# "I sell here, Sir, what all the world desires to have--POWER."

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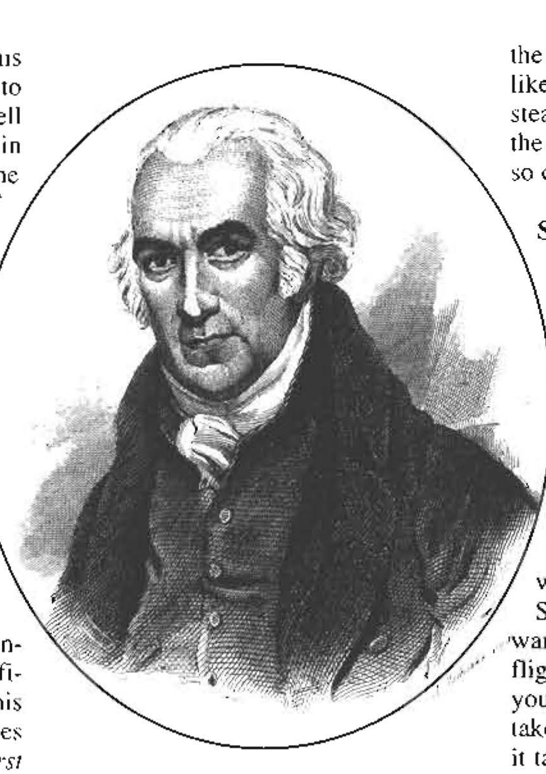
*THE INDUSTRIAL REVOLUTION was part of a larger revolution in human affairs. At the heart of that revolution lay the ancient and only recently rediscovered principle of feedback control. Feedback had a metaphorical meaning that reached beyond flyball governors and boiler float valves. And steam power had a metaphorical meaning that went beyond dirivng machines. Both technologies returned the control of their own lives to common people.*

MATTHEW BOULTON uttered his remarkable *double entendre* to James Boswell when Boswell visited the Boulton-Watt factory in 1776: "I sell here, Sir, what all the world desires to have—POWER." Boulton says a great deal about English thinking on the eve of the Industrial Revolution. For power, in both senses, was becoming the great English obsession.

Steam engines were England's gift to the world. Thomas Savery began it all with his steam *pump* in 1698. Thomas Newcomen followed with his first real steam *engine* in 1711. When Watt patented *his* first engine in 1769, steam engines had been around for seventy years. Almost 600 had been built.

Watt's invention of the external condenser immediately doubled the efficiency of steam engines. By 1784, his improvements had made steam engines four times more efficient. Watt's *first* engines only put out about 6 horsepower, not much more than the first Newcomen engines, but they were smaller and, in less than 20 years, Watt had increased the output to as much as 190 horsepower. In those days, a 190-horsepower engine would, by no means, fit under the hood of a car, as it might today. Those early engines were huge. The cylinders of the old Newcomen engines were from 2 to 10 feet in diameter. A Newcomen engine was a two-story structure. Watt's engines were more compact, but their cylinders were still 1-1/2 to 5 feet in diameter.



**James Watt (1736-1819)**

Yet, good as Watt's engines were, Kanefsky and Robey point out that they had not become the basis of English production by 1800. Just over 2000 steam engines had been built in England by the turn of the century; and, even now, fewer than 500 of *them* were the fine new Watt engines. Those machines never *were* a main source of power during the 18th century. *Most* power still came from water wheels and windmills. At best, the new steam engine works were only giving us a few hundred new horsepower per year by 1800. But two things *were* happening: steam had picked up those specialized tasks that were absolutely essential for the Industrial Revolution to take place, like pumping water out of mines. And steam was positioning itself to power the *really* heavy industries that would so change 19th-century life.

**Steam by 1800**

By 1800, the total installed capacity of all the steam engines ever built was about the same as one of our larger stationary diesel engines today. Most of the English countryside was still the bucolic world that Oliver Goldsmith wrote about. If you are to have any real hope of understanding what those engines meant, you have to understand what power really is–what the word horsepower *means*.

So I ask you to do an experiment. I want each one of you to run up several flights of stairs as *fast* as you can. Use your watch to measure how long it takes. Say you run up three flights, and it takes you 20 seconds. Now multiply the height of the stairs by your weight. If you weigh 150 pounds and the three flights go up 40 feet, then you have done 6,000 foot-pounds of work in 20 seconds. That is *300* foot-pounds a second. A horsepower is *550* foot-pounds a second, so you have generated just over half a horsepower.

Let me say that again. Multiply your weight by the number of feet you climb. Then divide by the time it takes you, and also divide by the number 550. You will get the horsepower output of your own body.

If you are in good shape, you can generate a *whole* horsepower in a short burst like that. But what if you climb all day? Can you climb a 6000 foot

### The Meaning of Horsepower

$$\text{Horsepower} = \frac{\text{(your weight in lb) (the height in feet you lift yourself)}}{\text{(the time in seconds that it takes you) (550)}}$$

Power in Watts = (746) (power in Horsepower)

| Power Supply | Power Output, HP |
|---|---|
| A laborer working all day | 0.05 |
| The cyclist who spent 4 hours flying the human-powered airplane, *Daedalus*, 74 miles | 0.25 |
| A farm horse working all day | 0.30 |
| A medieval water wheel | 3 |
| A medieval wind mill | 5 |
| An early 18th century steam engine | 12 |
| The largest 20th century steam power plants | 3,500,000 |

mountain in 8 hours? That's only about thirty foot-pounds a second–about a *twentieth* of a horsepower. This gets interesting when you compare *your* power with the machines that serve you. Suppose human *beings* had to power the generator that supplies a 150-Watt light bulb. It would take 15 people, doing five-man, eight-hour shifts, to keep that light burning. An automobile engine that generates 100 horsepower does the work of 2000 people. But when those people have to rest at the end of eight hours, the automobile keeps right on going. If everyone in America worked like a galley slave, they would barely generate enough electricity to power a small city.

The engines of our ingenuity are big and powerful, and we're no match for them. We have become absolutely dependent on huge supplies of power. Now, of course, the very magnitude of our power plants poses a real and present danger to our well-being.

A pre-Watt steam engine produced a few hundred times as much power as you can. A big modern power plant can produce a hundred million times as much power. So run up the stairs. Measure your own power output. Learn what a horsepower really *feels* like. Take a long close look at the enormous gulf between us and our machines. It is the only way to know what *really* happened to us at the close of the 18th century.

I personally get my best view of the eighteenth century by looking back upon it from the very early nineteenth century. And the handbook writer, the Rev. Dionysius Lardner, gives us one of those back windows to look through. Lardner wrote a famous handbook in 1827: *The Steam Engine Familiarly Explained and Illustrated.* That was 58 years after Watt's first patent. The book includes everything from a history of the steam engine to rules for railway investment speculators.

"In a [recent] report," Lardner writes, "it was announced that a steam engine ... in Cornwall, had raised 125 millions of pounds, 1-foot high, with a bushel of coals .... The great pyramid of Egypt [weighs 13 billion] lbs. To construct it cost the labour of 100,000 men for 20 years. [Today it could] be raised ... by the combustion of 479 tons of coals."

He goes on to write, "The enormous consumption of coals in the arts and manufactures, and in steam navigation, has excited the fears of ... exhaustion of our mines. These apprehensions, however, may be allayed by the assurance [of] the highest mining and geological authorities, that the coal fields of Northumberland and Durham alone are sufficient to supply [the present demand] for 1700 years, and ... the great coal basin of South Wales will ... supply the same demand for 2000 years longer."

Those reserves do little today to satisfy England's energy needs. Is Lardner's failure to recognize our constant craving for *more*, familiar? Well, so is what comes next: " ... in speculations like these, the ... progress of improvement and discovery ought not to be overlooked. ... Philosophy already directs her finger at sources of inexhaustible power. ... We are on the eve of mechanical discoveries still greater than any which have yet appeared." Lardner certainly underestimated our appetites. But, I suppose, he was right in perceiving the terrifying fact that human ingenuity will do more than we dare dream to meet frivolous wants as well as real needs.

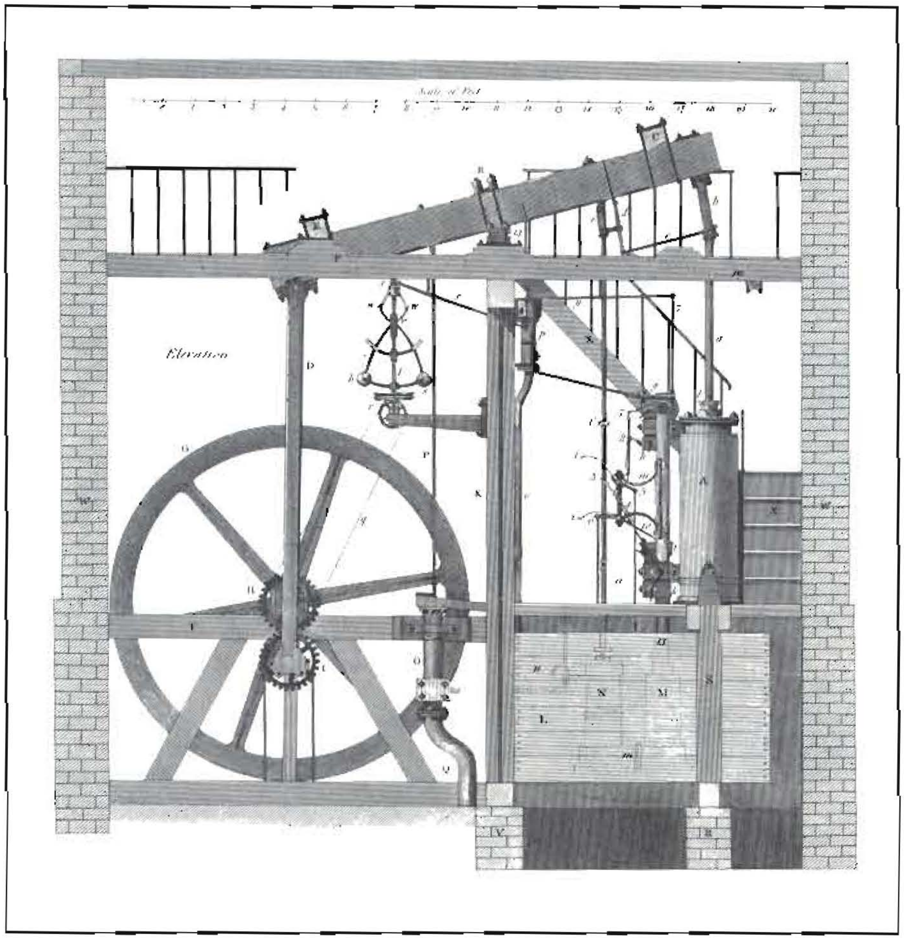
All this was a curiously English phenomenon. The energy crisis that Lardner shrugged off so easily in 1827 had become acute back in 1698. Miners had taken the coal out, all the way down to the water table. Without effective power sources to drive bailing pumps, they could go no further.

Thomas Savery pointed the way with his awkward steam pump in 1698. It looked like two huge wine flasks, side by side. You alternately filled each one with high pressure steam, driving water out and up a delivery pipe. Then you condensed the steam, sucking water up from a sump below. And you repeated the process. The aristocrat, Savery, called his machine the *Miner's Friend.* But it was a treacherous friend. Those great flasks were made of soldered copper held together with steel bands. That was no technology for holding steam at 100 psi. The flasks would blow up. Savery's pump found limited use.

By 1711, the Devon blacksmith, Thomas Newcomen, worked out the kinks in a new steam power system. He built a large cylinder with a piston in it. He filled the cylinder with steam at atmospheric pressure; then he squirted in cold water. The steam condensed, forming a vacuum and sucking the piston downward in a working stroke. No more need for a not-yet-existent pressure containment technology. Newcomen finally gave us effective practical means for getting at those huge inaccessible reserves of coal, those reserves that so filled Lardner with confidence a century later.

### France and Mme. Pompadour

In France, things went in a very different direction. Maybe we can get the flavor of it if I tell you a story. Around 1750, Louis XV's mistress, Madam Pompadour, wanted a water supply for



**A Boulton-Watt steam engine after 1789.**
Plate III. in *The Cyclopaedia, or, Universal Dictionary of Arts, Sciences, and Literature* Philadelphia, [*ca*.] 1825

her chateau at Crécy. The job of providing it fell to the noted French mathematician, Antoine de Parcieux.

Why a mathematician? Well, eighteenth-century rationalism was just catching up with the medieval water wheel by 1750. Power-producing water wheels had taken many forms, but the field had narrowed to two types by 1750, overshot and undershot wheels. The *velocity* of a stream directed beneath an *under*shot wheel forces it to turn. A stream enters *above* an *over*shot wheel. Then the weight of water falling through its blades forces the wheel to turn.

The question, "Which wheel gives the most power?" was, for de Parcieux, a fascinating Rationalist conundrum. He correctly saw that the overshot wheel would produce more power for the pumps at Crécy, but his calculations were in error and his experiments were crude. Isaac Newton had provided the intellectual apparatus for analyzing the water wheel in 1687, and the people who undertook to do these analyses, Euler, Bernoulli, and finally Leibnitz, form a roll-call of the great mathematicians and scientists in the middle eighteenth century. But it was the towering figure of the engineer, John Smeaton, who put de Parcieux's question to rest. Smeaton was the prototype of the 18th-century engineer. He designed the first *successful* Eddystone Lighthouse. He designed windmills.

### The Overshot Wheel

In 1754, Smeaton ran a systematic set of scientific experiments that made it clear the overshot wheel was better. About the same time, Euler's son, Johann, came to the same conclusion using a correct analysis. This was just 15 years before Watt patented a superior steam engine in 1769. It has been argued that Smeaton slowed the spread of steam power with his fine work on the water wheel. Well, if he did, it was like slowing a Sherman tank with a cardboard barricade.

Besides, Smeaton himself also analyzed Newcomen's steam engine. Then he greatly improved *its* performance as well. Out of his work came a version of the Newcomen engine that we call the Cornish Pump. By the late 1700's, the huge walking beam Cornish Pump was all over the mining regions of Southwest England. In 1791, Erasmus Darwin, poet and friend of James Watt, wrote about one:

> Press'd by the ponderous air the Piston falls
> Resistless, sliding through its iron walls;
> Quick moves the balanced beam, of giant-birth,
> Wields his large limbs, and nodding shakes the earth.

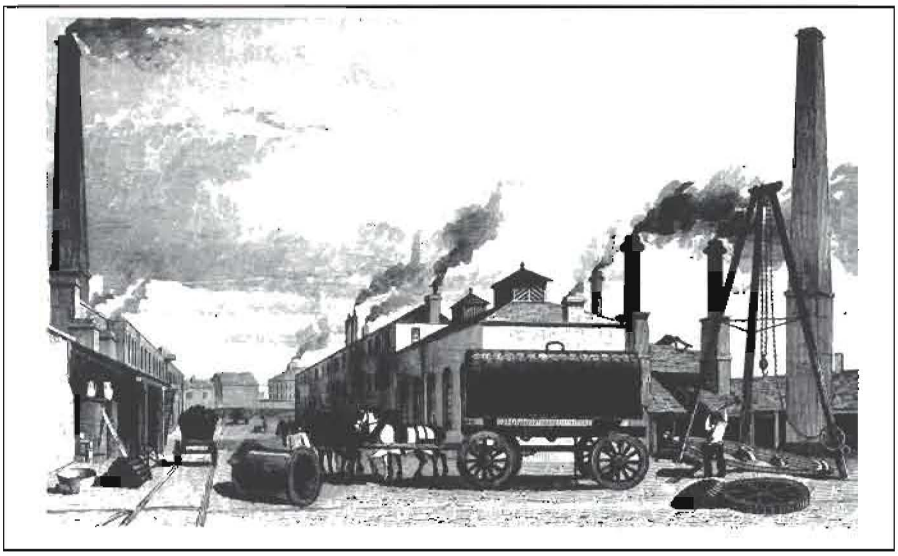
("The Economy of Vegetation," Canto I, ll. 259-62, in *The Botanic Garden*, 1791, *the possessive pronoun* it's *normalized.*)

The design of the Cornish Pump was robust. It was the natural machine to follow mining into the American West. Otis Young shows us a photo of one in Tombstone, Arizona, taken in the 1890's. We see a great iron beam, three stories high, driving a rod down, into the earth, powering stage after stage of pumps, hundreds of feet below. It empties tons of water a minute. It is a machine from before 1769, frozen in time.

For a while, those steam engines simply eclipsed water power. European theoreticians *had* set down a body of hydro-power theory. That theory re-emerged in the 1820s and '30s when France finally gave us the modern power-producing water-turbine. So the next time you visit Grand Coulee or Hoover Dam, try not to think about King Louis XV indulging Madam Pompadour with running water for their love-nest.

### French Royal Glass Works

Now, meet another mid-18th-century French technologist. While de Parcieux was analyzing water wheels for that summer pleasure-dome, a young man named Delaunay Deslandes joined the French Royal Glass Works. Deslandes did well there. In six years, he became the general manager and he held that job for 31 years. When he died, he left a manuscript *On the History of Glass Making*. It was more a memoir than a history. It showed what was happening in one French fac-



**Boulton's steam-engine manufactory and iron works.**
*Plate inscribed to Messrs. Rothwell, Hick & Co., drawn by Harwood, engraved by Watkins, published by Fisher Son & Co., London*

tory during the English Industrial Revolution. It is clear from the book that Deslandes found a real vocation in his work. He took great pride in it. It filled him up.

French plate glass was the best flat glass in the world when Deslandes was young, far superior to the crown glass and broad glass made in other countries. The French cast large plates in very hot molten glass. Then they rolled them out and ground them into high-quality panes for windows and mirrors.

Deslandes tried to learn what the English already knew about the chemistry of coal burning. You need very clean, intense heat to make plate glass. The English had perfected fine coking processes for their production of iron and steel. But *English* industrialists like Watt and Wedgewood had created seminars with the great scientists of their day. People like Deslandes were kept apart from *French* intellectuals. They did not have the same *means* for keeping up. By the end of the Industrial Revolution, France had lost its ascendancy, *even* in glass-making.

Deslandes' ideas about labor and management were progressive. He instituted workers' benefits. He knew that his product depended on his workers' pride and independent craftsmanship. If you looked carefully, you saw benevolent paternalism. But Deslandes was always there in the thick of things, not managing from a distant estate. Every time glass was poured, he arrived in full formal dress to observe, to make ceremony of the act.

He retired to a house near the factory. When he was 82, a bitter cold front threatened a company water-wheel with icing. He joined the workman fixing it. And there he died of exposure. The company that had *been* his life, finally *claimed* his life. Now, if so good and honorable a man as Deslandes represented France, then what did France lack that England had? The answer—Deslandes sustained an old order, shaded from the new winds of science and individualism. It took more than good masters to survive 18th-century revolution. It took people and institutions that could ride the tidal wave of revolution and use it to remake the world.

### The High Price of War

From Deslandes' old age until Napoleon went down at Waterloo, France put almost 30 years of its energy into strife. Revolution, and then war, had cost her dearly. Her roads, bridges, and merchant navy were in shambles. She had done little to keep abreast of the English Industrial Revolution. Her economy was stagnant. I said earlier that my best view of the eighteenth century is a backward glance from the early nineteenth century. Well now, as the smoke cleared, the extent of the *damage* also became clear.

Bradley and Perin tell about a young French naval engineer, Charles Dupin, who saw a chance to do his country *and* his career some good. He would go to England and study her secrets. France had been doing *that* even *before* the Revolution. In 1786 a French observer had said that English workers were, "haughty, quarrelsome, risk takers … easy to suborn. When a new machine produces gain … the French government can always be master of it in six months for a small outlay."

Of course, thinking like that had condemned France to a tag-along role in the *first* place. Now she had no choice. If France was to start over, she had to begin in England. Charles Dupin was upper crust. He had typical French training in math and physics. He had learned almost nothing of practical use. He was hardly kin to the "quarrelsome risk takers" who had built English industrial greatness, but he was not stupid.

### Educating the Working Class

In 1816, Dupin set out on his first information gathering raid into England. You catch the young man's arrogance in his reports. He sneers at the English when he can. But you also see a powerful gift for observation. He tells of steam dredges and harbor works. He writes about new processes. Most importantly, he sees the breakdown of class separation. He sees England educating her working class. In the end, Dupin returned to France to claim the political advantage he had gained by his visits. But now, as a member of the Chamber of Deputies, he did not forget what he had learned. Dupin became a champion of practical education. He set up free schooling for workers. He fought tirelessly for industrial reform. He became an important agent for France's industrial recovery in the 19th century.

Another young French aristocrat gives us a similar window into the 18th century. He was François Arago, born on the eve of the French Revolution. Arago trained at the École Polytechnique, Napoleon's great think tank. When he was only 23, the École made him a professor of mathematics. He did basic work in optics and electricity. He helped to prove that light moves in waves. He measured the speed of sound in ice. He worked on the polarization of light. His electrical work anticipated Faraday.

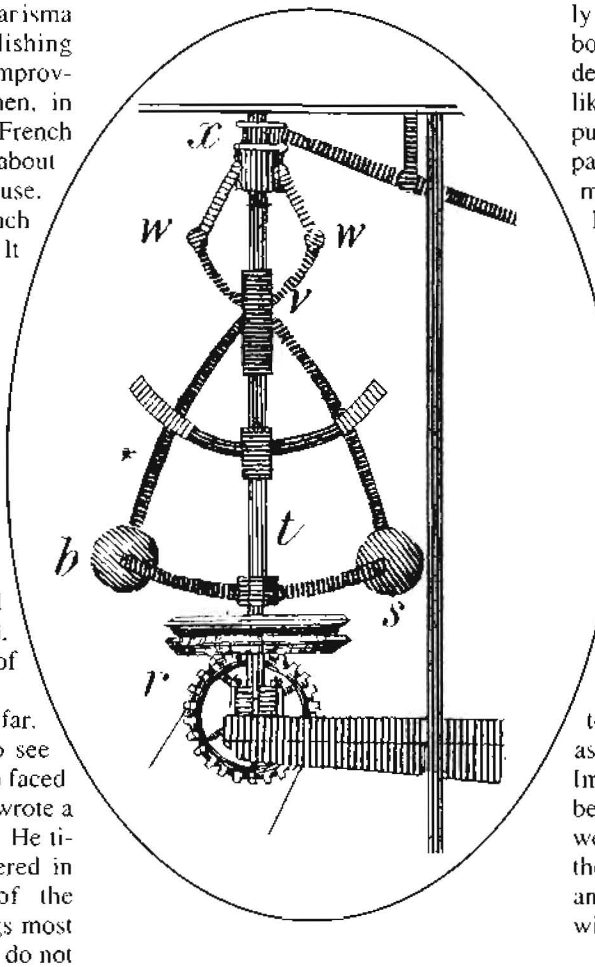
But Arago looked beyond all that science toward its *use*. His work on electricity found use in telegraph systems. He took part in the study of steam boiler explosions. In his mid-40s, he took up politics. His verve and charisma won liberal causes, like abolishing slavery in French colonies and improving conditions for sailors. Then, in 1834, Arago rose to address the French Academy of Sciences. He was about to take on a another radical cause. This lecture was one the French Academy was not ready for. It was about James Watt.

### Arago on Watt

Arago began by acknowledging two French thinkers who had the *idea* of a steam engine. But, he said, it took the *English* to put flesh and blood on the idea. The English built the actual engines. And the only science that had helped *them* was the science of their own shrewd observations. *And*, he added, those engines improved the life of the poor.

With that he had gone too far. French intellectuals preferred to see English machines as evil. Arago faced an angry outcry. Soon after, he wrote a second paper to defend himself. He titled it, "On Machinery Considered in Relation to the Prosperity of the Working Classes." It says things most of *us* take for granted: Machines do not steal jobs, they create them. Machines make goods affordable to the poor. And so on.

Arago celebrated the humanitarian impulse that drove people like James Watt in the *first* place. Watt really *had* created machines in the interests of the common people of whom he was one.




**Watt's Flyball Governor–shifting the control of power.**

From Plate III, the *Cyclopaedia*

### The Flyball Governor

I have been drifting from the mechanical power side of Boswell's *double entendre* into the political power side. The two are *certainly* inter-related. If means for large-scale power production was one thing that grew out of the eighteenth century, means for controlling that power was another. Perhaps the most dramatic element on Watt's engine was an item that he hid from view at first. It was his *flyball governor*.

Three questions here:

- What is a flyball governor?
- Why was it so important? and,
- Why had he hid it from view?

First understand why this gadget was so important.

Feedback control—mechanisms that sense a discrepancy and correct it —are absolutely shot through our world today. Feedback is *everywhere*. We hardly go through an hour of any day without using feedback devices, the float valves in our toilets, the thermostats in our rooms, the pressure control valves, and carburetion electronics in our automobiles.

This remarkable and ubiquitous part of our life was almost non-existent in 1700. Yet feedback had made its first appearance in Hellenistic North Africa—in that stunning age of invention and experimentation. Euclid and Archimedes worked in Alexandria. So did *engineers* like Philon, Ktsebios and Heron. Those engineers were *artists* who worked for wealthy patrons. Their work was intellectual play. They used it to dazzle and to entertain.

For example, reflect upon a banquet in about 100 B.C. A large bowl of wine sits on a center table with a spigot above it. We guests dip wine from the bowl. As the level drops, wine suddenly flows from the spigot to refill the bowl. It is an amazing sight. Inside the device, hidden from view is something like a ball-and-cock float-valve. It is pure feedback control. It senses, compares, and corrects the liquid level. It makes the correction by *itself* without human intervention.

This sort of thing was common in the Hellenistic world. One of the first feedback devices was the water-clock flow regulator. The 3rd-century engineer Ktsebios made the ancient water-clock into an accurate time-keeper by inventing a float stopper to regulate a constant flow of water into the indicator tank.

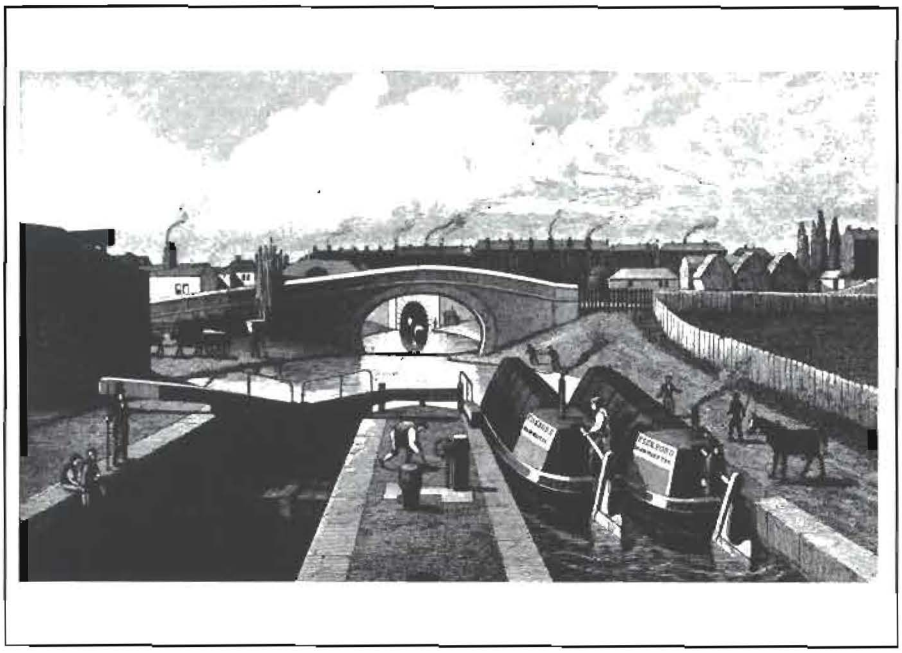
### Feedback and Freedom

Consider something about feedback, about the self-regulation of machines. When we let go of the knob, we relinquish control. For the totalitarian mind that is about as easy as doing a back dive off the high board. Imperial Rome gobbled Egypt up just before the birth of Christ. The Romans were great *users* of technology. But they did not contribute many new ideas, and they certainly did nothing more with the feedback concept.

Arab scholars and artisans kept the water clock alive, but they *also* ignored the feedback concept that regulated it. For 1300 years, the water-clock was the only vestige of the feedback concept in a totalitarian world. And in all that time, *neither the Romans, nor the Arabs, nor anyone else, had invented one new feedback device.* With the feedback-controlled water clock squarely in front of them, with scholars reading and copying Hellenistic literature, with all the access in the world to this wonderful idea, no new feedback device came into being for almost two millennia after the birth of Christ.

We could have made all sorts of devices with available technology–flow control, thermal regulation, windmill orientation, *etc.* These things were within grasp. Why did we not do anything with them?

Authoritarian thinking really *does* have trouble with feedback. It is antithetical to minds that want to write rules and see them obeyed. Feedback had come into being in a golden age of intellectual freedom. By 1300, the water-clock was all that remained of that inventive outpouring. Then, a new invention, with a whole new character,



**The double lock & east entrance to the Islington Tunnel, Regent's Canal.**
*Plate inscribed to Col. Drinkwater, drawn by Thomas H. Shepherd, engraved by F. J. Havell; published Aug. 25, 1827, by Jones & Co., 3 Acton Place, England Road, London.*

replaced it. The *mechanical* clock had no feedback features whatsoever. Its accuracy depended *entirely* on getting everything absolutely right at the start.

**Clockwork and Creation**

The orderly mechanical clock diverted the medieval imagination. Clockwork, with its wheels and gears, became the new metaphor for God's creation. God had ordered the planets just like clock-work, they said. He wound them up and set them in motion. So the last vestige of self-regulation evaporated. We embraced the concept of clockwork, and by the year 1700 we had stretched *that* concept to its limit.

Isaac Newton, who wrote down the physics of planetary motions, still thought that minor disturbances, by meteorites, for example, would destabilize planetary orbits. Newton did not catch on to the fact that orbits are stable. He believed that God, the heavenly clock-*maker*, had to intervene from time to time to readjust His machine.

The French Kings, the Louis's, did not reflect that view only in their fetish for elaborate clocks and clockwork toys. Their mercantile economic system reflected a clock-like concept of economic control. Of course, mercantilism slowly drove an over-regulated populace into revolution. The most important manifestation was the growing realization in England that *technology* could free the working classes. It would make it possible for the people who *made* goods to *own* those goods. That violated the clockwork mercantile equation. And sure enough, it is here in this gathering revolution that feedback suddenly welled up for the second time.

The revolution began among dissident Protestant English tradesmen. First, they built a network of canals. They began producing and moving goods about, far from London and away from central government control. Their revolution was quiet and thorough. Commoners laid hold of invention. After the blacksmith Newcomen invented the first steam engine, the game began in earnest.

We are surprised when we find intellectual and industrial giants like Josiah Wedgewood, Matthew Boulton, Erasmus Darwin, Joseph Priestly, James Watt, and William Herschel meeting in a revolutionary cell-group called the *Lunar Society*. They talked about science, technology, and social issues.

Joseph Bronowski said of the Lunar society, "What ran through it was a simple faith: The good life is *more* than material decency, but the good life must be *based on* material decency."

And so the float valve was the first feedback device to reappear in widespread use. It turned up as a water-level controller in the new steam boilers. These were mostly ball-and-cock float regulators. Those were soon followed by the first flush toilets with level controllers in their supply tanks.

Feedback played counterpoint to the brewing Industrial Revolution. It rode in on new claims to freedom. And our journey finally brings us to the Edinburgh and Glasgow locus. David Hume, James Watt, and Adam Smith were all heavily involved with exploiting feedback and their lives were interwoven.

Watt produced one of the first really *modern* controllers in 1789. His flyball governor was pure feedback of a very sophisticated form. The power-demands on any steam engine vary as users want more or less power. If you reduce the load without changing the steam supply, the engine speeds up until it is going too fast to use steam efficiently.

Watt solved that problem by spinning the governor with a belt from the flywheel. When the flywheel sped up, so did the governor. The inertia of the flyballs swung the arms outward driving a mechanism that closed down the steam supply valve. It was a combination of form and function that is pure poetry in motion. It was the feedback principle in its *purest* form.

The flyball arrangement had already been used in the late English windmills which had become an extremely high technology. The feedback-control fantail constantly wheeled their turrets around to keep them facing into the wind. Flyballs were used to adjust the pressure on the millstones. Otto Mayr explains that those flyballs were not true feedback devices. They did not sense an error and correct it to a desired value the way the float in your toilet tank senses the water level and adjusts it.

Watt knew about the flyballs in windmills and he wanted to avoid a patent fight. That is why he hid his governors from sight when, in fact, he had gone a huge step beyond the windmill flyball.

**Feedback in the Economy**

Now, let us look at Edinburgh's most famous feedback process, another even more startling application of the idea. David Hume applied the feedback idea in a remarkable and *completely* new way in 1752. Hume laid out a theory of self-regulation of the international money market. He said, "if the price level in a nation is lower than its neighbors, its exports will rise." That will bring in more money but it will also cause price levels to rise. Then the export of goods will drop, etc. That was a pure feedback description of the economy.

Hume's friend, Adam Smith *really* developed that kind of thinking a few years later with his feedback *Laissez Faire* economic model. Of course, *laissez faire* translates to something like "Let nature take its course" or *"Let things manage themselves."* Smith published his definitive challenge to Mercantilism, his *Wealth of Nations*, in 1776. It was *very* radical thinking. It was not only pure feedback. It was pure *revolution* as well.

**The Constitution as Feedback**

Smith's ideas now entered a world that was ready to think in these terms again. So, after 1800 years, the legacy of those brilliant North African engineers had finally born its fruit. The feedback concept was right at the *heart* of eighteenth-century revolution. The Alexandrian concept of *self-correction* is what democracy is all about. The language of the idea is shot through the American Constitution, which was developed at the same time as Watt's engine. The "checks and balances" that we prize so highly are the safety valves of a constitutional system. They are one more example of *pure* feedback control.

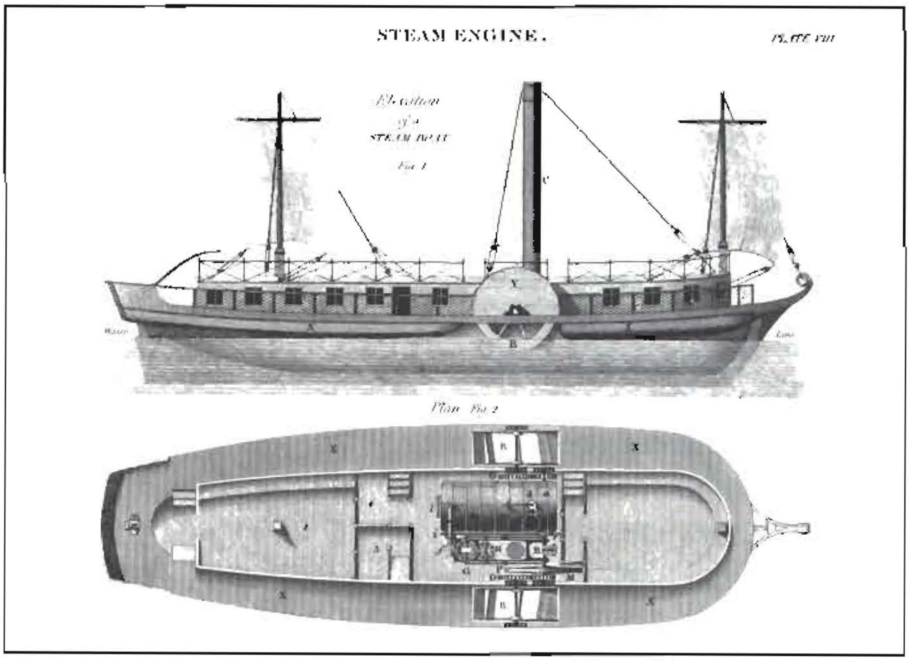
We took power away from princes and other leaders. We gave power over to a feedback controller, to our Constitution. We set up the machinery by which we could regulate ourselves. Today we are surrounded by feedback controllers. We wonder how we ever could have thought differently! Yet we did.

Today we are surprised that Newton saw God routinely interrupting the execution of His own laws to keep His creation running. But 18th-century rationalists saw God, not only as a clock-*maker*. They saw him as the Great Clock-*winder*, as well. To understand that concept, we must understand that our technology mirrors our world view. It defines what we are.

The mechanical clock was powerfully expressive of our *cultural* center of gravity for a long time. Today, the idea of the control valve is far more deeply subsumed into our language and our being than most of us realize. Our technology, of which our art and our machinery are both part, flows from some point deep within us. It is more powerful than kings and emperors. Ruskin said that "great nations write their biographies in three manuscripts, the book of their deeds, the book of their words, and the book of their art, and of the three the only trustworthy one is the last."

So we try to read the book of 18th-century art and technology. The people who ultimately create a civilization are not its leaders and its warriors. Civilizations are made by the people who actually have their *hands* on pencils, lathes, computers, chisels, oboes, and test tubes.

Matthew Boulton was doing more than making a witty reposte when he told Boswell that he sold "here, Sir, what all the world desires to have — POWER." He really was returning political power to the people when he sold them those great chuffing engines of James Watt's ingenuity.




**Elevation of a Steam Boat.**

Plate VIII, in *The Cyclopaedia; or, Universal Dictionary of Arts, Sciences, and Literature.* Philadelphia, [ca.] 1825.

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