HORSEPOWER

This note explains the concept of horsepower and links together mechanical horsepower, torque, and engine revolutions per minute.

Definitions

Circumference of a circle

The circumference of a circle is the length of its boundary. It is the product of π and the circle diameter, i.e. twice the radius.

$$\text{CIRCUMFERENCE} = 2 \times \pi \times \text{RADIUS}$$

Engine revolutions

rpm is the number of engine (crankshaft) revolutions r per minute mn.

$$rpm = \frac{r}{1\ mn}$$

Torque

t is a force around a given point, applied at a radius from that point. It is a measurement of rotational force over distance. Its unit is the pound-foot $lb{\cdot}ft$ (or newton-meter $N{\cdot}m$, with $1\ lb{\cdot}ft \approx 1.356\ N{\cdot}m$). $1\ lb{\cdot}ft$ represents $1\ lb$ of force acting at a perpendicular distance of $1\ ft$ from a pivot point.

$$\text{TORQUE} = \text{FORCE} \times \text{RADIUS} \quad \longrightarrow \quad \text{FORCE} = \frac{\text{TORQUE}}{\text{RADIUS}}$$

Work

Work is the product of a force acting on an object times the distance that the object moves. There is no time dimension in the definition of work.

$$\text{WORK} = \text{FORCE} \times \text{DISTANCE}$$

Power

Power means the rate of doing work, i.e. it has a time dimension. Power equals work done divided by time. It is expressed in units of foot-pound ($ft{\cdot}lb$) per minute mn or second s.

$$\text{POWER} = \frac{\text{WORK}}{\text{TIME}} \longrightarrow \text{POWER} = \frac{\text{FORCE} \times \text{DISTANCE}}{\text{TIME}}$$

Mechanical horsepower

hp is a made-up number due to James Watt (1736-1819) when he needed to compare the work of his steam engines with the one offered by horses. He defined 1 hp as the power[1] required to move

$$33000\,lb \text{ along } 1\,ft \text{ in } 1\,mn \longrightarrow 1\,hp = \frac{33000\,ft{\cdot}lb}{1\,mn}$$

or represented in seconds using $\frac{33000}{60} = 550$

$$550\,lb \text{ along } 1\,ft \text{ in } 1\,s \longrightarrow 1\,hp = \frac{550\,ft{\cdot}lb}{1\,s}.$$

Main relationship

The equation linking power hp, torque t, and engine revolutions per minute rpm is the following.

$$\text{HORSEPOWER} = \frac{\text{ENGINE REVOLUTIONS} \times \text{TORQUE}}{5252} \qquad hp = \frac{rpm \times t}{5252}$$

Explanations

Example of power computation

A constant tangential force of 100 pounds (100 lb) is applied to a handle of radius 1 ft, which rotates at 2000 rpm.

[1] Depending on the source, 33000 corresponds to 200 $lb \times 165\,ft$ (33000), or 180 $lb \times 181\,ft$ (32580), or using 180.96 ft (32572), which were all rounded to 33000.

First, we need the distance the handle travels per unit of time (minute).

$$\text{DISTANCE per revolution} = 2 \times \pi \times 1\ ft = 6.283\ ft \text{ per revolution}$$
$$\text{DISTANCE per minute} = 6.283\ ft \times 2000\ rpm = 12566\ ft \text{ per minute}$$

Then, to compute the power, we use the definition of power

$$\text{POWER} = \frac{\text{FORCE} \times \text{DISTANCE}}{\text{TIME}}$$

which becomes

$$\begin{aligned}\text{POWER} &= 100 \text{ pounds} \times \text{DISTANCE per minute} \\ &= 100\ lb \times 12566\ ft \text{ per minute} = \frac{1256600\ ft{\cdot}lb}{1\ mn}.\end{aligned}$$

Knowing that

$$1\ hp = \frac{33000\ ft{\cdot}lb}{1\ mn} \quad \text{or} \quad 1\ m = \frac{33000\ ft{\cdot}lb}{1\ hp}$$

we get the horsepower hp.

$$\text{POWER} = \frac{1256600\ ft{\cdot}lb}{1\ mn} = \frac{1256600\ ft{\cdot}lb}{\frac{33000\ ft{\cdot}lb}{1\ hp}} = \frac{1256600}{\frac{33000}{hp}} = 38.1\ hp$$

Engine horsepower

Now we use the same idea for an engine, with the piston applying a certain force on the crankshaft, which turns and travels a certain distance during a certain period.

We use the definition of force

$$\text{FORCE} = \frac{\text{TORQUE}}{\text{RADIUS}}$$

and the distance per minute

$$\text{DISTANCE per minute} = 2 \times \pi \times \text{RADIUS} \times \text{ROTATIONS per minute}$$

and plug both in the definition of power

$$\text{POWER} = \frac{\text{FORCE} \times \text{DISTANCE}}{\text{TIME}}$$

which gives

$$\text{POWER} = \frac{\frac{\text{TORQUE}}{\text{RADIUS}} \times 2 \times \pi \times \text{RADIUS} \times \text{ROTATIONS}}{1\,mn}.$$

Using $1\,mn = \frac{33000}{hp}$ and simplifying gives

$$\text{POWER} = \frac{\text{TORQUE} \times 6.283 \times \text{ROTATIONS}}{\frac{33000}{hp}} = \frac{rpm \times t}{5252} hp.$$

Note that at 5252 rpm, t and hp are equal. At any rotations below 5252, t is greater than hp. Above 5252 rpm, t is less than hp.

Examples

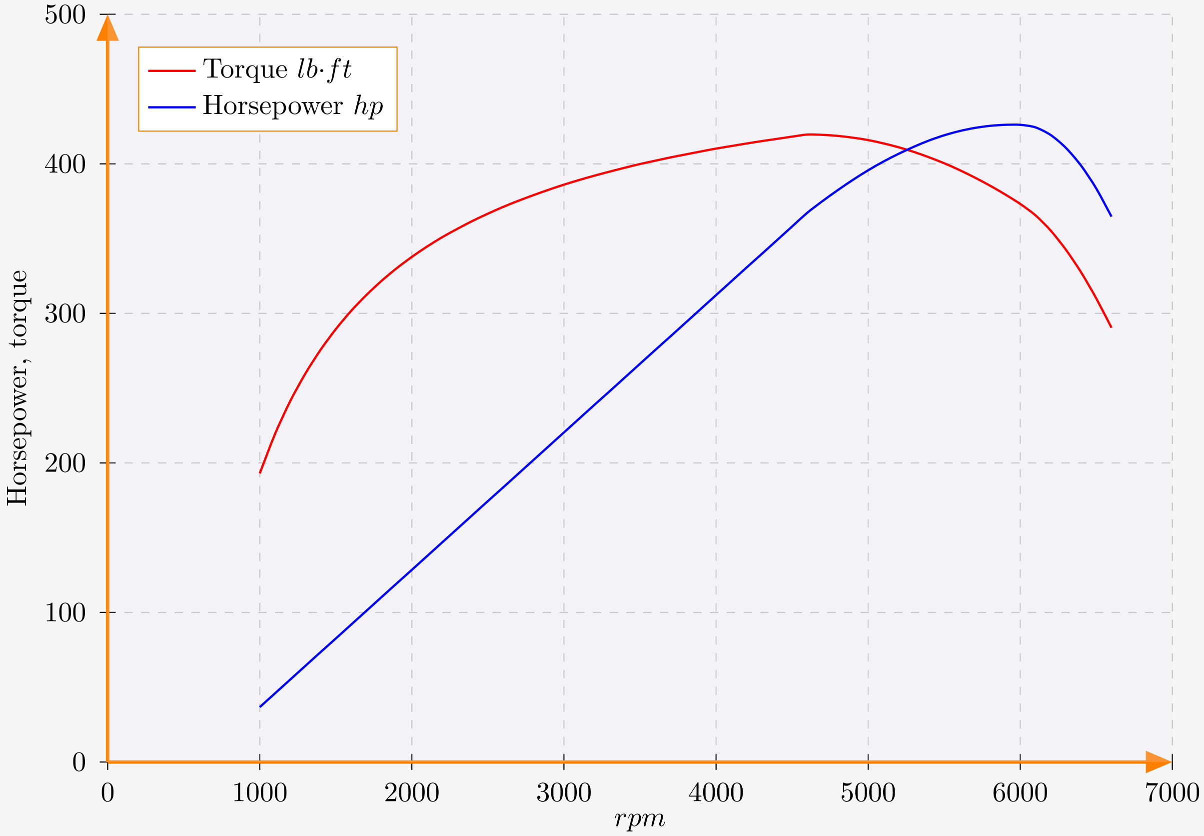

Figure 1: 2013 Chevrolet Camaro SS.

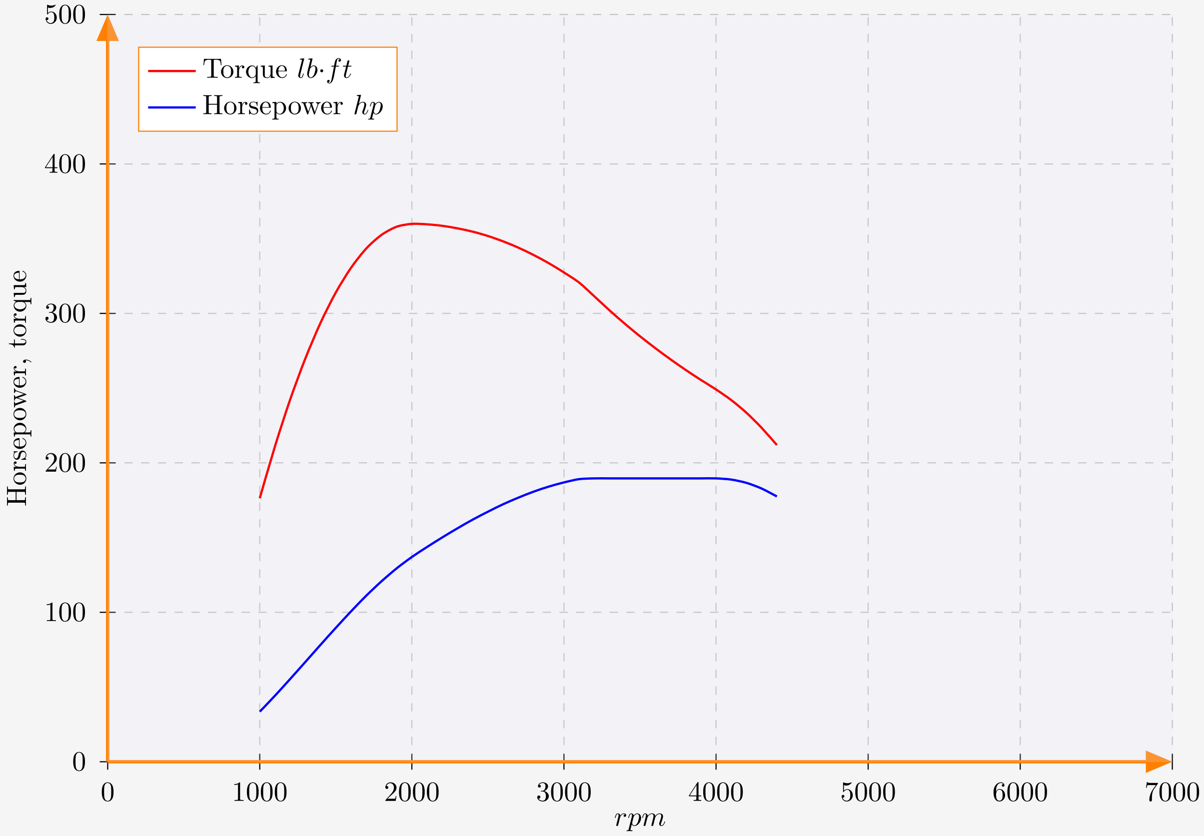

Figure 2: 1976 Cadillac Sedan deVille.

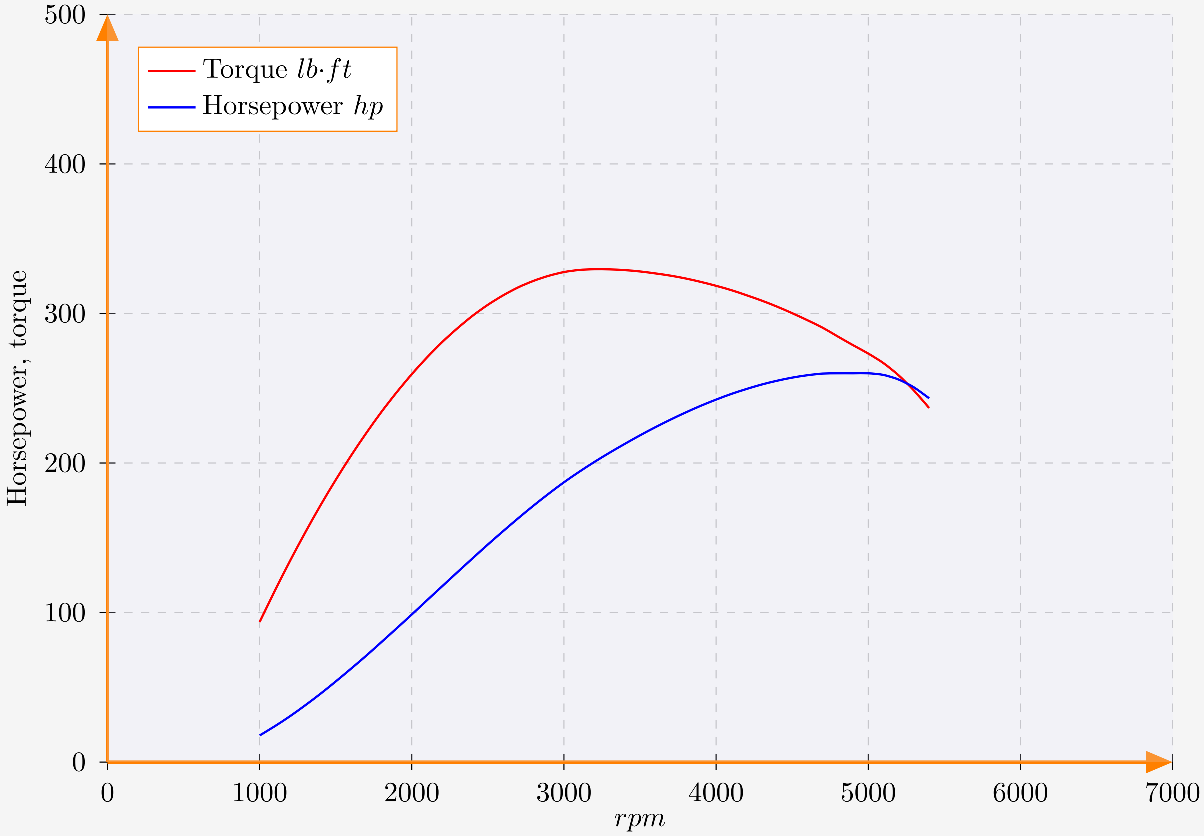

Figure 3: 1996 Cadillac Fleetwood Brougham.

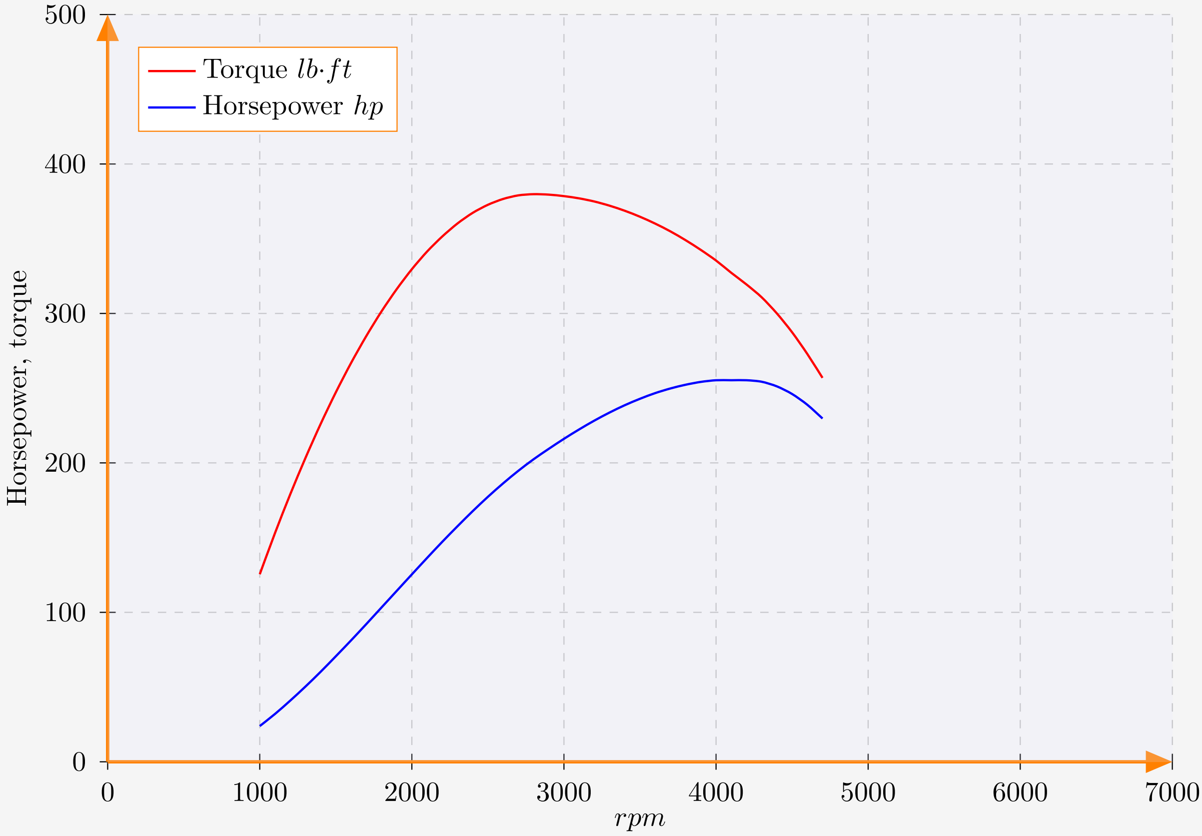

Figure 4: 1971 Buick GS 455.

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(compiled October 4, 2024)