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Aerodynamic Performance Investigation of a Vertical Axis Wind Turbine Instead of Conventional Ram Air Turbines of Airplane

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ABSTRACT: In the present work, aerodynamic performance of a straight-blade Darrieus vertical axis wind turbine is examined in order to use instead of conventional ram air turbines of airplane. These turbines can operate closer to fuselage and this leads them to have shorter torque arm for its drag force; therefore it makes more stability for the whole airplane. In addition vertical axis wind turbines generally generate their maximum power in lower tip speed ratios in comparison to horizontal axis wind turbines; this case also can reduce the possibility of shock waves phenomena on the turbine blades. Furthermore depends on required output power, proposed turbine emergence from fuselage is adjustable. In order to evaluate performance of proposed turbine, the ram air turbine of Airbus a320 is selected and its dimensions are chosen. The average of output power and drag force of proposed turbine are computed using 3D simulation and they are compared with those of ram air turbines of a320. Results show that proposed turbine with endplates produces almost equal average of power along with 19.3% less drag force in comparison to ram air turbine of a320. Overllay, performance of proposed turbine indicates its prominent potential to use instead of conventional ram air turbines.

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1- Introduction

In addition to Auxiliary Power Units (APU) of the airplane, in several, Ram Air Turbines (RAT) are also utilized [1]. Most researchers recommended belly-fairing of airplane as the best choice for RATs installation location [2].

Almost all of the conventional RATs are Horizontal Axis Wind Turbines (HAWTs). In the present numerical simulation, a three-blade straight Darrieus Vertical Axis Wind Turbine (VAWT) is proposed to use instead of the conventional types of RATs and its aerodynamic performance is compared with available data of the RAT of a320 airplane. The rotational axis of proposed turbine is perpendicular to flight direction in line of the horizon. Shorter torque arm for drag force of proposed turbine makes more stability for the whole airplane. In addition VAWTs produce their optimum power in lower Tip speed Ratios (TSRs) in comparison to HAWTs [3]; this case also can reduce the possibility of shock waves phenomena on the turbine blades.

2- Methodology

2- 1- Governing equations and numerical modeling

Both of the two and three-dimensional transient compressible turbulent flow is simulated using the Sliding mesh technique by the solution of Reynolds Averaged Navier-Stokes (RANS) equations with finite volume method. Also turbulence model $k\omega$-SST is utilized.

2- 2- Turbine geometry and computational domain

Airfoil section of NACA0021 with two chord lengths (C) of 0.2 m and 0.3 m is chosen. The turbine rotates in the positive direction of Z-axis. The azimuth angle of turbine is defined in X-Y plane and set to zero at Y-axis and increases counterclockwise. The radius (R=0.5 m) and the height (H=1 m) of the turbine are selected the same with a320. Generally, two solution domains of 2D and 3D are created to simulate the turbine. Each of them includes stationary and rotating zones. The 2D simulation is used to reach the TSR value which turbine produces its maximum output power, then at the obtained TSR, 3D simulation is conducted to evaluate turbine performance with the RAT of a320. Figs. 1 and 2, shows the domain for 3D simulation. The upper surface of domain is set as a wall of airplane fuselage.

2- 3- Boundary condition and grid generation

Constant free stream velocity of 70 m/s along the X-axis and static pressure at sea level condition of standard atmosphere have been applied at the inflow and outflow boundaries, respectively. Unstructured grid with about 3.5E+4 and 3.8E+6 control volumes for 2D and 3D simulations, respectively, are generated within the domain, except close to the turbine blades, over the rotating zone and the wall surface where structured grid is generated.

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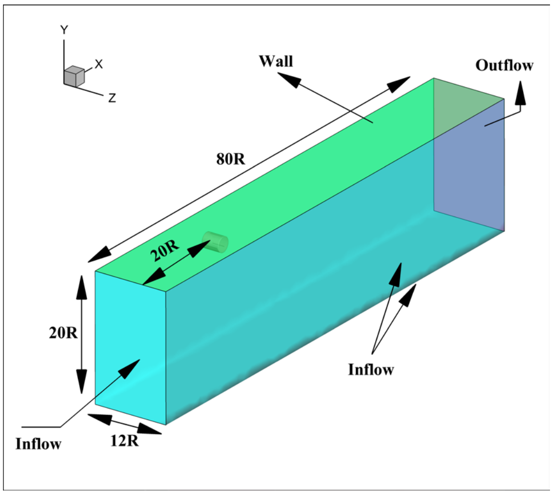

Fig.e 1. Solution domain and applied boundary conditions.

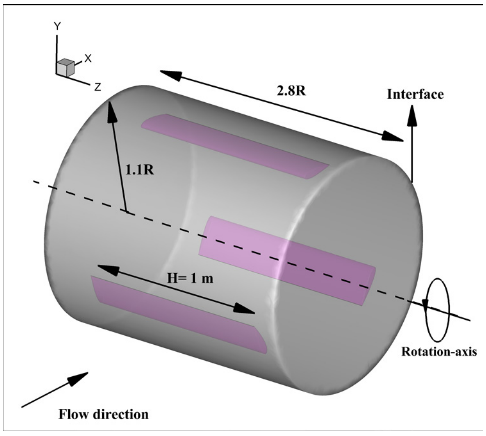

Fig.e 2. Rotating zone.

2- 4- Validation

The experimental data of Elkhoury et al. [4] for three-blade straight Darrieus VAWT is used to validate present 3D simulation results. As shown in Fig. 3 according to total errors of less than 4%, good agreement is obtained.

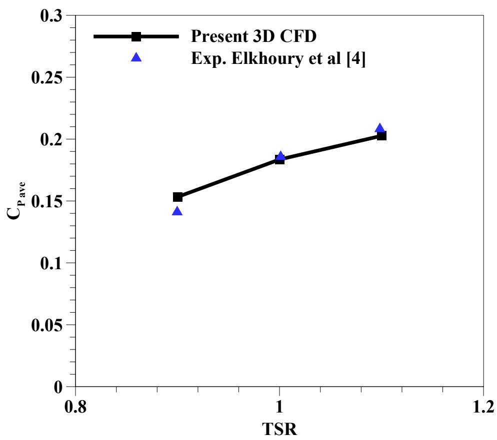

Fig. 3. Validation of present simulation using Ref. [4].

3- Results and Discussion

According to the results of 2D simulation in different TSRs in Fig. 4, turbines with chord lengths of 0.3 m and 0.2 m produce their maximum power at TSRs of 1.5 and 2, respectively.

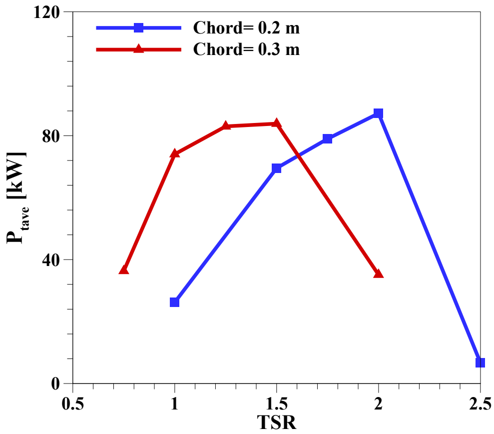

Fig. 4. Two-dimensional simulation results.

In the 3D simulation, five parameters are defined to compare with the RAT of a320 as below:

Average of output power, an average of turbine drag force, turbine swept area+ area of empty space between turbine and fuselage (occupied area), distance of turbine center to fuselage (arm length of torque) and TSR.

According to Table 1, except for power, proposed turbine shows good performance. In order to reach more power, height of the turbine is increased from 1 m to 1.1 m while the radius is kept constant. As seen in Table 2, output power of the turbine is improved; but it is better for the desired turbine to be in the same dimensions with the RAT of a320.

Table 1. Proposed turbine (H=1 m) and the RAT of a320.

	a320	C=0.2 m	C= 0.3 m
Power (W)	40	30.25	27.5
Drag (N)	3508.6	2773	2973
Occupied area (m^2)	1.36	1.1	1.1
Arm length (m)	0.97	0.6	0.6
TSR	3.6-5	2	1.5

Table 2. Proposed turbine (H=1.1 m) and the RAT of a320.

	a320	C=0.2 m
Power (W)	40	37.6
Drag (N)	3508.6	3259
Occupied area (m^2)	1.36	1.21

As shown in Fig. 3, six thin end plates (with dimensions of 0.3 m × 0.16 m) are installed at the ends of each blade to decrease the tip vortices effects and consequently increase the turbine power with H=1 m.

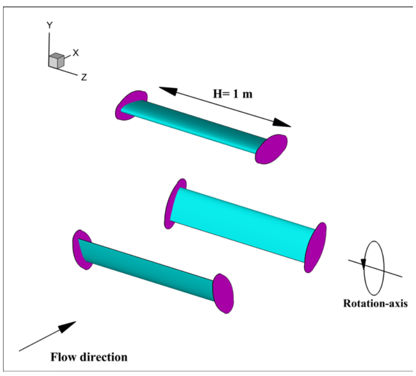

Fig. 5. Thin end plates installed at the ends of each blades.

As seen in Table 3, the proposed turbine performs only 4.5% less output power while its drag force and occupied area are 19.3% less than that of a320. This is the choice of proposed RAT with best performance.

Table 3. Proposed turbine with end plates (*H*=1 m) and the RAT of a320.

	a320	C=0.2 m
Power (W)	40	38.2
Drag (N)	3508.6	2830
Occupied area (m^2)	1.36	1.1

The proposed RAT can operates with less emergence yet. The diagram of output torque produced by each blade of the turbine indicates after about azimuth angle of 35° each blade starts to produce positive torque. Using this fact, extra simulation as shown in Fig. 6 is carried out while between azimuth angles of -30° and +30°, the turbine is located in an airplane fuselage.

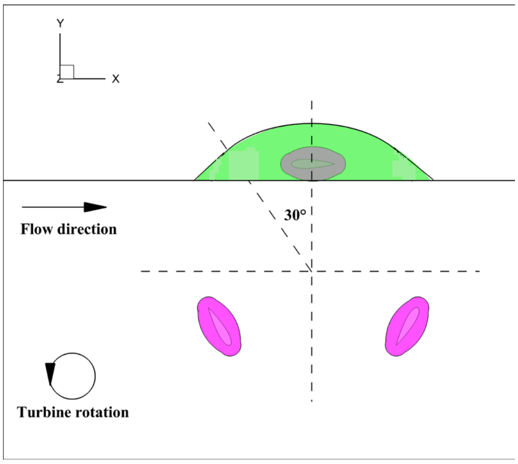

Fig.e 6. Proposed RAT with less emergence.

According to the results of Table 4, although the output power is dropped because of flow separation near the edge, but other parameters such as drag force, occupied area and arm length clearly are decreased.

Table 4. Proposed RAT with less emergence and the RAT of a320.

	a320	C=0.2 m
Power (W)	40	26.4
Drag (N)	3508.6	2732
Occupied area (m^2)	1.36	0.93
Arm length (m)	0.97	0.43

4- Conclusions

In comparison to the RAT of a320, the proposed RAT with thin end plates produces close output power with 19.3% less drag force and occupied area. It also has 38% less torque arm length. The RAT also can operate with less emergence but its output power drop should be considered.

Due to lower TSR operation, proposed RAT will have less difficulty with shock waves. Depend on RAT application, required power and airplane stability both proposed RATs can be the choice of future researchers.

5- References

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