THE BICYCLE AND SCIENCE - FROM DRAIS UNTIL TODAY

Hans-Erhard Lessing, Mannheim

In 1763 the Swedish Academy of Sciences posed the prize question, "if the waggons could be improved such, that the one and same horse can pull on the same way 70 liesspounds as easily, as it pulls 40 liesspounds on our common work waggons now" - an improvement of 75% was sought. The question and the competitors' solutions reverberated through the whole of Europe and therefore mark the beginning of the serious theory of the waggon. One competitor proposed wheels with a brass hub on steel axle to reduce friction - the beginning of brass bushings. Trial and error of the coachmakers gave way to procedures based on scientific principles (see fig.1).

What has this to do with the bicycle ? There are hints that Karl von Drais was well versed in the the theory of waggons (ref.2). In his application for a privilege on his Fahrmaschine (driving machine), a four-wheeler with cranked back axle, he writes in 1813: "I shall subject the strict mathematical proof, why the waggon should run well and stable, to the judgement of the public" (ref.4). Although this proof hasn't been found yet, this gives at least the hint, that he felt able to do so. His professors in Heidelberg had Faggot's cart in their collection (ref.3), the prize solution to the academy question, and in Rastatt, where his father served earlier, there was a coach manufacture with brass turning work which he might have seen.

But what can theory say about the waggon ? Let's look first into the theory of the wheel (fig.3) to which end we start from the friction theory of Coulomb - in a modern presentation (ref.5). According to him the force of dragging a - say - concrete block over a level concrete surface depends only on the force between the objects (here the weight of the block) and the nature of the materials. It is the same regardless of which side of the block makes contact. So we can give to the block a shape that has two protruding half rollers at the bottom - still the same friction for the same weight! But now let's have two rotating rollers. But surprise: If the block minus rollers has the same weight as before there should be no reduction of friction !!! Only that it is happening now between block and rollers. In the lowest sketch we have glued larger disks (wheels) to the rollers (axles). Now there is some gain: If we look at the energy to drag the block without or with wheels, we find, that the distance travelled is larger than the rotational distance travelled by the axle. Since the friction is located on the axle, we have less fricitional work there! The wheel behaves as a lever: it reduces friction, the larger its diameter and the smaller the axle diameter is.

Drais must have known this. In the description of his two-wheeler of 1817 he mentions "thinly turned axles and bushings" (visualized in Fig.4). His four-wheeler of 1813 already had "a polished back axle in brass bushings" (ref.6). So he was well aware of the problem of friction and actively tried to avoid it.

What does the Coulomb law of friction tell about the merits of a 2-wheeler as compared with 3- oder 4-wheelers ? Well, if we assume the same weight for every vehicle, we can distribute that weight evenly onto the wheels: each wheel of the 2-wheeler supports half the weight, so there is half the friction on each - which should be added for total friction. With the four-wheeler we have one fourth of the weight on each wheel, so only a quarter of the friction on each, but if we add those four contributions, we arrive at the same total friction. Fact is: Coulomb predicts the same friction for the same weight, regardless of the number of wheels.

It is my thesis that Karl von Drais observed empirically that this is cannot be true, since:

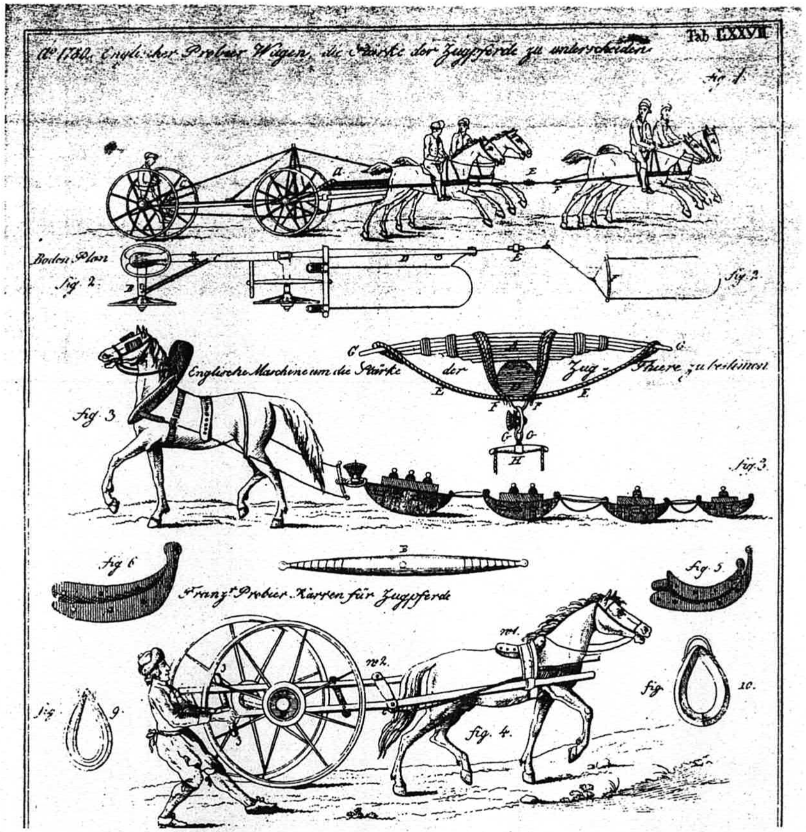
- he set out with a 4-wheeler in 1813 und ended up with a 2-wheeler in 1817.
- when coming out with the 2-wheeler in 1817 he offered at the same time 3- and 4-wheelers, too - so he must have experimented with all of them.
- in his description of 1817 he writes: "The 3- or 4-wheeled machines are not so well suited for travelling on the now common country roads". He was able to tell his experience in those qualitative words only, not in quantitative terms.

Although he is rather cryptic about the relative merits of the machines, I keep the thesis, that he arrived at the 2-wheeler by systematically omitting one wheel after the other (fig. 5). So this is the essence of his invention: the minimisation of rolling resistance by reducing the number of wheels as far as possible. One-wheelers are possible, as later years showed, and more favourable still, but are very hard to balance. And for the limited muscle power of man the easiest vehicle is the choice! With the advent of the railway physicist Osborne Reynolds showed that one has to consider the interaction between wheel and rail or soil or at the end of the century the interaction between tyre and macadam. Moreover there is a fixed friction within each bearing independent of load - these are the effects that reduce friction with fewer wheels - in contrast to Coulomb. Even today there is nothing like a simple formula for friction where one merely would insert the number of wheels! But if you see a lorry drive by with one back axle lifted up to save fuel - this is a the direct application of the Drais' observation.

A more detailed theoretical discussion of the velocipede is in a lecture in 1837 due to Thomas Stephens Davies (1795-1851), lecturer in mathematics at the Royal Military Academy in Woolwich (ref.7). According to him loading the wheels with heavy iron hoops would help them act as flywheels and prolong the ride, except on hills. Today we know that this inertia is already provided by the inevitable inert mass of the rider - quite the reverse: one tries today to make the wheels as light as possible!! Because to bring the wheels to rotational speed needs additional energy from the rider. It must have been the railway locomotives and steam engines with their flywheels that conveyed to the mechanical inventors the idea, that flywheels might be useful for human-powered vehicles, too. Put to the extreme this idea can be seen in the single-track railway velocipede of 1839 (fig. 6) - of course this presents only an additional burden!

The man to set things straight here, was the Glasgow University professor Rankine. In 1869, after the velocipede Michaux had arrived, he published a series of articles in the journal "The Engineer" (ref.8). This appears to be the only theory in the 1860's - small wonder that it was translated into French immediately (fig. 7). In 1873 followed the 'theoretical and practical essay on two-wheeled vehicles (velocipedes) of the French mine engineer Marchegay (ref.9).

The massive advent of the safety bicycle from Coventry brought a theoretical break-through in the 1890's. Questions of riding and direction stability were now tackled with involved mathematics and definitive textbooks were written by Carlo Bourlet in Paris (ref.11) and Archibald Sharp in London (ref. 10) the latter having been reprinted in our times (fig. 8,9). Ironically there is no German engineer's book around. German strengths were rider physiology and biomechanics in this century. Let me finish with a look at the bicycle's unique efficiency due to its ecological energy use (fig. 10, ref.12).



18th CENTURY: MEASUREMENT OF HORSE STRENGTH

Fig.

Theorie des Fuhrwerks

mit

Anwendung auf den Straſſenbau

von

C. [Claus] Krönke, [vielm. Kroencke]

Großherzogl. Heſſiſchem Oberkammerrathe ꝛc. zu Darmſtadt.

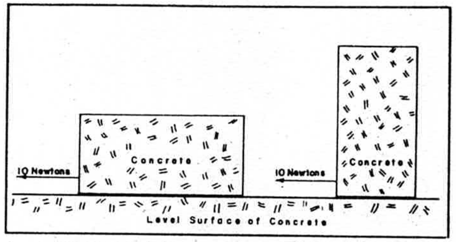
Mit Kupfern.

Gieſſen, bey C. G. Müller.

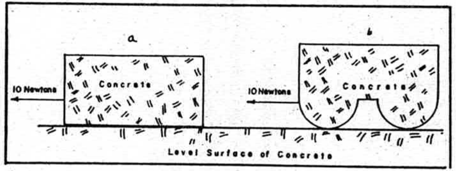
Subſcriptionspreis 1 Thlr. 16 gr. 3 fl.

[1811]

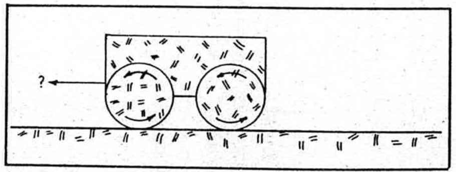
Fig. 2.



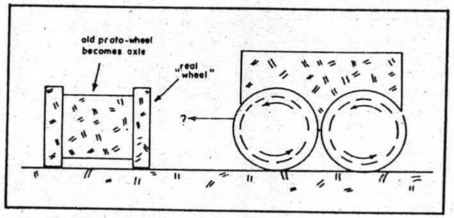
1. The force needed to drag a concrete block at constant velocity is not dependent on the position of the block.



2. Two concrete blocks of the same weight – one with cylindrical projections on the bottom.



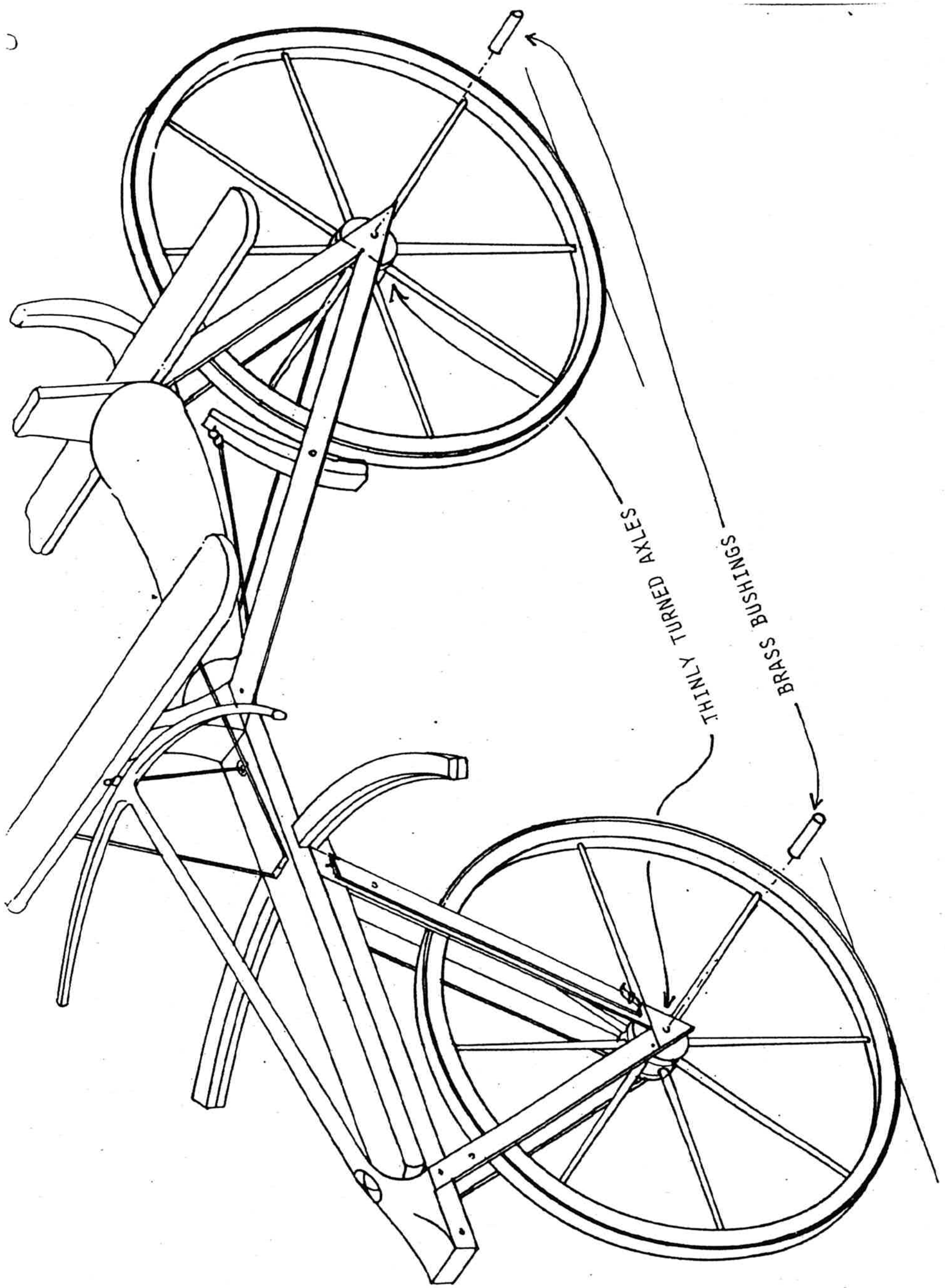
A block with protowheels.



Real "wheels."

WORK AGAINST FRICTION REDUCED BY $\frac{\text{AXLE DIAM}}{\text{WHEEL DIAM}}$

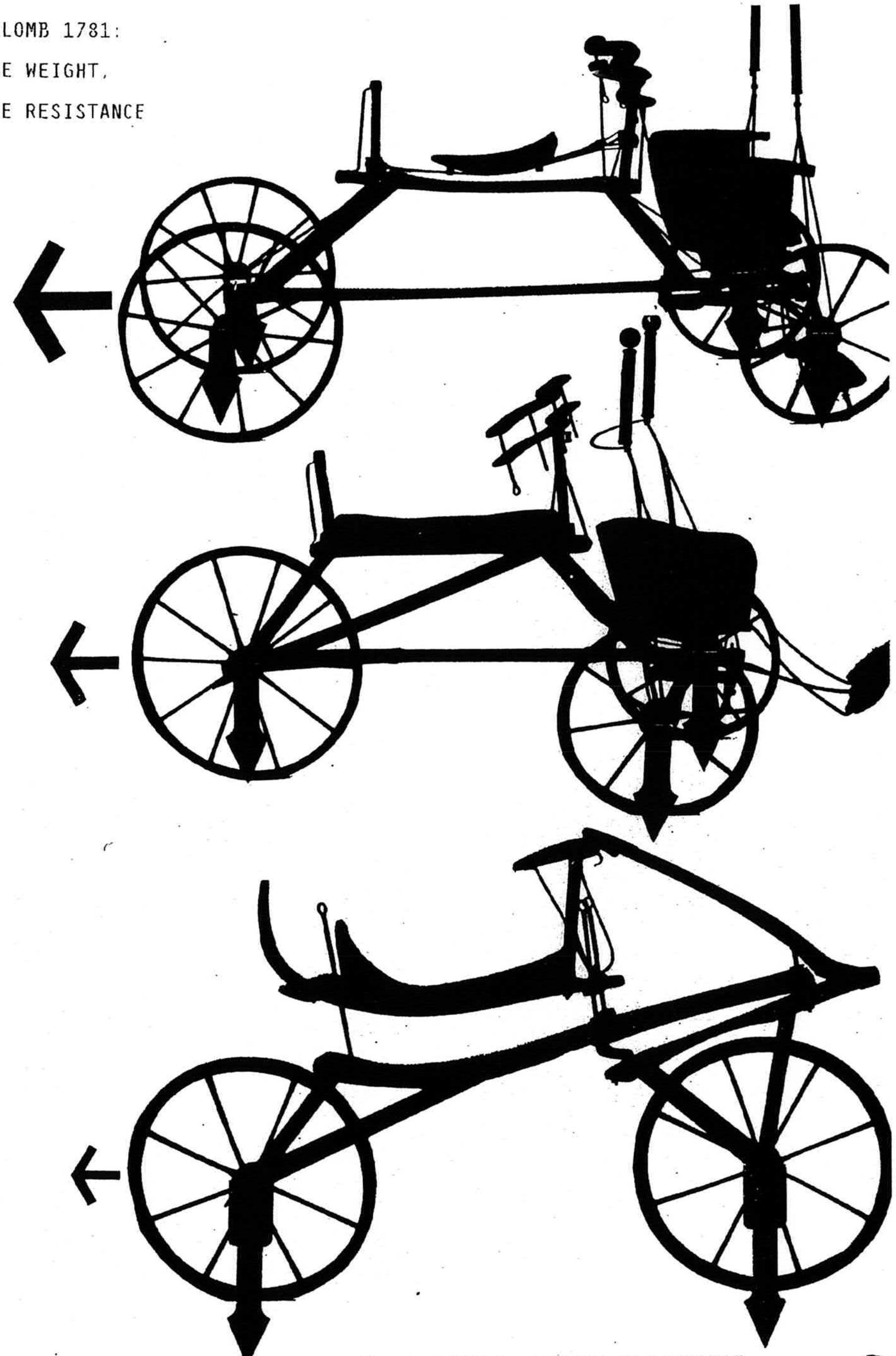
Fi



COULOMB 1781:

SAME WEIGHT,

SAME RESISTANCE



DRAIS: FEWER WHEELS, LESSER RESISTANCE

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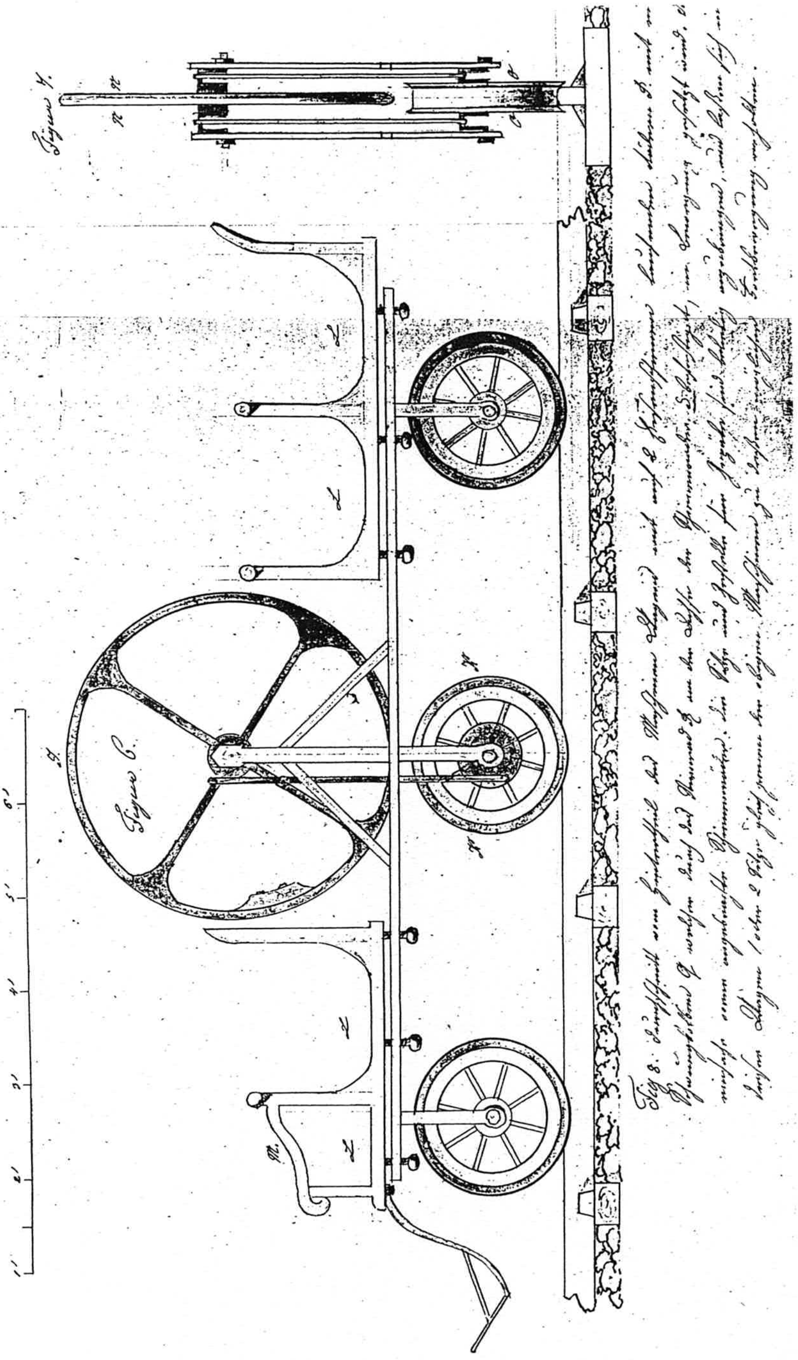
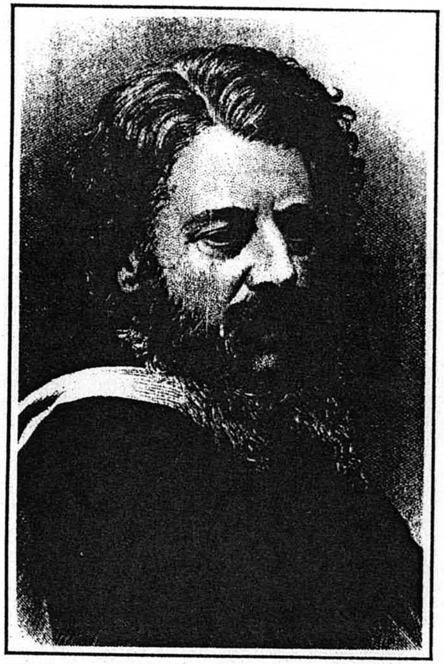
Fig. 6



BERNARD'S SINGLE-TRACK RAILWAY CAR 1839: FLYWHEEL USEFUL?



WILLIAM JOHN M. RANKINE (1820-1872)

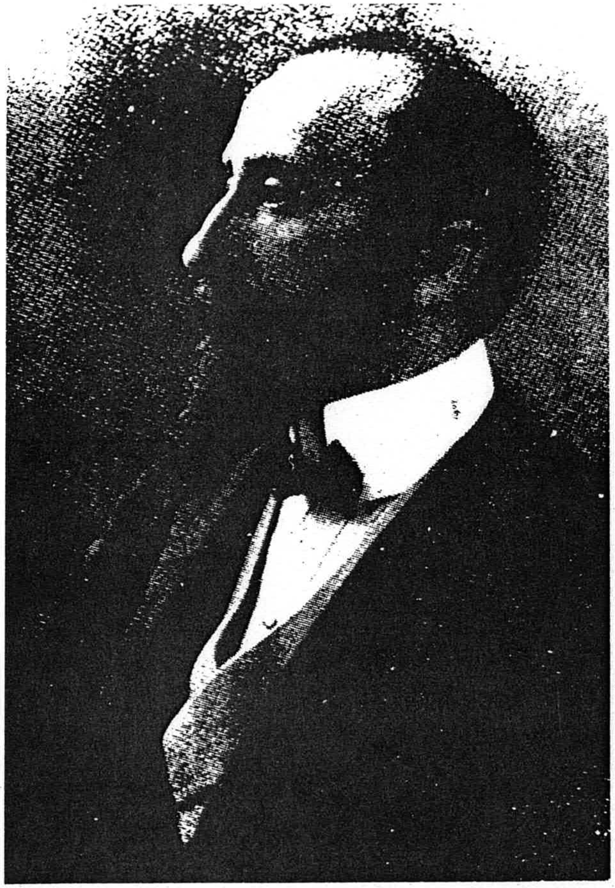
University of Glasgow

"ON THE DYNAMICAL PRINCIPLES OF THE MOTION OF VELOCIPEDES"

appeared in THE ENGINEER 1869

As an early example of technology transfer this appeared in France as a booklet:

"THÉORIE DU VÉLOCIPEDE", Paris 1870



CARLO BOURLET, Paris

Professeur á l'ÉCOLE DES BEAUX ARTS

"TRAITÉ DES BICYLES ET DES BICYCLETTES",

Paris 1894

"NOVEAU TRAITÉ DES BICYCLES ET DES

BICYCLETTES", Paris 1898

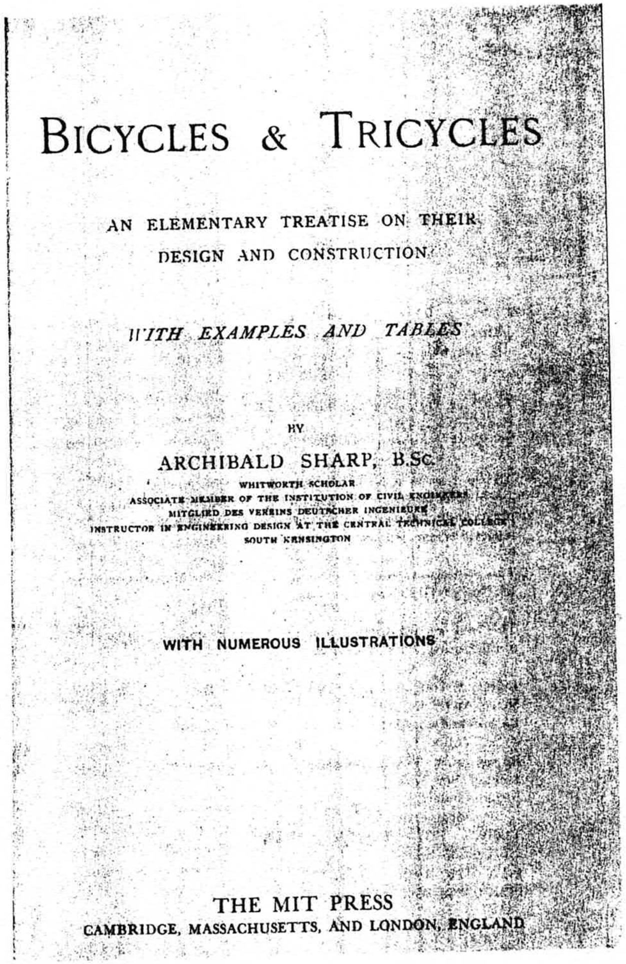
Vol.1 Équilibre et direction

Vol.2 Travail

"LA BICYCLETTE, SA CONSTRUCTION ET SA

FORME", Paris 1899

Fig. 8



BICYCLES & TRICYCLES

AN ELEMENTARY TREATISE ON THEIR
DESIGN AND CONSTRUCTION

WITH EXAMPLES AND TABLES

BY

ARCHIBALD SHARP, B.Sc.

WHITWORTH SCHOLAR
ASSOCIATE MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS
MITGLIED DES VEREINS DEUTSCHER INGENIEURE
INSTRUCTOR IN ENGINEERING DESIGN AT THE CENTRAL TECHNICAL COLLEGE
SOUTH KENSINGTON

WITH NUMEROUS ILLUSTRATIONS

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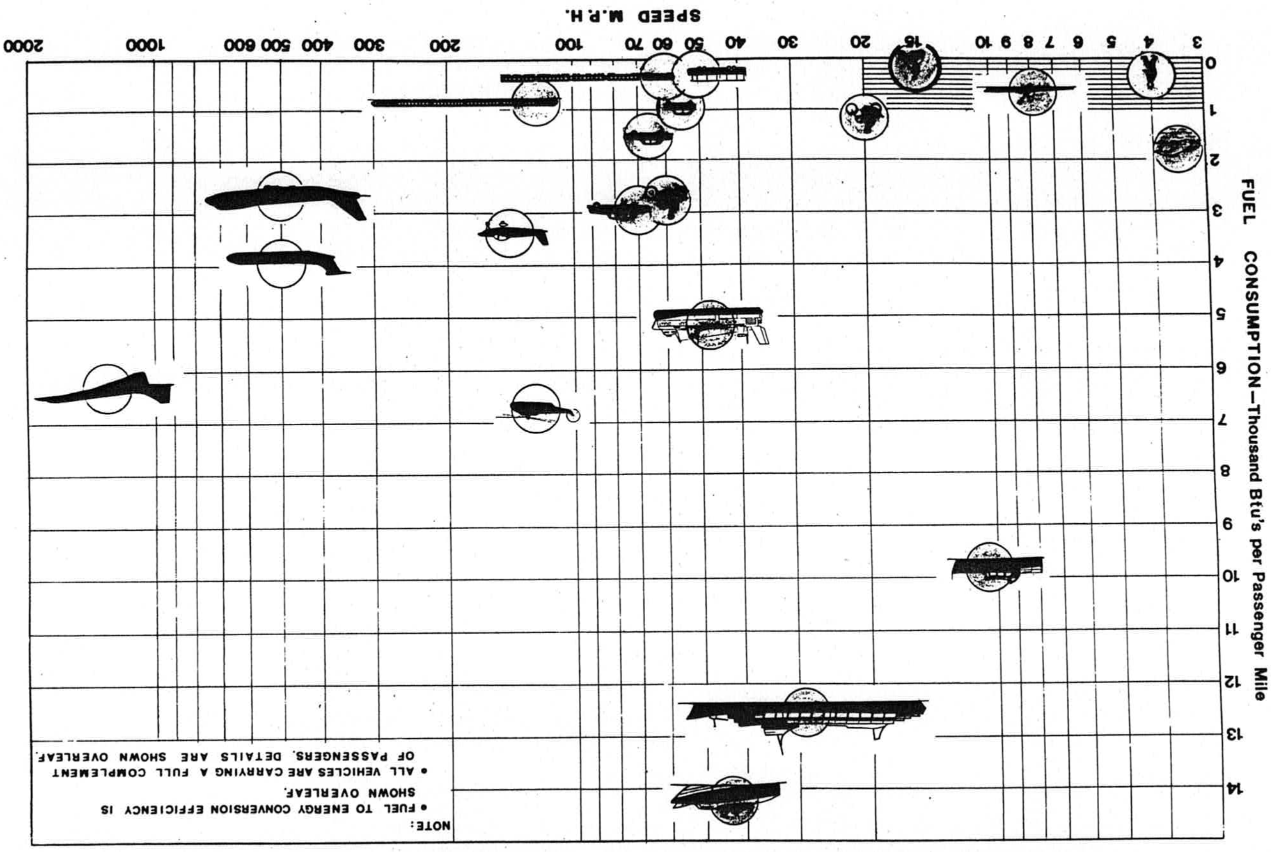
LONDON 1896, REPRINTED 1979

Fig

- FRIDAY EVENING DISCOURSE -
ROYAL INSTITUTION,
23rd February 1973.

FUEL CONSUMPTION (in terms of energy) v. SPEED
FOR VARIOUS MODES OF PASSENGER TRAVEL



NOTE:
- FUEL TO ENERGY CONVERSION EFFICIENCY IS SHOWN OVERLEAF.
- ALL VEHICLES ARE CARRYING A FULL COMPLEMENT OF PASSENGERS. DETAILS ARE SHOWN OVERLEAF.

Fig. 1(

					(ESTIMATE)			
Swimming	3.45	1	Fuel consumption is determined from food to energy conversion efficiency and H.P. required at feet or hands.	.5 (Estimate) (1500m World Record)	20%	1.8	1.18	280
Walking	4	1		.1 (Estimate)	20%	.32	.21	50
Canoe (K.I.)	7.9	1		.4 (Estimate) (10,000m speed)	20%	.65	.43	101
Bicycle (Moulton)	15	1		.18 (Measured)	20%	.15	.10	23
Small Motor-cycle	20	1	130 mpg		fossil fuel	1.17	.77	183
Large Motor-cycle	60	1	55 mpg			2.76	1.81	431
Small Car	55	4	40 mpg			.95	.62	148
Medium Car	65	4	25 mpg			1.52	1.00	237
Large Car	70	4	13 mpg			2.95	1.94	460
Coach (Moulton)	50	53	12 mpg			.248	.16	39
Train	60	450	1 mpg (Diesel, 118 galls London to Bristol)			.338	.22	53
Advanced Passenger Train	125	700	.25 mpg (Estimate)			.87	.57	135
Light Aeroplane	140	2	22 mpg (6.2 galls/hr)			3.38	2.22	528
Jumbo	500	347	.166 mpg (168,000 lbs London to New York)			2.63	1.72	410
V.C.10	500	145	.267 mpg (104,000 lbs London to New York)			3.93	2.58	613
Concorde	1300	132	.185 mpg (150,000 lbs London to New York)			6.26	4.11	974
Hovercraft (SRN 4)	48	609	.048 mpg (997 galls/hr)			5.15	3.38	802
Helicopter (Sea King)	130	24	.915 mpg (144 galls/hr)			6.9	4.52	1076
Motor Cruiser	10.3	6	2.5 mpg (4 galls/hr)			9.8	6.41	1529
S.S. Canberra	29	2300	.006 mpg (780 Tons/1000 Nautical Miles)			12.5	8.20	1951
Power Boat	43	6	1.8 mpg (24 galls/hr)			14.2	9.30	2220

ENERGY CONSUMPTION FOR VARIOUS MODES OF PASSENGER TRAVEL

basis of Chart Fig.14 in
'THE MOULTON BICYCLE' by Alex Moulton
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