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F02C 1/10 (2006.01) ***F01K 11/02*** (2006.01)
F01K 25/00 (2006.01)

(56) Documents Cited:
GB 2494888 A **GB 1565944 A**
WO 2014/111577 A2 **WO 2012/007705 A1**
WO 2007/129006 A2 **US 4878349 A**

(58) Field of Search:
INT CL **F01D, F01K, F02C**
Other: **WPI, EPODOC**

(54) Title of the Invention: **A heat engine inside a mechanical engine**
Abstract Title: **A heat engine and thermodynamic cycle**

(57) A turbine based heat engine comprising thermally conducting engine walls enclosing working fluid travelling round a closed conduit loop. The loop comprises a plurality of constrictions comprising, in serial flow, a tapered section, a throat, and a diverging section. Each constriction is provided with a turbine 5 arranged at the throat; the turbine being coupled to an electricity generator 4. The loop further comprises a pump arranged to accelerate the fluid around the loop. In use, the working fluid receives thermal energy through the thermally conducting walls thus raising the enthalpy and pressure of the working fluid, further work is done on the working fluid by the pump, again increasing the enthalpy and pressure of the working fluid. The working fluid enters the constriction, enthalpy and pressure falling, and kinetic energy increasing as the fluid flows through the tapered section, enthalpy and pressure falling again as work is extracted by the turbine, and enthalpy and pressure increasing as the working fluid passes through the diverging section. The thermal energy received through the thermally conducting walls may originate from a molten salt nuclear reactor.

Figure 5.

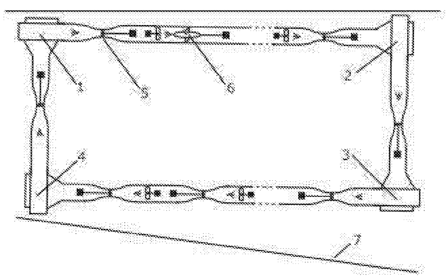

Figure 7.

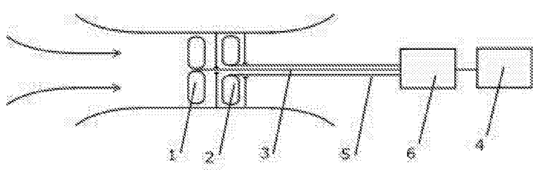

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Figure 1.

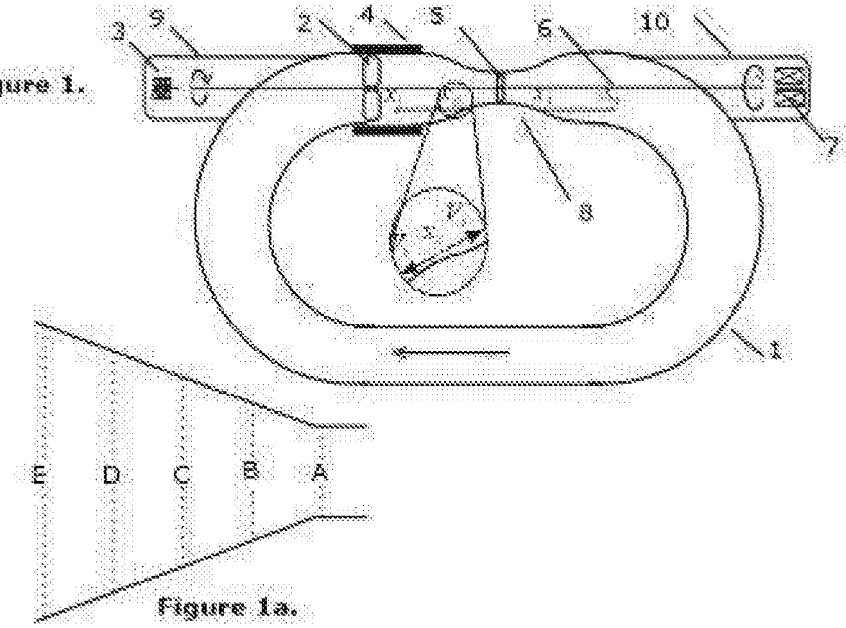
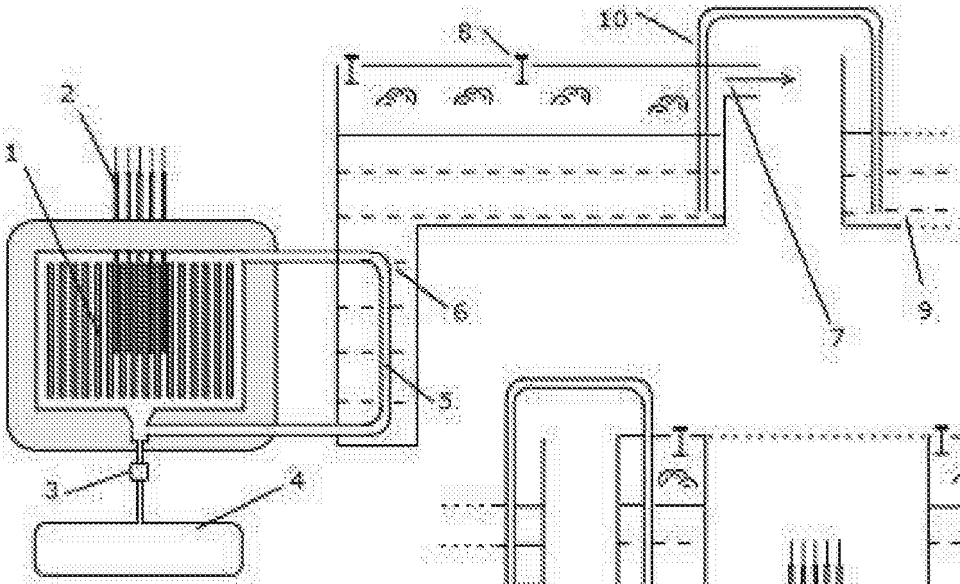


Figure 1a.



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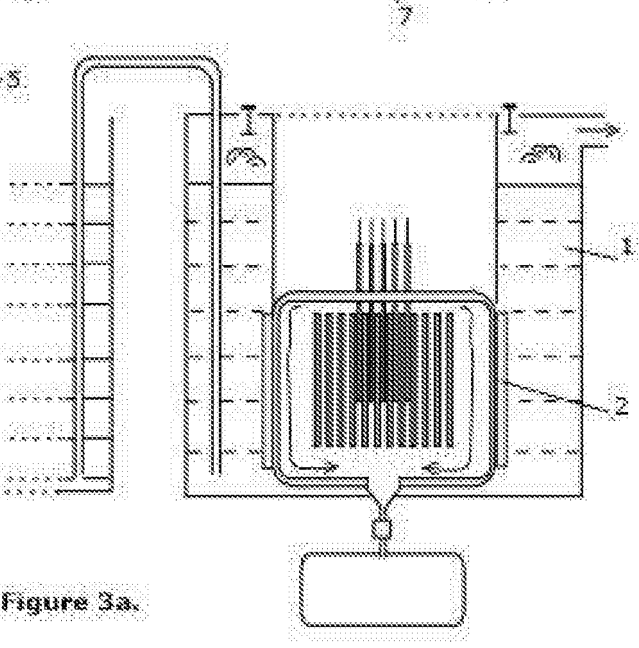
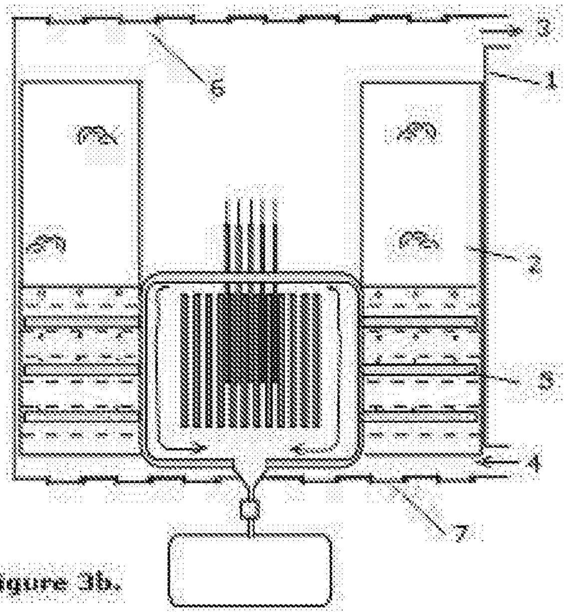


Figure 3a.



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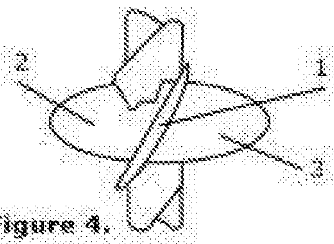

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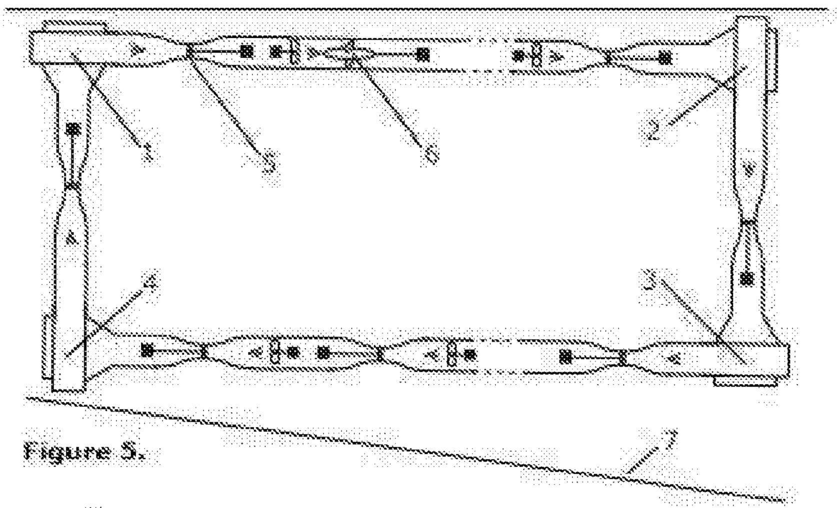

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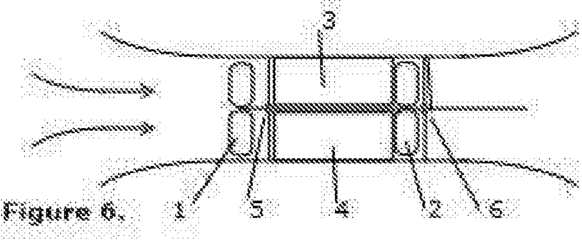

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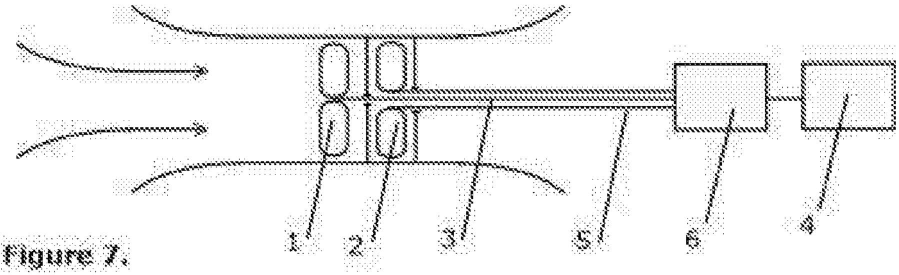

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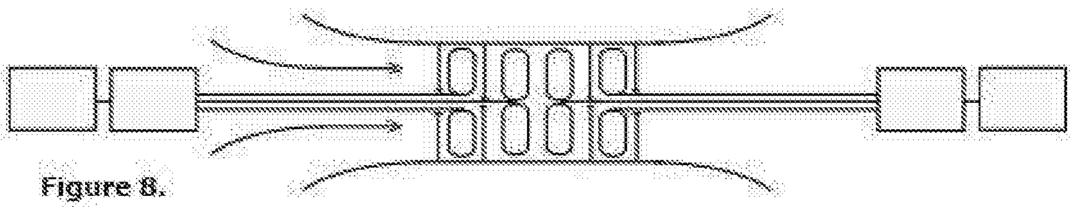

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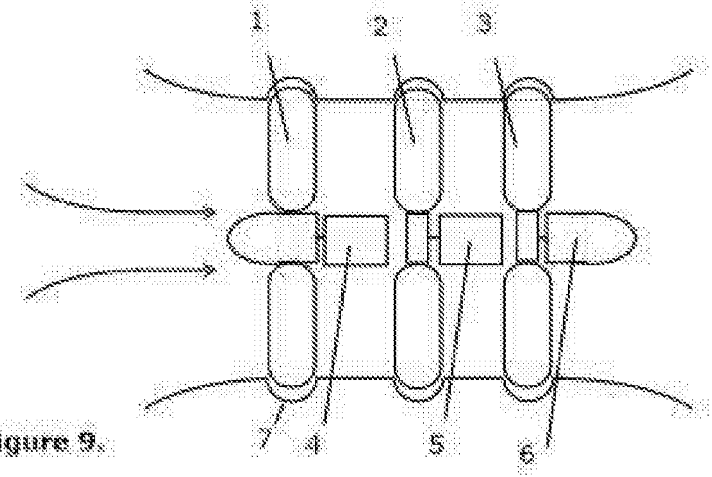

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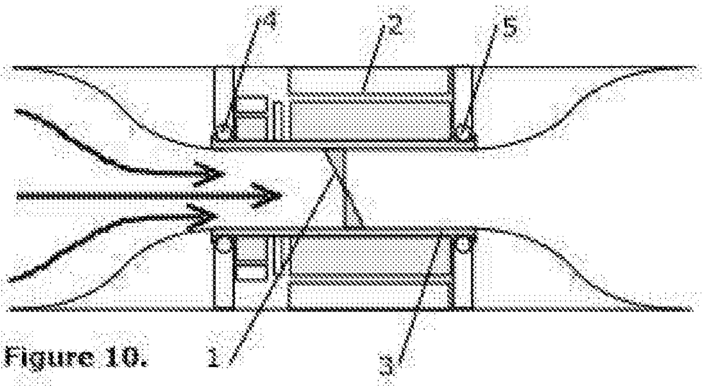

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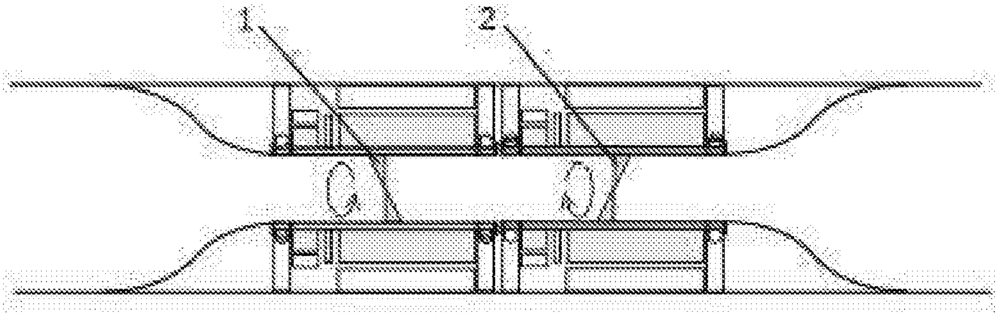

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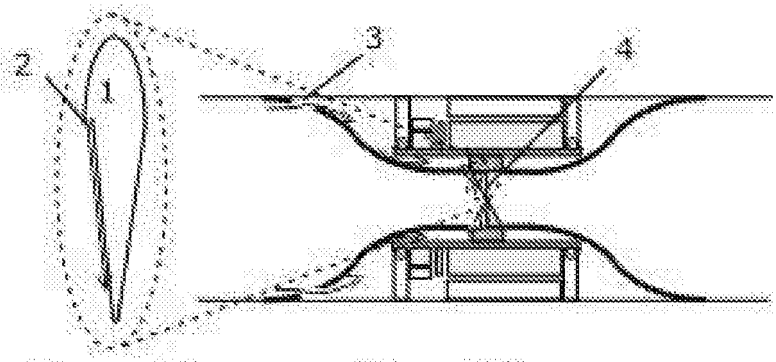
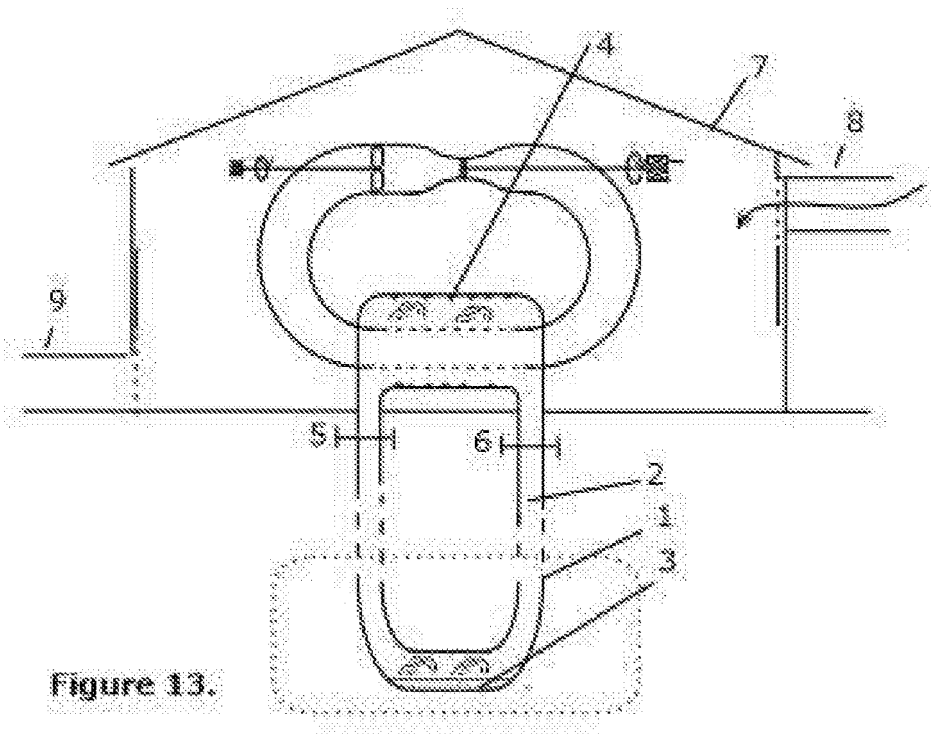


Figure 12a Figure 12b



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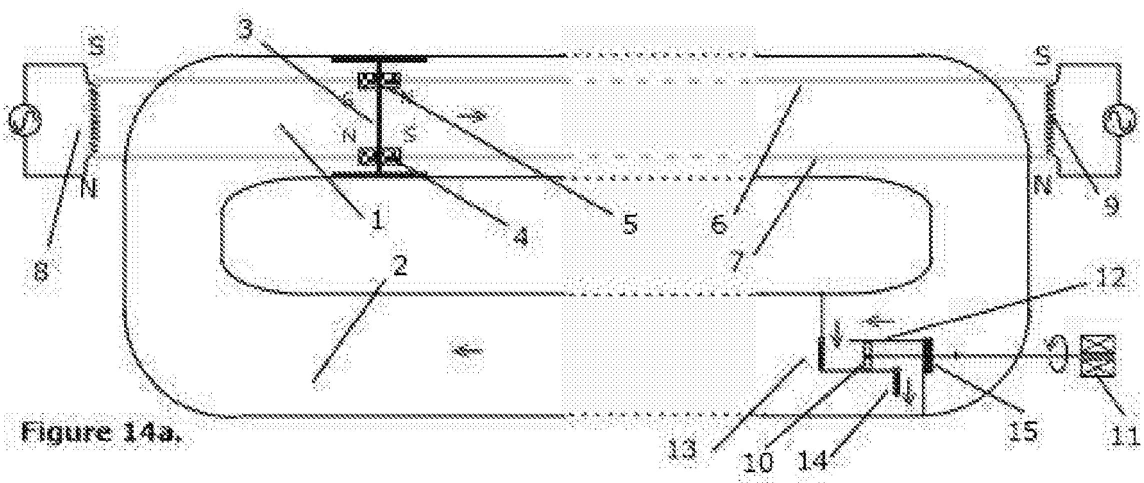


Figure 14a.

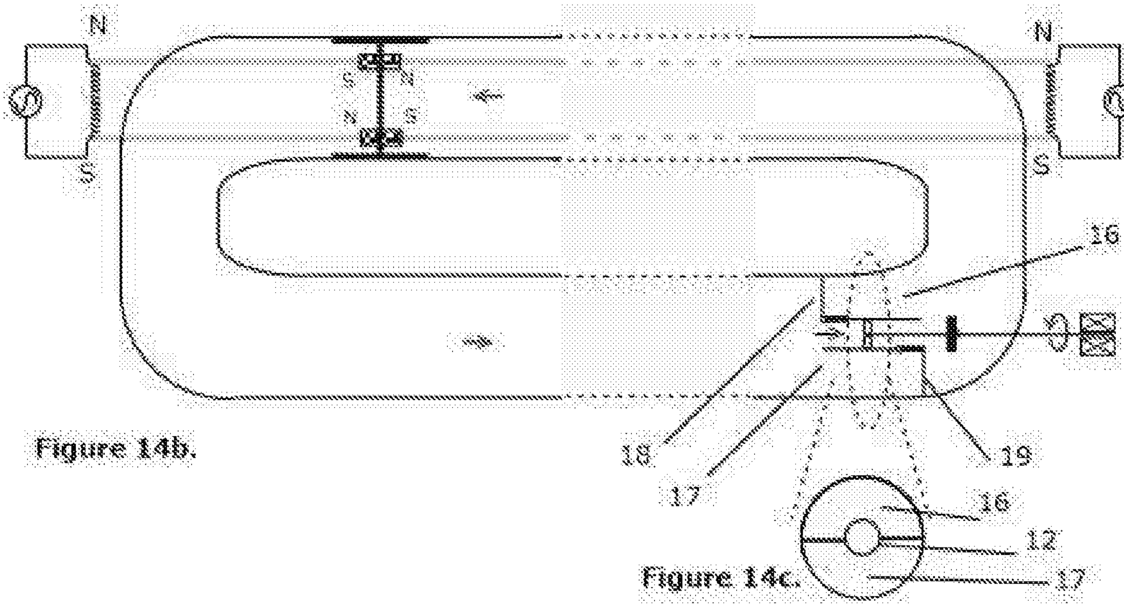
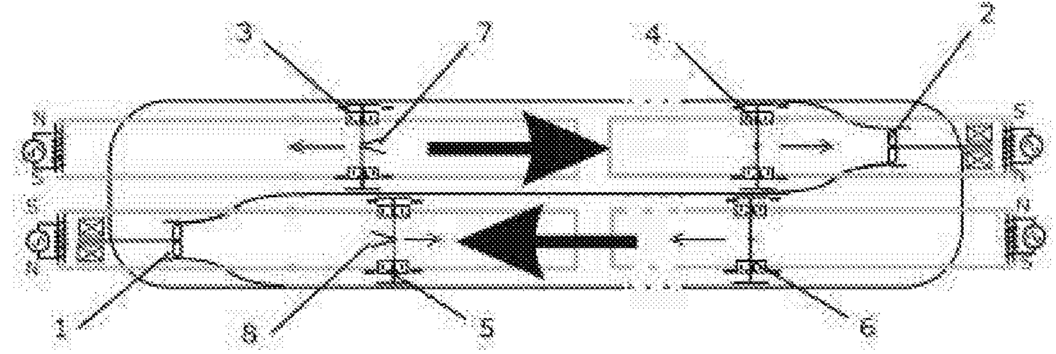


Figure 14b.

Figure 14c.



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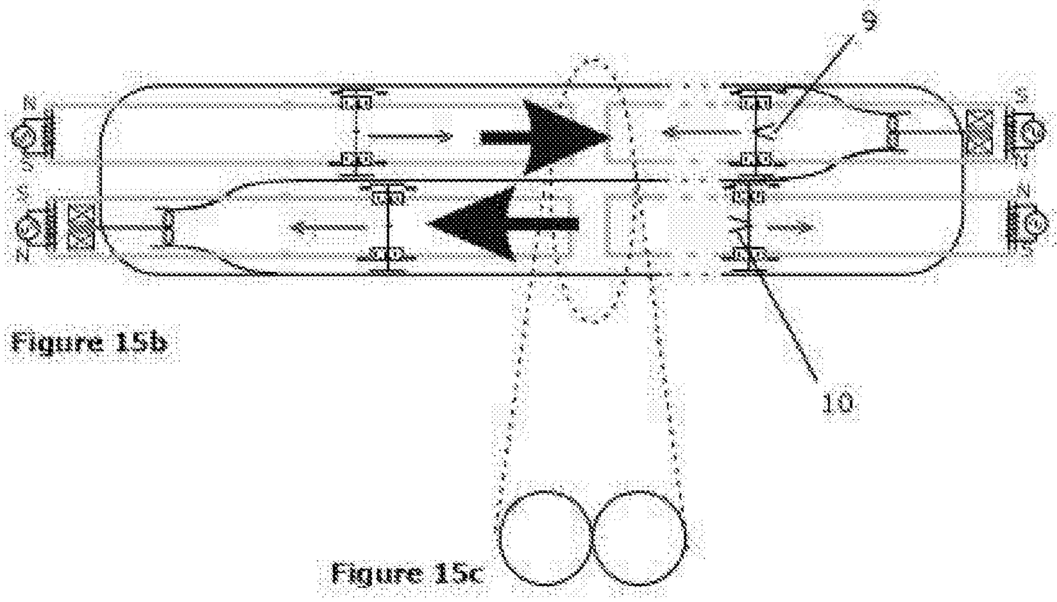


Figure 15b

Figure 15c

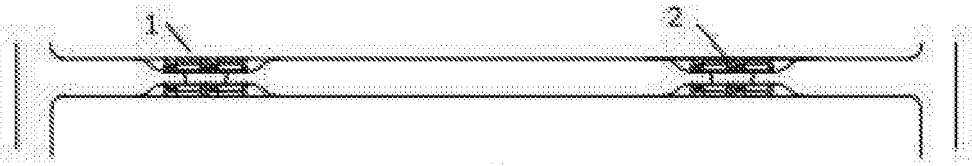


Figure 17a

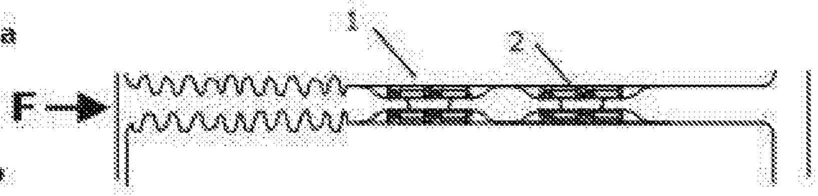
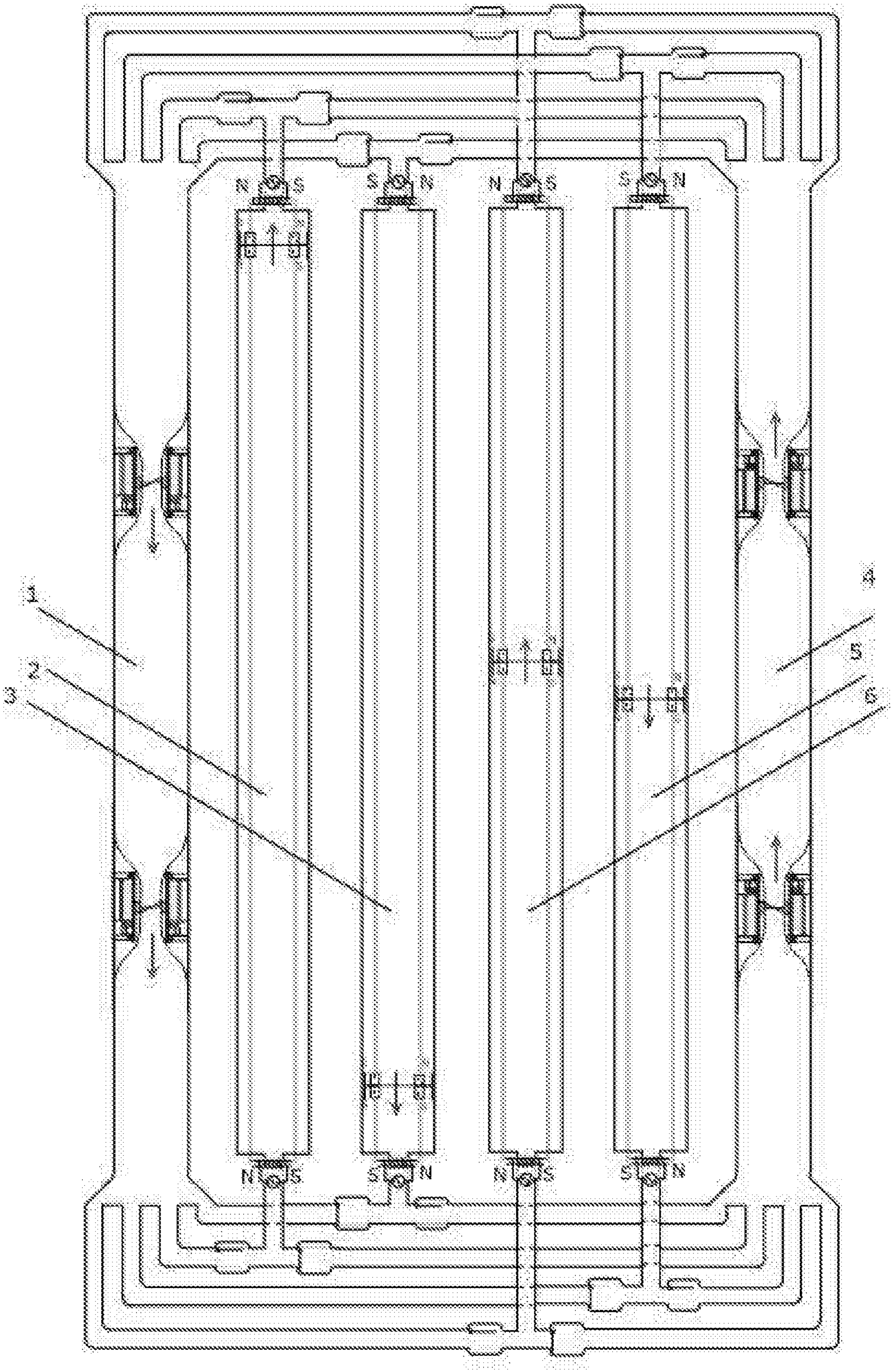
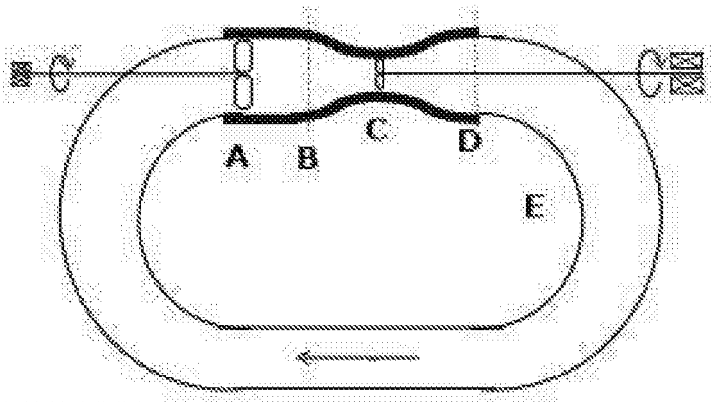


Figure 17b

Figure 16.





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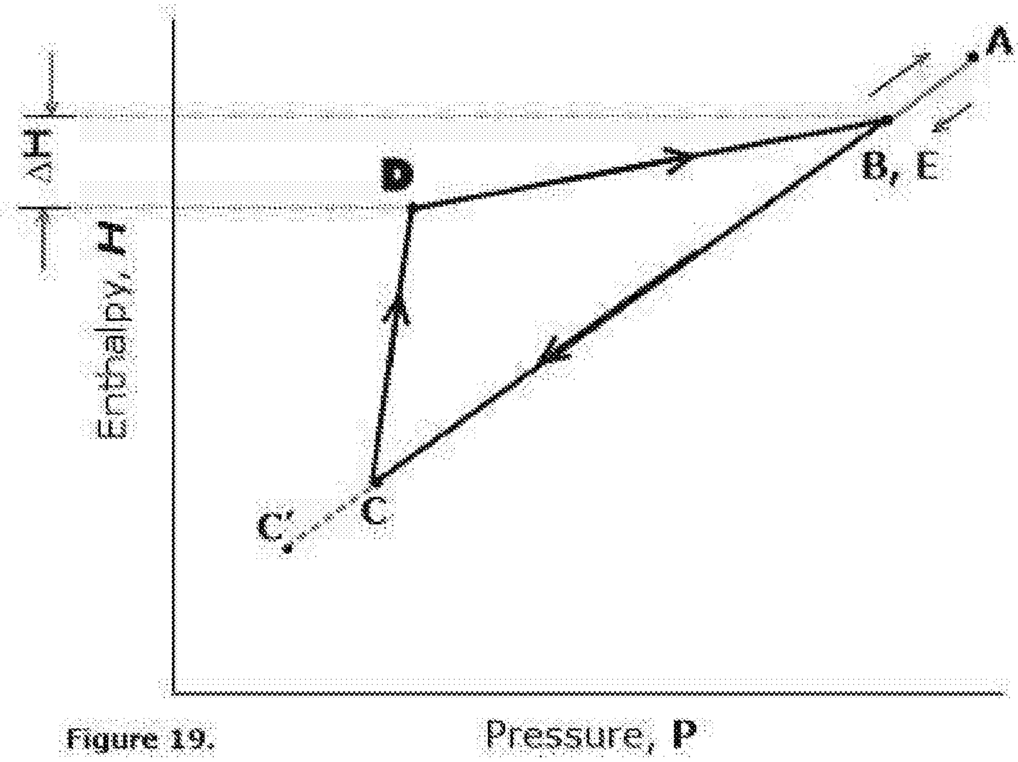

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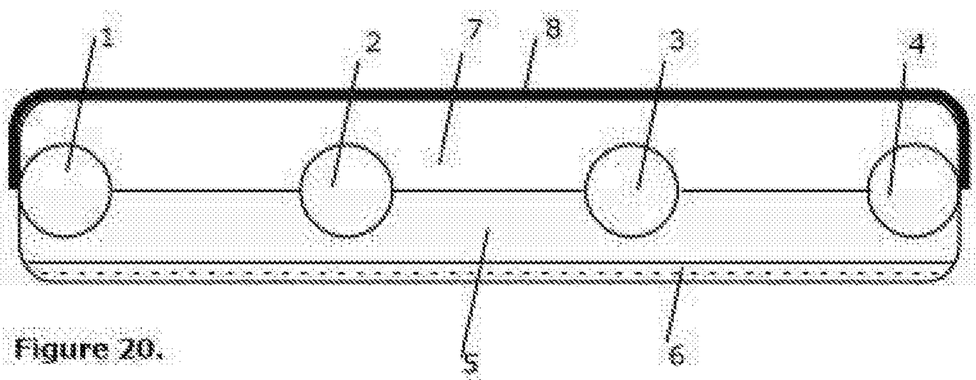

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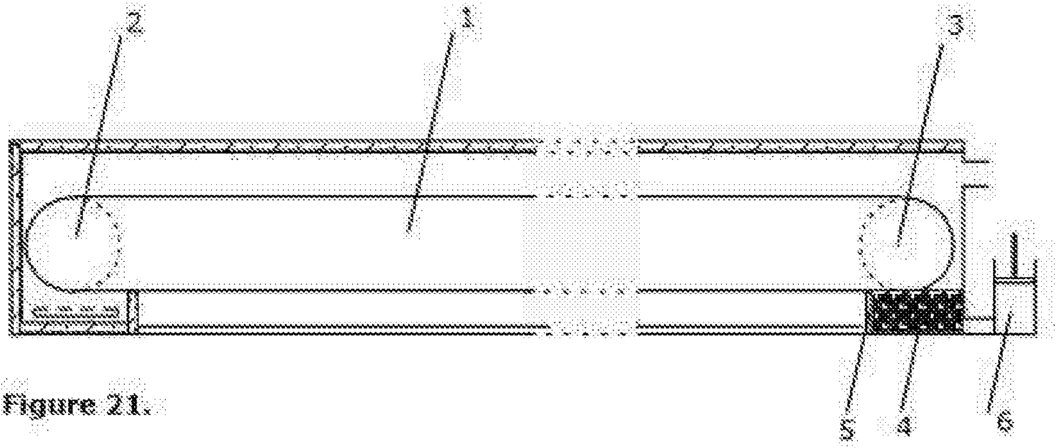

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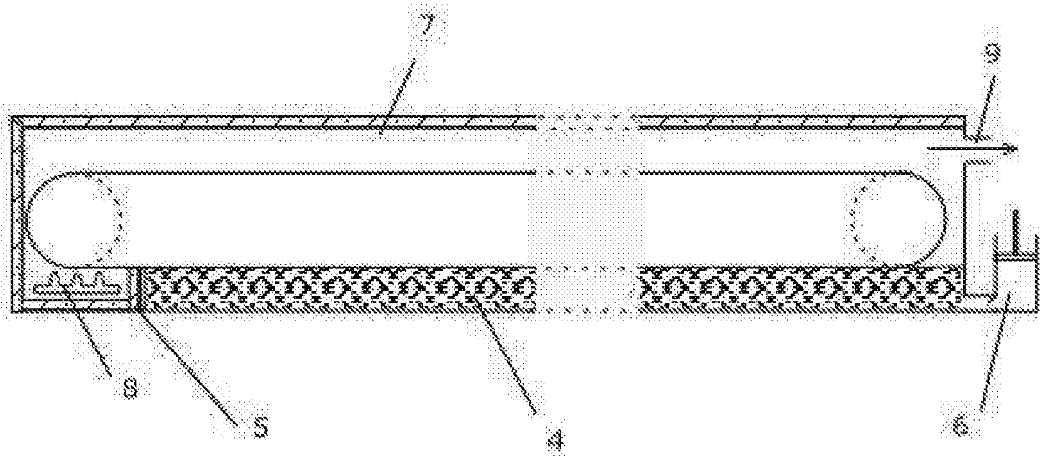

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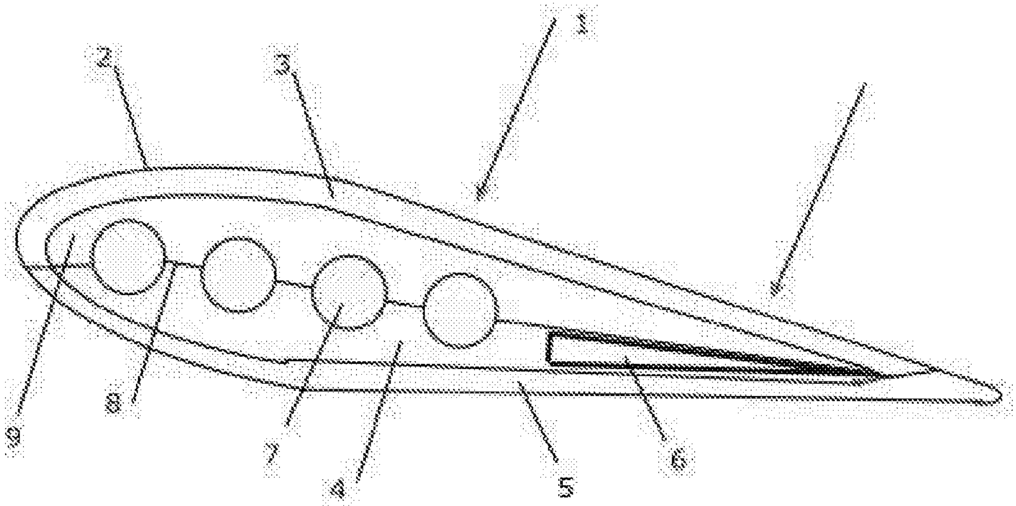
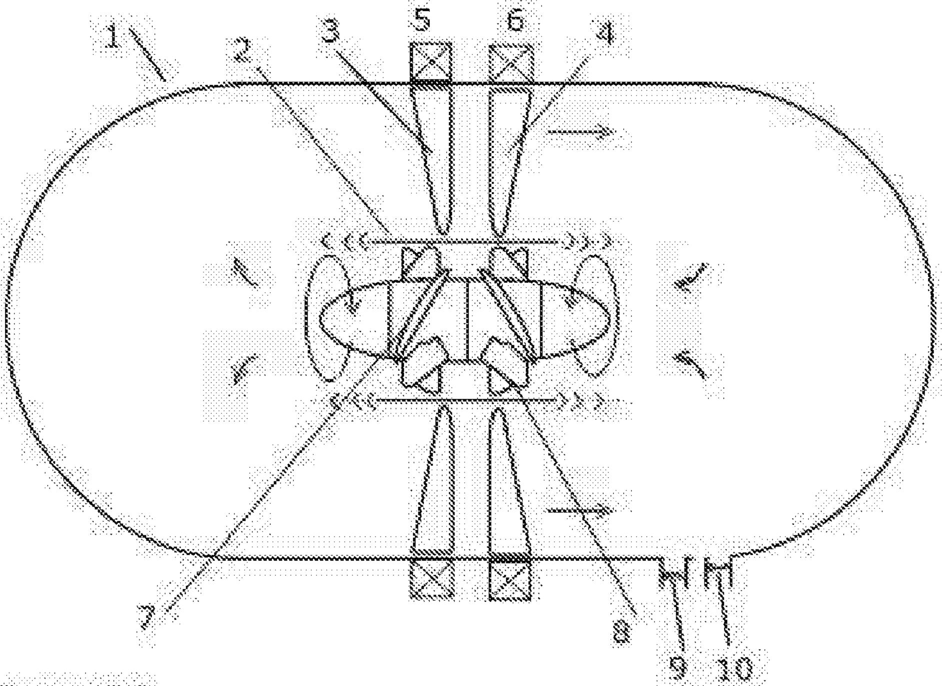


Figure 23



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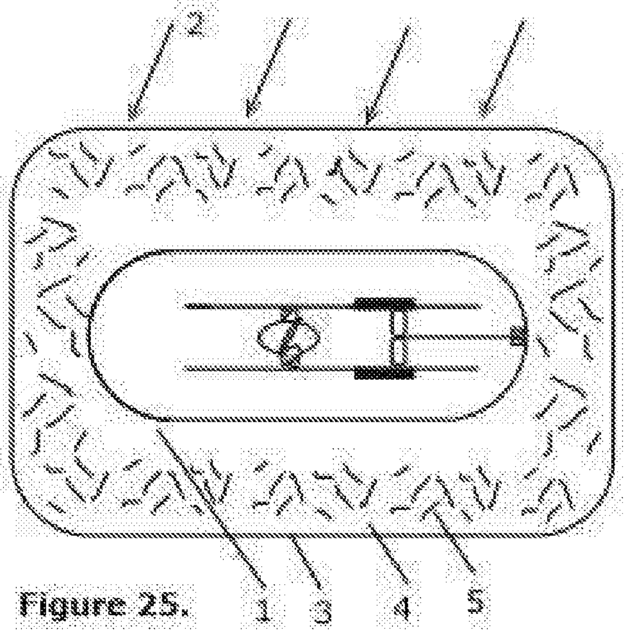

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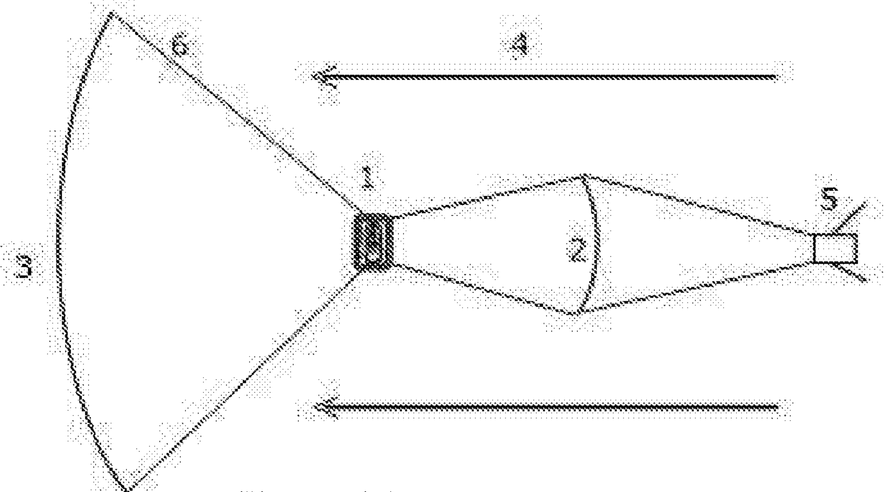

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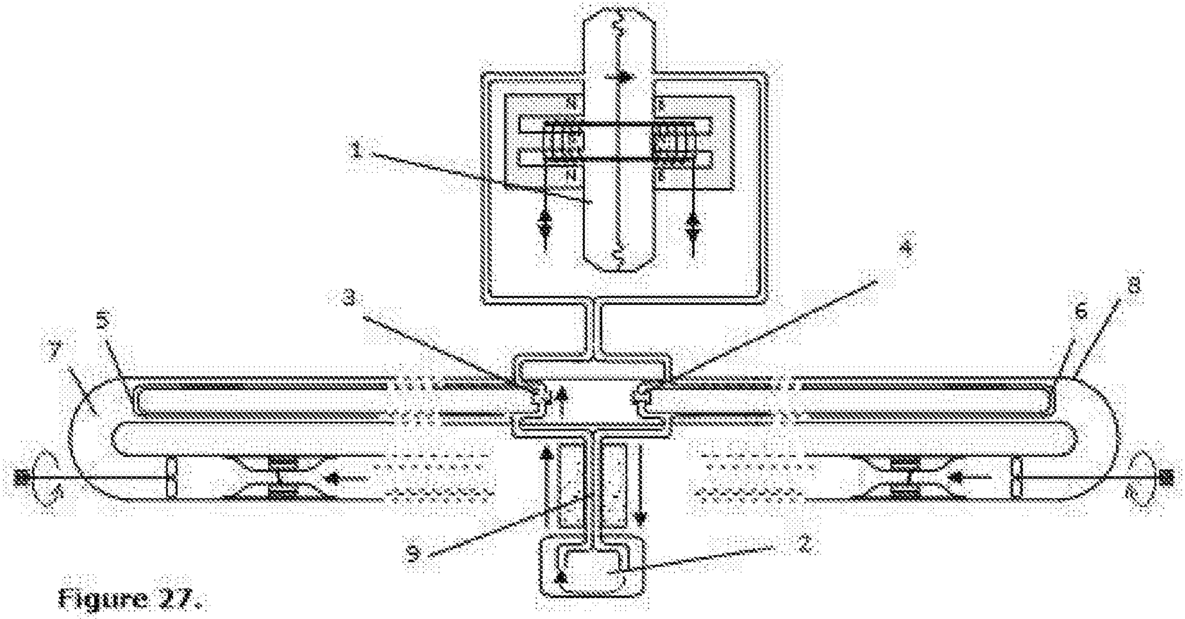

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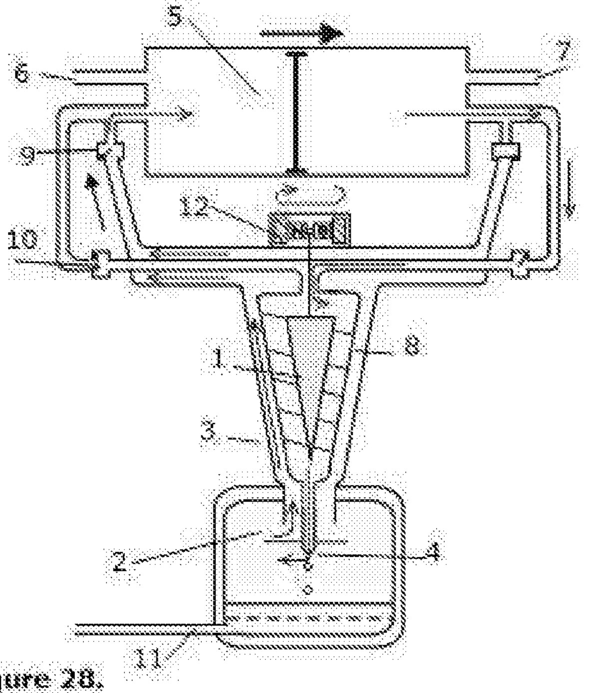

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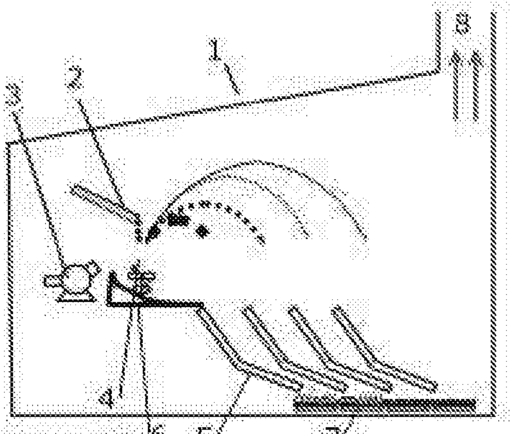

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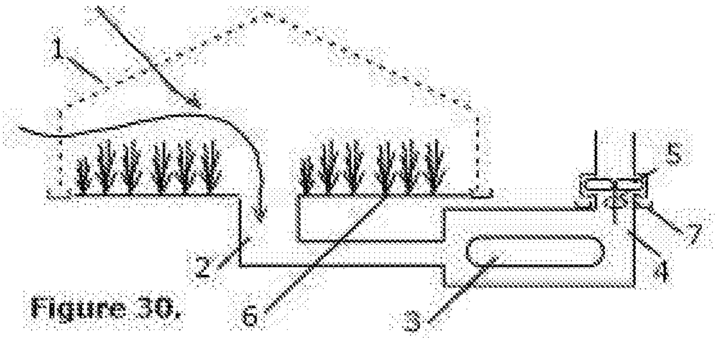

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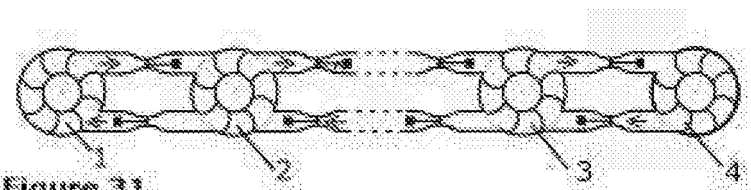

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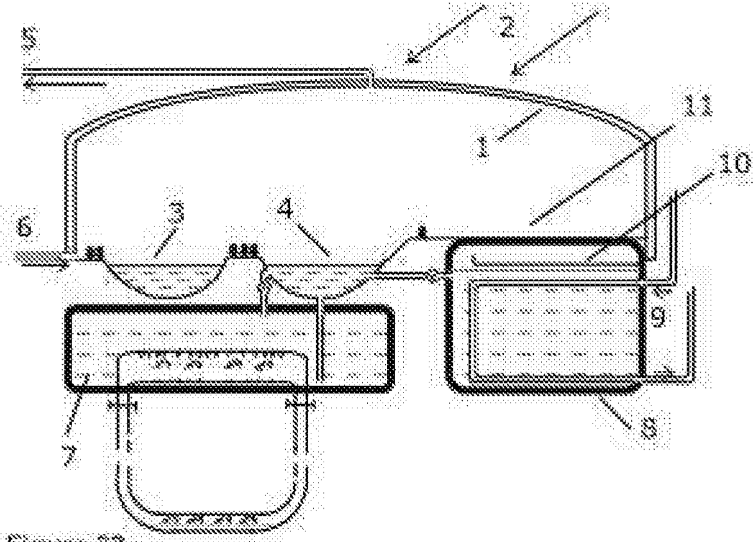

Figure 32

A heat engine inside a mechanical engine

Technical Field

This invention is a mechanical engine enclosing a plurality of heat engines.

According to the present invention there is a reversible mechanical engine that absorbs heat to conserve total energy, capable of efficiently converting heat or thermal energy into mechanical work and then generating electricity in spite of a large temperature gradient existing between the heat source and the interior of the engine, with the thermally conducting engine walls enclosing a working fluid travelling round a closed conduit loop including a plurality of constrictions with turbines coupled to electricity generators being placed at the throat of each constriction, with fans or other types of pumps being used to overcome drag, with additional work being done by the fan to accelerate the fluid to overcome reverse expansion of the fluid, against the direction of flow as it expands on re-warming, with the fan doing fractional additional work against the back pressure caused by the fluid impacting on the turbine blades, characterised by heat being required to maintain the steady state process, rather than initiate it, with the engine operating in accordance with a novel thermodynamic cycle, with the cycle having a related enthalpy-pressure chart for a single turbine version of the invention showing an increase in enthalpy and pressure as the fan does work on the fluid, with enthalpy and pressure falling as the fluid travels through a tapered tube towards a constriction, with fluid kinetic energy increasing, with there being a further fall in enthalpy and pressure as the fluid passes through the turbine and does work, with the enthalpy and pressure increasing again as the fluid passes through the diverging section of the constriction, with the kinetic energy falling, with there being a further increase in enthalpy and pressure due to heat flowing through the conduit walls, with the fluid passing through the fan a gain, so that, in the steady state, when the rate of electricity generation is balanced by the inflow of heat through the conduit walls, the cycle is repeated, with negative thermal feedback ensuring that just sufficient heat enters the invention to compensate for the net power generated, with the thermodynamic cold reservoir being inside the invention, so that heat rejected into the cold reservoir is recycled and not wasted.

Brief description of the drawings

Figure 1 illustrates an earlier version of the invention as revealed by the present inventor in GB 1116309.4.

Figure 1a depicts the converging region in enlarged view.

Figure 2 depicts a molten salt nuclear reactor (MSR) according to the invention.

Figure 3a depicts a variation on the MSR design including an outer water jacket.

Figures 3b depicts a variation of the invention with the outer water jacket replaced by an air filled chamber

Figure 4 depicts a simple form of turbine runner according to the invention.

Figure 5 depicts a closed loop of turbines according to the invention.

Figures 6 depicts two sets of turbine blades in the region of maximum constriction between the converging and diverging sections of the throttling part of the invention.

Figure 7 shows an alternative arrangement of two sets of turbine blades in series.

Figure 8 shows an arrangement that doubles the power output compared the arrangement depicted in figure 6.

Figures 9 shows an arrangement that includes three sets of successively counter rotating turbine blades.

Figure 10 depicts an integrated turbine and brushless alternator according to the invention.

Figure 11 depicts two turbine-alternator units in series according to the invention.

Figures 12a and **12b** depict a method of reducing skin friction according to the invention.

Figure 13 depicts a version of the present invention including an underground heat reservoir.

Figures 14a, **14b** and **14c** relate to a pair of closed loop connected hollow structural beams according to the invention.

Figures 15a and **15b** reveal a two beam version of the invention.

Figure 16 depicts a six beam version of the invention.

Figure 17a 17b depict a vehicle reinforcement beam according to invention before and during an impact that buckles the beam.

Figure 18 is the same as Figure 1 and uses the same numbering, but some lagging has been added.

Figure 19 is an enthalpy-pressure chart relating to the invention.

Figure 20 shows a transverse cross section through a road vehicle sub frame according to the invention.

Figure 21 depicts a longitudinal vertical cross section through the same device when operating in warm weather

Figure 22 depicts the same cross section through the device when operating in cool weather.

Figure 23 depicts a version of the invention suitable for incorporation in aircraft wings.

Figure 24 depicts a plenum chamber version of the invention.

Figure 25 depicts a version of the invention suitable for space applications.

Figure 26 depicts a space application of the invention which incorporates mirrors that also act as solar sails.

Figure 27 depicts a version of the invention that has been modified to form part of a refrigerator.

Figure 28 reveals a version of the invention also that can be used for liquefying a working gas.

Figure 29 reveals how the present invention can be used to capture and recycle the energy released as molten slag cools and solidifies.

Figure 30 explains how the present invention can be extended to convert a horticultural shadehouse into a combined power generating and fog catcher system for use in hot, arid but foggy climates.

Figure 31 depicts a version of the invention in which impulse pumps are used to drive liquid round the loop.

Figure 32 depicts a solar, geothermal and other fuel based thermal energy storage system for a community power station according to the invention.

The prior art

The present inventor, Courtney, has revealed a novel form of closed loop turbine based power generator in patent application PCT/GB2011000936. An essential feature of this invention is that a substance phase change occurs inside the body of the invention, releasing latent heat to power the turbine. During the course of experimental work on this prior turbine Courtney discovered the basic principles of a superficially similar turbine based power generator, but which has a crucial difference; no substance phase change needs to take place inside the casing that houses the turbine. This second invention is revealed in patent application GB 1116309.4.

Recent computer modelling and prototype building has highlighted major changes in the design features that need to incorporated in order for the invention to perform efficiently. These changes are supported by radical changes in the theoretical understanding that underpins the invention.

Disclosure of the invention

This invention is an improvement on the invention described in patent application GB 1116309.4. In particular, improvements in efficiency will be revealed. These will allow the new invention to usefully extract thermal energy from a primary source and convert it into electricity, even if the invention is operating at a temperature several hundred degrees cooler than the primary heat source.

Figure 1 illustrates an earlier understanding of the invention as revealed by the present inventor in GB 1116309.4. It is a closed metal conduit loop enclosing a working fluid, a fan and a turbine runner. The loop includes a throttling constriction. Experimental and computer modelling work has revealed that the explanation given for how the invention works was incorrect. The present invention is novel because engineers will be able to build a far more efficient and cost effective power generator after reading the present description.

Item **1** is a thermally conducting metal walled conduit. Item **2** is an axial fan used as a circulation pump for driving the working fluid round the system against the resistive force of viscous drag. It is driven by a motor **3**. An important function of the fan is that it replaces the expansion process used in existing heat engine turbines to create a pressure drop across the turbine. Elimination of expansion means that the working fluid does not need to be compressed in order for it to be re-circulated. The working fluid may be a liquid, vapour or a gas. However, the shearing forces produced by the rotating blades and pressure differences in general around the loop will tend to produce vapour bubble and cavitation problems if a liquid is used and driven through the system at useful power generating speeds. For illustrative purposes, the fluid will be assumed to be dry air, but it is emphasised that citing this fluid in no way limits the scope of the invention. The working air warms up slightly after work has been done on it. To prevent the loss of thermal energy an insulated sleeve **4** is added. Item **5** is a turbine runner coupled by a shaft **6** to an electricity generator **7**. In order to ensure that the turbine shaft does work at a higher rate than the shaft attached to the circulation pump, the air impacting on the turbine blades travels at a significantly higher speed than it exits the circulation pump blades. This increase in speed is achieved by placing the turbine inside a throttling constriction **8.** The invention is extended to cover different angles of convergence and divergence for the constriction. Items **9** and **10** are airtight cowlings covering the motor and generator respectively. These are not needed in large versions of the invention where there is space to accommodate the motor and generator inside the conduit.

For the device as a whole to produce a net output of power in the form of electricity, the output from the generator **7** must exceed the input to the motor **3**. As a general rule, the larger the size of the device, the easier it is to achieve a net power output. In the steady state, conservation of energy is achieved by the flow of thermal energy into the device, through the walls of the conduit. The external medium that acts as the heat source or warm reservoir can be solid, liquid, vapour or gas. It can even be a vacuum if heat rays fall on to the device and warm it.

We will now reveal the deeper understanding compared with patent application GB 1116309.4 that will allow engineers to construct a significantly improved power generator. But first, in order to further develop understand, a comparison with well know power generators will be made.

Prior art steam and gas turbines for generating electricity rely on a large difference between the entrance and exit temperatures to produce a correspondingly large pressure difference in accordance with the gas laws. This pressure difference is used to accelerate the working fluid so that its kinetic energy increases. The turbine-generator unit then converts the kinetic energy into electricity. The maximum theoretical efficiency is governed by the Carnot equation.

This tells us that steam or gas turbines that rely on sensible heat as their primary energy source and have external cold reservoirs can never be 100% efficient.

The present invention operates on fundamentally different principles. The law of conservation of mass tells us that the mass rate at which the working fluid flows must be the same at all cross sections of the variable diameter conduit, at right angles to the direction of fluid flow. (This is known to engineers as the fluid dynamics or mass continuity equation.) As a consequence, the kinetic energy must increase as the cross section area decreases and the flow speed increases to compensate. The law of conservation of energy requires a corresponding fall in the temperature of the fluid. (In fluid dynamic terms, for a lagged constriction, this equates to a drop in static pressure, with the pressure drop being caused by cooling and calculated using Bernoulli's equation.) In a similar manner, the temperature of the fluid must also fall as a consequence of doing work ton to drive the generator if there is no significant reduction in the kinetic energy of the fluid. (The kinetic energy falls marginally as the fluid density increases on cooling.)

The present invention can never be 100% mechanically efficient because a fan or other form of pump will always be required to overcome drag and other parasitic losses. However in the steady state, the present invention will only be required to draw in net heat from the environment to balance the net output of electricity. All of the low grade heat dumped back into the local environment as a result of friction, Joule heating and other losses, is not ultimately a heat loss from the system, because the invention works by drawing in heat from the same environment. This means that the present invention is capable of converting thermal energy from the environment into mechanical energy with 100% efficiency.

This is a novel extension of a known heat pump effect where a gas is throttled so that it cools below the temperature of its environment, allowing it to draw in heat through the thermally conducting walls of a converging – diverging constriction. This form of heat pump can also be 100% efficient at absorbing heat from the environment, but it can never be 100% mechanically efficient because work has to be done by a fan or other means to motivate the fluid, to overcome drag.

We will refer to **Figure 1** to explain the cooling that drives the known heat pump effect at a molecular level. A temperature drop for a mass of gas is an observable effect of a drop in the random kinetic energy (KE) of its molecules and vice versa. To explain the drop in temperature as the gas is throttled, we can compare two similar molecules at points x_1 and x_2. The molecule at point x_1, some distance from the converging walls of the device has the freedom to move randomly in any direction. This random KE is supplemented by the molecule taking a small share in the bulk KE of the gas which the molecule possesses by virtue of the fact that the gas experiences bulk movement though the constriction. A similar molecule at x_2, very close to the wall, is barred from moving through the wall, so it bounces off and its motion is no longer truly random. Statistically this rebound is likely to be converted into ordered motion in the direction of flow because the molecule has a drift velocity imposed on it, increasing its chances of bouncing off the wall with a forward velocity component parallel to the wall V_a, rather than in reverse direction V_b. Thus, the tapering walls of the constriction impose order, increasing bulk KE at the expense of a reduction in random KE. The reduction in random kinetic energy is observed at a macroscopic level as a fall in temperature. For as long as the wall continues to taper, more molecules per unit volume of fluid collide with the constraining walls and the ordered movement increases. That is bulk KE increases and gas temperature falls. If the collisions with the walls are perfectly elastic, the conversion from random KE to ordered KE is 100% efficient. The reverse is true in the diverging section of the constriction. A gas molecule at x_4 has more choice in the directions that it can move in compared with a similar molecule at x_3. Thus, as the gas moves away from the region of maximum constriction it experiences an increase in random KE, at the expense of a reduction in bilk or ordered KE. At the macroscopic level, this is observed as an increase in gas temperature at the expense of a reduction in bulk KE. That is, the gas slows down and warms up. In reality, thanks to drag forces, the collisions with the walls are not perfectly elastic and the fan has to do work on the gas to compensate. By definition, heat is thermal energy flowing from a warm to a cooler body. Consequently, if the walls of the constriction are thermally conducting, heat can flow into the working gas with 100% efficiency, even though the heat pump is less than 100% mechanically efficient. If it is desired to increase the temperature gradient between the external environment and the interior of the invention for refrigeration purposes, then the converging and diverging sections can be lagged and the heat drawn over a short section of maximum throttling, just behind the turbine rotor, or final turbine rotor if multiple rotors are employed.

An alternative way of understanding how the constriction produces cooling is to consider a constriction as a velocity ordering device. **Figure 1a** depicts the converging region in enlarged view. If **N** is the net number of molecules migrating in unit time through cross section **A**, then **N** molecules must also migrate through cross sections **B**, **C**, **D** and **E** in unit. But the cross section area at **B** is greater than the cross section area at **A**, so the mean speed with which the molecules migrate through **B** must be lower than through **A**. In a similar manner the mean speed of migration through **C** must be lower than through **B** and so on. As the mean migration speed increases from **E** to **A** then the mean kinetic energy due to ordered motion increases from **E** to **A** and the mean kinetic energy due to random motion decreases from **E** to **A**. At a macroscopic level this gradual reduction in the mean kinetic energy of randomly moving molecules moving from **E** to **A** is seen as a gradual fall in fluid temperature.

The present invention exploits this known cooling as a consequence of a fluid being throttled and also introduces a second cooling mechanist, when the turbine does external work without the working fluid coming to a halt.

The throttling section is symmetrical, with the cross sectional areas of the mouth and exit being identical. This means that if replacement heat is added to compensate for the work done driving the turbine, the fluid exits the throttle at the same speed, density, pressure and temperature as it entered the mouth. That is the system is essentially reversible and there is no net expansion of the working fluid as it transits the engine. This distinguishes it from known useful heat engines such as internal combustion engines, steam engines, steam and gas turbines. In each of these engines irreversible expansion takes place and the working fluid cannot be returned to its hot reservoir conditions simply by adding replacement heat.

The invention is extended to include fans that act in the manner of a jet pump with a small diameter coaxial fan directly accelerating the central streamlines and indirectly accelerating the peripheral streamlines by momentum transfer.

The invention is a self regulating negative feedback system that, in the steady state, only absorbs sufficient heat to offset the net output of power. If the external environment temperature increases by $\Delta\theta$, there is a temporary increase in the rate of heat flow into the engine until the internal temperature has also risen by $\Delta\theta$. If the external environment temperature falls by $-\Delta\theta$, there is a temporary reduction in the rate of heat flow into the engine until the internal temperature has also fallen by $-\Delta\theta$.

If the invention is considered as a hybrid heat and mechanical engine then, for a given $\Delta\theta$, raising the temperature of the environment decreases the Carnot efficiency of the heat engine, but, in an ambiguous way, increases the efficiency of the mechanical engine. In order to elaborate on these claims, it is convenient to use both Celsius and Kelvin temperature units.

The theoretical maximum efficiency η of a heat engine is given by the Carnot equation.

$\eta = 1 - Q_C/Q_H$ **Equation 1**.

Where Q_H is the amount of heat absorbed from the hot reservoir and Q_C is the amount of heat rejected into the cold reservoir.

If the thermodynamic temperature scale is used, the ratio of any two temperatures is equal to the ratio of the quantities of (sensible) heat taken in and then rejected by a reversible heat engine operating between the same two temperatures. This allows engineers to use the more convenient form of the Carnot equation,

$\eta = 1 - \mathbf{T_C/T_H}$ **Equation 2.**

Where $\mathbf{T_C}$ is the kelvin temperature of the cold reservoir and $\mathbf{T_H}$ is the kelvin temperature of hot reservoir.

If the temperature of the environment rises, then for a given $\mathbf{\Delta\theta}$, the Carnot efficiency η falls.

The following table, where the temperature drop across the turbine has been taken as 10 k, make this clear.

$\mathbf{T_H}$ (K)	$\mathbf{T_C}$ (K)	η	Percentage efficiency
110 k	100 k	0.09	**9**
310	300	0.03	**3**
510 k	500 k	0.02	**2**

On the other hand, increasing the ambient temperature can increase the efficiency of the mechanical engine, but only at the cost of increasing fan speed. If the temperature increases then the fluid density will decrease and the flow speed will have to increase, so that the mass of air passing a given point in one second remains the same. But the kinetic energy of the air increases with the square of the speed, so power output rises as temperature increases. However, this increase in speed can only be achieved by increasing the fan speed. Raising the temperature alone does not increase power output. A third factor to take into account is that the thermal conductivity of metals increases as temperature decreases. So, for given thickness, temperature gradient and area of metal wall, more heat flows through the walls at low temperatures than at high temperatures.

Consequently, unlike conventional heat engines, increasing the temperature of the hot reservoir alone leads to a drop in power generation efficiency for a given mass of fluid transiting the turbine. It can also be seen from the above table that the Carnot engine efficiency is low, meaning the present invention is bulky compared with existing commercially available heat engines. But Carnot efficiency needs to be distinguished from net heat input efficiency. The large percentage of rejected heat that remains inside the engine is recycled, so the invention still offers 100% heat input efficiency.

It should be noted that the term “reversible heat engine” is used in a limited sense with reference to the kelvin temperature scale, meaning that if work is done, heat can be pumped out of a cold reservoir and dumped into a hot reservoir. Two ideal heat engines working in tandem, one as a heat engine and the other in reverse as a refrigerator …would serve no useful purpose because there would be no net output of work and no net cooling. In reality most practical heat engines cannot work in reverse. So for example, it is not possible to capture the hot exhaust fumes from a car engine and pass them in reverse through a second engine, to end up with liquid petrol or diesel and cold air. In contrast, the present invention is reversible in the wider sense of the word in that the working fluid is restored to its original condition prior to generating electricity by adding replacement heat. This allows the invention to simultaneously deliver a net output of useful work and cool its local environment.

The invention may also be considered as offering a variation on the Venturi pump principle where a side tube in a throttled pipe is used to draw in fluid, commonly air, when air passes through the main pipe at speed. But with this important difference for the invention; instead of additional fluid being drawn in through a side tube and accelerated it is the fluid already inside and passing through the constriction that is accelerated.

This is why: For the present invention, the fluid that has entered the throttle tends to slow down as it does external work spinning the turbine blades. However, this tendency is offset by the low pressure to the posterior of the blades caused by the Bernoulli effect pumping the fluid forward. Thus placing the turbine runner at the throat of a converging-diverting pipe effectively doubles the power output of the turbine compared with the shaft power gained by simply slowing down a stream of fluid passing through the turbine blades. This important design feature was not discovered until after the filing of patent application GB 1116309.4. For the present invention, in its basic form as depicted in Figure 1, it is now recognised that the turbine effectively "sees" two sets of fan blades.

(i) *Before the turbine.*

The fan slightly compresses the fluid to allow it to overcome drag and also and keep it flowing. If the following diverging section of the pipe was removed and the fluid was allowed to expand into free space, then the absolute maximum power output would be equal to the kinetic energy lost by the fluid in unit time as it came to a halt. (In reality this absolute maximum is unachieved because exiting fluid has to move away from the rear of the turbine; the realisable maximum efficiency was determined by Betz et. Al., as 59%.) The net gain in electric power would be equal to the power output of the turbo-generator minus the power input to the fan. This net electric power would be gained at the expense of heat being drawn in through the converging side walls, with the fluid also cooling if required, so that total energy was conserved.

(ii) *After the turbine.*

In the closed loop system that is integral to the invention, the fluid does not come to a halt after exiting the turbine because the fan keeps it moving. However, the fan only needs to keep the fluid moving at the speed required for steady state movement through the wide part of the conduit or pipe. The faster moving fluid at the constriction throat, following its exit from the turbine, must gain its additional kinetic energy at the expense of cooling. This gain in kinetic energy results in a pressure drop behind the turbine that can be calculated using the Bernoulli equation. The pressure differential across the turbine blades thus caused, allows the turbine to do additional work by exploiting the phenomenon of lift.

The present invention is extended to include low boiling point vapours such as chloroethane. This chemical has a boiling point of 12.27°C. Consequently if it is used as the working fluid in temperate climates or similar temperature environments, the pressure drop on transiting the turbine will be greater than if air is used. This will increase the lift caused by the pressure drop behind the turbine blades, and therefore increase power output.

We will now use this deeper understanding to explain an important cause and consequence difference between devices that are classified as heat engines and the present invention.

Heat engines: Engineers will be aware that a heat engine is defined as a system that converts heat or thermal energy into mechanical energy. This means that heat is the cause and mechanical energy is the consequence.

The present invention:

The present invention is a device that first acts as a kinetic energy amplifier, achieving amplification in the converging conduit at the expense of cooling, and then does external work as it passes through the turbine at the expense of further cooling. It requires an input of mechanical energy, via the fan to keep it running. If the fan is switched off, friction rapidly brings the system to a halt. This contrasts with heat engines where an input of heat is required to keep the system running. If there is no input of heat to the present invention, power will be generated with the working fluid temperature falling to conserve total energy. The power output will gradually fall as the fluid cools so that its density increases and flow speed falls. Power generation will cease when the falling temperature causes mechanical failure or the fluid changes to a lower enthalpy phase and forms a liquid pool or solid beyond the influence of the fan.

This means that for the present invention, an increase in mechanical energy is the cause and the drawing in of heat is the necessary consequence, but only if a steady output of mechanical energy is required.

The present invention must still obey the Carnot equation, but it differs from a conventional textbook heat engine in that the cold reservoir is inside the engine. Consequently any heat rejected into the cold reservoir is recycled and not wasted.

In the trivial case where there is no throttling of the working fluid and the fluid passes through the fan and turbine blades at the same speed, the invention can generate electrical energy or shaft power indefinitely while simultaneously dumping waste heat into the environment, instead of demanding heat. However, this version of the invention would serve no useful purpose because the power input to the fan would exceed the power output from the turbine.

To summarise; the present invention is not a pure conventional heat engine with the difference being between cause and consequence.

(i) For true heat engines, heat is required to cause the engine to work. For the present invention, the drawing in of heat is a consequence of the engine doing external work.

(ii) For true heat engines, heat is required before the engine can start to do work. For the present invention, heat is only drawn in after the engine has done external work.

(iii) Heat engines require a large drop in temperature across the engine to deliver an efficient mechanical energy output. The present invention only requires a sufficient temperature gradient to draw in heat to balance the outflow of mechanical or electrical energy.

The present invention can thus be described as heat absorbing mechanical engine.

We will now list the roles of the fan or fluid pump.

(i) The fan is required to overcome drag.

(ii) It must keep the fluid moving round the loop in spite of its tendency to slow down having done work driving the generator.

(iii) The density of the fluid increases when it cools. Consequently, for a parallel sided throat that extends slightly in front of and behind the turbine blades, the fluid travels at a slightly slower speed after passing through the blades. When the fluid re-warms it expands in both directions, with and against the line of flow. The fan has to do a small amount of work, accelerating the fluid, so that all of the resultant movement is in the forward direction.

The present invention applies to fluids in general, including water. We will now make a comparison with Kaplan water turbines in order to further emphasise the novelty of the present invention.

In Kaplan systems a head of water is used to drive the turbine, with the water spreading into a wider diameter conduit or chamber immediately after transiting the turbine blades. The pressure drop causes lift, which causes the blades to rotate, allowing the turbine to do external work. The kinetic energy of the water falls, but its temperature substantially remains the same.

In contrast, if water is used for the present invention, the kinetic energy is essentially maintained and its temperature falls, with only a very small drop in kinetic energy due to the increase in density of the water allowing it to flow at a very slightly lower speed.

An important benefit of the invention relating to large temperature gradient systems will now be explained.
For a parallel sided plate of thickness x and cross section surface area A, the rate of heat flow dQ/dt, from the hotter to the colder surface, is given by the equation

$$\frac{dQ}{dt} = \frac{kA(\theta_1 - \theta_2)}{x}$$ <= **Equation 3**.

Where k is the thermal conductivity of the material, θ_1 is the temperature of the hotter surface and θ_2 is the temperature of the colder surface.

We will now use this equation to compare the performance of a modern steam turbine and the present invention. The Carnot equation, as commonly interpreted by engineers, tells them that for maximum thermal efficiency, the temperature inside the steam generating chamber or boiler should be as high as possible. This means that the temperature gradient $(\theta_1 - \theta_2)/x$ across the walls that separate the hot reservoir from the source of heat should be as small as possible. For given values of **k** and **A** in **Equation 3** this implies that x should be as small as possible. But, high temperatures also produce the desirable high steam pressures, so great care has to be taken to ensure that boiler does not explode. This threat and associated high temperature problems are of particular concern to the public with regards to nuclear fission powered steam generators.
In contrast, for the present invention, there is no merit in minimising the wall thickness x, for the partition between the heat source and the hot reservoir and no great benefit in minimising the thickness or maximising the thermal conductivity of the boundary between the hot reservoir and the interior of the invention. If the temperature gradient is low, more heat will flow into the interior of the invention than is required to sustain a steady output of electricity. Consequently the temperature of the working fluid inside the invention will pointlessly rise and introduce unnecessary safety hazards such as high fluid pressures. This means that for the present invention, for safety reasons, it is desirable to have a large temperature gradient across the boundary between the heat source and interior of the invention, if the temperature of the heat source is high.

In addition to improved safety, other benefits are gained by operating the invention at the lowest convenient temperature. Here are three examples.

(i) The viscosity of the working gas (assuming gas is used as the working fluid) and Joule heating losses of all the metal electric current carrying components increases with temperature. Consequently, running the invention at the lowest possible practical working temperature maximises the power output for a given size and design of the invention.

(ii) No prolonged warm up period is required to minimise the problems caused by different materials used in the construction of the invention having different coefficients of thermal expansion.

(iii) The low pressure differences between the inside and outside of the invention allow its walls to be made from thin gauge metal. This reduces weight and construction material costs.

The benefits of the invention being able to operate under large temperature gradient conditions will be illustrated with reference to molten salt nuclear reactors.

Existing molten salt reactors (MSRs) have several advantages compared with water cooled reactor designs.

(i) They can run at a higher temperature, offing a higher thermodynamic efficiency. The earliest MSRs operated at core temperatures of 650°C with new designs running at temperature of 700°C and higher.

(ii) Because the primary coolant is a molten fluoride salt, temperatures inside the core are high, but vapour pressures are low.

(iii) The inclusion of a solid salt freeze plug that only remains solid because it is cooled by a fan means that the design is inherently fail safe. If the reactor overheats, the plug is allowed to melt, with the molten salt dropping into an emergency dump tank, where it can cool and solidify.

(iv) MSRs can operate using high grade radioactive waste material from water cooled reactors as fuel.

This solves two water cooled reactor problems relating to fuel costs and safety:

The cost problem: After four years inside a water cooled reactor, the tubes that retain the fuel pellets suffer radiation damage and have to be removed with the residual nuclear fuel abandoned as waste. This makes poor use of the fuel because only 3% has been consumed, with 97% remaining. However, the cladding can be removed and the “waste” material dissolved in molten salt, so that it becomes the fuel for MSRs. This appeals to environmentalists because the high level nuclear waste material that has accumulated since the start of the nuclear age is estimated to be sufficient to power MSRs, delivering the bulk of the world’s electricity, for at least fifty years.

The safety problem: Our existing high level waste will remain dangerously radioactive for thousands of years. The waste material from MSRs only remains dangerously radioactive for a far shorter period of several hundred years.

We will now reveal how the high temperature gradients across heat transfer boundaries permitted by the present invention can be used to simplify MSR reactor design and also further improve safety.

Their first advantage is that, unlike existing MSR reactors, the new reactors will be able to operate efficiently at the lowest possible molten salt temperature consistent with molten salt flow through the heat exchanger and then back into the core of the reactor.

Hastelloy-N has a well documented record of resisting corrosion at molten salt reactor running temperatures and is suitable for reactor housing and pipe work construction. But the rate of corrosion increases with temperature, so safety margins and longevity are maximized if the reactor is run at the lowest possible operating temperature.

Figures 2 depicts a MSR according to the invention. It will be used to reveal additional advantages compared with existing MSR designs. In this figure item **1** is the reactor core, **2** is one of the control rods, **3** is the electrically or fan cooled freeze plug and **4** is the emergency dump tank. Standard components that are not novel for this patent application such as the salt purification circuits are omitted. Item **5** is one of a plurality of Hastelloy-N pipes used as heat exchange pipes. It carries hot molten salt from near the top of the reactor down though surrounding water in a water jacket **6** and then back into the reactor. In the example shown, the flow of molten salt is driven by natural convection, but a pump may be added, to improve the rate of flow. Steam at atmospheric pressure leaves the jacket at **7** and is used to provide fuel for the turbines as described in this patent application. A plurality of pressure release valves for example **8** are used to vent off the steam if the pressure inside the water jacket rises dangerously above atmospheric pressure. Item **9** is part of a water storage tank which supplies replacement water to the jacket, via a siphon **10**. A novel feature of the design is that the heat exchange pipe **5** is short in total length because it has a minimum of bends compared with existing MSR heat exchangers. This allows the molten salt to flow under natural convection conditions because the frictional resistance to flow is minimised. This simple design would not be feasible if the reactor was generating thermal energy to drive conventional steam turbines because a small temperature drop across the pipe walls would be required for efficient high temperature steam turbine operation. This in turn requires long coiled heat exchange pipes for a useful amount of high temperature heat to be transferred to the water. In this first example of the invention, the large temperature drop across a thin pipe walls allows the invention to generate sufficient steam to power the new turbines, even though the heat exchange surface area presented to the water is comparatively small. (In equation 3 above, for a given value of dQ/dt, the large value of $\theta_1 - \theta_2$ compensates for the small value of A.)

Figures 3a depicts a variation on the MSR design according to the invention. In this example the heat exchange pipe is dispensed with and the reactor is partially immersed in the water jacket **1**. The walls of the reactor are very thick compared with the heat exchange pipe depicted in **Figure 2**, but this is offset by the large surface area that the side walls and base of the reactor present to the water inside the jacket. This surface area can be further increased by adding heat exchange fins such as **2**. As in the first example, cooling of the molten salt in close proximity to the reactor walls allows the system to operate under conditions of natural convection. (In equation 3 above, for a given value of dQ/dt, the large value of $\theta_1 - \theta_2$ compensates for the large value of x.)

If the reactor side walls and base are constructed from metals that are welded or otherwise fixed together so that they function as a solid thick walled container then, as the reactor warms up to its operating temperature, the large difference in temperatures between the inner and outer walls will generate large hoop stresses, due to differential expansion. According to the invention these stresses can be reduced to an acceptable maximum by constructing the side walls and base in the manner of a series of close fitting nested containers. The layered containers in the nest would be constructed alternately from rigid and soft metals. For example, moving sequentially out from the centre of the nest, the inner container would be constructed from Hastelloy-N or steel followed by a soft malleable metal container, for example lead, followed by a steel container, then a lead container and so on. As the nested containers warm up, the metal of the soft metal containers could flow at right angles to the hoop stresses so that their contribution to the total wall thickness is reduced. Towards the top rim of the side walls, small gaps would be left for the soft metal to flow in to. To prevent the reactor core and inner strong containers sinking into molten lead or causing long term thinning of the solid lead in the base of the nested containers, ceramic or other high melting supports would be included in the soft metal layers of the base.

In a variation of this form of the invention depicted in **Figures 3b** the outer water jacket is dispensed with and replaced by an air filled chamber **1** totally enclosing the outer casing of the reactor. Hollow, sealed, partially water filled external fins such as **2** are cooled by air convection currents, with the hot air entering the power generator hall at a higher level than the reactor **3** and cold returning air leaving the hall and entering chamber **1** at a lower level **4**. Thermally conducting rods secured to the inside of the fins, for example **5** have roughened surfaces that act as nucleation centres, encouraging the water inside the fins to boil without bumping.

Pairs of failsafe high and low level trap doors for example **6** and **7** are held in place in the closed position by electromagnets, with different pairs of trapdoors being secured by electric currents generated by different generators inside the power generating hall. In the event of one or more of the generators failing to produce electricity, the linked pair of trapdoors opens, allowing a proportionate amount of external atmospheric air to enter the air filled chamber, providing proportionate compensatory cooling. For this form of the invention the reactor core can take the form of a hollowed out vertical cylinder with additional air convection currents flowing upwards through the hollow in the centre of the cylinder.

The MSR version of the invention will be useful for reducing the half life of high grade nuclear waste, but, because of public hostility to nuclear reactors, is only suitable for remote locations, well away from dense centres of population. Such remote reactors may be used to provide power for manufacturing liquid hydrogen fuel, reverse osmosis water desalination processes and the production of synthetic kerosene and other transport fuels.

Figure 4 depicts a simple form of turbine runner according to the invention. It is analogous to a Kaplan water turbine runner in that the pitch of the blades can be varied but, unlike a Kaplan turbine, two types of force are involved in producing torque, momentum transfer and lift. Also, the fluid keeps moving after transiting the blades instead of slowing down. The blades, for example **1** can have an aerodynamic profile so that additional lift contributes to the generation of torque. Classic aerodynamic lift in the manner of wind turbines alone is not adequate for generating torque because although the constriction accelerates the fluid so that its kinetic energy increases: (i) The fluid speed increases over the front and rear faces of the blades, so lift does not increase linearly with the square of the speed. (ii) As the cross section area of the constriction decreases compared with the cross section area of the wider conduit, kinetic energy at the constriction throat increases, but total blade area decreases, so the two opposing effects largely cancel out.

Optionally, a generator can be mounted inside the nose **2**, or tail of the runner, **3**.

We will now elaborate on some of the wording for the first claim, by expanding on what has been written earlier about the two force mechanisms acting on the turbine runner. Momentum transfer can only take place at the cost of the fluid experiencing a reaction force that tends to slow it down. In order to ensure the continuing circulation of the fluid, the fan must neutralise this tendency. But it only needs to do sufficient work to maintain flow in the wide part of the conduit with the fluid cooling to compensate for the higher kinetic energy required in the narrow throat. This novel feature of the invention, compared with a Kaplan turbine is claimed by adding the following phrase to the first claim, “With the fan doing fractional additional work against the back pressure caused by the fluid impacting on the turbine blades.”

We will now reveal further improvements subsequent to the filing of GB 1116309.4.

Computer modelling indicates that the fan has to do a significant amount of work driving the fluid round the bends in the closed loop depicted in Figure 1. To eliminate this on one of the bends, a centrifugal pump was used to drive the first prototype.

Figure 5 depicts a closed loop of turbines according to the invention with centrifugal pumps **1**, **2**, **3** and **4** doubling up as right angle bends for the loop. Work still has to be done against friction as the air passes through the centrifugal pumps, but this has to done whatever type of pump is used, centrifugal or axial. For illustrative purposes two different conduit plus enclosed runner profiles that produce throttling are shown. Runner **5** is housed at the throat of a tapered converging-diverging section of conduit and runner **6** is housed inside a parallel sided section of conduit, with the runner having a pronounced nose and tail to produce throttling. The fluid exiting at the blade tip end of the pumps is travelling faster than the fluid towards the root end. In order to minimise shearing forces between streamlines of fluid in the following converging section of the conduit, it preferably converges asymmetrically so that the path length between the tip end of a set of fan blades and the anterior turbine runner is greater than the distance from the root end of the fan blades to the anterior turbine runner, so that elements of fluid leaving different parts of the fan blade simultaneously arrive at the anterior set of turbine runner blades simultaneously. This asymmetric design also evens out the forces on the turbine blades at different points during their rotation. This minimises the resultant vibration of the blades due to the periodic variation of stresses on them. In general, where the design includes a plurality of successive rings of blades or rotors, each set of blades has a different natural frequency to its neighbours, to prevent resonance.

If this version of the invention is used for extracting thermal energy from hot flue gasses, then the turbine loop is enclosed inside a wider diverging insulated conduit **7** and the incoming gas is preferable sprayed with a fine mist of water, so that the gases are cooled until the gas is saturated with water vapour. This reduces the volume rate of flow and maximises the opportunity for trapping dust particles as condensation nuclei, when the water vapour condenses out, as heat is extracted by the invention.

The diverging external conduit produces a further speed reduction and an increase in the temperature of the flue gases, but the gases cool again thanks to heat extraction by the turbines. The central axis for the diverging conduit tilts downwards, with the turbine chain remaining close to the top interior of the conduit. This allows convection currents to move the warmer fraction of the air upwards towards the turbine chain. Longitudinal baffles can be added to encourage the warmer air to move into contact with the turbine chain from above and drip trays can be added below the turbine conduits to collect the condensation water. If necessary, the exiting slow moving flue gases can pass through a large set of rotating radial brittles similar to a giant bottle or chimney sweeping brush so that the remaining water droplets are captured on the bristles by surface tension and then centrifuged off.

We will now reveal recent improvements in the turbine part of the invention.

Figure 6 depicts the region of maximum constriction between the converging and diverging sections of the throttling part of the invention. Two rings of turbine blades, **1** and **2** are mounted on the same shaft but separated by flow straighteners of which two numbered **3** and **4** are shown. A ring of turbine blades being defined as a plurality of radial blades that rotate in the same plain perpendicular to the incoming air, before the air is deflected by the presence of the blades. Items **5** and **6** are shaft supporting bearings. When the air passes through the first set of turbine blades a rotational or swirling motion is imparted on the moving air in the opposite sense to the rotation of the turbine blades. The flow straighteners are required in order to substantially remove this swirling movement before the air interacts with the second set of turbine blades. This arrangement is mechanically simple and can approximately double the power output of the turbine unit as a whole, without increasing the work done against friction as the air passes through the converging/diverging region. However, this simplicity comes at a cost because work has to be done against friction as the air transits the flow straighteners. The diameter of the conduit at the position of the second set of turbine blades may be reduced slightly to maintain speed, allowing for the fact that the density of the air has increased as a result of cooling, due to having done external work, passing through the first set of blades.

Figure 7 shows an alternative arrangement of two rotors or sets of turbine blades 1 and **2** in series. These rotate in opposite senses with the first set of blades being connected by a shaft **3** to a generator **4**. A coaxial shaft **5** connects the second set of blades to a second generator **6**. The work done against friction driving the air past the flow straighteners is eliminated, but the fan still has to do extra work compared with single turbine blade set systems because friction is generated whenever air passes at speed through a set of turbine blades.

Alternatively a single generator can be used with the inner and outer coils of the generator rotating in opposite senses. A disadvantage of this single generator arrangement is that it makes the option of using brushless generators more complicated.

Figure 8 shows an arrangement that doubles the power output compared the arrangement depicted in figure 6, by virtue of utilising two sets of counter rotating turbine blades.

Figure 9 shows an arrangement that includes three sets of successively counter rotating turbine blades **1**, **2** and **3** with connected generators, **4 5** and **6** also being housed inside the constricted region. To avoid visual clutter, the supports for the generators have been omitted from the diagram. An innovative feature of the design is that the conduit is expanded locally, for example at **7**, with the blade tips residing in the expanded diameter regions. This allows the blade tips to have a good clearance of the side walls without reducing the size of the blades.
In general, versions of the invention that include an odd number of sets of counter-rotating turbine blades are useful when the turbine unit is downstream from an axial fan. This is because the action of the fan imparts a swirling movement on the air. So an odd number of sets of turbine blades minimises the swirling of the air that exits the final set of turbine blades.
In order to reduce the number of different types of components that need to be manufactured, the fan motor may take the form of one of the generators working in reverse as a motor.

Figure 10 depicts an integrated turbine **1** and brushless alternator **2** according to the invention. The turbine blade rims act as the roots and are embedded in the inner curved surface of a cylinder **3** which may also act as a throttling constriction throat. The rotating parts of the alternator (exciter armature, rectifying diodes and main field) are mounted coaxially on the external curved surface of the cylinder. The cylinder rotates on bearings **4** and **5** when air moves through the turbine at operating speed. The invention does not place any restrictions on the type of bearings used. For example they may rely on mutual magnetic repulsion forces.

Figure 11 depicts two turbine-alternator units in series according to the invention. The first and second sets of turbine blades, **1** and **2** rotate in opposite senses so that the angular momentum imparted on the transiting air by the first turbine is largely cancelled out by the second turbine.

The versions of the invention depicted in **Figures 5 and 10** can be combined with the rotating cylinder including a plurality of sets of turbine blades all rotating in the same sense, with an axial shaft passing through the centres of the blades with successive sets of counter rotating turbine blades being mounted on the shaft between each set of rotating cylinder mounted blades. That is, all of the shaft mounted blades rotate in the same sense, which is counter to the sense of rotation of all of the enclosing cylinder mounted blades. The axial section of sets (rings) of cylinder mounted blades can include bearings to support the rotating central shaft.

Alternatively, and also according to the invention, the central shaft may pass through clearance holes in the centre of each set of cylinder mounted blades, with the shaft mounted rings of blades having tips that run in bearing races set into the rotating cylinder.

Skilled engineers will be aware that in order to ensure that the frequencies of rotation are all the same, while maximising torque on the turbine shaft, the pitch of each successive ring of turbine blades will need to be varied in order to maximise the transfer of momentum from the moving fluid to the blades in directions perpendicular to the turbine shaft.

Skin friction increases with increasing air speed and decreasing orifice or conduit diameter. Skin friction as the working fluid passes through the conduit and turbine blades can be reduced by a number of methods already known to engineers. The scope of the present invention is extended to cover all known methods including suction of working fluid in through the blades, gaseous injection via small holes or slots in the blades, the inclusion of polymer or other high molecular weight additives to the circulating fluid, blades including micro-grooves or riblets analogous to shark skin, dimples having straight or curved side walls and curved or flat bases in the manner of golf balls, their reverse shapes in the form of protrusions and blades having compliant walls that respond to fluctuations in the turbulent boundary layer.

A novel variation on the gas injection method of skin friction reduction will now be revealed.

When the air is throttled as it passes through the constrictions between the turbine blades its static pressure drops compared with the air pressure in the widest parts of the conduit. This pressure difference can be exploited to extract a small fraction of the air transiting the widest part of the conduit and pump it out through small holes or slots in hollowed out turbine blades. **Figure 12a** depicts a hollowed out turbine blade **1** with air being injected into the main stream of the air through an illustrative slot **2**. **Figure 12b** shows a cross section through a turbine alternator unit with air being drawn into the alternator cavity at **3** and then injected back into the air flow at **4**. The injected air accelerates the air in the boundary layer, helping to prevent the air peeling away from the blade surface and creating turbulent flow.

This skin friction reduction feature of the invention is extended to include any form of porous turbine blade or other invention component that benefits from fluid releases into the boundary layer of the adjacent gas flow.

Skin friction can be reduced by allowing a non-corrosive electrically insulating liquid to be drawn out through small holes in the blades, with the liquid eventually settling out under gravity in a pool, with liquid from the pool being drawn back into the turbine blades by a working gas pressure difference.

The scope of the invention is also extended to cover all versions that improve efficiency by covering solid surfaces with friction reduction coatings.

It is to be understood that the scope of the present invention is extended to cover all working fluids that can circulate round the system. That is, the working fluid may be any liquid, vapour, gas or other small particulate fluid that has mass and can possess kinetic energy.
Each time the working fluid transits a ring of turbine blades and external work is done, the fluid cools and its density increases. In order to maintain a steady fluid speed between rings as the fluid cools the diameter of each throttling throat in the daisy chain loop can be reduced in small steps, with a step being introduced after each ring of turbine blades except the last.

The fan has to do work against the back pressure caused by the fluid impacting on each ring of turbine blades, with that fraction being inversely proportional to the square of the fluid speeds at the constriction throat and mouth, with the throat being defined as the narrowest cross area traversed by the fluid where the turbines are located and the mouth being defined as the largest cross area where the fan is located. For this reason it is preferable for versions of the invention that include a plurality of adjacent rings of turbine blades to have a large constriction mouth to throat area ratio to minimise the net work that has to be done by the fan to restore the fluid to its working speed(s) as it travels round the closed loop and generates power. Instead of each constriction region being served by a single fan, it may be served by a plurality of counter rotating fans in series.

Small versions of the invention may include generators that incorporate permanent magnets. The invention is extended to cover manual start-up systems for both the fan(s) and generator(s). For example, external friction drives coupled via a clutch to a bicycle rear wheel tyre, with the bicycle mounted on a stand, may be added.

We will now reveal how the invention can be extended to improve the efficiency of some existing technologies.

The net efficiency of gas turbines as used in power stations and elsewhere can be improved by pre-compressing the gases to be combusted and then cooling them prior to combustion, with their heat of compression being used to power the present invention.

The Birkeland–Eyde process for producing nitrogen based fertilizers fixes atmospheric nitrogen into nitric acid and does not require a supply of methane gas. However the electric arc required is very energy inefficient, compared with the Haber process. The present invention could overcome this disadvantage by using the large amount of low grade heat produced by the arc to generate additional electricity, to power the arcing process.

When the invention is used in under-developed courtiers it is important that the more vulnerable parts of the design are kept as simple as possible. This will allow people who already possess basic technical skills such as those required to make basic repairs to electricity powered water pumps, mopeds and tractors to repair and service the invention without substantive further training. Numerous variations on the core invention are revealed in this application, but it is important to minimize the range of fan motor, generator, other electrical and mechanical parts in order to minimize the costs of running spare parts business to service the users of the invention.

Geothermal energy promises humanity a virtually limitless source of energy, but existing Rankin cycle systems are unable to exploit most of this because of the high rock temperatures required to deliver a useful head of steam. In contrast, the present invention can exploit relatively cool geothermal energy as we will now reveal.
Figure 13 depicts a version of the present invention with a single turbine unit, with a single rotor or ring of turbine blades being drawn to reduce visual clutter. It is to be understood that in reality, a daisy chain of turbines and multiple rings of turbine blades can be used.
This version includes a heat reservoir **1**, preferably, but not essentially, taking the form of a large buried pool of water or open pore water saturated rock, of the order of tens or hundreds of metres below the surface of the ground. The heat reservoir is supplied with replacement heat from a deeper geothermal energy source. Consequently the temperature gradient between the reservoir and geothermal energy source is large by existing geothermal power generator standards. Thermal energy from the reservoir is transferred to the turbine unit by means of a convection heat pipe **2**. This pipe shifts a volatile vapour from a liquid or mixture of liquids **3** that evaporate at the lowest part of the pipe inside the reservoir to a condensation region in a lagged jacket **4**, surrounding a thermally conducting part of the turbine unit conduit. Latent heat released by the condensing vapour powers the invention. In mild weather the heat pipe is disconnected, for example by blocking the vapour flow at taps **5** and **6** when the lowest temperature in the conduit is above freezing. This forces the invention to absorb heat from the atmosphere in mild weather via the exposed parts of the thermally conducting conduit walls.

The invention is housed in a building or outhouse **7** which may be adjacent to a work place or residential building that requires air conditioning in hot weather.

(i) During hot weather when air conditioning is required, hot air from inside the residential building enters the outhouse via pipe **8**. It is cooled as it supplies thermal energy to the invention, with the cool air being returned to the building via pipe **9**. A drip tray or gutter is installed to collect any water produced by condensation.

(ii) During mild weather, when air conditioning is not required, mild air from the external environment enters the outhouse via **8** and, after being cooled, leaves via **9**.

Typically, mild weather operation closes down if the temperature falls and condensation water starts to form ice on the outside of the conduit.

An advantage of only drawing heat from the underground heat reservoir when absolutely necessary is that it gives the reservoir time to make a thermal recovery during mild and warm weather. Away from tectonic plate boundaries the geothermal gradient is is about 25 °C per km. This means that "ready made pipe work" for the heat pipe includes ventilation shafts for old mine workings and abandoned fracking wells. In these cases, water is used as the volatile heat transfer fluid.

Large power stations according to this version of the invention may be installed inside double glazed glass houses to trap solar energy and include high and low level air vents, enabling air that has been cooled by the invention to flow out of the lower vents. If a cool air retaining buffer zone of woodland is planted around the power station the trees are preferably quick growing species such as poplar and willow that can be harvested for use as fuel, as a supplement to the geothermal energy. The carbon dioxide released by burning the bio fuel can be captured and used in the production of synthetic kerosene, with the invention providing the necessary energy input.

Heat stored in the oceans offers an alternative to geothermal energy. In coastal areas, the power generating parts of the invention can be mounted on a pier, with the heat pump extracting thermal energy from the tidal waters flowing underneath. Such piers could be modified to provide coastal protection against wave damage or offer platforms for new road and rail transport routes.

Businesses that rely on a mixture of electricity drawn from the national grid plus some electricity generated internally using the invention running on low grade waste heat could use the version of the invention depicted in Figure 13 to re-warm the underground heat reservoir during off-peak periods by means of buried electricity cables and then use the same turbine unit to generate power for the grid during periods of peak electricity demand.

If schools and other institutions that make demands on the electricity grid out of synchronisation with national peak demands were equipped with such power stations, they could provide an input to the grid during peak demands. This would reduce the amount of spare generating capacity required by the grid, simply to meet short term demand during peak domestic use periods.

The invention can also be fuelled by the latent heat of fusion released when water freezes. Engineers will be aware that it is possible to freeze pools of water by extracting latent heat of fusion, to make ice rinks and also to manufacture synthetic snow by forcing water and pressurized air through a "snow gun".

The latent heat extracted by the ice making process could be used to power the present invention. Ice could be manufactured in a similar manner for cladding artificial ice climbing walls. This application of the invention would dispense with the normal requirement for a refrigerator to include a refrigerant fluid compression pump. The low boiling point refrigerant fluid would evaporate by thermal contact during the ice making process and then re-condense again at a lower temperature on the outer surfaces of the invention conduit.

For the synthetic snow making processes, heat could be extracted to fuel the invention by cooling the water to just above its freezing point and by harnessing the heat of compression of the air.

The following sequence of processes illustrates how carbon capture from the flue gases generated by burning fossil or bio fuels could also produce synthetic snow for urban leisure industries.

(i) Moisture and particulates would be removed from the flue gases using the invention as explained with reference to **Figure 5**.

(ii) The dry air would be cooled to about -50°C using the invention.

(iii) The air would be isothermally compressed at -50°C, with the heat of compression being used to power the invention.

(iv) The carbon dioxide condensing out during the compression process would be drained off

(v) The residual air would be adiabatically compressed so that it warms up to 0°C.

(vi) The compressed air plus water would be fired from a snow gun.

On a larger scale these snow and ice forming applications of the invention, combined with water pumps powered by the invention, could be used to stabilise outlier glaciers that are melting into the sea and raising sea levels. First the pumps would be used to collect the fresh melt water from under the glacier outlets. Then synthetic snow manufactured according to the invention would be sprayed onto the floating sections of the outliers so that they are forced down onto the sea bed.

Large pontoon versions of the invention could intercept warm ocean currents shortly before they reach the outflow areas of coastal Arctic and Antarctic glaciers. Extracting heat from the water for the purpose of power generation would cool the currents before they lap up against the outflow ice shelf. The power generated could be used to split water into oxygen and hydrogen, for commercial use. If necessary the ice shelf could be stabilised by liquefying the gases and injecting them back into the water, close to the base of the ice shelf.

Similar pontoon versions of the invention could be used for driving compressed air pumps, to aerate "dead" ocean zones were plankton have died and been eaten by oxygen consuming bacteria. Such swarms of bubbles would also whiten or increase the reflectivity of the sea surface, reducing its ability to absorb solar energy. On a smaller scale this form of bubble system could be used to aerate or agitate water in ponds, lakes and slow moving rivers, to discourage the formation of algae. Aeration would also provide the oxygen necessary for aerobic digestion of ammonia and nitrites.

The ability of the present invention to generate useful amounts of electrical power in spite of the heat source having a very low temperature compared with Rankin cycle systems allows the invention to be incorporated into structural beams. These could provide both power and air cooling.

Some illustrative examples that do not in any way limit the scope of the invention will now be revealed.

Figure 14a illustrates a pair of closed loop connected hollow structural beams, **1** and **2**. These may be made from any good thermally conducting materials for example metals, metal alloys or graphene. As for other versions of the present invention, any form of heat transfer fluid that possesses mass, including liquids vapours and/or gases may travel round the loop. The source of thermal energy for the generators may be either latent heat released by steam injected into the structural beam or sensible heat passing through the walls of the beam. For illustrative purposes, the working fluid is assumed to be dry air with heat being drawn in through the beam walls. Hollow beam 1 includes a dual chamber displacement pump as revealed by the present inventor in GB2306580. The piston **3** includes hollow cylinder shaped magnets **4** and **5** that ride on a pair of magnetically soft iron stator shafts **6** and **7**. These shafts are linked by soft iron cross pieces at their ends to form a closed magnetic loop. An alternating magnetic flux passes through the soft iron loop. This flux is generated by alternating electric currents passing through coils **8** and **9**. Optionally, magnets 4 and 5 may be electromagnets with brush connections picking an electric current from a pair of electrically conducting rails attached to a power supply. The conducting rails may rest on the soft iron rails, but be electrically insulated from them. With the polarities shown in Figure 2 the piston is moving to the right and the air is circulating round the hollow beam loop in a clockwise sense. Two design features minimise the fraction of the pumping cycle at the end of each transit, when the pumping action is minimal: (i) the alternating currents through the coils preferably have a rectangular waveform and (ii) the piston preferably impacts on elastic buffers at the end of each transit. If the beams are intended to absorb impact energy during an end on impact then the buckling strength of the soft iron stator rails can be improved by employing hollow rails filled with elastomeric foam.

Figure 14b is the same version of the invention half a cycle later, with the piston moving to the left and the air circulating round the hollow beam loop in an anticlockwise sense.

Turbine **10** is connected by a shaft to an electricity generator **11**. The turbine is enclosed in a cylinder **12**, which is mounted inside the beam **2**. Items **13** and **14** are (optionally) flap valves and item **15** is a disc shaped valve that rides on the turbine shaft.

A comparison of Figures 14a and 14b explains how the valves operate to ensure that the air always flows through the turbine in the same direction, irrespective of the direction of movement of the piston.

All valve movements are activated by the pressure gradients produced by the moving piston, with the pressure ahead of the piston being higher than the pressure behind it.

Valve **13** has two stable positions, either blocking the left end of cylinder **12**, (Figure 14a) or blocking a gap in the left end of the cylinder wall (Figure 14b).

Valves **14** and **15** work in cooperation. In Figure 14a valve **15** blocks the right hand end of the cylinder and valve **14** is open, allowing air to escape through a gap in the right hand side wall of the cylinder. In Figure 14b valve **15** has moved to the right and valve **14** has closed the gap in the side of the cylinder.

In the vicinity of the turbine and its surrounding cylinder, beam 2 is partitioned into two semi-circular channels **16** and **17**. These, combined with fixed end walls to the channels, **18** and **19** segregate the air entering and leaving the turbine. **Figure 14c** is a cross section at right angles to Figure 14b in the vicinity of the partition and uses the same numerical labels. It illustrates that cylinder **12** is concentric with its enclosing beam.

The scope of the invention is extended to cover all forms of piston that generate an oscillating air flow in hollow beam 1. Such beams could be particularly useful if incorporated into building structures such as computer data centres where the disposal of low grade heat is currently an expensive nuisance.

Figures 15a and **15b** reveal a two beam version of the invention in which the valves used to control the direction of air flow through the turbines **1** and **2** are mounted in the piston crowns. **Figure 15c** is a cross section view at right angles to Figures 15a and 15b. It shows how the two beams are butted up against each other.

This version includes four pistons **3**, **4**, **5** and **6** running on four different sets of stator rails. The valves, which may be for example pairs of flap valves or iris valves **7**, **8**,**9** and **10**, close to seal the crown during one half of the cycle, allowing the piston to drive the air forward, then open during the other half of the cycle, so that the air passes through the crown.

In both diagrams the bulk of the air flow is clockwise in sense.

In **Figure 15a** piston **3** is moving to the left and piston **5** is moving to the right. These movements tend to drive the air in an anticlockwise sense, but their effect is minimal because the pairs of flap valves **7** and **8** are open, allowing the air to pass through their piston crowns.

Figure 15b shows the system half a cycle later when piston **4** is moving to the left and piston **6** is moving to the right. These movements tend to drive the air in an anticlockwise sense, but their effect is minimal because the pairs of flap valves **9** and **10** are open, allowing the air to pass through their piston crowns.

When the pistons come to the ends of their strokes their contribution to driving the air through the turbines transiently falls to zero. In order to ensure continuous turbine output a phase difference of a quarter of a cycle between the pistons operating in the two beams can be introduced. For example, when pistons 3 and 4 are at the ends of their strokes, pistons 5 and 6 are in mid stroke.

Figure 16 depicts a six beam version of the invention with four beams **2, 3, 4, 5** housing pistons and two beams **1** and **6** housing turbines. The turbines are those as revealed above, for example, with reference to Figures 10, 11 and 12.

The pistons all operate out of phase by a multiple of a quarter of a cycle with each other and the valves open and close so that the air flow is always “down” through beam **1** and “up” through beam **6**. At the instance shown turbines in beam **1** are being serviced by pistons in beams **2** and **4**, with the piston in beam **2** reaching the end of its stroke a quarter of a cycle ahead of the piston in beam **4**. Simultaneously turbines in beam **6** are being serviced by pistons in beams **3** and **5**, with the piston in beam **3** reaching the end of its stroke a quarter of a cycle ahead of the piston in beam **5**. The electric currents motivating the pistons may vary at different points in their stroke to smooth out the air flow delivered to the turbines.

The inclusion of integrated turbine-generator units increases the local rigidity of the surrounding beam. If the beams form part of the sub frame of a vehicle, with the beams running from the front to the back of the vehicle, then it is advantageous for the bolts or other fixtures anchoring the units to their enclosing beams to shear under impact. In a front end impact this allows the front end of the beams to buckle, absorbing impact energy, while increasing the stiffness of those sections of the beams underneath the passenger compartment. **Figure 17a** depicts a vehicle reinforcement beam according to invention with turbine-generator units **1** and **2** in their working positions. **Figure 17b** depicts the same beam while a violent crash impact force **F** is buckling the front end of the beam. Turbine-generator unit **1** has been shunted to the right so that the right hand section of the beam under the passenger compartment remains intact.

Skilled engineers will be aware of technologies such as Slippery Liquid Infused Porous Surfaces, or SLIPS that prevent ice building up on cold surfaces. The present invention is extended to versions that employ such technologies, to allow the invention to extract heat from cool damp air without a build-up of ice on the beams.

Subsequent to the filing of GB 1116309.4, a deeper understanding of the thermodynamic cycle underpinning the invention has been gained. An Enthalpy-Pressure chart will be used to explain the cycle, but before this can be done in a useful manner, some of the variables will need to be isolated.

In the vicinity of the turbine, the heat change processes are complicated because there are two overlapping cooling and two heating effects.

With reference to Figure1,

Cooling (i) As the air is throttled and its speed increases, bulk kinetic energy is gained at the cost of the mean random kinetic energy of the air molecules falling.

(ii) Cooling due to external work being done.

Heating (i) The air temperature increases due to friction,

(ii) The fan does work on the air,

(ii) There is an increase in temperature due to the flow of heat through the metal conduit walls.

To simplify the analysis, the variables will be separated out by assuming that the region from the fan to the end of the throttling constriction is well lagged.

Lagging the conduit from the fan to the start of the throttling constriction is beneficial if the work done on the air by the fan raises the moving air temperature above ambient. Lagging the constriction is unwise because it wastes a good opportunity to draw in heat. But it has the analytical advantage that the two cooling mechanisms listed above can be separated out.

Figure 18 is the same as Figure 1 and uses the same numbering, but lagging **9** has been added from the fan to the end of the throttling constriction. Letters **A-E** have also been added. These correspond to points on the enthalpy-pressure chart which is presented as **Figure 19**.

The following explanation refers to both of the Figures, **18** and **19**.

A At **A** the fan does work on the air so the air warms to above ambient temperature. Prior to **A**, the air inside the conduit is assumed to be at ambient temperature.

B The air starts to cool as soon as it enters the lagged throttling throat. **B** is the point at which the temperature has fallen back to ambient.

C This is the point immediately after the air has transited the turbine. The air has cooled thanks to throttling cooling and also because the turbine has done work, powering the generator. There has also been some heating due to friction as the conduit tapers and as the air passes through the narrow gaps between the turbine blades.

C' Is the lowest point on the enthalpy-pressure chart that would have been reached if there had been no heating and corresponding pressure increase due to friction. (**Figure 19** only.)

D At the end of the lagged throttling constriction the air temperature is below ambient because the air has done net work driving the turbine.

E Heat flows in through the conduit walls so that (in this ideal analysis) the air temperature has been restored to ambient. **ΔH** is the net heat extracted from the environment during the cycle.

It may be that ideal conditions are not achieved and insufficient heat flows through the conduit walls to restore the temperature to ambient. If so, then the temperature at D will fall on successive cycles and the temperature gradient across the conduit walls will increase until thermal equilibrium is achieved with the rate of heat flow in through the conduit walls balancing the power output. It has been assumed that all of the friction heat losses occur in the vicinity of the turbine. This is not strictly true, but:

(i) The air travels relatively slowly through the wider conduit and fan.

(ii) The bends and long section of wide conduit will be absent in daisy chain versions of the invention such as that depicted in **Figure 5**.

(iii) For practical purposes, the nuisance value of the air friction is the same, wherever it occurs on the chart.

Variations on the invention relating to transport systems are presented below.

Figure 20 shows a transverse cross section through a road vehicle sub frame according to the invention.

This is a hybrid version of the invention that generates electricity by (i) extracting heat from the atmosphere in warm weather and (ii) by burning chemical fuel in cool weather. Items **1, 2, 3** and **4** are transverse cross sections through strengthening beams that offer a power generating capacity. They can extract heat from underneath the vehicle via a heat exchange chamber **5**. The chamber is partially filled with a heat exchange liquid such as a mixture of ethanol and water, **6**. Warm air underneath the vehicle evaporates the liquid which then releases its latent heat when it condenses on contact with the cooler power generating beams. In cool weather the beams receive heat from above from warm combustion fumes that are flowing through a cavity **7**. The top and sides of this cavity are thermally insulated **8** to prevent the heat from the warm fumes being wasted.

Figure 21 depicts a longitudinal vertical cross section through the same system when operating under warm weather conditions. Item **1** is a long hollow beam with "T" piece ends **2** and **3** These "T" pieces are used to couple adjacent hollow beams together. Item **4** is a compressed block of open cell elastomeric foam bounded at its left end by a piston **5.** The piston is contoured to provide a sliding fit for the whole of the cross section of the heat exchange chamber. A pump **6** pumps air into the open cell foam in cold weather so that piston **5** sweeps through the chamber driving the heat exchange liquid out into a storage tank (not illustrated.).

Figure 22 depicts the same cross section through the device when operating in cool weather. Piston **5** is locked in the end position shown and, following expansion of the foam, the pump **6** has been used in reverse to extract air from the expanded closed cell foam **4**. This reduces the thermal conductivity of the foam. Item **8** is a burner supplied with chemical fuel and air.

The burner heats the ends of the hollow beams above it, with the warm fumes transferring heat to cooler sections of the beams below as they flow through cavity **7.** The fumes are vented off at **9**. The bulk of the water vapour produced by combustion condenses out with the latent heat released being used to help power the device. The condensed water is drained off and drips onto the road. The invention is not limited in the type of chemical fuel that it consumes. The burner can be used to achieve complete combustion of the fuel with any electricity generated surplus to driving requirements being used to charge a battery. When the air temperature increases sufficiently for warm weather operation to resume, the piston lock is released so that air pressure from inside the combustion chamber drives the piston to the right, recompressing the elastomeric foam.

In another vehicle related version of the invention, the invention is mounted under the passenger compartment, with there being a small open ended front to back gap between the invention and the vehicle floor pan. An air dam or front spoiler is mounted in front of the invention to improve the down force on the vehicle. Preferably the air dam is slightly stiffer than the vehicle bumper, encouraging pedestrians to flip onto the bonnet, rather than under the vehicle in a pedestrian impact.

Figure 23 depicts a version of the invention suitable for incorporation in aircraft wings. During daylight hours, aircraft, especially those flying above the clouds can use the device to convert solar radiation into electricity. In the aeronautical version of the invention chemical fuel is burned to heat the underside of the hollow beams and radiant heat **1** is captured from above. The upper surface of the wing **2** is matt black or transparent to thermal radiation and an evacuated cavity **3** thermally isolates the beams from the air flowing over the wings. This is important in order to eliminate the risk of heat extracted from the moist airflow causing icing of the wings. The fuel heated cavity **4** below the hollow beams is thermally insulated from the external airflow under the wing by a blanket of low density insulating foam **5**, foe example aero gel. Item **6** is a fuel tank. The hollow beams **7** are well spaced out, the partition **8** has a thermal radiation matt black upper surface and the cavity immediately above the beams **9** is filled with air.

Figure 24 depicts a plenum chamber version of the invention. It will be useful for small scale domestic and business use. It can also be adapted for research applications. The chamber **1** houses an inner circular cross section pipe **2** that is permeable towards it ends so that a significant fraction of the fluid can pass through the permeable sections of the walls instead of having to make a sharp 180° turn in order to enter the central pipe. A second benefit of permeation by a fraction the air is that it reduces the thickness of the boundary layer inside the pipe. A pair of counter rotating fans **3** and **4** are driven by external motors **5** and **6**. A pair of counter rotating wide bodied turbine runners 7 and **8** enclose a pair of counter rotating generators (not shown). The merit of using two sets of counter rotating fan and turbine blades is that the swirling of the circulating fluid is minimised. Items **9** and **10** are lockable inlet and outlet valves respectively. They allow a working gas that has the same composition as the gas in the external environment to alter its static pressure if the external pressure changes significantly. They also allow moisture to be bled off after the case has been opened up for servicing. (After servicing the invention is covered with a thermally insulating blanket and run so that its temperature drops, forcing the moisture to condense out.) For this all other versions of the invention good thermally conducting materials can be used in the construction of fan blades, turbine blades and internal housings for electrical components to maximise the rate of heat dissipation into the working fluid.

This plenum chamber version of the invention with pressure equalisation features will be useful for future trips to the surface of the planet Venus, where the cloud cover is so thick that photovoltaic cells can generate very little electricity and where the atmospheric pressure increases rapidly as the space probe descends towards the planet surface.

The chamber **1** may be elliptical in cross section and enclose a plurality of circular cross section pipes similar to **2**. The plenum chamber may also have a flared end central conduit and dumbbell shaped ends to encompass the flares. These features will allow the air to travel at low speed as it reverses direction on entering or leaving the central conduit. This version could be mounted underneath the passenger compartment of a helicopter and optionally extend upwards to the sides of the passenger compartment so that it acts as buoyancy aid, allowing the craft to land on water and also provides a crush zone in the event of a vertically downwards accidental impact. An advantage of this installation in helicopters is that it would allow the conventional turboshaft to be replaced with an electric motor. This would increase fuel efficiency when flying at high altitudes. The system could extract heat from its external environment or by burning fuel, as for other transport related versions of the invention.

Plenum chamber versions of the invention could be used for burrowing into water or methane ice provided that the working fluid remained active below the ice melting temperature. For this application the burrowing face(s) would be fitted with heating elements. When moving downwards under gravity, the under face would be warmed. When travelling back upwards, towards the surface, the upper surface would be warmed. An advantage of this system for research purposes is that the ice would seal again, over the chamber, as it descended. This would minimise the risk of biological contamination if the chamber formed part of a capsule used for taking biological samples from ancient ice covered lakes. The combined capsule would include space for a phase change material and the capsule would descend or ascend in stages. While stationary, heat would be extracted from behind the capsule to operate the invention and then, by means of a heating element, used to increase the enthalpy of the phase change material. Heat would then be extracted from the phase change material, to drive the invention, to generate electricity, to melt the ice ahead of the capsule. For burrowing work on ice covered regions of Earth, a sterile load can be added for the decent, so that the mean density of the capsule exceeded that of the surrounding ice. This would allow regelation (the re-freezing of ice after it has melted under pressure) to assist the decent. For the return journey to the surface, the load would be jettisoned so that the up thrust created by surrounding melt water exceeded the weight of the capsule. This would create a net pressure on the upper face of the capsule, allowing regelation to assist ascent.

Figure 25 depicts a version of the invention suitable for space applications. This is based on a plenum chamber version of the invention **1** that it is powered by incident solar radiation **2**, with the chamber being housed inside an infra red radiation absorbing gas tight container **3** filled with a heat transfer gas **4**. A large number of slivers of Mylar® or other flexible thin film material such as **5** float around inside the body of the thermal transfer gas. In the event of the outer container being punctured by micro meteorites or small items of space debris, the slivers nearest the hole are drawn towards it by the escaping gas. They plug the hole and are held permanently in place by internal gas pressure. A reserve source of gas can be used to replace the lost gas if required. In an alternative version of the invention the gas tight container is constructed from or lined with a self healing material, for example a complex multiblock copolymer polyurethanem. Space versions of the invention can be transported in flat pack form, with the various collapsible components each including pneumatic tubes that can be inflated by compressed gas in a similar manner to how pneumatic tube supported tents and other collapsible structures are currently erected. The metal conduit components can be hinged with pre-shaped flexible pockets being filled with expanding polyurethane foam or similar expanding materials on site, to smooth out sharp bends and reduce turbulence. This version of the invention could be anchored to asteroids to provide power for the mining of minerals, or for powering ion guns, to provide propulsion, to change the trajectories of asteroids. The ion guns could also be used to de-orbit a satellite at the end of its working life.

The features of the version as depicted in Figures 23 and 25 can be combined with the beam being installed inside a dirigible or air ship, with the beam being part of the support structure. In this example the Mylar® or other flexible thin film material would take the form of small helium filed balloons.

Figure 26 depicts a space application of the invention in which the invention **1** is at the focus of a secondary converging mirror **2**, receiving radiant solar energy from a primary converging mirror **3** that also acts as a solar sail. Solar radiation **4** exerts radiation pressure on the primary mirror, with the secondary mirror being required to ensure that the resultant absorption of solar photon momentum occurs in a direction away from the sun. Item **5** is the space probe. Tethers for example **6** connect the probe, mirrors and power generator in a state of dynamic tension. The parts of the invention that are illuminated by solar radiation have matt black outer surfaces to maximise absorption of radiation and the parts in shadow are silvered, to minimise radiant heat loses.

The ability of the invention to generate power in spite of large temperature gradients means that it will be able to function efficiently inside spacecraft that are covered with heat absorbing tiles, to prevent the craft overheating during rapid descents to earth or through the atmosphere of other planets. This will be especially important for future spacecraft that make large demands on their power systems during descent, to operate electromagnets, to produce ionised gas plasma shields, to create a braking force by providing drag. If used for manned trips to Mars, the onboard version of the invention could be removed from the craft after landing and used to provide life support power for the crew and provide electricity, for splitting water, to produce hydrogen fuel for the return journey. Likewise, the invention could be used to generate fuel to change the path of any icy asteroids that threaten to hit Earth.

Radiant heat absorbing versions of the invention may also be used to supply power to a future generation of high speed trains that travel inside tubes that are evacuated to a low air pressure. The evacuated inner tube could be surrounded by an air filled outer tube that fulfils the role of the outer casing of the plenum chamber version of the invention. The outer tube would be mechanically decoupled from the inner tube, such that the outer casing could move slightly on visco-elastic mounts in high winds.

Figure 27 depicts a version of the invention that has been modified to form part of a cryogenic temperature refrigerator. This incorporates design features revealed by the present inventor in his earlier patent application GB 0907998. It could be used for example, for cooling superconducting electromagnet windings.
Item **1** is a dual chamber displacement pump which operates as disclosed in the earlier application. A diaphragm pump is shown, but alternatively, a piston may be used to separate the two chambers. For the present application the pump is lagged and connected to a lagged cold chamber **2**. Valves **3** and **4** open to allow the easy flow of working gas from the cold chamber to the pump, but close, forcing the working gas to flow through one of the long narrow bore copper pipes **5** or **6** on their way from the pump to the cold chamber. The gas entering the narrow pipes has been pre-heated due to compression by the pump. It then suffers additional heating as work is done against friction, driving the gas through the narrow bore pipes. These two causes of heating reinforce each other: the pump compresses the gas instead of displacing it because of the pressure drop caused by drag as the gas flows at speed through the narrow pipes. The copper pipes are housed inside lagged beams **7** and **8**, which as for other versions of the present invention, can extract heat from the pipes and convert it into electricity. Item **9** is a heat exchanger. The cooled gas exiting from the copper pipes suffers further cooling in the cold chamber because the gas pressure drops as gas is drawn back into the pump behind the piston.
On successive strokes the gas inside the cold chamber tends to cool because each batch of gas flowing into the chamber benefits by being cooled on passing through the heat exchanger **9**. An equilibrium temperature is reached

inside the cold chamber when the cooling is balanced by heat flowing into the cold chamber through its walls and from items such as superconducting coils being kept cool inside the cold chamber.

The earlier application GB 0907998 explains how jet pumps can be used to simultaneously produce expansion in the cold chamber and displacement in the pump. The present invention is extended to cover this option.

This form of the invention will be useful for reducing evaporation losses from liquefied hydrogen during transportation. The rate of electromagnetic radiation emission from a surface is proportional to its emissivity and its Kelvin temperature raised to the fourth power. Even if the invention is only used to cool the outer walls of a containment Dewar flask to a temperature higher than the boiling point of hydrogen, the fourth power relationship will result in the net radiation transfer into the hydrogen being significantly reduced.

Figure 28 reveals a version of the invention also incorporating a dual chamber displacement pump **5** that can be used for liquefying the working gas. A feature of the cryogenic refrigerator version of the invention explained with reference to Figure 27 is that friction opposition to gas flow is used as an asset because it allows the gas to expand in the cold chamber. **Figure 28** depicts a version of this innovation in which friction inside the turbine unit **1** is used to create a pressure drop inside the cold chamber **2**. In order to reduce visual clutter, the pipes and other items outside the turbine unit are depicted in reduced size compared with the turbine unit. The turbine rotor consists of a series of sets of blades on the same shaft separated by flow straighteners, as explained with reference to Figure 6 above but with the turbine housing **3** and diameter of successive sets of blades gradually tapering so the flow speed remains approximately constant as the gas cools and increases in density, having done external work. (The taper is exaggerated for clarity in Figure 28.) The drag forces increase as the width of the taper decreases. Cooling by doing external work driving the generator **12** can be continued until a limit is reached where the frictional heating due to drag is equal and opposite to the cooling produced by doing external work. A Joule-Kelvin nozzle **4** is added so that the final stage of cooling and liquefaction only occurs after the turbine unit has been exited. As the working gas liquefies, replacement gas is pumped into the dual piston chamber **5** on the inlet stroke via pipes **6** and **7**. Gas that does not condense out in the cold chamber **2** returns to the piston chamber **5** via an outer jacket **8** that also acts as a heat exchanger, so that the returning gas gradually warms up by indirect contact with the gas flowing towards the cold chamber. This outer jacket is partitioned and valves for example **9** and **10** are added so that gas travelling back towards the side of the piston on the inlet stroke comes into thermal contact with out flowing gas. The liquefied gas is drawn off via a pipe **11**. The system is heavily lagged to minimise heat flow from the environment. Alternatively, it is placed inside a larger lagged chamber that supplies heat for use according to the invention.

Many industrial processes produce large amounts of waste heat as a consequence of carrying out operations at high temperatures and subsequently cooling the processed materials. The invention is extended to cover these and an illustrative example will now be given.

The process of refining metal ores generates large quantities of hot molten slag as a by-product. Efficiently recycling the latent and sensible heat released as the slag cools has not been possible prior to the present invention. The main reason for this is that as the slag cools in a cooling pit or trough, the outer surface solidifies first. This skin has a low thermal conductivity, resulting in the mass of slag cooling slowly over a number of days, with the temperature of the heat released being too low for conventional turbo-power generators too exploit. In most cases, the cooling process cannot be accelerated by quenching the molten slag with water because the resultant steam reacts with the slag to produce toxic sulphur dioxide gas.

Figure 29 reveals how the present invention overcomes these problems. A well insulated building **1** houses equipment for fragmenting, cooling and size sorting the slag. Two arrays of power generators according to the invention are employed to exploit the heat released by the cooling slag. These are external to the building and are not shown. The molten slag enters the building via a heated slag gutter **2** that is fitted with a rose, with thin streams of molten slag being sprayed out by the rose. Air that has been cooled by one of the arrays of power generators is fed into an air blast granulator **3** that breaks up the streams of molten slag, blowing the granules towards the far side of the building. The granules are crudely sorted with the smallest granules that include the least fraction of residual molten metal being blown the furthest away. Rotating blades **4** break up the largest slag droplets. They also provide a draft of additional cooling air and an upward force encouraging all the droplets to stay in the air slightly longer while they solidify. The crudely sorted, externally solidified droplets fall on to an array of chutes, for example **5**. Item **6** is also a chute. The chutes have hollow cores that are cooled by sprays of water. The water vapour is then used as fuel for one of the arrays of power generators. The density and size graded granules of slag and metal are then moved out of the building on conveyer belts, for example **7**. Air that has been heated by the falling and solidifying droplets is extracted at **8** and is used to power a second array of power generators according to the invention.

Sulphur dioxide has several important industrial applications, for example as a precursor to sulphuric acid. According to the invention, molten slag can be quenched by water in an enclosed chamber in order to produce sulphur dioxide gas, with the hot gas being cooled, compressed and then liquefied, with the sensible and latent liberated being used to power the invention.

Some industrial and agricultural processes would work more efficiently if low grade heat was removed. An example of how this can be done according to the invention will now be given.

Figure 30 explains how the present invention can be extended to convert a horticultural shadehouse into a combined power generating and fog catcher system for use in hot, arid but foggy climates such as that prevalent in northern Chile. Item **1** is a simple building structure covered with loose weave polypropylene, polyethylene, stainless steel or other fabric used for conventional fog catchers as known to engineers. Item **2** is the entrance to a covered trench that allows air to travel from inside the structure to a remote plenum chamber power generator according to the invention **3**. Item **4** is a fan with air permeable blades coated with a hydrophobic film and driven by a motor **5**, powered by the invention. The power generator can be used primarily to provide electricity for the local community. When demand is below maximum generator output the surplus electricity is used to drive the fan. This draws foggy air in through the loose mesh fabric with a significant fraction of the fog being captured as potable water. Plants inside the structure **6** capture a second fraction of the fog. The saturated air provides thermal energy for the invention, with further condensation occurring as a consequence of the air cooling. A final fraction of the fog is centrifuged off by the rotating fan blades and captured in a gully **7**. If the shade house interior is used for growing saplings, the position of the house can be changed and a fresh trench dug when the saplings are sufficiently bushy to act as fog catchers and be self supporting in terms of their water needs.

In order to emphasize that the invention extends to the use of liquids, especially water as the working fluid, a version of the invention that includes pumps relying on impulse blades will be revealed. **Figure 31** depicts a version in which impulse pumps **1**, **2**, **3** and **4** are used to drive the liquid round the loop.

Figure 32 depicts a solar, geothermal and other fuel based thermal energy storage system for a community power station according to the invention that will be of particular interest in cooler climates. It provides leisure benefits for the local community in order to make the power station more acceptable close to densely populated areas. A large double or multiple glazed building **1** receives solar energy **2** during daylight hours.

Large volume pools of water **3** and **4** act as thermal reservoirs storing solar energy for when the sun is not shining. One pool could double up as fish and water plant stocked indoor feature with the second pool **4** also serving as a swimming pool. A high level lagged pipe **5** delivers warm air to the turbine hall (not illustrated) where multiple power generators according to the invention are housed. Cooler air at a temperature just above 0°C that has passed through the turbine hall re-enters the building through pipe **6**, optionally via a controlled choice of paths, including through air and stretches of sea water, river or an external lake where it is partially re-warmed. The pipe surrounded by air could be lagged, with the lagging split lengthwise in the manner of an oyster shell, with the inner surface of the lagging having a reflecting surface, so that, in the open position, the silvered surfaces reflect solar energy on to the pipe. The lake would store solar energy and also low grade geothermal energy from the earth below. In winter this pipe would help to chill the lake water, promoting ice formation on the surface for ice skating purposes. Alternatively, the air could be compressed inside the turbine hall, with the heat of compression being used as fuel. The compressed air would then be allowed to expand inside a diverging metal pipe, with the resultant cold air being used to cool brine below 0°C, for ice making purposes, for an ice rink. This pipe may include heat exchange fins inside the building so that the air re-enters the building at a temperature close to the ground level temperature inside the building. A lagged geothermal energy heated warm water reservoir **7** re-circulates the water and provides additional thermal energy to the swimming pool during cold weather. Item **8** is a second reservoir providing similar thermal benefits but with the water storing thermal energy at a higher temperature. A heating pipe **9** is used to move combustion fumes, water or other known heat transfer fluid through **8**. The primary heat would be obtained by burning some form of fuel, preferably local waste materials and bio-fuel grown in a local community forest. The combustion gases would preferably be captured and carbon dioxide extracted with a net release of thermal energy using a gas cooling version of the present invention. The space above the water line in **8** could be used as a sauna **10**. The controlled release of a small fraction of the heat from **8** would provide under floor heating for a community activity area **11** in cold weather. For example, this area could provide space for a cafe, games area, senior citizen's club and children's playground. The floor temperature could be controlled in a similar manner to the system revealed for motor vehicles above with reference to Figures 21 and 22. The community area could be illuminated with low level UVB radiation so that visitors obtain its health benefits, without running an excessive risk of contracting skin cancer.

Claims

A heat engine inside a mechanical engine

1. A reversible mechanical engine that absorbs heat to conserve total energy, capable of efficiently converting heat or thermal energy into mechanical work and then generating electricity in spite of a large temperature gradient existing between the heat source and the interior of the engine, with the thermally conducting engine walls enclosing a working fluid travelling round a closed conduit loop including a plurality of constrictions with turbines coupled to electricity generators being placed at the throat of each constriction, with fans or other types of pumps being used to overcome drag, with additional work being done by the fan to accelerate the fluid to overcome reverse expansion of the fluid, against the direction of flow as it expands on re-warming, with the fan doing fractional additional work against the back pressure caused by the fluid impacting on the turbine blades, characterised by heat being required to maintain the steady state process, rather than initiate it, with the engine operating in accordance with a novel thermodynamic cycle, with the cycle having a related enthalpy-pressure chart for a single turbine version of the invention showing an increase in enthalpy and pressure as the fan does work on the fluid, with enthalpy and pressure falling as the fluid travels through a tapered tube towards a constriction, with fluid kinetic energy increasing, with there being a further fall in enthalpy and pressure as the fluid passes through the turbine and does work, with the enthalpy and pressure increasing again as the fluid passes through the diverging section of the constriction, with the kinetic energy falling, with there being a further increase in enthalpy and pressure due to heat flowing through the conduit walls, with the fluid passing through the fan a gain, so that, in the steady state, when the rate of electricity generation is balanced by the inflow of heat through the conduit walls, the cycle is repeated, with thermal feedback ensuring that just sufficient heat enters the invention to compensate for the net power generated, with the thermodynamic cold reservoir being inside the invention, so that heat rejected into the cold reservoir is recycled and not wasted.

2. A reversible mechanical engine that initiates heat flow according to the first claim including runners consisting of successive rings of turbine blades (with a ring being defined as a plurality of radial blades that rotate in the same sense, in the same plain perpendicular to the incoming fluid, before the fluid is deflected by the presence of the blades) in series, inside a length of parallel sided conduit, at the throat of a throttling constriction, with the turbine shaft or shafts being connected to a plurality of generators, with the turbines

extracting kinetic energy from a moving fluid by momentum transfer, with the continuous flow behind the blades causing lift and with the blades also having an aerodynamic profile so that they create additional lift, with the fluid cooling rather than suffering a reduced rate of mass flow, with the fluid exiting the throat via a diverging length of conduit and being re-circulated through a closed conduit loop and the fluid being returned to its original thermal state by the addition of heat transferred from a second warmer fluid, external to the conduit, with the second fluid being separated from a primary heat source by a solid heat exchange boundary, characterised by the temperature drop across this primary heat exchange boundary being large and of the order of tens or hundreds of Kelvin, thus allowing the cross section surface are of the boundary at right angles to the heat flow to be correspondingly reduced or the thickness of the solid boundary increased compared with existing power generator heat exchange boundaries where the temperature gradients are required to be as small as possible, in order to maximise the thermodynamic efficiency of power generating heat engines receiving energy from a primary heat source.

3. A reversible mechanical engine that initiates heat flow according to the first claim, with the primary thermal energy originating inside a molten salt nuclear reactor, with thin walled heat transfer pipes carrying molten salt though a trough of water that boils at about atmospheric pressure, to provide thermal energy in the form of latent heat stored in steam for the generators, with the large temperature gradients across the walls of the heat transfer pipes permitting simple short lengths of pipe to be used, which in turn allows the molten salt to circulate through the reactor and heat transfer pipes under conditions of natural convection.

4. A reversible mechanical engine that initiates heat flow according to the first claim, with the primary thermal energy originating inside a molten salt nuclear reactor, with the reactor being immersed almost up to full height in a water jacket, with the water being heated by heat flow through the thick walls of the reactor, with the water boiling at about atmospheric pressure, to provide thermal energy in the form of latent heat stored in steam for the generators.

5. A reversible mechanical engine that initiates heat flow according to the first claim, with the primary thermal energy originating inside a molten salt nuclear reactor, with the reactor being immersed almost up to full height in a water jacket, with the water being heated by heat flow through the thick walls of the reactor, with the water boiling at about atmospheric pressure, to provide thermal energy in the form of latent heat stored in steam for the generators, with the hoop stresses in the thick reactor walls being reduced to an

acceptable safety maximum by constructing the roof, side walls and base in the manner of a series of close fitting nested containers, with the containers being constructed sequentially, moving out from the centre of the nest, from strong high melting point metal, for example Hastelloy-N or steel and a soft malleable metal, for example lead, with the soft metal flowing in directions that reduce the hoop stresses.

6. A reversible mechanical engine that initiates heat flow according to the first claim, with a plurality of turbine units, with each turbine unit being housed inside a different throttling section of conduit, these being linked in series in the form of a daisy chain, with replacement heat being drawn in through the conduit walls, with fans or other devices being used as pumps outside the throttling sections of the loop to overcome resistance to fluid flow, with the chain having right angle corners, with centrifugal pumps being mounted at the corners to serve the dual purpose of overcoming unproductive friction on pipe bends and turning the direction of fluid flow through a right angle.

7. A reversible mechanical engine that initiates heat flow according to the first claim, including centrifugal pumps wit the fluid exiting at the blade tip end of the pumps travelling faster than the fluid towards the root end of the same blade, with the following converging section of the conduit converging asymmetrically so that elements of fluid leaving different parts of a fan blade simultaneously arrive at the anterior set of turbine runner blades simultaneously.

8. A reversible mechanical engine that initiates heat flow according to the first claim, with a plurality of rings of turbine blades being mounted in series on the same shaft with flow straighteners being inserted between each ring of turbine blades to correct the unwanted swirling of the working fluid caused as a reaction, as the fluid passes through each ring of turbine blades.

9. A reversible mechanical engine that initiates heat flow according to the first claim, with a plurality of rings of turbine blades being mounted in series on different shafts with successive rings of blades rotating in opposite senses so that the rotational kinetic energy gained by the swirling fluid as a result of its transit through the first ring of blades is harvested by the second ring of blades, with the rotational kinetic energy possessed by the swirling fluid as a result of its transit through the third ring of blades is harvested by the fourth ring of blades and so on, up to the end of the series of turbine blade rings.

10. A reversible mechanical engine that initiates heat flow according to the first claim, with an odd number of rings of turbine blades being mounted in series on different shafts with successive rings of blades rotating

in opposite senses so that the rotational kinetic energy possessed by the swirling fluid as a result of its transit through an upstream axial fan is harvested by the first ring of blades, the rotational kinetic energy possessed by the swirling fluid as a result of its transit through the second ring of blades is harvested by the third ring of blades and so on , up to the end of the series of turbine blade rings.

11. A reversible mechanical engine that initiates heat flow according to the first claim, with the turbine blade rims of at least some rings of turbine blades being anchored to the inner curved surface or surfaces of one or more freely rotating axial cylinders which collectively also act as a constriction throat, with the rotating parts of the generator(s) such as the exciter armature, rectifying diodes and main field being mounted coaxially on the external curved surface of the cylinder or cylinders.

12. A reversible mechanical engine that initiates heat flow according to the first claim, with the turbine blade rims of a plurality of rings of turbine blades that are all rotating in the same sense being anchored to a plurality of curved surfaces of freely rotating cylinders which also act collectively as a throat, with the centre of rotation of each ring of blades housing a bearing that are used to support a rotating shaft attached to a plurality of rings of turbine blades that are free to rotate in the opposite sense to the blades mounted on the internal rim of the cylinder or cylinders.

13. A reversible mechanical engine that initiates heat flow according to the first claim, with the turbine blade rims of a plurality of rings of turbine blades that are all rotating in the same sense being anchored to a plurality of curved surfaces of freely rotating cylinders which also act collectively as a throat, with a rotating shaft attached to a plurality of rings of turbine blades that are free to rotate in the opposite sense to the cylinder wall mounted blades passing through clearance holes in the centres of successive cylinder wall mounted blades with the tips of the shaft mounted blades being supported and running in ball races mounted in the inner wall of the rotating cylinder(s).

14. A reversible mechanical engine that initiates heat flow according to the first claim, with at least some of the turbine blade rims anchored to the inner curved surface(s) of a plurality of freely rotating cylinders which also act collectively as a constriction throat, with the blades being hollow and open where they are mounted on the cylinder with the blades including slits or other types of apertures with passageways from the wider parts of the conduit allowing the throat pressure drop effect to draw in a fraction of the working fluid and then motivating it to flow out of the turbine holes and over the blades in order to reduce skin friction.

15. A reversible mechanical engine that initiates heat flow according to the first claim, with the turbine blade rims anchored to the inner curved surface(s) of a plurality of freely rotating cylinders which also act collectively as a constriction throat with the blades being hollow and open where they are mounted on the cylinder with the blades including slits or other types of apertures with passageways from the wider parts of the conduit allowing the throat pressure drop effect to draw in a non-corrosive electrically insulating liquid, with the liquid spreading out over the blades via holes in the blades, to reduce skin friction, then eventually settling out under gravity in pools, with liquid from the pools being drawn back into the turbine blades by a working gas pressure difference.

16. A reversible mechanical engine that initiates heat flow according to the first claim, with the diameter of each fluid throttling throat being reduced in small steps, with a step being introduced after each ring of turbine blades except the last, in order to maintain a steady fluid speed between turbine rings as the fluid cools and its density increases.

17. A reversible mechanical engine that initiates heat flow according to the first claim, with a plurality of hollow gas filled civil engineering or mode of transport structural strengthening beams incorporating at least one oscillating piston the sweeps out a fraction of the length of the interior of one of the beams with the compressed gas ahead of the piston being driven through a plurality of electricity generating turbines also inside a beam.

18. A reversible mechanical engine that initiates heat flow according to the first claim, with the generator being powered by heat released as drops of molten slag cool and solidify, with the droplets being formed from vertical streams of molten slag that are broken up by powerful blasts of air that have a horizontal component that also crudely size and density sort the granules formed as the droplets solidify, with the granules landing on chutes, with the smallest and lowest density granules falling on to chutes that are at the greatest distance from the line of fall of the original streams of molten slag.

Intellectual Property Office

Application No:	GB1418029.3	**Examiner:**	Mr Sean O'Connor
Claims searched:	all	**Date of search:**	21 November 2014

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1, 2, 6, 9, 11-13 at least	GB 2494888 A (COURTNEY) See whole document, particularly discussion of figure 7.
X	1, 2, 6, 9, 11, 12 at least	WO 2012/007705 A1 (COURTNEY) See whole document, particularly figure 1 and 9a and description thereof.
X	1, 2, 11 at least	WO 2007/129006 A2 (COURTNEY) See whole document, particularly discussion of figures 1, 4, and 5.
X	1 at least	GB1565944 A (CZAJA) See abstract, and figures 3 and 6, and description thereof. Note turbine arranged at nozzle throat.
A	-	US 4878349 A (CZAJA) See whole document; note turbine 13 arranged at throat of CD nozzle.
A	-	WO 2014/111577 A2 (CHAN) See whole document; note turbine 21 arranged at throat of CD nozzle.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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International Classification:

Subclass	Subgroup	Valid From
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