# A fluid turbine

## Field of the invention

This invention relates to a fluid turbine.

## Background of the invention

Most wind turbine systems comprise steel towers, which are made in sections and bolted together on-site. A wind velocity profile may be calculated using the following equation:

$V_y = V_x(H_y / H_x)^{\alpha}$, where $V_y$ is an unknown wind speed at height $H_y$, $V_x$ is a known wind speed at height $H_x$, and $\alpha$ is the wind shear exponent.

As wind speed increases with altitude, more wind energy can be captured and accordingly, a taller wind turbine captures more wind energy compared with a correspondingly shorter wind turbine. Additionally, wind turbulence also decreases with altitude. It is therefore advantageous to design taller wind turbines for generating electrical energy.

However, material costs for building towers of wind turbines constitute a significant portion of an overall system cost of wind turbines; for example, the material costs for building a tower for a small wind turbine (i.e. < 30 metres in height) may well form about 40-60% of the overall system cost. In addition, it is difficult to make steel towers having height of more than 100 metres which are light and yet strong. Consequently, there are not many wind turbine systems that reach altitudes of above 100 metres. Hence, available energy sources from wind above these altitudes are not effectively exploited.

## Summary of the invention

A first aspect of this invention relates to a fluid turbine comprising an aerofoil – for supporting a plurality of rotors – and a main body to mount the aerofoil. The aerofoil is pivotably connected to the main body to generate lift for the wind turbine when in use. With this arrangement, it is possible to control the motion of the fluid turbine when in use. The term “fluid turbine” should be construed as the turbine being operable in all kinds of gases (including wind) and liquids (including water).

The pivoted connection between the aerofoil and the main body may have a degree of freedom between 120 to 180 degrees. Specifically, the degree of freedom between the aerofoil and the main body may be 130 degrees. Such a degree of freedom allows orientation of the plurality of rotors to change accordingly during operation, which may accordingly provide good flight control of the fluid turbine when airborne.

Further, the fluid turbine may comprise a control device arranged to adjust a relative position between the aerofoil and the main body. This may ensure better flight control of the fluid turbine when airborne.

Specifically, the plurality of rotors of the fluid turbine may be operable to define corresponding swept areas, and the control device may be arranged to adjust the relative position between the aerofoil and the main body in such a way that the swept areas receive wind in a perpendicular direction. Because the swept areas of the plurality of rotors capture the most wind energy in this position, efficiency of the fluid turbine to convert wind energy to electrical energy may be maximised.

Further, the fluid turbine may comprise a flap at a trailing edge of the aerofoil, the flap being rotatable about an axis of the aerofoil. By arranging the flap in relation attacks by wind at angles of +/-20 degrees, the flap may stabilise or re-position the fluid turbine when airborne during operation.

Further, the aerofoil of the fluid turbine may comprise a fin arranged in relation to a plane of the aerofoil. Like the flap of the aerofoil, the fin may also stabilise the motion of the fluid turbine when airborne during operation.

Specifically, the plurality of rotors of the fluid turbine may have a diameter of 4m. Such a dimension of the fluid turbine may generate a rated power of about 10KW.

Optionally, the fluid turbine may further comprise an anemometer for measuring wind speed. The anemometer may be mechanical vane-type anemometer or a sonic anemometer.

Further, the fluid turbine may comprise a Global Positioning System (GPS) receiver for determining location of the fluid turbine when airborne.

Further, the fluid turbine may comprise a sensor. The sensor may be a 3-axis static G-force sensor, a dew sensor, a thermometer, or a static electricity sensor for detecting lightning.

Additionally, the fluid turbine may comprise a defroster for defrosting ice. The defroster may be a resistive strip arranged on the aerofoil.

Optionally, the fluid turbine may be operable to reach an upper altitude limit of 2000 feet when in use. Alternatively, the fluid turbine may be operable to reach an upper altitude limit of 1000 feet when in use.

A second aspect of the invention relates to a fluid turbine system comprising a anchoring station and the fluid turbine in electrical connection with the anchoring station.

The fluid turbine system may comprise at least one tether connected between the anchoring station and the fluid turbine, for anchoring the fluid turbine to the anchoring station.

A third aspect of the invention relates to a method of operating the fluid turbine system.

Specifically, this method comprises the steps of:
(a) rotating the plurality of rotors to generate a lift for the fluid turbine, the rotation of the plurality of rotors defining respective swept areas;
(b) measuring wind speed as the fluid turbine is lifted; and
(c) adjusting the relative position between the aerofoil and the main body when a first pre-determined wind speed is detected.

The step of measuring the wind speed may comprise measuring the wind speed at altitudes of 10 feet multiples. This allows calibration of the fluid turbine system to determine a wind shear exponent empirically.

The step of adjusting the relative position between the aerofoil and the main body may comprise detecting the pre-determined wind speed of 7m/s.

The step of adjusting of the relative position between the aerofoil and the main body may comprise positioning the fluid turbine in such a way that the swept area receives wind in a perpendicular direction. Because the respective swept areas of the plurality of rotors capture the most wind energy in this position, efficiency of the fluid turbine to convert wind energy to electrical energy may be maximised.

Further, the method of operating the fluid turbine may comprise unwinding of the tether so that the fluid turbine is lifted to an altitude with a second pre-determined wind speed.

The step of unwinding of the tether may stop when the second pre-determined wind speed of 12m/s is detected.

Further, the method of operating the fluid turbine may comprise winding of the tether to pull the fluid turbine towards the anchoring station.

A fourth aspect of the fluid turbine relates to a self-powered vehicle comprising the fluid turbine described above.

The self-powered vehicle may be a meteorological station, an airborne warning system, a flying billboard, or a communication station.

**Brief description of the figures**

Embodiments of the wind turbine will be described, by way of example only, with reference to the following figures of which:

Figure 1 illustrates an operational wind turbine system comprising the wind turbine in airborne connected to a anchoring station, the wind turbine having an aerofoil pivotably connected to a main body and two rotors (only one rotor is shown) attached to the aerofoil;

Figure 2a and 2b illustrates top and side views of the rotors and aerofoil of the wind turbine of the wind turbine system of Figure 1;

Figure 3 illustrates the pivoted connection between the aerofoil and the main body of the wind turbine of the wind turbine system of Figure 1;

Figure 4 illustrates a graphical representation of the various states of the wind turbine of the wind turbine system of Figure 1;

Figure 5 illustrates the wind turbine system of Figure 1 in an “idling” state;

Figure 6 illustrates the wind turbine system of Figure 1 in a “launching” state;

Figure 7 illustrates the wind turbine system of Figure 1 in an “ascending” state, in which the wind turbine is operating in a “power-assisted” mode;

Figure 8 illustrates the wind turbine system of Figure 1 in a “cruising” state, in which the wind turbine is operating in a “native” mode.

**Detailed description of the preferred embodiment**

Structure of the wind turbine

Figure 1 illustrates an embodiment of the wind turbine system 100 during operation. Specifically, the wind turbine system 100 comprises three main parts: (a) a wind turbine 101; (b) tethers 103; and (c) a anchoring station 105.

*(a) The wind turbine 101:*

The wind turbine 101 comprises a main body 107, an aerofoil 109 pivotably connected to the main body 107, and a combination of rotors 111 and dual-use motor-generator devices (not shown in Figure 1) connected to the rotors 111 being attached to the aerofoil 109.

The main body 107 provides structural strength to the wind turbine 101. Because the wind turbine 101 is designed to be airborne, light-weight material such as Aluminum (Al) alloy or carbon-fiber polymers are used to construct the main body 107. Further, the main body 107 has mounting points to which the aerofoil 109 and the tethers 103 are attached.

The aerofoil 109 is aerodynamically shaped and cambered, and comprises a rigid section and a flexible section. Like the main body 107, the aerofoil 109 is made from light-weight material such as Aluminum (Al) alloy or carbon-fiber polymers.

Figure 2 illustrates the relative arrangement between the aerofoil 109 and the main body 107. Specifically, the rigid section of the aerofoil 109 is pivotably connected to the main body 107 via a hinge 201. The pivoted connection between the rigid section of the aerofoil 109 and the main body 107 has a degree of freedom of 130 degrees.

Figures 3a and 3b show sectional views of the aerofoil 109 and wind turbine 101 when viewed from the top and the left of Figure 1 respectively. It is seen from these figures that the rigid section of the aerofoil 109 provides a skeletal structure to which dual-use motor-generator devices 113 are mounted. The rotors 111 are connected to the dual-use motor-generator devices 113 via a gearbox (not shown). Due to the aerodynamic design of the rigid section of the aerofoil 109, drag of the wind turbine 101 during airborne is reduced during operation.

On the other hand, the flexible section of the aerofoil 109 is configured for generating lift for the wind turbine 101 and for adjusting its position in air via aerodynamic forces during operation. Specifically, the dimensions of the flexible section of the aerofoil 109 are 3 metres in breadth (i.e. chord-wise) and 10 metres in length (i.e. span-wise).

Figures 3a and 3b show that the wind turbine 101 comprises two rotors 111. Each of the rotors 111 comprises a rotor hub and three equi-angularly spaced rotor blades extending from the rotor hub. Respective pitch angles of the rotor blades change when the relative position between the aerofoil 109 and the main body 107 changes. This is performed by a control device (not shown) arranged on the wind turbine 101.

Accordingly, aerodynamic profiles of the rotors 111 are changed during operation of the wind turbine 101 to perform the following two functions: (a) to generate lift forces directed perpendicularly to the ”swept area” of the rotating rotors 111 to which torque is applied; and (b) to absorb fluid forces moving into the “swept area” of the rotating rotors 111 to generated to rotate the rotors 111.

In Figure 3b, it is additionally seen that two control surfaces 110 (i.e. flaps) are installed on a trailing edge of the aerofoil 109. (Generally, it is understood that leading and trailing edges of the aerofoil 109 are defined by motion of the wind turbine 101 during operation.) These control surfaces 110 are rotatable about an axis of the aerofoil 109, and have their own electromechanical actuators driven by a computer onboard the wind turbine 101. Functionally, the control surfaces 110 modulate the amount of drag at the aerofoil 109 for stabilising and/or re-positioning the wind turbine 101 during flight by way of adjusting the control surfaces 110 in relation to right angle attacks by wind.

Moreover, the wind turbine 101 comprises a tail fin 115 arranged in a fixed position in relation to the rigid section of the aerofoil 109 – as seen in Figures 3a and 3b. The tail fin 115 stabilises the wind turbine 101 when airborne, and works in tandem with the tethers 103 to ensure that the wind turbine 101 heads automatically towards the strongest wind once the wind turbine 101 is in flight.

Further, the wind turbine 101 comprises dual-use motor-generator devices 113 that connect to the rotors 111. The dual-use motor-generator devices 113 can function either as a motor to drive the rotors 111 (and accordingly the rotor hub to rotate the rotor blades extending therefrom), or as a dynamo to be driven by the rotating rotors 111 to thereby convert mechanical energy into electrical energy. Specifically, the rotor hubs are attached indirectly to respective shafts of the dual-use motor-generator devices 113 via the gearbox having a gear ratio to increase a nominal rotational speed of the rotors 111 at optimal wind speeds to a nominal speed of respective shafts of the dual-use motor-generator devices 113.

Apart from the dual-use motor-generator devices 113, the wind turbine 101 also comprises a “Command-and-Control” [$C^2$] system (not shown) – which is part of the computer onboard the wind turbine 101 – for controlling motion of the wind turbine system 100 during operation. Specifically, the $C^2$ system monitors the wind speed at different altitudes, and transmits signals to control the position of the wind turbine 101 in airborne during operation.

Additionally, an anemometer (not shown) is arranged onboard the wind turbine 101 to measure wind speed at different altitudes. Specifically, the anemometer is a mechanical vane-type anemometer.

The wind turbine 101 also includes a 3-axis static G-force sensor (not shown) mounted on the rigid section of the aerofoil 109 to provide information of the altitude of the wind turbine 101 during operation. The sensor feeds back data to the computer onboard the wind turbine 101 so as to control its position during flight.

The wind turbine 101 may comprise other optional components. Also, different configurations of the wind turbine components as described above may also be possible.

For example, the main body 107 of the wind turbine 101 may include mounting points for attaching a parachute in case of operational failure of the wind turbine system 100. The main body 107 may be divided into foldable parts to facilitate transportation.

Whilst the pivoted connection between the aerofoil 109 and the main body 107 has a degree of freedom of 130 degrees, a range of such degree of freedom between 120 to 180 degrees may be designed instead.

Further, the rotor hubs may be directly attached to respective shafts of the dual-use motor-generator devices 113motor-generator.

Optionally, the anemometer may be a laser Doppler anemometer or a sonic anemometer, instead of the mechanical vane-type anemometer.

A Global Positioning System (GPS) receiver may also be provided on the wind turbine 101 for tracking its location in airborne during operation. In particular, the GPS receiver is used to deduce the altitude of the wind turbine 101 when airborne.

Dew and temperature sensors (i.e. thermometers) may be attached to the rigid section of the aerofoil 109 for monitoring climate conditions. If occurrence of icing is likely, defrosters – in the form of resistive strips – may also be installed at leading and/or

trailing edges of the aerofoil 109. Lightning detector – in the form of a static electricity sensor – may also be attached to the rigid section of the aerofoil 109 to estimate the risk of static electricity discharge.

Optionally, a photovoltaic (PV) solar cell may be arranged on the rigid section of the aerofoil 109 for allowing the wind turbine 109 to use solar energy for charging a battery onboard the wind turbine. This reduces reliance on the anchoring station 105 for power, and improves overall efficiency of the wind turbine system 100.

The wind turbine 101 may also have 1, 2 or 3-axis magnetic sensor, to assist in craft positioning, or detection of movement of actuators.

The weight of the wind turbine 101 is designed to be about 1080N, (based on a mass of 108kg of the wind turbine 101 and acceleration due to gravity of 10N/kg).

*(b) The tethers 103:*

The two tethers 103 (only one of the tethers 103 is shown in the wine turbine system of Figure 1) – which are light-weight, high strength, and electrically conductive cables – serve various functions such as: (a) anchoring the wind turbine 101 to the anchoring station 105; (b) transferring power between the wind turbine 101 and the anchoring station 105; or (c) relaying communications between the anchoring station 105 and the wind turbine 101.

Specifically, respective ends of the tethers 103 are attached to the wind turbine 101 at various attachment points. These attachment points are operable by an electromechanical actuator to move along an axis of the wind turbine 101 when activated. Respective opposite ends of the tethers 103 are anchored to the anchoring station 105 via winch pulleys that may be mounted on a turntable platform, which is in turn attached to a solid based of the anchoring station 105 so that a lift force of magnitude at the higher range end cannot detach the turntable from the anchoring station 105.

Although there are two tethers in the preferred embodiment, a single tether may be used for connecting the wind turbine 101 and the anchoring station 105. Nevertheless, the presence of two tethers provides better mechanical control of the wind turbine 101. Further, the presence of the two tethers acts as a safety measure of the wind turbine 101 in case one of the tethers were to break during operation.

Alternatively, a greater number of tethers 103 may be used, for greater control or to satisfy greater power transfer requirements. More importantly however, it should be noted that most jurisdictions require the tethers of any tethered craft flying above certain altitude (different for different jurisdictions) display bright markers spaced at prescribed intervals along the length of the tethers, the reason being clear visibility for other flying craft, to avoid accidents. Moreover, some jurisdictions require the tethers of craft flying between sunset and sunrise to display navigation lights of prescribed color, intensity, number and intervals along the tether's length. Thus, the tethers must meet these criteria, perhaps with integral current-sensitive bioluminescent paint, brightly colored as prescribed. Bioluminescence would be induced by the current being transferred between the wind turbine 101 and the anchoring station 105, thus satisfying the need for navigational lights. Speaking of the latter, prescribed number, color and type of navigation lights must be installed on the wind turbine 101 too, so it is allowed to fly. These may be installed either on top of the aerofoil 109, or on the main body 107

*(c) The anchoring station 105:*

The anchoring station 105 has a launch pad (not shown) for launching the wind turbine 101 during operation. The launch pad is actually a set of at least two latches capable of carrying the weight of the wind turbine 101 and electromechanically activated so when the wind turbine 101 is in position sitting on the lower part of the latch (hook), the latch is closed (by either electric motor, or spring-driven mechanism) securing the wind turbine 101 to the launch pad. In the absence of power, the wind turbine 101 will remain latched irrespective of wind speed or environmental conditions. Generated electrical energy received from the wind turbine 101 is regulated and conditioned at the anchoring station 105, before being provided to end users for local use or for sale to a grid. The anchoring station 105 also includes sensors and computers, which conduct system checks and run weather evaluation routines. Additionally, the sensors and

computers at the anchoring station 105 work in tandem with the computer on board of the wind turbine 101, to control flight of the wind turbine 101 during operation.

Further, the anchoring station 105 comprises the required power sources (e.g. batteries, fuel cells, electrolysis apparatus, etc) either for powering the rotors 111 of the wind turbine 101, or for powering end user applications. Extensiveness of such end user applications, along with the quantity and type of batteries, dictates the overall size of the anchoring station 105. For example, a 10kW grid-tied anchoring station 105 would have a footprint of about $2m^2$ and height of 1.8m. Also, the anchoring station 105 also houses a winch for winding or unwinding the tethers 103 during operation.

Optionally, the anchoring station 105 may house more than one winch if required. In certain configurations of the anchoring station 105, the batteries may be installed in a separate enclosure/building from that of the anchoring station 105, depending on the installation requirements. For example, in off-grid installations, a larger capacity of power storage may be desired, or it may be that environmental constraints require the batteries to be specially protected.

In view of the foregoing description, it is seen that the wind turbine system 100 is controlled by various firmware, embedded in separate computers either on board of the wind turbine 101 or at the anchoring station 105. The firm-ware controlled nature of the wind turbine system 100 therefore permits easy alteration of the system configurations where necessary, with minimal or no hardware modification.

Operation of the wind turbine system 100

The wind turbine system 100 generates electricity by deploying the wind turbine 101 in regions where there are optimal wind conditions such as wind speed of at least 12m/s for example. The wind turbine 101 operates at an altitude range of 30-2000 ft.

*Calibration:*

In the formula ($V_y = V_x(H_y / H_x)^a$) discussed above, the following parameters are known: (a) the altitude $H_x$ of the wind turbine 101 at the idling state (since design dimensions

of the anchoring station 105 are known); (b) the wind speed $V_x$ at the anchoring station level; (c) the desired wind speed $V_y$ and (d) the altitude of the desired wind speed $H_y$. However, the wind shear exponent $\alpha$ is unknown. To avoid costs and time on site surveys, the wind turbine system 100 is preferably calibrated as follows:

(1) The wind turbine system 100 is first powered up sufficiently for operation;
(2) The sensors and computers at the anchoring station 105 then detect a sustained minimum wind speed (e.g. 3m/sec);
(3) When the minimum wind speed is detected, the wind turbine 101 is launched from the anchoring station 105 and wind speed measurements are taken by the wind turbine 101 at every 10ft of altitude until it reaches a height of 600ft;
(4) Wind speed measurements are compared to the calculated values of the wind speed at the corresponding altitude, and thus the wind shear exponent is determined empirically.

At the altitude of 600 ft, the wind turbine 101 begins to produce power if the wind conditions are optimal (e.g. at least wind speed of 12m/s). Otherwise, the wind turbine 101 descends, which marks the end of the calibration process. It is thus seen that the wind turbine system 100 can be deployed at any location, without prior surveys or additional customization. Effectively, the wind turbine system 100 is ready to run 'out of the box'.

Figure 4 illustrates seven states (not to scale) of the wind turbine 101 for explaining the operation of the wind turbine system 100, these seven states comprising: (i) idling; (ii) launching; (iii) ascending; (iv) cruising; (v) descending; (vi) landing; and (vii) emergency landing, as will be described in detail below.

*(a) Idling:*

Figure 5 illustrates an "idling" state of the wind turbine 101.

In this default state, the wind turbine system 100 is powered and alert. The wind turbine 101 is positioned on the launch pad of the anchoring station 105, ready for launch (i.e.

the aerofoil 109 being positioned such that the rotor axes are directed upwards to the sky).

Alternatively, the wind turbine system 100 may be disabled for maintenance or for removal, or simply left in this state so long as it has the minimum power required by the computers and sensors. For example, a standard D-type battery would power the idle state for an estimated 6 months, in the absence of extreme temperatures.

*(b) Launching:*

Figure 6 illustrates a “launching” state of the wind turbine 101.

The launch of the wind turbine 101 depends on detection of the sustained wind speed (e.g. 3m/s) at the anchoring station 105. At such wind speed, the wind turbine 101 will require power from the anchoring station 105 for assisting the take-off. Thus, power is transferred from anchoring station 105 to the wind turbine 101 through the tethers 103 to rotate the rotors 111, providing a thrust force on the wind turbine 101 to lift from the anchoring station 105. Because the rotors 111 are powered by the anchoring station 105 via the dual-use motor-generator devices 113 to rotate in opposite directions in airborne non-vertical components of the rotors’ momentum of the wind turbine cancel out resulting in the wind turbine 101 ascending substantially vertically like a helicopter lift.

If the sustained wind speed at the anchoring station 105 is at least 7m/s, such a sustained wind speed generates some lift force on the aerofoil 109 to lift the wind turbine 101. The wind turbine 101 (or craft) cannot both climb as a helicopter and use lift from the oncoming wind; the wind turbine 101 climbs with power assist only as long as the wind speed is lower than the minimum required for lift (7m/sec in this example). At that point we deploy the flexible section of the aerofoil and swing the rigid section of the aerofoil forward, to prepare for generation. The rigid section of the aerofoil has only marginal lift capability, as it works as a regular wing (and thus requires far higher relative wind speeds to work). When descending, the lift from the oncoming wind is used to stay afloat, while winding down the tethers (and controlling the angle of attack on the craft, so the amount of lift is controlled too). When the wind speed approaches

the minimum (7m/sec) the rigid wing is flipped topside, the motors are powered and the soft wing is redeployed. From now on, descend is controlled by the rate of winding down the tethers and the speed of the rotors.

In the “launching” state, the wind turbine 101 is further pulled against the wind like a kite to gain a stronger relative wind speed compared with a particular sustained wind speed.

The launch is completed when the wind turbine 101 clears the launch pad of the anchoring station 105 to a height of 5m above it. The wind turbine system 100 is programmed either to proceed to the “ascending” state or to the “landing” state.

*(c) Ascending:*

Figure 7 illustrates an “ascending” state of the wind turbine 101.

In this state, the lifting of the wind turbine 101 is executed either in a “native” mode (i.e. relying on the aerofoil structure to generate lift for the wind turbine when airborne) or in a “power-assist” mode (i.e. transferring power from the anchoring station 105 to the dual-use motor-devices 113 on the wind turbine 101 via the tethers 103 to drive the dual-use motor-generator devices 113, to drive the rotors 111).

The rate of ascent of the wind turbine 101 in the “native” mode is typically 1m/s, while the rate of ascent in the “power-assisted” mode in the range of 0-2m/sec.

The wind turbine 101 typically operates in the “native” mode at altitudes with wind speed of at least 7m/s, and in the “power-assist” mode at altitudes with wind speed of less than 7m/s.

Similar to the operation of helicopters, the wind turbine 101 ascends or descends in a more or less vertical fashion at a rate as determined by the rotational speed of its rotors. The calculations in Appendix B assume a maximum rate of ascent of 2m/sec.

It should be appreciated that the lifting of the wind turbine 101 is done in sync with the unwinding of the tethers 103. Tension is maintained on the tethers 103 to exercise control on the wind turbine 101. The tension is measured using a cantilever jig on the tethers 103.

Optimisation of the wind turbine system 100 is done in the “ascending” state, where the $C^2$ system and the computer onboard the wind turbine 101 analyse the wind conditions based on sensor data. Accordingly, the altitude with optimal wind conditions (e.g. at least wind speed of 12m/s) can be detected for efficient power generation.

When the wind turbine 101 detects suitable wind conditions (e.g. at least wind speed of 7m/s), it switches from a “thrust” mode to a “power-generator” mode. In the “power-generator” mode, configuration of the wind turbine 101 is changed in such a way that the rotor axes face the wind head-on and the swept area of the rotor blades passes through a parcel of wind in a perpendicular direction to the general direction of the wind. This position of the wind turbine 101 is the most efficient, because the swept area of the rotors 111 captures the most energy from the wind to drive the dual-use motor-generator devices 113.

Specifically, the configuration of the wind turbine 101 is controlled by the control device to adjust the relative position between the aerofoil 109 and the main body 107. In the “power-generator” mode, the aerodynamic profiles of the rotors 111 capture the parcel of wind moving into the “swept area” of the rotating rotors 111 which accordingly drive the dual-use motor-generator devices 113 to generate electrical energy. The generated electrical energy is subsequently sent to the anchoring station 107.

For the wind turbine to be in the “power-generator” mode, it is configured to fly at an altitude of at least wind speed of 7m/s. Such a wind speed allows the aerofoil 109 to generate enough lift force to provide a thrust force on the wind turbine 101 for lifting the wind turbine 101 to higher altitudes with more optimal wind conditions (e.g. at least wind speed of 12m/s).

Accordingly, the power supplied from anchoring station 105 to the dual-use motor-generator devices 113 for driving the rotors 111 onboard the wind turbine 101 is switched off.

The low aspect ratio of the aerofoil 109 ensures a non-linear vortex lift, and thus, the lift coefficient (CL) can be as high as 1.4. Based on these parameters, the aerofoil 109 is able to generate a lift force on the wind turbine 101 of up to 108 kgN at wind speed of 7m/s. This allows the wind turbine 101 to lift the rotors 111, the dual-use motor-generator devices 113, as well as any additional payload if required. The following table presents a sample set of design parameters used in this discussion:

| | | |
|---|---|---|
| Wing area | $A$ | 30 $m^2$ |
| Wind speed (minimum) | $U_\infty$ | 7 m/s (25.2 km/hr) |
| Lift coefficient<br>(same as hang glider) | $C_L$ | 1.2 (maximum = 1.4) |
| Air density | $\rho$ | 1.2 $kg/m^3$ |
| Weight carrying capacity | $W = L = \frac{1}{2} C_L \rho U_\infty^2 A$ | 1058.4 N<br>(108 kg) |

As the wind turbine 101 cannot generate power of more than 2kW at wind speed of 7m/s (see Appendix A), it is more practical for the wind turbine 101 to continue its ascent – at its current position with the swept area of the rotors 111 capturing wind flow in a perpendicular direction – until the anemometer detects more optimal wind conditions (e.g. at least wind speed of 12m/s).

*(Appendix A shows a calculation of AC power generated at different wind speeds vs. altitude. This is used to calculate different yields by simply changing the ground level wind speed. Traditionally, wind speeds are measured at a standard height of 10 ft. With this calculation, the range of AC power generation can be determined from the range of wind speeds that the wind turbine system 100 operates in – i.e. 7-22m/sec. It is noted that within the altitude range 0-1000 ft, use of the wind turbine system 100 is suitable only at ground level winds higher than about 3m/sec so that the wind turbine 101 finds its cruising wind speed of 12m/sec.. Otherwise, electricity generation will be below the rated power of 10kW.)*

*(d) Cruising:*

Figure 8 illustrates a “cruising” state of the wind turbine 101.

At the altitude with optimal wind conditions, the wind turbine 101 cruises at that altitude for a pre-determined period of time to ensure that the optimal wind conditions persist. The “cruising” state is an inherently unsteady state as caused by the wind turbulence and external factors.

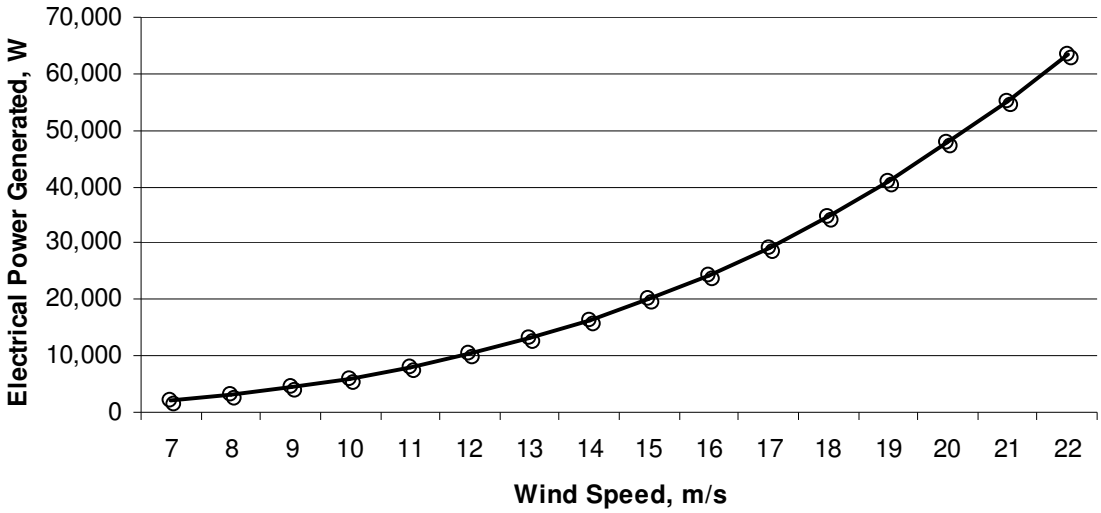
Dynamic balance of the wind turbine 101 is achieved by controlling the relative position between the aerofoil 109 and the main body 107

Like in the ascending state of the wind turbine, the swept area of the rotors 111 captures wind energy which accordingly drives the dual-use motor-generator devices 113 to generate electrical energy. The generated power is then sent to the anchoring station 105 via the tethers 103, where the power is conditioned before it is made available to end users.

The classical Betz’s limit of 0.59 (16/27) dictates that only a maximum of 59% of the energy available from the wind can be extracted. Assuming cruising wind speed of 12 m/s, the power available in the wind is about 1058 W/$m^2$ (at sea level, 15° C). The rotors 111 – which are each 4m in diameter – generate about 10.2 kW of electricity (after accounting for mechanical and electrical losses). About 62.6 kW of electrical energy can be extracted at the top end of the wind speed range of 22m/s that the wind turbine system 100 operates.

It should of course be appreciated that more energy may be harvested if rotors of larger diameter are used.

The graph below shows the relationship between wind speed and the generated electrical power with the above design specifications.




*Generated electric power vs wind speed.*

Continuous scanning of sensors' data allows the computer and $C^2$ system onboard the wind turbine 101 to decide if it is advantageous to change the altitude in search of more suitable winds.

The wind turbine 101 monitors the sensors' data and determines whether or not to ascend/descend in search of more optimal wind conditions. This is done in accordance with system mission parameters and dynamic load. In essence, the wind turbine 101 reacts in a non-linear fashion to dynamically changing environment, to ensure best possible capacity factor of the wind turbine system 100.

When the wind conditions are no longer optimal, or weather threatens the integrity of the wind turbine 101, it receives instructions for landing (see below).

*(Appendix B shows, by way of example only, the basic calculations for the power requirements of the "ascending" and "descending" states which yield a total power requirement of 9.552kW. In power-assist worst-case scenario, at a maximum climb rate of 2m/sec the wind turbine 101 will take approx. 305sec. to reach its upper altitude limit (approx. 305m) using 9.552 * (305/3600) ≈ 0.8kWh. In real life however, this will never be the case, as at wind speeds of 7m/sec and above the wind turbine 101 can climb in native mode. As shown in Appendix B, at 4m/sec ground level wind, it is expected to find 7m/sec wind at an altitude of about 21m. Even with the minimum launch wind*

*speed at 3m/sec, the 7m/sec wind is found at approx. 52m, therefore it would take about 26sec. for the wind turbine 101 to ascend to that altitude (with power assist), requiring approx. 0.069kWh.*

*Less-than-full-range ascend and descend are done in native mode 90% of the time and their frequency and magnitude depends on the wind regime at the deployment location. It is estimated that two such powered changes in altitude for each time the wind turbine 101 is launched, each of them resulting in a vertical movement of 50% of the total range. Therefore, the wind turbine 101 will need an extra 2 * 9.552 * (155/3600) ≈ 0.81kWh, for a total of 0.069*2 + 0.81 = 0.948kWh required per launch session.*

*The computers and all electromechanical components (winches, actuators, sensors, etc.) require an average of 0.22kW as long as the wind turbine 101 is airborne, and only 0.005kW when in the "idling" state. Assuming a duty cycle of 75%, the daily power requirement of the wind turbine system 100 is (24 * 0.75 * 0.225 * 0.5 ) + (24 * 0.25 *0 .005) + 1.59 ≈ 3.645kWh*

*Working at a cruising wind speed of 12m/sec, the wind turbine 101 will replenish this power in approx. (3.645*60)/10.297 ≈ 22min.*

*At the assumed 75% duty factor, this time represents slightly more than 2% of the time the wind turbine 101 is airborne (presumed generating electricity). Note that if using on-board Photo-Voltaics [PV], system power consumption during all activity but power assisted ascend/descend can be reduced or eliminated.)*

*(e) Descending:*

The "descending" state mirrors the "ascending" state.

Like the ascending state, the wind turbine 101 may operate either in the "power-assisted" mode – in which power is transferred from anchoring station 105 to the wind turbine 101 – or in the "native" mode – in which the aerofoil 109 is arranged to generate the lift for the wind turbine 101 to maintain the prescribed rate of descent.

In the “native” mode, the rate of descent of the wind turbine 101 is controlled by the speed of winding down the tethers 103. Just as in the “ascending” state, tension is maintained on the tethers 103 to exercise control on the wind turbine 101. The tension is measured using the same cantilever jig on the tethers 103.

*(f) Landing:*

The wind turbine 101 enters into the “landing” state from an altitude of about 5m above the launch pad of the anchoring station 105, until it is securely latched onto the launch pad. Depending on the wind speed at the time, the landing of the wind turbine 101 again may either be in the “native” mode or the “power-assisted” mode. In either case, the wind turbine 101 is descends vertically at a suitable rate until it latches onto the launch pad. After the wind turbine 101 lands on the launch pad, the rotors 111 are stopped from turning by use of brakes for safety considerations.

The wind turbine 101 then enters into the “idling” state.

*(g) Emergency Landing:*

The provision of this state is for precautionary to protect property and/or life, in the event of any catastrophic failure of the wind turbine 101 or unpredictable changes in weather conditions. This state combines the states of “descending” and “landing” of the wind turbine 101. The emergency landing is performed by controlling the tension and length of the tethers 103, such that the wind turbine 101 descends towards the anchoring station 105.

During emergency landing, the wind turbine 101 may rely on either autorotation or its aerofoil 109 to slow down its rate of descent to a controllable range. Optionally, the wind turbine 101 may comprise a safety device (e.g. a chute) to protect the wind turbine 101 in the event of operational failure of the wind turbine system or unfavourable weather conditions.

*(Autorotation is a condition where a helicopter's rotor is turned by the pressure of the air, exerted on the blades' bottom surface, as the helicopter loses altitude. However, as the rotor moves, it also generates lift, which slows down its descent.)*

Although the wind turbine system 100 has been described using a preferred embodiment, many variations are possible within the scope of the claims, as will be clear to a skilled reader, without departing from the scope of the invention as claimed. For example, the upper altitude range that the wind turbine can reach when airborne may be 1500 ft. Alternatively, the upper altitude range may be 1000ft or 500ft. Further, in the presence of strong winds at the anchoring station 105, the wind turbine system 100 generates electrical energy without take-off from the anchoring station 105. In this configuration, the wind turbine system 100 functions similarly to a tower-mount wind turbine system, in the sense that the generated power is directly transferred from the wind turbine 101 to the anchoring station 101 without the need to arrange the tethers 103 therebetween. It can be appreciated, that the wind turbine system 200 is operable to generate electrical energy either in airborne or when positioned at the anchoring station 105 (if the wind conditions at the anchoring station level permits). In the latter case, the structure and operation of the wind turbine system 200 are similar to tower-mounted wind turbine systems.)

Whilst it is preferred that the wind turbine 101 takes off from the anchoring station 105 upon the detection of a sustained wind speed of about 3m/s at the anchoring station 105, it should of course be appreciated that the wind turbine 101 may be powered by the anchoring station 105 to take off even if the sustained wind speed is lower than 3m/s. Optionally, the turning of the rotor blades may be done either automatically using an inertia actuator built in the rotor hub for example, or with a separate small motor connected to the rotor hub. Although each of the rotors 111 of the preferred embodiment has a diameter of 4m, smaller rotors having diameter of 1.6m may instead be used to give a smaller power rating. Moreover, the wind turbine 101 may be used for airborne advertisement, for laser performances in air, or for lighting up a construction site. In these instances, floodlights may be mounted onboard the wind turbine, which are powered using the electrical energy generated by the wind turbine 101. . Alternative applications for the wind turbine 101 include but are not limited to: meteorological measurements (telemetry); remote sensing; pollutant measurements;

signal broadcasting & relaying; bird rest & communication stations; airborne warning systems; high altitude camera systems (eg. for replacing blimps in major sporting events; high altitude insect zapper; rain maker; golf course lightning grounding system; high altitude antennas for cellular communication with planes; and use as a flying billboard (with options of video or laser shows).

Although the wind turbine 101 has been described to operate in air, it should again be appreciated that the same basic principles above apply when the wind turbine 101 is adapted to operate in water, whereby energy from moving water is converted into electrical energy. Accordingly, it should be appreciated that the wind turbine 101 is operable in fluids. The term “fluid” should be construed to cover all types of gases (including wind) and liquids (including water). Beyond that, the issue of scaling may be addressed, the concept may be used for simply sensing, producing milliwatts of electricity. Or, the wind turbine system 101 may be used as power scavenging system, deployed next to a highway for example,

Further, it should be appreciated that the various wind speeds that the wind turbine 101 detects and from which electrical energy is generated relate to “relative” wind speeds. For example, if the anchoring station 105 is mounted on a truck and the truck is driven at a speed of 3m/s in a direct opposite direction against a flow of wind moving at 4m/s, the “relative” wind speed would be 7m/sec, thus sufficient to lift the wind turbine 101 and produce electricity. More importantly, the relative wind (or fluid) speed is important because it may be decided, in some circumstances, to employ a special strategy to achieve a higher relative speed: Say if the wind turbine 101 cruises at 7m/sec at an altitude of 300ft, it can be forced in a steep descent at an angle to the wind (just like a kite flies to the side), the wind turbine 101 may easily reach speeds of 10m/sec or more, adding to a portion of the oncoming wind, to almost double the wind speed at the beginning. This may yield 8 times as much power. After say a descent of 200ft the wind turbine 101 is levelled and then allowed to slowly climb to its previous altitude, and the process is repeated. As no extra energy is expended to climb, a net energy is gained due to the increased relative speed of the fluid while the craft descends.

Also, although the anchoring station 105 is shown to be stationed on land, it should be appreciated that it may also be stationed on a sea bed or onboard a ship.

Indeed, many other variations are possible within the scope of the claims, as will be clear to a skilled reader, without departing from the scope of the invention as claimed.

5

# APPENDIX A

## WIND SPEED PROFILE

Below is a sample wind speed profile calculated for a=0.3 and $V_x$=4m/sec:

| Altitude, ft | Altitude, m | Wind Speed, m/sec | Power in Wind, W | Captured Wind Power, W | Mechanical Power at Generator, W | AC Power Generated, W |
|---|---|---|---|---|---|---|
| 10 | 3.05 | 4.00 | 986 | 465 | 419 | 377 |
| 20 | 6.10 | 4.92 | 1,839 | 868 | 781 | 703 |
| 30 | 9.14 | 5.56 | 2,649 | 1,250 | 1,125 | 1,013 |
| 40 | 12.19 | 6.06 | 3,432 | 1,620 | 1,458 | 1,312 |
| 50 | 15.24 | 6.48 | 4,195 | 1,980 | 1,782 | 1,604 |
| 60 | 18.29 | 6.85 | 4,944 | 2,334 | 2,101 | 1,891 |
| 70 | 21.34 | 7.17 | 5,679 | 2,680 | 2,412 | 2,171 |
| 80 | 24.38 | 7.46 | 6,404 | 3,023 | 2,721 | 2,449 |
| 90 | 27.43 | 7.73 | 7,121 | 3,361 | 3,025 | 2,722 |
| 100 | 30.48 | 7.98 | 7,829 | 3,695 | 3,326 | 2,993 |
| 110 | 33.53 | 8.21 | 8,530 | 4,026 | 3,623 | 3,261 |
| 120 | 36.58 | 8.43 | 9,225 | 4,354 | 3,919 | 3,527 |
| 130 | 39.62 | 8.63 | 9,914 | 4,679 | 4,211 | 3,790 |
| 140 | 42.67 | 8.83 | 10,598 | 5,002 | 4,502 | 4,052 |
| 150 | 45.72 | 9.01 | 11,277 | 5,323 | 4,791 | 4,312 |
| 160 | 48.77 | 9.19 | 11,951 | 5,641 | 5,077 | 4,569 |
| 170 | 51.82 | 9.36 | 12,621 | 5,957 | 5,361 | 4,825 |
| 180 | 54.86 | 9.52 | 13,288 | 6,272 | 5,645 | 5,080 |
| 190 | 57.91 | 9.68 | 13,950 | 6,584 | 5,926 | 5,333 |
| 100 | 60.96 | 9.83 | 14,609 | 6,895 | 6,206 | 5,585 |
| 210 | 64.01 | 9.97 | 15,265 | 7,205 | 6,485 | 5,836 |
| 220 | 67.06 | 10.11 | 15,918 | 7,513 | 6,762 | 6,086 |
| 230 | 70.10 | 10.25 | 16,567 | 7,820 | 7,038 | 6,334 |
| 240 | 73.15 | 10.38 | 17,214 | 8,125 | 7,313 | 6,581 |
| 250 | 76.20 | 10.51 | 17,859 | 8,429 | 7,586 | 6,827 |
| 260 | 79.25 | 10.63 | 18,500 | 8,732 | 7,859 | 7,073 |
| 270 | 82.30 | 10.75 | 19,139 | 9,034 | 8,131 | 7,318 |
| 280 | 85.34 | 10.87 | 19,776 | 9,334 | 8,401 | 7,561 |
| 290 | 88.39 | 10.98 | 20,411 | 9,634 | 8,671 | 7,804 |
| 300 | 91.44 | 11.10 | 21,043 | 9,932 | 8,939 | 8,045 |
| 310 | 94.49 | 11.21 | 21,673 | 10,230 | 9,207 | 8,286 |
| 320 | 97.54 | 11.31 | 22,302 | 10,527 | 9,474 | 8,527 |
| 330 | 100.58 | 11.42 | 22,928 | 10,822 | 9,740 | 8,766 |
| 340 | 103.63 | 11.52 | 23,552 | 11,117 | 10,005 | 9,005 |
| 350 | 106.68 | 11.62 | 24,175 | 11,411 | 10,270 | 9,243 |
| 360 | 109.73 | 11.72 | 24,796 | 11,704 | 10,534 | 9,480 |
| 370 | 112.78 | 11.82 | 25,415 | 11,996 | 10,796 | 9,717 |
| 380 | 115.82 | 11.91 | 26,032 | 12,287 | 11,058 | 9,952 |
| 390 | 118.87 | 12.01 | 26,648 | 12,578 | 11,320 | 10,188 |
| 400 | 121.92 | 12.10 | 27,262 | 12,868 | 11,581 | 10,423 |
| 410 | 124.97 | 12.19 | 27,874 | 13,157 | 11,841 | 10,657 |
| 420 | 128.02 | 12.28 | 28,486 | 13,445 | 12,101 | 10,890 |
| 430 | 131.06 | 12.36 | 29,095 | 13,733 | 12,360 | 11,124 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 440 | 134.11 | 12.45 | 29,704 | 14,020 | 12,618 | 11,356 |
| 450 | 137.16 | 12.53 | 30,310 | 14,306 | 12,875 | 11,588 |
| 460 | 140.21 | 12.62 | 30,916 | 14,592 | 13,133 | 11,820 |
| 470 | 143.26 | 12.70 | 31,520 | 14,877 | 13,389 | 12,050 |
| 480 | 146.30 | 12.78 | 32,123 | 15,162 | 13,646 | 12,281 |
| 490 | 149.35 | 12.86 | 32,725 | 15,446 | 13,901 | 12,511 |
| 500 | 152.40 | 12.93 | 33,325 | 15,729 | 14,156 | 12,740 |
| 510 | 155.45 | 13.01 | 33,925 | 16,013 | 14,412 | 12,971 |
| 520 | 158.50 | 13.09 | 34,523 | 16,295 | 14,666 | 13,199 |
| 530 | 161.54 | 13.16 | 35,120 | 16,577 | 14,919 | 13,427 |
| 540 | 164.59 | 13.24 | 35,715 | 16,857 | 15,171 | 13,654 |
| 550 | 167.64 | 13.31 | 36,310 | 17,138 | 15,424 | 13,882 |
| 560 | 170.69 | 13.38 | 36,904 | 17,419 | 15,677 | 14,109 |
| 570 | 173.74 | 13.45 | 37,496 | 17,698 | 15,928 | 14,335 |
| 580 | 176.78 | 13.52 | 38,088 | 17,978 | 16,180 | 14,562 |
| 590 | 179.83 | 13.59 | 38,678 | 18,256 | 16,430 | 14,787 |
| 600 | 182.88 | 13.66 | 39,268 | 18,534 | 16,681 | 15,013 |
| 610 | 185.93 | 13.73 | 39,856 | 18,812 | 16,931 | 15,238 |
| 620 | 188.98 | 13.80 | 40,444 | 19,090 | 17,181 | 15,463 |
| 630 | 192.02 | 13.86 | 41,031 | 19,367 | 17,430 | 15,687 |
| 640 | 195.07 | 13.93 | 41,616 | 19,643 | 17,679 | 15,911 |
| 650 | 198.12 | 13.99 | 42,103 | 19,919 | 17,927 | 16,134 |
| 660 | 103.17 | 14.06 | 42,785 | 20,195 | 18,176 | 16,358 |
| 670 | 204.22 | 14.12 | 43,368 | 20,470 | 18,423 | 16,581 |
| 680 | 207.26 | 14.18 | 43,950 | 20,744 | 18,670 | 16,803 |
| 690 | 210.31 | 14.25 | 44,531 | 21,019 | 18,917 | 17,025 |
| 700 | 213.36 | 14.31 | 45,112 | 21,293 | 19,164 | 17,247 |
| 710 | 216.41 | 14.37 | 45,691 | 21,566 | 19,409 | 17,468 |
| 720 | 219.46 | 14.43 | 46,270 | 21,839 | 19,655 | 17,690 |
| 730 | 222.50 | 14.49 | 46,848 | 22,112 | 19,901 | 17,911 |
| 740 | 225.55 | 14.55 | 47,425 | 22,385 | 20,147 | 18,132 |
| 750 | 228.60 | 14.61 | 48,002 | 22,657 | 20,391 | 18,352 |
| 760 | 231.65 | 14.67 | 48,577 | 22,928 | 20,635 | 18,572 |
| 770 | 234.70 | 14.72 | 49,152 | 23,100 | 20,880 | 18,792 |
| 780 | 237.74 | 14.78 | 49,726 | 23,471 | 21,124 | 19,012 |
| 790 | 240.79 | 14.84 | 50,300 | 23,742 | 21,368 | 19,231 |
| 800 | 243.84 | 14.89 | 50,872 | 24,012 | 21,611 | 19,450 |
| 810 | 246.89 | 14.95 | 51,444 | 24,282 | 21,854 | 19,668 |
| 820 | 249.94 | 15.00 | 52,016 | 24,552 | 22,097 | 19,887 |
| 830 | 252.98 | 15.06 | 52,586 | 24,821 | 22,339 | 20,105 |
| 840 | 256.03 | 15.11 | 53,156 | 25,090 | 22,581 | 20,323 |
| 850 | 259.08 | 15.17 | 53,725 | 25,358 | 22,822 | 20,540 |
| 860 | 262.13 | 15.22 | 54,294 | 25,627 | 23,064 | 20,758 |
| 870 | 265.18 | 15.27 | 54,862 | 25,895 | 23,306 | 20,975 |
| 880 | 268.22 | 15.33 | 55,429 | 26,162 | 23,546 | 21,191 |
| 890 | 271.27 | 15.38 | 55,995 | 26,430 | 23,787 | 21,408 |
| 900 | 274.32 | 15.43 | 56,561 | 26,697 | 24,027 | 21,625 |
| 910 | 277.37 | 15.48 | 57,127 | 26,964 | 24,268 | 21,841 |
| 920 | 280.42 | 15.53 | 57,691 | 27,230 | 24,507 | 22,056 |
| 930 | 283.46 | 15.58 | 58,255 | 27,496 | 24,746 | 22,272 |
| 940 | 286.51 | 15.63 | 58,819 | 27,763 | 24,987 | 22,488 |
| 950 | 289.56 | 15.68 | 59,382 | 28,028 | 25,225 | 22,703 |
| 960 | 292.61 | 15.73 | 59,944 | 28,294 | 25,465 | 22,918 |
| 970 | 295.66 | 15.78 | 60,506 | 28,559 | 25,703 | 23,133 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 980 | 298.70 | 15.83 | 61,067 | 28,824 | 25,942 | 23,347 |
| 990 | 301.75 | 15.88 | 61,627 | 29,088 | 26,179 | 23,561 |
| 1000 | 304.80 | 15.92 | 62,187 | 29,352 | 26,417 | 23,775 |

Highlighted are wind speeds at which UFT cruises on lift provided by the wind

# APPENDIX B

## POWER REQUIRED TO ASCEND/DESCEND

### 1. Theory.

From the Actuator Disk theory[1] for helicopters, the power required to ascend is given by

$$P = P_h\left(\frac{V_c}{2V_h} + \sqrt{\left(\frac{V_c}{2V_h}\right)^2 + 1}\right) \tag{1}$$

Where $P_h$ = power in hover,
$V_c$ = climb velocity, and
$V_h$ (hover velocity) = $v_i$ (induced velocity)

$v_i$ can be found from

$$v_i = \sqrt{T/2\rho A} = \sqrt{DL/2\rho} = P/T = (PL)^{-1} \tag{2}$$

Hover power, $P_h$, can be found from

$$C_P = \frac{P}{\rho A V_{tip}^3} = \frac{P}{\rho A \Omega^3 R^3} \tag{3}$$

Where $C_P$ can be found from Thrust coefficient, $C_T$

$$C_{P,total} = \frac{\kappa C_T^{3/2}}{\sqrt{2}} + \frac{1}{8}\sigma C_{d0} \tag{4}$$

Where $C_T$ can be recalculated from induced flow angle, $\lambda_h$ via

$$\lambda_h = \lambda_i = \frac{v_i}{\Omega R} = \frac{1}{\Omega R}\sqrt{\frac{T}{2\rho A}} = \sqrt{\frac{T}{2\rho A(\Omega R)^2}} = \sqrt{\frac{C_T}{2}} \tag{5}$$

The induced angle $\lambda_h$ can be calculated from parameters listed earlier.

$$\lambda_h = \frac{v_i}{\Omega R} \tag{6}$$

## 2. Calculations.

Using equations (1)-(6) above,

First, find the induced velocity during hover, $v_i = v_h$ from (2). Assuming a total weight of 140 kg the load is split to 70 kg on each rotor.

Thrust, T = Weight, W = 70 * 9.8 = 686 N

Blade radius, R ~ 2 m, thus the area $A = \pi R^2 = \pi(2^2) = 12.5714\ m^2$

Air density, $\rho = 1.225\ kg/m^3$

So, $vi = \sqrt{T/2\rho A} = \sqrt{686/(2*1.225*12.5714)} = 4.7194$ m/sec

Assume a rotor tip speed ($\Omega R$) ~ 20 m/sec (for good autorotation, and noise reduction).
Then, RPM = 20/2 = 95.5 rpm

The inflow angle $\lambda_h$ can be calculated from (6):

$\lambda_h = v_i/\Omega R = 4.7194/20 = 0.2359$

So, we can now get the thrust coefficient $C_T$ from (5):

$C_T = 2\lambda_h^2 = 2(0.2359^2) = 0.1114$

Assume Glauert's correction factor $\kappa = 1.15$, and using the high performance blade, where drag coefficient, $C_{do} = 0.1$ (over estimate to include all other drags). We can now calculate the $C_P$ in hover condition from (4).
The solidity $\sigma$ is the ratio of the blade area over the total disk area: (assume 3 blades, with blade chord C of 20cm = 0.2m)

$$\sigma = NCR/\pi R2 = NC/\pi R = (3*0.2)/\pi*2 = 0.0954$$

From (4), $C_{Ptotal} = \frac{kC_T^{3/2}}{\sqrt{2}} + \frac{1}{8}\sigma C_{d0} = \frac{1.15*(0.1114)^{3/2}}{\sqrt{2}} + \frac{0.0954*0.1}{8} = 0.0314$

So, from (3), $P_h = C_{Ptotal}\rho A(\Omega R)^3 = 0.0314*1.225*12.5714*(20^3) = 3870.134$ W

Assuming a maximum rate of ascent of 2 m/s, we can use (1) to get the net power (per turbine):

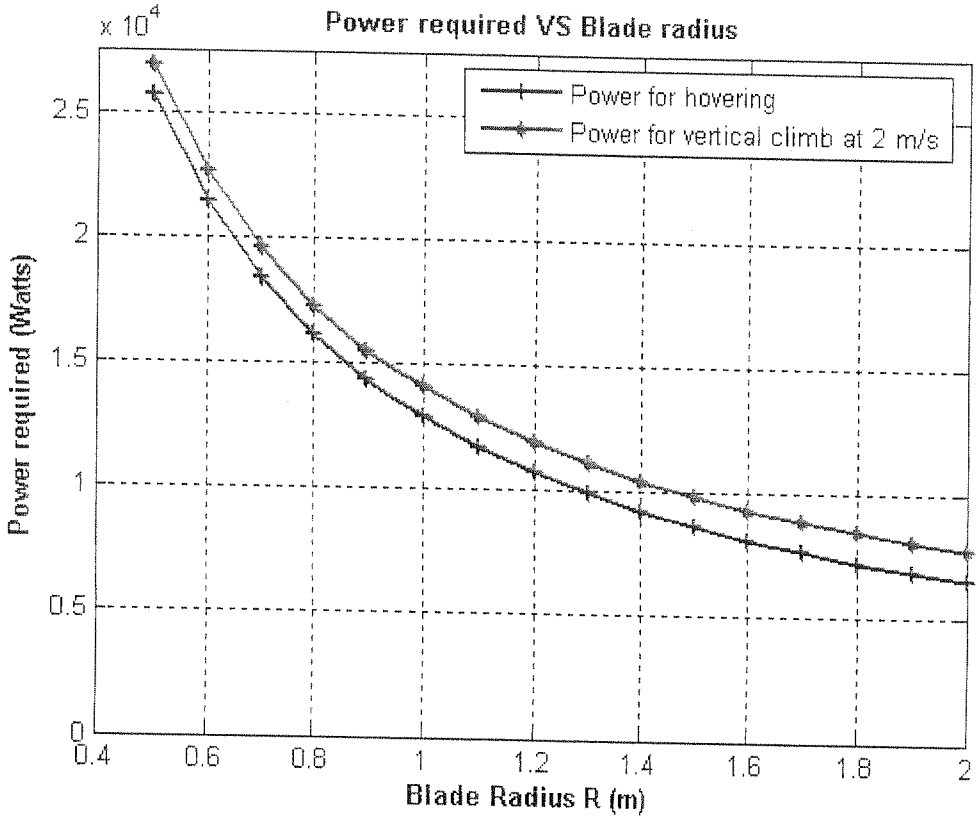
$$P = P_h\left(\frac{V_c}{2V_h} + \sqrt{\left(\frac{V_c}{2V_h}\right)^2 + 1}\right) = 3870.134*\left(\frac{2}{2*4.7194} + \sqrt{\left(\frac{2}{2*4.7194}\right)2 + 1}\right) = 4776.109$$

## 3. Conclusion.

This $P_{take\text{-}off}$ = 4.776 kW per rotor is below the expected production of >10 kW, thus the power ratio is < 1. We will be able to generate more power than we need to ascend/descend.

With two rotors, the maximum power required for take off, ascend and hovering at the above conditions is 2*4.776 = 9.552kW

The calculation above is for R = 2 m. For other radii, please see Fig. below:




*Required Power as a function of rotor radius.*

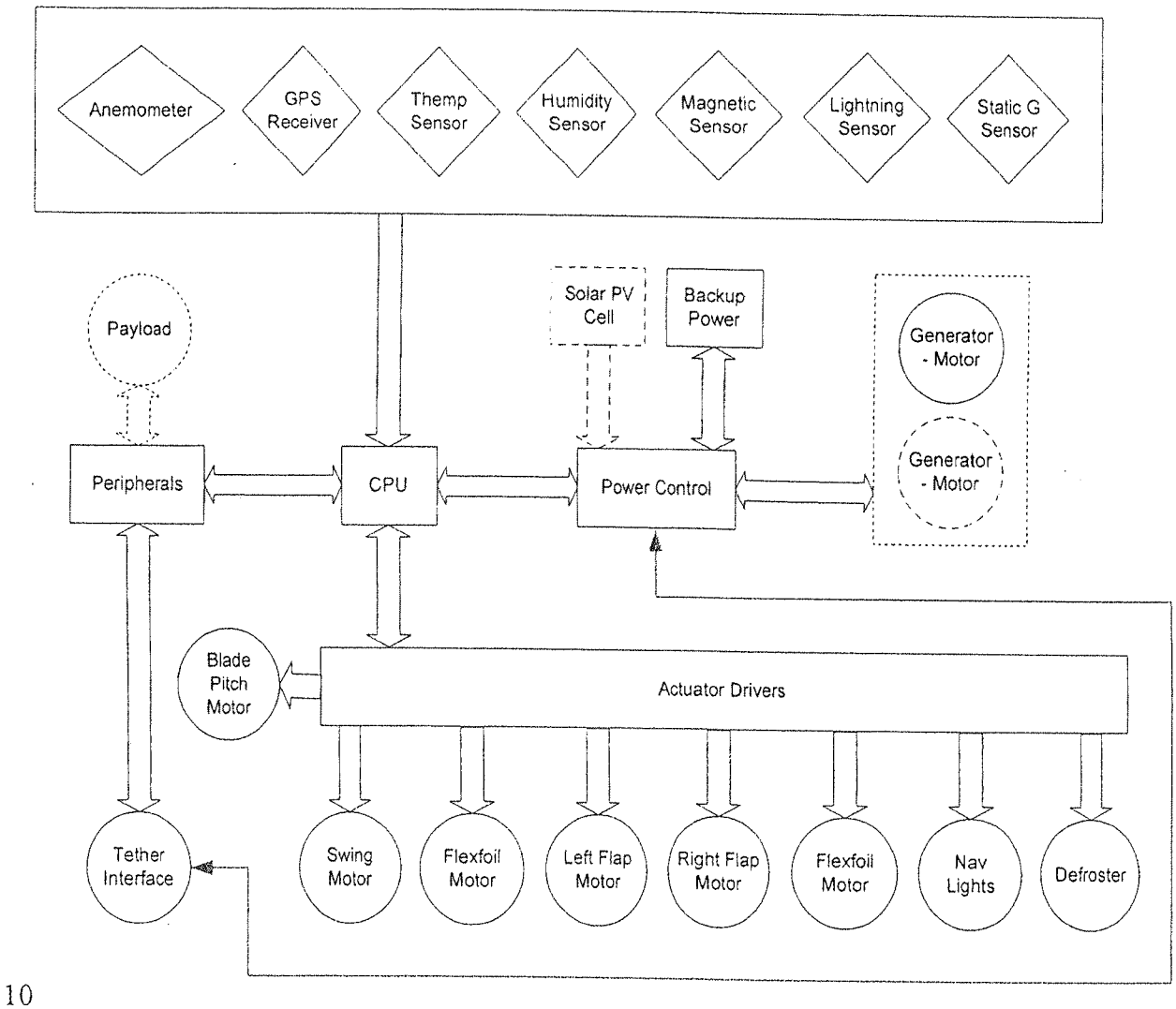
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[i] J. Gordon Leishmann, Principles of helicopter aerodynamics, 2nd ed, Cambridge Univ. Press

# Additional Detail on UFT

1. POD (Flying turbine) $C^2$:

Below is the block diagram of the POS $C^2$ System:

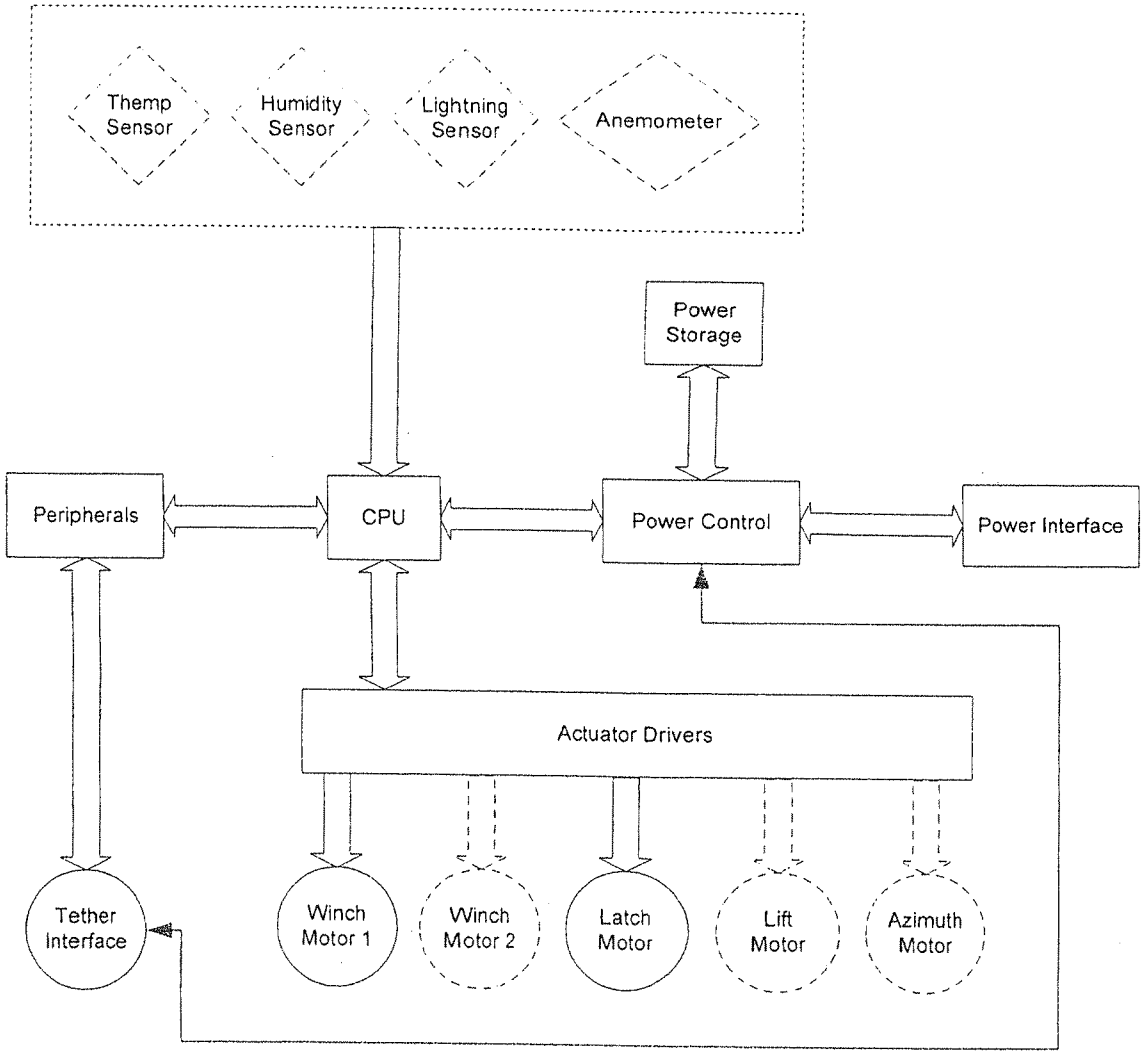



Accordingly, The CPU processes input from various environmental sensors as shown. With this info (and its firmware) the CPU makes decisions how and when to activate the various actuators to fulfill the mission. The Power Control module marshals the power transfer and generator-motor running parameters. The blue line designates the high power path (bidirectional). The Payload module is used optionally to control payload operations (when installed). Payloads may be surveillance or communications equipment, lightning, etc.

The tether interface decouples high power currents from low power ones and ensures safety. The backup power is used to power all actuators (and computer) in case of a catastrophic failure. Solar PV Cell is used to provide additional power for operation (if installed).

2. Ground Station $C^2$.

Below is the GS block diagram:




Same concept, except environmental sensors are optional here. In most cases they will not be needed at all.. Note that there may be one or two winch motors. Two motor configuration provides better control. The Lift motor (optional) is used to telescopically increase the height of the GS mast (the POD is parked on top of it) in order to bring the POD above surrounding obstacles, if the system is installed in such an environment.

The lift is accomplished by a simple screw drive - an electric motor drives a screw via several gears to increase torque and decrease speed.
The azimuth motor is one that drives the turntable (if equipped).

The Power Interface contains not only transfer switch(es) but also power conditioners (AC/AC converter, optional inline UPS if required to provide backup power).

3. POD flaps.

These are the control surfaces we discussed. Below is a drawing representing a side view showing the degrees of freedom +/-A. The length of the flaps is set to 1/5 (20%) of the wing chord C, while the angle A may be between 15 and 45%. Note that a large angle A does not necessarily mean that the flap will be deflected that much – the amount of deflection is determined by the CPU in response to environmental parameters:

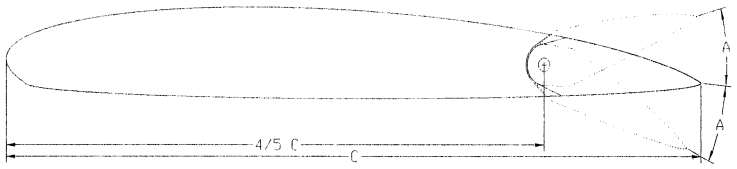
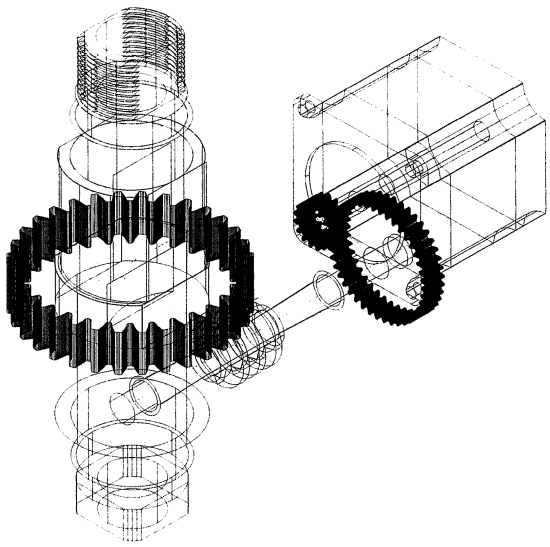



Fig 3. Rigid wing cross section showing flap, its pivot and end positions.

Typical rigid wing chord C is 80cm (0.8m). The total length B of the wing for the 10kW model we discussed is set at 5m.

There are two identical flaps, one on each end of the rigid wing, at positions between 60% and 90% of B/2 (half wing length), both driven individually by a small electric motor and a worm/worm gear pair, similar to the one shown below:



A stepper motor (optionally, a servo motor) drives a worm through a simple reduction gear. The worm is calculated such that it cannot transfer torque back to the motor.

Below is another cross section of the rigid wind, showing the attached motor-generator with an optional gearbox (rotor not shown):

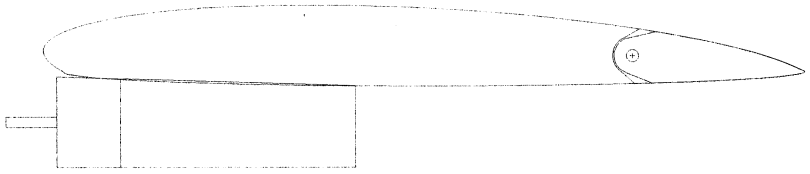


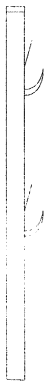
Fig 4. Rigid wing cross section showing flap, its pivot, generator-motor with an optional gearbox and shaft for mounting the rotor. Note that the generator-motor is mounted in a fashion such that the axis of its shaft is at an angle $\alpha$ to the wing baseline – $\alpha$ is the designed angle of attack of the rigid wing (i.e. when the rotor shaft is horizontal, the rigid wing is lifted to an angle $\alpha$ relative to the rotor shaft, so the wing can work).

4. Ground Station Mast (Launch Pad).
The Mast is generally vertical and is used as a mooring mast for the POD.
The drawing below shows detailed view of the top of the mast with integral latches. These are used for securing the POD when not in use.

The hook portions of each latch are fixed to the mast and bear the load of the POD. Also shown (open) are the movable parts of the latches, activated by either a spring (normally closed, open when a solenoid is activated), or an electric motor via a screw drive. In either case, the mechanism for latch activation is concealed within the mast itself, to protect it from the elements.

On top of the mast there is a shock absorber (commonly made of a suitable polymer) on which the rigid wing of the POD rests.

The portion of the mast shown in the above drawing is further suspended by a spring loaded shock absorber to the main body of the mast. Its purpose is to arrest shocks when the POD is brought down for landing.



5. Actuator movement for rigid wing relative to main body.
This is preferably done by a worm/worm gear arrangement driven by n electric motor, similar to the one shown above for the flaps, or it can be done by a screw drive.

## Claims

1. A fluid turbine comprising:
an aerofoil for supporting a plurality of rotors; and
a main body to mount the aerofoil,
wherein the aerofoil is pivotably connected to the main body to generate lift for the fluid turbine when in use.

2. The fluid turbine of claim 1, wherein the pivoted connection between the aerofoil and the main body has a degree of freedom between 120 to 180 degrees.

3. The fluid turbine of claim 2, wherein the degree of freedom is 130 degrees.

4. The fluid turbine of any of claims 1 to 3, further comprising a control device arranged to adjust a relative position between the aerofoil and the main body.

5. The fluid turbine of claim 4, wherein the plurality of rotors are operable to define respective swept areas, and the control device is arranged to adjust the relative position between the aerofoil and the main body in such a way that the swept areas receive wind in a perpendicular direction.

6. The fluid turbine of any of claims 1 to 5, wherein the aerofoil further comprises a flap at a trailing edge of the aerofoil, the flap being rotatable about an axis of the aerofoil.

7. The fluid turbine of any of claims 1 to 6, wherein the aerofoil further comprises a fin arranged in relation to a plane of the aerofoil.

8. The fluid turbine of any of claims 1 to 7, wherein each of the plurality of rotors has a diameter of 4m.

9. The fluid turbine of any of claims 1 to 8, further comprising an anemometer for measuring wind speed.

10. The fluid turbine of claim 9, wherein the anemometer is a mechanical vane-type anemometer.

11. The fluid turbine of claim 9, wherein the anemometer is a sonic anemometer.

12. The fluid turbine of any of claims 1 to 11, further comprising a Global Positioning System (GPS) receiver for determining location of the wind turbine in airborne.

13. The fluid turbine of any of claims 1 to 12, further comprising a sensor.

14. The fluid turbine of claim 13, wherein the sensor is a 3-axis static G-force sensor.

15. The fluid turbine of claim 13, wherein the sensor is dew sensor.

16. The fluid turbine of claim 13, wherein the sensor is a thermometer.

17. The fluid turbine of claim 13, wherein the sensor is a static electricity sensor for detecting lightning.

18. The fluid turbine of any of claims 1 to 17, further comprising a defroster for defrosting ice.

19. The fluid turbine of claim 18, wherein the defroster is a resistive strip arranged on the aerofoil.

20. The fluid turbine of any of claim 1 to 19, wherein the fluid turbine is operable to reach an upper altitude limit of 2000 feet in airborne.

21. The fluid turbine of claim 20, wherein the fluid turbine is operable to reach an upper altitude limit of 1000 feet in airborne.

22. A fluid turbine system comprising:

a anchoring station; and
the fluid turbine of any of claims 1 to 19 in electrical connection with the anchoring station.

23. The fluid turbine system of claim 22, further comprising at least one tether connected between the anchoring station and the fluid turbine, for anchoring the fluid turbine to the anchoring station.

24. A method of operating the fluid turbine system of claim 22 or claim 23, the method comprising the steps of:
rotating the plurality of rotors to generate a lift for the fluid turbine, the rotation of the plurality of rotors defining respective swept areas;
measuring wind speed as the fluid turbine is lifted; and
adjusting the relative position between the aerofoil and the main body when a first pre-determined wind speed is detected.

25. The method of claim 24, wherein the wind speed is measured at altitudes of 10 feet multiples.

26. The method of claim 24 or claim 25, wherein the adjusting of the relative position between the aerofoil and the main body comprises the step of detecting the pre-determined wind speed of 7m/s.

27. The method of any of claims 24 to 26, wherein the adjusting of the relative position between the aerofoil and the main body comprises the step of positioning the fluid turbine in such a way that the swept area receives wind in a perpendicular direction.

28. The method of any of claims 24 to 27, further comprising the unwinding of the tether so that the fluid turbine is lifted to an altitude with a second pre-determined wind speed.

29. The method of claim 28, wherein the unwinding of the tether stops when the second pre-determine wind speed of 12m/s is detected.

30. The method of any of claims 24 to 29, further comprising the winding of the tether to pull the fluid turbine towards the anchoring station.

31. A self-powered vehicle comprising the fluid turbine of any of claims 1 to 21.

32. The self-powered vehicle of claim 31, wherein the self-powered vehicle is a meteorological station.

33. The self-powered vehicle of claim 31, wherein the self-powered vehicle is an airborne warning system.

34. The self-powered vehicle of claim 31, wherein the self-powered vehicle is a flying billboard.

35. The self-powered vehicle of claim 31, wherein the self-powered vehicle is a communication station.