Materials • Mechanics • Physiology • Engineering • Aerodynamics

BIKE TECH

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TEST RESULTS

The Roval Wheel: How Much Faster?

Pierre Hugaud

This article originally appeared in the French cycling journal Le Cycle, *of which Pierre Hugaud is the editor. Michel Belly, a Canadian framebuilder, translated the article into English and relayed it to* Bike Tech.

When the Paris Cycle Show convened in 1977, aerodynamics was not yet a bicycling buzzword. Shimano's aerodynamic components and the oval tubing of Tange and Reynolds were still ideas on the drafting board.

At this show, a precursory aerodynamic design made its debut: Claude LeHanneur, a French engineer, introduced the Roval aerodynamic wheel. Significantly different from a standard wheel, the Roval has a contoured hub, a narrow, deep-section rim radially spoked together with oval spokes, and nipples recessed into the rim (See Figure 1). By departing from the traditional lacing patterns and paying close attention to the cross sectional profiles of the wheel's components, LeHanneur succeeded in designing a more aerodynamically efficient wheel.

Changing Speeds

An analysis of a rolling bicycle wheel's aerodynamics is complex because the wheel is both spinning in the air and moving through it. Also, each part of the wheel has a different drag coefficient, and the velocities of all points on the wheel are constantly changing with respect to the ground, or the still air.

If a bicycle is cruising at 30 km/h, then its

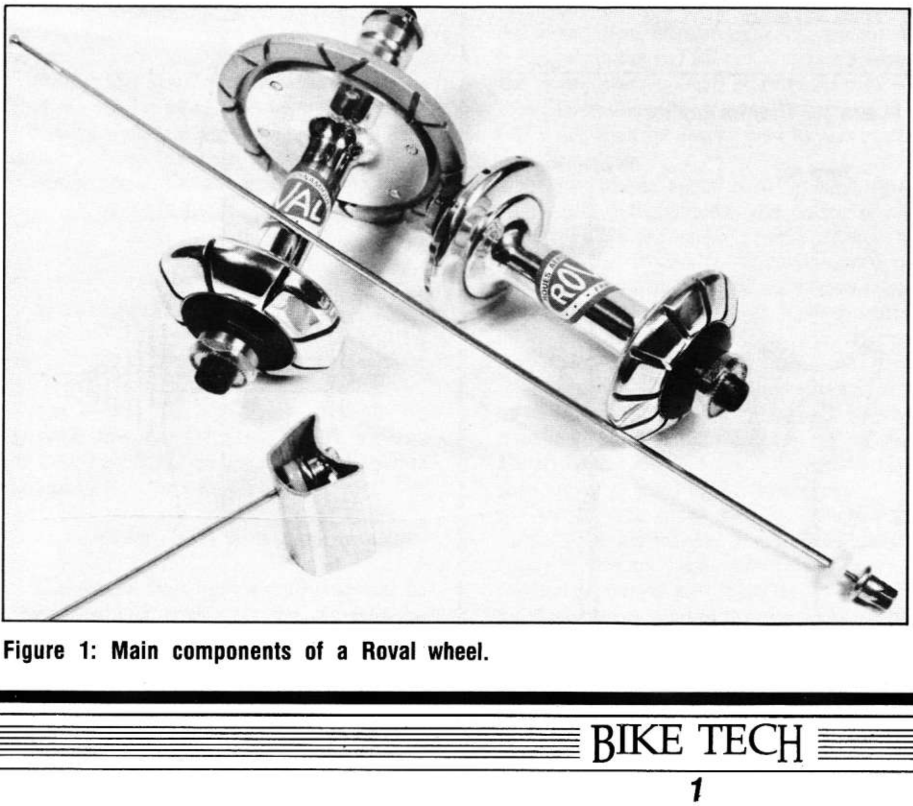

Figure 1: Main components of a Roval wheel.

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wheels are rotating with constant angular velocity. But the only portions of each wheel that move at this steady 30 km/h ground speed are the axles and quick-release skewers. All other parts are continually moving either faster or slower, depending on their positions in the wheel and relative to the ground.

If we follow the path of a point on the tire of one wheel in Figure 2, we'll see that it follows the humped curve traced to the right. This path also graphs the relative velocity of this point as it rotates through one revolution. The point will actually be at rest the moment it contacts the pavement, but will quickly accelerate to 60 km/h as it approaches a position at the top of the wheel.

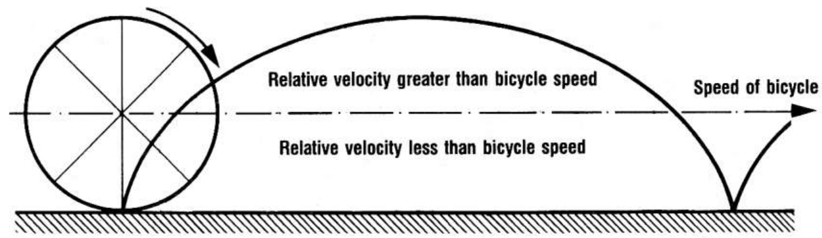


Figure 2: Position and relative velocity of a point on the circumference of a wheel.

George Retseck

Lost Power

Taming the aerodynamic behavior of a bicycle wheel is important because two wheels rotating at high angular and linear velocities disturb a lot of air. The amount of power required to move anything through air increases in value by the third power of the velocity of the object. Specifically,

$$\text{Power} = \frac{A C_D p V^3}{2},$$

where A is the cross sectional area of the object, C_D is the coefficient of aerodynamic drag of the object, p is the density of air, and V is the velocity of the object with respect to the air. The amount of power expended by a rider to rotate and translate a pair of wheels through the air depends upon a complex determination of the instantaneous relative velocities and drag coefficients of all parts of the wheels. Further complicating the issue, the rear wheel partially drafts the front wheel and it spins through turbulence churned up by the rider's legs and pedals.

Improved Design

While the calculation of the amount of drag of the two wheels is difficult, the reasons for a wheel's drag are not hard to see. A pair of thirty-six spoke wheels contains about 60 feet of round wire, which has a drag coefficient of 1.1 (See Figure 3a). Additional disturbance is created where the spokes cross. Spoke nipples, too, stir up the air, and a tire mounted on a shallow section rim presents a messy aerodynamic profile to the airstream (see Figure 3b). Clearly, a wheel's aerodynamics can be improved.

The Roval wheel addresses each of these aerodynamic problems and, at the same time, strengthens three of the traditional wheel's weak areas. Each wheel has 24 spokes that thread into nipples recessed in the rim, out of the airstream. The spokes are flattened into an oval cross section (C_D=0.4; see Figure 3a), and have T-shaped hammerhead ends.

These spokes pull straight from hub to rim, so they can be tensioned higher than spokes with elbow bends. Higher spoke tensioning allows the 24-spoke Roval wheel to be just as strong as a regular 36-spoke wheel.

The front wheel is laced in a radial pattern, as is the left side of the rear. Since a crossed spoke pattern is necessary to transmit the torsional load of pedaling, the right side of the rear wheel is laced cross one.

Strength and Rigidity

The Roval's rear wheel has dish, but there's a nifty design feature to counteract its weakening effects. The left side spoke bracing angle of a dished wheel is nearly twice the right side's (see Figure 4). The tensions in the right side spokes are, there-

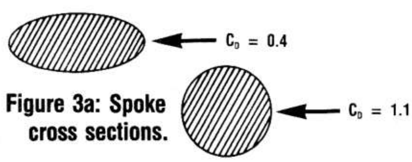


Figure 3a: Spoke cross sections.

Figure 3b: Tire/rim profiles.

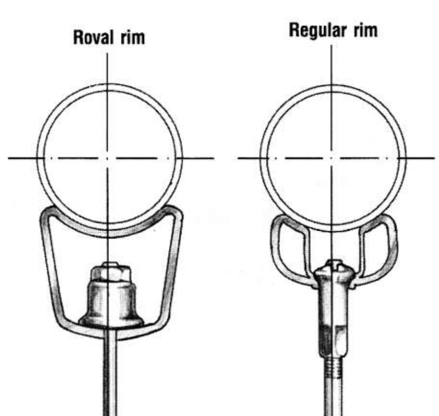
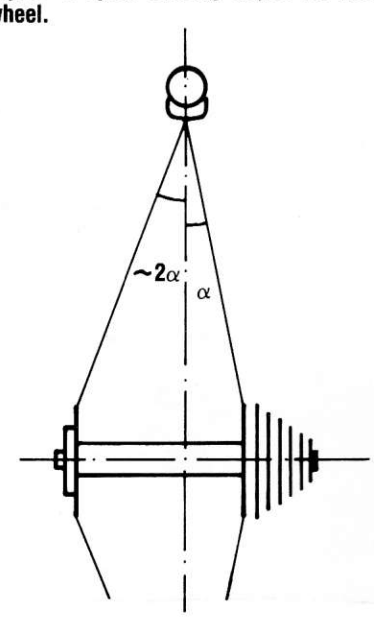


Figure 4: Spoke bracing angles for dished wheel.



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George Retseck

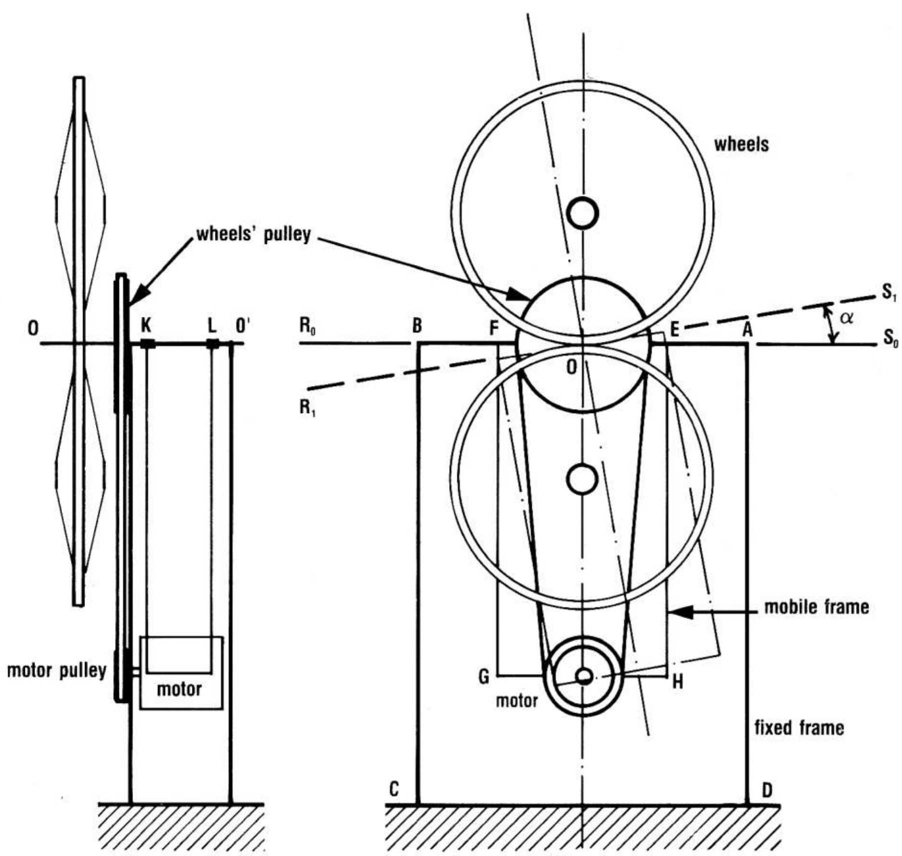


Figure 5: LeHanneur's test jig.

fore, nearly twice that in the left side spokes. This force imbalance makes for an unstable wheel. The Roval has twice as many spokes on the right side as on the left (16 vs 8), so the right side spokes have to be tensioned only half as much. This brings the tensions in all the spokes to nearly the same value.

Finally, the Roval rim has a deeper cross section, so the wheel will be more rigid in the radial plane . When mounted with a tire, this deep rim presents a cleaner aerodynamic profile to the air.

Test Jig

To quantify the aerodynamic efficiency of his wheels, M. LeHanneur built a test jig (see Figure 5) to measure the air resistance of regular and Roval wheels. The lower frame of the jig, ABCD, is fixed to the ground; the upper frame, EFGH, rotates around the axis 00′ on pivots K and L, and is driven by a motor with a belt and pulley. The motor is mounted on the upper frame to keep its torque from biasing the measurements.

The wheels turn with a motion similar to that of wheels rolling on the ground—the speed at the axis of the frame is zero and the speed at the outside of the wheels is twice that at the hubs.

The test jig also allows each wheel to take a turn drafting the other.

As the test jig spins, the wheels' air resistance will generate a reaction force that tilts the upper frame at an angle α. If a weight W is hung from the rod RS at a distance X from the pivots, the angle will be reduced back to zero. The value of the torque T on the upper frame can then be determined by the equation, $T = WX$.

If the rotational speed N of the jig is measured with a tachometer, the power of air resistance can be found by the equation, $P = 2\pi NWX$. For a simulated ground speed of 45 km/h (28 mph), M. LeHanneur found that regular wheels consumed 60 (.08 hp) watts of air power, while the Roval wheels consumed only 35 watts (.047 hp).

The estimated air resistance experienced by a rider crouched on a lightweight bicycle moving 45 km/h is 350 watts (.47 hp). If the Roval wheels effect a savings of 25 watts, then seven percent of the power expended by the rider to move him and his bicycle through the air will be saved. If additional losses to tire and bearing friction are added in, then the overall power savings at 45 km/h for a rider using a set of Roval wheels will be about six percent.

TEST RESULTS

Road Testing the Roval Wheel

Doug Roosa

M. LeHanneur's test effectively pointed out aerodynamic differences between Roval and conventional wheels, but I question whether the power savings measured on his test jig can directly translate into a similar savings for a rider. There are important differences between the aerodynamic environments of his test jig and a moving bicycle: the wheels displace more air in the jig during each revolution, the drafting conditions are different, and the turbulence stirred up by a rider's legs and the bicycle's components was missing.

One can argue that the aerodynamic behavior of the two sets of wheels will vary together under all test conditions, but I don't believe the relative power consumption difference of 25 watts measured at 28 mph will be the exact power savings experienced by a rider at that speed. The relative difference could be more or less under different test conditions.

Other Speeds

Still, even if we give M. LeHanneur the benefit of the doubt and assume that 25 watts is an accurate figure, it must be pointed out that this power savings is realized at a simulated speed of *28 mph*. The resulting six percent reduction in necessary power sounds impressive, but what happens at other speeds? M. LeHanneur provided no data, but we know the power savings will continue to grow for speeds higher than 28 mph, but will shrink quickly as the speed drops, because of the cubic relationship between power and velocity.

In addition, the percentage of a rider's effort devoted to overcoming wind resistance varies with the rider's speed. As Rob Van der Plas pointed out in our April 1983 issue, most riders plod along at ten mph, at which speed about half their effort goes to overcoming wind resistance and the other half, tire rolling resistance. When the rider's speed increases to 25 mph, overcoming rolling resistance demands $2^{1}/_{2}$ times the effort, but the power needed to overcome wind resistance increases 15.6 times, claiming 85 percent of the total.

The graph in Figure 1 clearly illustrates the relationship between power and speed. The top curve indicates the amount of power a rider must expend to maintain any speed

	Table 1			
	Time to Distance		Top Speed (mph)	
Trial	Regular	Roval	Regular	Roval
1	28.1	28.8	31.0	30.8
2	29.2	29.2	31.2	29.9
3	28.7	29.3	31.2	30.0
4	28.6	28.4	31.9	30.8
5	28.4	29.2	30.2	30.0
6	29.4	28.9	30.8	30.3
7	28.4	28.1	31.2	31.4
avg.	28.7	28.8	31.0	30.5

Table 2		
Time to Distance (sec)		
Trial	Regular	Roval
1	106.5	102.9
2	104.9	100.5
3	109.1	101.8
avg.	106.8	101.7

down a flat road with no wind; the bottom line is an estimated power curve for the same rider using a set of Roval wheels, based on the single data point provided by M. LeHanneur. Notice how little divergence there is in the two lines at speeds less than 15 mph. Clearly, the aerodynamic advantage of Roval wheels emerges only at very high bicycle speeds.

On The Road

One could simply consult this graph to predict the Roval wheels' performance on an actual bicycle, but in the spirit of real-time analysis, the *Bike Tech* R&D team decided to conduct its own set of roll-down tests to determine how effective Roval wheels really are. These simple on-the-bicycle tests reveal specific performance differences between Roval wheels and regular wheels.

To assure that any performance difference in our test was rooted in an aerodynamic difference, we eliminated as many other variables as possible between our sets of test wheels. The front wheels were matched to within 100 grams of each other, as were the two rears; more importantly, the rim weights were the same, so inertial differences were virtually eliminated. All four wheels were equipped with identical tires inflated to the same pressure. And the same bicycle, rider, and rider position were used for all the testing.

The first roll-down test was conducted on a steep (circa ten percent) grade approximately one-quarter mile long. The road was half rough (having recently received the infamous Pennsylvania D.O.T. tar-and-gravel treatment) and half smooth. The test rider was held and released from the same point, so he simply maintained the same crouched position during each run. Recorded time-to-distance and top speed results are entered in Table 1. Note the small difference between the two sets of wheels.

The second test, done two days later on a different, much longer hill almost a mile long with about an eight percent grade, was similar to the first. Test procedures and conditions were nearly identical, except that the road was smooth for the entire test stretch. The digital speedometer wasn't hooked up for this test, so only time-to-distance was recorded, but I know from past descents of this hill that a terminal speed in excess of thirty mph is easily achieved. Roll-down times are listed in Table 2. This time, there is a significant difference: regular wheel times averaged 5.1 seconds slower than Roval times (the standard deviations were a comfortable 2.1 and 1.2 seconds respectively for the two averages).

Analysis

If the Roval wheels are more aerodynamic than regular wheels, then they should allow the bike and rider to accelerate at a higher rate because more gravitational energy is available to increase their kinetic energy if less is dissipated to air drag. Also, a higher terminal velocity should be realized. But we know the power savings realized by better aerodynamics are noticeable only at speeds greater than 15 mph, so the acceleration rate differences between regular and Roval wheels will be very small at low speeds.

Top speeds in excess of 30 mph were reached in both tests, so why is a time difference measured in test two but not in test one? Quite simply, test one ended too soon. The bike and rider spent little time moving at speeds that brought out the aerodynamic advantage of the Rovals, and the minute predicted differences were not measurable with the speedometer and stopwatch employed for the test.

In test two, however, the bike and rider reached terminal velocity—and spent most of the run at this speed—so there was enough time for the more aerodynamic Rovals to show an advantage: they allowed a slightly higher top speed.

The conclusion, then, is that Roval wheels work—they are more aerodynamic than a comparable set of regular wheels. Their aerodynamic advantage is minimal at low speeds (which is the case for all aerodynamic components), but Rovals will offer moderate power savings to riders who bomb down hills and/or go very fast on the level.

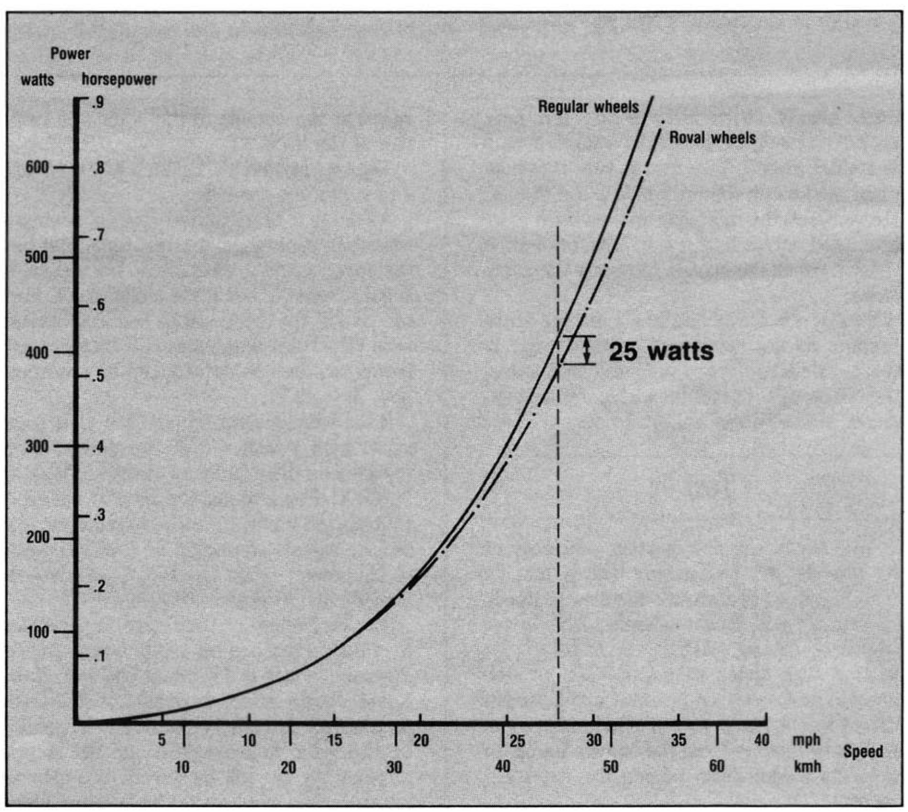


Figure 1: Power requirements to maintain a given speed with regular wheels and Roval wheels. No wind, level riding conditions (175-pound bike/rider.)

MATERIALS

Can Surface Finish Affect the Performance of Your Frames?

Mario Emiliani

This is Part 1 in a series of new articles exploring how different surface finishes can affect the performance of bicycle frames.

The surface finish on a bicycle frame is necessary both for durability and aesthetics. A good paint job protects the steel tubing from rust and enhances a frame's looks.

But the application of paint is the final touch in the frame's production. What's underneath the paint really determines how well and how long a frame's finish will last. It's very important that the framebuilder prepare the surface properly before applying the paint.

Unfortunately, one of the traditional methods of surface preparation—particle blasting—can actually degrade the frame's structural integrity by removing metal from the tube surfaces and/or initiating microscopic stress raisers that can generate cracks in the tubes. So we have the unhappy situation where in an effort to finish a frame for durability, the builder may actually shorten its life and compromise its performance by the most widespread of finishing techniques—particle blasting.

Surface Finish of Tubes

Steel tubes, as supplied to custom framebuilders and manufacturers, appear to be quite smooth. But a closer look will show numerous surface irregularities formed during fabrication. Figures 1a and 1b show the surface finish of Vitus 181 and Reynolds 531 tubings. The Vitus 181 has a grooved surface which is probably formed during a surface finishing operation or when the tube is butted. The Reynolds 531 tube appears to be pitted, but this is merely a surface oxide layer which, if removed, would reveal a grooved surface similar to the Vitus tubing. The interior of seamless tubing is also grooved when drawn over mandrels.[1] All frame tubes have the surface features shown in Figures 1a and/or 1b.

[1] *See "Straight Talk On Steel," by Mario Emiliani,* Bicycling, *July 1982, pp. 96-123.*

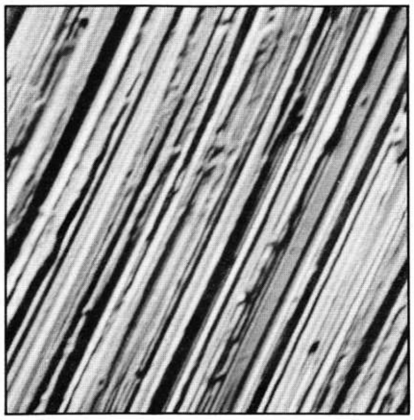


Figure 1a

Figure 1b

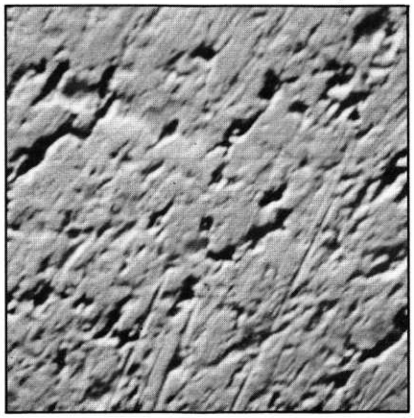
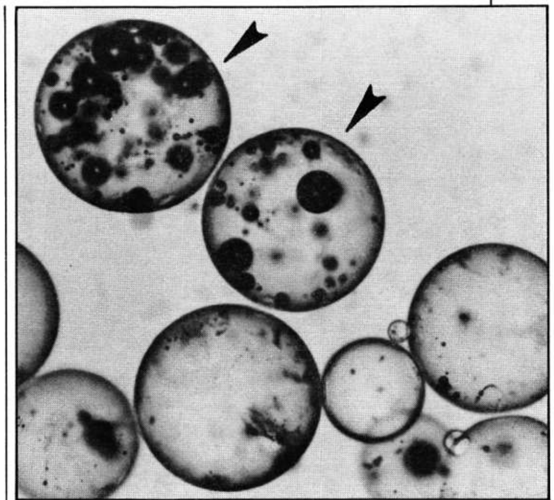


Figure 1: The surface finish of Vitus 181 (top) and Reynolds 531 (bottom) tubing. 200 times magnification.

Grooves and other surface irregularities on frame tubes are a potential problem because they can create an uneven distribution of stress. To avoid this, tubing manufacturers try to control the size of these irregularities within certain tolerances. But, they are not always successful. Framebuilders occasionally receive tubes with imperfections so severe (such as deep gouges) that they can't be used.

In the past, two of the biggest names in frame tubing, T.I. Reynolds and Columbus, stamped their tubes by deforming the metal to identify the manufacturer, tube gauge, and often, the short-butted end of the tube. Stamping can produce stress raisers, and this problem magnifies as the tubes become thinner. Framebuilders knew this, and a few suspected that it caused the failure of some of their frames, but they were reluctant to switch to other brands because of their high regard for Reynolds and Columbus tubing.

Recently, Columbus has changed its marking method from stamping to the process known as electrical discharge marking. In this process, a graphite electrode similar to a rubber stamp is molded into a reverse image of the Columbus dove. A negative charge is placed on the electrode and a positive charge is placed on the tube. A high-frequency pulse of direct current arcs through the electrode and an image of the dove is burned into the tube surface. This image is confined to the surface oxide layer, so while it clearly marks the new tube for identification, it comes off when the surface is cleaned; hence, it does not deform the tube. Other manufacturers now use similar non-destructive marking methods. Ishiwata and Tange tubing, and Reynolds' ultra-thin 753, for example, are marked with paint.



100 microns

Mario Emiliani

Figure 2a: Spherical glass impact beads. Note the air entrained in some spheres (arrowed). These defects can facilitate fragmentation upon impact. 125 times magnification.

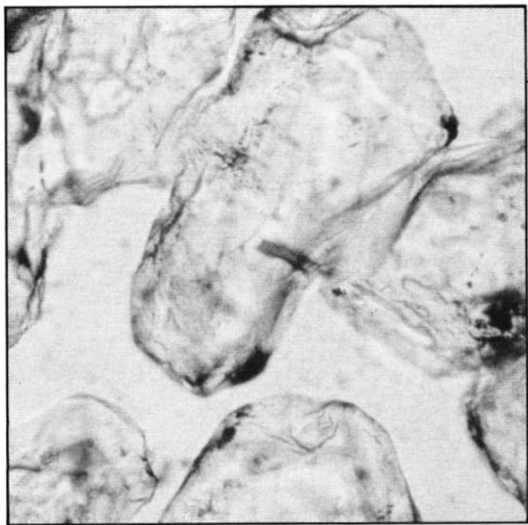
The surface finish of new tubing is an important consideration, but more for the tube's interior than its exterior, because the surface finish of frame tubing is modified during and after construction by sanding and/or particle blasting.

Particle Blasting

Particle blasting is a term used to describe the high velocity impact of solid particles upon solid surfaces for some beneficial effect. Particle blasting is frequently performed using sand—hence the familiar term sandblasting—but other non-metallic solid particles are also used. Glass beads, garnet crystals, and alumina are commonly used by framebuilders and professional painters.

The shapes of these particles are classified as either *spherical* or *angular.* The most common type of spherical particle is made from glass. Figure 2a shows glass impact beads 210 microns[2] in diameter. Particles

[2] *One micron = 10-6 meters = 0.00003937 inches*



Mario Emiliani

100 microns

Figure 2b: Sand, as well as most other types of particles used in sandblasting, has irregular shapes and sharp edges. 125 times magnification.

10 microns

Figure 3: Spherical particles impacting a frame produce symmetrical craters with small raised ridges along crater rims. 1000 times magnification.

such as sand, garnet, and alumina have sharp edges and are irregular or angular in shape. Figure 2b shows angular sand approximately 200 microns in diameter.

There are many situations in which particle blasting steel bicycle frames can be useful. For example, brazing flux residue, rust, and other surface debris can be easily removed to improve surface appearance and paint adhesion. Particle blasting is also a fast, inexpensive, and clean way to remove old paint. Particle blasting is so easy and effective that it is often done with little regard for overuse. There are, however, drawbacks to excessive particle blasting.

Erosion

One problem is that particle blasting removes or *erodes* metal from a frame tube. To prepare a surface for finishing, paint and rust are eroded by the impact of solid particles. Unfortunately, particle blasting removes metal in the same fashion as it does paint, although few people realize this because the metal loss is not as apparent as the paint loss. The amount of metal lost depends on the particles' shape and size, their velocity, and the length of time an area is blasted. The loss can be particularly substantial if a frame is particle blasted several times. Perhaps even worse than erosion is the cracking and pitting of the metal surface by the fast-moving particle stream. These surface irregularities, called stress raisers, will locally magnify stresses that can then initiate and propagate cracks throughout the surface and cause premature failure of the frame.

Particle Impacts

A spherical particle hitting steel produces a crater with a small raised ridge along its rim. No material is removed by a single impact, but very small subsurface voids are formed when metal is displaced to form the crater. Figure 3 shows a crater produced by a 210-micron diameter glass sphere. A few more particles striking in the vicinity of the first crater form more voids which link together to form a small crack. Subsequent impacts cause the crack to grow until a small flake, or *platelet,* of metal is removed. Thus, several impacts are needed to remove metal. Figure 4 shows two overlapping impacts which formed a platelet that is near the point of removal. The process of material loss is known as platelet formation.

Figure 5 shows an impact crater formed by a 200-micron sand particle. In contrast to impact sites produced by spherical particles, craters made by angular particles have irregular shapes and large, raised lips. If the volume of the lip in Figure 5 isn't equal to that of the crater, then metal has been removed. Nearly every impact by angular particles will remove metal; those which don't form large lips that are vulnerable to easy detachment by subsequent impacts.

Most materials used in particle blasting will fragment upon impact because they are brittle. Even spherical glass particles, particularly if they contain air pockets, can shatter into angular fragments. (See Figures 2a and 6.) If these fragments then ricochet into the frame, they can act like angular sand particles, either removing metal or becoming embedded in the surface. Subsequent impacts may remove these embedded fragments or drive them further into the metal. Your frame may be carrying thousands of glass or sand fragments that were embedded during the blasting process.

Material Loss

The removal of material by sharp-edged angular particles is called *cutting*. Platelet formation can occur simultaneously with cutting, but this depends upon the type of particles and velocity used. If the velocity is high, as in sandblasting, material loss by cutting is more likely to occur than platelet formation.

The cutting action of angular particles enables paint, flux, rust, and excess filler metal to be removed faster and more completely than if spherical particles are used. It's no wonder angular particles are the choice of framebuilders and painters. But the fact that angular particles can remove metal with nearly every impact means that the rate of material loss will be much higher than if spherical particles are used.

For a given velocity, large particles will produce greater material loss because the force upon impact is greater. Similarly, an increase in velocity (with no change in particle size) will also remove more metal, provided the particles do not fragment upon impact. But particle velocity is difficult to determine because it's a complex function of both particle size and particle-blasting equipment. For example, at a given pressure, small particles travel faster than larger particles made of the same material. Particle velocity also depends on the nozzle diameter of the particle blasting gun, the pressure used, and the distance between the nozzle and frame. Typically, framebuilders use particles ranging from 100-300 microns in size and they adjust their equipment to have particle velocities in the neighborhood of 100-300 ft/sec.

Mario Emiliani

10 microns

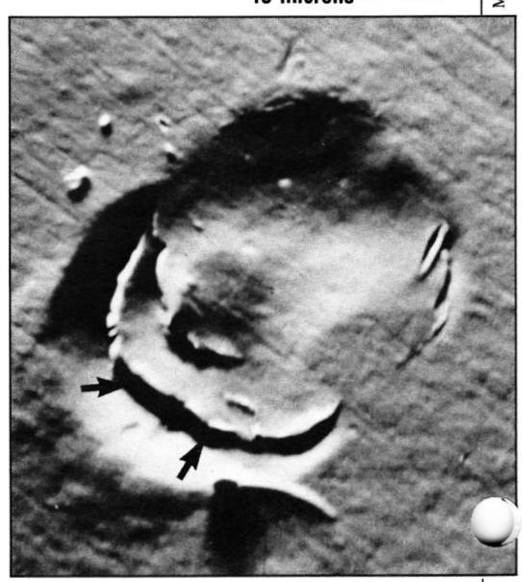


Figure 4: Only two overlapping impacts were needed to form a platelet (arrowed). One or two more impacts would have removed it from the surface. 1000 times magnification.

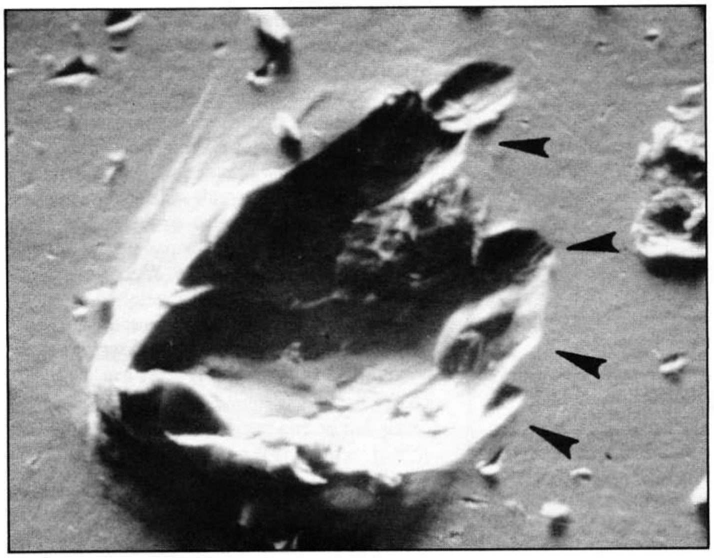


Figure 5: Craters made by angular particles have irregular shapes and large, raised lips. Notice the crater rim opposite to the lip is hardly deformed (arrows). This illustrates the efficient cutting action of angular particles. 1000 times magnification.

Figure 6: Fractured glass particles. 125 times magnification.

Mario Emiliani

George Retseck

Time Factor

A survey of framebuilders and painters showed that it takes one to five minutes to sandblast a top tube/head tube joint, and four to fifteen minutes to sandblast an entire (bare) frame before painting. But many frames, or portions of frames, are often sandblasted more than once. For example, some framebuilders sandblast immediately after the frame is brazed to see how well they've done. They then might file a bit, add braze-ons, re-braze gaps in the lugs, and sandblast again. If the paint job comes out badly, or if the frame owner decides to repaint it later, the frame will be sandblasted yet again. So it's possible that some frames are sandblasted for a total of 15 minutes or more. This may not seem like a long time, especially for a whole frame, but as Figures 4 and 5 show, only a few impacts are needed to remove metal. To better assess the damage caused by sandblasting, the number of particles impacting the frame must be determined.

The number of particles leaving a blasting gun will depend upon the equipment, operating pressure, and the size and type of particles used. Assuming one gram of sand particles leaves the gun each second, and after calculating the mass of a 200-micron spherical particle (I'm using spheres because it's easier to calculate their volume), roughly 100,000 particles strike the frame every second. So in 15 minutes of sandblasting, a frame can be hit by almost 90 million particles!

Because of the large number of particles involved, it's apparent that every square inch of a frame will be hit by thousands of particles. This can lead to significant metal loss. In addition to the type of particle used and operating conditions of the blasting equipment, the amount of material removed depends on the impact angle of the particles, the type of steel, and the amount of time the steel was heat treated during the brazing process. (After a steel frame is brazed, some portions will be weaker than others. "The Metallurgy of Brazing, Part 4" in the April 1983 issue of *Bike Tech* explains how the strength of steel tubing varies near a brazed joint.)

Erosion Tests

To better assess material loss rates in particle-blasted steel frames, I eroded two samples of Columbus SL tubing. The particles used in the test were 210-micron glass spheres and 200-micron sand. Both types of particles flowed at a rate of 1 $g/cm^2/s$, and were accelerated to a velocity of 175 ft/sec. The area eroded was 0.079 cm^2, or about one-eighth of a square inch. These tests were performed using a sophisticated erosion rig built at the University of Rhode Island. Figure 7 is a schematic dia-

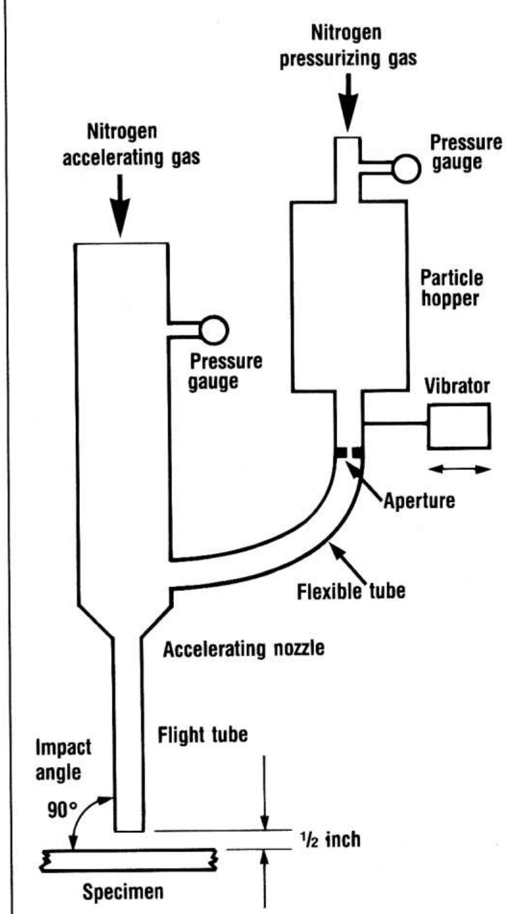


Figure 7: Erosion rig.

TABLE 1 Reduction In Wall Thickness Due To Particle Blasting

Specimen Type	Particle Type	Erosion Time, sec	Original Thickness, mm	Final Thickness, mm	% Change
Columbus SL	Sand	465	1	0.74	26
Columbus SL	Glass Spheres	465	1	0.87	13
Columbus SL	Sand	90	1	0.91	9

gram of the test equipment.

The impact angle significantly affects the erosion rate. Ductile targets, such as the steels used to make frames, exhibit the greatest material loss rates at low impact angles, about 25°. The lowest erosion rate is at 90°. But no matter what the intended impact angle is, many particles will hit at more acute angles because other particles interfere with their flight path, or because of peculiar angular rotations (especially true for non-symmetrical particles). In addition, the curvature of the tubes and the gun's angle to the tube will result in particles striking at all angles. Testing one specimen at all impact angles is impractical, so I used a microscopic impact angle of 90° to simplify testing (see Figure 7).

The Columbus SL specimens used in the tests were cut from a new fork blade. These samples were tested in the "as-received" condition, and had a yield strength of about 95,000 psi and a wall thickness of one millimeter. The strength of a steel depends upon its microstructure, which in turn determines the ease or difficulty with which metal is removed during particle blasting.

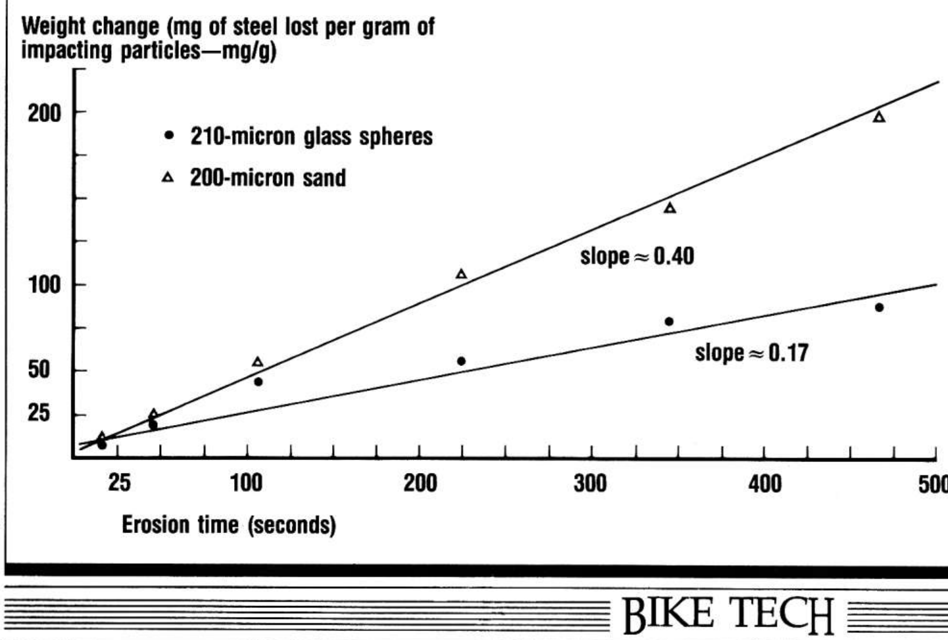
Work Hardening

It turns out that stronger steels erode faster than softer steels. This would seem to contradict logic, but can be explained as follows. Each impact causes permanent deformation which locally hardens the metal. This phenomenon is known as work hardening and can be demonstrated by simply bending a spoke, then rebending it the opposite way. You'll notice it's more difficult to bend it in the same spot again. Metals work harden because permanent deformations create atomic-sized irregularities that make it harder to further deform the metal. With this increase in strength, there is a corresponding drop in ductility. Further permanent deformation makes the metal harder and brittle, eventually causing failure. Strong steels can't work harden a lot because their structure already contains a large number of atomic-sized irregularities. Thus, only a small amount of permanent deformation (a few impacts) is needed to fully work-harden the metal. Following the first few impacts, significant material loss will occur as the hardened metal undergoes brittle fracture. Softer steels, however, are able to undergo larger amounts of permanent deformation without failure, and therefore are more resistant to material loss by particle blasting.

Each Columbus SL specimen was eroded for periods of 15 seconds, 30 seconds, one minute, two minutes, two minutes, and two minutes, for a total erosion time of seven minutes, 45 seconds (465 seconds). The specimens were accurately weighed at each of these time intervals to determine their weight change in order to chart a weight loss versus time curve. The results are given in Figure 8.

Figure 8: Erosion rates of Columbus SL tubing ("as received" condition)

Particle velocity—175 ft/s **Target material—Columbus SL** **Impact angle—90°**



George Retseck

Results

It's clear that the sand-eroded target lost the most metal. The total weight loss measured 15.9 milligrams, while erosion by glass spheres resulted in a 6.8-milligram weight loss. The erosion rate using sand was 2.3 times greater than when glass spheres were used. It's important to remember that the data given in Figure 8 are merely illustrative, since actual particle blasting conditions, and hence material loss rates, can vary considerably. For example, many more particles would strike at angles less than 90°, and it's likely that different particles, higher velocities, and higher particle concentrations would be used by a framebuilder.

Earlier in this article, I mentioned that it's possible to significantly reduce the wall thickness of tubes by particle blasting. Measurements of the reduction in wall thickness were made by photographing cross sections of the eroded areas. The results are given in Table 1.

The specimen eroded with sand and glass spheres had a 26 percent and 13 percent reduction in wall thickness, respectively. That's quite dramatic, and here's why: the specimens were eroded for seven minutes and 45 seconds in the same spot. An entire frame can be particle blasted in that time! To get an idea of the reduction in wall thickness for more realistic particle blasting times over small areas of the frame, I eroded another Columbus SL specimen for 90 seconds. The test conditions were the same as before, but only 200-micron sand was used because angular particles are normally used on frames. As Table 1 shows, there was a nine percent reduction in wall thickness. Had the tube been 0.5 mm thick, there would have been an 18 percent reduction, obviously a significant amount.

(Quite a few frame tubes have wall thickness of only 0.5 mm. The three main tubes in a Columbus Record tube set are straight gauge 0.5 mm. Double-butted Reynolds 531SL tubing has a mid-section thickness of 0.5 mm, as do the top and down tubes of Tange's No. 1. The Ishiwata 017 tube set's three main tubes are butted 0.7/0.4/0.7, and the exotic Reynolds 753 has a 0.7/0.3/0.7-

butted top tube. A wall thickness of 0.3 mm is 300 microns; that's not much bigger than the 200-micron sand).

Worst Case

It should be emphasized that this erosion test represents a worst-case condition. The Columbus tubing was in its strongest state and, as we saw, erosion of strong steels occurs at a high rate. Only some portions of a brazed frame will be like the test sample—the central sections of all the tubes will not have been annealed (weakened) by the heat of brazing. While all areas of a frame will be particle blasted, the time spent on the strongest (unannealed) areas will be short compared to the attention paid to the (weaker) brazed joints. And since the steel around the joints is weaker, it can endure more impacts before brittle-fracturing. Of course, if a frame is built with tubes that are ultra-thin at the joints, like Columbus Record or Reynolds 753, then great care must be taken when cleaning these areas with the blasting gun. The safest approach is to use only spherical glass particles on these delicate tubes, and blast a minimum amount of time.

Keep in mind, though, that material loss is only part of the problem. Any surface cracks, voids, or pits caused by particle impacts in areas where the frame is highly stressed can lead to frame failure. In Part 2 of this series we'll take a look at a frame that may have failed due to the effects of sandblasting. We'll also examine the theory and practice guidelines for safe particle blasting. Stay tuned.

Editor's note: Great caution must be exercised when sand blasting paper-thin tubing. Any overall reduction in wall thickness can severely compromise the tube's rigidity and strength. A rule of thumb is that any reduction in wall thickness will yield an equal reduction in both strength and rigidity. In the case of the Columbus fork blade sandblasted for 90 seconds, if we assume that the tube was blasted evenly all around, then a nine percent wall thickness reduction will result in an approximate nine percent reduction in both strength and rigidity. This estimation is approximate because the tube wall is not only getting thinner as material is removed, but the outside diameter of the tube is being reduced as well.

Reducing the diameter of a tube has drastic effects on its rigidity, with a change of a factor of k *in diameter resulting in a reduction in rigidity of about* k^3 *and a reduction in strength of about* k^2. *In this test, the effect of diameter reduction affects the strength and rigidity only a few percentage points above that wrought by reducing the thickness of the tubing wall. For a comprehensive discussion of how a tube's dimensional factors affect its strength and rigidity, see Crispin Miller's article in the August 1982 issue of* Bike Tech.

SPECIAL REPORT

On Brakes

Ed Scott

Ed Scott is the president of Scott/Mathauser Corp.

Ever since bicycles assumed their modern form at the beginning of this century, one component of the bicycle that has been considerably less than satisfactory is the brakes.

In relatively flat country and in dry weather most bicycle brakes are satisfactory. But in wet weather or down long steep hills, especially with a loaded touring bike, cyclists have been complaining for 80 years about inadequate brakes. It makes little difference whether they're centerpulls or sidepulls, and whether they cost $15 or $150. They can be beautifully polished, meticulously machined, and stamped with a near-holy name, but in practical use experienced cyclists have often admitted, "In the rain I can stop faster by dragging my feet."

Why is this so? A bike isn't a high-performance machine. Its basic purpose is to provide simple, safe, economical transportation. The bicycle was the precursor to the automobile, yet, while automobile brakes have evolved from two-wheel external band brakes, to internal shoes, servo shoes, four-wheel brakes, power brakes, disc brakes, and finally to power-boosted discs that will stop from any speed in any weather, bike brakes have only undergone a slow refinement of a basically bad design. With its slow speeds and two-foot discs (the wheel rims), a lightweight bicycle should be simple to stop.

Sidepull or Centerpull?

Even the descriptive terms for brakes are mixed-up and misleading. The key feature of a conventional caliper is not where or how the cable pull is applied, but where the arms are pivoted. This is the essential difference between side- and centerpulls. Sidepulls would be better termed "center pivots" because the cable pull can be arranged at the side, top, or in-between, by simply reorienting the primary arms. For an example of an in-between arrangement, look at the new Dia-Compe Aero brake. Likewise, the so-called centerpulls should really be called "side pivot" since this feature is what differentiates them from sidepulls.

Under normal braking conditions, the rear brake cannot be applied very hard, because a forward shift in the rider's center of mass reduces the rear tire's traction. Most of the braking must be done by the front brake, so it's important that the front brake be optimally designed. This includes choosing the correct type of brake for the front.

A centerpull is not the best brake to use on the front because the upward pull of the brake cable tends to flex the whole caliper upwards. This flexing, combined with the flexing caused by the rim dragging the caliper arms forward, upsets the firm contact of the brake pads on the rim. A sidepull is a better choice on the front because the upward cable pull is counteracted by the reaction push of the cable casing, so there's less caliper flex.

A centerpull is the better brake to use on the rear because the cable's upward pull on the caliper assembly helps counteract the downward pull on the caliper.

Design Flaws

If an engineer looked at examples of the best current sidepull and centerpull brakes, he or she would see a lot of questionable structural design. And there is an amazing similarity among almost all of the currently available caliper brakes, so they all suffer from the same design flaws.

Foremost in bad design is the choice of cross section for the caliper arms. Most arms have a cross section that is approximately a half-inch half-round. For braking duty, this is a very poor structural shape. Here's why: when a brake is applied standing still, the arms are stressed only in the plane of the cable pull. The half-round section is very rigid in this direction. But when a brake is applied on a moving bicycle, the rim tugs on the brake pads which pulls on the caliper arms. The caliper arm cross section is very weak when stressed in this direction, so the arms will flex.

To allow fender and tire clearance, the arms must sweep outward and then back in

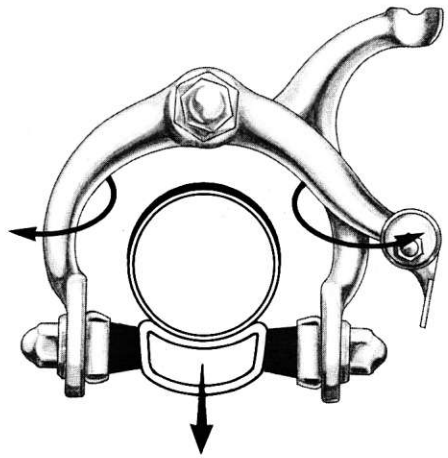


Figure 1: The caliper arms will twist when the rim tugs on the brake pads.

George Retseck

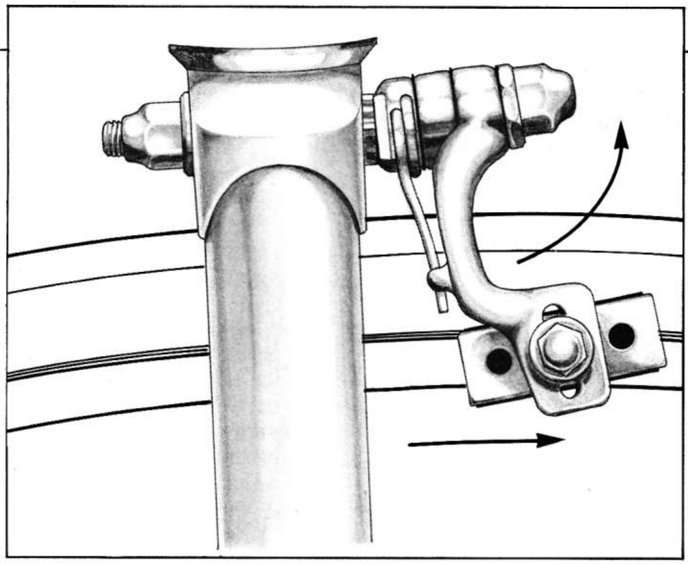


Figure 2: Thin mounting bolts bend outboard of the frame when the pads tug on the rotating rim.

towards the rim where they terminate with brake pads, which are far too thick. (Pads are replaced when worn down past the grooves or slots, but 50 percent of the pad is still left!) Because the arms sweep so far outboard from their mounting/pivot bolt and the wheel rim, the tugging force of the rim on the pads generates a strong torque in the arms. The half-round cross section is torsionally weak, so the caliper arms will twist and the brake pads will lose their firm contact with the rim (see Figure 1).

Adding Toe-In

To compensate for this twisting, knowledgeable bike mechanics bend the caliper arms with a wrench so that the forward ends of the brake pads contact the rim first. Then, when the arms are twisted by wheel motion, the pads rotate and make flat contact with the rim. Most brake manufacturers have totally ignored the need for this "toe-in" adjustment.

Scott/Mathauser entered the brake shoe business in February 1976 with a very high friction pad that offered more braking with less hand effort. We promptly discovered that a higher friction pad brought out the inherent weaknesses and drawbacks of all caliper brakes. The flexing and twisting discussed above is so great that we have to set the pads on test brakes with a full one-sixteenth-inch gap between the rim and the rear end of the brake pad. I then get up to full speed down a steep hill, slide back off the saddle and lay flat on it with my belly (to avoid pitch over). Then I apply the front brake quite firmly. The bike stops like I'd thrown out an anchor, and a brand new set of pads shows uniform contact from end to end. They've rotated one-sixteenth-inch over a length of 2¹/₈ inches—or almost two degrees of rotation—due to the twisting of the caliper arms.

There are additional problems with the sectional design of caliper arms. They have so short a bearing bore length at the pivot that the hole actually *stretches* during braking, allowing additional arm movement. And the upper arm, which isn't stressed anyway except in line with cable pull, is almost twice as heavy as necessary.

Excessive flexing also occurs in the caliper mounting bolts. All brake manufacturers use a six-millimeter mounting bolt. Under braking stress, the front bolt flexes upward and the rear one downward (see Figure 2). Larger, stiffer bolts aren't used because a larger hole in the fork crown would be required at the front, weakening this highly stressed area, while at the rear, a larger bolt would just about sever the skimpy brake bridge.

These six-millimeter bolts—an inadequate size—also serve as pivot bearings on sidepull brakes. Shimano has gone to a one-quarter-inch (0.14-inch larger) section outboard of the six-millimeter part that fits in the bike frame, while Universal, Modolo, and Galli use eight-millimeter (.315-inch). Beefing up the pivot post is a good idea, but the mounting end of the bolt is still six millimeters where it enters the frame and that's where it will bend. There is a remedy for this, however: if the mounting bolt is tightened very tightly, so the enlarged flange in the middle of the mounting bolt is pulled very hard against the fork crown or brake bridge, the main portion of the mounting bolt will be in pure tension and it will not bend.

But, the manufacturers use a flange of small diameter, and they taper the side that contacts the fork crown, so that instead of the nearly three-quarter-inch diameter contact surface available on most bikes underneath the headset bearing cup, the flange used is as little as .500 inches (Dura-Ace) or .575 inches (Campagnolo). I've never found one over .650 inches (Universal CX).

Brake manufacturers don't exploit the mechanical principle of pure tension that could be so effective in securing the front brake. They simply make front and rear the same, for convenience in manufacturing, and make the flanges small enough for the rear brake's bridge mounting surface. As a result, pure tension is not achieved, so under hard braking the mounting bolt stretches, the flange loses contact with the frame, and the caliper flexes.

Offset Hardware

Because of the thin, flexible six-millimeter mounting bolt, manufacturers keep the caliper arms' pivot point as close to the bike frame as possible. Then, to make sure that brake shoes clear the fork or seat stays, they offset the brake shoes outward from the plane of the pivot bearings and outward from the ends of the caliper arms. Thus, a hard application of the front brake causes greater pressure to be applied on the rearward ends of the brake shoes causing squealing, chattering and grabbing. Ideally, the center of each brake shoe should be in line with each arm's center and pivot bearing, so that more uniform pressure exists along the length of each brake shoe.

To secure a cable, some brake manufacturers use up to nine pieces of hardware. In order to produce the arms more cheaply and easily, the upper arms are more or less flat, and the cable hardware projects sideways out of the arm ends, pulling the cable out of the plane of the caliper arms. This misalignment is another source of flex. Both arms should have rotatable hardware, so that on wide or narrow rims, with new or worn pads, the cable core and casing will always be nicely aligned.

Quick-Release

Because brakes work so poorly and have such weak, flexible parts, it's necessary to ride with the pads quite close to the rims, so that no matter how hard you squeeze and how much the whole system flexes and stretches, the lever won't bottom out on the handlebar. If you break a spoke or bend a wheel, the pad-to-rim clearance can be increased with a quick-release, allowing continued riding, albeit with dangerously inadequate lever travel.

The other uses for a quick-release are to allow fast wheel changes during a race, or wheel removal when parking your bike, without having to readjust the brake after reinstalling the wheel. But why have a quick-release at all? It just adds weight and cost. Why not design a brake that doesn't need a lot of reserve lever travel, so there's always enough clearance for the tire to slip through the pads?

Logically, there should be as little lost motion or "sponge" in the system as possible.

Once the pads contact the rim firmly, the braking effect should be controlled by how hard you squeeze, rather than by how far you move a spongy lever.

Last But Not Least

Finally, consider the brake pads, the parts that do the real work of stopping a bicycle: Why are they made with slots and grooves? At first glance, these grooves act as escape routes for water and dust, keeping these friction inhibitors out from between pads and rims. After all, tire treads must be grooved to maintain traction on wet roads. But a rolling tire at each instant is in stationary contact with the road; any water between tire and road will be squeezed out and channeled away by the tread grooves. A wheel rim and brake pad are in sliding contact, and only the scraping action of the pad's leading edge can remove water from a wet rim.

Fred DeLong, in his book *Guide to Bicycles & Bicycling,* states "slots and grooves in the brake blocks gave poorer, not better, performance." In the rain, these gaps simply provide openings for more water to enter. There's also less frictional material in grooved brake blocks, and the free-standing buttons on many pads bulge sideways when compressed against the rim so that lever travel is wasted and the feel becomes spongy. This can be dangerous when the conditions are wet, because, as DeLong continues, "Block compressibility, especially when pads are severely slotted, can be so great that the lever may bottom (on the handlebars) when the extra force needed for wet stops is used."

Another practice meant to improve braking in wet weather—but actually worsens it— is texturing the sides of the rims. The knurls and dimples impressed into the rims are supposed to provide a rough surface for the pads to grab, but these rims have been dubbed "revolving reservoirs," because each dimple and groove captures and carries a drop of water to the brake pad. So, while textured rims may enhance dry weather braking, they make things worse in the rain.

Two years ago, cyclists were offered a major improvement: aerodynamics. If you threw away your brakes entirely, thus reducing their wind resistance to zero, your bike wouldn't go one-quarter of a mile an hour faster. So how on earth could you either measure or feel any improvement from rounding off the brake parts? And to achieve this rounded look, one manufacturer has made the shoes totally non-adjustable, forcing the use of tiny boat-shaped friction pads that wear out very rapidly and don't stop very well.

Other attempts to improve braking have been ludicrous: Brake shoes that slide against a wedge or ramp so that slight hand effort can create great pressure on the rim; compound or variable leverage caliper arms that are touchy to adjust and can overact and jam in dry weather; hydraulic brakes that add cost and complication while offering no real advantages; toggle action linkages that create too much shoe pressure and can jam or go over-center, etc. Collectively, they are like "curing leaky fountain pens by wearing rubber gloves." They all attack the problem at the wrong end, offering solutions no better than squeezing harder.

Cyclists aren't being served very well. They should be able to find more rigid and effective brakes that weigh even less than the lightest now available. But today's top brands of conventional caliper brakes are really nothing but a highly polished collection of very bad ideas.

All of these problems, drawbacks, and mistakes could be corrected with just a little thought, effort, and ingenuity. It has been said that those who criticize should also offer solutions. We're working on them. Let others do the same. At least we've spelled out the problems.

SPECIAL REPORT

On Scott's Brake

Doug Roosa

When we first received Ed Scott's manuscript on caliper brakes, it sent a small shock wave through *Bike Tech*'s office. Reactions were mixed: some were offended with his wholesale condemnation of caliper brakes; others were amused at his disrespectful attitude towards brake designers and manufacturers; others weren't impressed with his arguments.

After all, if a bicycle's brakes are strong enough to allow the rider to do a front wheel stand, then surely they deliver all the braking power one needs. Most bike brakes can do this with ease. Since a heavy-handed application of the brake levers can lock both wheels, why condemn the current lot of caliper brakes when the weak link to effective braking is either the rear tire traction or the threat of pitch-over?

No bike brakes work effectively in the rain; but, again, the limit to stopping a bicycle on a wet road may be in the available traction.

But once our emotional furor yielded to a more analytical attitude, it became clear that Scott's arguments centered around other problems that prevent a rider from using his

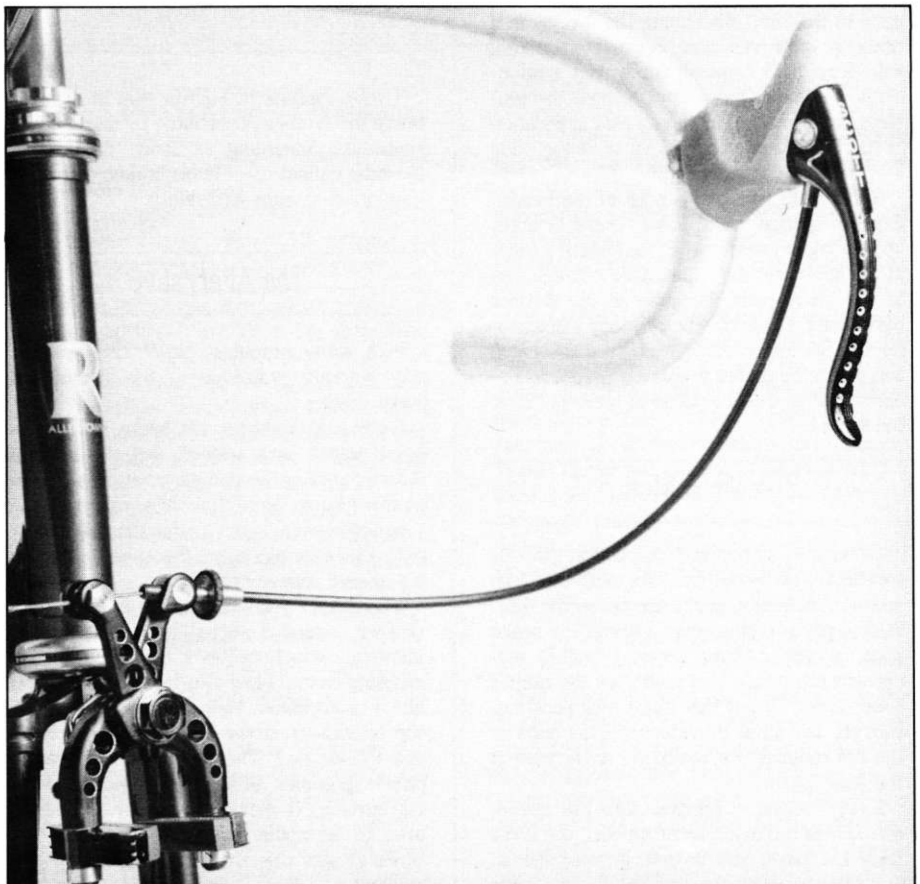


Figure 1: The Scott brake has little flex in its hefty caliper arms and direct cable routing.

or her caliper brakes to their maximum potential. Perhaps the design of a bicycle brake could be improved in a way that gives it an extra degree of "feel" by making the brake more responsive to the rider's input, and by making it simpler and safer.

If the World Were Perfect

Should an ideal brake system flex when you squeeze it, or should it have negligible motion upon application? There are arguments for both sides. Some experts, notably Shimano's assistant manager Shinpei Okajima, have told us the cyclist can control the bike better if the lever moves when it's squeezed harder. A physical change in lever position is less abstract than a change in muscle tension.

Not all well-designed control systems behave this way, though, and Ed Scott is clearly in pursuit of the virtues of a no-motion system. Let's look at the attractive aspects of the no-motion approach: Consider a brake lever that doesn't move when you squeeze it. This can be imagined if the brake's pads are allowed to ride infinitesimally close to a perfectly true wheel and all the mechanical components are perfectly rigid.

An application of force at the hand lever of this ideal brake would instantly engage the pads to the rim. Minimizing the motion in a brake is quite desirable because a brake's sole duty is to transmit force, not motion. Motion requires an amount of time to complete; any time lag between force application at the brake lever and response at the pads lengthens the braking time.

Additionally, if there is a lot of mechanical flex, or sponge, in a brake, there is a response lag between the application of a force at the lever and the appearance of this force at the brake pads, because all the flexible parts must "wind up" before they will transfer the full force. Also, friction in the cable and pivots degrades a brake's response because it absorbs an amount of force put in at the lever.

Too Much Motion

Of course, motion in a mechanical brake is inevitable: no wheel rims are perfectly true and no mechanical parts are perfectly rigid. And to get a large enough force at the brake pads, a caliper brake needs a built-in mechanical advantage that multiplies the rider's hand force. To get this force multiplication, though, any small movement of the pads to the rim requires a much larger movement at the hand lever.

Every cyclist is familiar with the consequences of too much lever motion: the lever feels too pliant and flexible in your hands. It's often possible to flex the lever all the way to the handlebars, particularly when braking in the rain.

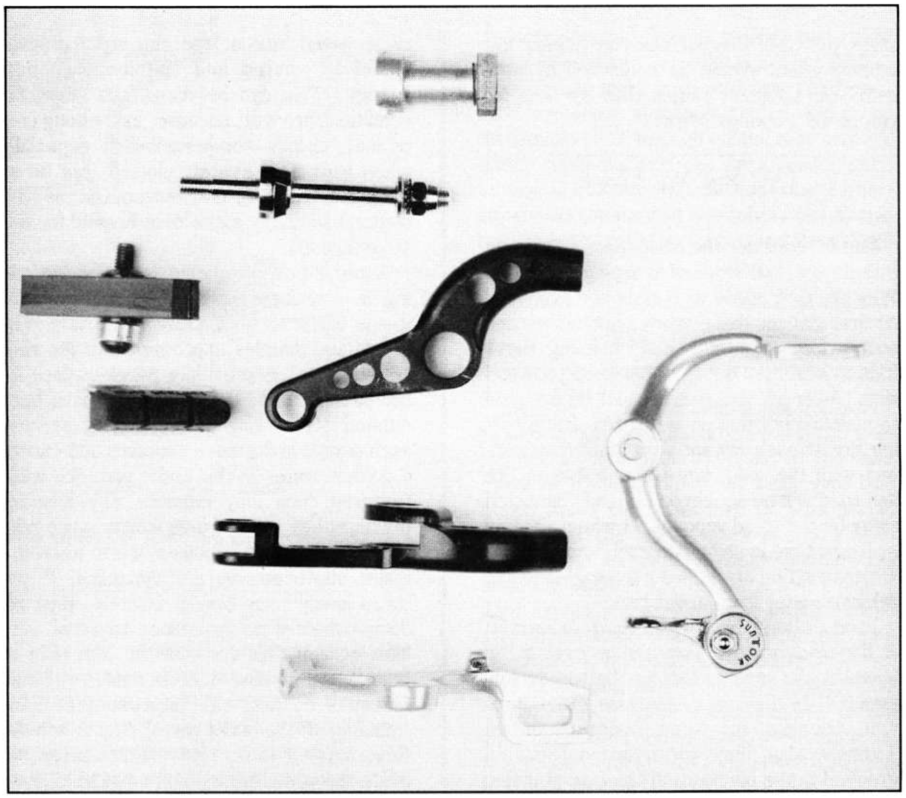


Figure 2: A side-by-side comparison between components of the Scott brake and a SunTour Superbe sidepull.

These sources of built-in slop in existing brake mechanisms contribute to vague brake response. According to Scott, this means the rider cannot operate his brakes with optimum performance and safety.

The Alternative

With some prodding, Scott sent us the only working prototype of his alternative brake design.

As Figure 2 shows, his brake has all the same pieces as a sidepull, but the striking difference is in the comparative proportions of the pieces. Note the thick calipers, the long brake pads, and the large diameter pivot bolt. Piece for piece, the Scott brake dwarfs a standard caliper brake.

The caliper arms are square in cross section with rounded edges. The two arms are identical, which reduces tooling and part stocking costs. They interleave at the pivot, like a piano hinge. Delrin® shims tighten up the tolerances in the hinge, so there is no side-to-side slop. The pivot bolt, sheathed in plastic, provides an ample low-friction bearing surface. (I measured the pivot bearing area to be about two-and-three-quarters times greater than that of a good Campy-like sidepull.)

The brake pads are the expected Scott/Mathauser compound—in both size and appearance—but they are mounted unlike any other brake pad. Each backing plate has an attached tube through which a hex head bolt passes and threads into the bottom of a caliper arm. Sandwiched among each mounting bolt head, backing plate tube, and caliper arm end, are two conical washers that allow a small amount of angular adjustment of the pad off the perpendicular from the arm. This allows the pad to meet the rim squarely, either in the radial or lateral plane. Toe-in can be simply set by loosening the mounting bolts and swiveling the pads. (Scott's recommendation for toe-in is to engage the pads on the rim, loosen the bolts, place a business card between the back side of each pad and the rim, and retighten the mounting bolts.) Regardless of the pads' orientation to the rim, they always remain on the center line of the calipers.

Scissors Action

The caliper arms are actuated from the top, like a pair of scissors. The cable, its attaching hardware, and the tops of the caliper arms are all aligned both in the plane of the caliper arms and with the centers of the brake pads. All the cable attachment hardware is free to rotate in the caliper arms. The cable runs through a threaded adjustment barrel and is secured with a two-piece bolt, similar to a seatpost bolt. The bolt is

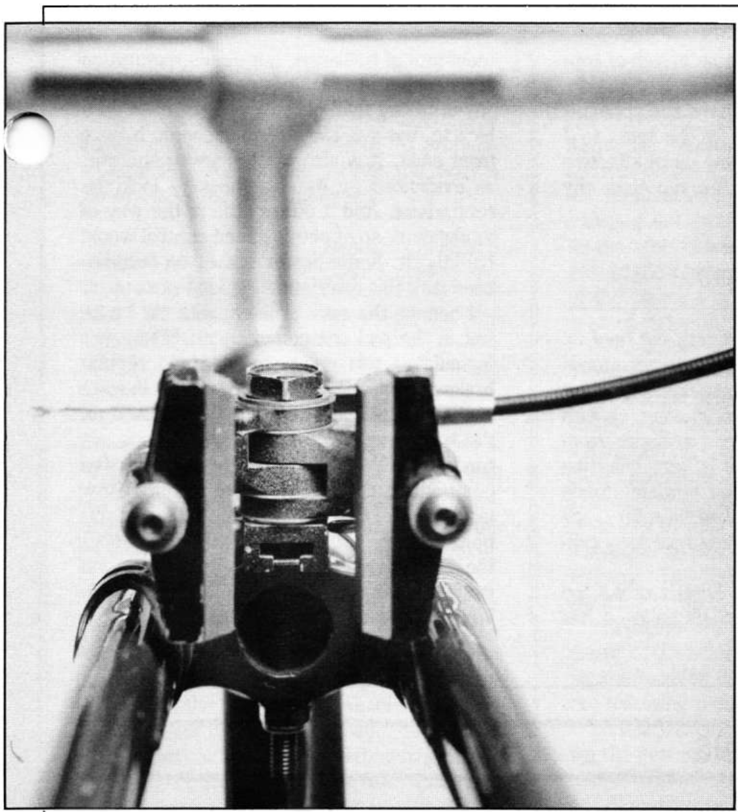


Figure 3: The large pivot and brake pads can firmly clamp a wheel rim. The T-slot at the back of the pivot allows the caliper to slide up and down on the head of the mounting bolt to adjust drop.

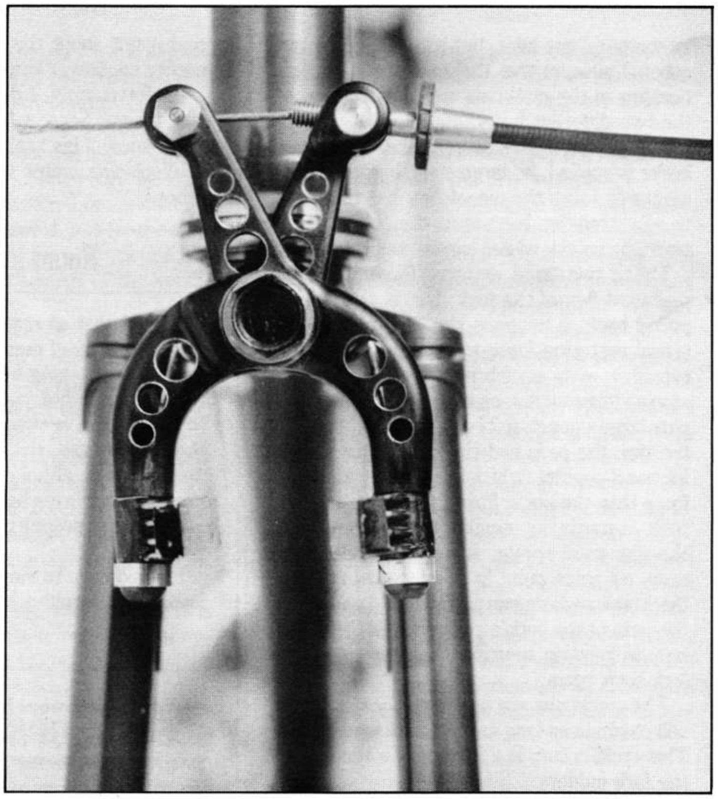


Figure 4: A variety of lightweight materials and several lightening holes offset the brake's massive appearance. It actually weighs less than most sidepulls.

slotted up the middle like a clothes pin. The nut has an internal sliding wedge and retainer pin. With the cable in the slot and the nut threaded up, the wedge forces the cable into firm contact with the end of the bolt's slot. Since the wedge is made of bronze and the end of the slot is machined, the cable suffers no flattening or kinking.

As Figure 1 shows, the cable enters the Scott brake lever, which is a Modolo aluminum lever, from underneath, so the cable (at least for the front brake) is as short as possible. The cable attachment hardware is reversible, so the cable can connect to the brake from either side.

The caliper assembly attaches to the bicycle with the usual six-millimeter bolt. The head of this bolt fits into a slotted mounting boss behind the pivot (see Figure 3). As in a Shimano Parapull brake, the caliper can be positioned for the proper reach by sliding the caliper on the bolt head. Once the reach is correct, a nut tightens the whole assembly. The brake's reach extends from 40 to 54 mm, and can go up to 60 mm with a simple set of extender bolts amd bushings. (I tried this extender set-up and found that it presented no problems.)

Metallurgist's Delight

Don't be fooled by the appearance of Scott's brake. It looks massive but it's actually lighter than most sidepulls. A comparison on our triple beam balance revealed the following weights:

Modolo Professional	196 grams
Shimano 600	171 grams
SunTour Superbe Pro	167 grams
Scott/Mathauser	152 grams

How does such a massive looking brake end up being so light? It's all in the materials. The calipers are machined out of a solid block of aluminum. The pivot is an aluminum bolt. The caliper mounting bolt is made from aircraft-grade, heat-treated titanium, as are the brake pad mounting bolts. The backing plates for the brake pads are made from magnesium alloy. Finally, the cable attaching hardware is stainless steel and the threaded adjustment barrel is plain old chrome-plated carbon steel. Throw in a couple of Delrin® washers, a plastic sleeve, and a steel spring, and you have 156 grams of exotic materials.

Front and Rear

The appearance of the Scott brake also suggests rigidity and here there are no suprises. Gone is any hint of flex in the caliper. Gone also is a quick-release. The only detectable sponge in the brake is in the lever and cable. This sponge is insignificant in actual use, because the caliper is so rigid and the pads have such a high frictional coefficient, that only a light touch on the brake lever generates a massive amount of braking power at the wheel. To give you an idea of how powerful this brake is, I installed it on the rear and found that, even with a drastic rearward weight shift, the rear wheel would lock instantly. It performed like a switch—either the brake was off, or the wheel was locked.

On the front, though, it proved quite effective. Sometimes. When installed on one bicycle, it would bring that bike to a halt quicker than any other single brake I've used. Part of the difference was in the quick response of the no-flex mechanism; part lay in the aggressive nature of the high friction pads. I approached the braking limit gingerly because without conscious bracing and weight shift, I invited pitchover. The Scott brake makes things happen fast.

Trouble Springs Forth

But when I installed the Scott brake on the front of another bike, it caused very disturbing behavior. An application of the brake produced an oscillation in the front fork so intense that I had to release the brake for fear of either losing control of the bike or doing damage to the fork. Repeated adjustment of the brake and dressing of the pads made no difference.

What is curious about this behavior is its intensity on one bike, but its absence on another. I suspect that the root of the oscillation lies in the materials and construction of the two different forks, and how they react to the power of the Scott brake. When the brake is applied, its large clamping force momentarily locks the wheel rim, but the large weight transfer increases the front tire's traction, so the wheel cannot skid.

These two large external forces cause a rearward flex of the fork, but as the fork is pulled back, it behaves like a spring: its internal restoring force increases as it is displaced from its equilibrium position. The restoring force increases with deflection until it gets large enough to break the pads' hold on the rim; the pads and rim then enter sliding frictional contact (which is a smaller frictional force than the static force). The fork springs back towards its equilibrium position, but like any good spring, it overshoots equilibrium. At some point in this forward motion, the brake pads regain a static hold and, with the help of the fork's restoring force (which is now pointing towards the rear), pull the fork back again.

The conditions are reset and the oscillation will continue as long as the brake is engaged. This cycle occurs in a fraction of a second, so the fork judders.

Pervasive Problems

If this is what happens, then it must occur to some degree on all front forks with any brake. Why was the oscillation noticeable only on one of two bikes that had the Scott brake, and why is it not noticed with other brakes? The answer to the second question may be that if it does happen on a bike with regular brakes, it's either too mild to notice because the pads can't grab tightly enough, or else the brake calipers are so flimsy *they* go into oscillation, rather than the more massive and tightly sprung front fork. (This may explain the screeching and squealing that occurs with some front brakes—the calipers oscillate, causing a vibration between the pads and rim that is in the audible range of frequencies.)

The answer to the first question may be that some forks are rigid enough to withstand the braking force of Scott's brake; some aren't. The fork that juddered in the grip of Scott's brake was built with Columbus SL tubing; the other is not marked, but I suspect it is a heavier, Tange fork.

Reprieve

For an additional test, I installed Scott's brake on a tandem with beefy, oversize fork blades and a massive crown. The results were very favorable: the judder was gone, and the brake gave a firm, stiff feel at the lever. Braking power was governed more by the amount of force applied than by lever motion. Two experienced tandem captains said it felt about the same as a pair of top-quality cantilever brakes.

(Unfortunately, I didn't have the opportunity to use Scott's brake in the rain, so I don't know if his brake is any more effective at displacing water from the rim than any other.)

Room to Improve

I doubt that all manufacturers will beef up the front ends of their bicycles to accommodate larger braking forces, so it is important to gauge whether your fork is stout enough to handle the braking forces available from the Scott brake. His brake is very effective on a tandem, although most tandems made now use cantilever brakes and therefore may not have the proper mounting hole for a caliper brake.

I would have to view Ed Scott's prototype brake as I would a precocious child—it has moments of brilliance, but needs maturation in its design. As it stands now, it is the most powerful and rigid brake I've ever used on a bicycle, but it is too strong for some bicycle front ends. It is also too touchy to operate, as evidenced by its eagerness to lock the rear wheel. And it offers little in the way of modulation, so effective speed control would be difficult. Some power brakes on automobiles lack this discriminating kind of control.

I believe the main problem with the brake lies in the pad compound. Scott/Mathauser formulated this compound to help regular brakes provide good stopping power in spite of their weak arms and pivots. But used on the beefed-up Scott caliper, these pads are too grabby. Perhaps with a less aggressive compound, the Scott brake would allow more control in scrubbing off a wheel's rotational energy. This change would not affect the brake's real strengths—its rigidity and responsiveness—but would let these strengths be used to their fullest.

IDEAS & OPINIONS

We at Bike Tech *welcome reader input. Whether you comment on an article, suggest topics we should report on, propose tests to answer nagging questions, or provide insight into the current and future state of bicycling, we are interested in your ideas.*

We know that many readers are engaged in designing and developing better bicycle components and human powered vehicles. We know that many others have the curiosity and knowledge to challenge the current state of bicycling science. And we know that everyone has ideas about how to improve the unique relationship between bicycle and rider.

This space will be a forum for your ideas. Besides the usual letters to the editor, it will include pertinent observations about the current state of bicycles and HPVs, suggestions for future directions in bicycling, and ideas about research and development that will add to the collective knowledge of the sport.

We hope you will find such an exchange of ideas rewarding and that you will be stimulated to contribute your own thoughts.

Pedaling Speed Research Planned

The present consensus on pedal speed during cycling training and racing is that, although there may be some loss of mechanical efficiency, high-speed pedaling can be tolerated better than low-speed pedaling at a given work rate. The basic rationale for this is that blood flow is restricted less if the muscle tension is less, as in the case of the higher pedal speeds.

The problem of remaining seated or standing to pedal when the work rate is near maximum may also be related to the problem of optimizing blood flow to the leg muscles rather than optimizing caloric expenditure. The difficulty in obtaining answers to these questions is that very little work has been done measuring leg muscle blood flow during cycling.

We have conducted a pilot study by measuring blood flow of the thigh with electrical impedance procedures immediately after exercise in an attempt to obtain an index of the muscle blood flow during exercise. The results were somewhat surprising. We observed that muscle blood flow immediately (~ 13 seconds) after the high pedal rates was less than that measured after the lower pedal rates. It is possible that the high pedal rates (100 rpm) do not allow sufficient time (short relaxation period) for adequate flow even with reduced muscle tensions during the contraction phase. If this is true, then it is suggested that there is some optimal pedal speed at a given work rate which would optimize muscle blood flow.

These are preliminary ideas based on a few observations. Much more work needs to be done. Before we can proceed, we want to fit a racing bike (preferably the subject's bike) to a standard ergometer so that we know precisely what the work rate of the individual is under various combinations of pedal speed and gear selections. The second thing we need is a rapid inflation system for thigh blood pressure cuffs so we can make the blood flow measurements immediately

(< 2 sec) after the exercise and before reactive hyperemia occurs.

As soon as we procure the necessary funds and equipment, we hope to produce results that will further define the body's preferences for pedaling speed.

James L. Hodgson
State College, PA

Questions About Bending Frames

Congratulations to Jacquie Phelan and Charles Cunningham for their article on destructive testing of steel and aluminum frames (August 1983, Bike Tech). However, I feel a few points must be addressed:

1. The tests did not take into account the effects of wheel and fork, both of which are likely to deform before the frame does. With this in mind, what exactly does the data prove? We all know steel frames are strong enough; is there a practical benefit to a stronger frame?
2. Figure 1 states that the vise supporting the frame and jack assembly "is not involved in the test forces." How was this conclusion arrived at? It would be interesting to do the tests by simply laying the whole apparatus on the floor to see how the data compare.
3. The frames tested were loaded (or strained) at such a low rate that the tests can be considered static. In reality, frames involved in accidents are loaded dynamically. The strength of a metal depends upon the rate at which it was strained. Generally, the higher the strain rate, the stronger the metal. If you could devise a test which suddenly delivers a load, of say, 1325 pounds (which is the static load needed to permanently deform the aluminum frame tested), you might find a greater load is needed to cause failure. In addition, a steel frame tested similarly may reveal failure loads more comparable to the aluminum frame.
4. Congratulations to Steve Potts and Scot Nicol for putting their names in print along with their product.

Mario Emiliani
Contributing Editor, *Bike Tech*

Reflector Refutation

The lamp and reflector article by Fred DeLong with John S. Allen, in the August *Bike Tech,* is unscientific and is biased against rear reflectors. Its errors start with the research by Dr. Helmut Zwahlen on which the article is based.

Dr. Zwahlen's research was for a lawsuit to demonstrate defects of rear reflectors. I don't contest his measurements, but the items he measured and cited from other sources do not apply to normal use or to typical accident situations. I know: in the trial, DeLong and Zwahlen testified on one side, I on the other! Before I could testify, the lawyer on their side settled for only 15 percent of the claim, a good indication of the weakness of the evidence.

Publication of Zwahlen's paper by the Transportation Research Board failed to meet normal scientific procedures and standards. The paper had been reviewed by the TRB Lighting Committee, but not the Bicycling Committee, which complained that several papers would not have been accepted if reviewed by experts on bicycling. I know: as a member of that committee, I complained in writing to TRB management about Zwahlen's paper.

Furthermore, DeLong has garbled the sense of Zwahlen's paper, reporting statements Zwahlen did not make. I comment on the following technical inaccuracies:

1. *Eye fixations:* The technique of showing the pattern of eye fixations is not original with Zwahlen, and his particular results do not demonstrate that drivers would not see cyclists in time to steer clear. Rather, they show that drivers on an empty road in darkness spend a considerable portion of the time looking where a cyclist should be. Furthermore, the pattern of fixations on an empty road may not be the same as when a cyclist is present—even before conscious recognition.

2. *Required lamp brightness:* Zwahlen did not "determine[d] that the intensity of the lamp must be 1,000 times the threshold of perceptibility . . . to gain the driver's attention 98 percent of the time." Such low effectiveness would cause a horrendous accident rate. Rather, Zwahlen used data developed to determine the brightness contrast required for airplane pilots to find airport lamps, a more difficult situation; the transferability of conclusions is suspect. To the contrast needed for a 98 percent rate for pilots, Zwahlen nonetheless arbitrarily added a 1000-time safety factor.

3. *Detected distance:* The "decision sight distance" cited by Zwahlen is the distance traversed by a vehicle as the driver recognizes a need to change lanes, finds a gap in adjacent traffic, and executes the lane change. This is not comparable to the accident situation considered, in which the driver must move only two or three feet to the left.

4. *Peripheral detection:* Zwahlen states that "A peripheral angle of ten or 15 degrees might be the most representative . . . for night driving conditions," and he investigated such performance. This would be beyond the left and right margins of the plot of eye fixations in DeLong's article. These peripheral regions are far from where a driver devotes most of his gaze—on the road ahead. Such an assumption is not based on actual accident situations and requires that lamps and reflectors be far brighter than actual traffic conditions require.

5. *Bicyclist recognition:* For the conditions under discussion, the driver need not "recognize the bicyclist, estimate size and speed, and so be able to anticipate the bicyclist's maneuvers." The bicyclist has only one proper course: to continue straight along the edge of the roadway. The motorist has only one proper course: to steer clear of the object ahead. Whether the motorist recognizes the cyclist is beside the point; if he thinks the cyclist is a stationary object, the cyclist's speed will give the motorist a little extra time to steer clear.

6. *Angular field of view of reflectors:* DeLong and Zwahlen both claim that "wide-angle" reflectors work on curved roads, while "narrow-angle" (20 degree) reflectors do not. The claim is false. For a curve giving a conservatively high 0.2g lateral acceleration of the overtaking motor vehicle, with a ten-mph bicyclist speed, I calculate that the reflector is within 20 degrees of facing the motorist for more than six seconds at all mo-

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D. FREE DISTRIBUTION (incl. samples) By MAIL, OR OTHER MEANS. (No News Agents)	383	900
E. TOTAL DISTRIBUTION (Sum of C and D)	9,929	10,495
F. OFFICE USE, LEFT OVER, ETC.	1,776	1,685
G. TOTAL (Sum of E and F)	11,705	12,180

torist speeds over 20 mph. The time period is longer at higher speeds.

7. *False comparison between CPSC and SAE reflectors:* Zwahlen, DeLong and Allen compare the minimum reflective powers of CPSC and SAE reflectors, and conclude that SAE reflectors are not as bright. But nobody recommends using reflectors that barely meet the SAE brightness requirements. The recommended reflectors have the 20 degree angle design of SAE reflectors, but are much larger and much brighter. They are marked SAE in order to be lawful for use where SAE reflectors are specified.

The laws of optics and the available materials prohibit a single corner-cube reflector element from operating over 100 degrees of arc (as required by the CPSC). Therefore, CPSC reflectors must divide their effective area into three separate areas, each covering a single, smaller arc. The SAE reflector can use all its area over the 40 degree arc, with half of its area effective for a few more degrees on each side.

8. *Undue emphasis on tall vehicles, curves and vertical curves:* We all know that reflectors are less optically effective when associated with tall vehicles, curves, and vertical curves. However, Kenneth Cross's studies revealed no accidents caused by this.

9. *Undue concern about reflectivity at intermediate distances:* DeLong and Allen don't give a quantitative example, but using their logic, a reflector actually matching the SAE specified minimum performances at 0.2 and 1.5 degrees will get dimmer as the driver gets closer than 600 feet. Both Zwahlen's tables and practical experience show that such reflectors are not made.

No investigations of which I know have developed scientific grounds for concluding that rear reflectors of the better types commonly available are unsuitable for cyclists to rely on.

John Forester
Sunnyvale, California

John Allen replies:

I find points 1 and 4 incontrovertible, but I have some problems with the others. In 3, a motorist may indeed have to change lanes to overtake a cyclist. In 5, failure to account for a cyclist's forward movement may lead a motorist to underestimate passing distance and to be forced to pull in too soon.

In 2, Zwahlen's 1000-time factor is arbitrary, but how is finding an airport beacon more difficult than finding a bicyclist's rear reflector or taillamp, which may compete with oncoming motor-vehicle headlamps? Forester has repeatedly stated that reflectors should be bright — as in his support of SAE reflectors in 7; experience shows that only the better reflectors match the brightness of automotive taillamps.

In 7, there is little argument: the article stated ". . . the actual performance depends on the quality of manufacture . . . it is harder for a [wide angle] reflector greatly to exceed its standard."

Similarly, the issue in 9 was raised by Zwahlen on the grounds that some manufacturer *might* make such reflectors. As Forester states, Zwahlen's own tests show that they are not made; but if they come to be, it won't be the first time performance has been downgraded to a specification.

The mathematical analysis in 6 is convincing, yet it is far from representing worst-case conditions in which several adverse factors reduce reflector effectiveness. Zwahlen has in fact provided a compelling mathematical model of a case in which poor reflector visibility on a curve led to an accident (see "More Light and Less Heat," *Bicycling*, April 1980).

Forester's point of view is important and welcome; he is always first to set a high standard of inquiry and to defend cyclists against frivolous and burdensome legal requirements. Like many conscientious cyclists, I agree with him about keeping the law conservative and about the poorer visibility of CPSC reflectors directly behind; but I nonetheless use more than the legal minimum of nighttime equipment, preferring added conspicuity for the worst-case situations even if significant reduction in risk has not been proven.

Superior Image and Vintage Hand Cleaner

In response to your request for information from your readership about various discoveries, I would like to share the following:

1) If you drink first and work on your bike second, the durability of repairs is very questionable.

2) Cheap wine is seldom of any value other than to use for hand cleaner.

3) It's helpful to have a chemist in your cycling club. We have access to a fast-drying solvent that keeps our chains and bearings the cleanest in our area.

4) In order to preserve an image of technical superiority and seriousness, subscribe to *Bike Tech* and refer to it often while on bike rides with others.

Sincerely and seriously (sort of) yours
Suzanne B. Toomey, Correspondent
Bombay Bicycle Repair Club
Buffalo, New York

Let Us Hear

We'd like *Bike Tech* to serve as an information exchange — a specific place where bicycle investigators can follow each other's discoveries. We think an active network served by a focused newsletter can stimulate the field of bicycle science considerably.

To serve this function we need to hear from people who've discovered things. We know some of you already; in fact some of you wrote articles in this issue. But there's always room for more — if you have done research, or plan to do some, that you want to share with the bicycle technical community, please get in touch.