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AERODYNAMIC PERFORMANCE OF NREL S833, S834 and S835 AEROFOILS

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ABSTRACT

Aerofoils are special profiles that constitute the aerodynamic shape of aircraft blades/wind turbine blades. In this study, The aerodynamic performance of S833, S834 and S835 aerofoils developed for wind turbines by NREL (National Renewable Energy Laboratory) according to turbulence models namely Spalart-Allmaras (S-A), RNG k-Ɛ and k-ω-SST have been investigated with help the CFD (Computational Fluid Dynamics) software Fluent. Pressure distributions, wind velocities of selected aerofoils are investigated. Also the pressure coefficients of these aerofoils are obtained and compared with the experimental values from the literature.

INTRODUCTION

Countries tend to use renewable energy sources more because of the fact that fossil fuels depleting, global warming and also increasing energy demand with enhanced living standards or welfare. Wind turbines are used to utilize wind energy, which is one of the most important renewable energy sources. Nowadays, there are different types of wind turbines according to wind direction (upwind or downwind wind turbines), axis of rotation (horizontal axis or vertical axis wind turbines), number of blades (one bladed, two bladed, three bladed or multiple bladed wind turbines) etc. Today, horizontal axis three-bladed wind turbines are widely used commercially because of their design advantages, high efficiency and reasonable costs. Horizontal axis three-bladed wind turbines (Figure 1a) which consist of tower, generator, gear box, hub, electric-electronic devices and blades, generate electric energy with the cycle of kinetic energy, mechanical energy and electric energy. In these turbines, the mechanical energy is taken from incoming wind using blades and transferred to the generator via low speed shaft, gearbox and high speed shaft. Due to the fact that the blade, the first element of the energy production chain, aerodynamic design of the blade affects the ratio of energy capture. The aerodynamic shape of the blade is formed by combining specific cross-sections that have different shape and size/dimension. The blade has three significant cross-section (circular, transition between circle and aerofoil, aerofoil) from root to tip (Figure 1b).

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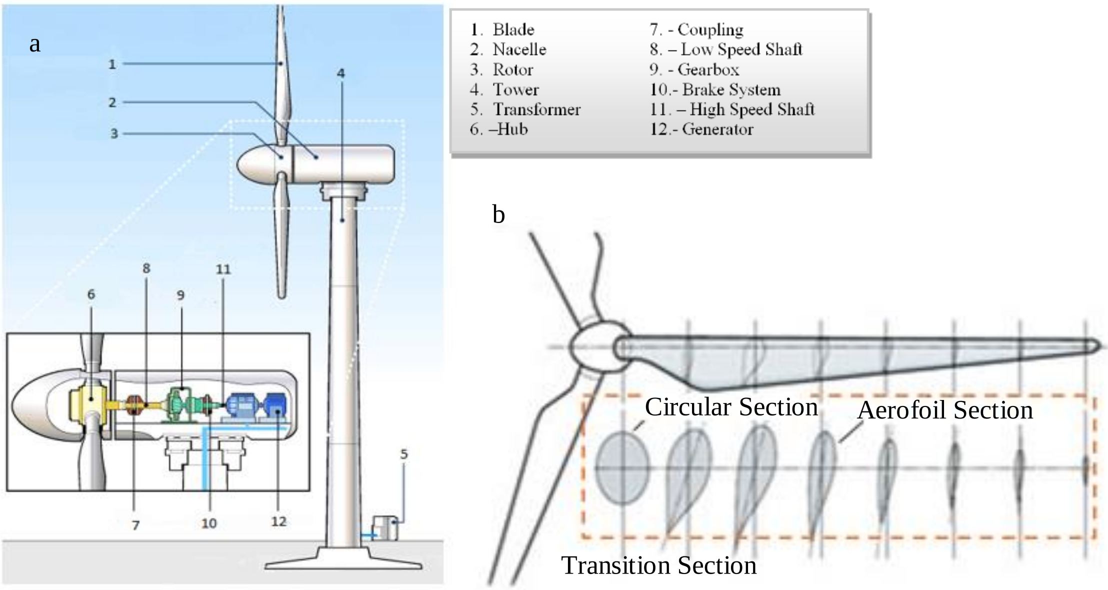

Figure 1. Wind Turbine and Blade Structure [Kaya, 2014; Kaya and Koc, 2015]

Aerofoil, generally used in aerospace applications, turbines and wind turbine blade structure, is a geometric form generating pressure difference between upper and lower surface to capture the kinetic energy of air. Aerofoils have first used in aerospace applications. However, there is a need for aerofoils with features such as high lift coefficient and low drag coefficient, at low wind speed for wind turbines. Various studies have been conducted to develop special aerofoils for wind turbines. These studies focused on the development of new aerofoils and investigating the aerodynamic performance of these aerofoils. Some of the important studies have been carried out by Tangler and Somers at NREL [Tangler and Somers, 1995], Timmer and Van Rooy by DELFT [Timmer and Van Rooy, 2003] and Bjork by FFA [Björk, 1990]. The studies on aerofoils have generally focused on the NREL S809 aerofoil specially designed for small and medium-sized wind turbines [Wolfe and Ochs, 1997; Sanei and Razazghi, 2018; Volikas and Nikas, 2019]. In addition, there are various studies on the aerodynamic performance of different aerofoils such as EPPLER 625, EPPLER 664, CLARK Y, EIFFEL 10, FX-69-PR-281, NACA MUNK M4, NACA 63-415, NACA 0018, NACA 4415, NREL S836 in the literature [Güleren and Demir, 2011; Villalpando, Regio and Ilinca 2011; Yao, Yuan, Wang, Xie, Zhou, Peng and Sun, 2012; Yilmaz, Cam, Tastan and Karci, 2016; Duz, 2016]. In these studies, laminar flow and different turbulent flow conditions have been taken into consideration for aerodynamic performance analysis of these aerofoils. However, limited studies have been found in the literature regarding the S833, S834 and S835 aerofoils recommended for use in wind turbines with a rotor radius of 1-3 m. In this study, aerodynamic performance of S833, S834 and S835 aerofoils have been investigated according to different turbulence models namely Spalart-Allmaras (S-A), RNG k-Ɛ and k-ω-SST.

NREL S SERIES AEROFOILS

Different types of aerofoils (NACA, SERI, FX, NREL S series) are avaible for both traditional aviation and wind turbine blades. The majority of the aerofoils used in horizontal axis wind turbine (HWAT) blades are originally developed for aircraft. But, the requirements in HWAT blades are significantly different from traditional aviation aerofoils., some dedicated airfoils have been designed i.e. NREL (National Renewable Energy Laboratory) S-Series Aerofoils *being the special purpose structures for HWAT blades with the development of interest in wind energy [Kaya, 2014; Kaya 2015; Hansen, 2017; El-Shahat, 2019]. Aerofoils recommended by NREL, for HWAT blades are demonstrated in Table 1 according to the rotor diamater [Somers, 2006; URL 1]. It can be seen from the table that S833, S834 and S835 aerofoils can be recommended for 1-3 diameter wind turbines in industry. The profile of S833, S834 and S835 aerofoils are shown in Figure 2 altogether.*

Table 1. Recommended NREL S-Series Aerofoils with Dimensions [Somers, 2006; URL 1]

Rotor Diameter	Root Section	Primary Section	Tip Section
1–3 m	S835	S833	S834
3–10 m	S823	-	S822
10–20 m	S804	S801	S802
	S804	S801	S803
	S807	S805	S806
	S807	S805A	S806A
	S808	S805A	S806A
	S821	S819	S820
20–30 m	S811	S809	S810
	S814	S812	S813
	S815	S812	S813
20–40 m	S814	S825	S826
	S815	S825	S826
	-	-	S829
30–50 m	S818	S816	S817
40–50 m	S818	S830	S831
	S818	S830	S832
	S818	S827	S828

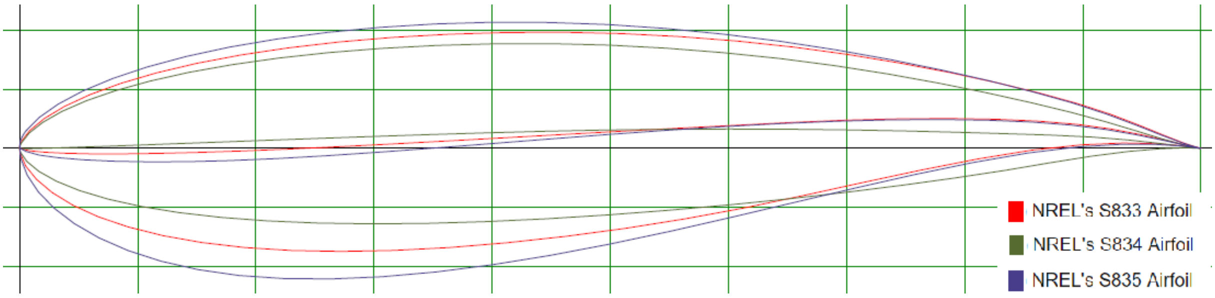

Figure 2. S833, S834, S835 Aerofoils (Airfoils) [URL 1; URL 2]

In this study the aerodynamic performance of NREL S835, S833, S834 aerofoils according to the different turbulence models (S-A, RNG k-Ɛ and k-ω SST turbulence models) have been analysed with help the Fluent software. The results obtained have also been compared with their experimental values from previous studies [Somers, 2006].

COMPUTATIONAL FLUID DYNAMICS ANALYSIS OF S833, S834, S835 AEROFOILS

Computational Fluid Dynamics (CFD) analysis is required to evaluate the aerodynamic performance S833, S834, S835 aerofoils. Figure 3 provides the procedure for CFD analysis of these aerofoils.

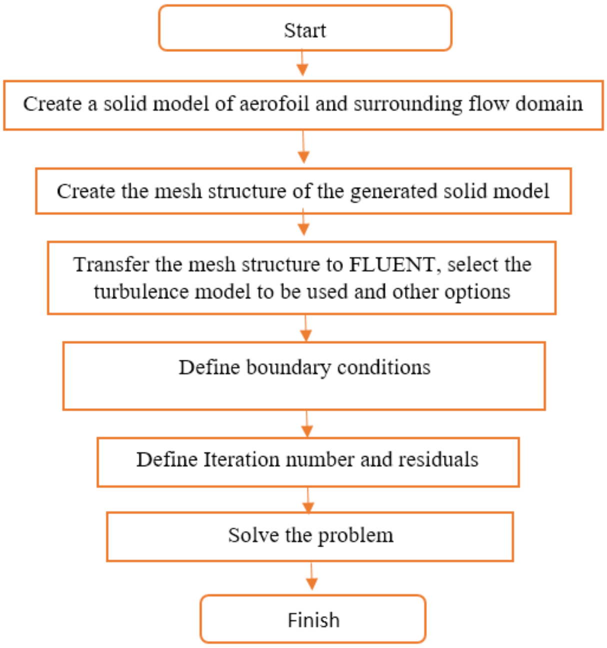

Figure 3. The basic procedure for performing a CFD analysis

In order to evaluate the aerodynamic performance of aerofoils (S835, S833 and S834), firstly, the aerofoil and flow domain around the aerofoil have been created using the Design Modeler module of ANSYS Workbench software In this study, due to the trailing edge of the aerofoils is sharp and the flow domain has been selected as a geometry consisting of semicircle and rectangle. Aerofoil is located near the center of the semicircle. The radius of the semicircle is determined as 15 times the chord length of the aerofoil (c); rectangular geometry dimensions are 15 and 20 times. according to the previous studies (Fig 4a).

One of the important parameters for numerical analysis is the mesh structure to be created in the flow domain. Since the most appropriate mesh structure for aerofoil in the literature c-shaped domain with quadratic cells, the mesh structure have been created c-shaped domain with quadratic cells. (Fig 4b). the generated mesh structure c-type structured consists of 10650 element 10853 node.

The quality of the mesh structure is evaluated by using Skewness and Orthogonal Quality parameters. In this study, average skewness and average orthogonal quality parameters of the mesh structure have been determined for S833, S834 and S835 aerofoils as 0.11029, 0.1125, 0.10576 and 0.94818, 0.94707, 0.95018 respectively. Since skewness of these parameters is close to 0 and orthogonal quality is close to 1, the mesh structure can be evaluated as quality. The generated mesh structure can be described as having enough quality to perform numerical analysis. In this analysis, the curved part on the left side where the air flow enters, upper and lower edges of flow domains are defined as the inlet, the right edge of the flow domain acts as a pressure outlet with atmospheric pressure and the aerofoil surfaces are considered as stationary walls with no slip condition (Fig 4c).

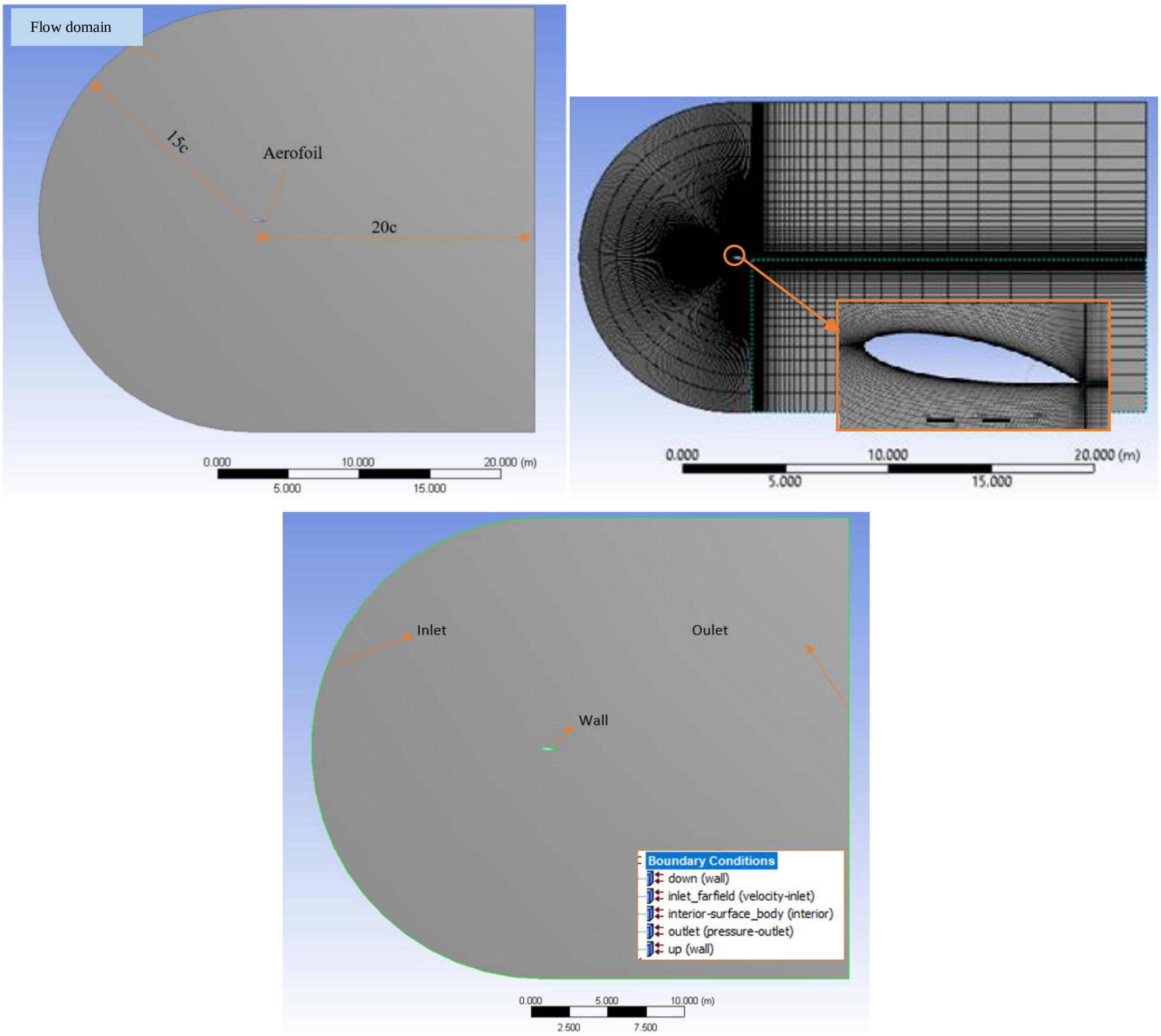

Figure 4. Solid Model, Mesh Structure and Boundary Conditions

In this study, the aerodynamic performance of the aerofoil have been determined according to the S-A, RNG k-Ɛ and k-ω-SST turbulence models and compared with the experimental values to determine the most suitable turbulence model for aerodynamic performance analysis. Obtained result in this study are given in next section.

RESULTS AND DISCUSSIONS

In this study, CFD analysis was performed according to different turbulence models in order to evaluate aerodynamic performance of selected aerofoils. The pressure distributions and the wind speeds around the aerofoil obtained as a result of these analyzes are given in Figure 5 and Figure 6 respectively. Figure 5 shows that negative pressures occur on the upper surfaces and positive pressures on the lower surfaces of the S833, S834 and S835 aerofoils. In addition, as a result of CFD analysis made according to different turbulence models, the pressures determined were close to each other. Figure 6 shows that, high wind speeds occur on the aerofoils, espacially at the upper edge near the attack side. In addition, it can be noted that wind velocities around the aerofoiles have similar behavior as pressure distributions.

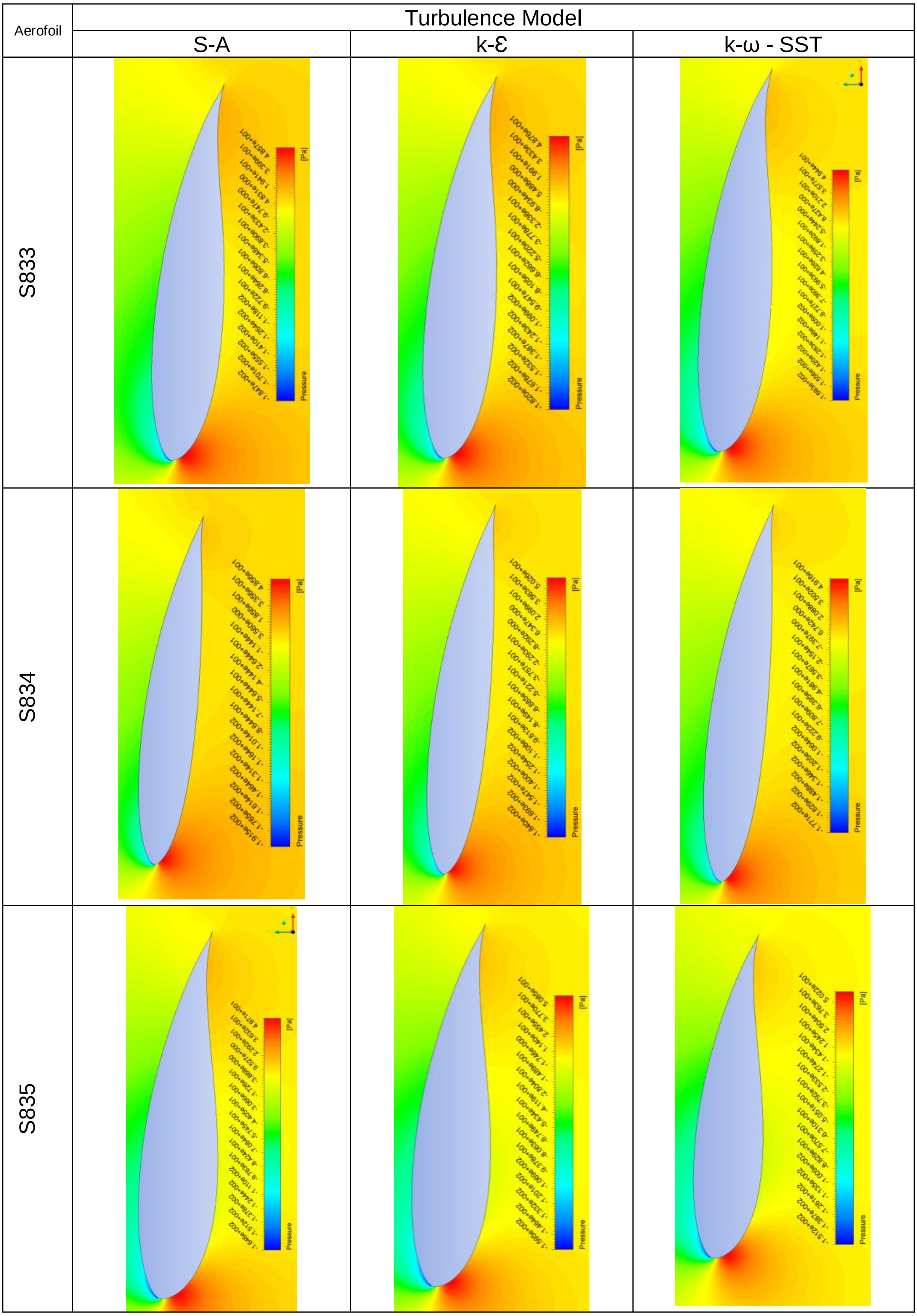

Figure 5. Pressure distributions of S833, S834 and S835 aerofoils according to the different turbulence model

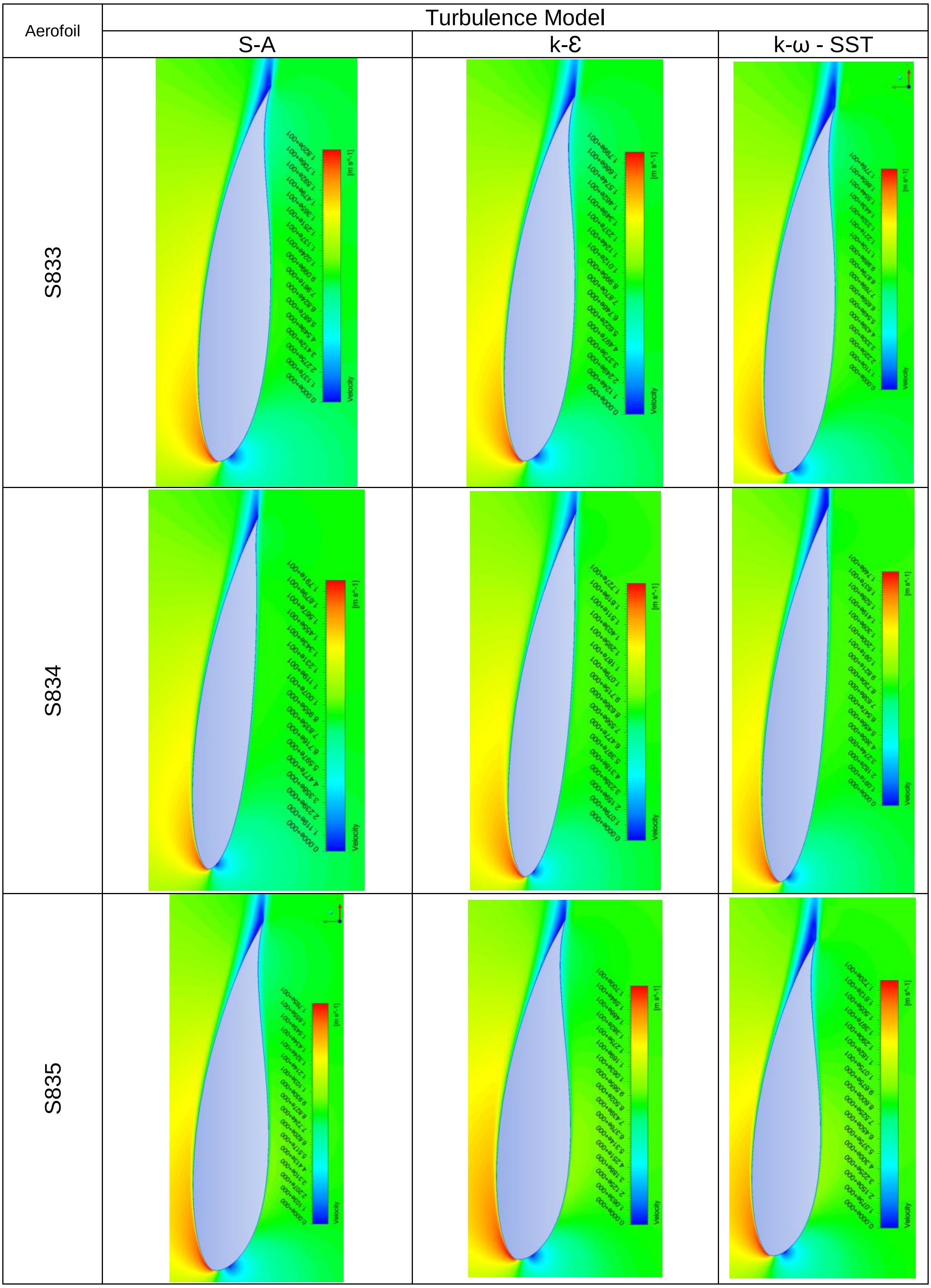

Figure 6. Wind velocities around the S833, S834 and S835 aerofoils according to the different turbulence model

The aerodynamic performance of S835, S833 and S834 aerofoils evaluated can be verified by comparing the experimental pressure coefficient (Cp) values found in the literature. For this purpose, pressure coefficients (Cp) of selected aerofoil have been determined and given in Figure 7, Figure 8 and Figure 9 respectively. Figures 7, 8 and 9 show that the pressure coefficients of the aerofoils are similar in character with experimental values except from the trailing edge of the aerofoil.

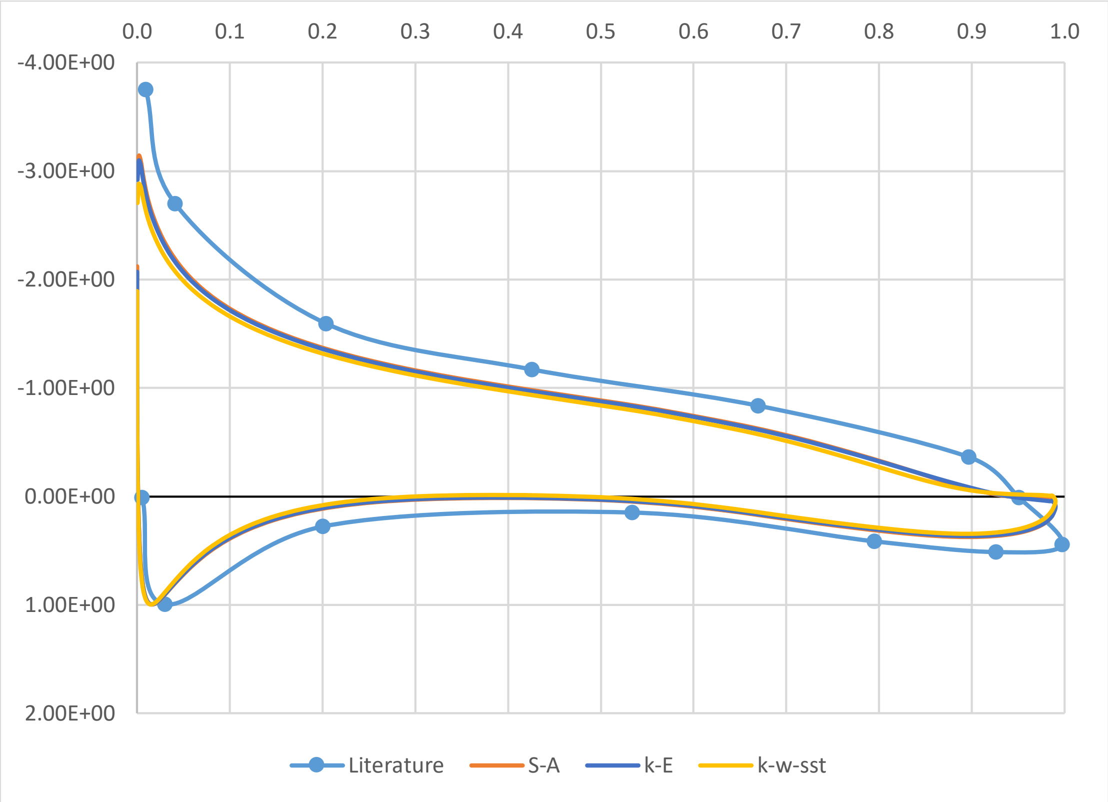

Figure 7. Pressure Coefficients of S833 aerofoil according to the different turbulence model

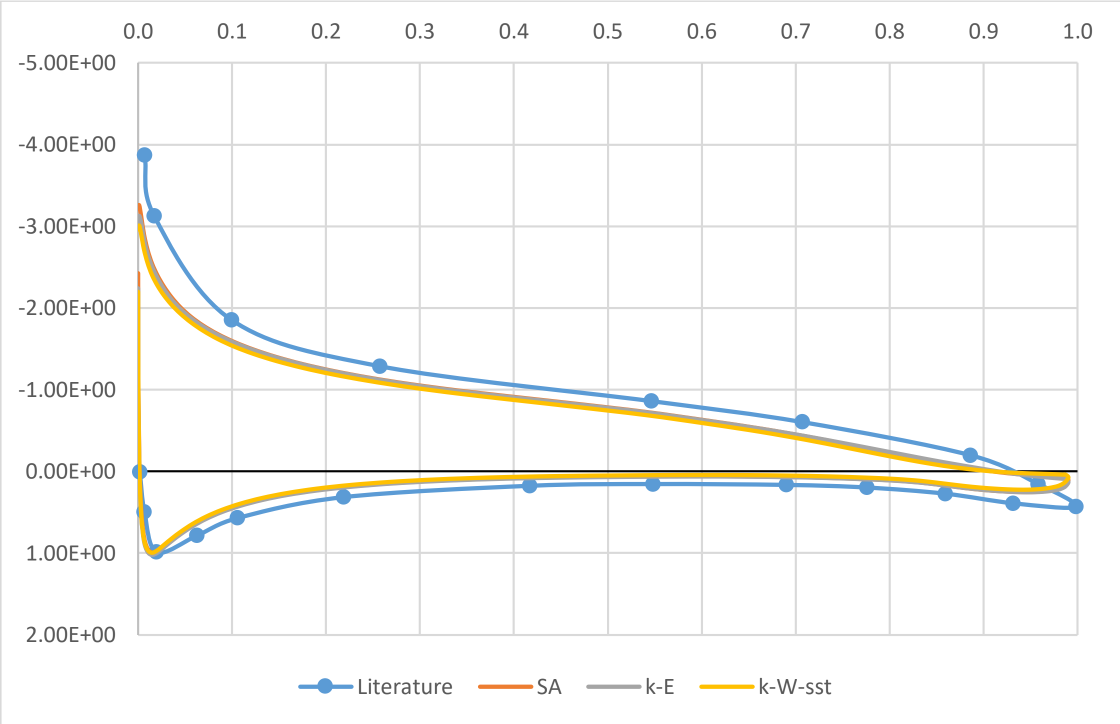

Figure 8. Pressure Coefficients of S834 aerofoil according to the different turbulence model

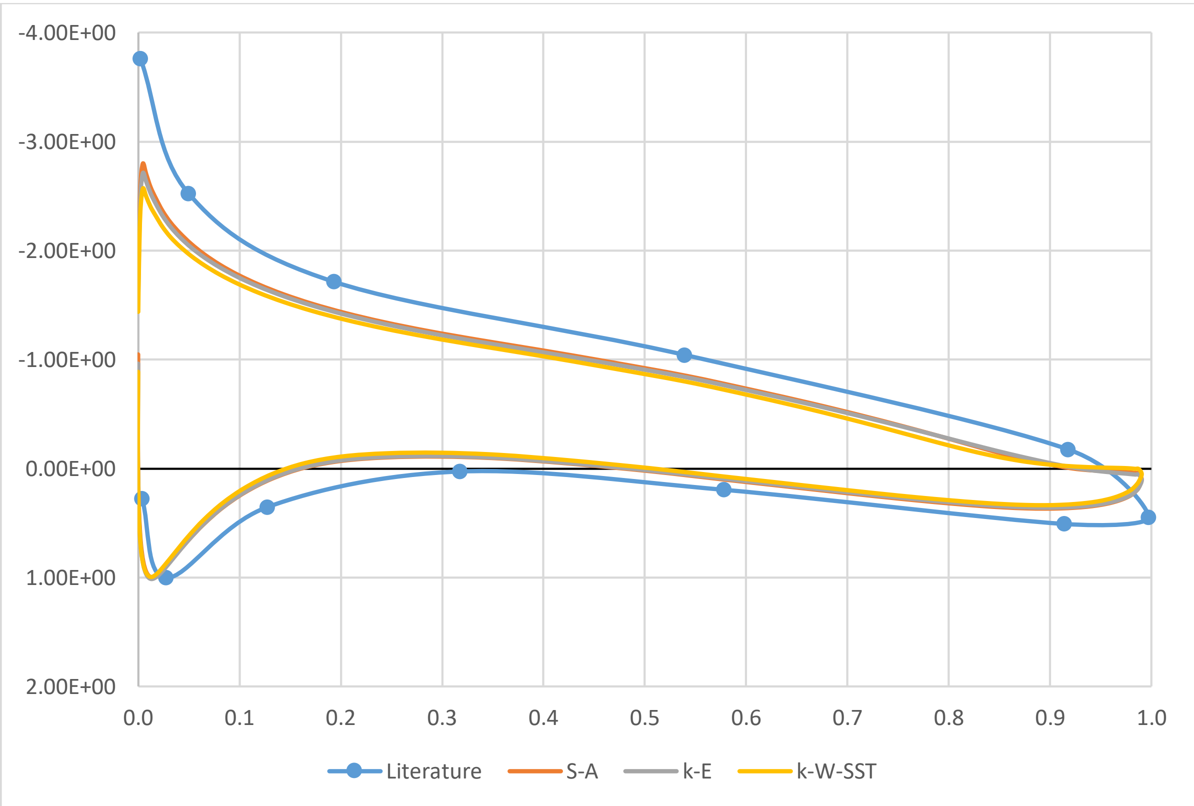

Figure 9. Pressure Coefficients of S835 aerofoil according to the different turbulence model

CONCLUSIONS

In this study, Aerodynamic performance of NREL S833, S834 and S835 aerofoils have been performed. Important results obtained from this study are summarized below.

- There are several studies on the aerodynamic performance analysis of various aerofoils from the studies in the literature, but there are limited studies on S833, S834 and S835 aerofoils.
- Negative pressures occur on the upper surfaces and positive pressures on the lower surfaces of the S833, S834 and S835 aerofoils. In addition, as a result of CFD analysis made according to different turbulence models, the pressures determined were close to each other.
- High wind speeds occur on the aerofoils, espacially at the upper edge near the attack side. furthermore, it can be noted that wind velocities around the aerofoiles have similar behavior as pressure distributions.
- The pressure coefficients of the aerofoils are similar in character with experimental values except from the trailing edge of the aerofoil.
- In this study, it was found that CFD analysis can be used to determine the aerodynamic performance of aerofoil. it is also recommended to use different turbulence models to investigate the aerodynamic behavior of the selected aerofoils at the trailing edge.

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