# Short Presentation Notes

## A – Introduction

An atmospheric vortex engine is a device for producing **an artificially created controlled vortex** to capture the mechanical energy produced when heat is carried upward by convection in the atmosphere.

**AVE** stands for Atmospheric Vortex Engine and also means "**HELLO**" in Latin. **FUTURE** is there because the **AVE** could be the solution to our energy needs and indicates that the photo has been touched up.

The vortex is formed by **admitting warm air in a circular arena via tangential entry ducts** thereby causing a vortex to form at the centre of the arena. The air is heated or humidified in **heat exchangers** located upstream of the entry ducts. A **roof** with a circular opening at its centre helps the convergence process. This mechanical energy is produced in **peripheral turbines**.

The **heat source** can be solar energy or waste industrial heat. The solar energy can be warm sea water or simply warm humid air.

The **driving force** for the flow is the reduced pressure at the base of the vortex. The air acquires angular momentum in the tangential entry ducts because the pressure is higher at the upstream end than at the downstream end. The **kinetic energy of the vortex is not captured directly**; instead the reduced pressure at the centre of the vortex is used to drive turbines. The turbines are not in the vortex. There is nothing close to the vortex to interfere with the natural vortex process.

An AVE could have a diameter of 200 m and a height of 100 m. the vortex could have a diameter of 20 m at its base and extend to a height of 15 km. Think of a small **vortex alone in the center of a large open roof arena**. The electrical power output could be 200 MW.

## Solar Chimney

The thermodynamic basis of the vortex engine is the **same as** that of the solar chimney. The solar chimney shown on the left was built in Spain in the 1980's had an electrical output of 50 kW and operated for 7 years. Its chimney was 200 m high, and the solar collector was a 200 m diameter greenhouse. The greenhouse increased air temperature by approximately 20 °C. The **turbine** which looked like a helicopter rotor was located at the base of the chimney. The proposed Australian solar chimney on the right would have a chimney 1 km high and an electrical capacity of 200 MW.

A chimney is **a cylinder in radial compression**. The pressure is higher outside the chimney than inside the chimney. The **draft** at the base of a chimney increases with chimney height. If you were to make an **opening in the side** of a chimney ambient air would be sucked in, would reduce the temperature of the flue gas, and would reduce draft. The fact that warm air rises higher in a chimney than without of a chimney was discovered long ago.

In the AVE, **the physical chimney is replaced with centrifugal force**.

In the AVE, **the solar collector is replaced with**: waste industrial heat or low temperature natural heat sources.

The **efficiency** of the solar chimney is proportional to its height: 0.2% for 200 m Spanish chimney, 1.5% for proposed 1 k m Australian chimney. The efficiency of a 15 km high atmospheric vortex engine could be up to 30%.

Cooling Towers

Industrial plants use cooling towers to **dispose of waste heat into the atmosphere**. The mechanical draft cooling tower at the upper left uses induced draft fans to draw air through falling water. Driving these fans can consume up 1 to 4% of the power output of a thermal power plant. The natural draft cooling tower at the upper right uses a tall stack to draw the air through the falling water and does not require fans, but it has a much higher capital cost.

**In the vortex engine**, the stack effect is achieved without the physical stack. The draft can be high enough to drive turbines and thereby increase the power output of the power plant.

In a vortex, convergence of ambient air is **prevented by centrifugal force**, **except** near the ground where tangential velocity and centrifugal force are reduced by friction against the surface.

A medium size **tornado** can produce as much **energy** as a large power plant.

A **large hurricane** can produce more energy than all the **energy** produced by humans in a whole year.

The energy production potential of the atmospheric vortex engine is very large because the solar heat collector can be **the earth's surface in its unaltered state**. Powering a city with solar energy would require solar collectors with an area **100 to 1000 times the area** of the city!

Photo of the Petrolia vortex

B - Energy and Entropy budgets

**Earth Energy Budget** according to NASA. Short wave solar radiation on the left is shown in **yellow**; long wave infrared radiation is shown in **red**.

<u>Osawa and Lorenz Entropy budget</u>

The figure on the **left** shows an **entropy budget** by Osawa and Lorenz. The equation below the figure shows how entropy production is calculated. There are four internal entropy production terms: three absorption terms and one turbulence term.

I drew the figure on the **right** to make it easier to see where the entropy is produced. The numbers are the same as in the figure on the left except that I changed the entropy units to mW/(K $m^2$) because I prefer to work with whole numbers rather than with fraction. I also **added the external entropy flux in red**. External entropy flux can be positive or negative; internally generated entropy can only be positive.

The overall entropy production can readily be calculated as shown by the first line of the calculation on the left. The earth surface receives solar radiation emitted at 5800 K emits infrared radiation at an average temperature of 255 K **therefore entropy is produced**.

The **numbers in yellow are the entropy produced when radiation is absorbed**. 95% of the entropy is produced by absorption. When radiation is absorbed, entropy is produced **instantly**. Energy degradation is instantaneous except for a small part, less than 0.5% which is converted to organic matter by photosynthesis. Nonetheless the organic matter produced over billion of years will be sufficient to meet human energy need for a few centuries.

The **green number is the entropy produced when heat is carried upward by convection** and that is the part that I will focus on. Osawa and Lorenz used the name turbulent entropy production to distinguish it from the three absorption entropy production terms. Turbulent entropy production is **not an instantaneous** process; it occurs when the heat is carried upward by convection as opposed to when the heat is received.

The **orange number is the total entropy production**, the three yellows plus the green.

The quantity of entropy produced is the same whether the heat is carried by convection, radiation, or conduction, **no matter what**. **Convection** is the only one entropy production we can do something about only entropy because it is **not instantaneous**. Transferring the heat with a **Carnot engine** would avoid entropy production.

C – Ideal Thermodynamic Cycle

Here is the thermodynamic cycle of the hurricane process by Kerry **Emanuel** of MIT. The air is heated by the sea surface at a temperature of 300 K and cooled at high elevation at lower temperatures. For a hot source temperature of 300 K, the efficiency would be 33%.

This is another way of showing the thermodynamic cycle. And this is the **equivalent atmospheric engine ideal cycle** for the same operating conditions.

This is the **Brayton gas-turbine ideal cycle. In both ideal cycles**, the air is heated from 290 K to 300 K at a pressure of 100 kPa and cooled from 189.4 K to 183.1 K at the 20 kPa level. The gas is heated a constant pressure, expanded in the turbine, cooled at constant pressure, and compressed back to its original pressure. The work produced by the expansion of the warm gas is more than required to compress the cooled gas and the excess is available to drive a load.

The work of compression appears **explicitly** in the gas-turbine case, and is not as evident in the gravity cycle. In the gravity cycle the gas expands as it rise and is compressed as it descends.

The compression ratio is 5:1 in both cases. The **efficiency** of an ideal Brayton cycle is strictly a **function of its pressure ratio**. The ideal cycle efficiency for a compression ratio of 5:1 is 36.9%.

The efficiency of an ideal cycles is the **efficiency of a Carnot engine** with hot and cold source temperatures equal to the **log average** temperatures at which the heat is received and given up. All **processes must be reversible** – which means that the **expansion process must be constrained**. The efficiency of reversible cycle **depends only on the average temperature** at which heat is received and given up.

The key to understanding thermodynamics is **simplification**. Engineers use ideal processes: with no friction loss, negligible velocity, and without temperature difference during the heat transfer. Real processes are difficult to analyze, but it is usually possible to conceive of ideal process that is easily to analyze. In reversible cycle analysis the size of the conduits is of no importance. The downflow **conduit can be much larger** in cross sectional area than the upflow conduit.

Conventional thermal engines reject heat **at temperatures close to the temperature at the bottom of the atmosphere**. Using a vortex to carry the heat upward would permit rejecting heat at the **temperature at the top of the top of the troposphere** thereby increasing cycle efficiency. This figure shows how using a vortex engine could increase the overall efficiency of a power plant from **35% to 48%**. The vortex engine would permit the use of **waste heat at**

**temperature too low** to be used when the heat sink is the temperature at the bottom of the atmosphere.

D – Work dissipation

Back in 1905 Austrian thermodynamist Max **Margules** used a piston covered closed insulated thermodynamic system to investigate how wind energy is produced. He calculated the energy produce when air masses exchange position.

**One dimensional models** like this are the most basic type of meteorological model. In order to understand what is going on you have to go **one step simpler** and specify that the air in the system has **uniform entropy** because with uniform entropy, no work is produced when air masses are moved isentropically.

The work can be calculated in many different ways all giving the same result.

1) From the **difference** between the heat received and the heat that must be given up to restore the initial condition.

2) From the heat received multiplied by the **Carnot efficiency** calculated using the temperature at which the heat is received and given up.

3) From the reduction in the total enthalpy of the system – the **Margules** method.

4) From the reduction in static energy (h + gz) or equivalently from the **total energy equation** universally used to calculate the minimum energy required to move a substance.

5) From **buoyancy force** time distance – **CAPE** (Convective Available Potential Energy).

CAPE is the most commonly methods of the five. Surprisingly CAPE does not consider work of expansion and compression. CAPE like hydraulic energy is based on reduction in potential energy.

The three states batch process clearly shows that the **mechanical energy is produced during lifting process 2-3**. The work is not produced during heating process 1-2 or cooling process 3-1. The re-arrangement process **can occur well after** the heating process therefore mechanical energy production can occur anytime after the heat is received.

**Margules** used a closed piston covered thermodynamic system but it is possible arrive at the same result with an **open thermodynamic system** like this one. When there is **no change in elevation** like in a gas turbine the work is the reduction in enthalpy; when there is **change in elevation** like in a hydraulic turbine the work is the reduction in potential energy. In the **AVE both terms** must be considered.

Early thermodynamists used **cylinders and pistons** and **automats** to explain how engines work. An **automat** is mechanism capable of **capturing, storing and releasing work reversibly**. The term robot was only invented 50 later. Here is a lifting process with a reversible / irreversible option.

The reversible process can be quiet. The irreversible process is noisy there is a pop every time the piston is unlatched and a bang every time the piston hits the travel stop.

Incidentally the AVE cycle is simpler than the Carnot cycle. A Carnot cycle requires two compressor stages and **two expanders**. The AVE cycle only requires **an expander**; the **compression occurs as the air descends which is far more efficient** than any mechanical compressor; most of the expansion occurs as the air ascends which is more efficient than mechanical expander.

E – Energy calculations

Here is the Ideal Process for the vortex engine. The complete ideal cycle is useful for understanding the energy transformation process but a partial cycle is sufficient for work calculation.

Air is expanded  isentropically in a turbine in process **1-2**, heated and humidified at constant pressure in a cooling tower in process **2-3**, and expanded isentropically in an upflow tube process **3-4**.

Here is a typical sounding with its CAPE of 2124 J/kg shown at the upper right.
The **green** line is the temperature of the environment.
The **orange** line is the temperature of an air mass rising from the surface.
The **red** line is the temperature of an air approaching equilibrium with sea surface temperature at 30.4 ℃ – temperature approach of 1 ℃, relative humidity 90%.

Here are results in table format for a range of approaches. The work increases as the air approaches equilibrium with the water. I was **surprised by the magnitudes of the work and velocities;** I was only trying to find an explanation for the energy of hurricanes. The results are sufficient to explain the kinetic energy produced in any vortical storm.

**The key** to solving the problem is that the work for upward flow process 3-4 is zero. The pressure at the base of the upward flow tube is calculated by assuming an approach to equilibrium, calculating the work during process 3-4 for **two** $P_3$

**guesses**, and then **interpolating** to determine the value of $P_3$ required the make the work $w_{34}$ zero.

The Bulletin of the American Meteorological Society published high quality dropwindsonde for **hurricane Isabel** in late 2006. When I saw the article, I decided to see if the data could explain the observed wind speed of **80 to 110 m/s**.

The Isabel data shows that the temperature of the air at the eyewall is approximately **1 °C** lower than the SST at the eyewall and that the relative humidity of the air at the eye wall is approximately **97%**. There was no longer any need to guess the approaches.

As you see from this table the agreement was fantastic. **An SST of 25.5 °C is yields a velocity of 77 m/s**; **An SST of 26.5 °C yields a velocity of 110 m/s.** In the previous table I kept the SST constant and varied the approaches; in this table I keep the approaches constant and vary the SST.

**The heat is transferred from the water to air by spray**. The spray droplets are cooled by evaporation and re-enter the sea at a lower temperature thus increasing the enthalpy of the air and decreasing SST. The SST surface temperature at the eyewall can be **3 to 4 °C lower** than SST before the hurricane. The results are in accord with Emanuel's maximum hurricane velocity chart where reduced SST is considered.

The hurricane heat transfer process is the **same as in a wet cooling tower**. Wet cooling towers are very effective at transferring heat from water to air. The heat transfer can be as high as **100,000 Watts per square meter** of ground surface.

**Process simulators** used to for all kinds of chemical processes are an alternate way of calculating work. The work is the reduction in the enthalpy of the air in expander #1. The cooling tower is simulated with a distillation tower; the upflow process is simulated with expander #2. The net work for upflow process 3-4 is expander #2 work minus gz. The simulator is set up to find the pressure $P_2$ for which the net work for upflow process 3-4 is zero. This simulation is based on a unit mass flow of air of 1 t/s. When the temperature of the water entering the distillation tower is increased, $P_2$ decreases and expander #1 work increases.

F – Subsidence

The temperature of the subsidizing air increases at the dry adiabatic lapse rate. **Subsidence must be slow** enough to give the subsiding air time to cool otherwise it would reach the surface at its **potential temperature**. The average subsidence rate cannot exceed **4 kPa or 500 m per day**. Air descending from the 15 km level must take about 30 days to descend to avoid warming up the environment.

Imagine **a number of columns** of subsiding air. Subsidence would tend to occur in the column that is the coldest, but subsidence warms the column and therefore the subsidence shifts to the next coolest column.

The **subsidence process can be an ideal polytropic process** even when the upflow process is irreversible adiabatic process. The downflow part of the cycle is ideal. Excess energy is mainly dissipated during upflow.

F – Entrainment

The **effect of entrainment** can be evaluated by making some assumptions about entrainment rate and seeing if the results match observations. An entraining updraft can be considered as a sequence of isentropic expansion and mixing processes. Here the entrainment per kPa is proportional to the difference in temperature between the updraft and its environment to some power.

Here is the result calculated in **2 kPa steps**. This figure corresponds roughly to an entrainment rate of roughly 10% per kPa. Without entrainment the temperature of the updraft follows this line; with entrainment it follows this line. Here is the effect of changing **ambient humidity**; the drier the environment the faster the cooling.

**Entrainment reduces both updraft temperature and height**. **Chimneys and vortices** reduce entrainment and therefore increase updraft height. Strong updrafts are common in abandoned chimneys or tall tanks.

Conclusion

Here is a comparison of the Earth's stored energy resources. The heat content of the water vapor in the bottom kilometer of the atmosphere is **twice the heat content** of all the Earth's petroleum reserves. The heat available by cooling the top 100 m of tropical water by 3°C is **20 times as much as the heat content of the oil** reserves. The heat released in an average hurricane is $5 \times 10^{19}$ Joules/day. Enough to **cool a strip of ocean** 500 km long by 100 km wide and 100 m deep by 3°C. The cooling effect of hurricanes on sea water is clearly visible on infrared satellite photos. The process is also responsible for **waterspouts** which can be well behaved. Friction losses become negligible once the updraft diameter exceeds a few tens of meters.

The energy production potential of the atmospheric vortex engine is far greater than that to other solar energy technologies because the solar collector is **the earth's surface in its unaltered state**; there is no need for a huge solar collector. A vortex engine increases the efficiency of thermal power plants by **reducing cold source temperature**. The AVE could alleviate global warming by reducing the quantity of fuel required to meet energy needs. The AVE could **remediate global warming** by lifting heat above greenhouse gases so that the heat can more easily radiate back to space.