GEOS 24705 / ENST 24705 / ENSC 21100
Problem set #6
Due: Tuesday Apr. 18

Readings: From Galloway, **"The History of Coal Mining in Great Britain"**, excerpts described below. You can find Galloway online here:

- Chapter I: (p.1-10). **"Coal of Late Coming Into Common Use..."**. *Read all, but skim the bit about Newcastle. Note early environmental regulation on p. 9-10.*
- Chapter II: (p. 11-18) **"Coal Comes Into Use for Domestic Purposes..."** *Skim very lightly, just get a sense for the long history of coal use in Britain.*
- Chapter III: (p. 19-27) **"The Increasing Scarcity of Wood Causes Coal to Come Into General Use For Domestic Purposes. First Difficulties in the Mines"** *Read all.*
- in Chapter IV, which is mostly about taxes and regulation, read only the paragraph on London's dependence on coal (p. 35)
- Chapter VI: **"Increase in Mining Difficulties. Improvements in Mining Appliances. Invention of Railways"**. (p. 52-67). *Read all. Note when Galloway talks about "engines" to pump out the mines on p. 57 he is using the term very generally, heat engines have not been invented yet. He is talking first about hydropower (water wheels) and later "horse engines". The first "railways" are also horse-powered.*
- Chapter VIII: (p. 76-82) **"Inadequacy of the Water-Raising Machinery, Invention of the Steam-Engine"**. *Read all. P. 77-78 covers problems with using renewables for pumping*.

Notes: prices are given in pounds (l), shillings (s, 20 to a pound) and pence (d, 12 to a shilling or 240 to a pound). A "fathom" is 6 feet, or about 1.8 meters. The "noxious gases" or "fire-damp" in the coal mines (p. 26) are methane; methane is often associated with coal seams.

Background – some history of the business and legal environment in which engine design occurred

The early development of engines is complicated by many different legal fights over intellectual property rights.

Thomas Savery, the inventor the first commercially used heat-to-work machine, was a sharp operator. He got a patent for his suction-pumping machine in 1699, and though patents in English law usually lasted 12 years, he somehow persuaded Parliament to extend his patent by another 21 years, so that it did not expire til 1733. That means that when Newcomen, after 14 years of tinkering and development, finally achieved a practical, commercializable, version of his true engine in 1712, Savery insisted that he owned all rights to the concept of raising water by means of steam. Savery's argument prevailed and Newcomen was denied a patent for his new invention. The only way he could get his invention to market was to (reluctantly) partner with Savery to start his business.

Savery himself was no intellectual property purist, and may have borrowed much of his idea from a 1662 book by the Earl of Worcester, who received neither credit nor royalty payments. Furthermore, the French theorist Papin had published extensively on possible steam engine designs, including a 1690 description of a piston-and-cylinder steam engine. (This design likely influenced Newcomen.) But still, Savery managed to get an "exclusive patent" for the entire concept of "raising water by fire." When Savery died in 1715, the patent was passed to his wife, who transferred the rights to a joint-stock

Papin, 1690

company called “The Proprietors of the Invention for raising water by fire.'' The London Gazette ran an advertisement in August 1716 stating that 'any person desirous to treat with the Proprietors for such engines' should meet with one of the proprietors who would be at a coffee−house in Birchin Lane every Wednesday to discuss terms’.

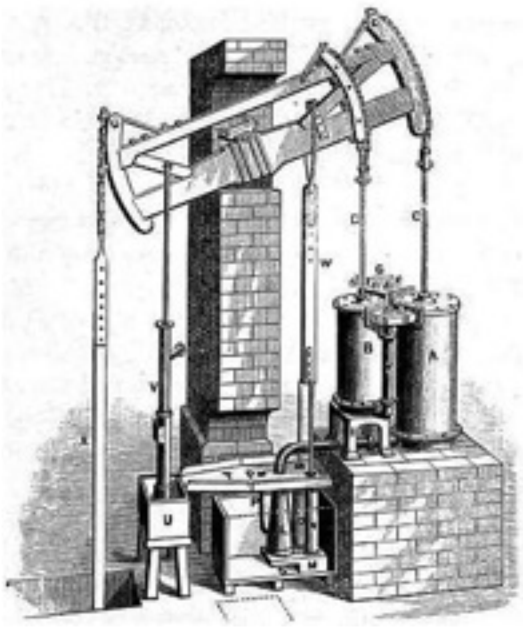
Patent protection may have contributed to periods of stagnation in engine design. There were few improvements in Newcomen's design for decades, other than the important step of automating the valves to make the engine self-acting. (Legend has it that that first advance was due to a boy named Humphrey Potter hired to operate the engine valves, who rigged up a system of ropes to do his job automatically. By 1718, an engine-builder named Henry Beighton had switched to the all-metal valve control you saw in the videos.) Innovation then paused. Wallace writes that this improvement "brought [the engine] into the form in which it continued, without any material change, for more than half a century" (Wallace, The History of the Steam Engine). Very little technological change happened in the next 50 years.

The golden age for development of Newcomen engines came only after Savery's patent had run out, in the 1770s-1790s. Once the patents expired, inventors like John Smeaton, James Pickard, and John Curr made significant changes. But why were these entrepreneurs working on Newcomen-type engines at such a late date, when Watt had already developed the superior external condenser in the 1760s? The answer is patents again: because Watt had of course patented the condenser (in 1769), and he not only aggressively defended his patent but also refused to license the technology to any competing manufacturers. Watt had the better design, but inventors could only work on the outdated Newcomen engine, which was in the public domain.

Watt's aggressiveness contributed to several other instances of sub-optimal use of technology. Pickard tried to open a new market for the Newcomen engine as a driver of factory machinery, and developed a crank mechanism that would adapt the Newcomen engine to convert its linear motion into rotational motion that could turn a driveshaft. Although the crank had been in use for centuries, Pickard in 1780 managed to get a 12-year patent on the broad idea of translating linear motion to rotational motion by means of a crank. Trying to be a tough negotiator, he refused to license his crank to Watt, unless Watt in turn agreed to license his condenser to Pickard. Watt refused, and sold his engines instead with the sun-and-planet gearing that he had developed to get around Pickard’s patent. (The gearing worked, but was more complex and less efficient). In the end, you might say that Watt won: he waited out Pickard's patent, and once it expired in 1794 immediately dropped the sun-and-planet gearing for the crank. Pickard on the other hand never managed to get his Newcomen-engine-with-crank system functional for factory use - the power delivered was too jerky to drive machinery.

Another instance of Watt’s litigiousness impeding the development of technology happened after Hornblower patented (in 1781) a compound engine: an engine that re-used the exhaust steam from the cylinder in a second, lower-pressure cylinder. The engine went into production briefly, but Watt sued and managed to win. The resulting litigation prevented the use of multiple-cylinder “compound” engines until Watt’s patent expired in 1800.

The expiration of Watt’s patents, as expected, meant a boom in steam engine purchases and a jump in innovation. Once the condenser was in the public domain, manufacturers promptly switched over to



Compound steam engine 1690

that better design instead. The expiration of Watt's patents therefore also meant the end of the Newcomen era.

You can see the text and diagrams of some of Watt's patents here. Note that Watt is shamelessly trying to patent a crank in 1781 despite Pickard's 1780 patent! And here is a long catalog of letters between Watt, his business partner Boulton, and their employees, including discussions of technical details, business transactions, and lawsuits. There are a few excerpts at the beginning and then just summaries, but even the summaries are interesting. At one point Boulton is mistakenly credited with Watt's inventions, and Watt writes back that he is troubled about the legal and financial implications, that he does not care "about the laurels" (i.e. about recognition) but that he does care about the money.

Besides the patent protection issues, there's another reason that Newcomen engines continued to operate long after Watt's invention. The engines lasted a long, long time, and they had been expensive to buy. Watt's improved efficiency could provide some cost savings but not enough to make it cost-effective for a mine owner to discard a perfectly operational engine, that represented a big capital investment, and buy a newer model. One of the longest-lived was the Newcomen engine at the Ashton Vale ironworks, built in 1750 and operational until 1900. It was described in detail by Wallace in a 1903 article. He writes: "*Over its 150 years of use, the South Liberty Engine worked for about 5 hours per day, for 6 days a week. The engine−man who was driving it in 1895 had driven it since he was a boy, his father and grand−father having driven it before him.*"

The Ashton Vale engine is important because its long life meant that it was the most extensively documented of the early Newcomen engines. In this problem set you'll use measurements from this engine in some of the problems below.

There was at least one Newcomen engine that was in operation even later than Ashton Vale, though its total lifetime was not quite as long. The Farme Colliery in Scotland had probably the last Newcomen engines ever to be built, one in 1810 and two in 1820. (See picture next page.) All three operated for over 70 years, and the 1810 engine ran for over a hundred years til 1923, meaning that it could be photographed in action. An article 1904 (with photographs!) called it "the last survivor of an otherwise extinct type." (Benjamin Taylor, "A Century-Old Colliery Engine – Last Survivor of the Newcomen Type", Power, p. 134, March 1904, see this link).

The colliery's engines were used for different purposes from the first Newcomen pumping engines — two were rotative "winding" engines to lift coal that incorporated more modern linkages — but all are true "atmospheric engines" using only the force of the atmosphere to drive the piston down. It's not clear why the colliery built such primitive engines, but it probably had something to do with the fact that the engines were home-builds: the 1810 was designed by a local blacksmith. The 1810 version even had manually operated valves, making them about a century behind their time. (The other designs aren't known). The simplicity of Newcomen's design meant that an engine could be built by a local craftsman and run for a century, something that is definitely not true of more modern technologies. For the colliery, these engines may have been a good investment.

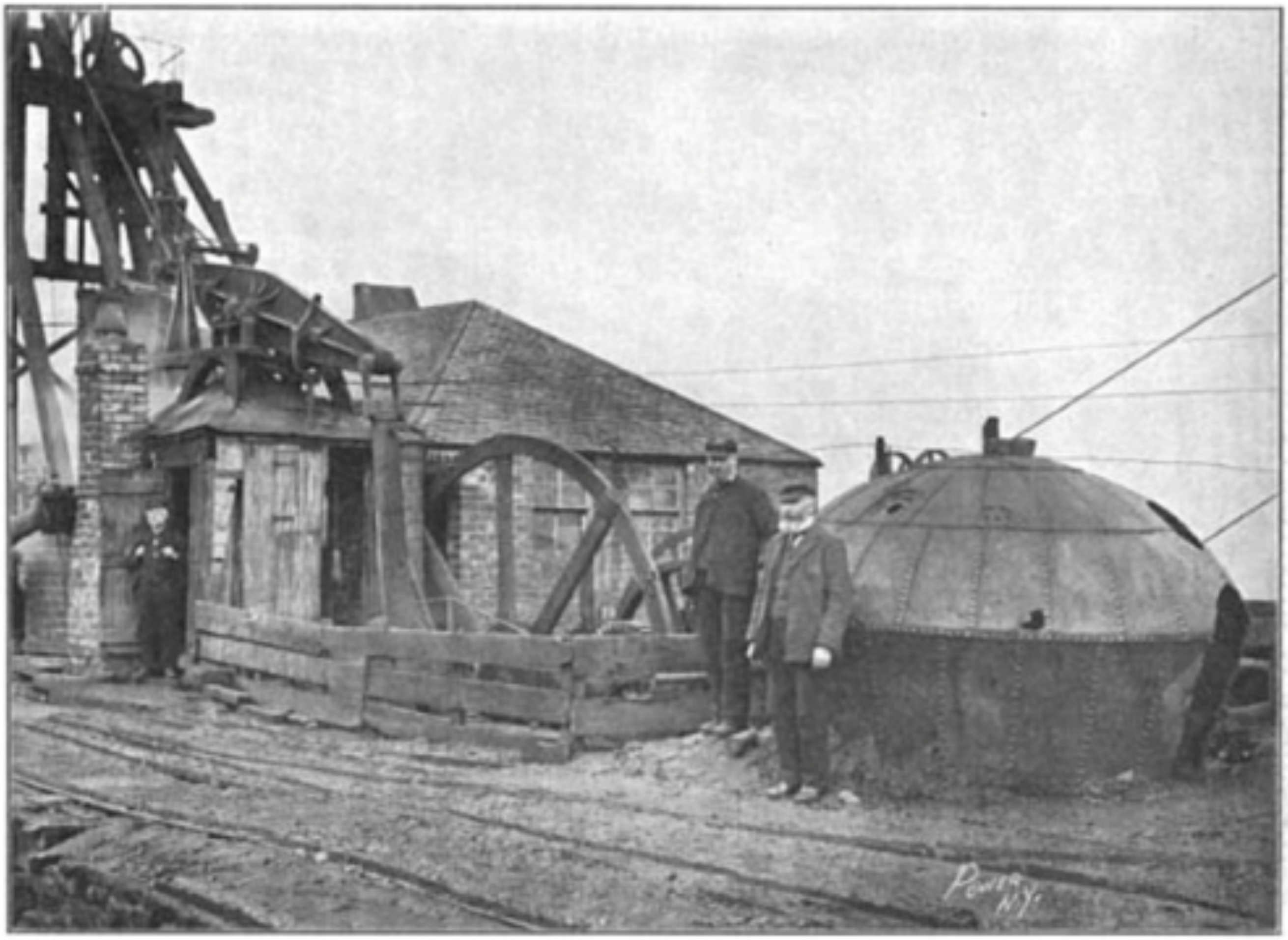


FIG. 2. EXTERIOR VIEW OF ENGINE, ETC. STANDING AGAINST THE HAYSTACK BOILER IS WILLIAM PARK, WHO DROVE THE ENGINE 40 YEARS AGO; AT HIS RIGHT IS TOM SMITH, WHO HAD CHARGE OF ENGINE 60 YEARS AGO AND STILL WORKS AT THE PIT HEAD. IN THE DOORWAY IS DUGALD DON, WHO HAS BEEN IN CHARGE OF THE ENGINE FOR THE PAST 18 YEARS.

Problem 1: History background

A. Raising water with Savery's engine: compute how high Savery's engine could have "sucked" up water by creating a vacuum. We said in class that atmospheric pressure is 14 pounds-force per square inch, and that this atmospheric pressure can therefore lift a column of water whose weight per area equals this force. What height is that? It is probably easiest to convert to Standard International (metric), where the density of water is 1 gram per cubic centimeter. Compare to Galloway's claims about what Savery's engine could do. (See slides.)

B. Coal history: Comment on something you found interesting from Galloway.

C. Patents: Write an appeal to the English courts, either as Newcomen complaining about the interpretation of Savery's patent or as Watt complaining about Pickard's. You can argue that the patent is over-broad, invalid on the basis of prior art, doesn't apply to your case, or any combination of these. Googling is good. Just a paragraph, no more, but try to add on what I've written above.

Problem 2: Growth in power use

In the previous problem set you estimated pre-modern (1700's) energy use with data from Braudel. In this problem you'll assess how energy use grows as the Industrial Revolution begins. New technology obviously became economically important very quickly, since in 1825 the French scientist Carnot wrote that steam engines were the foundations of the British empire:

"To take away to-day from England her steam-engines would be to take away at the same time her coal and iron. It would be to dry up all her sources of wealth, to ruin all on which her prosperity depends, in short, to annihilate that colossal power. The destruction of her navy, which she considers her strongest defense, would perhaps be less fatal."

How much extra energy did the coal-powered steam engine provide to the average Englishman? You'll use some literature values given below, and the figure at the end of Problem 5. The figure shows the growth in the power of an individual steam engine (L) and in engine efficiency (R). You'll estimate both input power and output as work.

A. Re-state your prior estimate of pre-modern per-capita power use (in W/person).

Write down your estimate of primary power use that you derived from Braudel in the last PS (and also give the mechanical work output). Then check your value by plotting it on the slide that shows historical per capita power usage in France and the Netherlands starting in 1800. (In 1800, steam usage was still minimal in continental Europe.) You can assume that this value for pre-steam-power Europe is also representative of pre-steam Britain.

B. Estimate British per capita power use in 1800 (in W/person)

In 1800, 25 years after Watt's first real production model, England had some 1200-2000 steam engines. (There were no accurate records kept, and estimates vary.) Estimate the work these engines do, and the input power they require. You can estimate the average output power of each engine from the figure in Problem 5 (L. hand panel), which shows the growth in power output of the best steam-engines over time. When you estimate average power, remember that older models persist; they don't get replaced immediately. In 1800, the fancy new Boulton and Watt engines made up less than half the steam engines in use in England.

You can assume for simplicity that all new steam engines power new economic activities – new mines and mills – and don't displace older uses of power. That means you can assume that all pre-steam-engine activities in A stay constant; just add a new steam contribution. The 1801 census lists 8.3M people in England (likely a slight underestimate).

C. What fractions of England's total power use & work did steam engines represent in 1800?

D. Estimate per capita power use in 1825 (in W/person, both input power and output work).

J.P. Harris has estimated that nearly 25 years later, in 1824, England possessed 5000 steam engines. The 1821 census lists 11M people in England; the 1831 census 13M.

E. What fractions of England's total power use & work did steam engines represent in 1825?

Problem 3: Virtual steam engine field trip

Since we have no opportunity to see a large-scale steam engine in action, take a virtual field trip.

A. **Newcomen engine**
We watched bits of a film about Newcomen 1712 engines in class. Watch some video here and answer questions. First, the film of a replica of Newcomen's 1712 engine, running fully operational: here. The engine noise is so loud that it's difficult to hear the commentary, but you can get a sense of the size, scale, complexity, and basic operation. **What is the stroke rate – how many piston strokes per minute?** Then this video has commentary and explanations about the engine (the Newcomen engine is covered in 1:57 to 4:34). At 3:57-3:53 you see a model of the whole system. **What is the function of each of the vertical pipes on the far right?**

B. **Watt engines.** Continue watching the video above, as the narrator begins to describe a Watt steam engine. This is a bit confusing pedagogically, because the engine they're showing isn't Watt's first (from 1769, 57 years after Newcomen's). Instead it looks like Watt's famous 1788 engine, with 20 more years of technological development improving on Newcomen's design. Also watch this video: From 0.25-0.4 you can see a small square moving; this is shown again 1:44-1:54. In practice a piece of paper would be placed here and a pen placed on the pressure gauge to produce an "indicator diagram", a visualization of the cycle of the piston stroke. We'll discuss this in class in more detail, but try to understand now and **describe what shape would be drawn. What does the x-axis mean? What does the y-axis mean?**

C. *(Optional)* Look at rapid the progression of Watt's engines. You can see Watt's earlier 1777 "Old Bess" engine here. You can compare this also to a video of a 1785 engine.) **What improvements do you see in the late-1780's engines that were not yet present in the 1777 one?**

C. **Early 1800's engines:** Crofton Pumping Station, 1807: this video. Then an 1832 engine built to run a dye factory, now owned by Jay Leno who produces this video. Watch bits and comment on improvements.

D. **Mid-1800's.** As often happens in industry, steam engines got larger and more powerful over time. Watch this video of the great beam engine built to pump sewage up from London's new sewers and dump it in the Thames River. This engine was part of the great public works project to clean up the fetid city. It began operation in 1865, over 150 years after the Newcomen engine, and nearly 100 years after Watt's first engine. (Some of what you see here is in fact part of an upgrade from 1899-1901, so nearly 200 years after Newcomen). Note the elaborate decoration for a sewage pump. Engines were celebrated in Victorian England in a way that we no longer celebrate our energy-conversion technology. The "Prince Consort" engine shown here was operational for 88 years (last run for pumping in 1953) before begin decommissioned. It was restored to operation in 2003. **Discuss what features are retained and what have evolved over time. (*Optional*): discuss why there is a "high pressure" and a "low pressure" cylinder.**

E. **Early 1900's Corliss engine.** A mill engine (not a pumper) with specialized Corliss valves, working from 1903 all the way until 1970. Video here. **Briefly discuss something interesting.**

F. *(Optional)* **Extant working steam engines.** Steam engines in factories have generally been supplanted by electric motors. But you can find a few hanging on, in rice mills in Thailand and Burma, sugar mills in India, one "planing" mill in the U.S. **Why do these particular uses lend themselves to steam power?** *Hint: the steam engine is an "external combustion" engine.*

Problem 4: Physics of the Newcomen engine

The Newcomen engine is called an 'atmospheric engine' because the only net force is that applied is by the atmosphere itself during the engine's downstroke, when atmospheric pressure pushes the piston down. The chain connections cannot transmit any upward force during the upstroke. In this problem set you'll use some data from the 1750 Ashton Dale engine, reported in a 1903 article and shown on the figures below.

Fig. 4. *Newcomen Engine at Ashton Vale Iron Works, Bristol.*

From a Sketch made in September, 1895. Erected about 1746-60. Dismounted 1900.

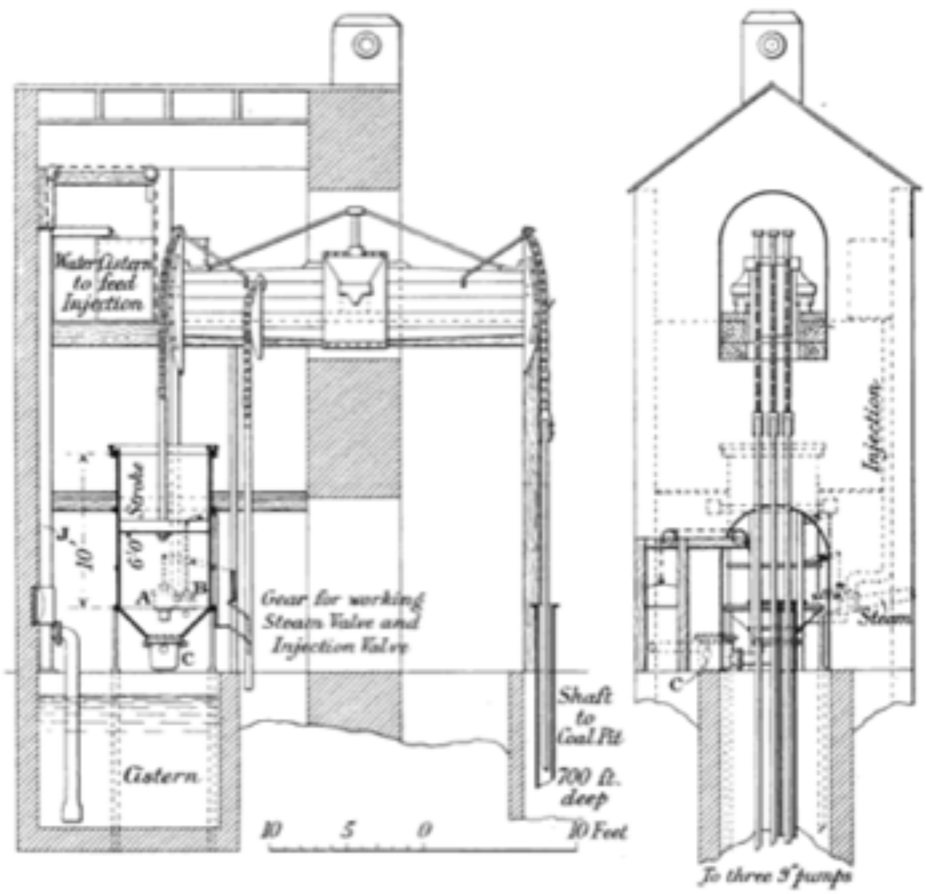
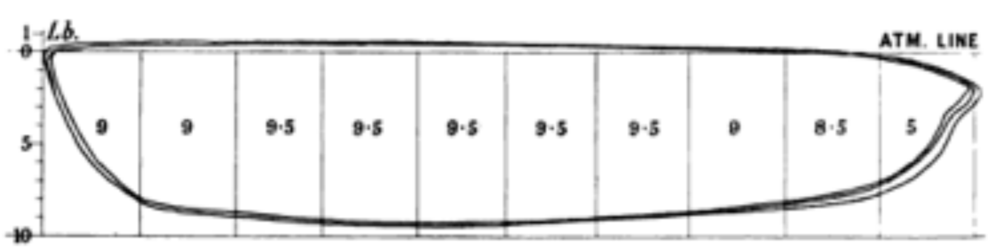


Fig. 5. *Indicator Diagram taken from above Engine, 27th May, 1895.*

Dia. of Cyl. 5' 6"
Stroke 6' 0" about
No. of Strokes per min. 10.

Boiler Pressure 2·3 lbs.
Vacuum Gauge, none fixed.
Time 3 p.m.

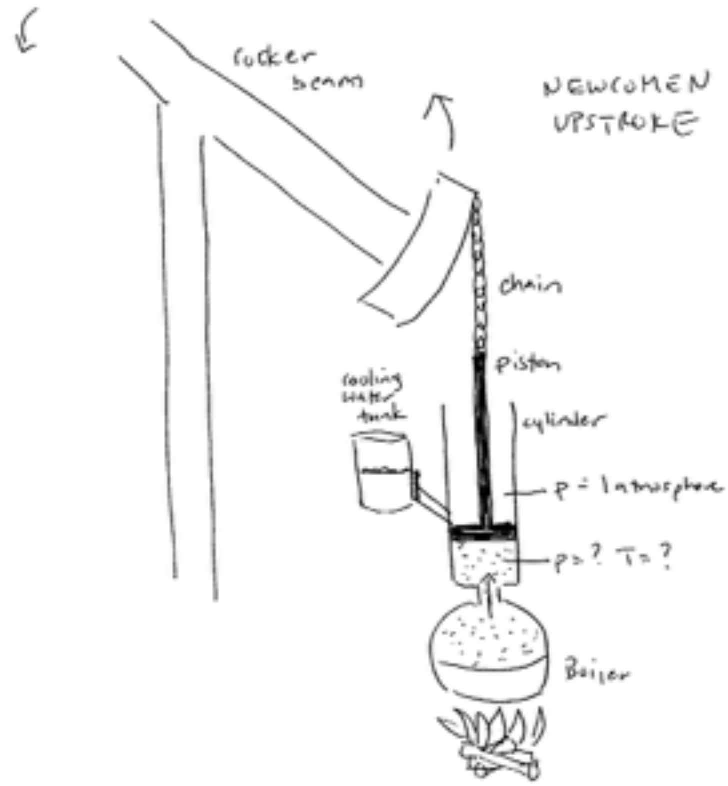


The units of the indicator diagram y axis are given as pounds but what's meant is really pounds per square inch (psi). Atmospheric pressure is 14 psi, or in SI units ~ 10^5 Pascal, where 1 Pascal = 1 kg m/s^2 per m^2)

Consider the different parts of the engine cycle:

Cylinder fill & upstroke

In the first part of the Newcomen engine cycle, the steam valve is opened and the cylinder is allowed to fill with pure steam (no air, or at least minimal air – mostly just water molecules). The piston is drawn upward by the rocking motion of the beam, increasing the volume of the cylinder, and the steam flows in to fill that volume.



A. **What pressure is the steam in the cylinder at, once the valve is opened?** State it based on physical reasoning. (Explain your thinking and consider: what would happen if you tried to increase the pressure in the cylinder?)

B. *(Optional)* **Given your answer in A, what temperature is the steam in the cylinder at? (**in Celsius). We'll call this T_{steam} in the problem. You can likely answer this from common knowledge; if not, consult the reading on steam.

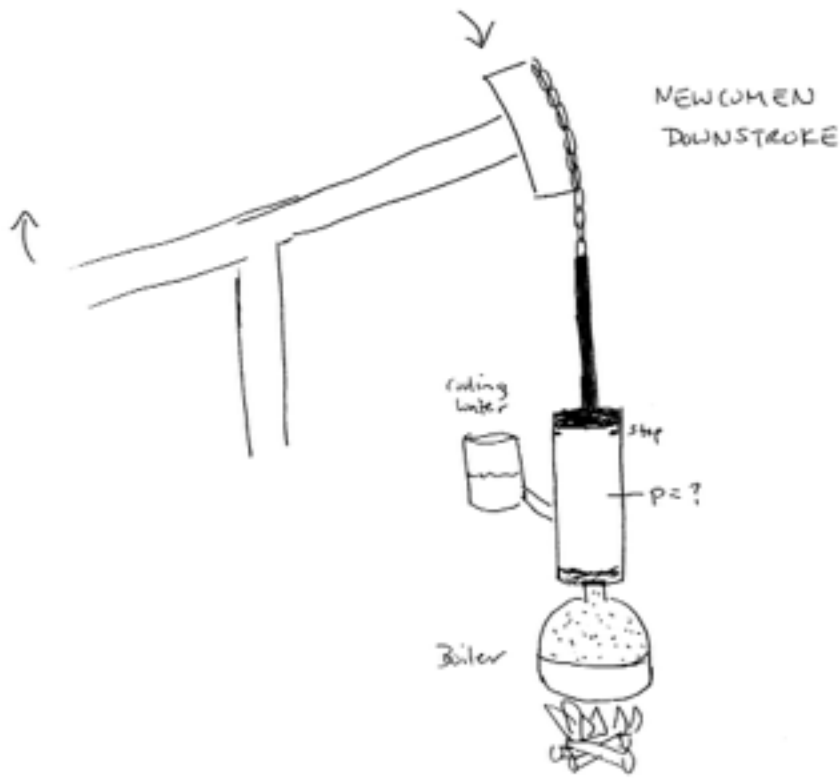
C. *(Optional)* The caption for Figure 5 above states that the boiler pressure is above atmospheric pressure by 2.3 pounds per square inch. **How is this possible?** Explain and discuss. What does this imply about the boiler temperature?

D. Begin to **draw an indicator diagram: show the evolution of pressure and location during the upstroke, as the boiler valve is opened and the cylinder fills with steam while the piston rises.** Then compare to the measured indicator diagram, and clearly mark this part of the engine cycle on it.

E. **If the real indicator diagram conflicts with your intuition, explain the discrepancy.** What real-world issues make the real diagram slightly different from what you predicted?

Condensation and downstroke

In the second half of the Newcomen engine cycle, cool liquid water is injected into the cylinder and the steam condenses. The piston is then pulled down to the bottom of the cylinder.



F. **What would the cylinder pressure be if the cylinder had been filled with pure steam and *all* of it condensed? What would the differential pressure be?** (That is, the net force/area on the piston, in pounds per square inch.) *(Note from the steam reading that it's not possible for ALL the steam to condense; there is always a little water vapor present, but ~98% of it can condense, so we can ignore the residual.)*

G. **Add this part of the cycle to your indicator diagram drawing. Then compare to the measured indicator diagram. What is the actual pressure inside the cylinder during this stage? What is the *net* force/area on the piston?** Clearly mark this part of the cycle on the indicator diagram.

H. **Estimate the work the engine can perform over one stroke, in Joules, both in the ideal case of F and in the actual case of G.** Remember that work is force x change in distance, or, alternatively, pressure (differential) x change in volume.

I. Go back to the Newcomen video linked in the slides and estimate the stroke rate of the engine. Compare to the stated stroke rate of the Ashton Vale engine.

J. **What is the power output of the Ashton Vale engine?** Give your answer in both Watts and horsepower. (*Optional):* estimate the power output of the Newcomen engine in the video too.)

K. Newcomen engines actually lost a lot of energy to friction, and only had mechanical efficiency of ~ 65% (That is, even after very large thermodynamic losses, a further 1/3 of the work that the engine manages to produce is lost to friction). **With this correction, what is the max effective pumping power of this engine, in Watts and horsepower?**

L. **What is the maximum mass of water the engine can pump from the mine per stroke?** The work required to lift a mass is m*g*h, and note that the pump is effectively lifting a column of water that extends from the depth of the mine to the surface - it's not lifting water just for the distance of the piston stroke. If needed, draw a diagram to convince yourself of this.

M. **Why is the diameter (bore) of the lift pump in the diagram so much smaller than the diameter of the cylinder? What would happen if you made the bore of the lift pump much larger? Much smaller?**

N. *(Optional)**:*** **Calculate the maximum bore for the lift pump for this engine. I**s this value consistent with the diagram?

Problem 5: Growth in efficiency of steam engines

Early engineers described the efficiency of pumping engines in terms of "duty", the foot-pounds of lifting work achieved for each bushel of coal burnt. (Remember that a pound in English units is both a unit of mass and of force - a pound-force is the force that gravity at the Earth's surface exerts on one pound-mass. A "foot-pound" is the energy required to lift one pound mass a height of one foot against gravity at the Earth's surface.)

The duty of the Ashton Dale engine was not recorded, but Smeaton made a survey of Newcomen engines in 1769: "Smeaton computed the duty of fifteen engines in the Newcastle-on-Tyne district, and found the average duty to be 5.59 millions of foot-pounds per bushel or 84 pounds of coal"

A. **What is the "duty" value for a hypothetical perfectly efficient engine?** (one in which all chemical energy in the coal was transformed into mechanical work). Smeaton estimated that one bushel of coal was 84 pounds. You can assume a coal energy density of about 30 MJ/kg.

B. *(Optional)* **Check Smeaton's estimate of the mass of a bushel of coal.** A British bushel is 8 (imperial) gallons, and each (imperial) gallon is 4.5 liters. The mass density of coal can vary by x2, but the most common type, "bituminous", has a density close to that of water.

C. **What is the efficiency of the Newcomen engines Smeaton describes**? That is, convert the numbers Smeaton gives for duty to a dimensionless efficiency.

D. *(Optional)* If Newcomen engines were being sold, then presumably they must allow more coal to be mined than it takes to run the engine in the first place. If this weren't true, no one would buy the engines. You can make a quick check of this with some crude assumptions. It's hard to relate the volume of water pumped to the volume of coal extracted, but you can try assuming a 1:1 relationship. (Same volume of coal extracted as water pumped). With this assumption, and ignoring other energy requirements for mining, **what is the "energy return on energy investment" of pumping?** That is, what's the ratio of coal extracted to coal used to power the pump? You can assume the efficiency from Smeaton and the shaft depth at Ashton Vale. This might sound complicated but it is actually a very trivial problem if you stay in English units: the units of duty can be very helpful!

The article from which the Ashton Vale diagrams were taken (Henry Davey, “The Newcomen Engine”, Practical Engineer and Engineer’s Gazette, p. 415, Oct. 1903) describes continued improvements in engine efficiency over time, reporting:

“1772. Smeaton made improvements in details, not altering the general construction, and succeeded in obtaining a duty of 9.5 millions”
“1776. Watt corresponded with Smeaton, and claimed 21.6 millions duty for his engines. Smeaton, after making experiments with Watt’s engines, laid it down as a general rule that the Watt engines did double the duty of the Newcomen.”

Duty improvements are discussed also in Walter, “The Engine Indicator”:

“The publication of performance tables in the Philosophical Magazine encouraged competition among mine captains; ‘Greatest Duty’ was a source of particular pride amongst these Cornish enginemen, and each vied to be at the head of the list. Consequently, Cornwall saw many of the earliest advances at first hand…”
“In August 1816, the old 45-inch Wheal Chance engine was altered from its original single-cylinder Watt configuration to a two-cylinder Woolf compound, Duty leaping from 25·37 million in July to 44·35 in September.”
“By 1839, the single-cylinder Cornish Engines, working expansively with high- pressure steam, were returning impressive performances: the 80-inch West Julia machine (120·9hp), with a piston stroke of eleven feet, gave a Duty of 73·94 million, and the Consolidated Mines 80-inch Davey engine (159hp) gave 70·35 million. During this period, steam pressures associated with these huge engines had risen from barely above atmospheric level to 30–40 lb/sq.in”.

Similar numbers are reported in a 2004 article (Nuvolari, “Collective invention during the British Industrial Revolution: the case of the Cornish pumping engine”, *Cambridge Journal of Economics*, 2004, figure below):

Fig. 1. Duty of Cornish engines.
Sources: Lean (1839), Pole (1844), Dickinson and Jenkins (1927), Barton (1965).

E. Are the duty values that Davey states consistent with the figure from Nuvolari above? Plot Davey's numbers on this figure.

F. Are the numbers and figure consistent with the argument that Watt's patents stifled innovation?

G. Vaclav Smil gives a longer-term but rougher version of this figure, along with a figure showing the growth in power of engines (below). Plot the power you calculated for the Ashton Vale engine on the appropriate spot on the left panel. Then translate the "duty" for 1772 and 1776 into a % efficiency and plot it on the right panel. Are they consistent?

(Note: The "duty" measured in the historical writings refers to work after losses to friction. Smil's figure below is likely the "thermal efficiency", in which case it refers to work before friction. In that case, to make a fair comparison, before plotting you should increase the duty values you got from the reports above. Ifyou had 30% losses to friction you'd multiply your "duty" numbers by 1.5. On a log plot you'd hardly see the difference, though.)

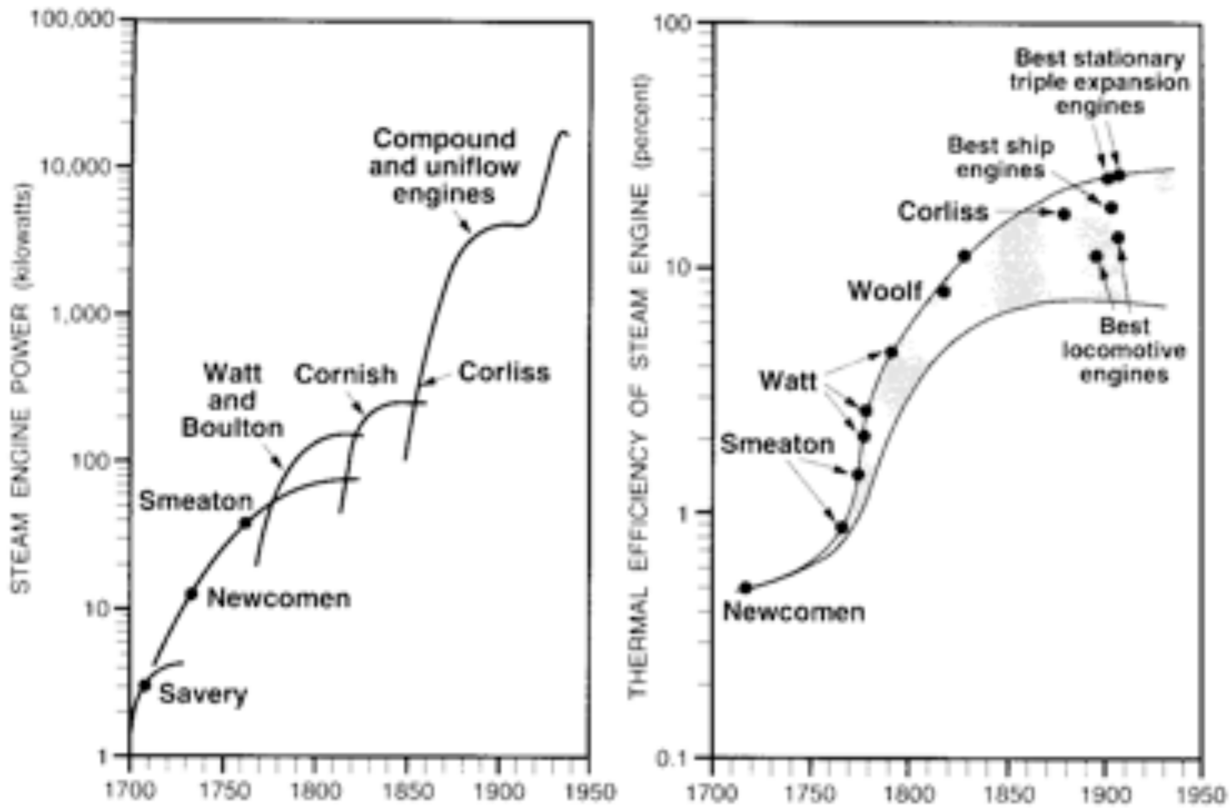


FIGURE 5.3 The rising power and improving efficiency of the best steam engines, 1700–1930. *Sources:* Plotted from data in Dickinson (1939) and von Tunzelmann (1978).

Problem 6: The beginnings of heat-to-work for transportation

In class we saw that the birth of the steam engine came when all the ingredients were present for one idea to set off a revolution. The coal mines had the fuel, the lift pump mechanism, a desperate need for a mechanism that would turn the fuel into work, a population of technically minded potential inventors, and a legal system that would reward innovation. Once stationary engines were adopted for use in mines, there were also all the ingredients to produce the next innovation, using the engines for mobile transport. The mines has working steam engines, technically adept employees used to repairing and improving the engines ('engineers'), and a system of rail transport used for carrying heavy carts filled with coal or ores. The only innovation required was to imagine replacing the horses that pulled the rail cars with steam engines. In this problem set you'll take a 'virtual tour' through the beginnings of the railroad era.

A. Read the beginnings of an 1897 Scientific American article on the history of the locomotive http://www.catskillarchive.com/rrextra/absa3.Html Read the 1st page, but you can skim pages 2-3. (Click on "To be continued" to advance to the next page.) What decade saw the first commercial use of locomotives for passenger transport? Why was there opposition to early locomotives? Discuss the differences you see between early (1830s) and later (1890s) steam locomotives in Figure 5.

B. Watch a 1927 silent film on the evolution of locomotive. The film was shot during an Ohio fair this year; be warned that commentary in the beginning is racist, as is reflective of its time. https://www.youtube.com/watch?v=HrI1tg2Jhrk If you want to see more detail, watch a computer animation of those locomotives here: https://www.youtube.com/watch?v=R41bCinxtuQ In both cases you can skip around. Comment on the changes over time in locomotives. Comment on the attitude towards technology evident in the 1927 narration.

C. For even earlier film, here is a compilation of footage involving locomotives shot by the Edison company between 1897-1906. These short films were shown to paying customers at the very beginnings of moviemaking: https://www.youtube.com/watch?v=EQzXCoQRbas At 6:44 you can see the 999 locomotive, which is currently housed in Hyde Park's Museum of Science and Industry.

D. Watch a longer modern video on the history of the steam locomotive. Watch Part 1 and beginning of Part 2. You can skip the intro of Part 1 and start at 4:15 if you want; watch to at least 3:50 in Part 2.
Part 1 https://www.youtube.com/watch?v=tINxBuHojnQ
Part 2 https://www.youtube.com/watch?v=rpNTw_XdlKs
Describe the "American type" 4-4-0 locomotive. This is the classic icon of the American West. Convert the power of these locomotives (given in horsepower) to kW and plot the starting and ending locomotives on the left panel of the figure in Problem 5.

Optional videos - watch and comment for extra credit

1938 documentary on making of a steam engine
https://www.youtube.com/watch?v=aHIEudnoRYU

1939 documentary on training drivers (skip around)
https://www.youtube.com/watch?v=r66FexPvyPQ