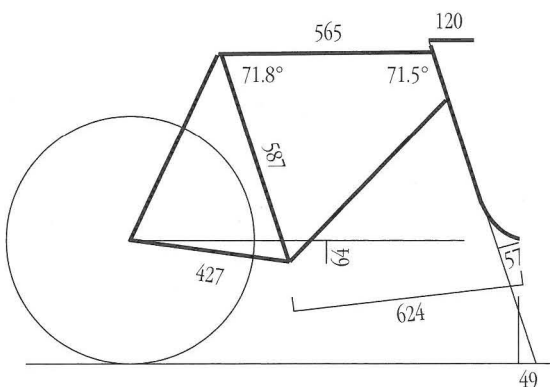
While measuring the lengths of a bicycle's tubes is relatively simple, accurately measuring the front end geometry is difficult without disassembling the bike. We placed the bicycles on a carefully leveled surface and used a precision angle finder to measure the angles of head tube, seat tube and top tube. Fork offset was measured with a long machinist's square, held parallel to the head tube. We also measured trail with a long ruler. Because the steerer axis is projected so far from the head tube, even a small angular error results in relatively large errors where the steerer axis intersects the ground, making this method unreliable. For the drawings, trail was calculated instead.

Bikes 1-4, 7, 9 were measured by both of us, and we estimate the accuracy to be within 3 mm and 0.3 degrees for all measurements, except 5 mm for geometric trail, front center and wheelbase. For each of these hikes, the calculated trail was within 6 mm of the measured trail.

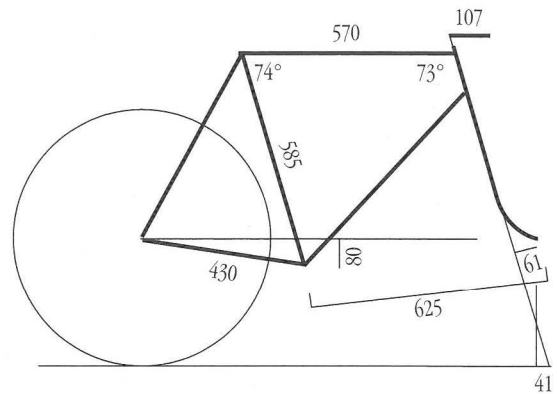
Bikes 5, 6, 8, 10-12 were measured by one person, and the accuracy is estimated to be within 5 mm and 0.3 degrees, except 8 mm for geometric trail, front center and wheelbase.



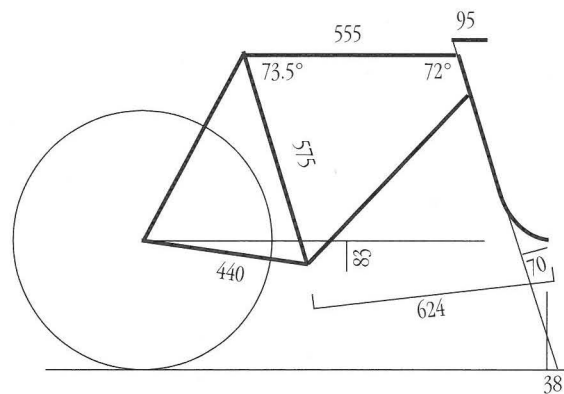
5. René Herse Camping No. 109 36148, 1948.²⁹ Englebert 650B Demi-Ballon tires (Width: 38 mm, Diameter: 662 mm). Wheelbase: 1033 mm. $f = 13.4$ mm. Ridden 0 km



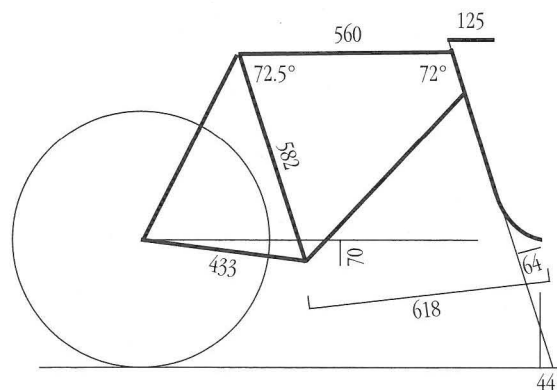
6. Alex Singer Camping No. 2711, 1985.³⁰ Wolber Super Tandem 650B x 32 mm tires (width: 32 mm, diameter: 652 mm). Wheelbase 1045 mm. $f = 14.7$ mm. Ridden 300 km (190 miles), longest ride: 64 km (40 miles): Stable, can be ridden no hands with 80 lbs. load at moderate or high speeds. Corners well.



7. Alex Singer Randonneur No. 1084, ca. 1954.³² Michelin Axial Select 700C x 25 mm tires (width: 26 mm, diameter: 684 mm). Wheelbase 1045 mm. $f = 11.4$ mm. Ridden 640 km (400 miles), longest ride: 310 km (195 miles): Stable, easy to ride no hands with heavy load at moderate or high speeds, corners great.



8. Alex Singer Randonneur No. 1179, 1962.³³ Wolber Sport 700C x 28 mm tires (width: 28 mm, diameter: 688 mm). Wheelbase 1050 mm. $f = 11.2$ mm. Ridden 800 km (500 miles), longest ride 405 km (255 miles): Stable, easy to ride no hands with heavy load at moderate or high speeds, corners great.



9. René Herse Démontable, No. 119 71, 1971.³⁴ Rivendell Roly-Polly 700C x 28 mm tires (28 mm wide, diameter: 684 mm). Wheelbase: 1040 mm. $f = 12.9$ mm. Ridden 400 km (250 miles), longest ride 160 km (100 miles): Stable, easy to ride no hands with load at moderate or high speeds, corners great.

Singer (Fig. 10) closely match those of the 1954 bike (Fig. 7) by the same maker, except the newer bike has 11 mm less fork offset.

I imagine that a variety of factors contributed to this trend: Many randonneurs began using narrower tires at higher pressures, even tubular racing tires (21.5 mm wide), reducing the pneumatic trail. Thus, the geometric trail was increased to compensate. As support cars became common in randonneur events, fewer people used handlebar bags, so wheel flop was not as big an issue as it had been. And with racing bikes dictating the fashions, forks with large offsets seemed antiquated to many buyers.

The result is not a happy one if you prefer cyclotouring the traditional way, with comfortable tires (28 mm or wider) and a bag full of the necessities for the road. Viewed alone, the newer bikes handle very nicely, and their riders certainly are happy with them. But riding them back-to-back with their ancestors, I found that the old machines simply handle better, because they are less sensitive to small inputs.

Tandems

For tandems, wheel flop is even more important than for single bikes, because much more weight rests on the front of the bike. In addition, with two riders, the involuntary inputs are larger and less predictable. In fact, a tandem that is overly sensitive to pedaling forces often will weave slightly from side to side as it travels down the road, requiring constant corrections from the captain (front rider). On such a tandem, it will be very difficult for both riders to get out of the saddle.

The best tandems do not display this oversensitivity. They are as easy to ride as single-bikes, because stoker movements are not transmitted into the steering. Getting out of the saddle even with inexperienced stokers is intuitive. These tandems use relatively steep head angles with large fork

offsets, resulting in very small geometric trail figures.¹⁸ Both the steep head angle and the small geometric trail minimize wheel flop. Wide tires are useful on tandems for a variety of reasons, including shock absorption and safety.¹⁹ If their increased pneumatic trail allows lower geometric trail figures, so much the better.

Camping bikes

The two French camping bikes (Fig. 5, 6) in this overview have larger geometric trail figures than their counterparts for lighter work. I do not know whether this is because they were intended to be ridden off-pavement (similar to the Routens, Fig. 4), or whether the added geometric trail is needed to carry the load. Compared to modern "touring" bikes like the Mercian (Fig. 14), the geometric trail figures still are very low.

While the Herse Démontable (Fig. 9) is not a full camping bike, it handles 14 kg (30 lbs.) of load without problems. Similarly loaded, the Mercian (Fig. 14) no longer can be ridden no-hands. Comparing these two bikes (equipped with the same tires) shows that it is counterproductive to endow a bicycle for loaded touring with excessive "stability-inducing" geometric trail. Because of the associated oversensitivity to small inputs, the effect is the opposite: The bike is harder to ride at moderate speeds. Carrying a large load on the front of such a bike (see p. 9) is not advisable. In fact, when I tried loading the Mercian (Fig. 14) with the same weight distribution (60% front, 40% rear) that worked so well on the Alex Singer (Fig. 6), the Mercian became close to unrideable.²⁰ So the fact that most American bicycle tourists traditionally have placed the bulk of their load on the rear wheel may have less to do with ignorance than with poorly designed bicycles.

Racing Bikes

In the 1940s, many racing bikes had geometries very similar to the classic French 700C cyclotouring bikes. With the advent of narrower tires (less pneumatic trail), geometric trail figures seem to have increased. The 1950s Learco Guerra (Fig. 11) appears to be a transitional bike – it probably was designed for narrower tires than the currently mounted 30 mm tubulars. Chuck Schmidt quoted geometric trail figures of 34 to 46 mm for a number of Italian racing bikes from 1939 through 1964.²¹ On the other hand, Claude Genzling shows geometric trail figures between 43 and 76 mm for various bikes of 1980s professional racers.²² Genzling's figures appear to indicate that there is very little agreement on how to design a well-handling racing bike.

One could argue that large geometric trail figures (and associated wheel flop) are desirable on racing bikes, which then react strongly to very small inputs – you "think them around corners." However, others have found that limiting "wheel flop" results in geometries that respond precisely to a given input and make for more pleasant handling and superior cornering. Wheel flop appears only to help initiate a turn, but once in the turn, adjusting the line on a bike with large geometric trail is difficult – the bike is too stable at high speeds.

Conclusions

A bicycle is pleasant to ride if it goes straight when the rider wants to go straight, and turns easily and predictably when the rider wants to turn. A bike that fights a turn is as unpleasant as one that deviates from a straight line with every small, involuntary input. This means that bikes should have just the right amount of stability, while not being overly sensitive to small inputs.

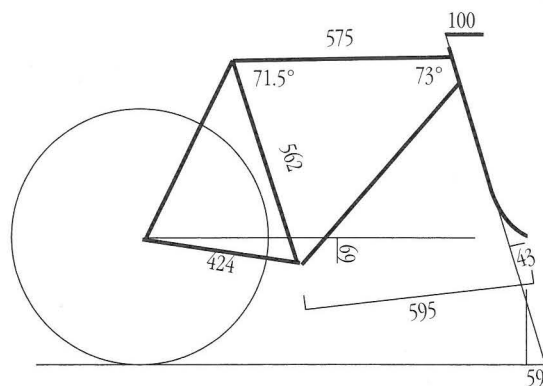


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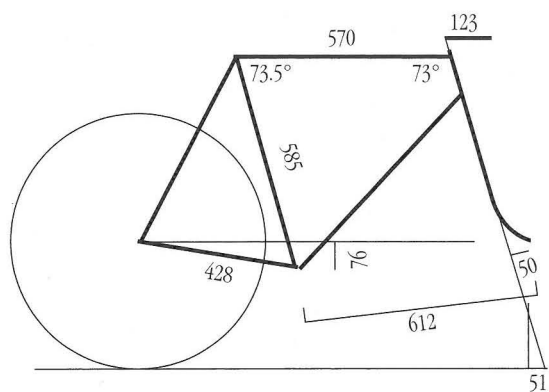
Experiencing Wheel Flop and Oversensitivity

To experience wheel flop and oversensitivity to small inputs, ride to the top of a long straight, not too steep hill. Let the bike roll from a low speed. Try to ride no-hands.³⁸ At first, this will be impossible, as the bike veers off course and shifting your weight does not provide enough correction. As the bike accelerates, you will be able to take your hands off the handlebars, but the bike will swerve as each correction "overshoots" the straight-ahead and sends the bike off to the other side. The swerving diminishes as you pick up speed, until finally, the bike will ride perfectly straight, reacting to your inputs exactly as intended.

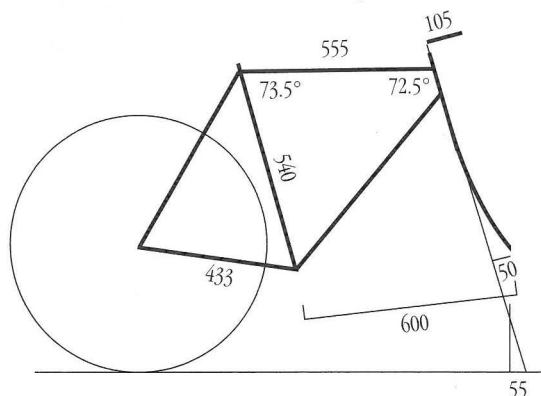
The speed at which this happens roughly corresponds to the speed at which the bike stops being overly sensitive to small inputs. This speed varies between less than 16 km/h (10 mph) for many of the old French cyclotouring bikes, via about 28 km/h (18 mph) for the Mercian (Fig. 14) to more than 40 km/h (25 mph) for an old Bike Friday with 20" wheels that I used to ride.



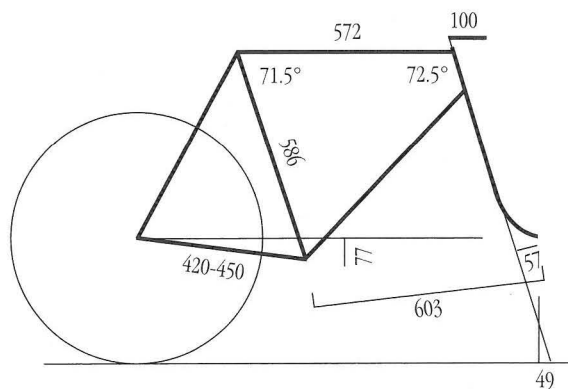
12. Rivendell custom, 1999.³⁵ Rivendell Rolly-Polly 700C x 28 mm tires (width: 27 mm, diameter: 682 mm). Wheelbase 1010 mm. $f = 16.6$ mm. Ridden ca. 40,000 km (25,000 miles), longest ride 1200 km (750 miles): Stable, difficult to ride no hands with heavy front load at moderate speeds, corners great. Toeclip overlap with fenders and 172.5 mm cranks.



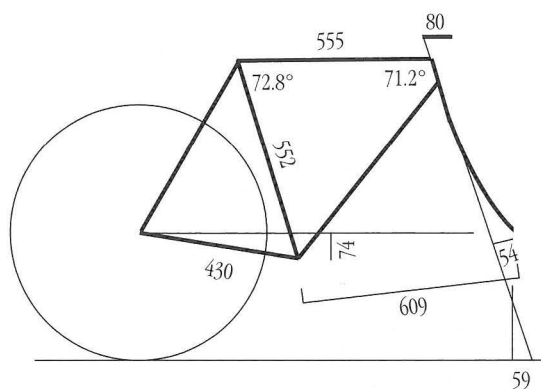
10. Alex Singer Randonneur No. 3272, 2000. Michelin Axial Pro 700C x 23 mm tires (width: 24 mm, diameter: 678 mm). Wheelbase 1032 mm. $f = 14.3$ mm. Ridden 50 km (31 miles): Only significant difference to 1954 Singer (Fig. 7) is smaller fork offset: Bike reacts stronger to small inputs.



13. Co-Motion Nor-Wester 57 cm, 2004.³⁶ Rivendell Ruffy-Tuffy 700C x 28 mm tires (width: 27 mm, diameter: 682 mm). $f = 15.9$ mm. Ridden 378 km (236 miles), longest ride 150 km (94 miles): Stable, difficult to ride no hands with heavy front load at moderate speeds, corners great.



11. Learco Guerra racing bike with Campagnolo Cambio Corsa, ca. 1950s.³¹ Clement Campione del Mundo tubular tires (1995 model, width: 30 mm, diam.: 670 mm). Wheelbase 1010-1040 mm (adjustable). $f = 14.1$ mm. Ridden 320 km (200 miles), longest ride: 64 km (40 miles): Stable, pleasant cornering.



14. Mercian King of Mercia loaded touring bike, 1990.³⁷ Rivendell Rolly-Polly 700C x 28 mm tires (width: 27 mm, diameter: 682 mm). Wheelbase: 1028 mm. $f = 17.9$ mm. Ridden 24,000 km (15,000 miles), longest ride 335 km (210 miles): Stable, corners fine. Oversensitive with a tired rider or full handlebar bag.

Remarkable similarities

Numerous factors influence how a bike handles, including many that are beyond the scope of this article: weight distribution, wheelbase, Q factor and many more. I cannot claim to understand exactly how these interact. However, I was astonished that all factors involved appear to counteract each other to the degree that bikes with very different front end geometries have very similar, pleasant handling characteristics. That a Mercian (Fig. 14; 71° head angle; 59 mm geometric trail) offers similar cornering and stability as a Singer (Fig. 7; 73° head angle, 41 mm geometric trail) came as a surprise. This probably is the reason why most performance bicycles of the last 70 years have used head angles between 68 and 75 degrees, even though the same geometric trail figures could be achieved with almost any head angle. In this range of head angles, the various factors (geometric trail, wheel flop, gyroscopic forces) apparently balance each other to make for pleasant handling. Similarly, it appears that a wheel circumference of about 660-680 mm provides the best combination of gyroscopic forces and pneumatic trail with these established geometries.²³

Geometric trail: Less is more

The differences between the bikes tested for this article are in the details. Compared to standard "sport touring" geometries with relatively large geometric trail, the old French cyclotouring geometries are less affected by weight on the front wheel. They corner with greater precision: The response of the bike could be called "linear" to the rider's inputs, making adjusting one's line in mid-corner intuitive. They only require a light touch on the handlebars to direct them exactly where one wants to go. No-hands riding in a straight line and around curves at moderate (or high) speeds poses no problem.

They are easier to ride straight when tired, because they react less to small, involuntary inputs. As a result, they also are less affected by crosswinds and pedaling forces. The larger fork offset moderately improves shock absorption and minimizes toeclip overlap, providing additional advantages. Despite relatively low geometric trail figures, these bicycles are perfectly stable at all speeds. They exhibit none of the "twitchy" characteristics that many predict.²⁴

Tire size (and pressure) are important

The increased pneumatic trail of wider tires at lower pressures stabilizes the bike. Thus, bikes with wider, lower-pressure tires require less geometric trail than bikes with narrow, high-pressure tires. Bike designers often overlook this factor, yet I found it to be of critical importance in this test. It is remarkable how similar the 1954 700C Alex Singer (Fig. 7) and the 1952 650B René Herse (Fig. 3) handle. Their head angles are the same (73°), but their fork offsets are very different (61 mm vs. 73 mm), resulting in different geometric trail figures (41 mm vs. 26 mm). It appears that the increased pneumatic trail of the wide 650B tires of the Herse compensates for its reduced geometric trail.

On the other hand, with almost identical front end geometries and geometric trail figures, the 1962 700C Alex Singer (Fig. 8) and the 700C Herse Démontable (Fig. 9) are close to perfection in every respect, while the 650B Jo Routens (Fig. 4) is sluggish (too stable) on pavement, because the wider tires of the 650B Routens add pneumatic trail.

Because their stability is close to a threshold, it is of paramount importance that the classic French cyclotouring bikes are ridden with the tire size and pressure for which they were designed. Using narrower tires at higher pressures makes them unstable.

A "fits-any-tire" bicycle, which must be stable with the narrowest tires, always will be fraught with compromises in handling and stability. Wider tires slightly increase geometric trail. At the same time, pneumatic trail and gyroscopic forces increase. Together, these factors change the feel of the bike. Just like most bicycle builders would shudder at the thought of replacing the fork on a given bike with one that provides radically different offset, so should bicycles be designed for a certain tire size.

Wider tires are better

Pneumatic trail has the advantage of not causing wheel flop. Wider tires with more pneumatic trail allow lower geometric trail figures and thus less wheel flop. This results in a more neutral, linear handling and avoids oversensitivity to small inputs.

It may be difficult to design a bike with narrow, high-pressure tires that handles well at moderate speeds: A bike with little pneumatic trail must derive more of its stability from geometric trail, which in turn increases wheel flop, causing "overreaction" to small, involuntary inputs. This is even more true for a load-carrying bicycle or tandem.

Less geometric trail for wider tires

Opposite from current thinking, my experience suggests that bicycles with wider tires, designed to be ridden at lower speeds, require less geometric trail than those with narrow tires ridden at high speeds. However, bikes designed for off-pavement use need more geometric trail to make up for the reduced pneumatic trail on loose surfaces. In the end, stability is derived from the "sum" of geometric and pneumatic trail.

Empirical data still is best

The above is only a first stab at trying to explain the empirical data from riding numerous bicycles over the same courses, with the same loads. Even if the explanations may not be entirely correct, there is little question that these bikes behave the way they do. Why this is so, is secondary for their riders. The drawings are provided to serve as examples for the design of future cyclotouring bicycles.

Clearly, there is no magic number for geometric trail. While the often-quoted range of 50-60 mm may work well for racing bikes with narrow, high-pressure tires, it is too much for cyclotouring bikes.

It is interesting to compare the extremes in this test: The 1947 Alex Singer (Fig. 2; 11 mm geometric trail, $f = 3$ mm) offers adequate stability, but no more. On the other hand, it is very insensitive to small inputs. A little too insensitive, in fact: A little more wheel flop might be useful to make the bike more "communicative." The Singer would make a good beginner's bike, as it is difficult to "overcorrect" on this bike.²⁵ Contrasting this, the Mercian (Fig. 14, 59 mm geometric trail, $f = 17.9$ mm) is too stable at speed, making mid-corner corrections difficult or impossible. But at moderate speeds, it is overly sensitive to small inputs, eager to veer off course under a tired rider.

For my personal taste, I find the 1952 René Herse (Fig. 3) to be the most pleasant bike for 36-40 mm-wide 650B tires. For 700C x 28-30 mm tires, all three old 700C cyclotouring bikes (Fig. 7-9) offer handling that is as close to perfection as any I have ridden. For off-pavement riding, it is hard to beat the 1952 Jo Routens (Fig. 4).

There may be other geometries that work well for a given purpose, but for a "real-world" bicycle with a moderate or heavy load, I have not yet experienced anything that could be considered an improvement over the French cyclotouring bikes from 50 years ago.

Notes:

Mark Vande Kamp assisted in measuring most of the bikes shown here. George Gibbs (Il Vecchio Bicycles), Mike Kone, Helen and Neville March, and Terry Zrmhal loaned bikes for this test. This article was reviewed by John Bayley, Mike Kone, John Olsen, Jim Papadopoulos and Mark Vande Kamp.

- 1 For an introduction, see Papadopoulos, J., 2004. Steering and Balancing. In: D. G. Wilson, *Bicycling Science*, MIT Press, Cambridge, p. 263.
- 2 Jim Papadopoulos, 2005, personal communication.
- 3 For example, <http://www.faqs.org/faqs/bicycles-faq/part2/section-25.html>, status 1/18/2005.
- 4 Heine, J., 2001: The French Randonneur Bicycle. *Rivendell Reader* 24: 33.
- 5 Calculating trail requires some simple trigonometry. Alternatively, a trail calculator is available at <http://www.kreuzotter.de/english/elenk.htm>, status 1/31/2005.
- 6 For example, http://www.sheldonbrown.com/gloss_tp-z.html, status 1/10/2005.
- 7 For example, see: Experiments with Rake & Trail, *Rivendell Reader* 31, p. 30.
- 8 Bill Boston's "Accutrax" software calculated that a 1947 René Herse (see Ref. 24) was "off [the] scale in the unstable range" see <http://search.bikelist.org/getmsg.asp?Filename=framebuilders.10303.0155.eml>, status 1/9/2005.
- 9 Marc Muller proposed "steering angle" as a determining factor whether a bike is twitchy (see 7). However, the "steering angle" of the 1952 650B René Herse (Fig. 3) is only 4.43°, much less than the 9.5° postulated as the lower threshold for a stable bike.
- 10 For a detailed discussion, see 1.
- 11 Jim Papadopoulos, 2005, personal communication. Another factor is that when the handlebars are turned, the center of gravity of the bike shifts sideways, amplifying the lean. This is more pronounced on a bike with more trail.
- 12 Carlo Bourlet (1866-1913), Professor of Mathematics and Sciences at the Sorbonne and the Ecole des Arts et Metiers. He wrote: "Traité des bicyclettes et des bicyclettes" (Masson et Gauthier-Villars, Paris, 1894), re-edited as "Nouveau traité des bicyclettes et des bicyclettes" (Masson et Gauthier-Villars, Paris, 1898) and "La bicyclette, sa construction et sa forme" (Gauthier-Villars, Paris, 1899).
- 13 Bernadet, E.: Cyclotechnie, Etude de la Direction (Study of Steering), *Le Cycliste* 9/10, 1962 (reprinted from an unspecified 1937 issue of *Cyclo-Magazine*).
- 14 It is possible that some of the relatively steep head angles on the large frames were selected to avoid excessively long front-centers. However, I believe it is more reasonable to explain the slacker head angles and more fork offset on smaller frames as a measure to avoid toeclip overlap.
- 15 Because the Singer does not react to small inputs, frame alignment is critical: At first, riding no-hands required leaning my body far to the right, despite the frame being as close to perfectly aligned as possible. Turning the ("perfectly" dished) front wheel around solved this problem, because the correction required was extremely small – the normal variations inherent in any tire were enough. On a bike that reacts to smaller inputs, the initial misalignment would not have been noticeable, as the rider would have corrected for it instinctively by leaning imperceptibly to one side.
- 16 The narrower tires were about 57 grams (13.6%) lighter, causing a slight reduction in the self-stabilizing gyroscopic force, which may have contributed to the instability.
- 17 While this weight may seem excessive, it is commonly carried by randonneurs who pack food for several hundred kilometers of riding, plus clothes, spare tubes and tools.
- 18 Thomas, H. and J. Heine, 2004. Why the old Tandems Handle so Well. *VBQ* Vol. 2, No. 3, p. 28.
- 19 If a tandem's narrow front tire gets caught in a rut, the rider cannot lift it out as they can on a single bike. A wider tire is less likely to get caught in a rut.
- 20 The flexible Blackburn aluminum racks on the Mercian may have contributed to the problem. The Singer is equipped with custom racks brazed from tubular steel.
- 21 <http://search.bikelist.org/getmsg.asp?Filename=classicrendezvous.10501.2216.eml>, status 1/31/2005.
- 22 Genzling, Claude, 1997: *Corps/Matière/Géométrie – le dessin de la performance*. 175 p. Ecole des Beaux Arts de Metz. ISBN 2-909588-00-03-3.
- 23 Heine, J., 2004: Choosing Your Wheels: History, Comfort and Rolling Resistance. *VBQ* Vol. 3, No. 2, p. 25.
- 24 <http://search.bikelist.org/getmsg.asp?Filename=framebuilders.10501.0754.eml>, status 2/25/2005. Other examples can be found in the same archive.
- 25 Ernest Csuka of Cycles Alex Singer said about the geometry: "Well, that was influenced by fashion. We wanted to make modern bikes, and to make them look different from the laid-back pre-war bikes, we increased the head angles to 73 or, on taller frames, even 74 degrees. We did that for a year or so, then found that a head angle around 73 degrees offered the best ride and handling." Personal communication, 2005.
- 26 For photos of this bike, see Heine, J. and J.-P. Pradères, 2005: *The Golden Age of Handbuilt Bicycles*. Vintage Bicycle Press, Seattle, p. 54. ISBN 0-9765460-0-0.
- 27 For a photo of this bike, see *VBQ* Vol. 3, No. 2, p. 25.
- 28 For a detailed ride report, see *VBQ* Vol. 3, No. 2, p. 1.
- 29 For photos of this bike, see *The Golden Age of Handbuilt Bicycles* (Ref. 26), p. 70.
- 30 For photos of this bike, see *The Golden Age of Handbuilt Bicycles* (Ref. 26), p. 150.
- 31 For photos of this bike, see *On The Wheel* # 11 (Oct/Nov 1999), p. 26-27.
- 32 For a photo of this bike, see *VBQ* Vol. 3, No. 2, p. 25.
- 33 For photos of this bike, see *The Golden Age of Handbuilt Bicycles* (Ref. 26), p. 132. For a detailed ride report, see *VBQ* Vol. 1, No. 1, p. 14.
- 34 For photos of this bike, see *The Golden Age of Handbuilt Bicycles* (Ref. 26), p. 144. See also p. 12 of this issue.
- 35 For photos of this bike, see *VBQ* Vol. 1, No. 3, p. 12.
- 36 Head and seat angle taken from Co-Motion web site. See also p. 22 of this issue.
- 37 For photos of this bike, see *VBQ* Vol. 1, No. 2, p. 19.
- 38 This is a theoretical experiment only. *VBQ* will not be responsible for any injuries.

Designing A Bicycle

Bottom Bracket Height

Many believe that a lower bottom bracket makes a bike handle better. For the bikes shown here, bottom bracket height (calculated from wheel radius minus bottom bracket drop) varied between 259 mm (1947 Alex Singer, Fig. 2) and 272 mm (1971 Herse Démontable, Fig. 9; 1999 Rivendell, Fig. 12). All of these are low values by modern standards. The differences in handling found in this test do not correlate with bottom bracket height, indicating that at least for relatively low bottom brackets, a few millimeters do not make much of a difference.

Seat Angle

Many of the old cyclotouring bikes have seat angles that are steeper (73-74°) than is the current fashion. On the other hand, most old racing bikes have very shallow seat angles (71-72°). Why do racers need shallower seat angles than cyclotourists?

What really counts is setback – how far the seat is behind the vertical plane of the bottom bracket. Setback depends not only on the seat angle, but also on the saddle (newer "plastic" saddles usually provide more than traditional leather ones) and seatpost (newer designs usually provide less).

Many believe that more setback facilitates better climbing. I found this to be true when pushing a relatively big gear; as racers on bikes with a limited gear range often had to do. In my experience, as long as I am spinning, the difference in setback between the bikes tested here does not affect my climbing abilities. For my saddle height of 74 cm, the difference in setback between seat angles of 74° and 72° is only 2.5 cm – for which I apparently can compensate by sliding backwards on the saddle when climbing hard. However, on every bike, I tend to move the seat back toward the end of the range of adjustment, indicating that I prefer bikes with more setback.

Compromises

Frame design is a matter of compromise. Each factor influences a host of others. A bike with a slack seat angle (to provide more setback for the saddle) will have a shorter front-center and may suffer from toeclip overlap. More setback also requires longer chainstays to provide clearance for rear wheel and fender behind the seat tube. A small frame, especially one with a short top tube, will require a shallower head angle and more fork rake, if toeclip overlap is to be avoided. A good bike is characterized not by one parameter, but by the combination of compromises that provides the best ride.

Handlebar Width and Geometry

Until the early 1970s, most bicycles had relatively narrow handlebars (between 35 and 40 cm), even though wider bars were available. A few decades ago, handlebars gradually became wider (today: 42 to 46 cm). Many believe that wider handlebars offer better control. Others scale bars to the width of the rider's shoulders for comfort.

For bicycles with a modern "high geometric trail" geometry, wider bars may be useful. Because these bikes react strongly to small, involuntary inputs, a longer lever reduces the magnitude of these inputs. And the added leverage may be useful to control excessive wheel flop.

The geometries of the old cyclotouring bikes make sense with narrow handlebars: The bike requires little force to keep on course – no need for added leverage. And the bike can handle small involuntary inputs, so there is no need to reduce the inputs by using wider bars.