Materials • Mechanics • Physiology • Engineering • Aerodynamics

BIKE TECH

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IN THE LAB

Mechanics of Braking Performance

Part 1: Design of the Shimano New Dura-Ace Braking System

Shinpei Okajima

Auto racing drivers always demand good brakes on their cars, but not because they plan to come to a screeching halt during the race. Rather, they need the precise *maneuvering ability* that a fine-tuned braking system can deliver. For this reason, improvements in car brakes have kept pace with other automotive developments, such as greater engine horsepower and better suspensions. As a result, the millions of drivers on the road today all take for granted that their brakes will perform flawlessly.

But in bicycle racing, the role of brakes has been undervalued for a long time. And the primitive state of many bike brake systems today is a reflection of this.

The situation is about to change, however. Now that races are becoming faster, and riders of more nearly equal ability are competing, high-performance bike brakes can be a real competitive advantage. This is what is meant by the phrase, "good brakes can make you go faster." Of course, brakes still need to perform their basic function: stopping the bike as efficiently as possible. Especially on commuting and touring bikes, brakes are needed for panic stops and for maneuvering through traffic. And ATB riding is always more fun if unlimited braking force is available.

Mr. Okajima is Assistant Manager of the Development Section in Shimano's Technical Division in Osaka, Japan. He has played a major role in developing Shimano's "New Dura-Ace" line of components, including the braking system described in this article, and the SIS indexed shifting system, discussed in his article in April 1985 Bike Tech. *Mr. Okajima also races as an amateur in the Japanese equivalent of Category 2 events.*

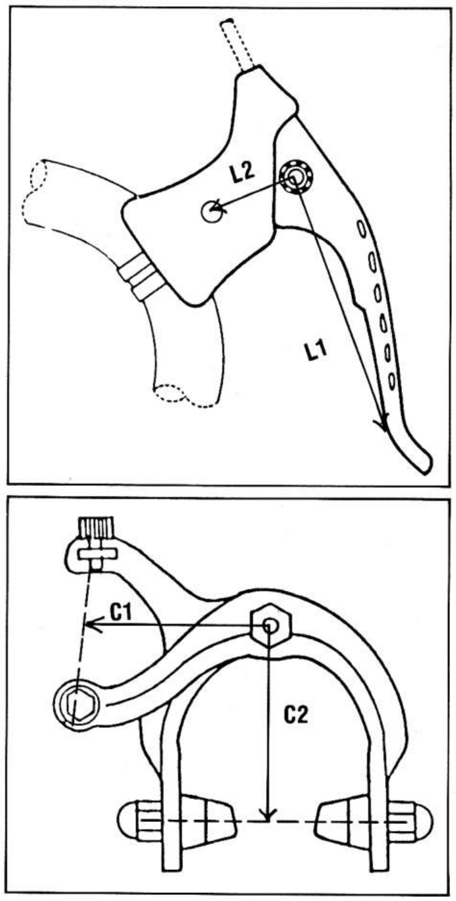


Figure 1: The "geometric" mechanical advantage of brake levers and calipers is determined by lever-arm distances as follows:

M.A. of lever = L1/L2
M.A. of caliper = C1/C2
M.A. of cables = 1
M.A. of system = (L1/L2) × (C1/C2)

IN THIS ISSUE

Our brake research project at Shimano is aimed, therefore, not only at increasing the braking *force* delivered by the system, but also seeks to refine the degree of braking *control* available to the rider.

How is this achieved? In four words: "less friction, less flex." Specifically, our tests found that conventional brake designs suffer from large friction losses, a problem we found easy to correct, in part by use of lubricant-filled nylon inserts. Once this was done, we concentrated on increasing the stiffness of the caliper arms (through computer-aided design) and cable housings (by using flat-wound steel casings).

The end result is the New Dura-Ace brake set, on the market for nearly a year, and the new Shimano 600 brake package, scheduled for release in early 1986. By actual on-road tests, we have demonstrated that these new Shimano systems show as much as 14 percent *shorter* stopping distance, compared to Campagnolo Super Record components. In this *Bike Tech* article (Part I), we focus mainly on the R&D evaluations leading to the New Dura-Ace design. In Part II, scheduled for the next issue, we will report on a thorough stopping-distance comparison of both new Shimano systems against Campagnolo.

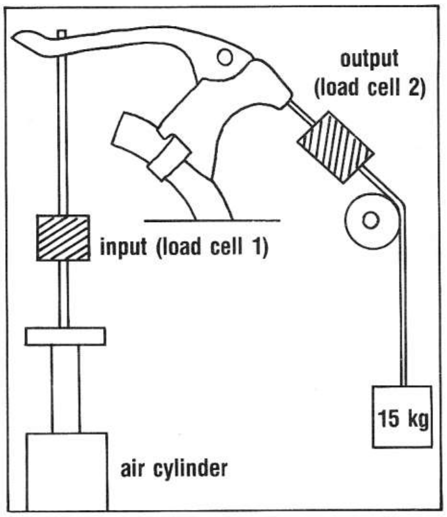


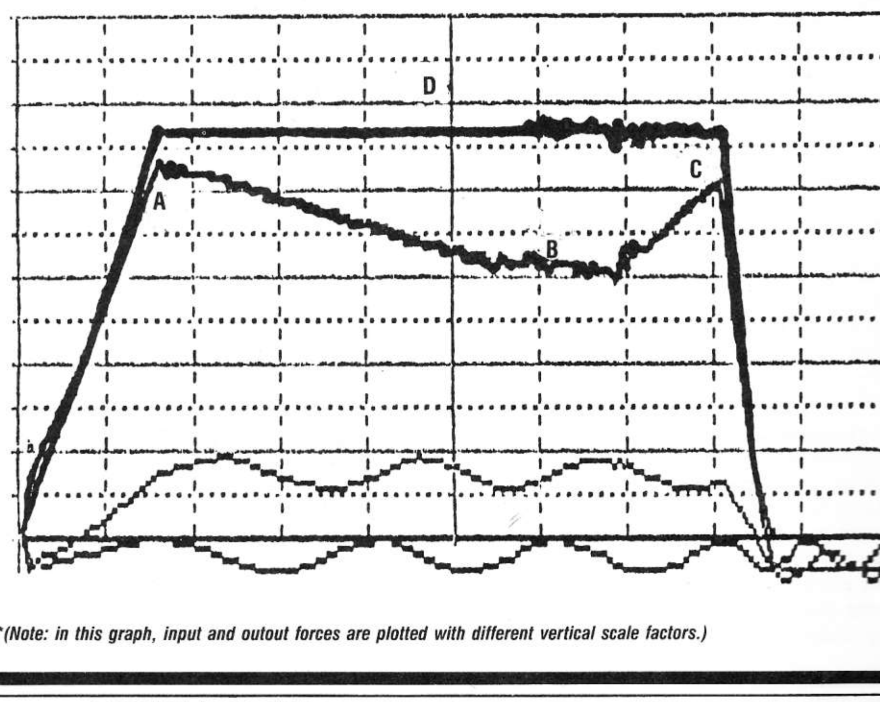
Figure 2: Test setup to measure efficiency and "elastic recovery" of brake levers. The air cylinder, under control of an automatic programmer, applies linear ramp displacements in alternating directions, corresponding to the "apply" and "release" phases of brake operation. Time for a full cycle is 10 seconds. Load-cell data *versus* time are recorded digitally; typical data are shown in Figure 3 below. The 15 kg dead weight corresponds to a hand-lever force (load cell 1) of about 8 lbs. The same load-cell equipment is also used to measure efficiency and recovery of brake cables and calipers.

"Geometric" Mechanical Advantage

One variable the designer *cannot* adjust arbitrarily is the mechanical advantage of the braking system. Mechanical advantage is the multiplying factor by which the rider's force on the hand-lever is amplified at the point where the brake blocks compress the wheel rim. The two components which generate mechanical advantage are the hand-levers and the caliper arms. If everything in the system were *perfectly rigid* and had *no* losses due to internal friction, then mechanical advantage would be simply a *geometric factor*; that is, it could be calculated by measuring the lengths of the mechanical lever arms of the brake handles and calipers (see Figure 1). This geometric definition of mechanical advantage is not the whole story, but it is useful as a starting point for the designer.

Ideally, the brake system should provide as large a mechanical advantage as possible, so that large braking forces could be produced with minimal hand effort. But in practical designs, a mechanical advantage of about 5 is the highest that can be achieved. The major constraint here is the "law of leverage;" this says, essentially, that to increase a system's mechanical advantage you

Figure 3: Typical force-*versus*-time data from brake lever efficiency test. Point A is the start of "pull" stroke, point C is the end of "release" stroke, and point B is the instant when pulling stops and release starts (i.e., when air cylinder reverses direction approximately 4 seconds after the start of the cycle). Point D is the relatively constant output force reading on load cell 2. (Note that output force becomes somewhat erratic during the release stroke.) Load-cell data from points A, B, C, and D are used to calculate brake-lever efficiency and recovery as follows: efficiency = D / (B mechanical advantage)
recovery = C / A



(Note: in this graph, input and outout forces are plotted with different vertical scale factors.)

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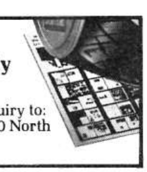


Figure 4: Results of brake efficiency tests. Mechanical advantage is calculated directly from dimensional measurements L1, L2, C1, and C2. Efficiency and recovery are measured by load cell setup shown in Figure 2 above.

	Shimano New Dura-Ace	Campagnolo Super Record
Lever mechanical advantage	4.2	4.2
Lever efficiency	95%	90%
Lever recovery	95%	85%
Cable mechanical advantage	1.0	1.0
Cable efficiency	70%	55%*
Caliper mechanical advantage	1.2	1.2
Caliper efficiency	95%	80%
Overall mechanical advantage	5.04	5.04
Overall system efficiency	63%	40%

**Tested with unlined cable housing.*

must either increase the travel distance at the input point (hand-lever) or decrease the travel distance at the output point (brake shoe). This law is in direct conflict with two operational requirements for the brakes: 1) the size of an average rider's hand sets an upper limit to the maximum possible lever travel distance, and 2) the need for a wheel-clearance gap sets a lower limit to the minimum allowable travel distance at the brake shoes.

Other constraints also come into play. As mechanical advantage is increased, for example, the caliper arms and cable housings must be made stiffer (thus bulkier) to resist the larger forces. Also, if the mechanical advantage is made too large, the rider loses an important sense of control, since the difference between "light braking" and "pitchover" would be but a few grams of finger pressure.

Juggling all of the above trade-offs leads to the conclusion that a mechanical advantage of about 5:1 is optimal. In other words, brakes with a much smaller mechanical advantage could be improved by a geometric re-design to modify the lever-arm distances. However, we find that most existing top-line sidepull brakes, such as Campagnolo Super Record, are already close to our "ideal" mechanical advantage of 5:1 (see Figure 4). For the Shimano New Dura-Ace design, we specify a "geometric" mechanical advantage of 5.04:1; this is achieved by a ratio of 4.2:1 at the hand-lever and 1.2:1 at the calipers.

The real world now enters the discussion: brake components are *not* perfectly rigid, and they all *do* have friction losses. Thus we introduce the term "efficiency" to help separate these factors from the purely geometric mechanical advantage discussed above.

Efficiency

We define "efficiency" in a way that is easy to measure and that can be applied to either the whole braking system or to any component part (levers, cables, or calipers). A known input force is applied to the system (or component) and the actual output force is then measured (see Figure 2); the ratio of input to output, after factoring out the (known) geometric mechanical advantage, is defined as "efficiency" (see Figure 3).

With this definition, efficiency tells you what percentage of the rider's hand-force (at the levers) is actually transmitted into useful braking action at the blocks, or, conversely, how much force is consumed by internal friction in the system. Force measurements taken while the components are *in motion* (points B and D in Figure 3) express the *dynamic friction* characteristics of the system, while the static "breakaway" friction is shown in the droop that occurs from point A to B on the graph.

From tests like that shown in Figure 3, we found that conventional brake components suffer from surprisingly large friction losses. These losses are a matter of concern for three reasons:

1) greater hand-force input causes rider fatigue,
2) friction dulls the sense of braking control and precision, and
3) to overcome friction, stronger return-springs are needed, which, in turn, have adverse effects on factors #1 and #2.

For these reasons, we decided to attack friction losses as a priority in the new Shimano designs. The result is that a lubricant-impregnated nylon material ("Dura-Con") is used at all points of moving contact in the New Dura-Ace and new Shimano 600 parts. In particular, we found that friction between the caliper arm and return-spring, a chronic problem area, benefits from this treatment (see Figure 5).

Figure 4 shows the results of these improvements. Overall efficiency of the Campagnolo SR system is about 40 percent, while for the New Dura-Ace system, it is about 63 percent, an improvement by a factor of more than $1^1/_2$. Another way to say this is: with a hand-lever input of 10 kg (about 22 lb), the force pressing the brake pads against the rim[a] in the Campagnolo system is about 20 kg (10kg × 5.04 M.A. × 40%), *versus* about 32 kg (10kg × 5.04 M.A. × 63%) with New Dura-Ace.

Instruments On-Board

For a better understanding of the dynamics of bike braking, moment-by-moment recordings of the important variables, during real on-road performance, are needed.

For this purpose, we equipped a standard road bike with battery-powered 7-channel instrumentation as follows: 6 strain-gauge force transducers on the front and rear brake levers, caliper arches, and brake shoes, plus a speedometer on the front wheel. The electronics were set up to take 100 data samples per second on each of the 7 channels. Data from each run was collected on a cassette tape recorder, and later played back into a minicomputer for analysis and graphing.

Our test riders were 3 experienced cyclists with an average weight of 67 kg [148 lb]. The instrumented bike itself, including the recorder and battery, weighed 16.5 kg [36 lb]. Thus, the total weight of bike plus rider averaged 83.5 kg [184 lb]. To minimize the effects of the extra on-board weight, we mounted the instrument package low on the bike near the center of gravity.

The tests were run on a straight track of flat, dry asphalt at the Shimano factory. Since the track was indoors, we were working at room temperatures with negligible wind. Two separate test series were run: one with the riders in "upright" position

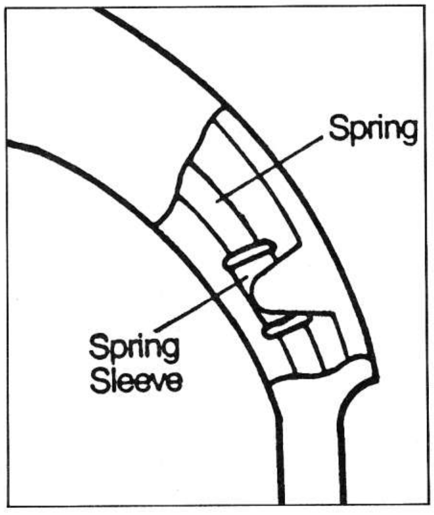


Figure 5: In new Shimano 600 design, a lubricant-filled plastic sleeve reduces rubbing friction between caliper arms and return spring.

[a]*For clarity, we distinguish between "braking force" (the force pressing the brake pads against the rim) and "stopping force" (the overall resultant force that slows down the bike/rider).*

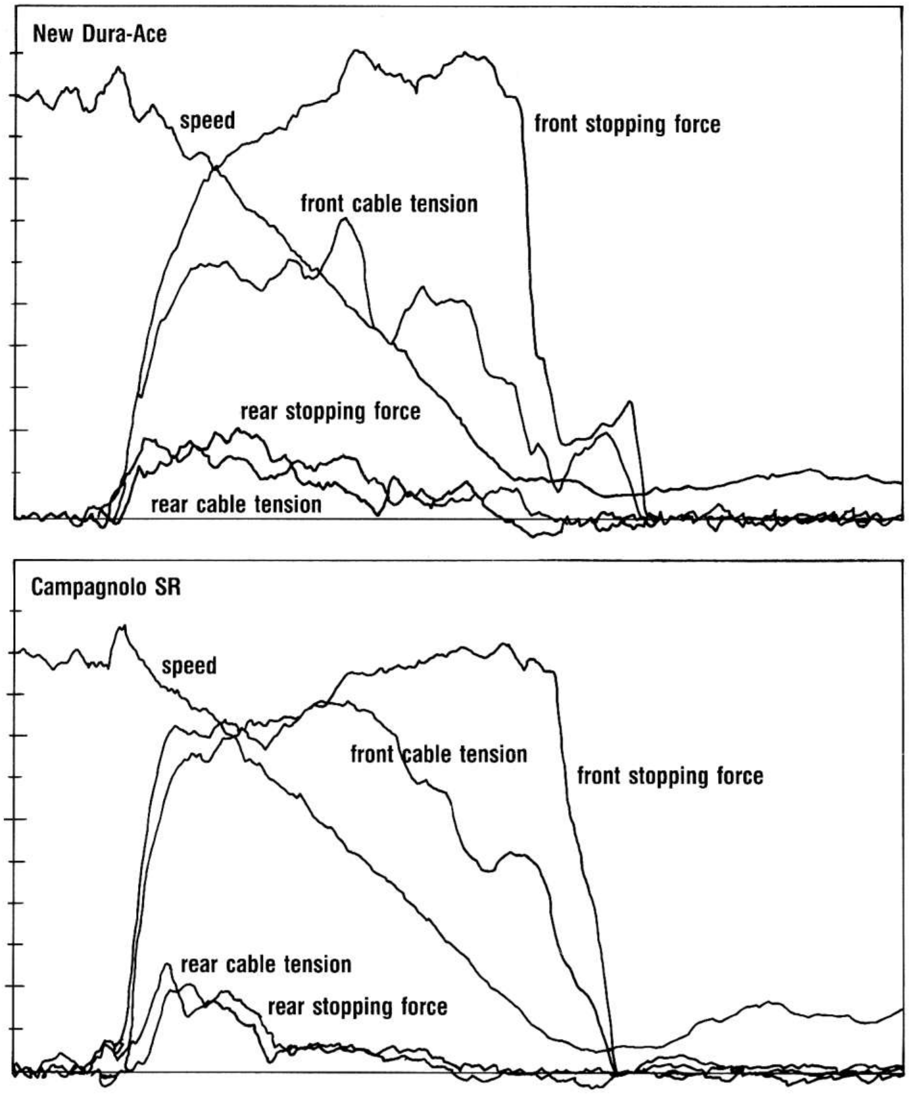


Figure 6: Typical data from Instrumented Brake Tests. Rider making panic stops from 25 mi/hr; hands in drop position. Note that rear brakes contribute very little stopping force.

(braking with hands on top of brake hoods) and one with riders in "crouched" position (braking with hands on the handlebar drops). We did not know, at first, which riding position would yield the more consistent data.

Each test proceeded as follows: the rider pedaled up to a starting speed of 40 km/hr [25 mi/hr], then positioned his hands on the brake levers in the designated position, and, upon reaching the target point, applied both brakes as hard as possible. Stopping distances were determined directly by tape-measure as well as by integrating the speedometer signal. Skidding of the front wheel was detected by noting any discrepancy between the speedometer integration and the actual tape-measured stopping distance.

Typical data for one rider recorded in 3-second periods is shown in Figure 6, and a summary of the results for all 3 riders during 3 trials each is given in Figure 7.

The summary table shows that the New Dura-Ace performs better than the Super Record system in several ways. Stopping distance, for instance, is about 15 percent to 18 percent *shorter* with the New Dura-Ace brakes. (Note also that, as expected, stopping distance in drop position is somewhat shorter than in upright position for both brands of brakes.) Another measure of brake performance, "response time" (defined as time elapsed after brake application before a specified stopping force is reached) is also less with the Shimano system.

Dynamics

The most valuable use we found for the moment-by-moment data was for gaining insight into the dynamics of the braking process. For example, the maximum instantaneous deceleration we measured on each run was in the range of 8 to 9 m/sec^2, and our

Figure 7: Instrumented Brake Test Results. Averages of 3 trials by each of 3 riders.

Riding Position		UPRIGHT (hands on brake lever bracket)			CROUCHED (hands on drops)		
Brakes Under Test		Shimano New Dura Ace	Campagnolo Super Record	Shimano as % of Campagnolo	Shimano New Dura Ace	Campagnolo Super Record	Shimano as % of Campagnolo
Stopping Distance [meters]		12.93	15.67	82.5%	11.57	13.39	86.4%
[feet]		42.42	51.41		37.96	43.93	
Stopping Force [kg][a]	- average	34.7	24.2	143.6%	38.3	33.5	114.3%
	- maximum	50.1	32.4	154.6%	54.6	44.3	123.1%
Deceleration [m/s^2][b]	- average	4.67	3.70	126.2%	4.73	4.17	113.4%
	- maximum	8.00	6.73	118.9%	9.37	8.43	111.1%
Cable Tension [kg][a] at Brake Caliper	- average	25.7	22.2	115.8%	26.6	29.07	91.5%
	- maximum	37.8	32.9	114.9%	40.6	42.4	95.9%
Response Time [sec]		0.112 (time to reach 10kg stopping force)	0.149	75.2%	0.143 (time to reach 20kg stopping force)	0.162	88.3%

[a]*conversion factors: kg × 9.8067 = Newtons, kg × 2.2046 = lbs.*
[b]*conversion factor: m/s^2 × 3.2803 = ft/sec^2.*

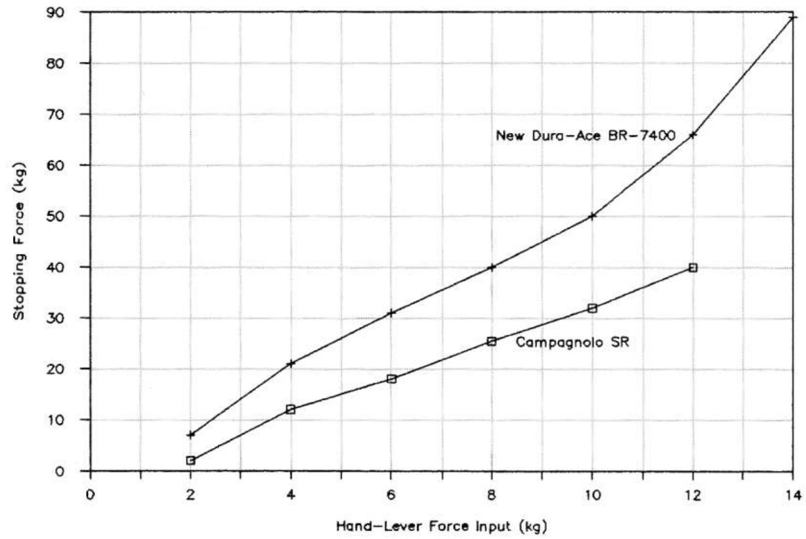


Figure 8: Results of "treadmill" tests. With the bike coasting at 40 km/hr, a known *constant* hand-lever force (deadweight) is applied, and the resulting stopping force (from the caliper-mounted strain gauges) is recorded. Data points plotted here are averages of three trials at each level of input.[d]

highest individual reading was 9.37 m/sec^2. According to conventional theory[b], the maximum possible deceleration (without forward pitchover) is about 5.45 m/sec^2 (i.e., 0.56 G). We explain this apparent discrepancy by noting that the Whitt and Wilson analysis is essentially "static," i.e., it calculates only the deceleration needed to initiate the pitchover motion, and does not consider the dynamics of what actually happens when a greater deceleration is momentarily applied. Such a dynamic calculation requires knowledge of the polar inertial moment of the bike/rider system about the front-tire contact patch, and is a subject for our further study.

In any case, the practical implication of this observation is this: braking decelerations of *more than* 0.56 G (the Whitt/Wilson "theoretical maximum") can in fact be achieved for very short instants. Of course, skilled riders have known this for years: they "pump" the brakes and, when pitchover just begins, they release braking pressure just enough to return to 2-wheel contact. Most of the time, these fluctuations happen so fast that they are probably instinctive on the rider's part, rather than conscious. Nevertheless, we now have reason to say that a high-performance (quick-response, low friction) brake system can help the fast-braking rider in making these ultra-rapid high-G maneuvers. Indeed, the Figure 7 data show that New Dura-Ace brakes averaged consistently higher peak decelerations than the Campagnolo SR system.

[b]*F.R. Whitt and D.G. Wilson,* ***Bicycling Science****, 2nd Edition, The MIT Press, Cambridge, MA, pages 197-198.*

Stopping Force

We also ran the instrumented bike through a series of tests on an indoor "treadmill" (i.e., a large wheel whose rotary inertia was similar to that of a rider in linear motion). These tests were similar to those reported by Rob van der Plas at the German TUV Laboratory in Essen[c].

The main purpose of our tests was to apply a known *constant* hand-lever force (deadweight) and then measure the resulting average stopping force[a] via the caliper-mounted strain gauges. The results (see Figure 8) basically confirm the "efficiency" data reported above. That is, for a given hand-lever input force, the New Dura-Ace produces a stopping force about 50 percent larger than that produced by the SR system. The good agreement between these two independent tests is encouraging; it suggests that either method could be used as a realistic brake performance test.

Part II of this report, scheduled for the next issue, will report the results of stopping-distance tests on the new Shimano systems.

[c]*Rob Van der Plas, "Stopping Power - Brake Blocks on Test,"* ***Bicycle*** *Magazine (London, England), February 1985, pages 34-39; and "Stopping Power II," /****Bicycle****, September 1985, pages 38-39.*

[d]*On level ground, average stopping force F is given by the formula:*
$F = M \times V^2 / (2 \times D)$, *where*
M = *total vehicle mass,*
V = *initial speed when brakes are applied, and*
D = *total stopping distance*

SAFETY

Believing is Seeing

Bicycle Headlights Test Report

David Sellers

It's probably fair to say that lights are one of the most under-developed components on the bike. That's exactly the reason we started, two years ago in Rodale Press' Product Test Department, a series of tests on a wide variety of headlights and taillights. We wanted to report on the state-of-the-art and see what areas might need improvement. The "Night Sight" article in July 1985 *Bicycling* summarizes of this work for the general reader.

In this *Bike Tech* report, we explain in detail how the headlight tests were done, and present a large amount of the background data. (See June 1985 *Bike Tech* for a report on the reflector tests.) In particular, you'll find here a complete listing of the headlight beam-intensity data, actual night-photos of the lights "in action," and time-versus-voltage discharge curves for battery lights. Such data will be valuable in developing new and improved bike light systems. But you'll also find it useful even if you are just looking for further insight into buying new lights, or getting the most out of your existing equipment.

In Table 1, you'll find a list of the headlights we tested, along with their electrical ratings, bulb data, and measured light output. These lights were selected to be fairly representative of products that were available at the time of the tests, and cover all three types of systems that are in use (battery-powered, generator-powered, and hybrid systems incorporating both battery and generator).

Conspicuity

What do we really want from a bike headlight? In a word or two, to *see* and *be seen.* Ideally the light should illuminate a large patch of road as far ahead of the bike as possible. Obstacles like potholes, sewer grates, and dead animals can come up quickly, so you want to have time to recognize them and react by braking or swerving. If your total time for recognition plus reaction is about two seconds (a conservative value), then,

David Sellers is Project Manager in the Rodale Press Product Testing Department.

Table 1: Electrical ratings, measured light intensity and other data on headlights in the test.

			Electrical Ratings		Photometric Data Measured Light Intensity (candela)					
Manufacturer, Model Number	Retail Price	Weight (oz)	Power Source[5]	Bulb Data model #, watts volts, amps.[6]	Zone 1	Zone 2	Zone 3	Zone 4	Avg. Zones 1-4	Comments
Cycle Pro #77-10-000	$7.95	11.3	GEN: 3w, 6v at 8.3mph[7]	#1482, 2.4w, 6.0v, 0.4a	80.0	18.0	4.6	1.0	25.9	*12*
Panasonic #MD-88K	$13.95[1]	11.5	GEN: 3w, 6v at 8.3mph[7]	#1482 or #605, 3.0w, 6.0v, 0.5a	258.0	29.0	10.5	1.96	74.8	*12*
Rinder #107	$9.50	8.2	GEN: 3w, 6v at 11.3mph[7]	#1482, 3.0w, 6.0v, 0.35a[11]	58.0	18.0	5.3	1.64	20.7	*12*
Schwinn #04265	$12.95	12.1	GEN: 3w, 6v at 25mph[7]	#1482 or #605, 3.0w, 6.0v, 0.5a[11]	156.0	40.0	11.0	0.44	51.0	*12*
Cycle Pro #77-10-060	$11.20[2]	3.0[4]	GEN: 6w, 12v at 9.33mph[7]	#89K, 6.0w, 12.0v, 0.5a	112.0	46.0	12.8	2.8	42.0	*13, 15*
Cycle Products #333	$8.99[2]	3.0[4]	GEN: 3w, 6v at 15mph[7]	#1482, 2.7w, 6.0v, 0.45a	17.0	19.5	16.0	1.8	13.5	*13, 15*
Cycle Products #338	$9.99[2]	4.8[4]	GEN: 6w, 12v at 12mph[7]	#89, 6.0w, 12.0v, 0.5a	297.0	84.0	31.0	2.9	103.0	*13, 15*
IKV #015300		2.7[4]	GEN: 3w, 6v at 12mph[7]	Special Halogen 2.4w, 6.0v, 0.5a	600.0	13.0	5.6	1.2	154.0	*13, 15*
Panasonic #MD-85C	$15.92[2]	3.4[4]	GEN: 3w, 6v at 21.7mph[7]	#1482 or #605, 3.0w, 6.0v, 0.5a[11]	158.0	24.0	8.3	0.4	47.0	*14, 15*
Panasonic #MD-855-B	$18.95[2]	5.2[4]	GEN: 3w, 6v at 21mph[7]	#1482 or #605, 3.0w, 6.0v, 0.5a[11]	82.0	43.0	13.5	0.2	34.6	*14, 15*
Rinder #130		4.6[4]	GEN: 3w, 6v at 25mph[7]	#1482, 2.1w, 6.0v, 0.35a	190.0	40.0	8.5	0.28	59.0	*13, 15*
Sanyo #NH-050-SBE	$15.92[2]	2.8[4]	GEN: 3w, 6v at 13.3mph	#1482 or #605, 3.0w, 6.0v, 0.4a	262.0	48.0	9.3	0.16	79.8	*12*
Schwinn Le Tour #04190	$18.95[2]	4.2[4]	GEN: 3w, 6v at 11mph[7]	#1482, 2.4w, 6.0v, 0.4a	692.0	6.1	2.6	0.16	177.0	*13, 15*
Schwinn Traveler #04280	$11.95[2]	5.6[4]	GEN: 3w, 6v at 9mph	#1482, 2.4w, 6.0v, 2.4w	112.0	25.0	5.6	0.16	35.0	*13, 15*
Sears #48103	$9.99[2]	4.8[4]	GEN: 3w, 6v at 9mph	#1482, 2.7w, 6.0v, 0.45a	175.0	54.0	7.8	0.48	59.0	*13, 15*
Sears #48112	$12.95[2]	7.5[4]	GEN: 6w, 12v at 14mph[7]	#89 or #1155, 6.0w 12v, 0.5a	86.0	132.0	68.0	1.44	71.0	*13, 15*
Soubitez #305-L	$34.95[2]	3.0[4]	GEN: 3w, 6v at 12.3mph[7]	Special Halogen, 2.4w, 6.0v, 0.4a	743.0	13.3	3.8	0.28	190.0	*13, 15*
Soubitez #305-809-101	$19.95[2]	2.8[4]	GEN: 3w, 6v at 10mph	#1482, 2.4w, 6.0v, 0.4a	345.0	12.6	3.6	0.16	90.3	*13*
Union #98-39	$19.20[2]	4.7[4]	GEN: 3w, 6v at 10mph[7]	#1482, 3.0w, 6.0v, 0.5a	378.0	23.0	6.0	0.16	101.0	*13, 15*
Union #98-14	$10.45[2]	4.2[4]	GEN: 3w, 6v at 13mph[7]	#1482, 2.4w, 6.0v, 0.4a	444.0	11.4	2.8	0.16	114.6	*13, 15*
Berec #305	$9.99	9.3[4]	2 D cells[8]	#PR-6, 0.75w, 2.5v, 0.3a	178.0	8.5	2.8	0.16	47.0	*14*
Cat Eye #HL-200	$5.90	6.1[4]	2 D cells[8]	#14, 0.75w, 2.5v, 0.3a	102.71	3.68	0.65	0.05	26.8	*14*
CEV #5619	$6.15	4.7[4]	2 C Cells[9]	#14, 0.75w, 2.5v, 0.3a	71.0	3.37	1.04	0.32	18.9	*13*
Cycle Products #302	$5.99	4.8[4]	2 C Cells[9]	#14, 0.75w, 2.5v, 0.3a	40.0	4.9	2.77	0.26	12.0	*13*
REG #698	$7.95	1.8[4]	2 AA cells[10]	#233, 0.5w, 2.5v, 0.2a	6.85	2.89	0.98	0.9	2.7	*14*
Roadlight	$48.95[3]	4.3[4]	Hitachi lead-acid gel-cell, rechgable 6v, 4amp-hr., mounts on seat tube, 29.2 oz. with mount.	Special Halogen, 4.95w, 4.5v, 1.1a	706.8	76.0	20.0	4.25	201	*12*
Spartan Hala-Beam	$41.00[3]	17.6[4]	Gould lead-acid gel-cell, rechgable., 6v, 4.5amp-hr, mounts on seat tube, 39oz. with mount.	G.E. H7551 Halogen sealed beam; 8.0w, 6.0v, 1.33a	304.0	278.0	46.0	2.0	157.5	*14*
Wonder	$7.95	5.0[4]	Special 4.5v, flat, European type battery, avail. in bike shops, 4.2 oz.	#13, 0.7w, 3.5v, 0.2a	69.0	3.55	0.86	0.09	18.3	*14*
Velo-Lux	$69.95[3]	21.5	6v Ni-Cad battery pack, 1.2 amp-hr, Sanyo dynapower type generator, modified for higher output, 9 oz.	Special Halogen, 4.0w, 6.0v, 0.66a	531.0	163.0	24.0	0.16	179.0	*13*
Bicycle Lighting Systems	$33.00	31.5	*17*	G.E. 4512, 2.5w 4.7v, 0.5a	125.8	16.3	17.5	0.88	40.1	*14*
Alternate Bulbs	$12.00 each		*17*	G.E. H7551, 8.0w, 6.0v, 1.33a	314.7	199.5	90.0	1.8	151.7	*14*
Alternate Bulbs	$12.00 each		*17*	G.E. H7553, 12.0w, 6.0v, 2.0a	456.0	433.0	63.0	3.8	238.0	*14*
Alternate Bulbs	$12.00 each		*17*	G.E. H7554, 20.0w, 6.0v, 3.3a	582.0	485.0	99.0	4.0	291.0	*17*
Alternate Bulbs	$12.00 each		*17*	G.E. 4411, 35.0w, 12.8v, 2.75a	1206.0	195.0	197.0	6.5	399.0	*17*
Alternate Bulbs	$12.00 each		*17*	G.E. H7610, 50.0w, 12.8v, 4.0a	2757.0	691.0	103.0	12.8	891.0	*17*

when you're traveling 15 miles per hour (22 feet per second) your light should shine about 44 feet ahead. It's also good to have some light on the road in the immediate vicinity of the front wheel. This will keep obstacles that you spotted from further away from getting lost in shadow as you get closer to them and prepare to swerve.

Another job of a bicycle lights is to alert other motorists to your presence. Since nighttime collisions with cars are a major cause of injury to cyclists, this aspect of light performance is most important of all. *Conspicuity* is the term that refers to an object's ability to visually call attention to itself. For bike headlights, conspicuity *from the side*, as well as from straight ahead, is a factor. Many lights, through random scatter, emit at least some recognizable light to the side, but some lights are much better at this than others, as we found in photometric tests.

There's an ongoing debate in some quarters as to exactly how bike lights "should" perform (see February 1984 *Bike Tech*, page 16, and "Ideas & Opinions," in this issue, for example.) One reason for this debate is that there is no definition (yet) of a "standard" measure of conspicuity that could apply to all cases. The surrounding visual environment plays a major, hard-to-control role. And recognition is a psychological as well as optical process.

In any case, a point of general agreement is that a light must be *much* brighter than its surroundings to be recognized on the road. In particular, perceptual tests show that a driver who is not anticipating the presence of an object will generally fail to see the object unless it is more than about 1000 times brighter than the dimmest object than the driver could detect if his eyes were fully adapted to total darkness. In short, this means that a light which looks bright to you, the rider, with partially dark-adapted eyes, will seem much dimmer to motorists gazing into their car lights. Add to this the fact that bike lights are often competing for attention in less than ideal conditions—rain, fog, poor driver vision, drunkenness, etc.—and you see the overriding importance of conspicuity.

Light Bulb Physics

The single most important factor which determines the brightness of a headlight is the choice of bulb. In Table 1, we list the bulb ID number, along with it's rated wattage, voltage, and current draw, for the bulbs that were factory-supplied in each light. (We don't know whether manufacturers consistently use the same bulb type in their headlights, or randomly switch bulbs according to what is "available.") In any case, the bulb's electrical wattage rating is a good clue to it's light output. Among the lights we tested, electrical wattage covered an incredible 100-to-1 range; from a maximum of 50 watts (in the **Kearney** system with **GE #7610** bulb), which equals a small car headlight, down to a mimimum of 1/2 watt (in the **REG #698**), about the size of a penlight bulb. Most of the other lights fell in the 2 to 3 watt range. Thus, if you're looking for a *really bright* headlight, you should first ask about the wattage of the bulb.

The bulbs' rated "nominal voltage" is also important. In fact, the light output of incandescent bulbs is *extremely sensitive* to the applied voltage. According to manufacturers' empirical data, the bulb's light output is proportional to the applied voltage raised to the 3.5 power, and the bulb's lifetime (before burnout) is inversely proportional to the 12th power of the applied voltage.

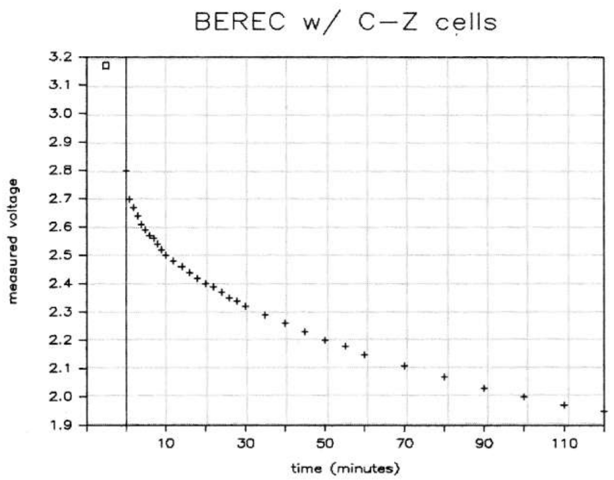
This means that a *slight increase* in voltage will cause a *significant increase* in light output, and a *large decrease* in bulb life. Example: a mere 5 percent increase in voltage (0.3 volts in a 6 volt system) will increase the light output by about 18 percent, and will cut the lifetime in half. Thus, it's no surprise that running a generator at high speeds will cause repeated bulb failures, and conversely, that a slightly discharged battery will produce a noticeably dim light. Unfortunately, few of today's bicycle lighting systems include a voltage regulation circuit to compensate for variations in generator or battery voltage.

Halogen bulbs produce roughly twice as much light, compared to conventional bulbs of the same physical size and electrical wattage rating. Halogen bulbs are still "incandescents" (they have a glowing filament), but the halogen gas (usually iodine or argon) that fills the glass envelope allows the filament to operate at a higher temperature since it supresses evaporation of metal ions from the filament. Unfortunately, halogen bulbs are even more sensitive to voltage fluctuations than conventional bulbs.

Another point to remember is that individual light bulbs of the nominally "same" type can vary quite a lot from each other. This means that you might drastically change your light's output just by switching to a different bulb of the same part number. For our photometric tests, we used the bulbs as supplied with the test lights. But in a separate experiment, we tested several bulbs of the same type from the same manufacturer, in one light. We found that the range of light output varied by roughly +/- 15 percent about the average of the group. We were told by bulb manufacturers that halogen bulbs and the larger sealed beam incandescents show much better uniformity than the small "flashlight" type bulbs.

The position of the filament in the bulb has an large effect on the resulting beam pattern. This is because the pattern of illumination is actually an image, somewhat distorted, of the filament projected onto the road. We found that, with some lights, the beam pattern could be improved simply by rotating the bulb a fraction of a turn so the filament was exactly horizontal or vertical. For these lights, we positioned the bulb to produce the brightest central spot.

1—Price includes taillights.
2—Price includes generator and taillight.
3—Price includes entire system: headlights, battery, taillight, charger, wiring, and mounting hardware.
4—Weight of headlight only without battery or generator.
5—For generators, manufacturer's nominal voltage and wattage output ratings are given. MPH indicates the road speed, according to our tests, at which the generator produces its nominal rated voltage.
6—Closest equivalent bulb designation from General Electric Miniature Lamp Catalog. Nominal bulb wattage, voltage, and amperage given.
7—Conventional design generator drives by contact with tire sidewall.
8—Weight of two "D" cells: 5.8 oz. carbon zinc, 9.4 oz. alkaline.
9—Weight of two "C" cells: 2.8 oz. carbon zinc, 4.7 oz. alkaline.
10—Weight of two "AA" cells: 1.1 oz. carbon zinc, 1.6 oz. alkaline.
11—Indicates equivalent bulb designation listed is not necessarily a close match.
12—Headlight mounts on front fork blade.
13—Headlight mounts on handlebar stem.
14—Headlight mounts on handlebar.
15—Generator mounts on rear seat stay.
16—Complete system including headlight assembly with H7553 lamp, 7" taillight, lead acid rechargeable battery, charger, space lamp, bulb and plugs: $150.00.
17—Alternative batteries available from Bicycling Lighting Systems:
—Gates Lead-Acid rechargeable battery; nominal 6-volt, 4.5 amp-hour, weight: 42 oz., $50.00
—Gould Gelyte rechargeable battery; nominal 6-volt, 6 amp-hour, weight: 40 oz., $50.00



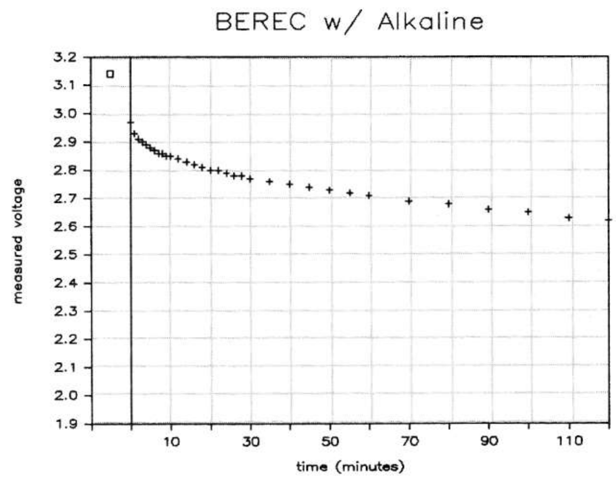
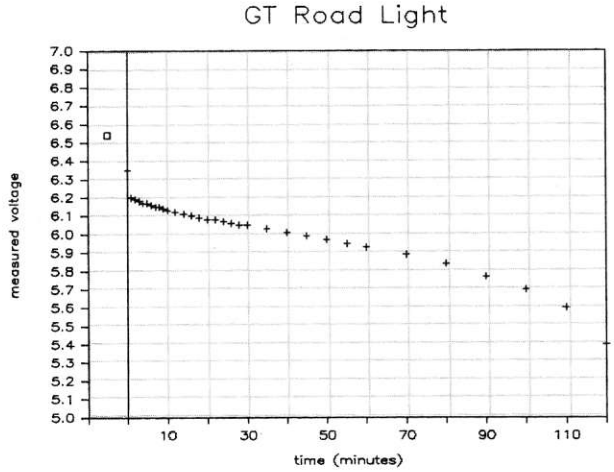
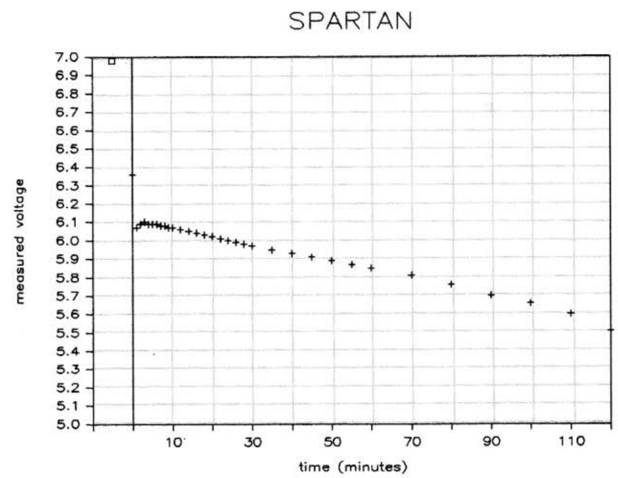


Figure 1: Typical graphs of battery voltage *vs.* time.





Batteries

Batteries are assigned a "nominal" voltage rating, but the *actual* operating voltage is usually less than this rating and diminishes with time as the cell discharges. And as the voltage drops, the light becomes dimmer (according to the 3.5 power law mentioned above). In planning our light intensity tests, we at first intended to use fresh or fully-recharged batteries in each light. But we felt that this would not be realistic, since most riders do not install fresh batteries for each night ride. So we decided to measure how battery voltage changes with time, in each battery-powered headlight, by operating the unit with fresh (or freshly charged) batteries and measuring the voltage across the bulb every few minutes for periods up to 2 hours.

The resulting voltage-*versus*-time graphs (Figure 1) are quite revealing. In all cases, the voltage diminishes rapidly in the first few minutes of operation, and then continues dropping at a slower rate. After examining these curves, we decided that the voltage after *one-half hour of operation* of the light would be a realistic "standard" value to use in the photometric tests. One reason for this choice was that the voltage decrease was much less drastic here than in the first few minutes of operation. So, for each battery light, we noted it's voltage at the one-half hour point, and applied that voltage to the bulb for the photometric tests.

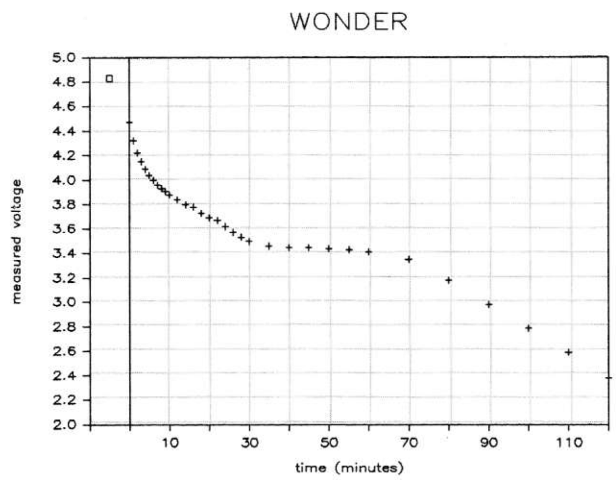
Which type of battery is best? The standard carbon-zinc cells are the cheapest, but their capacity is substantially reduced at the current drains (approximately 0.3 amp) imposed by small bike lights. Our voltage-vs-time tests in Figure 1 illustrate this for the **Berec 305** light. Note that, with carbon-zinc cells, the battery voltage drop after 2 hours' usage is much greater than with alkaline cells. Another disadvantage is that C-Zn cells don't store well in hot environments and perform poorly in the cold. Thus, if you want non-recharge batteries for regular night-riding, you'll probably find alkaline cells to be more reliable and economical, despite their higher cost.

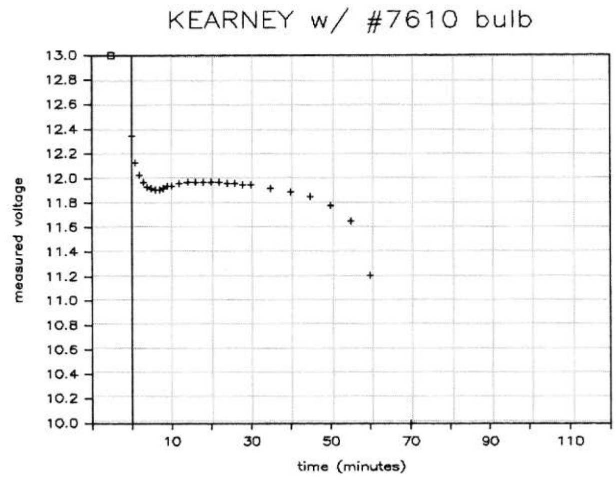
For higher power outputs, you'll probably need rechargeable cells. Nickel-cadmium cells are an order of magnitude more expensive than throw-aways, but they can be recharged hundreds of times, and can tolerate deep discharge without damage. However, ni-cads require regular (every couple of months) maintenance charges even if they are not being used. They are not unduly affected by temperature variations, and they supply a rather constant voltage during the discharge cycle, providing relatively constant illumination. (Non-rechargeable batteries show a more drastic drop in voltage as they discharge.) However, ni-cads grow dim very quickly when their charge finally is depleted; see, for example, the sharp drop in voltage in the **Kearney** light with **GE #7610** bulb after one hour of continuous use.

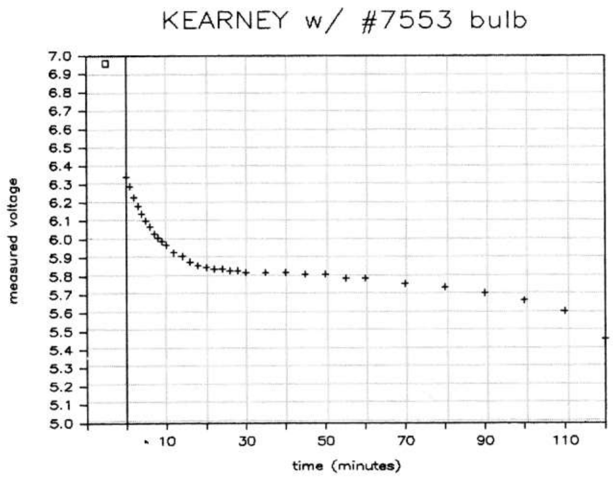
Lead-acid batteries, also called gel-cells, are the alternate choice for high capacity power sources. They are cheaper than ni-cads, but they can be damaged by deep discharge. In any case, all rechargeable batteries are *heavy* and must be taken off the bike for recharging (unless you have the **Velo-Lux** combination system).

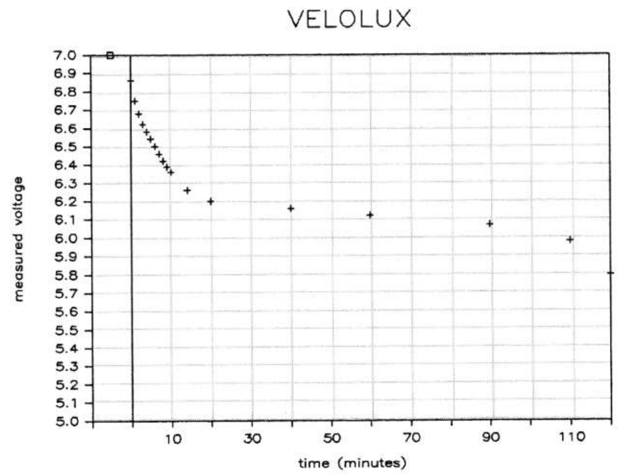
Generators

In designing our test for generator systems, we had to deal with the fact that a generator's output depends on the speed of the bike. Using a set of training rollers powered by an electric motor, we determined the bike speed necessary to achieve the system's rated voltage with the headlight *on*. These results are listed in Table 1 in the "Power









Source'' column, and the variety is surprising. Most systems reach their rated voltage at reasonable speeds, between 10 and 13 mph, but the **Schwinn** and **Rinder** systems make you pedal at 25 mph for full output.

We also discovered, in pilot tests, that the generators change their output characteristics as they warm up. (The data mentioned in the previous papgraph was taken with the units cold.) Thus. for purposes of the light intensity tests, we decided to *disconnect* the generators entirely, and apply the manufacturer's rated voltage to the bulb directly from an independent power source. It's true that this procedure *ignores* the different speed-*versus*-voltage curves of the different generators, but it seemed to be the only way to produce consistent results.

The **Velo-Lux** unit is a clever hybrid; it uses a ni-cad battery built into the lamp housing, and includes an optional generator which can power the light, or charge the battery (with light off), or both, while riding. This system could be doubly cumbersome or doubly convenient, depending on your preferences. We decided to test this system exclusively as a *battery*-type system, since the interactions between generator and battery would be difficult to quantify without extensive further tests.

Photometry Grids

Our main purpose was to measure the headlights' light output via photometry testing. The two industry standards for such tests are: British Standard AU-155, introduced in 1973, and ISO Draft Proposal 6742/1, which is currently under review in more than a dozen countries through the International Standards Organization in anticipation of final acceptance.

Both standards specify measurement procedures and set forth *acceptance values* (the minimum light intensity needed to "pass"). Since it takes countless hundreds of data points to describe a beam pattern completely, measurements are called for at only a limited number of points. Unfortunately, the two standards call for *different* measurement points (though there is some overlap) and also have different acceptance values.

We have combined the grids from both BSA and ISO to produce the measurement layout shown here in Figure 2. This resultant grid specifies light intensity measurements at 28 points. Most of these data points are located near the center of the beam pattern (within 10 degrees up or down, and 20 degrees left or right of the beam's center). To measure the headlight's conspicuity from viewing positions to the *far* left or right of the beam center, extra grid data points are included in the four extreme corners of the grid layout.

Our grid is labeled with two different vertical axes because the two standards specify different ways for aiming the headlight and for establishing the origin of the coordinates. BSA defines the origin of coordinates as the brightest spot in the beam. ISO says that the body of the light must be aligned straight ahead and horizontal (which is defined as the 0-degree point), and then requires that the brightest spot must fall 3 1/2 degrees vertically down from this position, and 0 degrees to the left or right. Moreover, ISO requires that light intensity must not exceed 120 candela anywhere above the 0 degree vertical line, presumably to avoid the headlight beam shining in the eyes of an oncoming motorist. Note also that ISO requires a much brighter spot in the center of the beam: 400 candela minimum versus BSA's 100 cd minimum.

Test Set Up

In the test set-up, a light-tight partition with a small hole near its center was constructed near the center of a light-tight testing room (see Figure 3). The basic idea is

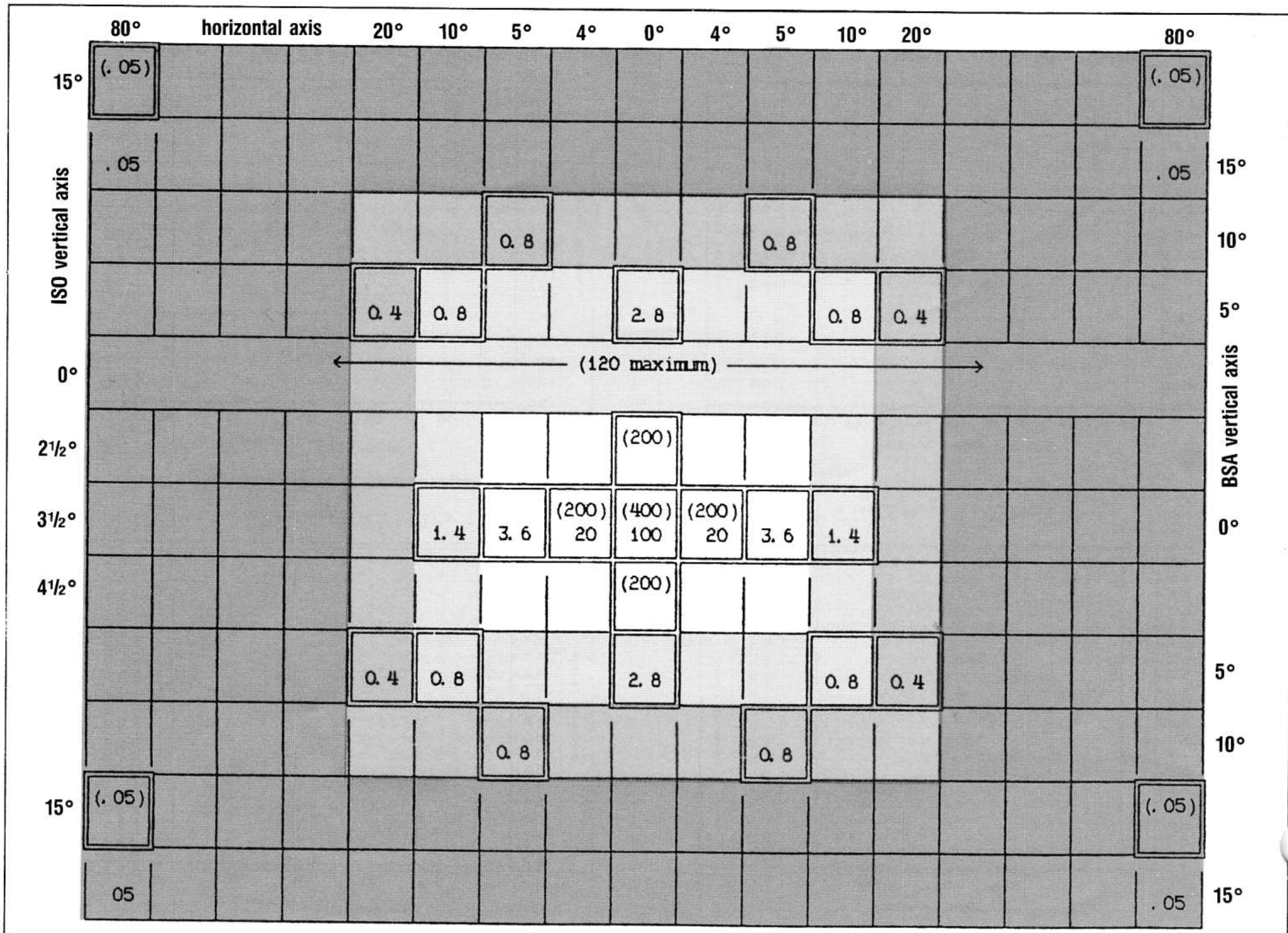


Figure 2: Headlight beam intensity was measured at points with double outlines. Numbers are the minimum values (in candela) specified by ISO (in parentheses) and by BSA. Shading indicates Zones 1 through 4 for averaging results reported in Table 1.

to allow only a narrow beam of light, corresponding to an exact position in the beam pattern, to reach the photometer.

To be able to scan all parts of beam pattern, we mounted each bike light in a *goniometer* fixture (see Figure 4) that can rotate up and down, and left and right, in angular increments measured in degrees from the beam centerline. Moving the goniometer along these two axes of rotation allows any selected part of the beam pattern to be aimed through the hole and be measured, independent of other parts of the pattern.

Our measurements were taken with a Minolta Illuminance Meter set on a tripod exactly 10 meters away from the goniometer. We calculated the intensity of the light source (I) from our measurements of illuminance (M) using the equation: $I = M \times r^2$, where I = source intensity, in units of *candela* (the SI unit of luminous intensity, abbreviated *cd*, equal to lumens per steradian), M = illuminance measured in *lux* (the SI unit of illuminance, equal to lumens per square meter) which expresses the amount of light at a point in space being illuminated by a distant light source, and, r = distance from source to photometer (10 meters).

A test was started by mounting a bike light in the goniometer. Then, with an "aiming board" temporarily placed over the hole in the partition, we adjusted the light so that its brightest spot (or other obvious features corresponding to the center of its beam) was projected on the center of the aiming board. The aiming board was then removed and a second, smaller partition with a hole was raised along the beam centerline. This insured that no stray light could find its way to the illuminance meter.

Electrical current was suppled by a DC power supply and an adjustable precision voltage regulator. Voltage at the bulb terminals was monitored with a digital voltmeter.

To summarize the data from the 28 coordinate points on the beam grid, we defined four arbitrary "zones" (see Figure 2). These zones are roughly concentric rings progressing outward from the center. For each zone, we averaged the light intensity measurements from all the points in the zone, and entered the result in the appropriate columns in Table 1. We also report the overall average of all four zones grouped together.

And The Winner Is...

We were amazed at the vast differences in useful light output among the products tested. The best light is about *330* times brighter than the dimmest light!

The small inexpensive battery lights, as a group, were all incredibly dim. The lights with built-in generators were also seriously lacking in power, though the **Panasonic** unit was brighter than the others of this type. No lights with remote generators will win any prizes for performance, though some are much better than others. Often the differences in shape of the beam patterns were as significant as differences in total light output. We found 12 volt generators to be brighter than 6 volt; and the use of halogen bulbs to

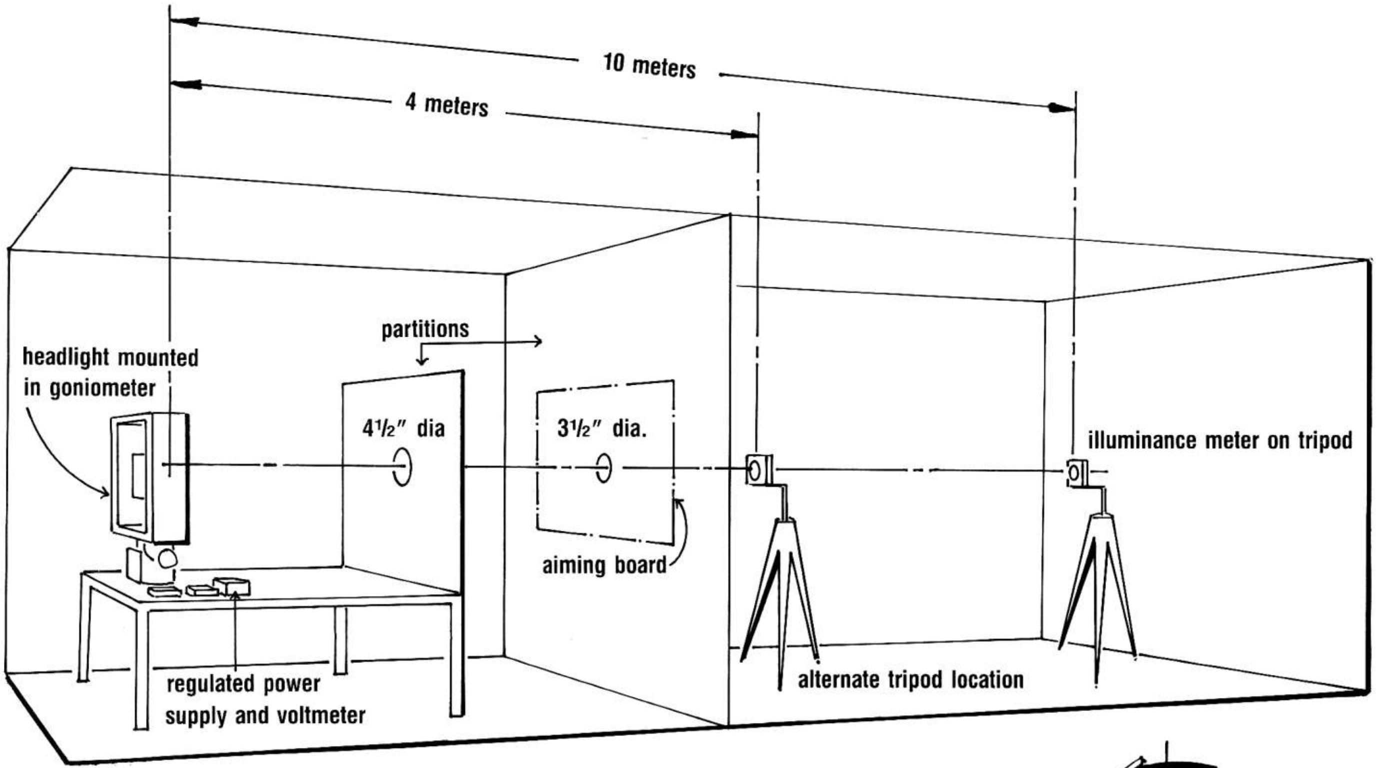


Figure 3: Text Room Layout.

be an effective feature.

For really brilliant lighting performance, one must consider the larger rechargeable battery-powered lights. Ed Kearney's products dominate this group in terms of sheer power, with his 50-watt **#7610** sealed beam unit putting a dazzling amount of light on the road. The cost in money and weight (batteries) to support these powerful lights may make them impractical for some riders. Kearney does offer cheaper light/battery combinations that also perform nicely.

Finally, the **Velo-Lux** deserves a good rating for its flexibility (battery, generator, or both), compact design, and respectable illumination.

Night Photos: What You See Is What You Get

But how does the illuminated road "really" look to the rider? To answer this, we took nighttime photographs of the beam patterns in a realistic setting. Each headlight was set up on a stationary stand (camera tripod) at handlebar height and supplied with a constant, regulated voltage (the same voltage used in the photometry tests). A Nikon 35 mm camera with 50 mm focal length lens (roughly the same as the eye's 53 mm focal length) was set on a tripod at simulated rider's eye-height (slightly above and behind the bike light). We used *identical* exposure settings for all of the photos (shutter aperture of f2, and shutter speed of 1 second, with Kodak ASA 1000 speed black-and-white film).

For distance markers, we placed white wood blocks on the roadway at 10 foot intervals (see Figure 5), and also placed street signs and a car in the scene. The photos were taken on an overcast, moonless night with no sources of stray light (e.g., streetlights) that could obscure the results.

Note that these photos do not show *exactly* what the night rider would see. The human visual system can adapt itself to a much greater range of conditions than any black-and-white camera. For example, with a dim headlight, the rider's eyes become more "dark-adapted," (i.e., the pupils open wider and the visual pigment lightens), thus making the scene appear almost as bright as if a stronger headlight were in use. The night photos take no account of this physiological adaptation of the visual system.

Still, the night photos can be useful because, in a purely *optical* sense, they offer an exact measure of the amount of light reaching the rider's eye. Moreover, they go a step beyond the lab photometry measurements (where the lights were aimed directly at a vertical wall) by projecting the light's beam outward toward a realistic scene. Simple geometry says that the beam pattern on a vertical wall will be different than that obtained when the light shines onto the open road. In short, the beam pattern you will see on the road is more like what is shown in the night photos than is measured in the ISO or BSA photometry tests.

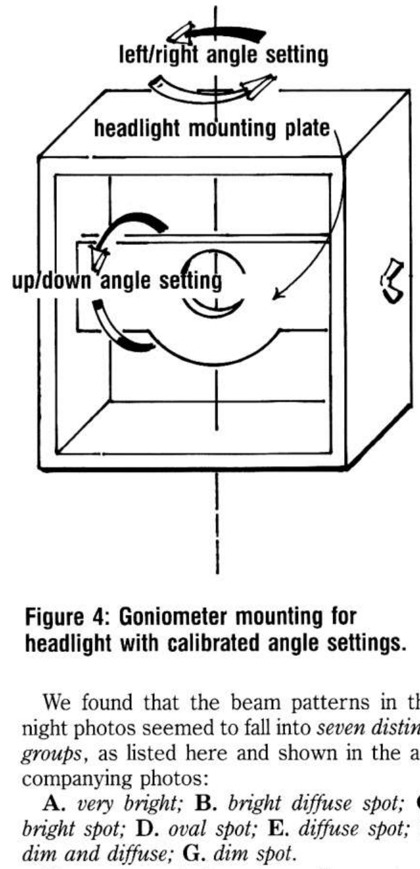


Figure 4: Goniometer mounting for headlight with calibrated angle settings.

We found that the beam patterns in the night photos seemed to fall into *seven distinct groups*, as listed here and shown in the accompanying photos:

A. *very bright;* **B.** *bright diffuse spot;* **C.** *bright spot;* **D.** *oval spot;* **E.** *diffuse spot;* **F.** *dim and diffuse;* **G.** *dim spot.*

There seems to be no overall consensus among riders as to which beam pattern is best. Perhaps the ideal would be to have an *adjustable* beam pattern, so that either wide-angle or bright-spot illumination could be selected. The moveable reflector system found on quality flashlights could probably be adapted for this.

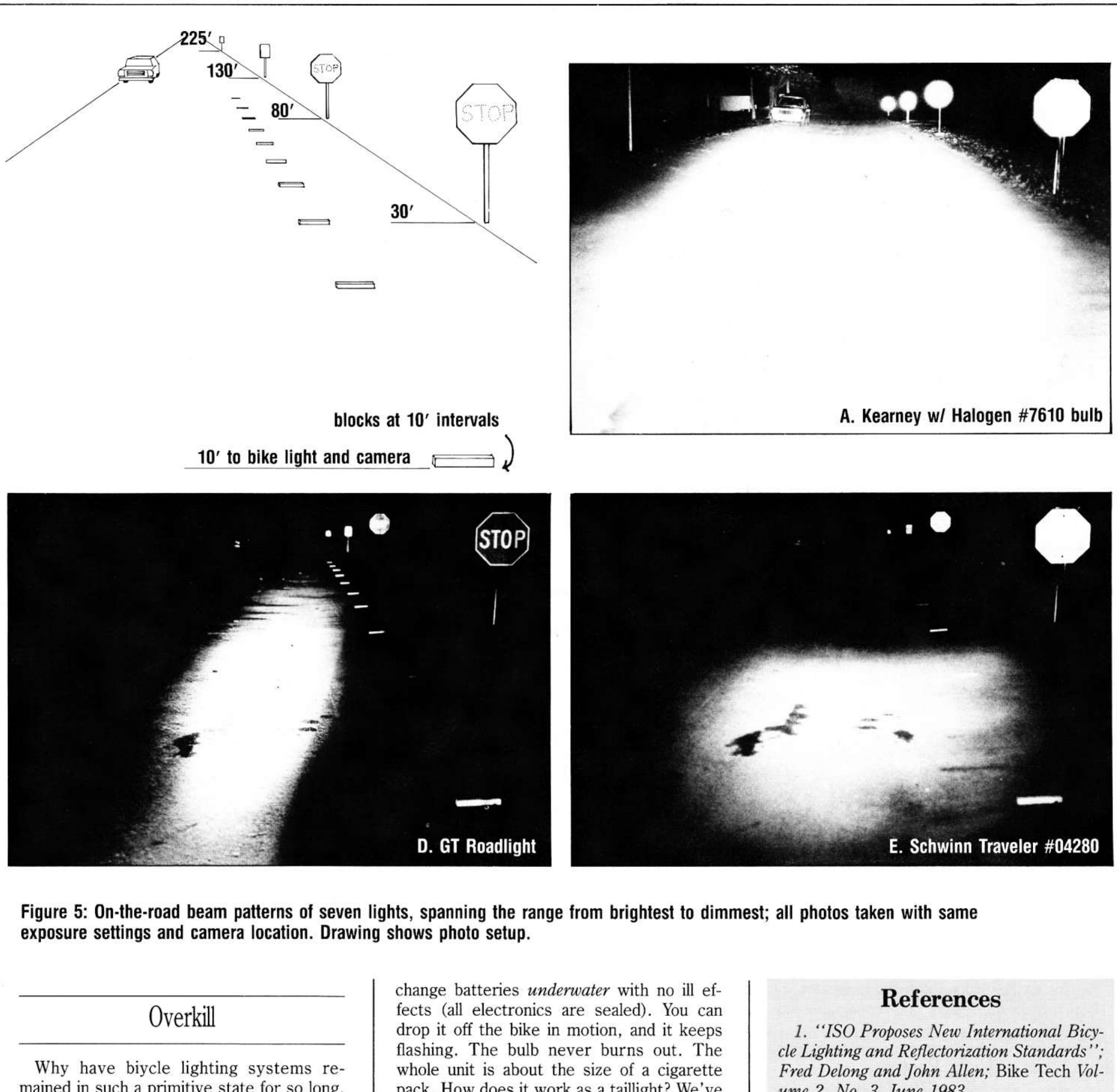


Figure 5: On-the-road beam patterns of seven lights, spanning the range from brightest to dimmest; all photos taken with same exposure settings and camera location. Drawing shows photo setup.

Overkill

Why have biycle lighting systems remained in such a primitive state for so long, compared to the developments in most of the other components on the bike? It's certainly not for lack of technology in electronics and optics.

For example, we know of riders who, for their own night travels, refuse to use commercially-made bike taillights. Instead, they ride with a Coast Guard approved marine distress flasher strapped to ther underseat tool bag. This little unit was designed for use on life rafts and disabled watercraft, so they could be spotted from the air. It's guaranteed to be visible from nine miles away at a 1200 ft altitude. With a Xenon-gas strobe (the type used in photographic flash units) and a mercury battery, it runs for nine hours on one charge. Is it reliable? You can change batteries *underwater* with no ill effects (all electronics are sealed). You can drop it off the bike in motion, and it keeps flashing. The bulb never burns out. The whole unit is about the size of a cigarette pack. How does it work as a taillight? We've found that every passing car hesitates about a half-block away while the driver tries to figure out what it is. It doesn't even have a Fresnel lens to produce the "ideal" taillight beam pattern, but no matter: it's *real* conspicuous. (You can buy one for about $60. through boating suppliers or military surplus channels; ask for Navy Stock No. 6230-00-067-5209. Some areas may have legal restrictions against using such a strobe on the highway.)

Maybe this is overkill. The point, however, is that compact, high-performance lighting systems have already been designed. Where are the manufacturers who will turn this technology into affordable bike lights?

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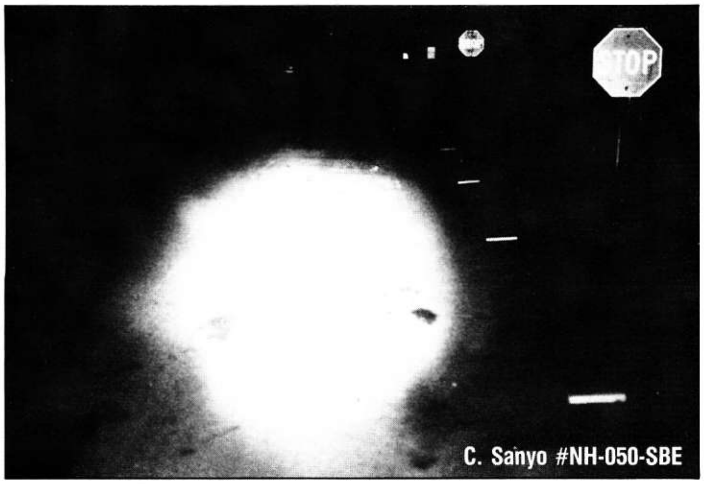
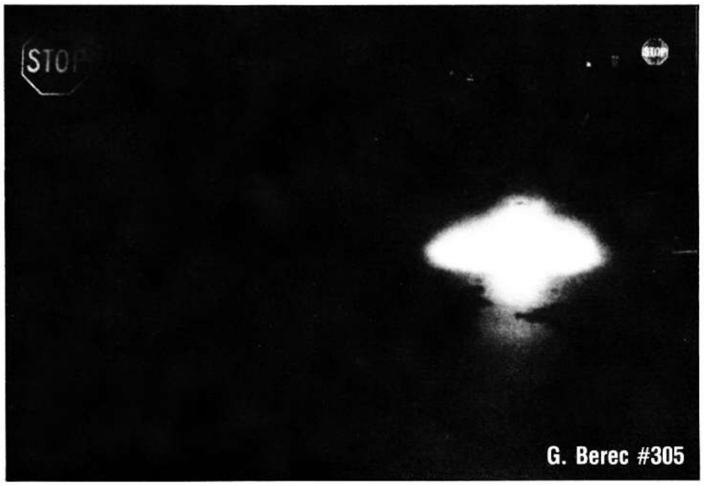
4. *ISO Standard 6742/2: Cycles - Lighting and Reflective Devices - Photometric and Physical Requirements - Part 2; International Standards Organization, 1984. Copies are available from American National Standards Institute, 1430 Broadway, New York, NY 10018 for $16 plus $3 postage.*

B. Velolux



C. Sanyo #NH-050-SBE

F. Cat Eye #HL-200



G. Berec #305

IDEAS & OPINIONS

Superstitions

As always, cycling is full of superstition, as shown by material in *Bike Tech* for June 85.

The paper on reflective materials is quite absurd. First, it repeats the two silly superstitions that motorists at night don't look along the road ahead, and that motorists deliberately smash into anything that they see that is not a cyclist. Surprising as• these seem when so stated, they are the literal meanings of the statements that detection must be by peripheral rather than foveal vision and that motorists must recognize cyclists in order to avoid them. (Yes, Zwahlen tested detection by peripheral vision, but only because that suited the legal controversy that paid him, and nowhere in his paper is there a demonstration that this would be the method of detection in normal roadway circumstances.) Then, instead of testing the good reflectors that are available, the author tested the reflective fabrics and tapes (which are not very bright), and compared these to the CPSC bicycle reflectors that we know have been designed to be dim for their size and weight.

Likewise the papers on the stiffness of bicycle wheels have little practical relevance. Take torsional stiffness. The difference between 4X and 2X wheels is about 0.001 inch at the pedal for a 200-pound rider with full weight on the pedal in 40″ gear, and of course only a portion of that is lost (hysteresis loss). The lateral deflection is listed in millimeters per pound of lateral force for force values up to 120 pounds or so (when the rims start to fail). In very exaggerated pedaling the cyclist might get the bicycle to 10 degrees to the apparent vertical, which implies a side load of only about 20 pounds. In most cycling there is practically no side load, and lateral stiffness or strength is important only when spokes are broken or in improving the probability of a quick restart after an accident (i.e., with a wheel still intact).

The radial loads of up to 600 pounds are also far in excess of what is applied, and the test block through which they were applied is not a good model of the action of the tire. The tire applies the load forces to the rim largely by changing the forces on the bead wires, and only in accordance with the footprint of the tire against the road. High radial forces can only be applied for extremely short periods of time, as when going over a bump. Radial stiffness under high load has no practical effect on the efficiency of cycling (because of the short times involved) and practically none on success (because failure is typically caused by point contact between the rim and the rock, at a much lower radial load than the tested range).

An old adage in science says that it is far more important to ask the right question than to get an accurate answer to the wrong question.

John Forester
Sunnyvale, CA

The editors reply

The test fixtures used by Akers and Price for the wheel stiffness tests are available for use by other experimenters who wish to test various wheel configurations and report on the results. Access to an "automatic" testing machine (such as an MTS or Instron) is not necessary, but it would be helpful. The measurements could just as well be taken by hanging dead weights on the wheel, and measuring deflections with a dial indicator. So, let us hear from those who wish to pursue such tests.

The question of dynamic-versus-static loading, raised by John Forester, is important. It's certainly a tougher job to measure wheel performance under real-time riding conditions since, as Forester points out, the largest forces (riding over a bump) last for only fractions of a second. One reason for reporting the purely static measurements of Akers and Price is that, if and when dynamic real-time data is collected, the static data can be compared against it to see the difference. Maybe, with luck, such a comparison will show that static measurements really are a good indicator of dynamic on-road performance.

In fact, we have sponsored a series of dynamic wheel performance tests, using strain-gauge equipped wheels with the signals brought out through slip rings to a portable datalogger. These tests are now in progress, and we plan to report on the results in a future issue.

Athletics vs. The Bank Account

To the Editor:

This letter is intended as a general comment, but it was inspired by the article in the August 1985 issue that describes a so-called revolution in front derailleurs, i.e. the Browning Automatic.

Over the years I have noted that inexperienced athletes become obsessed with every new gimmick in cycling technology. To this, I say there is no substitute for fitness, courage, and skill born of experience! Anyone who has done enough racing and training knows, in the end, that it is "5% bike and 95% rider."

Furthermore, I think it is a crime against true athleticism to constantly inflate the cost of riding competitively on a bike. Let's not forget that the profit motive is part of the reason why manufacturers develop aero wheels, weird helmets, rubber suits, $35,000 bikes, and other such expensive gadgets. I applaud Greg LeMond for his remarks in *Winning*, where he voices his desire to eliminate the expensive advantages and to make cycling a sport where it is athlete *versus* athlete and not pocketbook *versus* pocketbook.

I agree that it is beneficial to improve the efficiency of the bike. But in competitive circumstances, we must draw the line somewhere for the sake of fairness to all. Let's see if all this technology can give us a safer, more reliable, and *less* expensive racing bike that will encourage the growth of the sport, and leave the gimmicks to rich tourists and the like.

A final point: In extremely demanding, hilly criteriums where a missed shift is a disaster, I offer a simple and cheap solution. Use a freewheel that allows you to stay in the large chainring all the time. A Super Record rear derailleur will handle 26T, and anyone that can't take a hill in 52×24 or 52×26 isn't going to solve his problems with the SIS or Browning systems.

To balance this letter a bit, I would like to extend my appreciation of *Bike Tech* for its informative and relevant articles.

Jeffrey Mennies,
Free Wheeling Bicycle Shop
Margate, FL

Brandt on Wheels

I was pleased to see some measurements made on wheels in the June edition of *Bike Tech*. However, the presumption, by Mr. Akers and Mr. Price, that European roads are inferior to roads in the USA, and that small flange hubs serve to smooth these rough roads, introduces questions about objectivity. The value of large or small flange hubs seems not to be part of this research. However, there are interesting data included in this report which, if analyzed, might add to our understanding of wheels.

The author points out that spoking patterns have some effect on wheel stiffness, but how important these differences are is left unanswered. I believe that a little information can become misinformation. One might be moved to draw incorrect conclusions in wheel design based on the measured differences, some of which are certainly subordinate to other opposing considerations.

In the follow-up article, Mr. Flower tries to put some perspective into the data and how it fits with analytical work. In response to his question on lateral stiffness shown in my book, I wish to point out that the curves in Figure 17 are for a single pair of spokes as shown in Figure 18. The title under the graph fails to indicate this. Figure 17 demonstrates that left and right tension and lateral stiffness are unequal in offset wheels. They show, for instance, that when cutting all the left spokes, the right spokes will not become slack. This can be observed when dismantling a tensioned wheel.

Jobst Brandt
Palo Alto, CA

Bob Flower replies:

Thanks to this clarification that Figures 17 and 18 apply to just a single pair of spokes, *rather than to the* complete spoked wheel, *Jobst Brandt's figures for lateral wheel stiffness are now in much better agreement with the experimental results of Price and Akers.*

DESIGN

History of the Glued Aluminum Bike Frame

Note: The "glued" aluminum bike frame was recently patented here, at least partially, last fall (U.S. Patent #4,479,662 issued October 1984 to Ateliers de la Rive of Saint-Chamond, France). The patent holder is known in the U.S., through association with Bador S.A. of St. Etienne, France, as the builder of VITUS 979 ("Duralinox") aluminum frames and forks. The patent makes specific claims concerning adhesive-bonding methods using cast lugs with a "conical taper" (preferably 3 degrees) at the ends to promote uniform spreading of the adhesive. The technical data in this patent file is of definite value to framebuilders working with similar methods; the general history of the process, by J. DePaillat and translated here, is also of interest.

The idea of using aluminum for frames is an old one, and goes back to the United States in the early 1900s. A French poster from the period 1910 to 1914 already mentions a manufacturer, a Mr. Rupalley of Paris, with an aluminum bike, stripped of all accessories, weighing only 8.5 kg (18.7 lb.)!

Numerous aluminum frames were built between 1935 and 1950, including certain commercial models. Thus, it's not a question of innovation, but of evolution, which allows us today, thanks to technical progress, to envision industrial production creating competition frames in plastic, fiberglass, carbon-fiber, and titanium.

The first commercially-practical aluminum models of several builders and innovators were exhibited at the French bicycle trade show in 1932. Mr. PY, in particular, presented an aluminum frame assembled using steel joints with the aid of internal conical couplings, a frame made in quantity by Automobiles Delage and Gnome & Rhone.

This frame was used on September 9, 1933 by former racer Marcel Berthet when he covered 48.04 km (30.20 mi.) in one hour at the Princes Park. The Delage bike weighed 7 kg (15.4 lb.), had a low "careenage" (aerodynamic drag), and was equipped with Duralumin gears designed by Marcel Riffard (the famous builder of Caudron airplanes). This performance approached that of Eddy Merckx in Mexico and proves that the racer's "careenage" has much more of a bearing than the aerodynamics of the bike frame itself!

At this time, other manufacturers used various assembly techniques, including:

—**Aviac,** with Dural tubes, whose ends were expanded inside molded lugs,
—**Caminade,** with octagonal tubes screwed into exterior lugs,
—**Hurtu,** with tubes positioned in a mold, and joints cast over these tubes (a method "reinvented" by the Japanese around 1973),
—**Mercier,** with internal lugs that locked the tubes in place by expanding inside them,
—and numerous soldered or bronze-welded models.

The forks of these bikes were often made of aluminum, and sometimes cast in one piece (monobloc construction).

After World War II, the fashion and necessity of bicycle commuting prompted an increase in production of bicycle lines such as those of Mercier and Gnome & Rhone. Between 1945 and 1950, Indochina imported 300,000 to 400,000 copies of Mercier's **Mecadural** bike!

In 1943, the "Centre Technique de l'Aluminum" was equipped with a test bench used until 1958 to test numerous bike frames, and even motorcycles. On this bench in 1947, a complete strain gauge evaluation along with road tests was carried out on aluminum frames, the first testing of its kind in the world.* This important work has served as a base, in recent years, for calculating frame designs, tube dimensions, lug designs, and the choice of alloys.

The first frame assembled with "Araldite" adhesive was undoubtedly built by Mr. Boisis, with the collaboration of the Trefimetaux Center for Silver Research in 1948 or 1949. The results, although very conclusive, were not exploited commercially due to the bicycle "crisis" of the 1950's.

It was only in mid-sixties that an Italian engineer, Mr. Falconi, presented a "screwed and glued" frame at the Milan Trade Show, which was manufactured several years later in a mid-priced line under the name **Alan.** The tubes, of 2 millimeter thickness, were threaded and screwed into the external joints with "Loctite" glue to avoid loosening of the threads and to lock up the entire joint. This frame was distributed by Gitane in France for several years.

The experience in gluing aluminum alloys acquired in aeronautics, railroads, automobiles, industrial vehicles, and skis inspired us to reconsider the Boisis idea in 1973, resulting in the construction of a prototype with Ateliers de la Rive and a frame builder from Givors, Mr. Miosotti.

To obtain a light frame as rigid as a steel one, with snug fittings and large gluing surfaces, long molded external lugs were perforated and trimmed to lighten them to the eye, and to avoid the look of "plumbing" joints and internally machined for good fit.

Thanks to Miosotti's design, this frame was beautiful. Several of them were made; most of these are still rolling today, including one which was used by Cyrille Guimard in the Paris-Nice race, with a stage victory to its credit. However, the prototypes were not followed up by industrial production because the machine-finishing of joints, and especially the required finishing touches, were difficult problems that strongly penalized this design.

At that same time, other techniques were perfected and exploited, such as:
—C.M.P. of Lyon made a frame with externally screwed joints, similar to the Caminade solution, and then made a second generation frame in which the tubes were bolted and glued to the molded joints by a quarter-turn mounting of the bayonette type,
—Sabliere, also of Lyon, made soldered frames, whose beautiful construction required highly-skilled craftmanship.

Two years ago, the [adhesive-bonded frame] project was taken up again by Ateliers de la Rive and Angenieux C.L.B., with the collaboration of Lauzier Co. to develop the molded parts, and 3M Co. to provide suitable adhesive.

The important breakthrough consisted of pressing the tubes onto internal lugs rather than into external ones, which reduced or eliminated the final machine finishing and refined the visual "step" of the lugged joints by eliminating it. A cone-shaped fitting with a slight taper was adopted in order to improve the press fit of the joint and to improve the wetting of the joint with adhesive.

Finally, a new technique has appeared with the **Hautiprod** frame, conceived by Mr. Hautier, who, when he directed Gitane, adopted the **Alan** frame. On this frame, the countersunk, screwed joint design ensures that the frame tubes are securely locked into the lugs.

Why have we chosen, among all solutions, to promote the completely glued frame? It is because we believe that this technique best exploits the qualities of aluminum alloys, not only in the tubes but also in the cast fittings, and in particular because of the great reliability of glued aluminum structures.

It is also the lightest solution: The weight of a whole frame with fork does not exceed 1,800 grams (3.96 lbs.)! It also allows great manufacturing flexibility: Small or medium-sized production runs require little investment, while full-scale production can take advantage of many of the fabrication steps.

**Editor's note: A report on this testing was published (in French) in the technical journal* Revue de l'Aluminum, *October 1949, pages 89-95. The article, titled "Mesure des Efforts en Marche Normale sur un Cadre de Bicyclette," by Francois Flusin, contains the following English summary:* "The Centre Technique de l'Aluminum has carried out measurements of the importance of stresses in certain joints of an A-G5 bicycle frame under static loads of 198 lbs. The maximum fatigue was recorded in the fork with a figure of 7,111.6 psi. Dynamic measurements made either at the testing stand or actually on the road show that the corresponding overloads can be in the neighborhood of 100% of the static values. The conclusion to be drawn of such tests is that the value of stresses in certain points is relatively small, and that a greater reduction of weight is still possible. This should lead to further progress in frame construction." *This report is remarkable because it clearly anticipates the questions, such as fatigue strength and fork design, that interest framebuilders today.*

Mr. J. DePaillat is an Engineer in the Cycle Department of Ateliers de la Rive, St. Etienne, France.

Materials • Mechanics • Physiology • Engineering • Aerodynamics

BIKE TECH

Bicycling Magazine's Newsletter for the Technical Enthusiast

STATEMENT OF THE OWNERSHIP, MANAGEMENT AND CIRCULATION OF BIKE TECH REQUIRED BY ACT OF OCTOBER 23, 1962: SECTION 4369, TITLE 39, UNITED STATES CODE, FILED, OCTOBER 1, 1985. BIKE TECH is published 4 times a year at 33 East Minor Street, Emmaus, PA, 18049, publication and general business offices.

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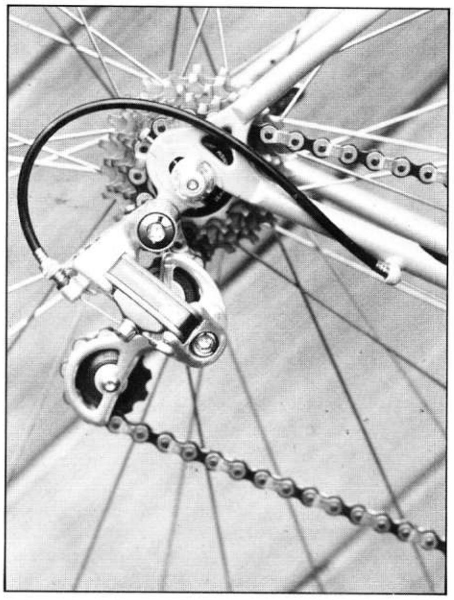

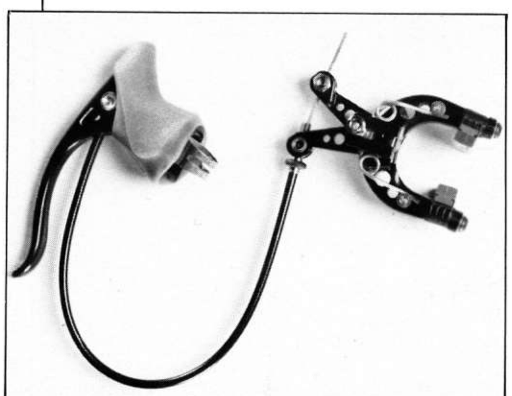

DUPONT'S NEW TWIST IN COMPOSITE FIBERS: The DuPont Company, well-known to cyclists as the maker of Kevlar high-tensile fabrics and Nomex honeycomb, announced plans to become a full service supplier of *all* the components needed to produce fiber-composite structures. This includes adhesives, resins, yarns, woven fabrics, and design/testing services, according to Mike Bowman, director of Dupont's composites group. DuPont recently purchased the carbon-fiber production facilities of Exxon Enterprises (source of the ill-fated Graftek G1 bikes of the mid-70's), and is now developing several low-cost Kevlar and carbon hybrids. If you are designing bicycle frames or other components that use structural composites, you should probably be in touch with DuPont. For a copy of Dupont's "Access Guide" to composite materials, or a subscription to the *KEVLAR UPDATE* newsletter, contact Jim Mondo, Recreation Products Group, DuPont Composites Venture, Center Road, Wilmington, DE 19898. . . . **CLINIC ON COMPOSITES:** This summer, DuPont will sponsor free workshops to demonstrate fabrication methods for composite structures. Hand lay-up, vacuum bagging, and filament winding are some of the procedures to be shown. The workshops will be held at the Experimental Aircraft Show in Oshkosh, Wisconsin, August 1 to 8, 1986. For details, contact Experimental Aircraft Association Headquarters, Wittman Airfield, Oshkosh, WI 54903; phone 414-426-4800.

◀ **SHIMANO INTRODUCES INDEXED SHIFTING TO THE 600 EX LINE:** The Shimano Index System (SIS) that was introduced in the New Dura-Ace line last year has now been applied to rear derailleurs and shift levers in Shimano's 600 EX range. Faster and easier shifting is possible with the SIS system because fine adjustments of the shift lever are not needed (see April 1985 *Bike Tech*). The new 600 EX shift lever (Model SL-6208) was designed for a lighter touch than the New Dura-Ace shifter, and also features an improved ball-detent and an adjustment spring. The new 600 EX rear derailleur (Model RD-6208, see photo at left) has several improvements over the old model, including rubber O-ring seals on the pivot arm bushings. And most important, according to John Uhte, Assistant Technical Manager of Shimano Sales Corp., is that all Shimano freewheels now on the market are compatible with the SIS system. If you're not sure you've got a newer, compatible freewheel, look for the word "SIS" next to the teeth number stamped into the freewheel's cog.

Other new products from Shimano include an **ALL-SPORTS PEDAL:** The Shimano Model PD-T100 (see photo at left) was designed for triathlalons, all-terrain bikes, and general all-around sports riding. With the same sealed axle design as the Shimano 600 pedal, the new pedal can be ridden with cleats or, by slipping in the flat sole plate, with jogging shoes or sneakers. Also new is the **ECONOMICAL BIOPACE CRANKSET:** the Shimano Model FC-B124 is identical in all dimensions to the regular Biopace, but is made by a less expensive die-casting process rather than by forging. The econo-Biopace will be available with either 170mm or 175mm cranks in the 28T/38T/48T gear range. March 1986 is the expected date for availability of all these Shimano products. (Shimano Sales Corp., 9530 Cozycroft Ave., Chatsworth, CA 91311).

◀ **THE SCOTT SUPERBRAKE:** In June 1985, the Scott/Mathauser Corp. released the production version of a radically new caliper brake system (see photo at left). A prototype was reviewed in detail in December 1983 *Bike Tech*. The brakes' "oversize" caliper arms, machined from solid aluminum, are said to be exceptionally stiff and twist-resistant, but weigh less than one ounce each. The symmetry of the single-arm pivot is designed to avoid the centering problems of sidepulls. The brake's reach is adjustable from 39 to 57 mm, via a slotted mounting plate, and can be extended to 63 mm with an extender bolt. The most ultimate aspect of the new Scott brake set may be the price: in the vicinity of $200 retail. **Framebuilders take note:** For proper clearance in mounting the Scott Superbrake, you need to pay attention to a few special dimensions on your fork crown layout. Contact Ed Scott at the following address for specific details: Scott/Mathauser Corp., Box 1333, Sun Valley, ID 83353 (208-726-5432).

REFLECTIVE MATERIALS UPDATE: Do cycling vests and reflectors really make nighttime riding any safer? Committee F-22 on "High-Visibility Materials for Safety" of the American Society for Testing and Materials (ASTM) worries about this question, and will meet in January 1986 to discuss possible solutions, such as new tests and standards for reflective materials. Their concern was prompted partly by the experiments of Richard Blomberg of Dunlap Associates, which found shortcomings in the performance of conventional bike reflectors and reflective fabrics (see February 1985 *Bike Tech*. The F-22 committee has already issued Standard F-923, "Guide for Understanding the Properties of High Visibility Materials for Individual Safety." This document contains many hard-to-find definitions and practical explanations of the concepts involved. For more information on the ASTM Committee F-22 meeting, contact R. Blomberg, Dunlap Associates, 17 Washington St., Norwalk, CT 06854 (203-866-8464); or Robert Morgan, ASTM (215-299-5505).

◀ **REYNOLDS ANNOUNCES 501 SL DOUBLE BUTTED TUBES:** A new CrMo tubeset designated "501 SL" was on display by TI Reynolds at the Paris Cycle Show in October. The 501 SL has double-butted main tubes and, for the first time in Reynolds' CrMo specification, "wide oval" taper gauge fork blades and light gauge seatstays and chainstays. The alloy has an ultimate tensile strength rating of 116,000 psi, and Reynold's claims it can be brazed at temperatures up to 2000 deg F with minimal post-braze loss of strength. Reynolds is aiming the 501 SL tubeset mainly at manufacturers of sport bicycles in the mid-price range. Contact John Temple at Sturmey-Archer of America, 1014 Carolina Drive, IL 60185 (1-800-323-9194).