# BEYOND TELESCOPIC FORKS

## WHEN, HOW, WHY AND WHY NOT

*Telescopic forks, utilizing coil springs and hydraulic dampers, have been a technological fixture for 40 years. Why? Where's something better?*

*By Kevin Cameron*

*RADD*

*Yamaha YZR500*

Almost without exception, modern high-performance motorcycles use telescopic forks. Telescopic fork development has kept pace with the sports motorcycle's needs so closely that no racer has won a major championship, or even a race, on any other kind of front end for nearly 30 years. Even so, real problems remain in motorcycle front end design—problems crucial to the safety and performance of both race bikes and street machines—and engineers continue to search for innovative solutions. Specifically, these have to do with the speed of steering response and the difficulty of steering a machine accelerating out of a corner.

Before we examine the alternatives to today's standard telescopic fork, it's helpful to know how engineers arrived at the system as it's used on current street and race bikes, how it works, and what its advantages and disadvantages are.

Front-end design as we know it today is nothing more than a kind of stalemated compromise among the major variables. As front suspension and steering are currently implemented, the only ways to get faster response are to reduce front-wheel spinning mass (as in the shift to 16 inch wheels), to steepen steering geometry, and to cut wheelbase by any means possible.

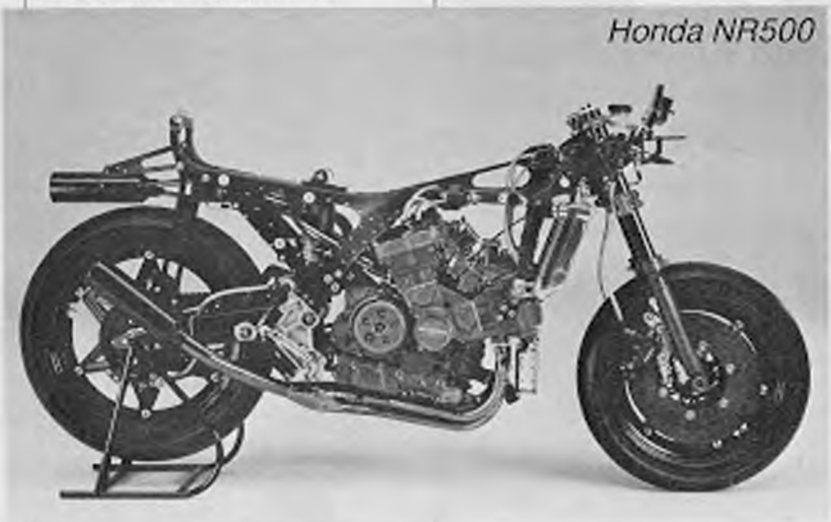
Sounds simple enough. But mixing a short wheelbase with a powerful engine makes an accelerating machine run wide out of corners; moving the engine and rider forward counteracts this and permits faster acceleration, but it also makes low speed steering heavy. The only available cure for this heavy low-speed steering is steeper steering geometry, which is unstable unless combined with a very stiff chassis and high-quality suspension. Change one variable and you affect all the others.

A motorcycle's front wheel, and the way it attaches to the machine, has some seemingly simple but crucial tasks to perform. First of all, something's got to hold the front end up. Second, the machine needs a steering mechanism. Third, the bike must be stable—it mustn't constantly threaten to "get away" every time its rider's mind may wander.

From the beginning, motorcycles borrowed the bicycle's simple steered fork, a system which carries the wheels between the "tines" of the fork, whose "handle" pivots in steering bearings above the tire. The axis of these steering bearings, if projected downward, hits the road ahead of the point at which the tire touches it. Like a furniture caster, the rolling tire then naturally tends to trail back into line behind the steering axis if deflected.

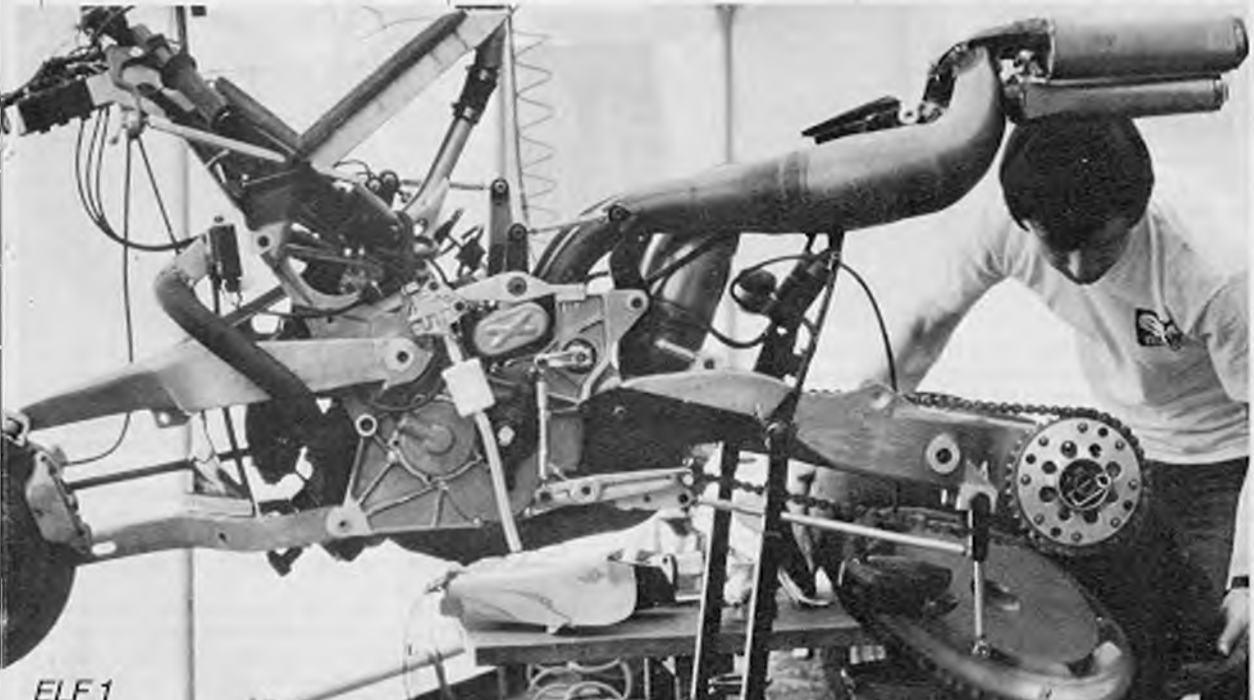
The important variable in this caster effect—trail—is measured on the road surface as the distance between tire-contact point forward to the projection of the steering axis. The steering axis may pass through the axle centerline, or it may not. If it doesn't, the distance between the two is called offset. For less intuitive reasons, the steer axis is inclined backward at an angle called rake. In cornering, steer-axis rake, acting with trail and the weight on the front tire, allows the front wheel to fall naturally to the steer angle that will make the machine hold line. To further complicate matters, the exact profile and deflection characteristics of the front tire also exert a powerful influence on steering.

The search for rigid yet light teleforks led Honda to carbon fiber tubes on the oval-piston NR500


Honda NR500

the front wheel, producing extra steered mass that can lead to steering oscillations. Consider the simplest mechanical oscillator—the pendulum. Here we have mass (the pendulum bob), a restoring force (gravity, always tending to make the pendulum point straight down), and a driving force (the clock's escapement), giving the pendulum a little push every cycle or half-cycle, and always in step with it. Damping force is also present—the friction of the air and of the pendulum pivot. The pendulum swings at a natural frequency, determined by its geometry and its restoring forces.

A motorcycle's front end is also a mechanical oscillator. In this case, the angular inertia of the steered assembly is the mass, the caster of the steering geometry and gyro effects of the spinning wheel provide restoring forces, and the driving forces may be impulses from the road, from an out-of-round or out-of-balance front wheel, or vibrations in frame or fork. The damping forces are provided by the tire. Like a pendulum, a motorcycle's front end also has a natural frequency. When any force shakes it, the bars will wobble at about 8–10 cycles per second. If the damping is adequate, it kills the oscillation almost instantly. With less damping or more driving force, a steady wobble may result. If energy enters the system faster than damping forces take it out, the wobble can build up without limit, resulting in loss of front tire grip and an eventual crash.


ELF 1

Again, a change in one variable affects all the others. Rake and trail, geometrically interrelated, are a prime example. If you increase rake, trail increases with it. And trail—the measure of the caster effect—strongly influences stability. As you would expect, more trail makes the steering harder to deflect and yields increased high-speed stability but heavier steering. Reducing trail lessens the self-stabilizing effects but also lightens the steering and increases responsiveness to rider inputs.

There is a classic dichotomy, a schism, between stability and responsiveness: Make the geometry more stable (more rake and trail) and it better resists all deflecting influences—including the rider's efforts to steer. Make it less stable (less rake and trail) to obtain the benefits of quicker response and the front end will also respond more strongly to unwanted influences such as chassis flexure or bumps. Steering rake is weight-dependent, that is, a high rake angle combined with a high forward weight bias will make low-speed steering very heavy.

With a steered fork, the wheel-support structure and suspension pivot with

In the ELF 1, the front shock was positioned above the engine on linkage, and all chassis components—steering structure, fuel cell, front and rear swing arms—hung on the engine cases. It was a radical concept—too radical.

# BEYOND TELESCOPIC FORKS

This hub-center steering Ner-A-Car of the 1920s

At around 35–40 mph, front tire rotation is in step with the wobble frequency, so any lateral waviness in the tire can act as a driving force in step with the wobble frequency. Normally, the presence of the rider's hands on the bar provides enough extra damping to prevent a problematic wobble from developing; riding hands-off at this particular speed allows some machines to develop a noticeable wobble. Above or below this speed, the driving force from the tire is either too fast or too slow to excite wobble effectively. At any speed, some oscillation is present, though it might occur at an amplitude that renders it unnoticeable. The rear of a machine also "weaves," swinging from side to side at a characteristic frequency. Changes to steering affect this oscillation as well.

An increase in the steered mass of the front end, or a redistribution of its mass farther from the steering axis, often intensifies oscillation. Anything that increases the damping—a wider or softer tire, reduced tire pressure, the rider's hands, or the presence of an actual steering damper—will tend to reduce the amplitude of such oscillation.

The rake and trail commonly used today strikes a balance; it's the most responsive setting that will still give adequate stability with the present chassis and suspension. Current sport bikes can use 26 degrees rake and under four inches of trail because, along with fairly effective suspension dampers, they have chassis three to five times as stiff as those from 10 years ago. When components improve further, steering geometry will again become more radical.

Modern road race bikes have shortie wheelbases of under 54 inches, steering heads set at 20–25 degrees, and just enough trail. Fifteen years ago, when weak, tiny forks and frames constructed of pipe were the rule, the entire chassis acted as a mechanical oscillator, twisting and bending, wobbling and weaving at will unless strongly controlled by a heavy 30-degree-plus rake and four and a half inches or more of trail. Such bikes did indeed corner as if on rails. By the same token, these "chopper geometry" machines were about as easily steered as locomotives.

Despite the advances, problems remain with conventional front forks:

(1) Because the entire front suspension steers with the wheel, ample mass is available to store the energy of a potentially dangerous wobble.

(2) The power of modern brakes can stop even street motorcycles at rates of more than one G. A high-rate stop therefore produces a force at least equal to the machine's weight at ground level, which is then multiplied by the leverage of the long fork assembly before being fed into the frame through a pair of small, closely spaced steering head bearings located high above the engine. A heavy frame structure is required when reacting to bearing forces of a ton or more.

(3) When a tele-equipped machine brakes, it pitches forward, tilting the fork assembly to a reduced rake angle. This results in a loss of trail, and a potential loss of stability.

(4) Teleforks are pro-dive, meaning their rake angle produces a force component during braking that tends to compress the fork. This is in addition to normal forward weight transfer.

(5) The wheelbase of a telefork-equipped machine changes with every suspension movement—because the front wheel moves back slightly as the suspension compresses. This causes tire loadings to change somewhat as the suspension moves.

(6) During braking, the sliding joints of a telescopic fork are heavily side-loaded. This tends to cause binding and harsh suspension action. Everyone is fa-

...with stiction or static friction — the larger force required to start something sliding than to keep it sliding. On forks of older design, even with no brakes applied, this stiction force can easily amount to 50 pounds. Under braking, it rises to much higher figures.

Forks are now built with low-friction Teflon-coated bushings, and stiction has been reduced by some 80 percent, but telescopic forks are still stiffer under braking than otherwise. This results in force spikes as the fork follows its jerky descent that must be borne by the small front tire. Rear suspension development, through the use of rolling contact suspension bearings and sophisticated damper units, has taught engineers that tires work much better when they're free from such force spikes.

(7) At their present level of design, teleforks are denied the use of any kind of rising rate linkage.

(8) Though they could easily be, thus far, sophisticated gas-pressurized dampers have not been widely applied to telescopic forks.

[illegible]

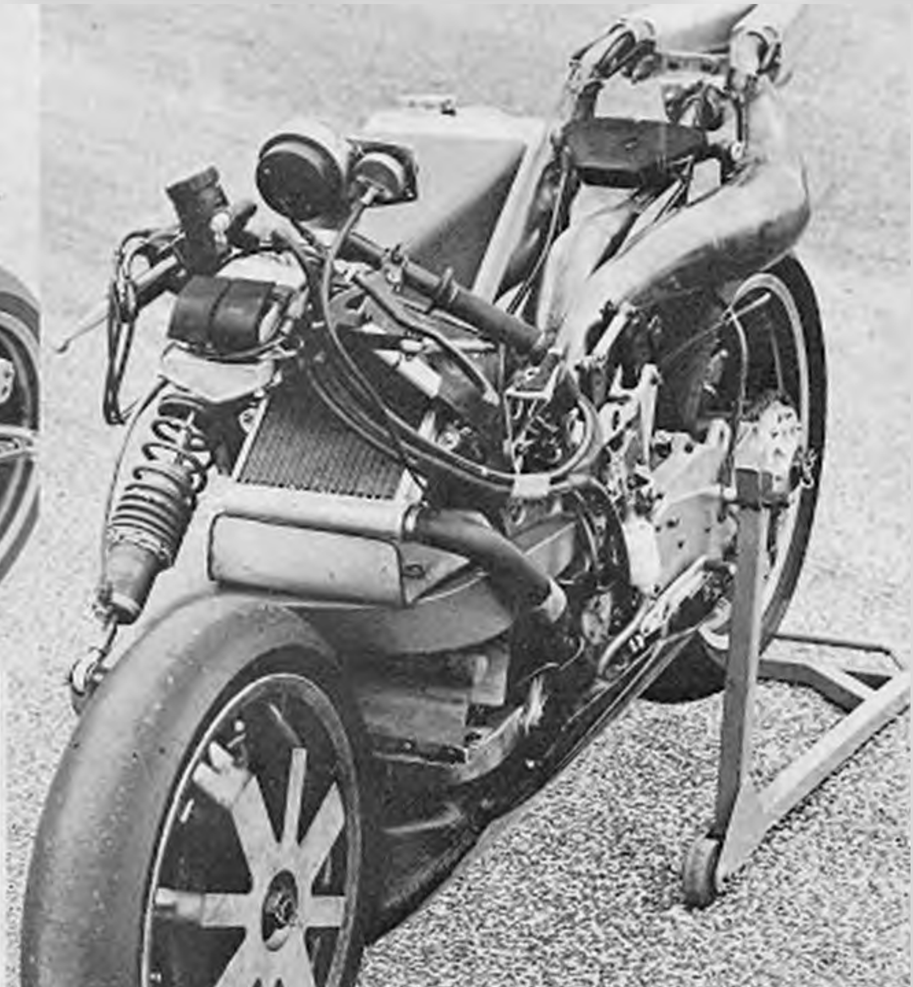

The Simons upside-down fork places the large-diameter sliders at the top, where the greatest stiffness is required.

(9) On the matter of significantly quickening steering response there is no prospect of any imminent breakthrough.

Of these objections to the telefork, only the last is really serious. Items 1,2,6,7 and 8 need work but have not been crippling disadvantages. Others problems, such as 3, 4 and 5, have proven to be more theoretical than real.

The telescopic fork didn't become a standard fixture on production motorcycles until after World War II. The earliest forks came literally straight off bicycles. When speeds required some bump protection, engineers added short bottom links. Purists complained about every kind of suspension—and with reason: it's hard to beat a rigid fork for steering pre-

# BEYOND TELESCOPIC FORKS



Though the ELF 2 used the same basic chassis and [illegible]

[illegible]

[illegible] and the new [illegible] systems were all pretty bad.

Through the 1920s and '30s [illegible] experimented with many types of front suspension, but the conflicting require[illegible] defied a [illegible] solution. As speeds rose and brake forces in[illegible]creased, [illegible] needed more travel, but increasing suspension travel only [illegible] other inadequacies.

The short [illegible] era was followed by 20 years of girder forks. In this design, the wheel axle [illegible] between the [illegible] of a [illegible] fork, [illegible] attached to the fork crown through two vertically [illegible] sets. This whole girder rose and fell with the wheel as it moved over bumps, with the links defining the wheel's path. The [illegible]—and therefore stability—of the design depended on the stiffness of the girder and its four links, and on the tightness of the eight [illegible]. With a girder fork, [illegible] was [illegible] to acceptable performance.

[illegible] to the [illegible] pivoted fork worked extremely well, [illegible] hub-center steering, used on the Ner-A-Car [illegible] of the [illegible] bicycle steering pivot, located above the wheel at the end of a long fork, the Ner-A-Car's pivot was [illegible] inside the wheel hub, raked back at only 14 degrees. The [illegible] was necessary to give [illegible] short trail [illegible] "fork offset" could be provided [illegible] small wheel hub.

Hub-center steering has the advantage of eliminating [illegible] steered mass, plus the weight and bulk of the tall steering head structure. The Ner-A-Car proved remarkably stable, [illegible] because its low steered mass [illegible] energy for a really good head shake. However promising the Ner-A-Car's steering may have been, [illegible] with the steered fork, the public had already [illegible] a motorcycle ought to look—and that was that.

By the later 1930s and early '40s, the girder fork, [illegible] could no longer cope with the speed and powerful brakes of racing motorcycles. Link breakages became routine, and [illegible] didn't help. The telescopic fork—simple, robust, and able to accommodate longer travel—offered a solution. From 1935 onward, BMW, adapting developments from aircraft-related work, [illegible] damped telescopic forks on its production and racing motorcycles. The new [illegible] bended and suffered distortion from [illegible] drum brakes, but their critics could propose nothing better.

In the early post war period, as brake performance improved and powerful machines like the Italian multis grew more and more unstable at speed, brake dive induced trail loss caused increasing concern. Manufacturers with these special problems turned to the leading link fork, whose brake torque can be reacted into the links to counter or eliminate brake dive. This, engineers reasoned, would eliminate trail loss and improve stability. Leading-link forks also eliminated sliding friction and permitted use of newly available coil-over type tubular dampers instead of the more primitive and hard to service internal dampers of teleforks.

On the other hand, link forks need pivots, and the only solution that offered reasonable rigidity was the use of preloaded pairs of tapered roller bearings. That, and the difficulty of making a link fork structurally rigid, meant a lot of steered mass with its potential oscillation problems. Moto Guzzi won numerous world road racing titles on leading links in the 1950s, but as tire grip improved, the poor lateral bending resistance of leading links became a problem. In the meantime, builders like Norton and Matchless, being less burdened by the problems of engine power, continued with the tele.

The mainstream builders still voted for the telescopic fork, which rewarded them with adequate performance. Forks on the production bikes of the 1960s were certainly no more than adequate, designed for instant manufacture, made to indifferent tolerances, often equipped with laughable damping. They were as weak as the frames that carried them; disc brakes on street designs of 1968-72 could provoke a frightening hop, in

which the fork slammed forward and back at low frequency and the motorcycle bounded alternately between front and rear tires. Poor damper performance, inadequate tube stiffness, and excessive frame flex in the steering head area conspired to create this dismal—and dangerous—result.

After years of work, it is now accepted that a heavy or fast machine needs a telefork with large-diameter stanchions of 40 millimeters or more. Fork travel should be kept to a minimum, because

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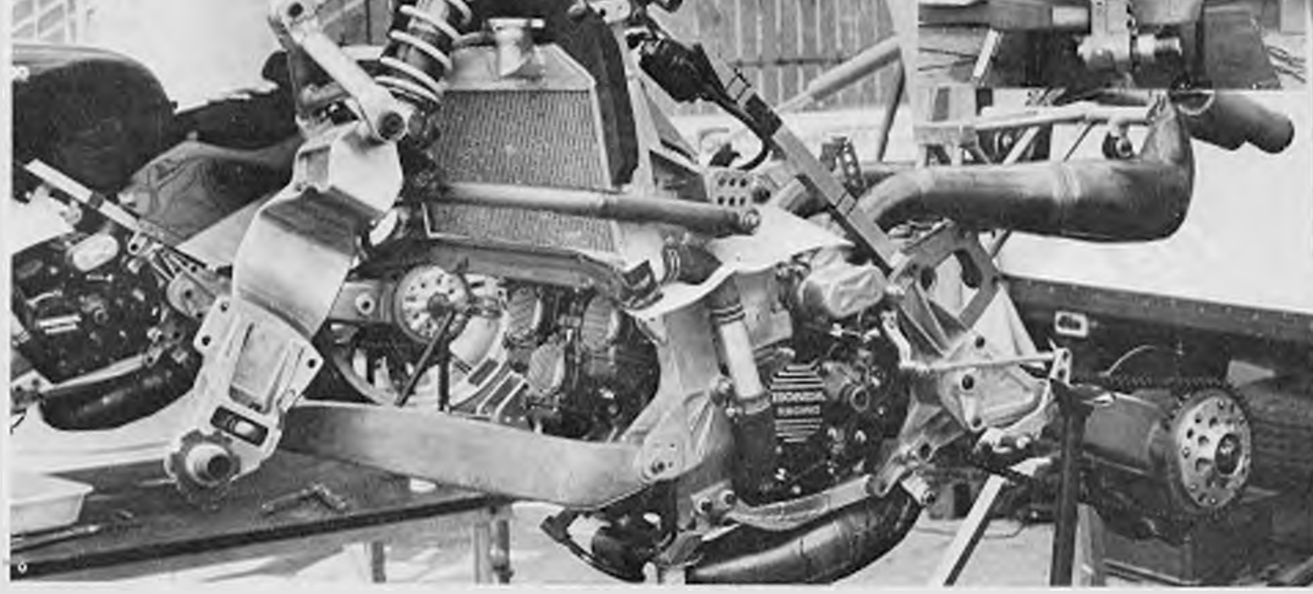
[illegible]



the longer the fork, the more susceptible it becomes to bending and twisting forces. General opinion holds that 5.5 inches travel is about right for street bikes, with road racing machines handling optimally with less. Excessive travel means exaggerated attitude changes under braking, and reduced stability. A front end that wallows makes it hard to hold the machine [illegible] into a turn. For road racing machines, stiffer suspension and damper settings offer the old virtue of the rigid frame: steering precision.

A large-diameter front axle helps resist twist, as does a stiff [illegible] fork brace. Fork crowns must be both heavy and deep, with preferably two pinch bolts at each engagement. For example, the tubes in racing designs are often knurled where they pass through the crowns. Also, size-for-size, roller bearings give 40 percent more rigidity than ball bearings. The temptation is to lighten the frame while strengthening the fork, but reduced stiffness in the head area compromises the performance of the best forks.

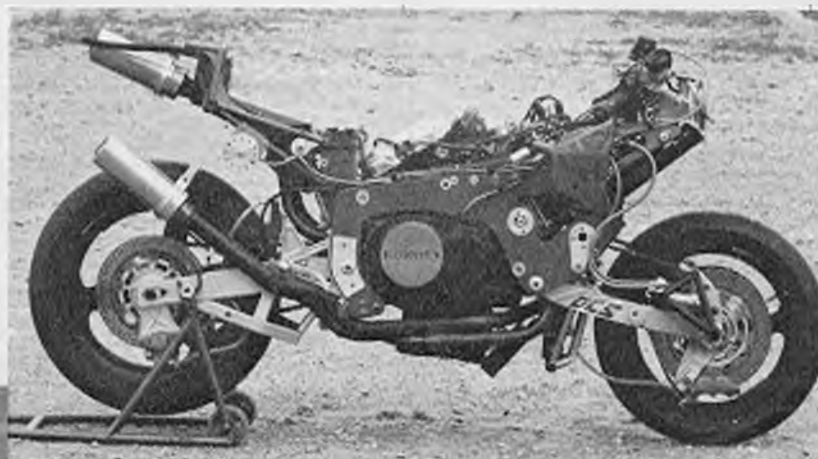
The stiffer the fork tubes are, and the less they bend under braking, the tighter their internal clearance can be without danger of binding. Even with all that's known about the telefork today, some recent production super sports designs arrive with such sloppy fork tolerances that the bushings must be hand-shimmed to eliminate rattling and clanking. On the other hand, some makers are so confident of their telefork rigidity they put all the damping, including separate bump and rebound damping functions, in separate fork legs.

The famous Ceriani fork that carried so many road racers of the 1960s, and so many dirt-trackers of the 1970s, had only 35mm tubes, but street bikes of today often have tubes measuring 40 or more millimeters. At constant wall thickness, tube stiffness rises as the fourth power of O.D. (outside diameter); at constant weight, stiffness rises as the square of diameter, so the temptation is to design very large O.D., thin-wall tubes. In the process of adding lightness, engineers can go astray. One year at Daytona, Gary Nixon had everyone fumbling for thin-wall tubes when he returned from practice with a set of experimental tubes bent back against the engine by his hard braking. Steel has its limitations, which is why at least two GP teams have tested or raced forks fabricated from a composite of carbon fiber.

A different approach to fork stiffness is to turn the whole device upside down, as Moto Guzzi did years ago and Simons does today. A swing arm's [illegible] tapers, becoming thickest at [illegible] level where the bending couple is the greatest. Shouldn't a fork, with its greatest stress coming just where the stanchions enter the lower fork crown, be designed in the same fashion? The upside-down fork places the larger diameter female member at the top, where the greatest stiffness is required, and the wheel attaches to the steel stanchions. For a given weight, such a fork is stiffer than a conventional one, but complications arise in attaching fenders and brake calipers.

Because certain designers (most recently Yamaha and Bimota) maintain at least a theoretical interest in telefork trail

# BEYOND TELESCOPIC FORKS




Though similar to the [illegible] system, the [illegible] Bimota fork uses hydraulic rather than mechanical steering. The fork's two-sided swing arm provides symmetrical load paths, and permits conventional dual-disc braking.

loss due to brake induced pitch. They've tried mounting the fork legs at a greater angle than the steering axis. This system allows the wheel to move backwards as the suspension compresses, preserving the trail and maintaining stability, but it also increases the fork's pro-dive tendency.

At the moment, refinements have done much to address traditional criticisms of teleforks. Racing and super-sports bikes alike ride on highly developed teleforks, and they work. Trail loss and reduced stability under braking are no longer problems; the 100 percent weight transfer that occurs during hard braking makes reduced trail act as more than enough, and stability is provided by rigid chassis and good suspension. Yamaha's notable GP road-racing success campaigning a machine without anti-dive hardware calls into question the soundness of the whole idea.

Still, engineers are nervous. What if some new concept proves better than the tele? Those fork designs which substitute smooth rotation for the spikey stiction of the tele all share the benefit of enhanced brake performance. Some alternative front ends also lay claim to weight reduction and increased stiffness. Let's review some of the leading alternatives to the telescopic fork.

### *DiFazio Hub-Steerer*

This descendant of the Ner A Car and the old T.T. Wallis design has been built in many forms since 1968 by Jack and Richard DiFazio of Frome, England. One test example surprised and pleased no less a rider than 20 year veteran road-racer Mick Grant.

In this setup a swing arm projects forward from in front of the engine, and at the center of its axle is a stubby, five-inch kingpin, raked back at some small angle and provided at top and bottom with steering bearings. A short piece of approximately five inch I.D. (inside diameter) tubing fits over those bearings such that their axis spans a diameter of the tubing. This tube can now pivot to right or left a few degrees to provide steering lock limited by interference between the axle and the open ends of the tube. The ends of this short tube carry large diameter ball bearings on which the wheel itself rides.

This design offers a potentially strong structure, because loads pass through symmetrical paths (the two beam swing arm) straight rearward at engine level toward the rear arm pivot, rather than making the roundabout trip up a long fork to a conventional steering head, then back down through a frame to the rear pivot. The need to carry the front wheel on ultra thin section, large I.D. ball bearings brings the usual tricky problem of setting up such bearings, whose life is limited even at relatively low rpm. The lack of space inside the hub makes it impossible to provide much steer axis offset, so the choices of rake and trail are limited. Kingpin angle is controlled by lever arms rising from either end of the front axle, vertically up to a link that projects forward from the chassis, above the tire. This arrangement can be made to give constant trail under braking. Steering is through linkage.

### *Bimota Tesi Hub-Steerer*

Better-known than the DiFazio system but of similar type, the Bimota Tesi uses hydraulic rather than mechanical steering. Both these setups are stress-symmetrical, that is, identical load paths are provided on each side of the central plane.

### *ELF Hub-Steerer*

Honda has taken some interest in the ELF projects, and Suzuki's Falco Rustyco design study shares the ELF's


By locating the steer axis in the plane of a ... front wheel, both the RADD chassis and Foale ... offer a full range of offsets, rakes and trails.


Like ELF, the Foale and RADD designs use a lower single-sided swing arm which allows quick tire changes but requires a single-disc brake.


With the Foale system [illegible] RADD [illegible] [illegible] steering [illegible] to com[illegible] ass as the wheel moves [illegible]ward.

# BEYOND TELESCOPIC FORKS

general concept. Here's how it works. The ELF-type hub-steerer uses a pair of forward projecting, single-sided arms, one above the other. The forward ends of these are ball-jointed to carry a steering upright, from the side of which projects the front-wheel spindle. The front wheel is deeply dished to allow the two ball joints to lie in the wheel's central plane. A line drawn through the two joints defines the steer axis which, owing to the dished wheel, can be offset to the rear of the axle as in tele designs,

[illegible]

allowing use of conventional rakes and trails. Variation in length and angle of the two arms can provide constant trail and/or anti-dive.

ELF machines have large trails and so steer heavily. Why? The traditional reason for using a lot of trail is to mask inadequacies elsewhere. The ELF designs have evidenced a number of problems, such as wheel hop, ball joint breakage and porpoising. And because almost everything on these machines is so radical, teething problems have been especially severe. For example, by insisting that the engine function as part of the frame, the ELFs impose engine vibratory stress on every part. Furthermore, with the sensitive steered wheel supported from one side by cantilever arms, rigidity is difficult to achieve and may explain the need for large trail. Also, the many necessary bearing bosses contribute weight, and provide an [illegible] elsewhere

Despite coming close to winning in endurance, the ELF machines have been frustratingly mid-field at best in GP racing. Disappointed by lack of racing success, ELF will next try a [illegible] design in which the upper end of an extended steering upright slides through a guide tube into the frame—much like a McPherson strut auto suspension. This will increase rigidity, but must also reintroduce sliding friction.

### Foale-RADD Semi-Hub-Steerer

Independently conceived by Tony Foale, Tonbridge, England, and James Parker, Santa Fe, New Mexico, the Foale-RADD uses the lower single-sided arm of the ELF type, connecting to the lower end of a steering upright, but the upper end of the upright reaches up above the tire to become ball-jointed to a central forward projecting upper A-arm. The steer axis still lies in the plane of the dished front wheel, and, like the ELF type, this design permits a full range of offsets, rakes and trails.

The RADD design steers directly through universal joints and a splined, sliding shaft, while the Foale uses linkage. The long upright enables twisting loads to be carried at lower stress than on the ELF. The cantilevered spindle of both ELF and Foale-RADD designs lends itself to quick tire-changing, but the asymmetrical arms may impose steer effects when they deflect under stress.

### Hossack/Fior Design

A less radical and likely more workable concept (independently conceived by Norman Hossack, London, England, and Claude Fior, [illegible], France), this system is a girder fork whose suspension links are not steered. Instead, the four key links of the old girder fork merge into two forward-projecting, horizontally pivoted A-arms, attached to the front of the chassis at conventional steering-head level. Each arm carries a ball joint at its forward end, and the two ball joints carry the girder, serving as both suspension pivots and steering bearings. A line drawn through the ball joints defines steer axis. These designs are easily [illegible], and the full range of rakes, trails, and offsets is available. Steering is by linkage.

The positioning of the two A-arms in the Hossack-Fior requires a [illegible] steering head tower above the engine, but the broad base of the two A-arms means the stress fed through them and into the chassis is much less concentrated than in the case of telefork head bearings. Both of these developments have enabled use of steep head angles like those of major-team GP bikes, indicating good inherent stability.

Kenny Roberts, curious about the Fior system bike that appeared in practice at the French GP in 1981, asked what it was intended to accomplish. "Eliminate chatter," he was told. Front-end chatter is a resonant bouncing of the front tire during cornering, often associated with front-end bind, damper cavitation, or inadequate steering head support. In its worst form, chatter makes it impossible to hold line, and the machine runs wide. KR [illegible] he remarked, "Yup, you got rid of the chatter and now you've got hop."

Hop, described as lower-frequency, higher-amplitude movement than chatter, and hop is common in unconventional front ends. Chatter may be associated with the mass-spring system of front wheel/front tire. The lower frequency of hop is almost certainly the result of gross structural flex—as it was on early disc-braked machines with their spindly fork tubes. All makers of novel front ends make great claims for stiffness, but the likely fact is that the "hoppers" have components elsewhere which are too light and therefore prone to flexing. ELF attacked the problem by attaching the damper directly above the steering upright, but the hop remains.

### *Leading and Trailing Link Designs*

Alternatives exist in more conventional pivoted forks, such as the Sharp and Foale leading-link designs and the Offenstadt trailing link. The Rib fork, of special interest in motocross, uses a complex knee action and combines both leading and trailing links to achieve extreme travel without wheelbase change or trail reduction. Either excess steered mass or rigidity problems attend these forks, all of which also require steering-head towers.

### *Really Odd Stuff*

Thought provoking if not practical for motorcycles is the Mantzel wheel, whose suspension movement is provided by allowing the rim to move with respect the hub, but only in the same plane.

Members of the press were recently treated to rides in a special Corvette whose Lotus-designed suspension operates without springs or dampers. Instead, hydraulic rams powered from an engine-driven pump, control wheel position. Instructions as to how and when the wheels are to move originate with a computer, acting on information gathered from accelerometers at each corner of the car. When an accelerometer detects a disturbance, the computer acts to lift or drop the appropriate tire or tires in such a way as to cancel it. The system is said to be miraculously comfortable, stable, and free from such annoyances as roll and pitch. Such an achievement suggests the feasibility of a motorcycle front end in which the front axle's position and orientation in space would be determined in a similar manner. The desired steering or suspension behavior could be programmed into such a contraption, but it would be neither light nor cheap.

It's well to remember, however, that motorcycles have passed through several stages of becoming ever more powerful, fast, and complex only to be repeatedly slashed back to bare essentials by the requirements of a fluctuating world economy. Any replacement for the telefork—simple, light and relatively inexpensive to produce—will need a similar simplicity for long-term success.

The Fior and Hossack bikes have won local races and, like the ELF, are the brain children of auto racing engineers. Each of the alternatives listed eliminates sliding stiction, and so is potentially useful in helping braking action. The hub steering designs have minimal steered mass. All except the pivoted forks could easily use rising-rate suspension linkages and allow use of the full range of excellent gas-pressurized rear suspension units. Most could eliminate brake-induced trail loss.

Designs that use ball joints will inevitably suffer the pivot stiction and wear troubles that have driven such joints out of usage in the best rear suspensions. Motorcycle tires are disturbed by levels of stiction that a car tire can ignore, and motorcycle steering is much more sensitive to looseness and flexibility than that of a car. It will be especially difficult to combine adequate stiffness and light weight in the designs that support the front end from a single side. Stress symmetry—at least for the front, steered wheel—seems essential for success.

In short, no model here unites all desired characteristics in a single design. The most significant fact to emerge from all the designs tested so far is that nothing offers to solve the central problems: obtaining significantly faster, stable steering response from a motorcycle, and making it steer out of corners.

To steer, you first must roll the machine over on its side. To do that, you countersteer the front wheel—away from the desired turn. The resulting sideways front wheel movement, acting over the lever-arm of the wheelbase, slowly countersteers the rear wheel as well, so that both front and rear wheels steer "out from under" the machine around the turn. This sideways movement at the front again acts—slowly—over the ponderous lever-arm of the wheelbase to steer the rear wheel as well. This explains the present preoccupation with ultra-short wheelbases, but alternative front ends offer no more relief here than do telescopics—because both are bound by the same steering geometries.

While it may sound stick in the mud to say, there's little point in change for its own sake. Really fast steering response can be achieved, but only by steering the front and rear wheels simultaneously. Here's how the turning process would look with two-wheel steering: the rider countersteers to initiate the turn, and both wheels simultaneously steer, whipping out from under the machine to roll it over into the turn. In this process, the wheelbase doesn't matter, because there is no delay as the front wheel tries to steer the rear wheel with the wheelbase as lever arm. Once the machine is rolled in, front and rear tires steer towards the turn center, and in a fraction of a revolution develop cornering forces simultaneously at both ends of the machine. At this point, the rear wheel assumes a straight-ahead direction, and steering corrections are made by front wheel alone. There's no delay in developing the force at the rear because we don't have to wait for the steered front tire to drag the front of the chassis around to establish a steer angle and cornering force at the rear.

Making such an idea work would be a nightmare, but conceptually it offers big gains in speed of steering response, and separates handling variables from wheelbase so that off-turn wheelies can be eliminated and turned into acceleration.

Racing and sports motorcycle design remains stuck on the issues of how to get the machine turning in minimum time, and how to make it steer out of corners. Alternative front ends do not address these issues any more than telescopics do—because both are simply ways of doing the same job, using the same geometric concepts even if the actual parts are different. Trail loss was the issue in 1960, but we have since found other ways to get stability. Stability used to be the issue back in 1980, but better chassis have fixed that. Rear tires were a big issue from 1975-83, but thanks to radial construction that problem, too, has become manageable. Weight will always be an issue no matter how vehicles are built.

What major problem do alternative front ends solve, or even address? So far they don't steer better than teles. Their supple compliance offers advantages in braking and justifies continued work. Some may offer weight advantages, but so far only at a sacrifice of rigidity or stability.

So why the big fuss about alternative front ends all of a sudden? Well, marketing technology can be a big problem if you run out of technology. People who saw rising rate linkages and anti-dive devices on GP bikes thought they were trick, and when they appeared in the showroom, they snatched them up. Never mind that most of the rate rise has been designed out of the latest racers and never mind that the World Champion's 500 GP ride uses no anti-dive.

Anti-dive and rising rate are streetbike features now; rising rate finds its best application in carrying passengers without bottoming, and street chassis may still need anti-dive as protection against trail loss, even if racers do not. If an alternative to the telescopic fork can be made to work almost as well as the older design, it might help sell a few bikes. But if you see a forkless machine in the showroom any time soon, it will be for this reason alone.

In the longer term, development may suppress the drawbacks of current alternatives to the point that the compliance advantage of alternative designs will stand as reason enough for taking over the front-end job. There will be no front end revolution—just a new look at the same old concepts. The real problem of a motorcycle's front suspension, despite the restless vitality of the ideas presented here, remains untouched. ■