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An Innovative Treadmill-Magnus Wind Propulsion System for Naval Ships

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Abstract: The Magnus force was successfully employed by Flettner in his ship Buckau operating with two large propelling cylinders. The spinning cylinders produced propulsive force from the wind on seas as a clean and free source of energy. The rise of fossil fuel costs, extinction of fossil fuel resources, and environmental issues such as global warming and pollutions produced by fossil fuels have caused a renew interest in Flettner type propulsion in naval ships. This is becoming a hot topic in Europe and the rest of world. Many other applications of producing high lift values from spinning symmetrical cylinders have failed due to high values of drag force and also rapid increase of frictional torques. In this paper, the new application of Treadmill-Magnus, wind driven propulsion system is introduced which can be effectively used for any size ships. To show validity of the concept, the NACA0020 aerofoil section with treadmill skin is computationally investigated at the low Reynolds number of 8.2×10^4. The viscous fluid flow solutions were obtained at variety of treadmill speeds of the aerofoil skin and different incident angles. The results show that high lift to drag ratios may be obtained using treadmill motion.

Keywords: Magnus effect, propulsion, treadmill motion, NACA0020 aerofoil, CFD.

1. INTRODUCTION

1.1. Patent Review Coverage

The first successful device based on Magnus effect was patented in the year of 1923-1928 [1,2], when Anton Flettner has developed and manufactured the first ship operating with Magnus force using two large cylinders to propel his ship, Buckau (Fig. **1**).

Since that success, the potential of producing high lift forces by rotating bodies in comparison with low lift force values of aerofoil type devices have attracted many researchers in different fields of Engineering. Some 19 patents for using Magnus force in aeronautical applications were proposed in 1930 which indicates the impact of Flettner's rotor ship on industry [3] (Fig. **2**).

Since then many patents have been produced in the areas of naval or aerospace applications utilizing the Magnus effect and many experimental and numerical researches have been conducted on the determination of aerodynamic forces from rotating cylinders. But, very few devices were operated successfully [3]. Flettner built two rotor ships, named Buckau and Barbara, but none of them were commercially successful. The Flettner-rotor worked successfully but the oil crisis was over again so that the era of sailing ships was over. Flettner type ships were faced with skepticism about the practical use of a rotating cylinder. Questions rose such as whether Flattner ship withstands against hurricane or how vibrations can be handled. But Flettner was convinced that the Magnus ship would replace all sailing ships in the future and filed the German Patent in 1923 [2], which was also protected in the United States in 1928 [1].

Fig. (1). Wind driven Flettner ship using Magnus effects [1].

1.2. Current & Future Developments

Recently, the Flettner type rotor is becoming again a hot topic in naval engineering because of the energy costs and the rise of problems with climate change [3]. In 2010, the new ship Enercon E-Ship1 has used four Flettner type rotors as auxiliary propulsion system for delivering wind turbine parts [4] (Fig. **3**).

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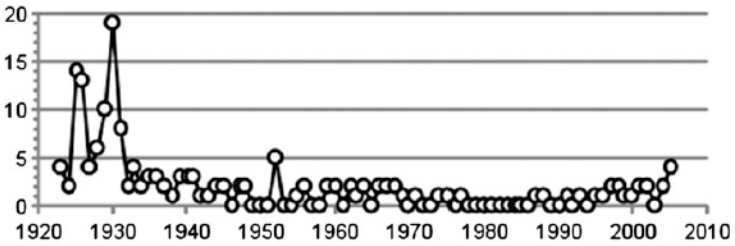

Fig. (2). Summary of patent applications worldwide in Magnus effect [3].

Fig. (3). The new Enercon E-Ship1 [4].

Fig. (4). New versions of the Flettner ship using controlling flow disks.

New ideas are under research studies such as multiple cylindrical rotors with controlling disks as shown in (Fig. **4**).

A comprehensive review of the Magnus effect devices in aeronautics was recently given by Seifert [3] who believes "there are no specific methods available on how to design the lifting device of a rotor airplane or the rotor airplane airframe." Sedaghat *et al.* [5] have examined the theories for modeling Magnus effect in wind turbines with cylindrical rotors and concluded that the drag to lift ratios of circulating cylinders are too high to harvest wind energy efficiently in Magnus wind turbines. They later discovered that replacing the circular cylinder with a circulating aerofoil may substantially enhance a new generation of wind turbines with utilizing a circulating aerofoil instead of spinning cylinders [6].

1.3. Conflict of Interest

Anton Flettner were also invented the treadmill principle of using a moving surface around an aerofoil, in the year 1923 for ship and airplane applications, which was granted by a German patent [7] (see Fig. **5**); but, no computational or experimental studies was found in literature to address this.

Samani and Sedaghat [8] have examined the application of such an aerofoil in a novel vertical take-off Micro Air Vehicle (MAV). To our knowledge, some computational or experimental efforts were made towards analysis and simulation of spinning cylinders in the leading or trailing edges of aerofoil such as shown in (Fig. **6**) [9].

Other research were purely conducted to obtain lift and drag of spinning cylinders [10-16]. Seifert [3] has stressed that up to now, there are no specific methods available on how to design the lifting device of a rotor airplane or the rotor airplane airframe and new design methods that can show performance of a rotor airplane during flight are re-

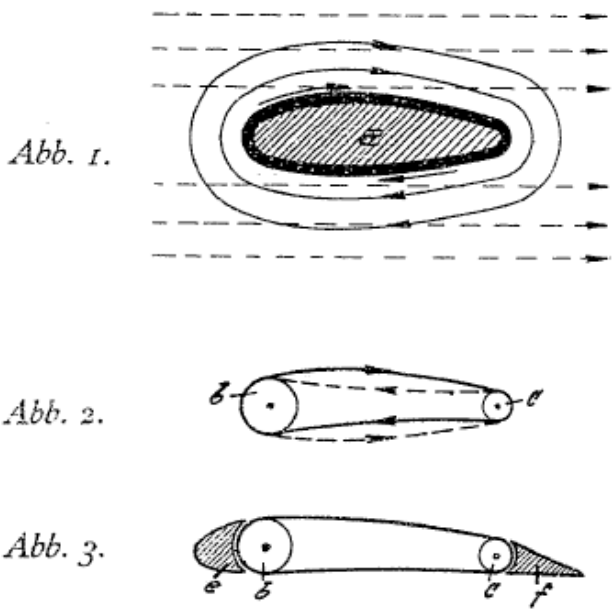

Fig. (5). The concept of circulating aerofoil: (1) an ideal full circulating aerofoil; (2) a practical simple full treadmill system; (c) a practical partial circulating aerofoil [7].

quired. Moreover, he insists that the negative Magnus force or gyroscopic effects in the case of especially micro aerial vehicles must be considered because their flights occur at low Reynolds numbers.

2. THE TREADMILL-MAGNUS AEROFOIL SYSTEM

In this paper, the possibility of using circulating aerofoil to produce Magnus force is investigated for the tick aerofoil NACA0020 to be substituted in a Flettner type ship instead of rotating cylinders. A schematic of the cross section of such naval propulsion system is shown in (Fig. **7**).

In this study, a fluid flow solver was used to solve the Reynolds Averaged Navier-Stokes (RANS) fluid flow equations in a C-type mesh around the rotor sections. The aerofoil cross section is assumed to be the NACA0020 as a test case to examine possibility of such wind driven propulsion system in naval ships.

2.1. Computational Study and Results

Sedaghat [17] has developed a class of implicit, high resolution, total variation diminishing (TVD) scheme to solve the governing fluid flow equations around two dimensional aerofoil flows. The Reynolds Average Navier-Stokes (RANS) equations of the governing compressible flows utilize Baldwin-Lomax turbulence model in general coordinate system. The method is extension, for solving viscous compressible flows, of the original upwind and symmetric TVD schemes developed by Yee [18] for computation of inviscid flows. An algebraic- hyperbolic grid generator is used to generate C-type orthogonal meshes around aerofoil sections with proper clustering of mesh points in the boundary layer.

In this paper, the NACA0020 is circulated with treadmill speeds of 0.2, 1.0, 3.0, and 5.0, which is the ration of the circulating aerofoil to wind speed. The computational results of lift and drag coefficients are shown in the (Fig. **5**) for the aerofoil at incidence angles of 0, 5, 10, 15, 20, 30, and 35 degrees. The angle of attach (AoA) is defined as the angle between the chord line and the wind speed as shown in (Fig. **4**). Here, lift and drag coefficients are defined as:

$$C_L = \frac{L}{\frac{1}{2}\rho c U_\infty^2}, C_D = \frac{D}{\frac{1}{2}\rho c U_\infty^2} \quad (1)$$

In Equation (1), ρ is the air density, c is the aerofoil chord length, and U_∞ is the wind speed experienced by the

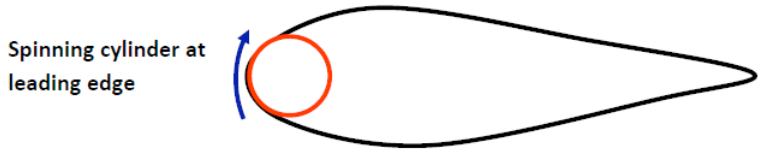

Fig. (6). Rotating cylinder in wing configuration.

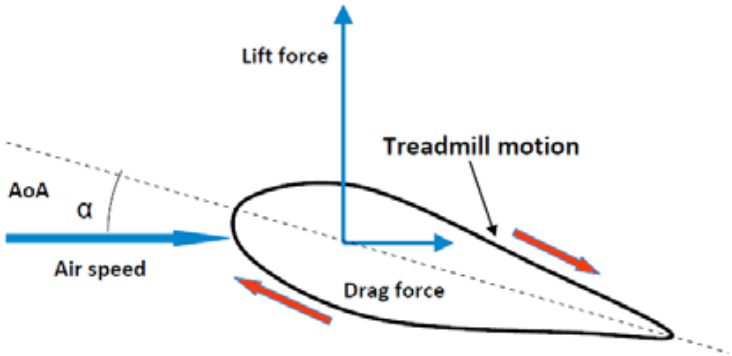

Fig. (7). The schematic of a fixed wing with treadmill motion.

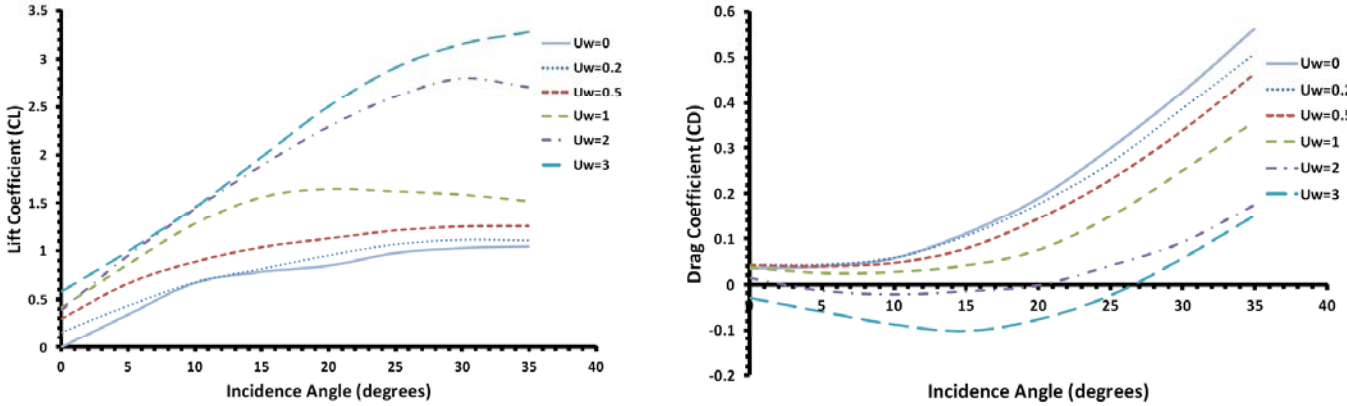

Fig. (8). Lift and drag coefficient with different treadmill speeds for NACA0020 aerofoil.

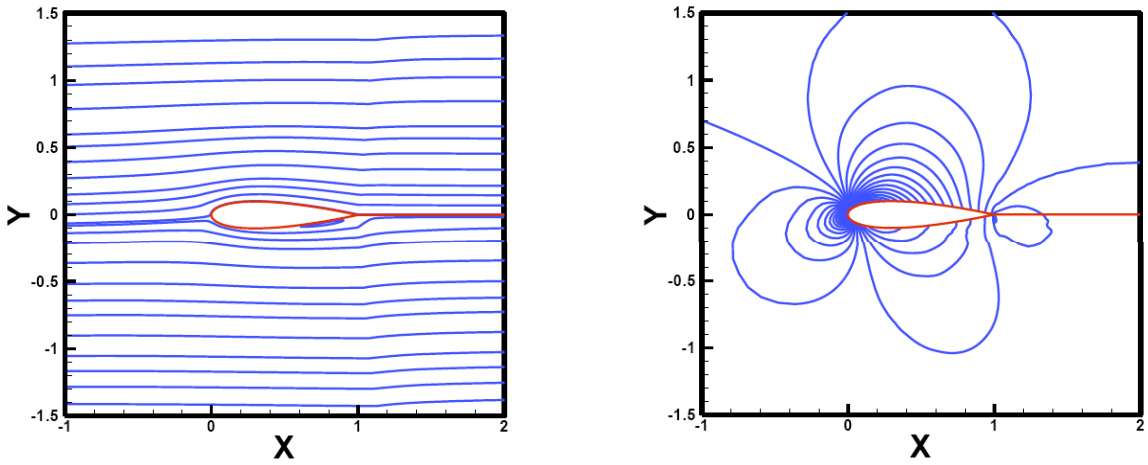

Fig. (9). (**a**) Streamlines (left) and (**b**) pressure distribution (right) around the circulating NACA0020 aerofoil at zero incident angle and the dimensionless circulating speed of unity.

ship. Here, *L* is the lift force def perpendicular to the wind direction as sketched in (Fig. **4**), which is calculated from the cumulative forces of pressure and shear stress over aerofoil surfaces. Similarly, drag force *D* is defined as cumulative forces of pressure and shear stress in parallel direction of wind.

As shown in (Fig. **8**), the ults indicate that by increasing the treadmill speed the lift coefficient has increased up to more than three times of the NACA0020 aerofoil with fixed walls; interestingly, the drag coefficients has decreased favorably by increases of treadmill speeds. For lower incidence angles than 10 degrees, the lift and drag coefficients are increasing and decreasing functions of the treadmill speed; respectively, whether this range can be used to produce sufficient lift for a Magnus rotor in a ship needs to be further investigated using experimental approaches. Hence, the proposed treadmill motion has led to higher lift coefficient several times larger lift values than fixed skin aerofoil. On the same time the drag was also reduced considerably and remains small up to incidence angles of 15 degrees (below 0.1) and become negative at higher treadmill speeds than 2; however, for higher angle of attack than 15 degrees the drag force become considerable.

Figure **9** shows an example of streamlines and pressure distribution around the circulating aerofoil at zero incidence angle and dimensionless circulating speed of 1. As seen in this figure, the streamlines (Fig. **9a**) are uniformly passes over the aerofoil surface except near lower aerofoil surface where a separation zone is observed. The high pressure zone is more pronounced as seen in (Fig. **9b**) in the lower leading edge which clearly shows a non-uniform distribution of pressure due to circulating effect of the aerofoil surfaces. Here, both pressure and viscous effects are acting effectively in both sides of the aerofoil surfaces leading to higher lift force but lower drag force. These findings, although very promising, still require experimental validation in wind tunnel to prove its benefit in naval applications.

3. CONCLUSIONS

It is shown here that the Magnus force can be produced by circulating NACA0020 aerofoil as the rotor of a Flettner type ship. This type of propulsion uses wind as a free source of energy over the seas and oceans where plenty of such energy is available for slow moving large naval ships. There is a renew topic of using Flettner type propulsion in recent years due to rapid changes and instabilities in oil market. This paper is particularly addresses a novel propulsion wind

driven system in new generation of ships. The computational results for a typical rotor cross section NACA0020 reveals that it is possible to obtain high lift while reducing drag for Magnus rotor; although, it is possible to optimize lift to drag ratios by varying incidence angles to increase maneuverability and efficiency of such propulsion system with a proper control system. This may not be possible using a cylindrical Magnus rotor. The finding of this study is aimed to be continued by experimental measurements and manufacturing a prototype model ship if receives fund.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

Declared none.

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