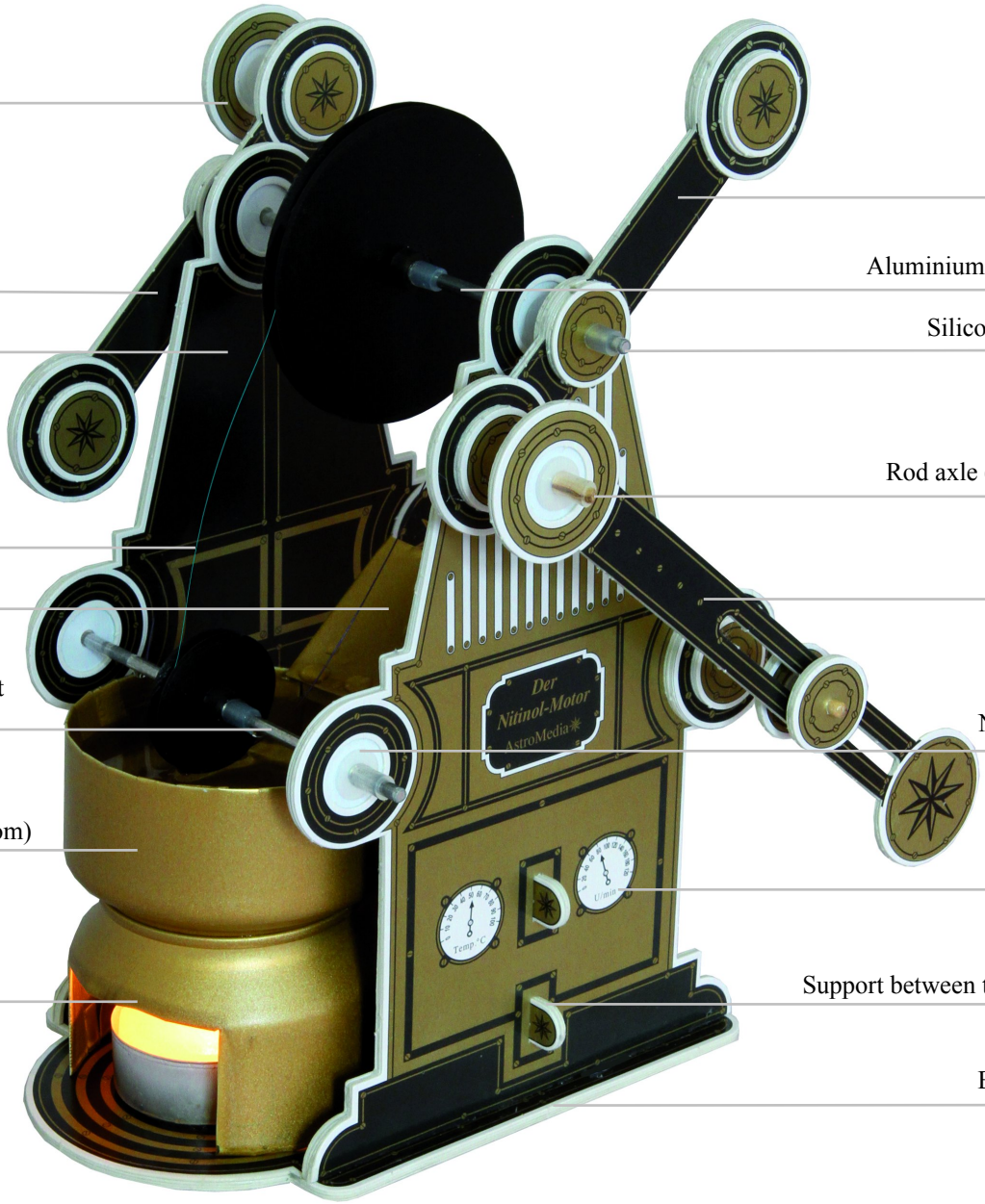
KLAUS HÜNIG / HORST WAGNER

The Nitinol Engine

a cardboard kit for a fully functional Nitinol Engine, powered by warm water



AstroMedia

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What is Nitinol?

Nitinol is a metal alloy made from roughly equal amounts of nickel and titanium. It was discovered in 1959 by William J Buehler and Frederic Wang at the Naval Ordnance Laboratory (NOL) of the US Navy. This is also the origin of its name: Ni+Ti+NOL. One of the extraordinary properties of Nitinol is that it becomes hard and flexible like spring steel if it is heated above a certain temperature. As soon as the temperature drops, Nitinol instantly becomes soft and bendy again. The actual transition temperature can be influenced by adjusting the ratios of nickel and titanium in the alloy. The Nitinol wire in this kit has a transition temperature of about 45ºC.

The really surprising property of Nitinol is the so-called Shape Memory Effect. At temperatures above 500ºC it is possible to impress a shape into a Nitinol part. However much you deform it at low temperatures, as soon as the transition temperature is reached, the part will instantly recover its impressed shape, developing a surprisingly large amount of force whilst doing so. This transition from the soft state (called “Austenite”) to the hard state (called “Martensite”) and back can be repeated over and over again. The reason for this is that the crystalline structure of the Nitinol is shifted when the transition temperature is reached: the nickel and titanium atoms change their positions relative to each other.

An alloy with this property is called a shape-memory alloy (SMA), and Nitinol is the most famous one of them. The effect has been used technically for quite some time, for example in robot actuators and as stent grafts in endovascular surgery. There have also been invented a number of engines that use Nitinol to convert thermal into mechanical energy, but none of them has crossed the line to economical success so far. Nevertheless, the future potential of this remarkable alloy has definitely not been fully realised yet.

How does the AstroMedia Nitinol Engine work?

The principle of this engine was invented in 1985 by Frederic Wang, one of the original inventors of Nitinol. The wire ring is soft and bendy at room temperature and adopts a nearly elliptical form when fitted to the drive wheel and running wheel. As soon as the water in the boiler reaches 45ºC, the part of the Nitinol wire that is immersed, will instantly harden and form a straight line. You will be able to see this by the deformation of the ellipse. At the same time, the lower part of the drive wheel tries to keep the wire bent, so the straight part has to move towards the space between the two wheels, where it can cool down and become soft again. But now the next part of the wire is dunked into the hot water and makes the transition to the straightened state, so the whole process starts all over again. This leads to a continuous rotation of the wire and the two wheels.

It turned out to be extremely complicated to produce an efficient, but inexpensive ring of Nitinol that was needed for this kit in large quantities. Only through the work of Nitinol scientist Horst Wagner, that took several years, was it possible to produce this kit and offer it for a reasonable price.

Contents:

- 6 pre-punched sheets of 0.5mm cardboard
- 1 ring of ⌀ 0.3mm Nitinol wire
- 6 bearing discs d3.3mm x D20mm made from 1mm PVC
- 12 washers d3.2mm x D7mm made from 0.5mm Nylon
- 2 aluminium shafts, ⌀ 3mm x 115mm and 130mm
- 1 running wheel, d3.1mm x D60mm
- 1 drive wheel, d3.1mm x D30mm
- 1 silicone tube d1mm x D2mm x 110mm
- 1 wooden peg, ⌀ 3mm x 200mm
- 1 this construction manual

You will also need for assembly:

- A flat, level worktop
- Standard solvent based all purpose glue, e.g. UHU, Evo-Stik Impact, B&Q All Purpose Glue. **Do not use water-based glue**: it softens and warps the cardboard, and doesn't stick properly to the printed surfaces. Solvent based glues also dry much faster, especially if you thinly coat both sides and then blow a couple of times across the surface.
- Some sandpaper or our AstroMedia file set 400.SBF to deburr the ends of the aluminium shafts and the wooden axles.
- An empty 500ml aluminium drinks can for the furnace and the boiler (alternatively two 330ml cans) with 67mm diameter.
- A small, sharp pair of scissors to cut the drinks can (e.g. nail scissors).
- Some sticky tape.
- A tea light for the furnace.
- A sharp knife with a fine point (thin carpet knife, craft knife, scalpel), to cut the thin holding tabs of the pre-punched parts, the silicone tube, and to start the cut in the drinks can.
- A cutting board or mat, made from hardboard, plastic, or wood. Self healing cutting mats are ideal as the material re-closes after each cut.
- **Optional**: Golden spray paint for the furnace and the boiler.
- **Optional**: A 10mm syringe to fill the boiler

Tips for successful construction
Please read before commencing!

- Every part has its name and/or part number printed on front and/or back. The part number consists of a letter and a number: the letter denotes the finished part, the numbers denote the order of construction. The part number can be recognised by its rectangular frame, e.g. C2.
- Places needing glue are marked in grey. On each of these grey areas you will find a part number followed by an arrow in a square: B4 → The part number in these glue marks denotes the part that will be glued in this place. Please note that some glueing areas are slightly smaller than the parts that will be glued to them. This ensures that grey areas will be completely covered.
- When glueing equally shaped parts on top of each other, take care that all edges are flush.
- We recommend that you do not tear the parts out of the cardboard sheet, but cut through the thin connecting tabs to make sure that the edges stay smooth. Only remove the parts as you need them, but take note that some parts are located within others: everything that carries a part number will be needed, apart from 4 extra disks [M1] that are not used, but can serve as spare parts.
- Before starting to glue parts together, make sure that all cutouts, holes, and slits are opened. The 3mm axle holes can easily be pushed through with the wooden peg.
- Cut off two parts of 30mm and two parts of 38mm length from the wooden peg. This is easily done by pushing a sharp knife into the wood and rolling the peg back and forth a few times, until you can break off the part. The shorter parts will become the axles of the rods, the longer ones will become the guides. Sand down the rough ends of the parts. The remaining 6cm long peg is spare and can be used to glue parts with holes exactly flush on top of each other.
- Deburr the ends of the aluminium shafts with sandpaper or a file.

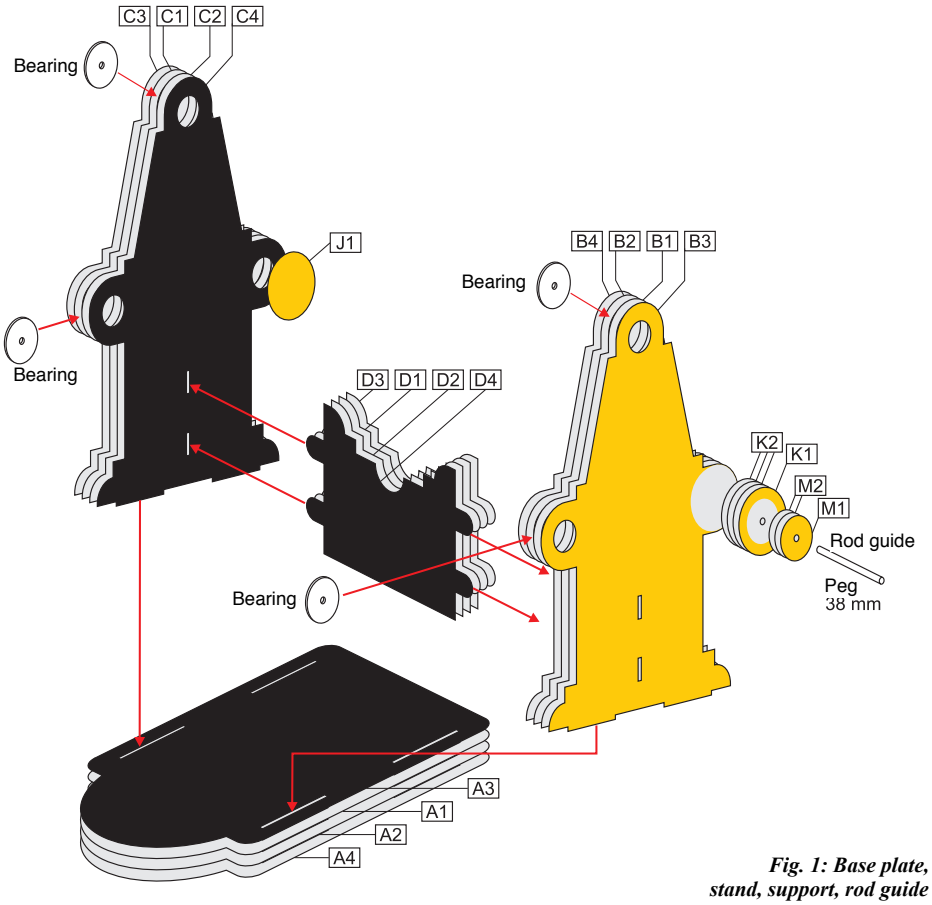


Fig. 1: Base plate, stand, support, rod guide

Instructions:

The Base Plate

The base plate (see Fig. 1), like many other parts of the engine, consists of four layers of 0.5mm thick cardboard. The ones printed in grey are sandwiched between the coloured ones. This way the finished parts have a thickness of 2mm and, after drying, have a stability comparable to plywood.

Step 1: Glue the two middle parts [A1] and [A2] of the base plate back to back as indicated by the glue marks.

Step 2: Glue the base plate top [A3] onto one side of the middle parts and the bottom [A4] onto the other one. Let dry thoroughly. ***Tip:*** *It's best to fill in your name and year of build now - it's much harder once the engine is completed.*

Stand 1

To ensure that the two stands hold the two aluminium shafts for the drive and running wheels safely, PVC disks are fitted as bearings (see Fig. 1). The vertical stability of the two stands is achieved with a support that is fitted between them as a bracket. The outsides of the stands are printed in gold, the insides are black.

Step 3: Glue the grey middle parts [B1] and [B2] back to back and then onto them the outer part [B3]. On the inside there are now three recesses of the same size as the PVC disks. Two of these are printed gold and black on the outside, the third one is printed grey. Press a PVC disk flush into each of the first ones, the grey one stays empty.

Step 4: Glue the inside [B4] onto the middle part. Let dry thoroughly.

Stand 2

The second stand is a mirror-inverted version of the first one. The construction is exactly the same, only the lower bearing disk is fitted in the opposite recess (see Fig. 1)

Step 5: Glue the grey middle parts [C1] and [C2] back to back and then onto them the outer part [C3]. Push the two bearing disks into the recesses that are printed gold and black on the outside and leave the one empty that is printed grey on the outside.

Step 6: Glue the inside [C4] in place. Let the stand dry thoroughly.

The Support and Fitting of the Stands

(see Fig. 1)

Step 7: Glue the grey middle parts of the support [D1] and [D2] back to back as indicated and then onto them the outer parts [D3] and [D4]. Let the glue set.

Step 8: Check that the rounded tabs on the support fit through the slits in the stands. If necessary you can squeeze them together a bit. First without glue, fit the support between the two stands. The support is pushed into the black side of the stands with the golden name plate facing towards the holes without bearing disks.
Tip: *Pull on the tabs from the outside until the edge of the support lies flat against the stand.*

Step 9: Remove the support from the stands, apply glue to its edges and the inner parts of the tabs and glue the stands and support together.

Step 10: As a test, put the stands onto the base plate. The sides with the bearing disks should face the round part of the base plate, which will later carry the furnace and the boiler. On the bottom edges of the stands are two protruding ridges which fit into the slits in the base plate. Once you are happy with the fit, glue the stands and support in this position onto the base plate.

Crank 1

The function of the two cranks is to turn the circular motion of the running wheel into linear motion through the two rods. The hole near their centre, the hub, is reinforced with cardboard disks and will later be fitted to the upper aluminium shaft. The hole through the shorter end of the crank holds the axle for the rod (wooden peg, 38mm, see Fig. 2). The longer end of the crank holds a counterweight made from cardboard disks to reduce the unbalance.

Step 11: *Crank 1:* Glue the grey middle parts [E1] and [E2] back to back as indicated and then onto them the outer parts [E3] and [E4].

Step 12: *Counterweights:* Glue two large disks [J2] and [J3] on top of each other and then this block onto one of the grey areas at the long end of the crank. Now glue three small grey disks [L2] on top of each other and then a coloured disk [L1] on top of the pile. The complete stack is then glued onto the grey glue area of the large block. Now turn the crank over and repeat the above steps for the other side.

Step 13: *Reinforcement of the hub:* Glue a disk [M1] on top of a disk [M2] and glue this block on one side of the hub in the middle of the crank. Now glue one disk [M1] on top of three disks [M2] and glue this block onto the other side of the hub. Make sure that the central holes are exactly on top of each other, so that the crank will be at right angles to the shaft. ***Tip:*** *you can push the rest of the wooden peg or one of the aluminium shafts through the holes to check that it is perpendicular to the crank.*

Step 14: *Rod axle:* Glue one disk [L1] (without hole) onto a disk [M2] (with hole). Glue this block onto the short end of the crank on the same side that also holds the hub reinforcement made from only two disks *(see Fig. 2)*. Now glue one disk [M1] onto three disks [M2] and glue this block onto the opposite side of the crank (onto the side which holds the 4 disk thick hub reinforcement). After the glue has set, push a 30mm long wooden axle fully into the hole and check that it is at right angles to the crank. Glue it into this position.

Crank 2

The second crank is identical to the first one, so the necessary steps for its construction are abbreviated.

Step 15: *Crank 2:* Glue the grey middle parts [F1] and [F2] back to back as indicated and then onto them the outer parts [F3] and [F4].

Step 16: *Counterweights:* Glue two large disks [J2] and [J3] onto the long end of the crank and then three small grey disks [L2] and a coloured one [L1] on top. Repeat for the opposite side.

Step 17: *Hub:* Glue a disk [M1] and a disk [M2] onto one side of the hub. Glue a disk [M1] and three disks [M2] onto the other side.

Step 18: *Rod axle:* Glue one disk [L1] and one disk [M2] onto the side of the crank that holds only two disks on the hub. Glue one disk [M1] and three disks [M2] onto the opposite side and glue a 30mm long wooden axle into the hole.

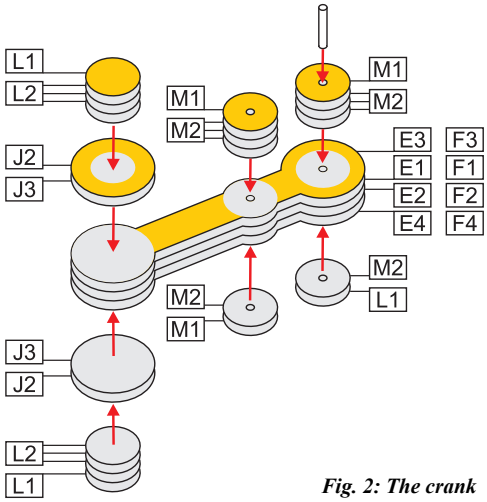
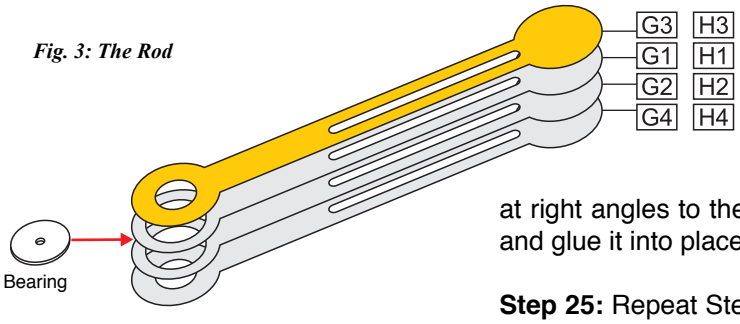


Fig. 2: The crank

Fig. 3: The Rod



Rods 1 and 2

The two rods transform the rotation of the cranks into linear motion. A wooden peg fitted to the side of the stand sticks through a long slit in the rod and guides its motion.

Step 19: Glue the grey middle parts [G1] and [G2] back to back and then onto them one outside [G3]. Now glue a plastic bearing disk into the recess and then glue the other outside [G4] on top *(see Fig 3)*.

Step 20: ***HINT:*** *Please note that due to an error in parts of the print run, the glue note on the back of [H2] reads [C1] instead of [H1].* Repeat Step 19, using inner parts [H1] and [H2], the last bearing disk, and outsides [H3] and [H4].

The Rod Guides

The two 38mm long wooden pegs are fitted to the stands on the sides that don't hold bearing disks, using stacks of disks (see Fig. 1).

Step 21: Glue a large disk [J1] onto the inward facing round glue marks on both stands.

Step 22: Glue four large grey punched disks [K2] on top of each other and a coloured punched disk [K1] on top of the stack. Then glue the whole stack onto the glue mark on the outside of one stand.

Step 23: Glue two small grey punched disks [M2] together and a small coloured disk [M1] on top of them. Glue the stack onto the large disks.

Step 24: Push one of the 38mm long wooden pegs into the hole until it touches the disk on the inside of the stand. Check that it is at right angles to the block of disks and glue it into place.

Step 25: Repeat Steps 22 to 24 for the other stand.

The Drive Wheel

The drive wheel is the smaller of the two plastic wheels. Both wheels are secured to the aluminium shafts with short pieces of silicone tube. The shafts are secured in the bearing disks the same way. To avoid friction between the silicone tubes and the PVC bearing, nylon washers are fitted in between.

Step 26: Using scissors or a sharp knife, cut the silicone tube into 14 pieces of 7mm length.

Step 27: Slide the drive wheel onto the shorter of the aluminium shafts and secure it exactly in the middle of the shaft with a piece of silicone tube on either side. The wheel is wedged between the tube pieces so that it turns with the shaft, not on it.

Step 28: Push the shaft first through the Nitinol wire ring and then from the inside through the lower bearing disks in the stands. Fit nylon washers on the outside of the stands and secure the shaft in place with two pieces of silicone tube. The shaft should be free to move about 5mm sideways in the bearings.

The Running Wheel

Step 29: Slide the running wheel onto the longer aluminium shaft and secure it exactly in the middle with a piece of silicone tube on either side.

Step 30: Push the shaft first through the wire ring and then through the two upper bearing disks. The shaft is now protruding about 20mm on either side. Fit a nylon washer and a piece of silicone tube on either side, but make sure that the shaft can still move about 5mm sideways.

Step 31: Fit the wire ring into the grooves of the two wheels. The fit is rather loose, giving the wire enough space to form a straight line where it is heated by the water.

Assembly of Rods and Cranks

Step 32: Fit a piece of tube on either of the wooden rod axles so that 10mm of the axle is protruding. Now fit a washer, then the rod with its bearing disk, another washer, and finally a piece of tube to hold it all in place. The rod bearing should have a couple of millimetres side clearance on the axle. Assemble the other crank and rod the same way.

Fitting the Cranks to the Shaft

Step 33: Fit the cranks onto the ends of the running wheel shaft with the rods facing outwards. Secure them in place with the last two silicone tubes, so that the cranks turn with the shaft and are offset by 180° to each other. This will lead to the smoothest operation of the engine, but it will also run at any other angle you choose.

Fitting the Rods to the Guides

The rods are moving back and forth on the wooden guides in their slits. Two blocks of cardboard disks hold them in place.

Step 34: Glue two disks [M2] together and then onto both sides a disk [M1]. Make three more of these four-layer blocks. If you don't have enough disks [M2] left, you can use the spare disks [M1].

Step 35: Fit a block on either of the wooden guides on the stands, add nylon washers, the rods with their slits, another set of washers, and finally the last two blocks of disks.

The rods should have a side clearance of about 1mm between the blocks.

Step 36: Turn the running wheel by hand and make sure that all bearings run smoothly and that the ends of the rods don't hit the rims of the blocks.

This concludes the construction of the engine itself.

The Furnace

The furnace and boiler are made from a standard aluminium drinks can with 67mm diameter. The can will be cut and folded so that the bottom forms the boiler and the top forms the furnace. You will need either one 500ml can or two 330ml cans. With a bit of luck you will find cans that have a nice print, so you don't need to spray paint them later. Cutting the cans is not hard, you just need to be careful with the sharp edges whilst working on them. The finished parts won't have any sharp edges. The two templates simplify the cutting and make sure that the height of the finished furnace/boiler combination is exactly right, so that the wire is immersed in the water, but doesn't catch on the rim. The continuous lines are cut lines, the dashed or dotted ones are folding lines.

Step 37: Cut out the rectangular Template A along the line with the scissors symbol (1). Also cut out the square window in the centre, which will be used to tape the template to the can. Don't cut along the lines (2) to (4) just yet. ***Tip:*** *If you make a mistake or you need a replacement for the furnace and boiler at a later date, you can download the templates with the instructions from our website www.AstroMedia.co.uk, and drinks cans are available everywhere.*

Step 38: Put the drinks can upside-down on your work surface. If the can doesn't stand upright, you need to remove the ring pull. Pull the template across a table edge so that it fits snugly around the can with the lower edge standing on the work surface. If the can has the right diameter, the shorter edges of the template will meet exactly. First secure one edge on the can with sticky tape, then pull the template tightly around the can and tape the other edge in place. Stick some tape over the little window to make sure the template can't slide up and down.

Step 39: With a sharp, pointed knife, make an incision just above the template. Cut off the top of the can along the upper edge of the template, using a pair of small, sharp scissors (e.g. nail scissors). ***Tip:*** *If the can is large, there will be enough left over for the boiler.*

Step 40: Now cut through the can along the cut lines marked (2). ***Tip:*** *If you always start your cut with the tip of the scissors on the end of the line, all cuts will be the same length and you will get a nice straight edge when the flaps are folded over.*

Step 41: Cut out the parts marked (3) and make the incisions marked (4).

Step 42: Remove the template and fold all flaps into the inside of the can top to form a nice smooth edge all around. ***Tip:*** *You can use the scissors for this, but it works as well using your fingers, if you are careful not to cut yourself.*

Step 43: Finally you need to remove the lid of the can. Starting from the hole, cut out the lid so that a 6-8mm wide rim remains. Make incisions into this rim every 8mm and fold the so produced flaps into the inside of the can top.
The furnace is now finished. There should be no more sharp edges or corners. The two rectangular openings let you push a tea light into the furnace and make sure that the flame can breath. Check that the furnace doesn't wobble and that it is exactly 45mm high.

The Boiler

The rim of the boiler will also be folded over, so that you can't cut yourself on its edge. The wing that juts out on one side is a drip gutter. It will catch water that sometimes drips from the running wheel. The boiler will sit safely on top of the furnace because its bottom will slot into it.

Step 44: Cut out the rectangular Template B along the line with the scissors symbol (1), as well as the two square windows.

Step 45: Stand the can upright onto your work surface, pull the template over the table edge, and fit it to the can like the one before in Step 38. Secure it in place with sticky tape along the short edges and over the two windows.

Step 46: Cut off the excess part of the can along line (2) and make the incisions along the lines (3), ending at the dashed line.

In the next step the flaps are folded inwards along the dashed line, and outwards along the dotted lines.

Step 47: Remove the template and sharply fold inwards all flaps along the rim. Then fold the three larger flaps behind the drip gutter. Now fold the gutter along the rim into the boiler and then back outwards just underneath the flaps behind the gutter. This way the gutter extends a few millimetres into the boiler *(see Fig. 4)*. Finally bend the gutter a bit rounder so that all drips will safely run back into the boiler.

Inserting Furnace and Boiler

Step 48: Hold the boiler under the drive wheel, so that the gutter is underneath the running wheel and the rim touches the shaft of the drive wheel. Now push the furnace underneath, with one opening facing forwards, and put the boiler on top. The shaft is now slightly above the rim of the boiler. If the shaft or the wire ring rub on the boiler, you need to adjust it a bit.

Now your Nitinol Engine is ready for its first run, congratulations! You are one of the few people on Earth who have built and own such an unusual engine.

Please read before running your Nitinol Engine

- ✳ **Never let your Nitinol Engine run without supervision!**
- ✳ **Don't let the tea light burn down to more than one quarter: the wax can become so hot that it self-ignites!**
- ✳ **Children should only use the Nitinol Engine under adult supervision. Attention: the water temperature can reach 50°C**

Starting the Engine

1. Fill the boiler with water until the drive wheel with the Nitinol wire is immersed a few millimetres. You can use a milk jug, a small watering can, or a 10ml syringe for this. If you fill the boiler with warm water, the engine starts quicker.
   Tip: *Remove spilt water straight away to avoid damaging the cardboard.*
2. *Light a tea light and push it into the furnace.*
3. *Wait about 5 minutes until the water is about 45°C warm. When the submerged wire begins to straighten out, you can start the engine with a slight push. If all parts move without too much friction, the engine might even start on its own.*
4. *To increase the lifespan of the Nitinol wire ring, we recommend to limit each running period to about 20 minutes.*

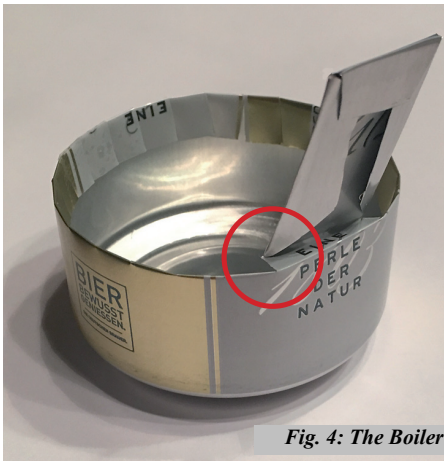


Fig. 4: The Boiler

Questions and Answers:

Can you adjust the cranks so that they are parallel and not out of phase by 180°?
Try it out! The engine won't run quite as smoothly, but the movement will look even more powerful.

Can you power something with the Nitinol Engine?
Of course you can! One example is the AstroMedia Ferris Wheel that was originally developed to be powered by our Steam Engine. You can drive it either from the drive wheel shaft or from the running wheel shaft if you remove one of the rods. There are many options, try them out!

Where can I buy spare parts, e.g. a spare Nitinol wire ring?
Get in contact via AstroMediaShop@gmail.com or order directly from our website www.AstroMediaShop.co.uk.

The wire sometimes jumps off the drive wheel. What can I do?
Move the drive wheel on its shaft towards the side the wire jumps off to. If the drive wheel shaft has enough side clearance, it automatically moves sideways to keep the wire in its groove.

The Engine doesn't run. What can be the reason for this?
1. Check that all shafts have enough side clearance and turn easily.
2. By slowly turning the engine over by hand, check that the rods don't hit the cardboard disks on the guides.
3. Check that the water is warm enough. If the tea light wick is too short, it might not produce enough heat.
4. Make sure that the wire ring doesn't rub on the drip gutter as it expands when getting warm. Either bend the gutter a bit steeper or move the furnace and boiler slightly further backwards towards the stand support.

We hope you enjoyed building this Nitinol Engine and that you have a lot of fun running it. Please get in contact if you have questions, suggestions, or ideas concerning this kit.
We are looking forward to your emails to AstroMediaShop@gmail.com

Understand Science

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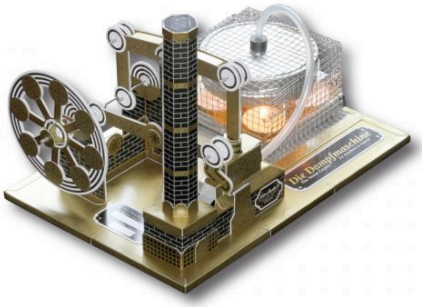
The Orrery



The Steam Engine

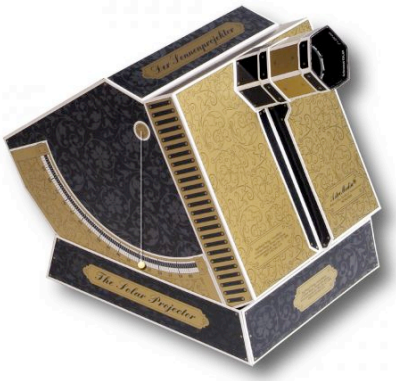
The Newton Telescope

The Universal Sundial

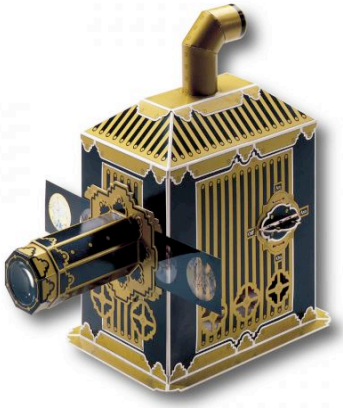
The Sextant

The Stirling Engine

The Stardial



The Solar Projector



The Magic Lantern

and many, many more .....

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