Latent Power Turbines™

Courtney. W, West. R,
Latent Power Turbines Ltd
Dalrymple. S, Arch. J, Nichol. M.
C-Tech Innovation Ltd

© Latent Power Turbines Ltd
April 2015

Project summary

A Latent Power Turbine is a heat engine inside a mechanical engine.

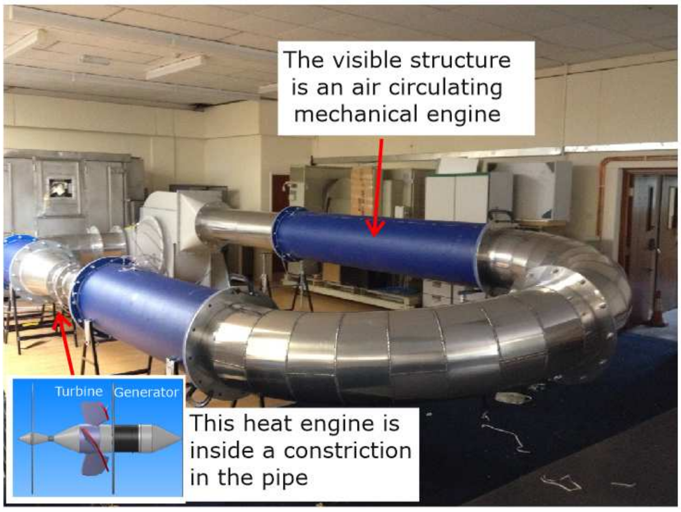

Figure 1. Our proof of concept Latent Power Turbine.

The introduction of an air circulating mechanical engine allows a Latent Power Turbine to deliver a higher efficiency than the Carnot equation predicts without violating the laws of thermodynamics.

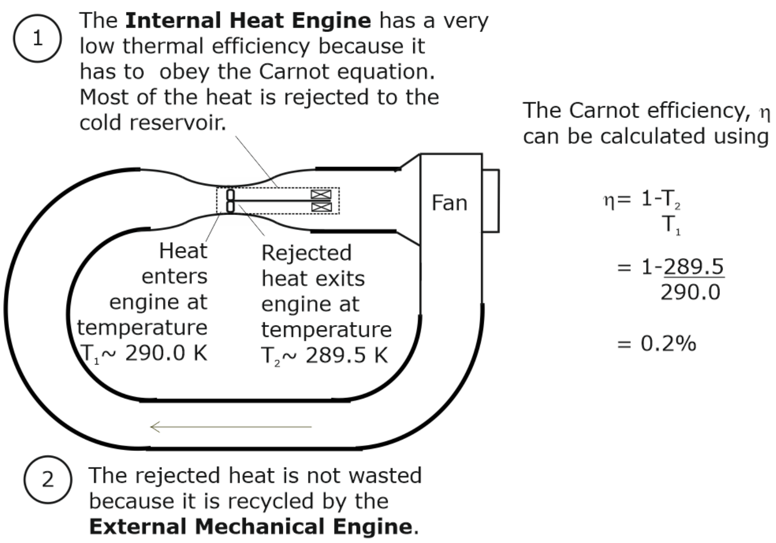

Figure 2. The internal heat engine must obey Carnot's equation and at the intended operating temperatures has an extremely low thermal efficiency. However by using an external mechanical engine to recycle the rejected heat, the external mechanical engine mimics the behaviour of an extremely efficient heat engine.

The theory of operation suggests that Latent Power Turbines have the potential to:

(i) Generate electricity by extracting heat from room temperature air.
(ii) Deliver air cooling in warm environments as a bonus.

At the end of the project we concluded that

The Latent Power Turbine concept is valid.
But a bespoke turbine design will be required
to deliver a net output of power.

We made four predictions about how the rig would behave.
Three were met; the fourth, relating to a net output of power failed.

Patent protection is listed as references [1-5] below.

****

Early research

TSB funded project 130037, Lancaster University, 2009-10. [6]

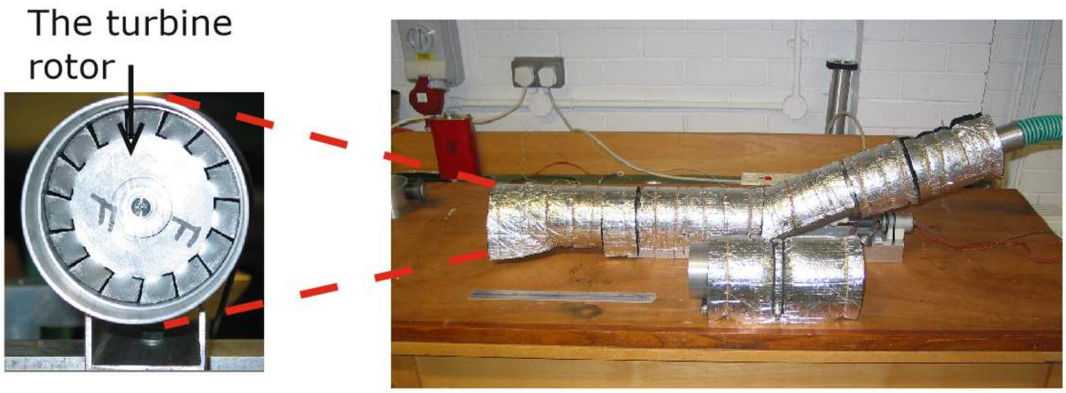

Figure 3. The test rig for the Lancaster University research 2009-10. The rig was designed to simulate the thermodynamic processes inside a hurricane.

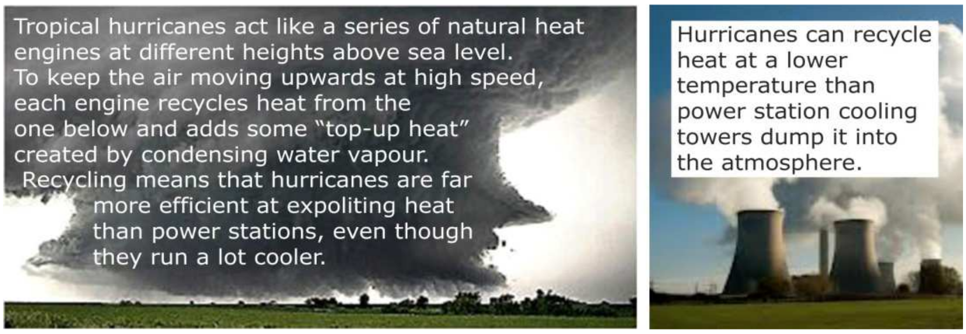

Figure 4. Hurricanes ***appear*** to be more efficient than a Carnot engine because they receive a steady supply of "top-up heat" produced as the moist hurricane air cools and latent heat is liberated.

Our aim was to demonstrate that by mimicking hurricane action it should be possible to harness the latent heat stored in steam turbine exhaust vapour.

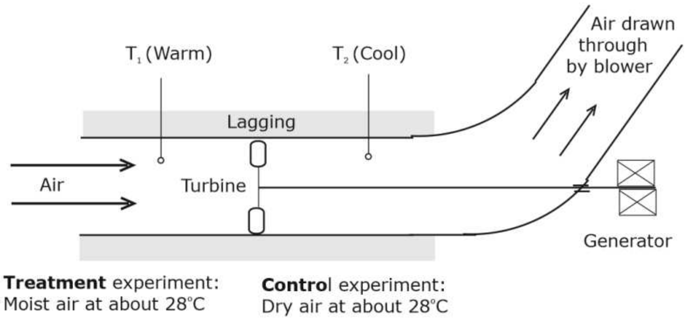

Figure 5. The turbine rotor throttled the air in the manner of a Venturi constriction. This meant that the dynamic air pressure dropped and the air transited the turbine blades at a lower temperature than 28°C. It was impractical to measure the air temperature at the location of the moving blades. So we estimated this by using the Bernoulli equation to estimate the drop in pressure and equating the gain in kinetic energy to a fall in internal energy.

The gases investigated are compressible. Nevertheless, changes in pressure can be estimated with a fair degree of accuracy using Bernoulli's equation. This states that for an incompressible, non-viscous fluid undergoing steady flow, the pressure **(p)** plus the kinetic energy per unit volume (**1/2**x density, **ρ** x velocity, **v** squared) plus the potential energy per unit volume (density, **ρ** x acceleration due to gravity, **g** x height **h**) is constant at all points on a streamline.

Thus,

$$\mathbf{p + 1/2\rho v^2 + \rho g h = A\ constant}$$

We argue that this equation requires a correction term for the moist air calculations.

Any tendency to cool on passing through the rotor would result in the production of small condensation droplets and the release of latent heat. Consequently, the temperature and pressure drops would be reduced compared with the flow of dry fluid. On exiting the rotor, the latent heat processes would be reversed, with heat being absorbed as the water droplets evaporated.

In order to produce an equation that allowed for the release of latent heat an additional term dQ_l /dV was added. The term dQ_L /dV represents the latent heat lost/gained per unit volume of static fluid. Thus the generalised form of Bernoulli's equation is

$$\mathbf{p + 1/2\rho v^2 + \rho g h - dQ_L /dV = A\ constant}$$

Volume was used as part of the correction term, to ensure dimensional consistency.

When condensation occurs and latent heat is liberated, the minus sign is retained in front of the latent heat term. A positive sign is used if evaporation occurs and latent heat is absorbed.

The literature search did not find any references to a Bernoulli equation correction term for latent heat, but revealed several references to a correction term for sensible heat changes, for example, Segletes and Walters [9].

Prior to the Second World War, research was done into condensation inside turbines, but with the view to eliminating it as a nuisance. In 1937 Binnie et. al. [10, 11] investigated the steam pressure drop in convergent-divergent nozzles. They noted that under certain circumstances condensation occurred close to the throat of the constriction, with the release of latent heat and a sharp increase in pressure. Bennie's experimental results are consistent with our correction term.

Summary of our Lancaster University experimental results

(i) The moist air experiments were expected to deliver a measured efficiency *higher* than that calculated by the Carnot equation.

(ii) The dry air experiments were expected to deliver a measured efficiency l*ower* than that calculated by the Carnot equation.

In reality, both experiments appeared to deliver a higher efficiency than calculated using the Carnot equation.

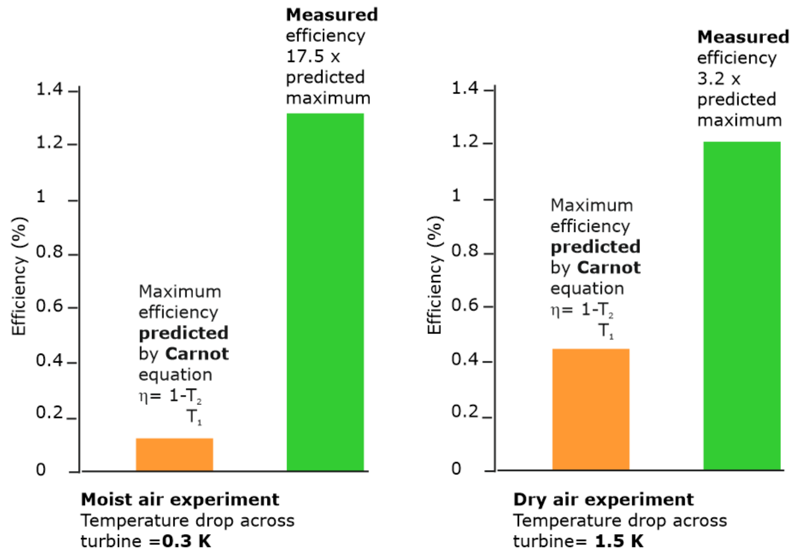

Figure 6. The dry air experiment also created an illusion that the Carnot equation had been violated.

The diagram below indicates three mechanisms that may be responsible for creating this illusion.

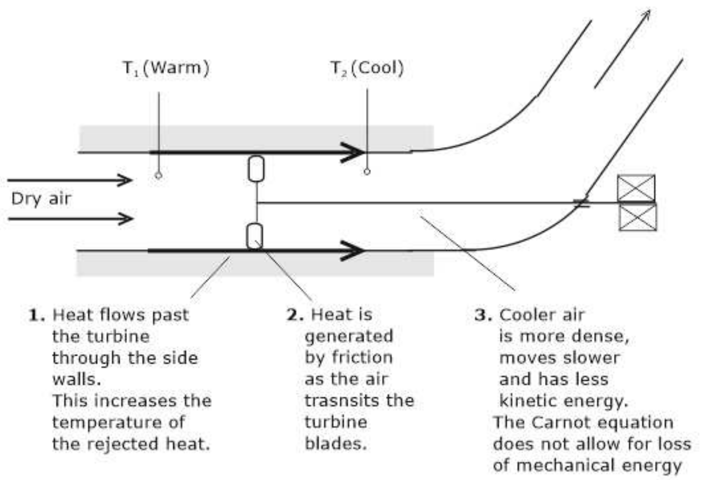

Figure 7. Three possible explanations for the anomalous dry air results.

None of these mechanisms appeared to be of great practical use but they were important because they allowed us to break free from conventional thinking on gas and wind turbine design.

In particular we considered the possible merits of placing a small wind/gas turbine inside a throttling constriction.

We were inspired by an ancient method for cooling buildings in hot climates.

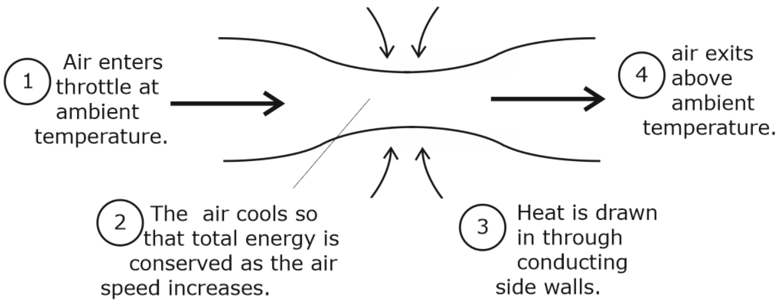

Figure 8. The Venturi heat pump effect.

This throttling concept has been exploited for cooling in hot climates for many centuries.

In the laboratory a fan or pump is required to pull the air through the constriction.
In hot climates, a low pressure region behind a building, in the lee of the wind, is used to draw air through the building.

We decided to take the concept one stage further by placing a turbo-generator type heat engine inside the constriction region.

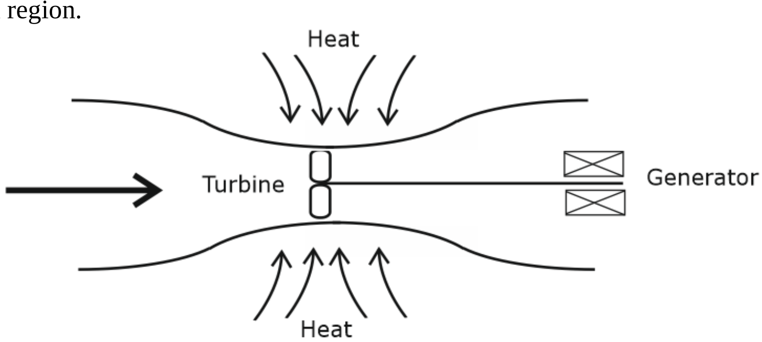

Figure 9. A heat engine inside a Venturi heat pump.

Additional cooling is produced as the turbine does work generating electricity. But, the addition of the turbine creates extra drag, so the pump has to work harder.

To achieve meaningful results it was necessary to scale up the design, to reduce work done against drag as a fraction of power output.

****

The current Latent Power Turbine project

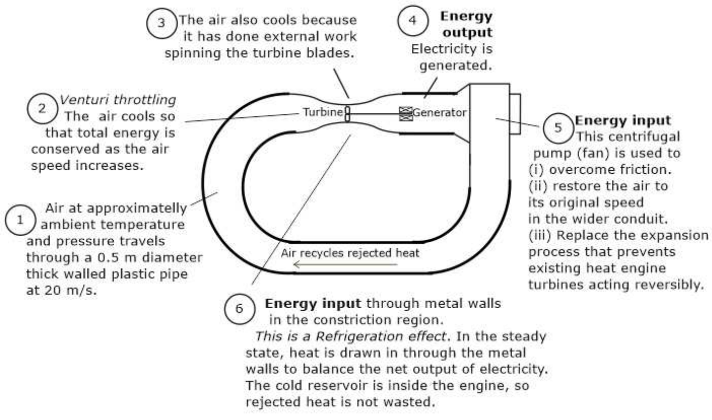

Figure 10. The Latent Power Turbine concept.

Our original plan was to drive the air through the wider part of the conduit at 20 m/s.
But,
(i) the cannibalised air conditioning fan that we used as a turbine rotor
and
(ii) the segmented bends that were installed to keep within budget,
combined to reduce the air speed to well below this value.

The Black box equivalent of an LP Turbine™

The diagram below shows a heat engine black box inside a mechanical engine black box.

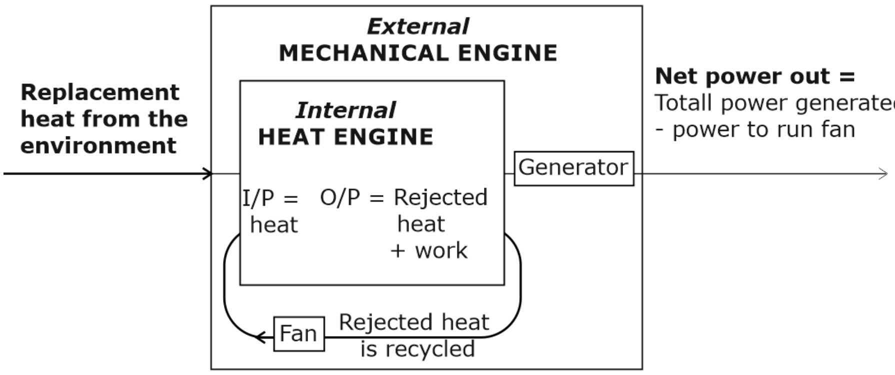

Figure 11. The internal heat engine must obey the Carnot equation and has a low thermal efficiency. But the external mechanical engine presents the *illusion* that it is a 100% thermally efficient heat engine.

1 Key outcomes from the present project

The rig was used in four different configurations during the project.

(i) **Open loop**.
Our aim was to obtain information about the fundamental level of drag before the turbine was added and the loop completed.

(ii) **Closed loop, but *without* the turbo-generator installed**.
This allowed baseline airspeed measurements to be made before the turbo-generator was added.

(iii) **Closed loop *with* the turbo-generator installed**.
This delivered results consistent with theory but the turbine rotor produced a lot of drag and the power output was low.

(iv) **Closed loop + turbo-generator + stator blades to direct the air on to the turbine blades at a more efficient angle.**
This did improve turbine efficiency but at the unacceptable cost of significantly increasing drag. So overall, there was a net reduction in power output.

We made four predictions. Three of them were met.

1.1 First prediction

The power generated will exceed the power possessed by the air in the wider conduit due to its kinetic energy.

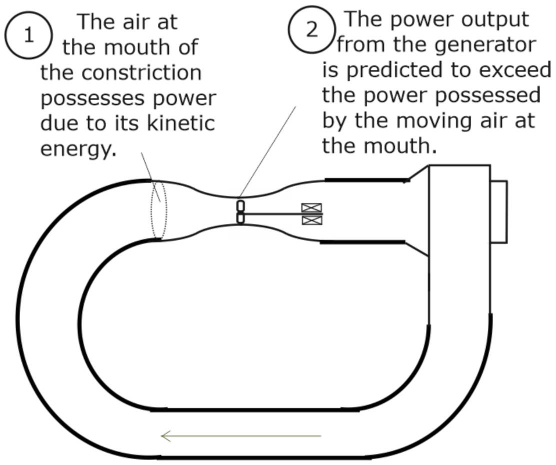

Figure 12. This prediction was fulfilled. But the turbo-generator only delivered about 10% of its theoretical maximum output. We assume that this was due to poor turbine design.

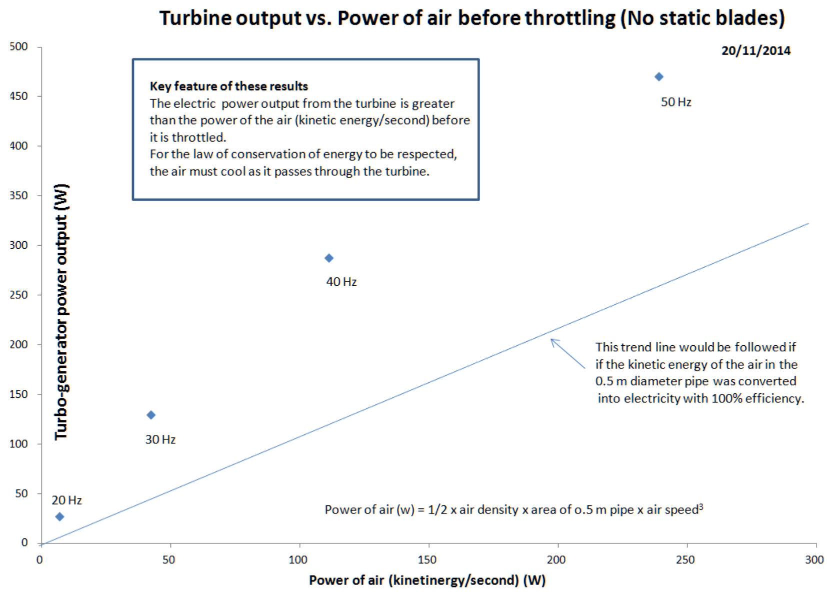

Figure 13. The four data points show the measured power output. They are consistently above the 100% trend line. This enables us to claim that,

> The power generated exceeds the power possessed by the air due to its kinetic energy before throttling.

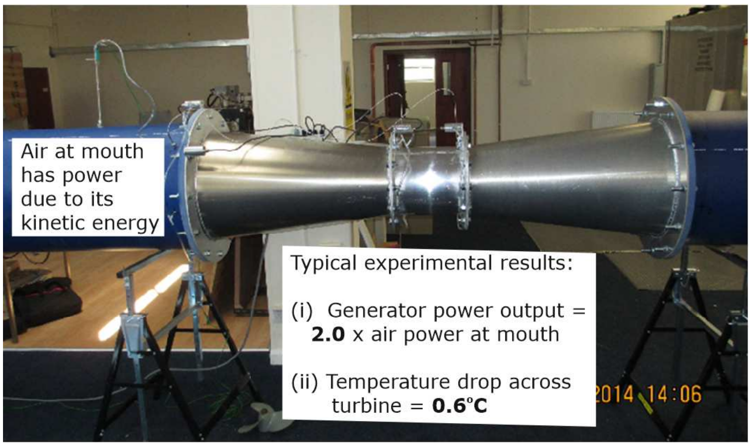

Figure 14. The first prediction was fulfilled in all of the power generating experiments that we carried out.

1.2 Second prediction

The LP Turbine will simultaneously generate power and produce a refrigeration effect, cooling its environment.
This prediction was fulfilled.

In order to obtain the results shown in Figure 16 below, an environment chamber was built around the metal walled throttling section of the loop and a heater used to raise the temperature to well above room temperature.

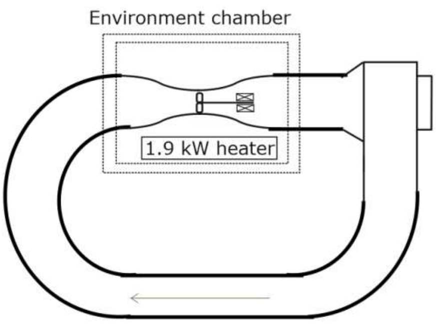

Figure 15.

(i) The heater was switched on and the excess temperature inside the chamber stabilised at +34 °C (K) after twenty minutes.

(ii) The excess temperature fell by 4 °C to +30 °C when the fan was running at 45 Hz and the turbo-generator was running to generate 307 W of electricity.

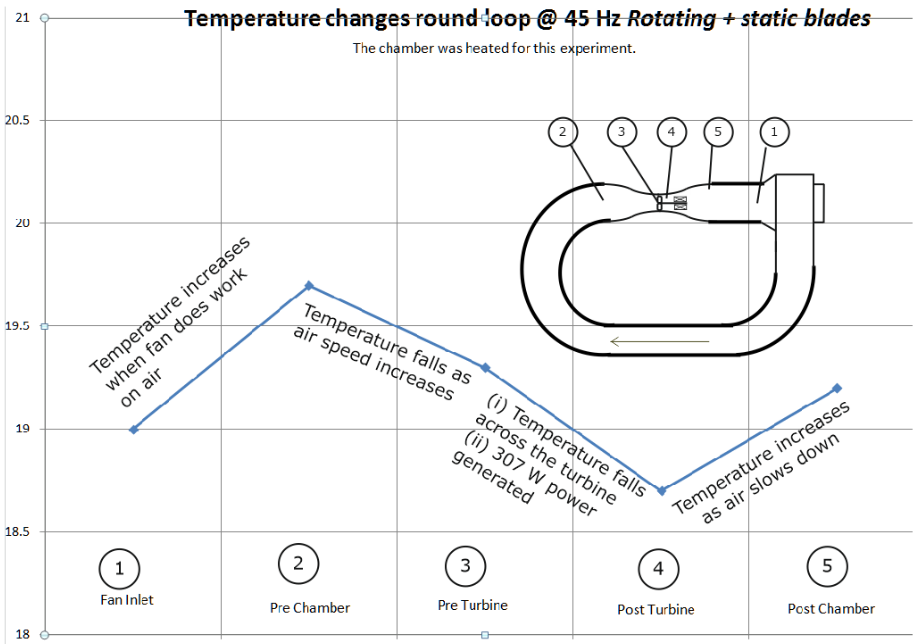

Figure 16. The Latent Power Turbine generated electricity and cooled the heated air inside the chamber.
\
Figure 17 below shows the same data as Figure 16 but with additional notes about the cooling processes.

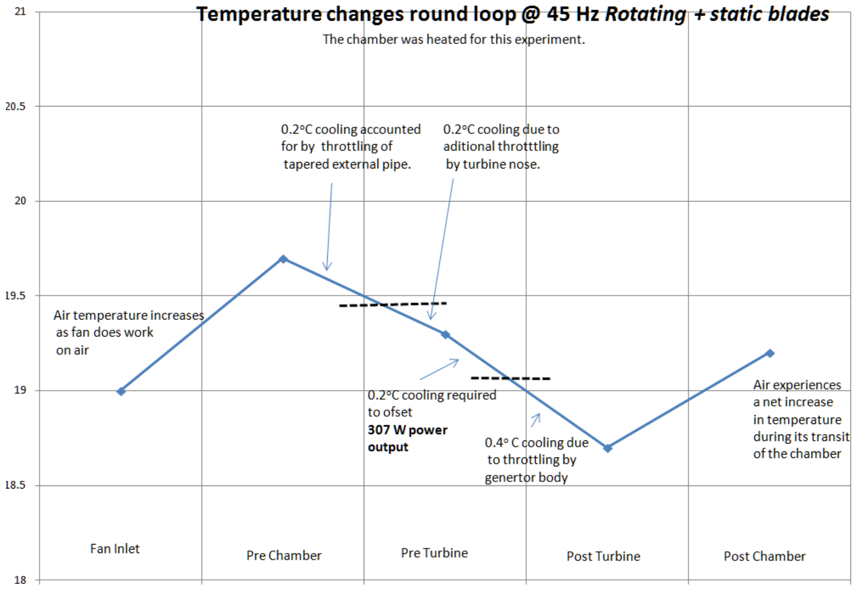

Figure 17. The expected thermal energy lost was calculated using values for the specific heat capacity of the air at constant pressure and the rate of mass flow.

1.3 Third prediction

A common concern for engineers we have talked to was that the temperature differences across the conduit walls were so small, that the heat flows would be negligible.

To counter this scepticism we predicted that,

> Even when the temperature gradients are small, sufficient heat will flow through the constriction side walls to allow the system to deliver combined power generation and air cooling.

We tested this prediction by removing the environment chamber and heater so that the temperature difference between the inside and outside of the constriction walls was as small as we could make it.

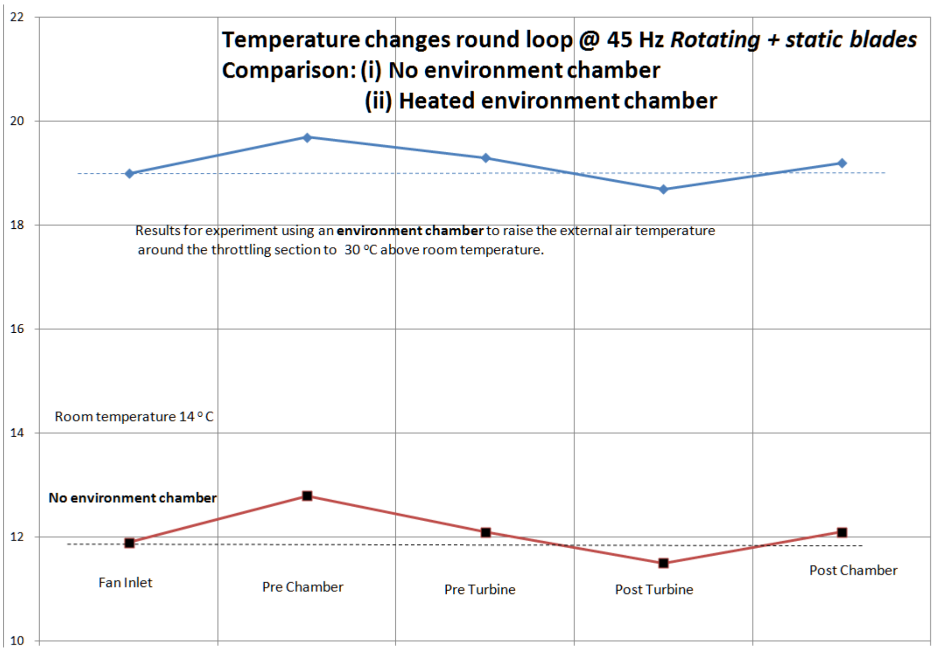

Figure 18. Even when the temperature gradient across the conduit walls was small, combined power generation and air cooling was still exhibited.
Below, we examine the subtle differences in temperature profiles in detail.

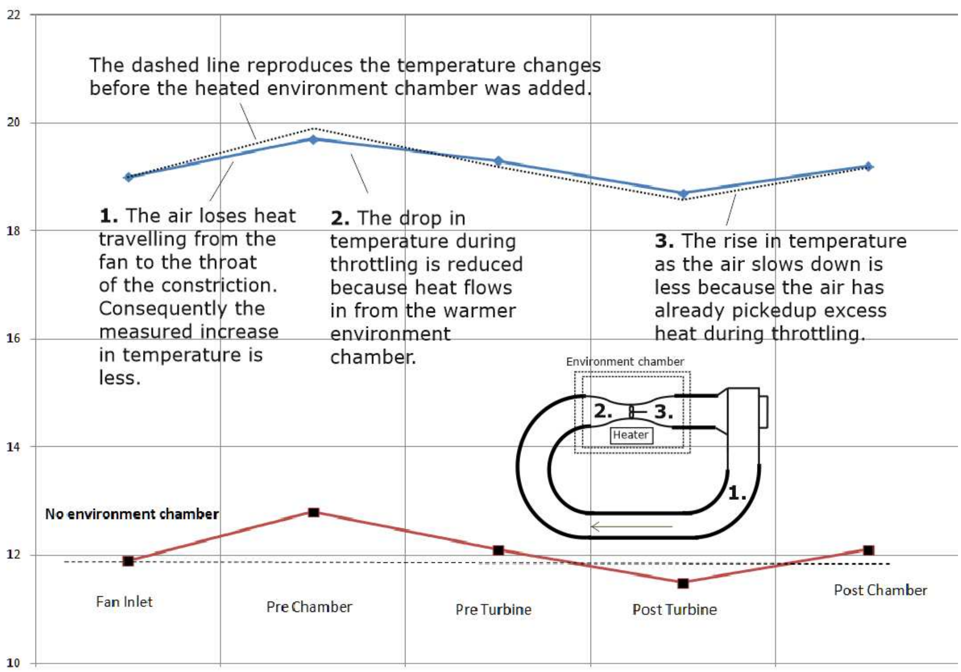

Figure 19. The small differences in temperature profiles are consistent with LP Turbine theory.

1.4 Fourth prediction

The power output from the generator will exceed the power input to the fan.

This prediction was clearly not met because the power demand made by the fan was approximately ten times higher than the power generated.

The failure to meet this prediction was put down to the low turbine efficiency combined with the large amount of drag.

Here is a clue that suggests why our design was inadequate.

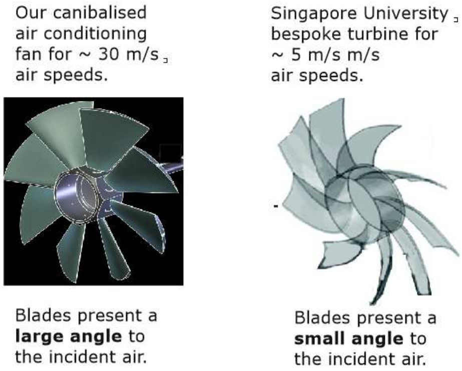

Figure 20. As for our work, the Singapore turbine was housed inside a parallel sided pipe.

We have written to the corresponding author of the Singapore University research paper [8] twice requesting comments on our turbine design But no reply has been received.

2 Additional outcomes from the project

2.1 Open loop results – No turbine

(i) Velocity profile across pipe

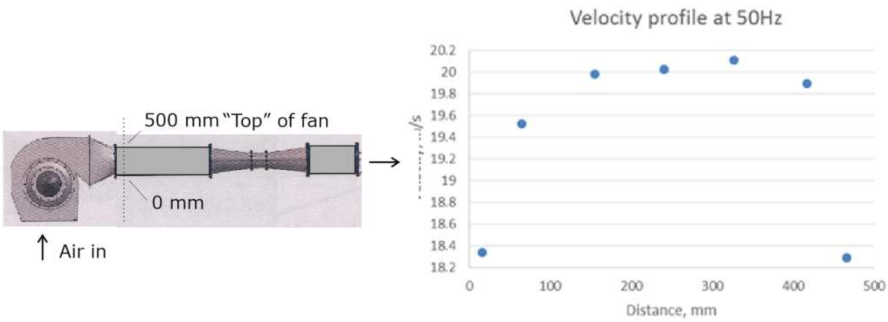

Figure 21. The profile indicated that when the fan was used to *push* the air through the constriction region, the flow rate was higher towards the top of the fan.

(i) The practical outcome was that we decided to reposition the fan so that it *pulled* the air through the constriction.

(ii) In a patent application filed the following month [5] we revealed (among many other novel features) how this asymmetrical air flow profile could be countered without the need for a long air flow stabilising pipes by employing an equal and opposite asymmetrical taper in the throttling region.

(iii) Average velocity for different fan speeds

Velocity in m/s			
	Fan Speed		
Position	41Hz	50Hz	60Hz
0.968d	14.9	18.2	22
0.865d	21	25.8	29.7
0.679d	21.1	26.5	30
Average	16.3	20.1	23.4

For comparison, the average wide pipe velocity at 40 Hz fell to 7.7 m/s when the loop was completed and the turbine added. It then fell further to 7.3 m/s when the static deflector blades were added. This figure is slightly misleading in favour of the closed loop values because in the open loop experiments, the fan has to do extra work ejecting moving air from the pipe against the opposition of a static atmosphere.

To a first approximation, the power possessed by the air due to its kinetic energy = ½ x ***dm*/*dt*** x $\boldsymbol{v}^2$. Where ***dm*/*dt*** is the rate of mass flow and ***v*** is the average air speed.

dm*/*dt = cross section area of the pipe x air density x ***v***.

This means that the power due to kinetic energy varies with $\boldsymbol{v}^3$.

Consequently the approximate 50% reduction in air speed caused by closing the loop and adding the turbine reduced the power possessed by the air **by a factor of 8**.

[A more precise calculation would require the average speed to be replaced by the root mean cubed speed.]

2.2 What form of energy transfer should the turbine employy - *momentum transfer or aerodynamic lift?*

Momentum transfer implies that the moving air impacting on the front face of the turbine blades *pushes* the blades around.

If the blades have an **aerodynamic profile** so that air travels round the back of the blades faster than the front, then the lower air pressure behind the blades *pulls* the blades around.

Funded by a £5,000 innovation voucher, Sheffield University [7] modelled aerodynamic lift for us.

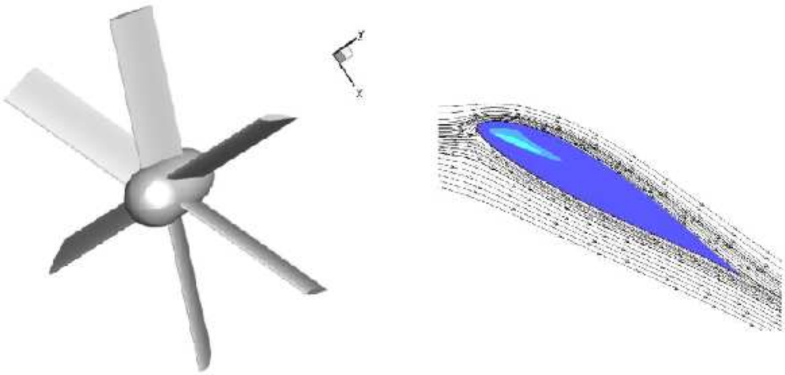

Figure 22. Illustrations from the Sheffield University report [7].

The Sheffield design called for the blades to have an aerodynamic profile so that the air travelled over the two faces of the blades at different speeds. In contrast, momentum transfer did not require aerodynamic profiling.

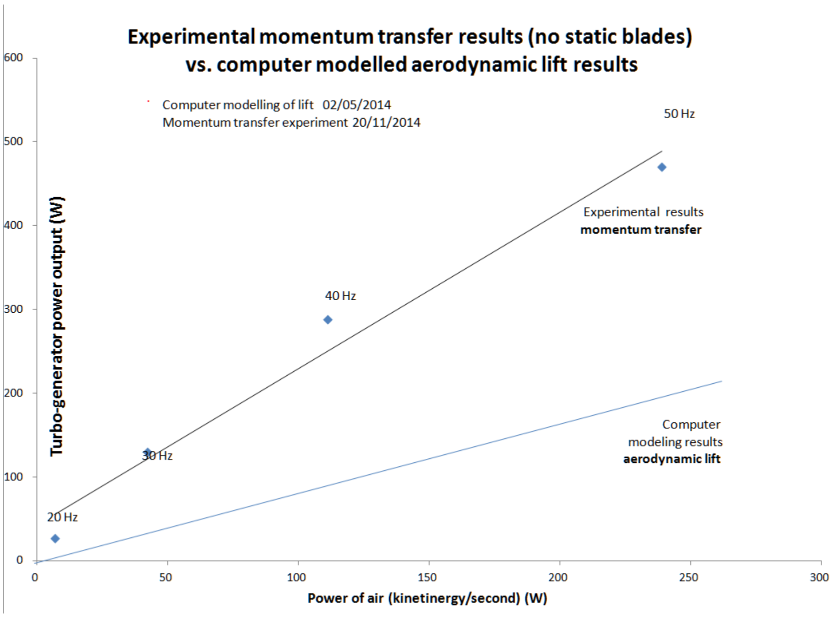

Figure 23. Momentum transfer delivered superior performance to aerodynamic lift.

With the benefit of hindsight, the reason for the poor performance of the aerodynamic lift design became clear. Throttling the air increased its speed, increasing the lift per unit area of blade. But this was largely offset by the reduction in blade size.

It is likely that the turbine rotor used for the project did in fact benefit from lift, but not in a manner that relied on the blades having an aerodynamic profile.

This is how we think that lift was generated:

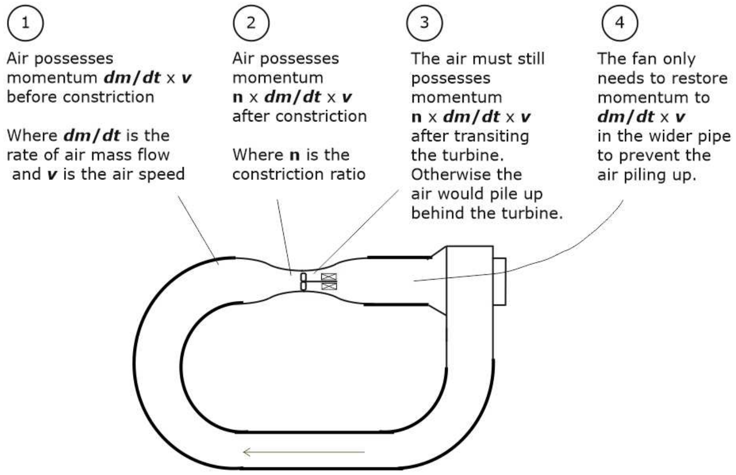

Figure 24. Strictly speaking, based on our Lancaster research, there is a slight drop in momentum after transiting the turbine because the air has cooled and its density has increased.

If we consider this argument in energy terms, then:

(i) The kinetic energy on exiting the turbine has to remain at *about* ½ x ***dm/dt*** x $(nv)^2$.
[We insert the word *about*, because the air density has increased.]

(ii) But the fan only has to restore the kinetic energy in the full width section of the pipe to ½ x ***dm/dt*** x v^2.

(iii) The difference in kinetic energies is ($\mathbf{n}^2$-1) x ***dm/dt*** x v^2.

(iv) The extra kinetic energy appears at the expense of the air cooling while transiting the turbine. [It is this acceleration of the air across the turbine that causes the temperature drop across the turbine. If the rotor had acted in the manner of an outdoor wind turbine that obeyed Betz law, the air would have slowed down, losing kinetic energy, but maintaining its temperature.]

(v) The cooling produces a pressure drop behind the turbine, which in turn generates lift.

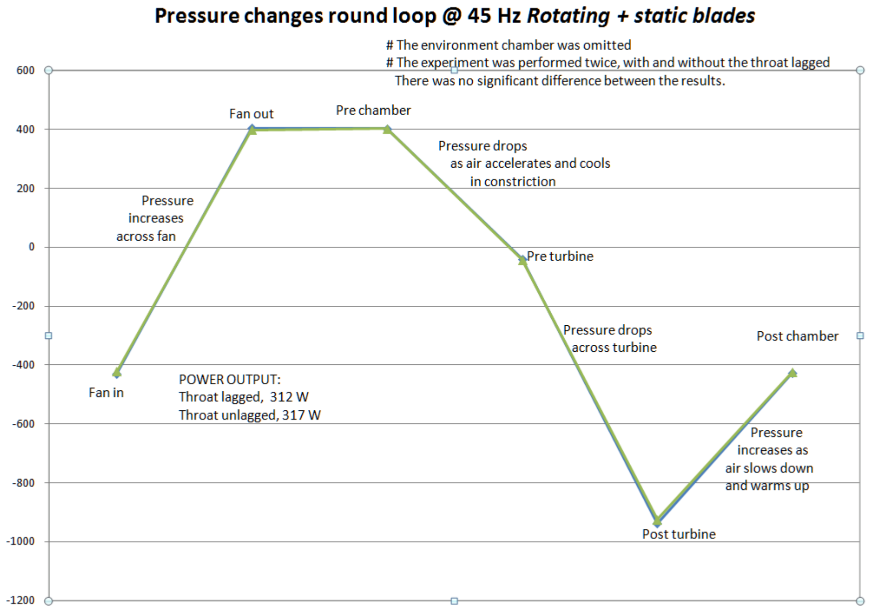

Figure 25. All of the closed loop experiments produced similar pressure changes around the loop.

The influence of stator and rotor blades on drag

In an attempt to increase turbine efficiency, a set of stator blades was placed in front of the rotor blades.

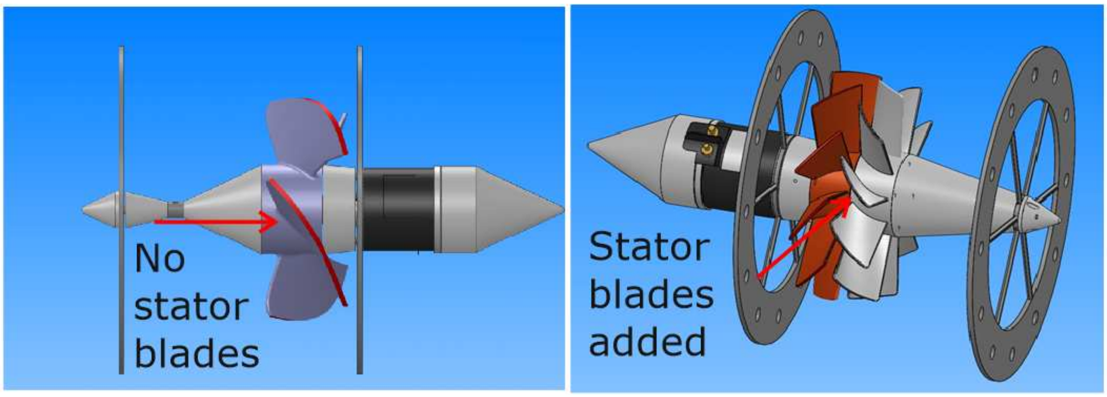

Figure 26. A second set of cannibalised air conditioning fan blades was used as stator blades. Their addition allowed the air to approach the rotor blades at an improved angle of attack.

The graphs below show that this had mixed consequences.
Improved turbine efficiency was delivered. But at the unacceptable cost of increasing drag so that the kinetic energy of the air entering the mouth of the constriction was reduced.

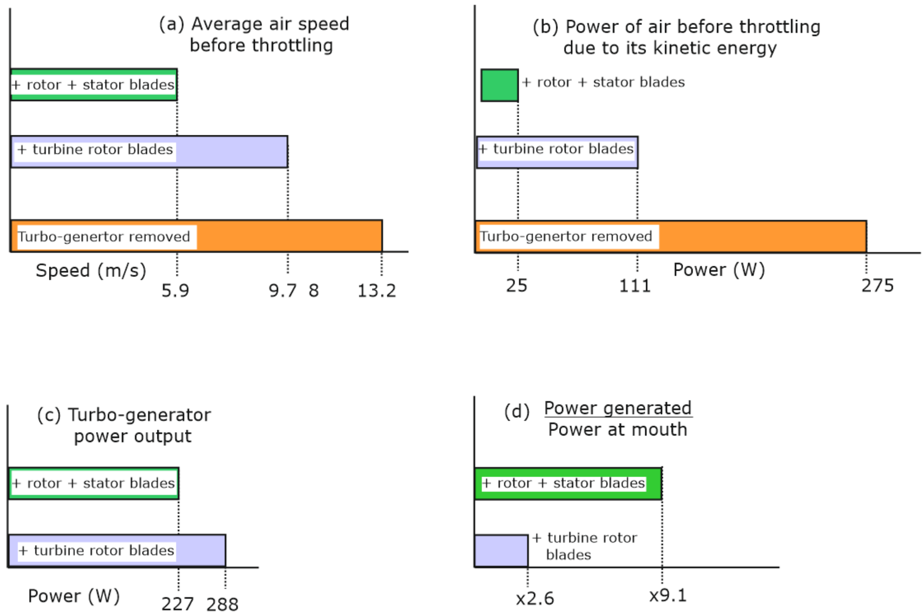

Figure 27. The environment chamber was removed and a fan speed of 40 Hz used for the above experiments.

Observations:

(i) The gain in turbine efficiency resulting from the addition of the stator blades was outweighed by the reduction in air speed.
(ii) The kinetic energy of the air entering the mouth of the constriction is approximately proportional to the cube of the average air speed. Consequently relatively small reductions in air speed equate to large reductions in kinetic energy.
(iii) Overall these results support the assumption that the turbine has an avoidably low efficiency that can be corrected by using a bespoke turbo-generator design.

2.4 Surface treatments we have investigated (Literature search only)

(i) Bio-mimicking surface treatments inspired by sharks skins, gecko foot pads and lotus flowers only offer a modest reduction of about 2-3% in drag at turbine transit speeds.
(ii) The Amazonian pitcher plant inspired SLIPS treatment could provide an effective anti-icing coating for the outer mechanical engine walls. This would allow the extraction of thermal energy from damp atmospheric air in the UK in winter.

3 What do we want to do next?

Our existing rig is a very useful asset for use in the next stage of LP Turbine design.

3.1 Some costs for rig improvement work

Improved turbine design

Companies supplying this service include NEL, East Kilbride and Nuaire, Caerphilly.

One man-year of computer modelling commissioned from a specialist turbine design company is estimated to cost £230,000. [But the job may be done in far less time.]
3D printing of the turbine blades and manufacturing other parts will cost extra.
Project managers cost £900/day, Design engineers £700/day and Technicians £600/day.
The official number of working days a year is 219.

Smoother bends
Our current rig incorporates segmented bends that cost £800 per 90 degree bend
Smoother fibreglass reinforced plastic bends could be purchased for about £2,000 per 90 degree bend.

3.2 Moving towards a commercial product

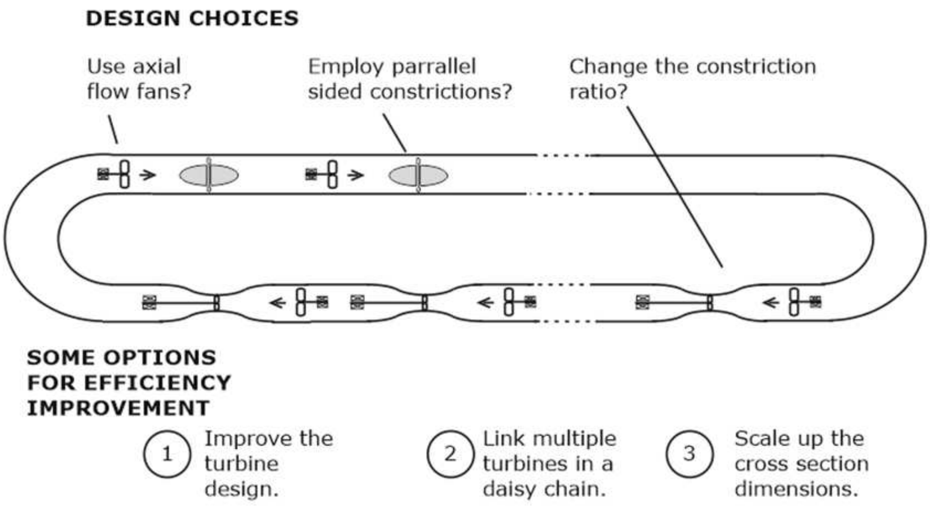

Figure 28. There is plenty of scope for improving the LP Turbine design.
Axial flow and centrifugal fans will deliver different flow patterns to the turbine rotor because of the angular momentum imparted by an axial flow fan. The angular momentum presented to the rotor will also vary, depending on whether a tapered conduit or parallel sided conduit and large nose in front of the rotor are used to throttle the air flow. The possibility of reverse flow in the manner of a vortex tube will also have to be investigated.

3.3 The difference between large and small scale LP Turbine power units

(i) **Megawatt scale power stations** are likely to employ several daisy chain loops of turbines.

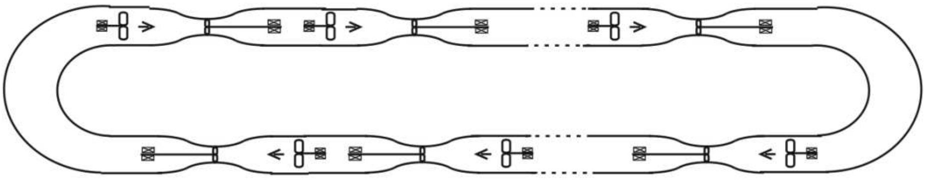

Figure 29. An LPTurbine daisy chain.

(ii) **Kilowatt size power** generators will have a plenum chamber design.

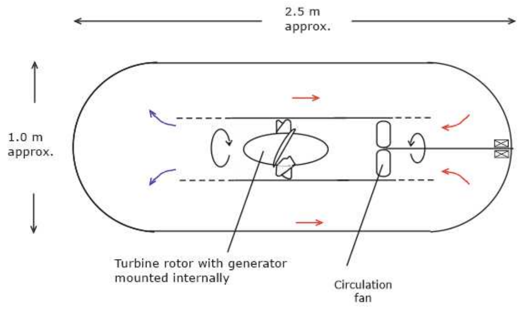

Figure 30. A plenum chamber LP Turbine

APPENDIX

Getting our current rate of progress into perspective.

	Power from nuclear fusion	Power from LP Turbines
The offer	The prospect of virtually unlimited low carbon power, using deuterium extracted from sea water as fuel.	The prospect of virtually unlimited low carbon power, using low grade heat from the environment.
The engineering challenge	Contain hot plasma at a temperature of 100 million ^{o}C under fusion conditions.	Improve the turbine design and reduce the drag forces.
The cost of a prototype delivering a net power output	Building the International Thermonuclear Energy Reactor (ITER) will cost 13 billion Euros.	£250 k to build a plenum chamber version with an efficient low drag turbine. [0.2% of the cost of building the ITER.]
Delivery requirements	A national grid + highly skilled engineers.	A local micro-grid + moderately skilled engineers.
Years in development to date	Sixty	Five
Delivery time from now	Ten – twenty years	Two-three years
Waste product	Radioactive waste produced by high energy neutrons hitting reactor walls.	A cooler environment.

REFERENCES

[1] Courtney, W. A., Patent GB 2427249 “Combined power generator and water desalination plant”.

[2] Courtney, W. A., Patent application GB 0807276.1 “Improved saturated vapour driven turbine system”

[3] Courtney, W. A., PCT/GB2011/000936 “Phase change turbine incorporating carrier fluid”

[4] Courtney, W. A., Patent Application GB 1116309.4 “Hybrid heat engine” Filing date 22 September 2011.

[5] Courtney, W.A. Patent Application GB 1418029.3 “A heat engine inside a mechanical engine” Filing date 12 October 2014.

[6] LP Turbines Ltd, technical report for TSB, Project Number: 130037, 03 March,2011

[7] N. Qin and Z. Chen, Department of Mechanical Engineering, University of Sheffield, Design of a Latent Power Turbine, 02 May 2014.

[8] Performance of a prototype micro wind turbine in the manmade wind field from air conditioner of buildings, K.H. Goh Fei Duan, School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore, 639798.

[9] Segletes, S. B. and Walters, W. P., A note on the application of the extended Bernoulli equation, International Journal of Impact Engineering**,** Volume 27, Issue 5, May 2002, pp. 561-576.

[10] A. M. Binnie and M. J. Woods. The pressure distribution in a convergent-divergent steam nozzle. Proc. Inst. Mech. Engrs. 138 (1937), pp9-266.

[11] A. M. Binnie and J. R. Green, An electrical detector of condensation in high speed steam. Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences, Vol. 181, No. 985 (December 31, 1942), pp. 134-154.