Horsepower and Steam

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For thousands of years buffalos and horses ploughed fields and lifted water while camels and donkeys and mules trudged on trade routes. All that was changed by fire and steam. The story begins in England in 1698 with a patented water pump. That pump was a failure but it started a revolution.

Savery

Thomas Savery made a steam powered water-lifter. His lifter had two tanks, two fireboxes, pipes and taps. The idea was simple enough. You boiled water and filled a tank with steam, condensed the steam to make a vacuum and used that to lift water. You shut and opened taps and used steam at high pressure to push that water upwards: then you closed and opened the taps and started again. The idea was to lift water out of mines with the "motive power of fire". Good idea: very good idea, but there were problems. His riveted tanks leaked steam and when they put his water-lifter near the bottom of a mine they raised the pressure in the second tank so high it exploded. He did sell two or three to wealthy men to put water into header tanks at their country houses but otherwise he was a business failure, except for one thing: he had friends in high places. He got parliament to give him sole rights to steam powered things for 21 years. When a decade later Newcomen did make working stream-driven pumps and did sell them to miners for lifting water he had to share the profits with Savery.

Savery did something of more lasting value: he compared an engine with a horse. There were no scientific journals in those times (and no internet) but there was a magazine called the *Miner's Friend*. In 1702, Thomas Savery wrote this in *The Miner's Friend*:

> So that an engine which will raise as much water as two horses, working together at one time in such a work, can do, and for which there must be constantly kept ten or twelve horses for doing the same. Then I say, such an engine may be made large enough to do the work required in employing eight, ten, fifteen, or twenty horses …

Translating that into modern English …

> An engine that will raise as much water as two horses can replace the ten or twelve horses needed to keep a two-horse pump working 24 hours a day, seven days a week. A much bigger engine could replace a 20 horse pump.

Savery's idea was used years later by Watt to advertise improved steam engines. Some accounts suggest that Watt invented and defined the horsepower but, as so often happens, he borrowed an earlier idea. Savery did that too. When he made his water-lifter he took ideas from a 1662 book by Edward Somerset, the Marquess of Worcester. We do know that Savery compared engines with horses before Watt because we have a dated copy of the *Miner's Friend* with his article.

Newcomen and Watt

Newcomen (with Savery) manufactured huge single-stroke beam engines from 1712 that were safe (they worked with just air pressure), but were wasteful of coal and steam. His pistons were badly made and leaked steam. They had to be sealed by pouring water over the piston. The engine delivered power on the down-stroke and the cylinder was cooled and reheated for the next intake of steam. https://en.wikipedia.org/wiki/Newcomen_atmospheric_engine#/media/File:Newcomen_atmospheric_engine_animation.gif

James Watt was an instrument-maker in Glasgow and had friends and associates at the University who gave him work. Through his university contacts he got to work on a small Newcomen engine and slowly came to understand the problem. He designed an engine that didn't need to be reheated each stroke. By 1769 Watt had teamed up with a rich man and had a full-size working engine that would do what a Newcomen engine would do with a third of the steam (coal). Further developments followed. Boulton-Watt engines went into mines and factories. By 1800 Watt was rich, famous, and retired. http://www.egr.msu.edu/~lira/supp/steam/wattbio.html

This original Boulton-Watt engine was as big as a three-story house and delivered about 30 horsepower. It has been rebuilt as a monument on a road near Birmingham. There is just one Boulton-Watt engine in England (from 1812) that still works. https://en.wikipedia.org/wiki/Crofton_Pumping_Station#Description

The writer feels a slight personal connection to Watt because of an unexpected coincidence.

> *"He was in a small country house in a village in NZ as a young man, having dinner with a friend from work. Her Husband was English. After dinner he noticed dozens of clean new-looking books with leather covers in rows on shelves in the lounge and picked one up and opened it. He was astonished to see a slip of paper glued inside the front cover with the words* ***Ex Libris*** *in fancy letters and the clearly readable signature of James Watt. They were Watt's books, handed down in the family for a hundred and fifty years. This one had illustrations of levers and linkages on page after page. The husband was a direct descendent. He said that when he left England, he didn't know what to do with the books, so he brought them with him. The pages were a little yellow with age but the letters and the colours in the blocked printed diagrams were bright and clear. That book had not been opened for all that time. The only other person to read it was probably Watt himself.*

The modern horsepower

If a constant force F moves through a distance d (in the direction of F) in a time t, the power relationship is in its original form (that for lifting water).

$$P = \frac{F \cdot d}{t}$$

When force is measured in Newtons, distance in metres, and time in seconds, the unit of power is the Watt.

Two horsepower (by definition) pulling a single furrough plough (not shown).

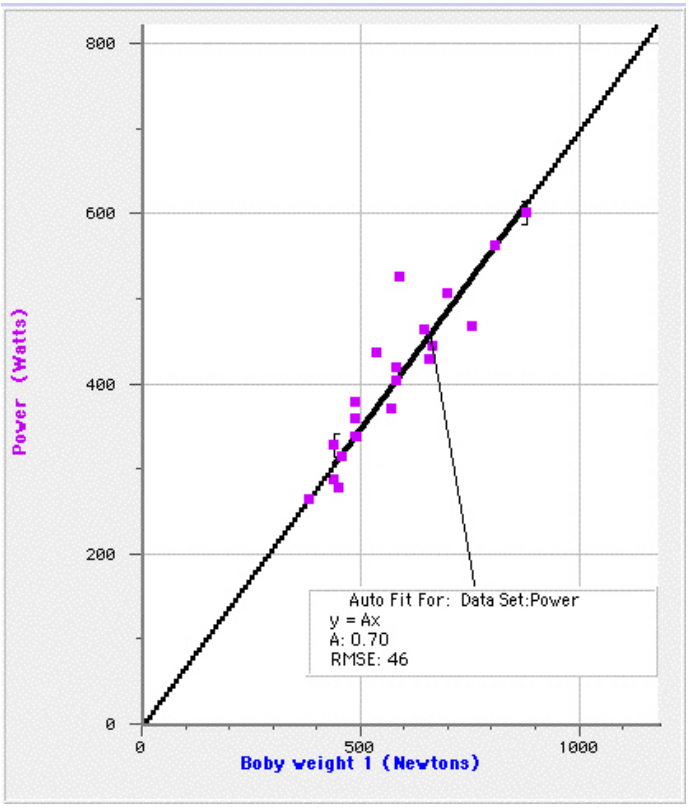
Manpower

Watt defined the horsepower as 33 000 foot-pounds per minute. In modern units one horsepower is 746 W. For continuous power output over an eight-hour working day that describes a very large horse. Most horses do less than that. We can define the *manpower* in Newton metres per second and measure that by climbing steps.

Measurements

For continuous power output we could use a very long flight of steps up a hill, like the 3000 steps in the Yellow Mountains of China that the writer climbed some years ago, but it would be more convenient to use metered gym equipment. For short-time maximum power output we could time people running up a flight of stairs three or four metres in vertical height.

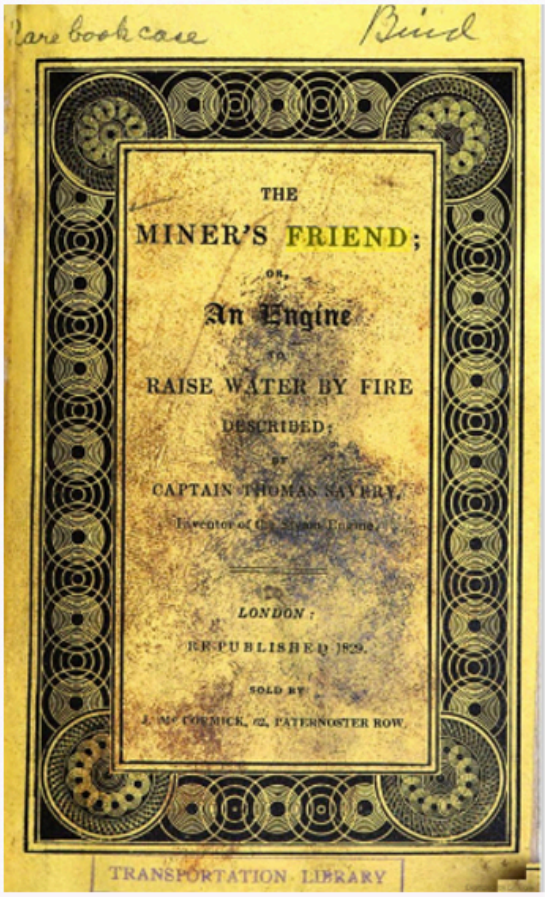
Data for a mixed class of M4 students (boys and girls) are shown below.



The data show that to a first approximation human power output is proportional to body-weight with no obvious difference between boys and the girls except that girls are on average lighter. Larger students have higher maximum short-time outputs of less than one horsepower. (Sustained human power output is closer to 100 Watts.)

Footnotes

The Miners Friend from 1702 is on the web. In particular a sense of the times can be gained by reading the petition to the King that heads the article.



TO THE KING.

SIR,

Your Majesty having been graciously pleased to permit an experiment before you at Hampton-court, of a small model of my engine described in the following treatise, and at that time to show a seeming satisfaction of the power and use of it; and having most graciously enabled me, by your royal assent to a patent and act of parliament, to pursue and perfect the same. By which your royal encouragement, it being now fully completed, and put in practice in your dominions, with that repeated success and applause, that it is not to be doubted but it will be of universal benefit and use to all your Majesty's subjects. Of whom, your Majesty being the universal patron and father, all arts and inventions that may promote their good and advantage, seem to lay a just and natural claim to your Majesty's sacred protection.

It is upon this consideration I am encouraged, with a profound respect, to throw this performance of mine, with the author, at your Majesty's royal feet, most humbly beseeching your Majesty, that, as it had birth in your Majesty's auspicious reign, you will vouchsafe to perpetuate it to future ages by the sanction of your royal approbation, which is the utmost ambition of,

May it please your Majesty,
Your Majesty's
most humble, most loyal,
and most obedient Subject,
THOMAS SAVERY.

http://himedo.net/TheHopkinThomasProject/TimeLine/Wales/Steam/URochesterCollection/Savery/index.htm

The quote below is taken from a second document from the same source …

The (elderly) gentleman examined her (our engine) very minutely, put a few pointed questions, and asked our reason for making her in that form? My brother, seeing he understood the subject, said that we made her to try what we thought was an improvement, and for this experiment we required another cistern and air-pump; and he was beginning to show what was properly Mr. Watt's engine, and what was not, when Miss M'Gregor stopped him by saying, "Oh, he understands it; this is Mr. Watt." I never at any time saw my brother so much excited as he was at that moment. He called on me to join them saying that "*this was Mr. Watt*!"

http://himedo.net/TheHopkinThomasProject/TimeLine/Wales/Steam/URochesterCollection/Hart/Rem.htm