The science of model flying: Energy

The word energy is derived from the ancient Greek word ἐνέργεια (pronounced energeia), meaning activity. It was probably used first by Aristotle around the fourth century BC.

The energy that exists in the universe now is the same as it was just after the big bang. It is just arranged differently. Energy can neither be created not destroyed, just changed from one form to another. That is a fundamental law of physics. It is part of the science of thermodynamics, which literally means ‘heat movement’, though a more general term would be energy movement.

Why does that matter to you as a flyer? You and your models are all part of energy movement. Every breath you take, every time you launch a glider, every material you use when building, every solder joint you make and every time you charge your batteries you are part of energy movement. The outcome has a name. It is called entropy.

Entropy is a measure of complexity. At the start, all of the energy in the universe was concentrated in one place. It was structured very simply. It had zero entropy. As the universe expanded and matter formed the energy became spread out into many different forms. Its complexity increased, let’s call it chaos. Its entropy increased. Its temperature fell.

In the end energy will probably be evenly spread out and entropy will be maximum. The temperature everywhere will be about 6 kelvin (K), which is 6 degrees celsius above absolute zero. Much of the universe is nearly there now. It is called cosmic background radiation and was first measured at 3 K by Penzias and Wilson in 1965. One of the greatest ever examples of serendipity is described in Penzias’ history below. At the very end, when energy is spread evenly, there will be no temperature differences to cause energy to flow so nothing can happen any more. As T. S. Eliot wrote in his poem ‘The Hollow Men’, ‘This is the way the world ends, Not with a bang but a whimper.’

Penzias and Wilson

Arno Penzias (1933 living)
Penzias was born in Munich, Germany, the son of Justine (née Eisenreich) and Karl Penzias, who ran a leather business [lederhosen?]. At age six, he and his brother Gunther were among the Jewish children evacuated to Britain as part of the Kindertransport rescue. Later, his parents also fled Nazi Germany, and the family settled in the Garment District of New York City in 1940. In 1946, Penzias became a naturalised US citiizen.

Penzias went on to work at Bell Labs in New Jersey, where, with Robert Wilson, he worked on ultra-sensitive cryogenic microwave receivers, intended for radio astronomy observations. In 1964, on building their most sensitive huge horn aerial and receiver, (Picture 1) they heard background radio noise that they could not explain. It was far less energetic than the radiation given off by the Milky Way [our galaxy] and it was isoptropic [equal from all directions], so they assumed their instrument was subject to interference by earth-bound sources. The horn proved to be full of bat and pigeon droppings, which Penzias described as "white dielectric material". Removing it made no difference. Having eliminated all sources of interference, Penzias contacted Robert Dicke, who suggested it might be the background radiation predicted by some cosmological theories. The pair agreed with Dicke to publish side-by-side letters in the Astrophysical Journal, with Penzias and Wilson describing their observations and Dicke suggesting the interpretation as the cosmic microwave background radiation (CMB), the radio remnant of the Big Bang. This allowed astronomers to confirm the Big Bang, and to correct many of their previous assumptions about it.

With Wilson he won the 1978 Nobel Prize in Physics for their discovery.

Robert Wilson (1936 living)
Robert Woodrow Wilson was born on January 10, 1936, in Houston, Texas. He studied as an undergraduate at Rice University, also in Houston, and then earned a PhD in physics at California Institute of Technology. He worked at Bell Laboratories until 1994, when he was named a senior scientist at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts.

Wilson was one of the twenty American recipients of the Nobel Prize in Physics to sign a letter addressed to President George W Bush in May 2008, urging him to "reverse the damage done to basic science research in the Fiscal Year 2008 Omnibus Appropriations Bill" by requesting additional emergency funding for various national science institutions. He was elected to the American Philosophical Society in 2009.

Based on articles in wikipedia

Picture 1
From pinterest.com

OK, you'll be dead long before the end of the universe, so you ask again why does it matter? No whimper for you, thanks. And of course we cannot yet be sure how the universe will end, nor even if it will. Some think it will expand for ever. Some think it will collapse back to a point. Now that would be some thermal! More fun than the 'Restaurant At The End Of The Universe' from 'The Hitchhiker's Guide To The Galaxy.' Some even think it is formed from digital data (1 and 0), like a large hologram, where each 1 or 0 represents the existence or not of something as yet undecided. As the universe gets bigger there is a greater number of the 1 and 0 states so it becomes more complicated. If that was true its state just before the big bang would be a single 1.

It is also worth noting that mass and energy are the same thing. When you add energy to something its mass rises, normally just a smidgeon. That is described in Einstein's famous equation $E = m c^2$. E is energy in joules, m is mass in kilograms and c is the velocity of light in ms^{-1}. The value of c is very large (3×10^8 ms^{-1}) so a tiny change in mass involves a vast amount of energy. This is what generates heat in stars and in our nuclear reactors and weapons. When you charge a 2.2 Ah 3S battery from flat its mass goes up by about 10^{-12} kg. Better shift it back a tiny bit to keep the centre of gravity right.

One oddity. Entropy must increase in any energy conversion. Chaos must increase. How then can highly organised things be created where entropy clearly falls, for example a human being or indeed a model glider, both created by structuring atoms from chaotic nature? The answer is that the creation process must produce more chaos than the loss of chaos in the created, organised thing. This is why whenever we make something we make muck, including greenhouse gases and other waste materials, and we increase entropy. And that includes processes that recycle materials, so the human race must learn to make and use less if it is to survive this century, at least until we produce all our energy from the sun or nuclear fusion as sources and learn how to recycle our muck properly. If we don't then the earth will carry on in a rather more watery, acidic and warm state, but we humans won't. Perhaps Thomas Malthus will prove right. Look him up in wikipedia. Maybe it's what happened to Mars. They have found evidence of past water and life there, which might give us an idea of how the earth could end up.

Have you played bricks with a small child? You sit on the floor and pile the bricks into a tower. The child then knocks the tower down and demands that you pile it up again, for ever. This is an excellent model of entropy and of course the joys of parenthood. The pile of bricks is ordered and has low entropy. Knock them over and chaos and entropy increases. Rebuild and entropy drops again, though your muscle activity increases it even more somewhere else. Entropy is one way to see the direction of time. Record the tower game on video and see if there is a way you can play it backwards. If not you can imagine it. The bricks jump up from the jumble on the floor into an ordered state. So you can tell which way time flows by seeing whether entropy falls or rises. A free swinging pendulum is an extreme example. It causes very little increase in entropy on each swing. Put another way the swing only becomes slightly less each time due to energy being lost into the surrounding air. You would have to watch a recording for a long time to see whether it, and time, ran forward or backward.

Types of energy

Potential – gravitational and electrical
Kinetic – linear and rotational
Chemical – chemical bonds and changes in batteries
Heat – internal combustion engines
Electrical - other than chemical
Magnetic – motors and servos
Elastic potential – bungee and rubber motors
Light and other EM waves – navigation lights and radio signals
Sound
Surface energy e.g. surface tension
Nuclear
Ionisation

https://sciencestruck.com/types-of-energy

An impressive list I am sure you'll agree. What's more impressive is that all but the last two are at work in our models. What about sound? Sound is, especially if you have a sound system to imitate engines and other noises of a scale model. And what about the hiss and whistle from a glider when it pulls out level from a fast dive? Surface tension is, if you are trying to take off from smooth water or you wick glues into narrow gaps by capillary action.

Efficiency

Every time energy changes from one form to another some is wasted, meaning not becoming the energy you want. For example when our muscles convert the chemical energy in our blood sugars into work, such as lifting something, about 80% of the energy is turned into heat in the muscles. Only 20% is used for the lift. The heat is not necessarily waste as our 'warm-blooded' mammalian body needs our body temperature to be kept up. That is why we shiver when we are cold. It is making our muscles generate heat.

So if we lift something only a fifth of the energy is turned into the energy we intended. I use that to estimate the power I generate when cycling. I can't justify the cost of power-reading pedals. We describe this as an efficiency of 20%, and give it the Greek letter eta (η).

So efficiency η = useful energy / total energy used
It is always less than 1 (see perpetual motion machines later)
We then multiply it by 100 to turn it into a percentage.

Here are some typical efficiencies as a %

Petrol (gas) engine	25
Automotive diesel engine	45 why you get lower fuel consumption
Gas turbine using kerosene	60
Electricity generation	35 depending on process used
Electricity supply system(UK)	77 though varies a lot world wide (97 - 29 in 2014)
Human muscle	20 though varies a lot with fitness
Electric motor	90
Filament lamp bulb	under 10 and could be much less
Fluorescent lamp bulb	60
Light emitting diode	90
Loudspeaker	around 5
Lightweight road bicycle	95 but remember muscle losses
Electric convector heater	Nearly 100 but note losses in generation and supply
Gas condensing boiler (furnace)	95
Oil condensing boiler	90

The above are typical values I gleaned from a variety of data sources. As a rule of thumb for heat engines the hotter the energy starts out, and the cooler it finishes, the more efficient the engine. That's also why condensing boilers are much more efficient because the flue gas is cooler. The engineer Sadi Carnot wrote the defining equation for what he called an 'Ideal Engine' meaning a 'perfect' one:
Efficiency = (high temperature – low temperature) / high temperature
Temperatures are in kelvin, where absolute zero is zero K (-273 ºC) and each degree is the same size as a celsius one. For water, boiling point is roughly 373 K and freezing point 273 K.

Let's look at a theoretical petrol engine example
Low temp = 300 K (exhaust) which is 27 celsius or 'pretty warm' in fahrenheit
High temp = 1100 K (cylinder)
Efficiency = (1100 – 300) / 1100 = 0.73 or 73%

Wouldn’t that be wonderful? Sadly, practical engines are very much less efficient. However the principle of getting the greatest difference in temperatures applies. The very high combustion temperatures in gas turbines are one reason for their greater efficiencies.

Logically you can see why this is true from kinetic theory. This tells us that heat energy is stored in the kinetic energy of the particles. They stop at absolute zero so all energy will have been extracted. An engine that emits gas at zero kelvin will be 100% efficient.

I am still puzzled why model turbines use up the fuel so quickly though - much quicker than a glow or petrol engine producing similar power. Anyone know why?

Sadi Carnot (1796 - 1832)

Nicolas Léonard Sadi Carnot was born in Paris into a family that was distinguished in both science and politics. He was the first son of Lazare Carnot, who chose his third given name Sadi after the Persian poet Sadi of Shiraz. Lazare was an eminent mathematician, military engineer, and leader of the French Revolutionary Army.

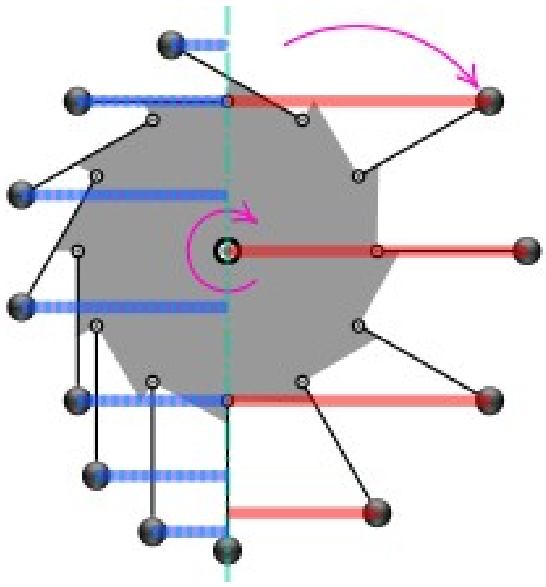
After education at the Ecole Polytechnique in Paris he joined the French Army as a military scientist and physicist and was later described as the "father of thermodynamics." He published only one book, Reflections on the Motive Power of Fire (Paris, 1824), in which he expressed the first successful theory of the maximum efficiency of heat engines and founded the new discipline of thermodynamics. Carnot's work attracted little attention during his lifetime, but it was later used by Rudolf Clausius and Lord Kelvin to formalise the second law of thermodynamics and define the concept of entropy. Based on purely theoretical study, such as improving the performance of the steam engine, Carnot's intellect laid the groundwork for modern heat engines, such as car and gas turbine engines. Carnot retired from the army in 1828. He was locked up in a private asylum in 1832, suffering from "mania" and "general delirum", and he died of cholera shortly after, aged 36, at the hospital in Ivry-sur-Seine.

Based on an article in wikipedia

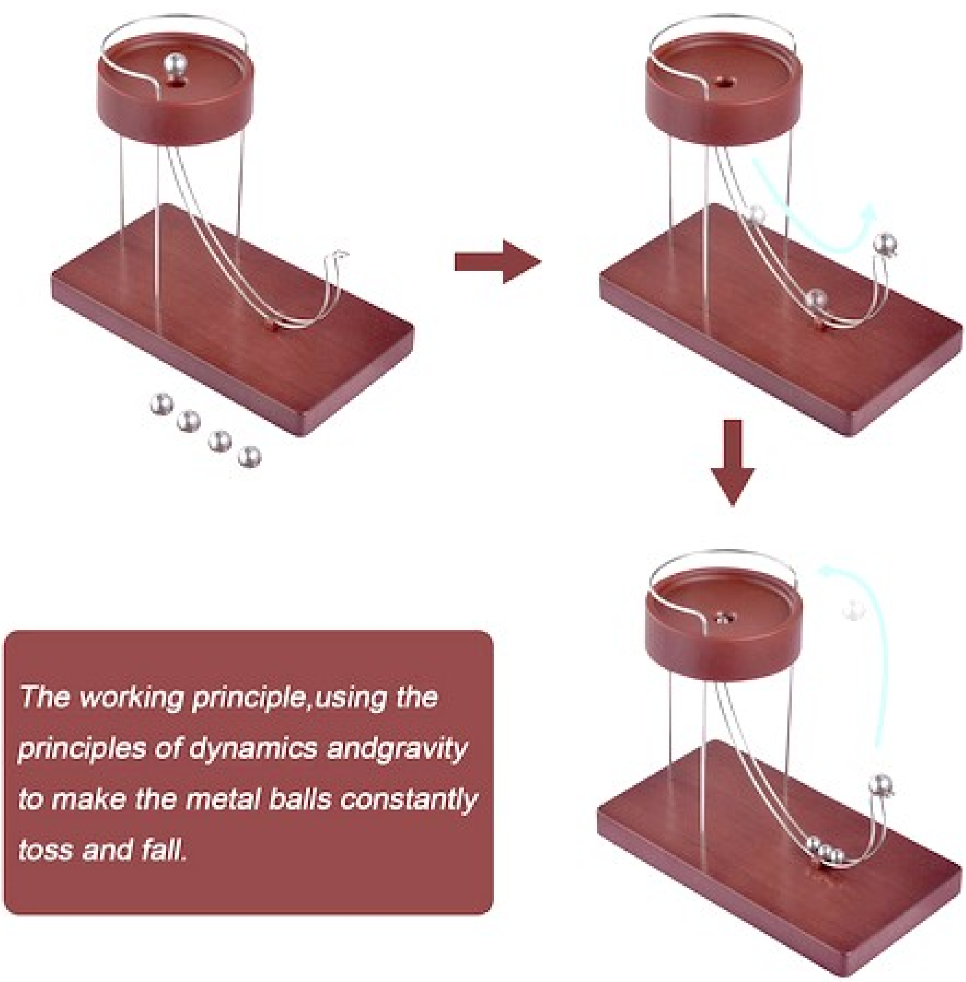
Perpetual motion

So what about perpetual motion machines? Some look very convincing but none of them work. You can buy models on AliExpress that you can use as a talking point, but make a point of looking for the power lead, which is the giveaway but not shown in Picture 3.

Picture 2 looks as though it ought to work. The weights on the right have long moment arms so should turn the wheel with more weights from the left falling over to replace them. However note that are many more weights on the left.



Picture 2
From wikipedia



Picture 3 from AliExpress

The closest we get to perpetual motion is the current that continuously flows in superconducting wire loops that have no electrical resistance. Examples are MRI body scanners and the large hadron collider. However these wires must be cooled to a few degrees above absolute zero by liquid helium. However well insulated they are, energy is used to keep them cold. It's one reason why we shouldn't waste precious and limited helium on balloons and silly voices.

Chemical energy

Even though electrical energy conversions tend to be the most efficient, energy is wasted when we charge our batteries. About 60 to 70 % of the energy we put in gets stored as a chemical change. Generating and transmitting electricity have losses as we saw earlier. The charger itself also wastes energy. If a mains charger is used you might only get 6 to 20% of the energy it uses back out of the battery. However some mobile phone and laptop charging systems can achieve much better than that. There is a link at the end for details.

What is certain is that despite their inefficiencies the total pollution and wastage of rechargeables is less than single-use batteries.

Gravitational potential energy

Gravitational potential energy is the energy of height. You have just manually towed your glider to its ceiling and you release it. It has the energy you gave it by pulling it to a height. This is called gravitational potential energy. It is weight times height or mgh. What is g? It is what you multiply mass in kg by to get weight in N. Near the earth it is about 10. If using imperial units it is 32 as 1 lb weighs 32 poundals force. And yes, there is a unit of energy in the fps (foot pound second) imperial system. It's called the foot-poundal (ft-pdl) and is 0.042 joules or 0.0004 British Thermal Units or 0.00001 food Calories. I like to promote the cubit as a really traditional length unit to the imperial diehards at the field. If it's good enough for Noah it's good enough for me.

To get the model up in the air you worked against its weight and lifted it by a vertical distance. This is called doing work. Work done is force times distance. The weight acts straight down so it is vertical distance that counts. As it is energy it is measured in joules. One joule is the work done when a force of one newton is moved by one metre. Or you lift an apple from the ground under the tree and pop it in your pocket. 'Get out of my orchard!'

So the glider now has potential energy equal to its weight multiplied by its change in altitude. A 2 kg glider, which weighs about 20 newton, if lifted 100 m, will have 2000 J of potential energy. If there are no thermals nor slope lift that's all the energy the glider will ever have in this flight. How will it be used? As the glider slips through the air it experiences drag. That is a force. Remember work (energy) is force times distance. The less drag there is the further it can go for its 2000 J. Suppose the drag is 10% of its weight. It can go 10 m forward for every 1 m it drops vertically. Wait a minute that's glide angle! Yes the glide angle is the result of potential energy being used to do work against drag. You can now see why less drag gives a better glide angle. That's why the sleek, polished glass ship with hidden control linkages can have a glide angle up to forty. Any advance on forty for a model?

In the above case when dropping 100 m the glider should move forwards by 1000 m. I can feel a silly idea coming on. Perhaps I should use the distance travelled from a certain height, which is recorded by my FrSky GPS telemetry, to check whether that is true. Just need a dead-air day. Mind you, with the extra atmospheric energy of global warming, dead calm days are an increasing rarity. As I have said before it's a race between climate change and the CAA/FAA to destroy our hobby.

Kinetic energy and aerobatics

Kinetic energy is the energy of movement. Numerically it is half the mass times the speed squared $\frac{1}{2}mv^2$. Now let's do some glider aerobatics. This is very different from duration flying with minimum sink. Let's think of a simple inside loop. You will already have some speed but not enough for a loop. Put your nose down and dive. You gain speed and kinetic energy by converting it from potential energy. When you judge the speed to be enough pull your nose up to complete a loop. If not enough then think quickly enough to try a stall turn instead before you reach zero speed. 'That's what I intended to do.'

For pure gliders, aerobatics is always about having enough height and potential energy to complete the manoeuvre, then regaining height from slope or thermal lift ready for the next.

My new challenge

I have invented a new game – sorry, challenge. At least I think it is new, so let me know if it isn't. You get your glider up to the maximum allowed height for your field, say 122 m. When your telemetry tells you that you are there you push the nose down vertically and gain speed. Then do a loop. Then another vertical drop and another loop. The challenge is how many loops you can do in the 122 m. In dead air I can do seven with a Bixler 1.1. It is trimmed to instability as my mate Keith always tells me when he flies it. In a thermal I have managed thirteen. I decided to try it with a smoother ship with a folding prop - my foamie 2.4 m Phoenix - and managed thirteen in dead air. The wings on my ASW flex too alarmingly to try it with that.

What energy changes are going on here? You lose potential energy (height) and turn it into enough speed, or kinetic energy, to do the loop. The perfect technique is to gain just enough kinetic energy to carry you over the top then to dive just enough to gain speed for the next loop. There will of course be a loss of energy due to drag which is why the top of your first loop is below your starting height. Give it a try but please don't blame me if the final loop is into negative altitude.

https://www.idc-online.com/technical_references/pdfs/electrical_engineering/Battery_Chargers_and_Energy_Efficiency.pdf

Last edit 22 February 2023