Locomotive energetic performance

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***Abstract*—Here we introduce a parameter, Energetic Performance (EP), which is defined as the product of energetic efficiency and average speed. EP is determined for various mechanical and biological modes of human locomotion, providing an informative basis of comparison.**

In evaluating transportation choices, efficiency is an important and well-characterized consideration [1]. Average speed is also important, since people are paid by the hour and "time is money." For a payload object that begins at rest, follows a trajectory and returns to rest, we can determine object mass, distance traveled, thermal energy expended and transit time. From these values, the energetic efficiency and average speed may also be determined. Multiplying energetic efficiency and speed yields a parameter that is expressed in seconds, which we call Energetic Performance. EP is analogous to specific impulse as defined for rocket motor performance (i.e., thrust divided by propellant weight flow). The consumable of concern in rocketry is propellant, and here we evaluate performance with respect to thermal energy. One may think of EP as momentum times distance divided by energy. Momentum is equivalent to an impulse force acting during an interval of time. Since force times distance is work, and has the same units as energy, time is left in the numerator.

Table I gives efficiency, speed and EP for various modes of human transportation. Unless noted, all vehicles are assumed to be utilized by a single occupant. Efficiency is determined by estimating the number of passenger-kilometers obtained per unit of thermal energy present in the fuel consumed. A gallon of gasoline is assumed to be equivalent to 133 megajoules of thermal energy. Typical human mass is assumed to be 70 kg. The human body is assumed to be 25% efficient in converting the caloric content of food into mechanical work [2]. Moped vehicles are assumed to be ridden without pedaling.

The most complex efficiency determinations were those of electric vehicles. Wavecrest™ estimates the range of their M-750 electric moped at 8.9 m/s to be 25 km. Fully charging a SAFT™ nickel-metal hydride battery pack equivalent to the one used in this moped (model 30 VHDL) required 2.8A at 41V for 3 hours. This charge profile did not include a balancing charge that must be performed every 20 cycles. Battery charger power supply efficiency is 90%. Electrical transmission efficiency is 96%. Net efficiency of the generating facility at the other end of the powerline is 33% [3]. Thus, one may travel 25 km using 4.35 megajoules of thermal energy released at an electrical powerplant. In a similar manner, efficiency of an inverted pendulum transporter was determined from the manufacturer's (Segway™) data. It is suspected that much of the energy consumed by this device is used to keep it upright.

TABLE I.
ENERGETIC PERFORMANCE OF VARIOUS TRANSPORTATION MODES.

Mode	Efficiency (pass-km MJ^{-1})	Efficiency (kg-m J^{-1})	Speed (m s^{-1})	EP (s)
Faired bicycle[a]	13.90	0.973	33.5	32.62
Racing bicycle[2]	14.90	1.043	8.9	9.32
Touring bicycle[2]	23.80	1.666	5.4	8.94
Touring bicycle[2]	9.90	0.693	8.9	6.20
Electric moped	5.80	0.406	8.9	3.63
Airliner (full)[1]	0.40	0.028	120.7	3.38
Intercity train (full)[1]	1.70	0.119	20.1	2.39
Gas moped[b]	2.89	0.202	8.9	1.81
Hybrid auto, hwy[c]	0.79	0.056	29.1	1.61
Urban bus (full)[1]	0.90	0.063	11.2	0.70
Hybrid auto, city[c]	0.73	0.051	13.4	0.69
Human walking[1]	5.00	0.350	1.8	0.63
Segway™	1.40	0.098	3.6	0.35
Typ. auto, city[d]	0.24	0.017	13.4	0.23
SUV, city[e]	0.11	0.008	11.2	0.08

[a]Kyle Edge pedalled by Matt Weaver. [b]Revopower Wheel™. [c]Honda Insight™. [d]Ford Taurus™. [e]Hummer H2™.

Streamlined human powered vehicles excel in EP because of the relatively efficient human engine and the designer's careful attention to aerodynamics. The electric moped has the best EP of all motor assisted vehicles considered. Commercial airliners also perform well because people are willing to crowd themselves into an aerodynamically optimized fuselage for fast, long distance travel.

References

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