AN AERODYNAMIC PERFORMANCE ESTIMATION OF LINEAR MOTION AIRFOIL S1223 USING XFOIL

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Abstract: This paper presents a kinematic analysis pertains to low Reynolds number linear motion airfoil using XFOIL. Low Reynolds number (10^4 to 10^6) airfoil found extensive use in the field of RPVs, MAVs and UAVs now a days. In a view same can be used to generate electricity for low wind speed conditions in urban areas. It is very well known that aerodynamics performance of any airfoil is of prime importance in aviation and turbo machinery. Higher lift or lift to drag ratio for varying angle of attack and Reynolds number is of interest. An analysis here is carried out for different combination of Reynolds number, Angle of attack and free stream velocity. It is also proved that for lift type machines section with higher lift is considered to be most efficient for any combination of flow and control variables. The aim of present work is to gather information regarding behavior of low Reynolds number airfoil S1223 for linear motion to suit power generation application with available polar data using XFOIL. From graph and analysis it can be seen that a limited lift is produced enough to drive smaller units with specific angle of attack and Reynolds number combination. However more external devices can be added or flow control methods can be employed to achieve higher airfoil efficiency with a consortium of such portable. It is intended to provide useful knowledge for future studies.

Keywords: linear motion, XFOIL, Low Reynolds number Airfoil, S1223

I. INTRODUCTION

In recent years, the global concern with generation of electricity by exploring the sources of non-renewable energy resources has increased. The use of non-conventional energy sources and decentralized power generation are alternatives to reduce the exploitation of conventional energy resources and its adverse effect, contributing to a sustainable development of societies and promotion to green energy. Beside this the aerial vehicles like MPVs, RPVs and UAVs based on low Reynolds number are also of keen interest due to its efficient flight performance under such unfavorable conditions.. Wind harvesters works on lift principle got good potential for electricity generation but in urban area due to more unfavorable air condition rotary turbine are not performing as per expectations. In the most recent works, the aerodynamic performance of linear motion airfoil S1223 have been studied using XFOIL.

The range of Re numbers of natural and man-made flyers is shown in Figure 1. Low Reynolds number airfoils typically have natural laminar flow over most, if not all, of the chord length. These airfoils are primarily used in hand-launched gliders, hobby model aircrafts, and ultra-light hand gliders. Natural laminar flow also occurs for most birds in fight and little creatures like bees or flies. Recently, both the civilian and military sectors have shown an increased interest in the development of these low Reynolds number airfoils, due to an increased usage of UAVs that operate at low speed or high altitude [1].

Lissaman [2] has done quantitative divisions between high, medium and low Reynolds number airfoil which is;

High Reynolds number airfoil, $Re > 3 \times 10^6$
Medium Reynolds number airfoil, $5 \times 10^5 < Re < 3 \times 10^6$
Low Reynolds number airfoil, $Re < 5 \times 10^5$

In the extensive summary of the history of low Reynolds number airfoil development by Carmichael [3], the author divided the Reynolds number spectrum into twelve regions, covering from fractional Reynolds numbers to over 10^9.

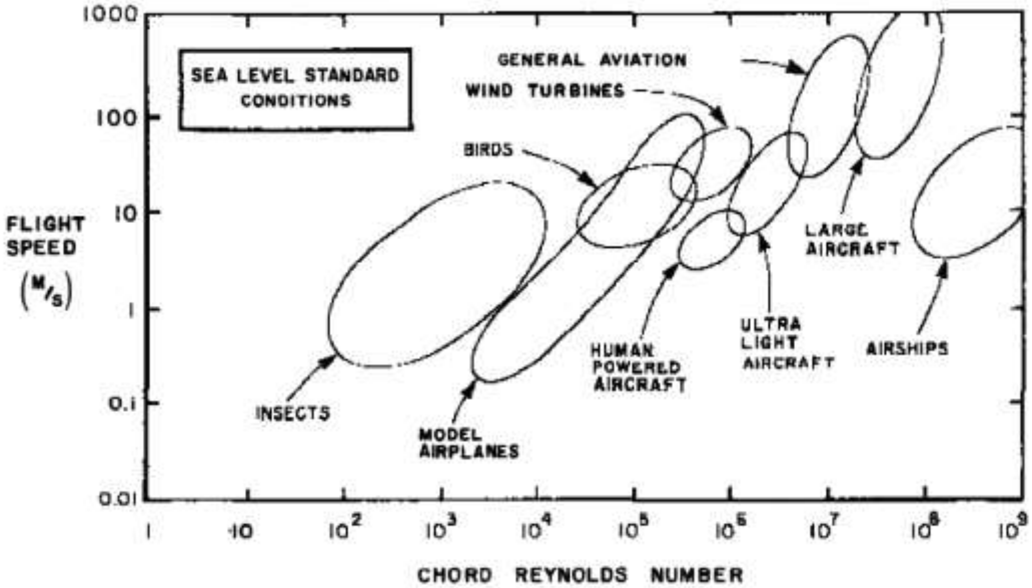

Figure 1 Flight Reynolds-number spectrum [2]

II. AERODYNAMIC CHARACTERISTICS OF AIRFOIL

Consideration of the various physical quantities which may be involved in the generation of the aerodynamic forces of lift, drag and pitching moment lead to the following standardized relations As shown in Figure angle of attack is the angle of the airfoil chord line relative to the direction of the flow. The lift force acts perpendicular to the flow direction and the drag force acts parallel to the flow direction. Thus, the directions of the lift and drag forces relative to the airfoil change with angle of attack. Also, the pitching moment is often taken about reference point called the aerodynamic center.

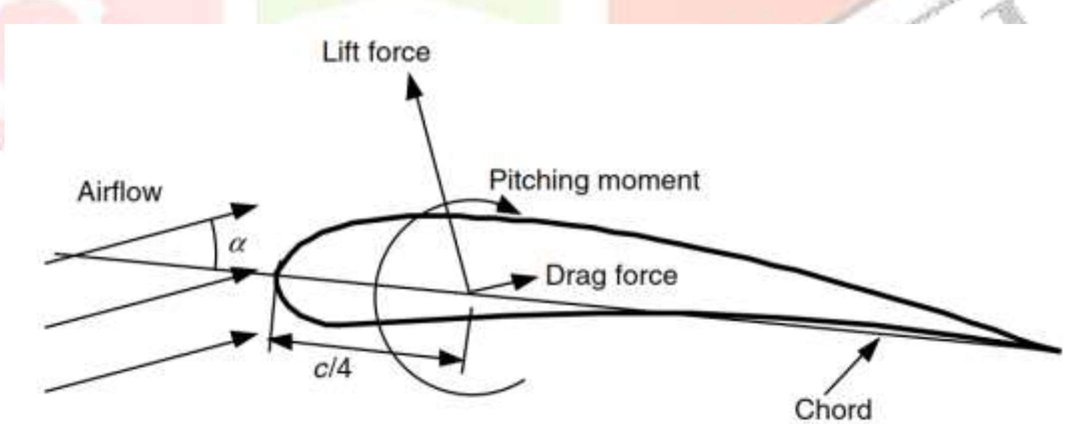

Figure 2 Forces and moments on an airfoil section, α- angle of attack; c- chord. The direction of positive forces and moments is indicated by the direction of the arrow [4]

$$Lift\ , L = \frac{1}{2}\rho . V_{\infty}^{2} . C_L . A$$
$$Drag\ , D = \frac{1}{2}\rho . V_{\infty}^{2} . C_D . A$$

$$Pitching\ moment\ , M = \frac{1}{2}\rho . V_{\infty}^{2} . C_{M} . c . A$$

The respective coefficients C_L, C_D and C_M represent the performance characteristics of the particular airfoil. Their values are controlled by the airfoil shape and by other physical quantities associated with the fluid flow. Major parameter among these is the angle of attack, which is the angle between the direction of flow and the airfoil chord line. The coefficients are also affected by the frictional behavior of the flow, which is represented by the Reynolds number parameter Figure 3.

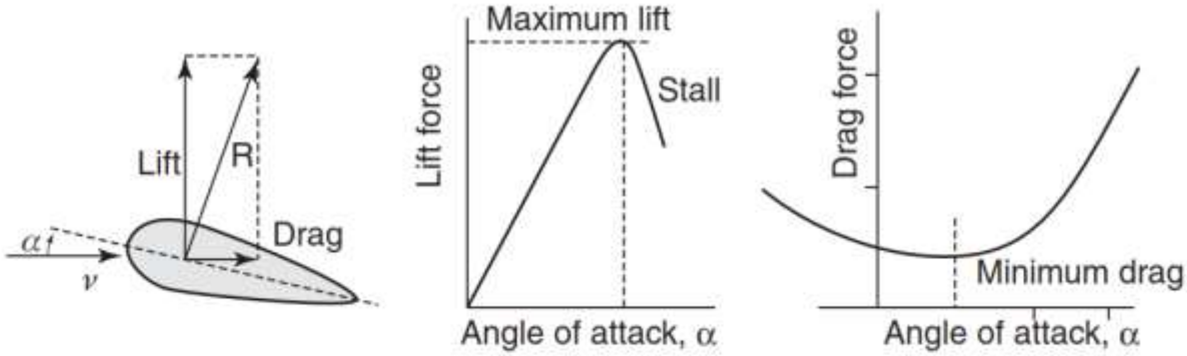

Figure 3 Relationship between lift force, drag force and angle of attack for an airfoil [5]

When the airfoil is not symmetrical and the upper surface is curved more than the lower surface, then a lift force occurs because the pressure decrease and speed increase in the upper surface is larger than the pressure decrease and speed increase in the lower surface. Positive or non symmetrical airfoils cause airplanes to fly and wind turbines to produce energy. Each type of blade has an optimal value of that produces maximum lift and minimal drag which can be conclude by calculating maximum lift/drag ratio. (see Figure 3).

III. THE AERODYNAMIC PERFORMANCE ESTIMATION OF LINEAR MOTION AIRFOIL S1223

In this paper,S1223 airfoil has vertical reciprocating motion. Thus airfoil with linear motion experience relative wind velocity (V_r) at an angle γ as shown in Figure 4.

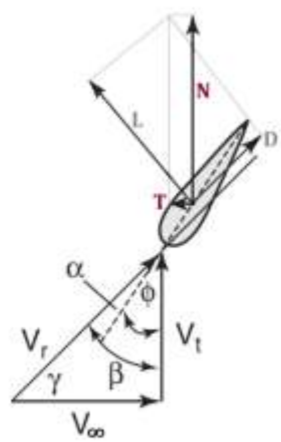

Figure 4 Relationship between angle of attack, pitch angle and angle between relative velocity and tangential velocity [5]

from above Figure 4 Relative wind velocity (V_r) can be given by,

$$V_r = \sqrt{V_{\infty}^2 + V_t^2}$$

and the Relative wind velocity angle is,

$$\gamma = \tan^{-1}\left(\frac{V_t}{V_{\infty}}\right)$$

The angle of attack (α) plus the pitch angle (ϕ) is equal to the angle of relative velocity with the direction of motion of the blade (β).

$$90 - \gamma = \beta = \alpha + \phi$$

The conceptual diagram for linear motion reciprocating type S1223 airfoil is depicted in Figure 5.

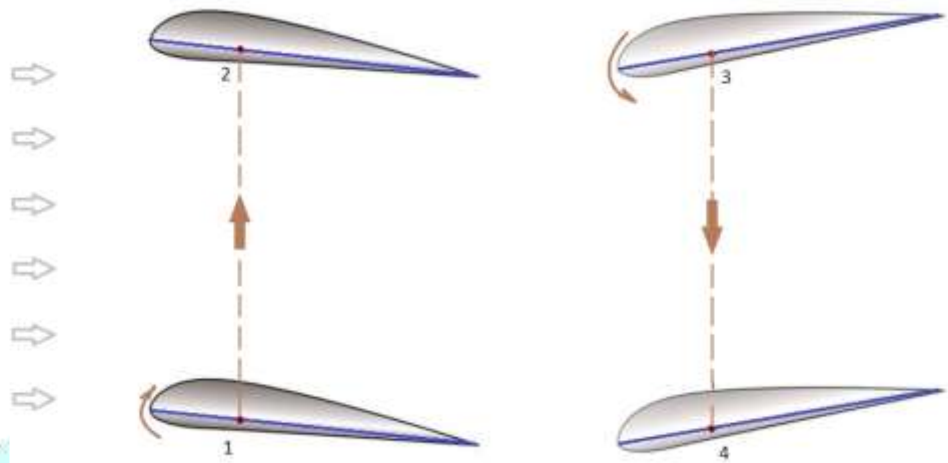

Figure 5 concept of linear motion of airfoil S1223

The normal force (N) perpendicular to wind direction and thrust force (T) experienced by the airfoil can be given as under respectively

$$\text{Normal force, } N = L \cos\gamma + D \sin\gamma$$

$$\text{Thrust force, } T = L \sin\gamma - D \cos\gamma$$

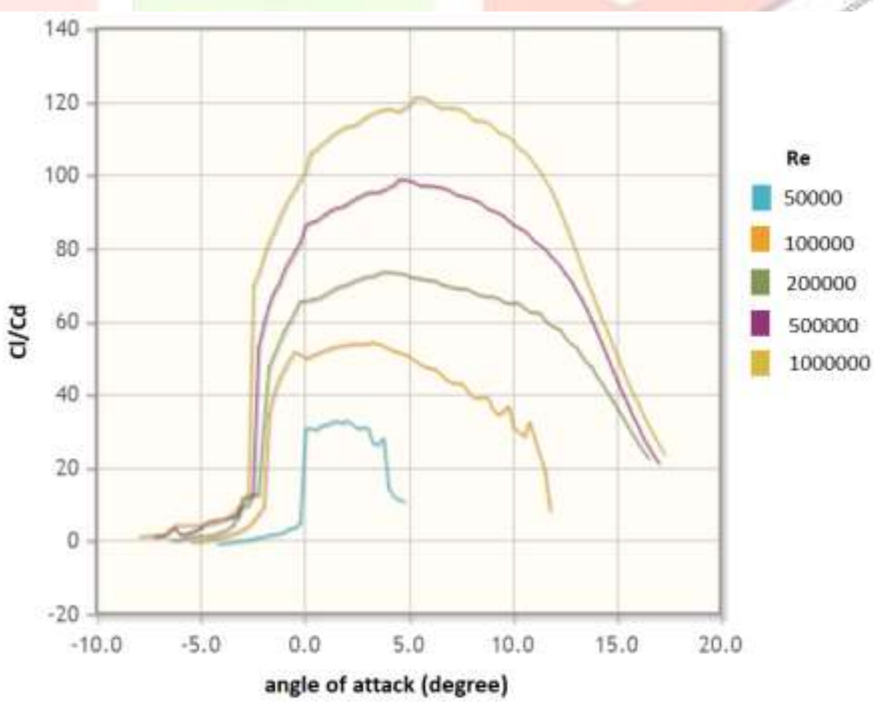

Figure 6 C_L/C_D polar for S1223 computed by XFOIL

For this paper one non dimensional number is been introduced, similar to Tip Speed Ratio (TSR) in case of wind turbine, called Velocity Ratio (V.R.) which is ratio of blade velocity to wind velocity. It can be represented mathematically as,

$$V.R. = \left(\frac{V_h}{V_\infty}\right)$$

XFOIL is widely-used, in academia and parts of industry for quick preliminary estimates of airfoil performance due to its ease of use and versatility [6] Aerodynamic performance comparison of S1223 airfoil between experimental data and XFOIL, performed by Wei Shyy et.al. [7] concluded that, overall the XFOIL code does a better job. XFOIL is run several time to compute airfoil polar data at various Reynolds number in range of 5×10^4 to 1×10^6 (Figure 6).

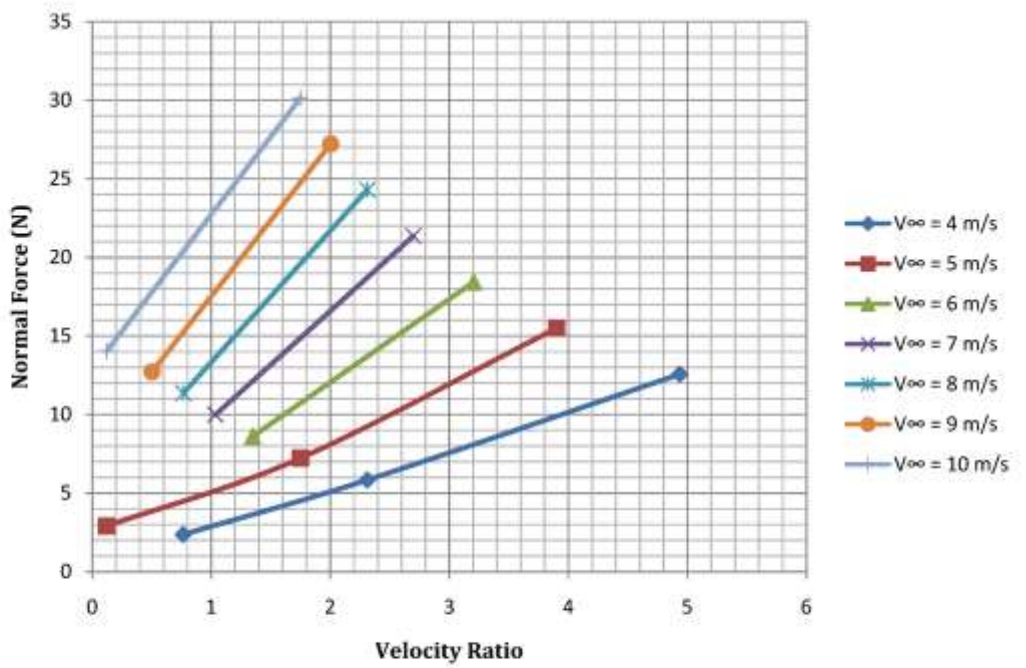

Figure 7 Normal force versus V.R. for S1223, chord = 150 mm

The driving force for conceptual linear motion airfoil can be computed using normal force (N) equation stated above for particular wind speed and blade velocity. For the required purpose data to be collected are design C_L and C_D pertaining to specific chord Reynolds number. These data are taken from Selig [8] and computed using XFOIL for S1223 airfoil. The airfoil polar for S1223 computed by XFOIL are shown in Figure 7.

IV. CONCLUSION AND DISCUSSION

In past years, seminal work based on other than reciprocating motion airfoils have been done and various patents had also been registered. But only few possess combination of high lift airfoil for low wind speed and reciprocating motion for intended purpose. In this paper for S1223 it can be concluded that with increase in Reynolds number the maximum C_L=C_D ratio also increases but within range of design alpha 2 to 6 degree. It also shows good aerodynamic performance with poor wind condition. These results shows scope for development of linear motion wind harvester as one of the most suitable wind harvester to extract wind potential for urban area in roof top application.

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