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ENERGY TRANSFER FROM AIRBORNE HIGH ALTITUDE WIND TURBINES: PART I, A FEASIBILITY STUDY OF AN AUTOGIRO-GENERATOR FROM AN EXISTING HELICOPTER

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ABSTRACT

Current designs of ground based, wind energy extraction systems have limitations of wind instability and high cost of installations. The efficiency of these systems is optimal for a nominal speed and decrease sharply for higher or lower winds. This paper introduces large air rotors at high altitude for powerful and relatively stable air stream out of ground effect. This first part deals with an existing helicopter that is transformed to an autogiro for power generation. The helicopter is linked to the ground with a cable that connects the airborne generator to the ground power grid. In our case the air rotor system flies at an altitude of about 4 km that is statistically the best compromise between power available and altitude. Two versions of the helicopter are considered: electrical (motors-generators) and hybrid (turboshafts + generators). In the electrical version, the electric motors power the helicopter that climbs up the required altitude and lift the cables. At this point, the motors are switched to generator-mode and the helicopter keeps altitude as an autogiro and generates energy. The hybrid solution adds the generator(s) to the helicopter. The hybrid-helicopter climbs with the turboshafts and then trip-off the engines to work as an autogiro-generator. We used is the largest available helicopter : the CH47 Chinook. This choice is because it is economically convenient to use the largest wind generator possible. Both fully electric and hybrid solutions proved to be technically feasible. However, the pure electric solution requires a huge amount of power from the power grid (7 MW), therefore has relatively high installation costs. For this reason, the hybrid solution is more practical. The average power produced is more than 0.8 MW. Unfortunately, the cost per kWh is two order of magnitude higher than the carbon produced one. Therefore, this solution is convenient only when you have problems to take the fuel or the grid to the place where energy is needed. Helicopter/autogiro stability and control systems enable to change altitude and to deal with emergencies. This airborne system provides the following main advantages: power production capacity higher than conventional ground-based small rotor designs; the installation is environmentally friendly also for the propeller noise.

Keywords: airborne wind turbine, autogiro, electric power generation, green energy, hybrid helicopter.

INTRODUCTION

Wind power generation units are now over two hundred thousand worldwide, with a gross nominal capacity of more than 300 GW. The European Union has about 100,000 MW installed, while the United States and China are around 50,000 MW each. Most of these power units are ground based with an average height of about 150m [1] [2]. At this altitude, the average wind speed is below 10 m/s. At higher altitude (12-13 km), it is possible to find winds up to 51 m/s (latitude 22° N). Windmills close to the surface are affected by high variability and by ground interference. On contrary, winds at altitude are more constant, with global capacity of the order of magnitude of the GW. For this reason, recent years have seen a significant amount of research in the technology meant to extract electric power from high altitude winds. At an altitude of 10m, the standard wind average speed is 6 m/s. At 5 km, the average wind speed is about 20 m/s. This value doubles when you reach 10 km of altitude. Since the available power goes with the third power of the velocity, the energy available from the wind at 5 km is 37 times the one at 10m. This figure reaches 300 times at 10 km. What makes the advantage gorgeous is the fact that speed at altitude is more constant. Therefore, you can design your airborne wind turbine to work most time at nearly maximum efficiency especially if the airborne system has the possibility to change altitude. On the contrary, ground based turbines have null efficiency at very low and very high speed, Wind speed always increases with altitude? However, the altitude at which winds are strongest varies with weather conditions. Worldwide, 95% of the time the optimal altitude is below 6,000m. Table-1 shows the capacity factors for two different altitudes at various locations.

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Table-1. Capacity factors for different locations at two reference altitudes.

Location	Country	4, 570 m	10, 670 m
Gough Island	South Atlantic	78%	95%
Misawa	Japan	63%	94%
Gagetown N.B.	Canada	70%	92%
Nottingham	England	64%	85%
Beijing	China	46%	85%
Tasmania	Australia	60%	84%
Buenos Aires	Argentina	50%	82%
Moscow	Russia	51%	78%
King Fahad Int Airport	Saudi Arabia	46%	78%
Lyon	France	40%	78%
Munch	Germany	38%	73%
Madrid	Spain	32%	73%
Patiala	India	23%	72%
Milan	Italy	24%	70%

The capacity factor is the ratio between the energy available and the maximum energy available. Therefore, it is an indication of the wind velocity variability. In this paper our airborne generator will work on Bologna (Italy - 44° 29' N; 11° 20' E) at an altitude of 4, 150m. The average wind speed is 27.6 m/s.

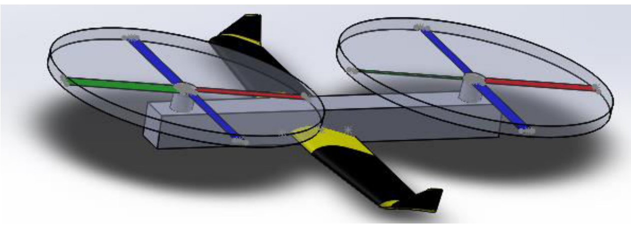

Figure-1. The proposed solution (aerial generator - "helicopter").

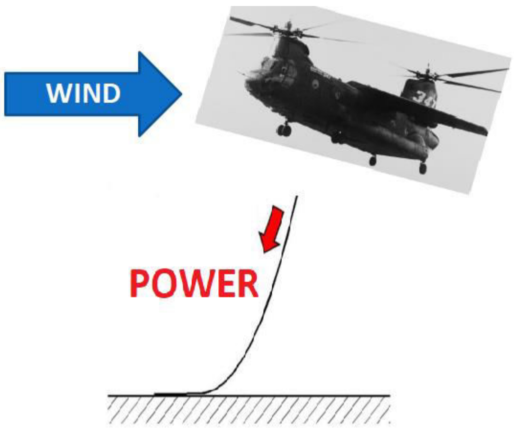

Figure-2. The proposed solution (complete system).

THE PROPOSED SOLUTION

In this paper, a very large helicopter (CH47 Chinook) [3] working as an autogiro is used for the power generation. The advantage of this helicopter is that it is relatively easy to transform it in an Unmanned Aerial Vehicle (UAV), passing through the Optionally Piloted Vehicle (OPV) option. This is due to the availability of an autopilot and a computerized fly by wire control system for this helicopter. Therefore, a stability and control systems is already available along with the ability of changing altitude. The choice of the large helicopter is because it is more economical to transform and to operate from a single ground station. The helicopter has the advantage that it can reach the altitude autonomously towing the cable and it can choose the best altitude within the design maximum to find the best wind. In case of emergency, it can drop the cable and land or it can carry the cable to the ground. It is already certified and designed to fly. Therefore, the transformation from a cargo aerial vehicle to an airborne power unit is easier. The proposed high altitude power system is introduced in Figures 1 and 2. That includes dual rotor system with generators, support wing (Figure-1), cable (Figure-2). A ground-based device allows changing cable length and airborne system altitude. The modified Chinook helicopter works in autogiro mode for lift and power generation. In the first virtual prototype (Figure-1) the fuselage has been elongated and an additional wing has been added like in the prototype of the '70 (BV 347). It is not difficult to launch the airborne rotor(s) system by using the generators as motors with the additional help of the support wing. In this case, the system works as an electric helicopter, with the cable that supplies power and the "helicopter" that points the nose toward the wind. In alternative, it is also possible to use the original helicopter power plant for the "helicopter

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mode” and to add generator(s) for the “autogiro mode”. In this case, the helicopter uses the original thermal power plant to reach the altitude. The control is similar to the one of the original helicopter. As the altitude is reached, the helicopter turns to autogiro mode, with the rotors that generate both lift and energy. Additional lift is given by the wing that, as it will be shown in the following paragraphs, improves the overall performance of the system.

HELICOPTER-GENERATOR AERODYNAMIC PERFOMANCE-AUTOGIRO MODE-(CFD)

To obtain results in a reasonable time it is necessary to introduce many simplifications in the CAD model. The first of these operations is to remove all the appendages with negligible dimensions compared to the most interesting elements. The landing gear, the engine gondolas, the side tanks and the complex shapes of tail and head have thus been eliminated. Therefore, the drag will be underestimated. In the first, large wing solution, the main body was increased in length to allow that the front rotor blades do not interfere with the rear ones. In this way, the mechanical connection between the rotors is optional. Finally, the main body was shaped like a parallelepiped with width=2.5m, height=2.5m and a length of L=26m. In this way, the sparse matrix solver of the CFD software automatically rounds the edges in the most efficient way from the computational point of view [4-18]. In addition, the rotors and their connections have been reduced to simple extruded cylinders to which we have connected the blades. For the blades, we choose a symmetrical NACA 0006 airfoil. Tables 2 and 3 summarize a few simulation data. After various tests, the best compromise for the wing airfoil is the Eppler 442.

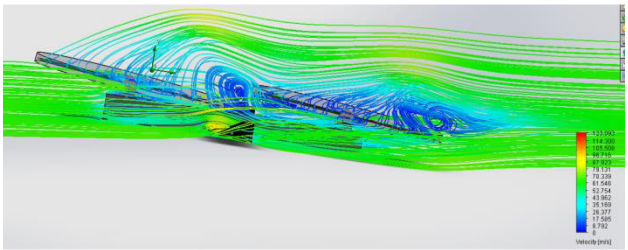

Figure-3. The large wing solution (complete system).

Table-2. Boundary conditions for CFD simulation (see also Figure-3).

Rotor speed (take off)	32 rad/s
Rotor speed (autogyro)	10 rad/s
Air speed (autogyro) X	27.53 m/s
Air speed (autogyro) Y	3.87 m/s Y: 9.42 m/sY
Lift	Load along Y
Drag	Load along X
Air	ISA at 4,150m

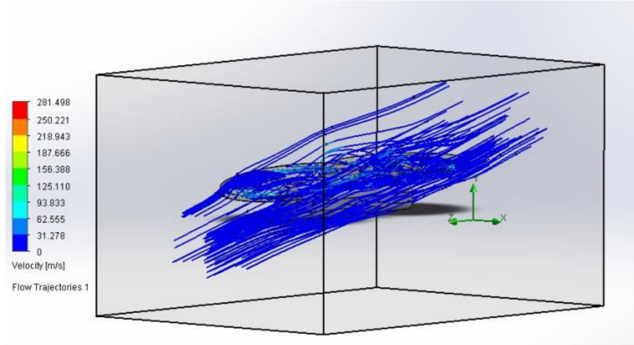

Figure-4. The small wing solution.

From the CFD simulation (Figures 3 and 4), the optimal performance in autogiro mode with a *windspeed*=27.6 m/s is with rotors inclined of 6 DEG rearwards. In this condition, we have approximately 500kN of lift and 50kN of drag, with an efficiency of 10. The fuselage is inclined rearword of 8 DEG. A second solution was optimized for this application [19]. This small wing system has the original Chinook fuselage (CH47), without engines and landing gear nacelles. The wing is smaller and the optimum incidence is $attitude_{autogiro}$=24 DEG. In this case, the rotor blades have a NACA 64A212 airfoil. The better efficiency of the short helicopter is due mostly to the fuselage drag and interference in autogiro mode. An optimized design would require a much thinner fuselage to contain drag. However, in this feasibility study the original helicopter fuselage was kept in order to simplify estimations. In addition, the use of an existing helicopter for the prototype would reduce the cost. Table-3 summarizes the aerodynamic performance of the helicopter generator without wing, with small wing (Figures 4 and 5) and with large wing (Figure-3). The large wing configuration is also more problematic from the point of view of the control. The wing is so beneficial that should be included in the final design. The airfoil of the wings is the Eppler 442 for both the designs. The small wing and original fuselage is more convenient.

Table-3. Performance of the different configurations. Autogiro mode.

Configuration	Lift [kN]	Drag[kN]	Efficiency
Without wing (autogyro)	300	32	9
Small wing	450	38.5	11
Large wing	500	50	10

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Table-4. Performance of the different configurations compared with the "helicopter without wing". Autogiro mode.

Configuration	Lift [%]	Drag[%]	Eff. [%]
Without wing (autogyro)	100	100	100
Small wing	150	120	122
Large wing	166	156	111

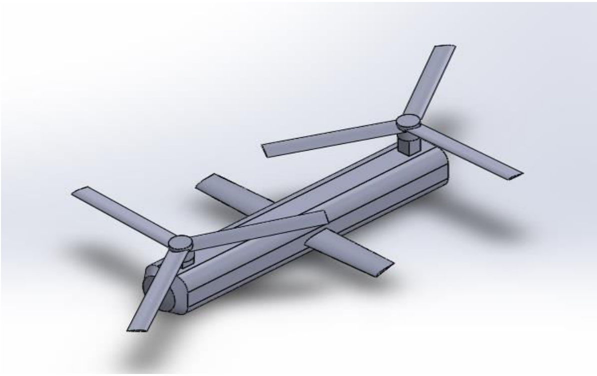

Figure-5. Very simplified CFD model of helicopter-generator with small wings.

The penalization of the wings at takeoff is less than 20% of the lift (small wing). Small and large wind data are summarized in Table-4. The small wing does not have the winglets since they penalize the lift in helicopter mode. To optimize the overall performance, the two wings should have different length. However, this further optimization is beyond the scope of this paper.

Table-5. A few data of the two wings.

Configuration	Span[m]	A[m^2]	AR [-]
Small wing	15	28	8
Large wing	31	147	6.5

Cable mass estimation

The nominal operating altitude of the wind turbine is L=4,150m. It is assumed that the wind turbine is allowed to move in the vertical of the anchorage for a length corresponding to an angle not greater than 15 DEG. Therefore the maximum theoretical cable length will be L_c=4,296m (1).

$$L_C = \frac{L}{\cos(15°)} = \frac{4150}{\cos(15°)} = 4296m \tag{1}$$

The horizontal distance traveled by the wind turbine is x=1, 112m (2).

$$x = L \cdot tg(15°) = 4150 \cdot tg(15°) = 1112m \tag{2}$$

However, the actual behavior of the cables must be considered. The length taken into account up to now, in fact, is the straight line (which corresponds to the distance between the wind turbine and the ground connection point). For a more realistic study, the catenary formed by the cable given by the integration of the funicular of the load must be considered. The catenary is the curve according to which a heavy, perfectly homogeneous, flexible and inextensible wire is positioned, having its ends at two fixed points. In the specific problem, the catenary will have to pass through the points (0; 0) and (1112; 4150), plus there must be a displacement downwards of the quantity ***a***=390 (3).

$$L = a \cdot \cosh(\frac{x}{a}) - a \quad \Rightarrow \quad a \approx 390 \tag{3}$$

By executing a line integral from 0 to 1112 [m] of the catenary equation (4), we obtain a cable length of 4,479m (4).

$$y = a \cdot \cosh(\frac{x}{a}) - a \tag{4}$$

In this way, only the effect of the mass is taken into account. Therefore, we will take a cable along L_c= 4,500m. An electric transformer must be installed on the ground, to raise the voltage reducing the section. Common medium tension, aluminum-alloy wires are available up to 36, 000 [V]. It is then necessary to evaluate the amount of energy that will be transferred through the cable. Since, during the deployment phase, the airborne wind turbine works as a helicopter, we will assume to install the same power of the CH47F that has two turboshafts of 3,529 kW each. Therefore, the total power installed will be about ***P***=7 MW. The current will be 250A (5)

$$P = V\, I \cos(\varphi) \Rightarrow I \approx 250A \tag{5}$$

For this current intensity, aluminum alloy, insulated commercial cables have a weight of about 1,200 kg/km. The cable will therefore have a total mass of 5,400 kg. To this figure, it is necessary to add the weight of the transformer on the "helicopter-generator". A transformer 36,000/1,000 V - 1,000Hz can be installed with a mass of about 1,200 kg. The total mass of the electric transfer system will be 5,400+1,200= 6,600 kg. Aerodynamic loads on the cable are negligible and its tensile strength is easily improved by adding aramid fibers to the outer polymeric insulation. Aramid reinforcement is available from a few cable manufacturers as a customized solution.

Power output

The CH47F helicopter has a lift of 19,000kg at 4150m with 80% throttle. The installed power is 7,058 kW. We assume that it is flat rated up to the cruise altitude (2,252m ISA). Therefore, at 4,150m the CH47F available power $Power_{4150m}$is reduced by the air density ratio (6)

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$$Power_{4150m} = Power_{CH47F} \frac{\rho_{4150}}{\rho_{cruise}} Throttle = 7058 \frac{0.806242}{0.981236} 0.8 = 5070kW \quad (6)$$

The wing will increase the lift of 50% ($Wing_{overlift}$=1.5). Further assumptions are on the efficiency of the rotors in helicopter mode (η_{eli}=0.8) and in windmill mode ($\eta_{windmill}$=0.2). The estimated power output of the wind turbine $P_{windturbine}$≈800 kW (7).

$$P_{windturbine} = Power_{4150m} Wing_{overlift} \frac{\eta_{windmill}}{\eta_{eli}} Tan(attitude_{autogiro}) = \quad (7)$$

$$5068 \times 1.5 \frac{0.2}{0.8} Tan(23.64) = 832kW$$

To check the value it is possible to evaluate the $P_{windturbine}$ through the drag calculated by the CFD (Table-3 $Drag_{smallwing}$=38.5 kN). With this approach, we obtain a $P_{windturbine}$≈1,000 kW (8). The difference of 20% may be due to fuselage interference that gives additional drag and to the efficiency of the rotor.

$$P_{windturbine} = Drag_{smallwing} Windspeed = 38.586 \times 27.8 = 1072kW \quad (8)$$

The average energy yearly production will therefore be E_{year}=3.84 GWh (9) with an availability of the wind turbine of $Days_{year}$=200 days x year.

$$E_{year} = P_{windturbine} Days_{year} 24 = 800 \times 200 \times 24 = 3.84GWh \quad (9)$$

Electric system mass, hybrid case

In this case, we simply add a generator on the transmission of the Chinook helicopter. We will also have the additional wing. The hybrid Chinook power generator uses the turboshafts for the helicopter mode and the generator (with the turboshafts off) for the autogiro mode. In this case, the cable should transfer only the generator power (800kW). Therefore, the current would be (10)

$$P = V\, I \cos(\varphi) \Rightarrow I \approx 28A \quad (10)$$

For this current, aluminum alloy, insulated commercial cables have a weight of about 600 kg/km. The 4.5 km long cable will therefore have a total mass of 2,700 kg. To this figure, it is necessary to add the weight of the transformer on the "helicopter-generator". A transformer 36,000/1,000V - 1, 000Hz can be installed with a mass of about 200 kg. The total mass of the electric transfer system will be 2, 700+200=2, 900 kg. We would have to install on the power turbine shafts two 400 kW generators running at 33,000 rpm. Each generator with regulator will have a mass of about 250kg, for a total of 500kg. The additional mass of the hybrid Chinook would therefore be 2, 900+500=3, 400kg. The helicopter that would need only the fuel necessary to arrive at 4, 150m and for an emergency descent can easily carry this load. The advantage of the hybrid Chinook is that it does not necessitate of 7 MW at takeoff and climb from the electric power grid.

System mass estimation

The small wing pure electric "helicopter generator" is a Chinook with retractable wheels. The CH47F has an empty mass of 11,148 kg and can lift 19,000 kg at 4,150m ISA. Assuming that the empty mass of the CH47F is the same of our "helicopter generator", we should add the mass of the energy transfer system of previous paragraph (M_{el}=6,200kg). The total mass of our "pure electric Chinook power generator" is therefore M=17,348kg (11).

$$M = M_{helicopter} + M_{et} = 11148 + 6200 = 17348kg \quad (11)$$

The mass margin is enough to compensate the effect of the wing and the aerodynamic loads on the cable; therefore, the wind turbine system seems to work in "helicopter-mode" during system deployment. The hybrid Chinook mass is 3, 400 kg for the "electric system" to be added to the original turboshaft-power-system. The total mass of the hybrid Chinook is therefore 11, 148+3, 400+1, 000=15, 548 kg, well below 19,000kg.

Cable load estimation

The drag at the maximum wind speed admissible which is 9 times the average one (Table-3: $Drag_{nominal}$=38.5 kN) is $L_{maximumspeed}$=347 kN(12).

$$D_{maximumspeed} = Drag_{nominal} 9 = 38.586 \times 9 = 347kN \quad (12)$$

The vertical component of the load at a nominal inclination of the cable of 15 DEG from the vertical is $L_{vertical}$=1,348 kN (14). The total cable load will be therefore L=1,392kN (15).

$$L_{vertical} = \frac{D_{maximumspeed}}{\tan(15)} + M_{cable} g = 1348kN \quad (14)$$

$$L = \sqrt{L_{vertical}^2 + L_{horizontal}^2} = 1392kN \quad (15)$$

This load is reasonable for our cable if aramid fibers are inserted in the insulant.

Cost estimation

From official Bell data the 206L4, the costs per hour are: 216.65 USD for airframe maintenance and 322.47 USD for powerplant maintenance (Feb. 2017). Helicopter costs goes linearly with normal takeoff weight, therefore the Chinook will cost just for maintenance more than $USD_{maintenance}$=5,000 USD a hour (16).

$$USD_{maintenance} = Bell_{206L4} \frac{W_{CH47}}{W_{206L4}} = 5075USD \quad (16)$$

If the Chinook flies 200 days a year for a total of $Hours_{year}$=4800 [h]. The cost of the capital will be $USD_{capital}$=3,347 USD (17) with an interest rate $\boldsymbol{r}$=10%.

$$USD_{Capital} = USD_{aerogenerator} (1+r)^{\frac{Life}{Hours_{Year}}} / Life \quad (17)$$

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This value is calculated with a total life of the aero-generator *Life*=20,000 [hr] and a purchase cost of $USD_{aerogenerator}$=45 million USD. To this figure the insurance, personnel and rental costs should be added. The yearly insurance is about 20% of the purchase cost, the labor is 96 USD per hour (Bell data) and rental costs are assumed 1,000 USD per month. If you need 10 people to run the aero generator round the clock, the total hour cost of the aero generator will be 9,824 USD. This figure is reasonable since, from official data, a British RAF Chinook costs approximately 8,000 USD x hour. The cost of a kWh will be 12.28 USD per kWh with a power output of 800kW. This airborne generator is not convenient. The actual cost per kWh in Italy is less than 0.1 USD per kWh. Therefore, we should reduce the cost of two orders of magnitude. A complete redesign of the system is required. This redesign is introduced in the part 2 of this paper. However, the hybrid Chinook has the advantage of generating power without the necessity of massive fuel and electric power supply. For this reason, the additional costs may be reasonable for a few applications.

CONCLUSIONS

Current designs of ground based, wind energy extraction systems have limitations of wind instability and high cost of installations. The efficiency of these systems is optimal for a certain speed and decrease sharply for higher or lower winds. This paper suggests increasing power per unit by large air rotors at high altitude for powerful and relatively stable air stream out of ground effect. This first part deals with the transformation of an existing helicopter that is transformed to power generation. The helicopter is linked to the ground with a cable that connects the generator to the ground power grid. In our case the air rotor system flies at an altitude of about 4 km that is statistically the best compromise between power available and altitude. Two versions of the helicopter are considered: electrical (motors-generators) and hybrid (turboshafts + generators). In the electrical version, the electric motors power the helicopter that climbs up the required altitude and lift the cables. The cable supplies the power to the helicopter through the power grid. Once the helicopter reaches the desired altitude, the motors are switched to generator-mode and the helicopter keeps altitude as an autogiro and generates energy. In this case, the motor system should output 7MW, while the generator outputs only 0.8-1 MW. The hybrid solution adds to the original helicopter a 1 MW electric power generation system. The helicopter climbs with the turboshafts and then trip-off the engines to work as an autogiro. In this case, a much small electric cable is necessary. The helicopter we used is the largest available: the CH47F Chinook. This choice is because it is economically convenient to use the largest wind generator possible. Fully electric and hybrid solutions proved to be both technically feasible. However, the pure electric solution requires a huge amount of power from the power grid (7 MW), therefore has relatively high installation costs. For this reason, the hybrid solution is more practical. The average power produced is more than 0.8 MW. Unfortunately, the cost per kWh is two order of magnitude higher than the carbon produced one. This solution is convenient only when you have problems to take the fuel or the grid to the place where energy is needed. Stability and control systems enable to change altitude and to deal with emergencies. This airborne wind system provides the following main advantages: power production capacity higher than conventional ground-based small rotor designs and the installation is environmentally friendly also for the propeller (low) noise.

REFERENCES

[1] Piancastelli L., Pirazzini A., Cremonini M., Cassani S., Calzini F., Pezzuti E. 2018. The optimization of power generation in low-cost mass produced wheeled wind turbines. ARPN Journal of Engineering and Applied Sciences. 13(15): 4466-4474. EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[2] Piancastelli L., Frizziero L., Rocchi I. 2014. A low-cost, mass-producible, wheeled wind turbine for easy production of renewableenergy (2014) Far East Journal of Electronics and Communications, 12(1): 19-37. EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[3] AA.VV. TM 1-1520-240-10 - Operator's Manual For Army Model Ch-47d Helicopters And Updates. 2003. Washington, D.C.

[4] L. Piancastelli, L. Frizziero, G. Donnici. 2015. The Meredith ramjet: An efficient way to recover the heat wasted in piston engine cooling. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(12): 5327-5333, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[5] L. Piancastelli, L. Frizziero. 2014. Turbocharging and turbo compounding optimization in automotive racing. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(11): 2192-2199, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[6] L. Piancastelli, L. Frizziero, G. Donnici. 2015. Turbomatching of small aircraft diesel common rail engines derived from the automotive field. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(1): 172-178, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

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[7] P.P. Valentini, E. Pezzuti E. Computer-aided tolerance allocation of compliant ortho-planar spring mechanism. Int. Jou. Of Computer Applications In Technology, 53: 369-374, ISSN: 0952-8091, doi: 10.1504/IJCAT.2016.076801

[8] E. Pezzuti, PP. Valentini PP. Accuracy in fingertip tracking using Leap Motion Controller for interactive virtual applications. Int. Jour. On Interactive Design And Manufacturing. pp. 1-10, ISSN: 1955-2513, doi: 10.1007/s12008-016-0339-y

[9] E. Pezzuti E, PP. Valentini P. Design and interactive simulation of cross-axis compliant pivot using dynamic spline. Int. Jour. On Interactive Design And Manufacturing, 7: 261-269, ISSN: 1955-2513, doi: 10.1007/s12008-012-0180-x

[10] L. Piancastelli, S. Cassani. 2017. Maximum peak pressure evaluation of an automotive common rail diesel piston engine head. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(1): 212-218, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[11] L. Piancastelli, S. Cassani. 2017. Power Speed Reduction Units for General Aviation Part 2: General Design, Optimum Bearing Selection for Propeller Driven Aircrafts with Piston Engines. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(2): 544-550, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[12] L. Piancastelli, S. Cassani. 2017. High Altitude Operations with Piston Engines Power Plant Design Optimization Part V: Nozzle Design and Ramjet General Considerations. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(7): 2242-2247, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[13] L. Piancastelli, M. Gardella, S. Cassani. 2017. Cooling System Optimization for Light Diesel Helicopters. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(9): 2803-2808, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[14] L. Piancastelli, S. Cassani. 2017. On The Conversion Of Automotive Engines For General Aviation. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(13): 4196-4203, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[15] L. Piancastelli, S. Cassani. 2017. Convertiplane Cruise Performance with Contra-Rotating Propeller. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(19): 5554-5559, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[16] A. Ceruti, T. Bombardi T. and L. Piancastell. 2016. Visual Flight Rules Pilots Into Instrumental Meteorological Conditions: a Proposal for a Mobile Application to Increase In-flight Survivability. International Review of Aerospace Engineering (IREASE). 9(5).

[17] Piancastelli L., Cremonini M., Cassani S., Calzini F., Pezzuti E. 2018. Intake and exhaust position optimization in the cooling duct of diesel helicopters. 2018 ARPN Journal of Engineering and Applied Sciences. 13(17): 4811-4819.

[18] Piancastelli L., Cassani S., Pezzuti E., Pompei L. 2018. Multi-objective optimization of the cooling system of a diesel helicopter. 2018 ARPN Journal of Engineering and Applied Sciences. 13(16): 4610-4616.

[19] Caligiana G., Liverani A., Francia D., Frizziero L., Donnici G. 2017. Integrating QFD and TRIZ for innovative design. Journal of Advanced Mechanical Design, Systems and Manufacturing. 11(2).