BIKEMASTER User's Manual
By Don Axtell, 9 October, 1987

To run BIKEMASTER type the following :

RUN SDISK:[SAG.DVA.PROGRAM]BIKEMASTER.EXE

BIKEMASTER displays a list of 19 variables as shown below. Together they help to calibrate and quantify any bicycle ride so that predictions can be made on future rides. Knowing how each of these variables interact with the others, the user will become a master of his bike. To use this program, simply choose a variable and enter a new value. BIKEMASTER then automatically makes all adjustments to the other variables and updates the display. Both old and new values are shown side-by-side for ease of comparison. Each of these 19 variables is covered in the following pages.

BIKEMASTER - Learn to be the master of your bicycle

A-Distance to ride(miles) =	1.8	1.8	1.8	0.0
B-Road gradient (percent) =	10.5	10.5	10.5	0.0
C-Elevation change (feet) =	997.9	997.9	997.9	0.0
D-Weight of bike (pounds) =	25.0	25.0	25.0	0.0
E-Weight of rider(pounds) =	180.0	180.0	180.0	0.0
F-Rolling friction =	0.01000	0.01000	0.01000	0.00000
G-Wind friction factor =	0.01621	0.01621	0.01621	0.00000
H-Wind speed (mph) =	0.0	0.0	0.0	0.0
I-Wind angle (0deg=head) =	0.0	0.0	0.0	0.0
J-Gear ratio =	43.6	43.6	43.6	0.0
K-Pace or Cadance (rpm) =	59.9	55.5	48.0	0.0
L-Speed (mph) =	7.8	7.2	6.2	0.0
M-Time (minutes) =	13.9	15.0	17.3	0.0
N-Weight load (pounds) =	21.4	21.4	21.4	0.0
O-Rolling load (pounds) =	2.0	2.0	2.0	0.0
P-Wind load (pounds) =	1.0	0.8	0.6	0.0
Q-Total load (pounds) =	24.4	24.3	24.1	0.0
R-Work (pound_miles) =	44.0	43.7	43.3	0.0
S-Power(pound_miles/hour) =	189.8	174.9	150.0	0.0

Enter Item, Value :

A - DISTANCE (in miles) :

Distance is how long the ride is or will be. A long trip should be broken down into sections, with each section having a constant Gradient (B). Only one section can be considered at a time. A change in Distance will affect Elevation (C), Time (M), and Work (R).

B - GRADIENT (in percent) :

Gradient is a measure of how much uphill (+) or downhill (-) slope there is on the ride section considered. Gradient is defined as the number of vertical feet change for each 100 feet of horizontal. Gradients greater than 10 are very steep hills. A change of Gradient will affect Elevation (C), Cadance (K), Speed (L), Time (M), Weight load (N), Wind load (P), Total load (Q), and Work (R). If the change in Gradient causes a Speed (L) greater than 35 mph, then Speed is set to 35 and Power (S) is changed.

C - ELEVATION (in feet) :

Elevation is the vertical change from the beginning to the end of the ride section. Positive Elevation is uphill. When Elevation is changed, Gradient (B) is recalculated, and then all other changes are based on the new Gradient.

D - BIKE WEIGHT (in pounds) :

Bike weight is the weight of the bicycle plus any additional equipment. A change in Bike weight affects Cadance (K), Speed (L), Time (M), Rolling load (O), Weight load (N), Total load (Q), and Work (R).

E - RIDER WEIGHT (in pounds) :

Rider weight is combined with Bike weight (D) to get the total weight. A change in Rider weight affects Cadance (K), Speed (L), Time (M), Rolling load (O), Weight load (N), Total load (Q), and Work (R).

F - ROLLING FRICTION (unitless) :

Rolling friction is a factor which is multiplied by the total weight (D+E), which results in Rolling load (O). A change in Rolling friction affects Cadance (K), Speed (L), Time (M), Rolling load (O), Total load (Q), and Work (R). Appropriate values for Rolling friction are :

TIRE SIZE / ROAD CONDITION	ROLLING FRICTION
Thin tire / Smooth road	.010
Thin tire / Rough road	.020
Fat tire / Smooth road	.020
Fat tire / Rough road	.025
Fat tire / Loose dirt	.040

G - WIND FACTOR (unitless) :

Wind factor is multiplied by the square of the relative Speed to get Wind load (P). A change in Wind factor affects Cadance (K), Speed (L), Time (M), Wind load (N), Total load (Q), and Work (R). Because the wind equation uses the square of Speed, the choice of Wind factor becomes more important at higher Speeds. Wind factor changes according to riding position as shown below :

RIDING POSITION	WIND FACTOR
Crouched low, hands on bottom bars	.00801
Hands on top bars, drafting in group	.00801
Hands on top bars, no drafting	.01621
Sitting upright or standing	.02414

.012 HANDS ON BOTTOM, NO DRAFTING

H - WIND SPEED (in miles per hour) :

If there is a constant wind during the ride, its speed should be entered here. The direction of the wind is entered in (I). A change in Wind Speed affects Cadance (K), Speed (L), Time (M), Wind load (P), Total load (Q), and Work (R).

I - WIND DIRECTION (in degrees) :

Wind direction is 0 for a headwind and 180 for a tailwind. Wind Direction, Wind speed (H), Speed (L), and Wind factor (G), all go into the equation to calculate Wind load (P). A change in Wind Direction affects Cadance (K), Speed (L), Time (M), Wind load (P), Total load (Q), and Work (R). A headwind means more Wind load and a slower Speed.

J - GEAR (in inches) :

Gear is calculated by taking the number of teeth in the front sprocket divided by the number of teeth in the back sprocket and multiplying by the wheel diameter. Gear multiplied by 3.14 would equal the number of inches of forward movement for each rotation of the pedals. The tables on the next page list Gears for all tooth combinations for both 26" and 27" wheels. A change in Gear affects Cadance (K) only, as Speed (L) is kept constant.

K - CADANCE (in revolutions per minute) :

Cadance is a measure of how fast the pedals are rotating. A change in Cadance affects Speed (L), Time (M), Wind load (P), Total load (Q), Work (R), and Power (S). Typical Cadance values are :

TYPE OF PEDAL	RANGE	OPTIMUM
With toe-clips	50-120	90
Without toe-clips	50-90	70
Up steep hills	40 minimum	70

TECHNICAL DATA
FOR YOUR CONVENIENCE

GEAR CHART FOR 26" WHEEL

TEETH REAR SPROCKET	Number of teeth, Chainwheel (large front sprocket)														
	36	38	40	42	44	45	46	47	48	49	50	51	52	53	54
14	66.9	70.6	74.3	78.0	81.7	83.6	85.4	87.3	89.1	91.0	92.9	94.7	96.6	98.4	100.3
15	62.4	65.9	69.3	72.8	76.3	78.0	79.7	81.5	83.2	84.9	86.7	88.4	90.1	91.9	93.6
16	58.5	61.8	65.0	68.3	71.5	73.1	74.8	76.4	78.0	79.6	81.3	82.8	84.5	86.1	87.5
17	55.1	58.1	61.2	64.2	67.3	68.8	70.4	71.9	73.4	74.9	76.5	78.0	79.5	81.1	82.9
18	52.0	54.9	57.8	60.7	63.6	65.0	66.4	67.9	69.3	70.8	72.2	73.7	75.1	76.6	78.0
19	49.3	52.0	54.7	57.5	60.2	61.6	62.9	64.3	65.7	67.1	68.4	69.8	71.2	72.5	73.9
20	46.8	49.4	52.0	54.6	57.2	58.5	59.8	61.1	62.4	63.7	65.0	66.3	67.6	68.9	70.2
21	44.6	47.0	49.5	52.0	54.5	55.7	57.0	58.2	59.4	60.7	61.9	63.1	64.4	65.6	66.9
22	42.5	44.9	47.3	49.6	52.0	53.2	54.4	55.5	56.7	57.9	59.1	60.3	61.5	62.6	63.8
23	40.7	43.0	45.2	47.5	49.7	50.9	52.0	53.1	54.3	55.4	56.5	57.6	58.8	59.9	61.0
24	39.0	41.2	43.3	45.5	47.7	48.8	49.8	50.9	52.0	53.1	54.2	55.3	56.3	57.4	58.5
25	37.4	39.5	41.6	43.7	45.8	46.8	47.8	48.9	49.9	51.0	52.0	53.0	54.1	55.1	56.2
26	36.0	38.0	40.0	42.0	44.0	45.0	46.0	47.0	48.0	49.0	50.0	51.0	52.0	53.0	54.0
27	34.7	36.6	38.5	40.4	42.4	43.3	44.3	45.3	46.2	47.2	48.1	49.1	50.1	51.0	52.0
28	33.4	35.3	37.1	39.0	40.9	41.8	42.7	43.6	44.6	45.5	46.4	47.4	48.3	49.2	50.1
29	32.3	34.1	35.9	37.7	39.4	40.3	41.2	42.1	43.0	43.9	44.8	45.7	46.6	47.5	48.4
30	31.2	32.9	34.7	36.4	38.1	39.0	39.9	40.7	41.6	42.5	43.3	44.2	45.1	45.9	46.8
31	30.2	31.9	33.5	35.2	36.9	37.7	38.6	39.4	40.3	41.1	41.9	42.8	43.6	44.5	45.3
32	29.3	30.8	32.5	34.1	35.8	36.6	37.4	38.2	39.0	39.8	40.6	41.4	42.3	43.1	43.9
33	28.4	29.9	31.5	33.1	34.7	35.5	36.2	37.0	37.8	38.6	39.4	40.2	41.0	41.8	42.5
34	27.5	29.1	30.6	32.1	33.6	34.4	35.2	35.9	36.7	37.5	38.2	39.0	39.8	40.5	41.3

GEAR CHART FOR 27" WHEEL

TEETH REAR SPROCKET	Number of teeth, Chainwheel (large front sprocket)														
	36	38	40	42	44	45	46	47	48	49	50	51	52	53	54
14	69.4	73.3	77.1	81.0	84.9	86.8	88.7	90.6	92.6	94.5	96.4	98.4	100.3	102.2	104.1
15	64.8	68.4	72.0	75.6	79.2	81.0	82.8	84.6	86.4	88.2	90.0	91.8	93.6	95.4	97.2
16	60.8	64.1	67.5	70.9	74.3	76.0	77.6	79.3	81.0	82.7	84.4	86.1	87.8	89.4	91.1
17	57.2	60.4	63.5	66.7	69.9	71.5	73.1	74.6	76.2	77.8	79.4	81.0	82.6	84.2	85.8
18	54.0	57.0	60.0	63.0	66.0	67.5	69.0	70.5	72.0	73.5	75.0	76.5	78.0	79.5	81.0
19	51.2	54.0	56.8	59.7	62.5	64.0	65.4	66.8	68.2	69.6	71.1	72.5	73.9	75.3	76.7
20	48.6	51.3	54.0	56.7	59.4	60.8	62.1	63.5	64.8	66.2	67.5	68.9	70.2	71.6	72.9
21	46.4	48.9	51.4	54.0	56.6	57.9	59.1	60.4	61.7	63.0	64.3	65.6	66.9	68.1	69.4
22	44.2	46.6	49.1	51.5	54.0	55.2	56.5	57.7	58.9	60.1	61.4	62.6	63.8	65.0	66.3
23	42.3	44.6	47.0	49.3	51.6	52.8	54.0	55.2	56.3	57.5	58.7	59.9	61.0	62.2	63.4
24	40.5	42.8	45.0	47.3	49.5	50.6	51.8	52.9	54.0	55.1	56.3	57.4	58.5	59.6	60.8
25	38.9	41.0	43.2	45.4	47.5	48.6	49.7	50.8	51.8	52.9	54.0	55.1	56.2	57.2	58.3
26	37.4	39.5	41.5	43.6	45.7	46.7	47.8	48.8	49.8	50.9	51.9	53.0	54.0	55.0	56.1
27	36.0	38.0	40.0	42.0	44.0	45.0	46.0	47.0	48.0	49.0	50.0	51.0	52.0	53.0	54.0
28	34.7	36.6	38.6	40.5	42.4	43.4	44.4	45.3	46.3	47.2	48.2	49.2	50.1	51.1	52.1
29	33.5	35.4	37.2	39.1	41.0	41.9	42.8	43.8	44.7	45.6	46.6	47.5	48.4	49.3	50.3
30	32.4	34.2	36.0	37.8	39.6	40.5	41.4	42.3	43.2	44.1	45.0	45.9	45.8	47.7	48.6
31	31.4	33.1	34.8	36.6	38.3	39.2	40.1	41.0	41.8	42.6	43.5	44.4	45.2	46.2	47.0
32	30.4	32.1	33.8	35.4	37.1	38.0	38.8	39.7	40.5	41.3	42.2	43.0	43.9	44.7	45.6
33	29.5	31.1	32.7	34.4	36.0	36.8	37.6	38.5	39.3	40.1	40.9	41.7	42.5	43.4	44.2
34	28.6	30.2	31.8	33.3	34.9	35.7	36.5	37.3	38.1	38.9	39.7	40.5	41.3	42.1	42.9

L - SPEED (in miles per hour) :

This might be the most important variable. When changes are made to the other variables, the rider should look at what happens to Speed. If Speed is already known from an actual ride, it is entered here and Power (S) will be calculated, thereby calibrating the ride. A change in Speed will affect Cadance (K), Time (M), Wind load (P), Total load (Q), Work (R), and Power (S).

M - TIME (in minutes) :

Just like Speed (L), if time is already known, it can be entered here. A change in Time will affect Cadance (K), Speed (L), Wind load (P), Total load (Q), Work (R), and Power (S).

N - WEIGHT LOAD (in pounds) :

Weight load cannot be input. It is the result of total weight (D+E) and Gradient (B). A positive value means uphill and work is required. A negative value means downhill, and energy is available to help overcome Rolling load (O) and Wind load (P).

O - ROLLING LOAD (in pounds) :

Rolling load cannot be input. It is the result of total weight (D+E) and Rolling friction (F). Rolling load is always positive and acts to slow the bicycle down.

P - WIND LOAD (in pounds) :

Wind load cannot be input. It is the result of bike Speed (L), Wind speed (H), Wind direction (I), and Wind factor (G). Wind load increases greatly at higher speeds.

Q - TOTAL LOAD (in pounds) :

Total load cannot be input. It is the sum of Weight load (N), Rolling load (O), and Wind load (P). A higher Total load means a lower Speed (L).

R - WORK (in pound-miles) :

Work cannot be input. It is calculated as Total load (Q) multiplied by Distance (A). For uphills, Work is a measure of how tough the hill is, and can be compared with Work levels for other hills. The following page contains a list of hill climbs and their related Work levels.

HILL CLIMB	DISTANCE	ELEVATION	AVE.GRADE	MAX.GRADE	WORK
Mt. Hamilton Road					217.4
Hill # 1	6.0	1660	5.2	6.0	82.0
Hill # 2	3.2	780	4.6	5.0	40.0
Hill # 3	6.5	1900	5.8	6.0	95.4
Dunne Ave.					135.0
Hill # 1	1.0	420	8.0	10.0	18.8
Hill # 2	4.3	1590	7.0	7.0	72.8
Hill # 3	3.0	900	5.7	6.0	43.4
Saratoga Gap/Hwy 9	6.6	2200	6.3	8.0	103.1
Soda Springs Road	5.6	2250	7.6	10.0	101.3
Montebello Road	5.3	2100	7.5	11.0	94.8
Quimby Road	5.1	2050	7.6	15.0	92.3
Bonny Doon Road	6.4	1700	5.0	10.0	85.4
Black Road	4.5	1800	7.6	12.0	81.1
Sierra Road	3.7	1800	9.2	12.0	78.5
Felton-Empire Road	3.9	1600	7.8	14.0	71.8
Mt. Charlie Road	4.7	1200	4.8	18.0	60.7
Old Santa Cruz Hwy	5.4	950	3.3	5.0	56.1
Hecker Pass Road	4.5	900	3.8	5.0	50.0
Calaveras Road	3.0	950	6.0	10.0	45.1
Metcalf Road	1.8	1000	10.5	12.0	42.7
Hicks Road (Almaden)	1.6	700	8.3	12.0	31.0
Hicks Road (Guadalupe)	1.0	750	14.2	16.0	31.0
Bernal Road	1.0	470	9.0	10.0	20.8

S - POWER (in pound-miles per hour) :

Power is a measure of how strong the rider is or must be. A value of 375 equates to one horsepower. Usual values are between 100 and 200. If Power is negative as happens on some downhills, that means that the brakes would need to be applied. Once an existing ride is entered into BIKEMASTER, a Power level is obtained. That level of Power is then kept constant while other variables are changed to predict how the rider would do on other rides. The maximum power level for any one rider decreases as the length of ride increases.

The plot of Speed versus Power compares two Wind factors for a roadbike racing on a flat smooth surface. The two Wind factors are for drafting or not drafting. This plot also shows that minimizing the Wind resistance helps alot to conserve energy.

The next plot, Speed versus Gradient compares a mountain bike with a roadbike. The main differences here are the rolling resistance (.02 to .01) due to the fat tires and the fact that a mountain bike weighs more. The plot shows that a 5% grade will cut a rider's speed in half and a 10% grade will cut it in half again. Downhill flying is much faster on a roadbike because of the lesser rolling resistance, with speeds of 40 mph at a 7% grade without pedaling.

The Table, Biking up Metcalf Hill, compares a roadbike with a mountain bike for equal amounts of Power. Without having to work any harder, the roadbike beat the mountain bike by 4.0 minutes, a reduction of 20% off the mountain bike time. This demonstrates the importance of having the right equipment.

The next table compares four different bicycles. Included is both a cheap and expensive mountain bike and a cheap and expensive road bike. Weight savings and rolling friction are the biggest reasons in buying a more expensive bike.

The following chart presents the logic used in developing the Wind factors. Terminal velocities were taken for different skydiving positions. Some of these skydiving positions were then equated to riding positions on a bicycle. A factor, K, was then found by using BIKEMASTER with a very steep (-99%) downhill gradient. Different factors were tried until the Power came out to be zero at a Speed equal to the expected terminal velocity.

The next page presents all of the equations that are used inside BIKEMASTER. Often, not every variable can be calculated directly, and so an initial guess is made and then iterations are done using these equations until the final answer matches the initial value.

UNITED TECHNOLOGIES CHEMICAL SYSTEMS

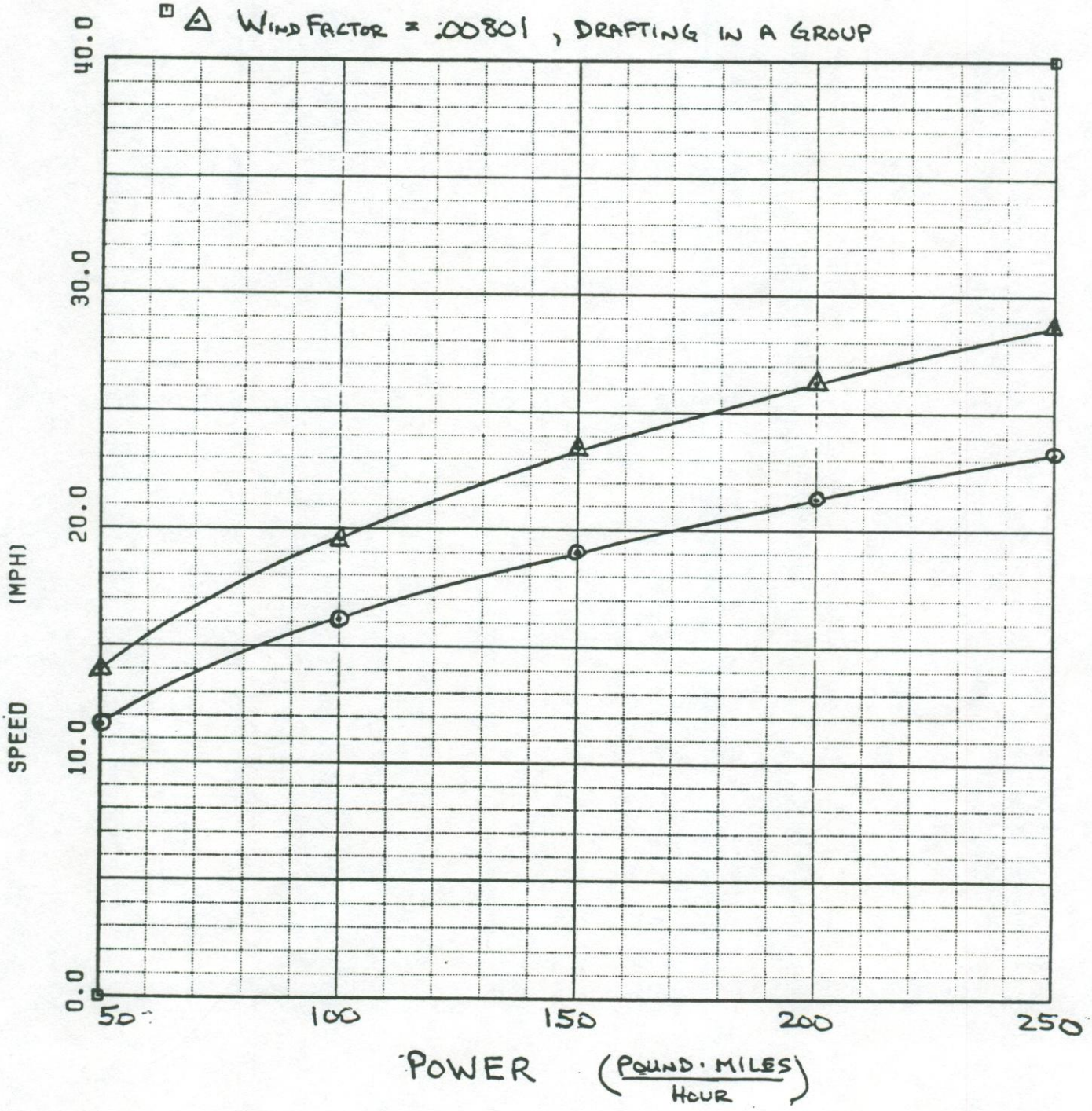
6-JUL-87

SPEED vs. POWER, ROADBIKE

GRADIENT = 0.

⊙ WIND FACTOR = .01621, NO DRAFTING

□ △ WIND FACTOR = .00801, DRAFTING IN A GROUP



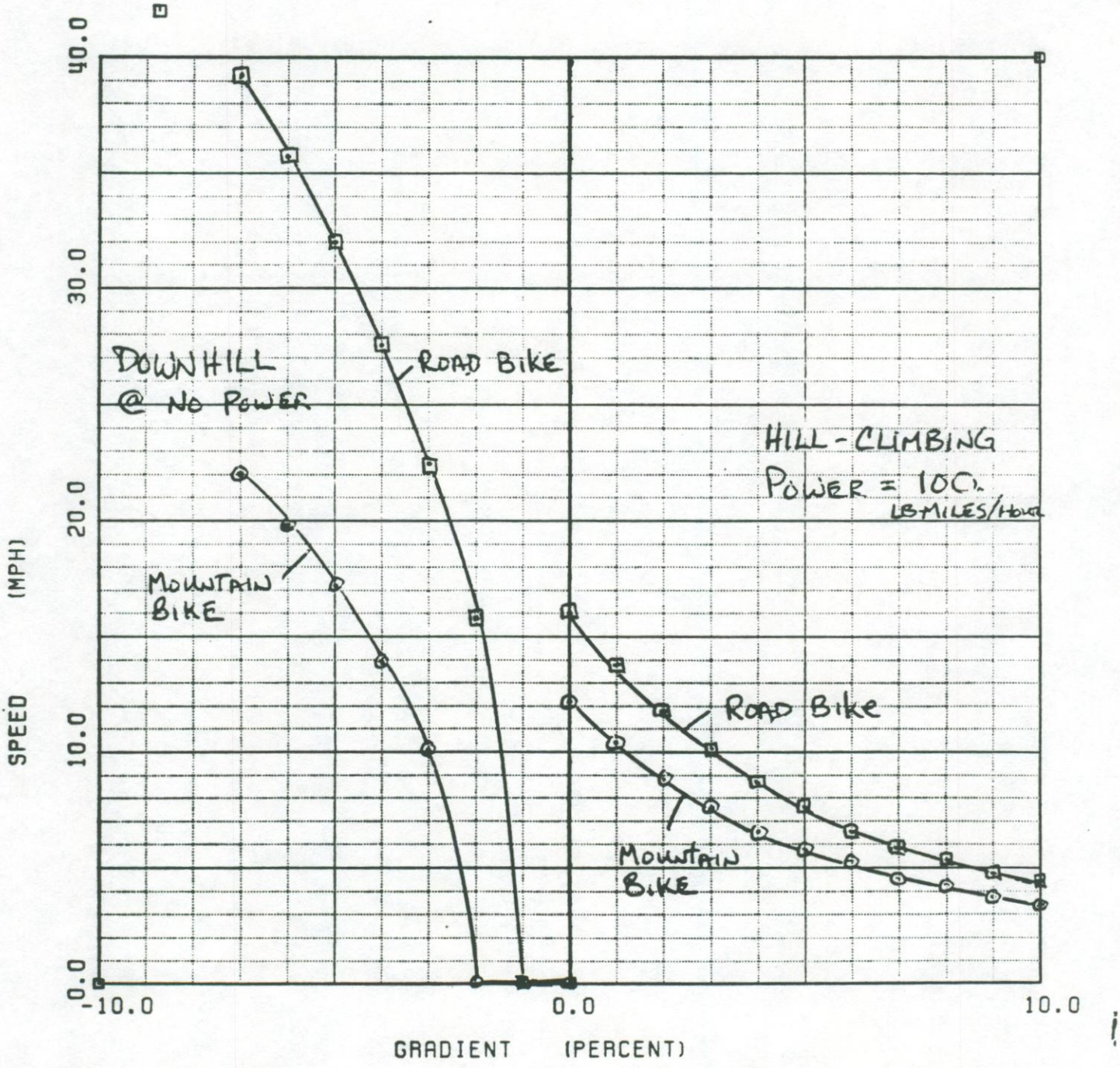
UNITED TECHNOLOGIES CHEMICAL SYSTEMS

6-JUL-87

SPEED VS. GRADIENT

DOWNHILL @ NO POWER

UPHILL @ P=100



Biking up Metcalf Hill

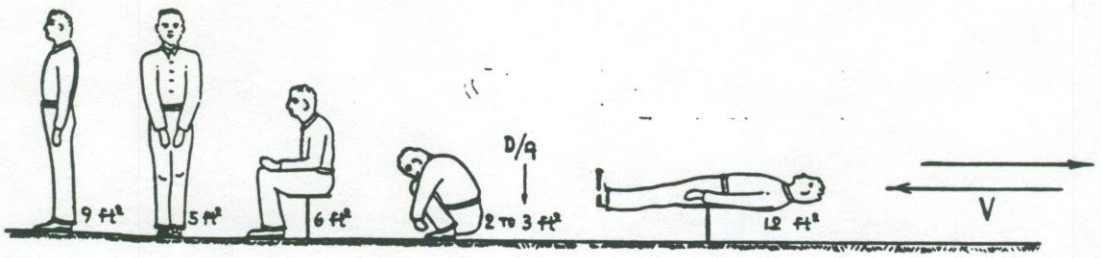
	Mountain Bike	Road Bike
Distance	1.8 miles	1.8
Gradient	+10.5 %	10.5
Elevation	+998. ft	+998.
Rolling friction	.02414	.01621
Wind Factor	.020	.010
Bike Weight	55 lbs.	25
Rider Weight	180 lbs.	180
Total Weight	235 lbs	205
Gear	36.2	43.6
Cadance	51 rpm	53
Speed	5.5 mph	6.9
Time	19.7 minutes	15.7
Weight Load	24.5 lbs	21.4
Rolling Load	4.7 lbs	2.0
Wind Load	0.7 lbs	0.8
Total Load	29.9 lbs	24.2
Work	53.9 lb.miles	43.6
Power	164.5 lb.miles/Hour	166.4

Bike Selection

	A	B	C	D
TYPE	ROAD	ROAD	MOUNTAIN	MOUNTAIN
PRICE	$120	$600	$120	$600
WEIGHT	35 LB	20 LB	50 LB	28 LB
# GEARS	2 x 5	2 x 6	2 x 5	3 x 6
CHAIN RING	42/52	42/52	39/52	28/38/48
FREE WHEEL	28/24/20/17/14	26/22/19/17/15/13	28/24/20/16/14	32/26/23/20/17/14
WHEEL DIAMETER	27"	27"	26"	26"
TIRE WIDTH	1¼"	0.8"	2.125"	1.8"
TOE CLIPS	NO	YES	NO	NO
ROLLING FRICTION	.015	.010	.020	.015
HIGH GEAR	100.3	110.0	96.6	89.1
LOW GEAR	40.5	43.6	36.2	22.8
WIND FRICTION FACTOR	.01621	.00801	.02414	.02414

7/2/87
D. AXTELL

WIND DRAG



DRAG AREA (ft^2)	TERMINAL VELOCITY (AIR)		SKYDIVE Position	Bicycle RIDING Position	K
	ft/sec	mpH			
1.2	365	249	DIVING	—	
2.0	283	193		—	
3.0	231	158	BALL	USE DOWN BARS	.00801
6.0	163	111	TUMBLE	USE TOP BARS	.01621
9.0	133	91	FLAT	Sit Upright	.02414

$$\text{VELOCITY}_{(FT/SEC)} = \frac{400}{\sqrt{\text{DRAG AREA}_{(FT^2)}}}$$

$$\text{WINDLOAD}_{(\text{POUNDS})} = K \cdot (\text{SPEED}^2_{(\text{MPH})})$$

FROM FLUID-DYNAMIC DRAG by HORNER

EQUATIONS

Weight = Bike Weight + Rider weight

$$SPEED = GEAR * PACE * \pi * \frac{1\,ft}{12\,in.} * \frac{1\,mile}{5280\,ft} * \frac{60\,min}{1\,Hour}$$

$$TIME = DIST / SPEED * \frac{60\,MIN}{1\,Hour}$$

$$ELEV = DIST * GRAD / 100. * \frac{5280\,ft}{1\,mile}$$

$$GRAD = ELEV / DIST * 100 * \frac{1\,mile}{5280\,ft}$$

$$SPEED = DIST / TIME * \frac{60\,MIN}{1\,Hour}$$

$$PACE = SPEED / GEAR / \pi * \frac{12\,in}{1\,ft} * \frac{5280\,ft}{1\,mile} * \frac{1\,Hour}{60\,Min.}$$

$$ANGLE = TAN^{-1}(GRAD/100)$$

$$XLOAD = WEIGHT * SIN(ANGLE)$$

$$YLOAD = WEIGHT * \cancel{FRICTION}^{ROLLING} * COS(ANGLE)$$

$$ZLOAD = (WIND * COS(WDIR * \pi/180) + SPEED)^2 * WFRIC$$

$$LOAD = XLOAD + YLOAD + ZLOAD$$

$$POWER = LOAD * SPEED$$

$$WORK = POWER * TIME * \frac{1\,Hour}{60\,MIN}$$

$$WORK = LOAD * DIST$$
$$LOAD = WORK / DIST$$
$$ZLOAD = LOAD - XLOAD - YLOAD$$

1 Horsepower = 550 ftLB/sec = 375 LBmiles/Hour

UNITED TECHNOLOGIES CHEMICAL SYSTEMS

3-DEC-87

POWER LEVEL VS. TIME

WEIGHT=180+25 ROLL.F=.010 WIND.F=.01621

BEST TIMES FOR BERNAL, METCALF, SARATOGA