Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 7 (3): 426-433, 2007
ISSN 1812-5654

A Study on Aerodynamic Properties of Some NACA Profiles Used on Wind Turbine Blades

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Abstract: In this present study, fourteen different Re numbers, four different NACA profiles and lifting and drifting coefficients have been found by Snack 2.0 Computer program. By those determined values appropriate sliding rates of wind turbine blade profiles for each angle of attack have been calculated. For the determined four different NACA profiles correlations between the sliding numbers and the angle of attack, between the most convenient angle of attack and fourteen different Re number and lifting numbers and angle of attack have been revealed and depicted in a chart form. In addition, for the fourteen various Re numbers correlation between the lifting and drifting rates has been found out.

Key words: Wind turbine, sliding number, blade profile, attack angle

INTRODUCTION

Industrial development and increasing life standards are increasing the significance of energy requirement in our country and all around the world every time. Nowadays most frequently fossil based energy sources are used. But, very few countries obtain those energy resources. That situation makes those countries which do not possess those resources dependent on those countries having sufficient related sources. Especially, treatment and use of oil products derived from fossil based energy sources create damage on the environment and human health. Due to those facts alternative energy sources and especially renewable pure energy sources are getting more significant. Wind energy is one of the energy source considered as pure and renewable energy source. Especially, North European countries pay close attention to wind energy and in order to gain from it plenty of investigations and projects are being carried out.

Wind turbines are used in the production of wind energy. There are two types of wind turbines used commonly. Those are vertical axis wind turbines and the horizontal axis wind turbines (Vardar, 2002). In order to provide electricity more commonly horizontal axis wind turbines are preferred. In the world, when we examine the development of horizontal axis wind turbines it is seen that during 1980s wind turbines were used possessing 50 kW power and 15 m rotor diameter and tower height in the range of 10 and 15 m. But, nowadays, wind turbines possessing power up to 5 MW and rotor diameter up to 120 m, tower height in the range of 100 and 120 m (Klug, 2001). Establishment of huge magnitude wind energy production plants in recent years has enabled significant increases in the establishment of wind stations. World wind stations powers have reached to 59206 MW at the end of the January 2006 while it used to be corresponding to 47574 MW at the end of the January in 2006. Those figures indicates 24.45% rise in the power of world wind stations (Ressiad 2006).

When wind turbines are examined, rotor end speed rate, chord length of blade profiles and sliding rates and Re values of wind are found as significant factors pertaining to power provided from wind (Piggot, 1998). When the fact is considered that air is composed of small size molecules it is possible to assimilate that there is an average distance between those molecules. Further to that fact, Re value is defined as the proportion between the average distance of air molecules in which solid substance moves and the length of typical solid substance. Pertaining to profiles used on wind turbine blades Re value is the correlation between the chord value and the wind speed. Whereas the chord length as one of the factor influencing the Reynold value is subject to wind turbine rotor diameter, blade number on the rotor and rotor end speed rate (Piggott, 2006). End speed rate of the rotor refers to the rate of circumferential speed of a point in r distance from the rotor midpoint to wind speed (Özdamar and Kavas, 1998). Sliding rate varies subject to blade profiles. Sliding rate refers to the rate of lifting power of the blade profile to blade profile resistance coefficient (Vardar, 2002).

Purpose of this study exhibits some of the aerodynamic properties of some NACA profiles used on

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the wind turbine blades. In that scope, most convenient Re value, angle of attack, chord length of wind turbines, sliding rate, lifting and drifting coefficients, strength and minimum pressure coefficients have been considered. In the study, Snack 2.0 computer software have been utilized for the determination of lifting and drifting coefficients, strength and minimum pressure coefficients.

MATERIALS AND METHODS

Material: In the present study, some of the blade profiles put forward by NACA have been selected (Dresse, 2000). Those selected profiles are depicted in Fig. 1.

The selection of blade profile standards were based on the standards presented by National Advisory Committee for Aeronautics (NACA). First figure used in profiles indicates its height on y axis in % form when we think profile is located on a coordinate system (height of curvature), the second figure indicates its position on x-axis as % value (curvature position) last two figures indicates the thickness of blade profile as % (Dreese, 2000).

Method: In the present study implemented Re figure, chord length, rotor end speed and sliding rate are calculated by means of the following equations indicated as the Eq. 1-4.

Re figure varies according to chord length of blade profile and wind speed. (Piggott, 2006)

$$Re = 68500.C.v \quad (1)$$

Chord length is subject to wind turbine rotor diameter, blade numbers located on the rotor and rotor end speed rate (Piggott 2006).

$$C = \frac{4.D}{\lambda^2.B} \quad (2)$$

End speed rate of the rotor varies depending on the blade numbers located on rotor (Piggott, 2006).

$$\lambda = \sqrt{\frac{80}{B}} \quad (3)$$

In the present study, also lifting and drifting coefficients of the 0 and 20 degree angle of attack blade profiles have been calculated by Snack 2.0 Computer program. By plotting those calculated numbers into the related places in the following formula sliding numbers have been found for each of the profile's angle of attack.

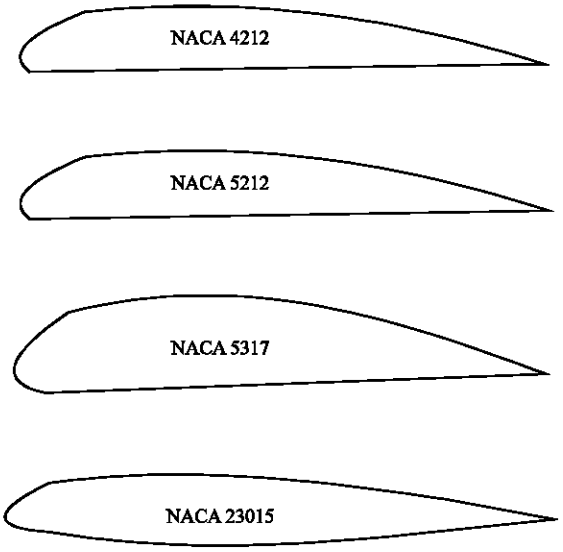

Fig. 1: Selected profiles

$$\varepsilon = \frac{C_L}{C_D} \quad (4)$$

By the equations presented above determined Re number is included into the evaluation of minimum and maximum values range of Re numbers for each blade profile. In those value ranges, for each of the blade profiles 14 in different Re number correlations between the angle of attack have been determined. By means of those correlations, for each blade profiles most suitable angle of attack values have been found. For those provided most convenient angle of attack rates correlation between Re values and correlation between lifting rate and angle of attack have been depicted in a chart.

In the study, Snack 2.0 Computer program was used for correlations of Re lifting and drifting rates on every blade profile has been found out. Later on, for the most suitable angle of attack Snack 2.0 Computer program was implemented for the determination of the momentum and minimum pressure coefficients of the profiles.

RESULTS

In the present study primarily Re values of the Chord lengths of the profiles and wind speed rates have been found. Chord rate is correlated with rotor diameter, blade number on the rotor and rotor end speed rates. Those correlations are stated by the Eq. 2 and 3. Based on those equations in the calculations performed based on blade numbers varying between 2 and 24 range used in the wind turbines and rotor diameter ranges between 2 and 100 m chord lengths have been found out as 0.1 and 5 m.

Table 1: Chord length, end speed rate and variation of Re values subject to rotor diameter and wind speed values on two wing rotor

Rotor diameter (m)	End speed rate	Chord length (m)	Wind speed (m sce^{-1})	Re rate
2	6,325	0.1	3	20,550
2	6,325	0.1	5	34,250
2	6,325	0.1	7	47,950
2	6,325	0.1	9	61,650
2	6,325	0.1	11	75,350
2	6,325	0.1	13	89,050
2	6,325	0.1	15	102,750
2	6,325	0.1	17	116,450
2	6,325	0.1	19	130,150
2	6,325	0.1	21	143,850
2	6,325	0.1	23	157,550
2	6,325	0.1	25	171,250
100	6,325	5.0	3	1,027,500
100	6,325	5.0	5	1,712,500
100	6,325	5.0	7	2,397,500
100	6,325	5.0	9	3,082,500
100	6,325	5.0	11	3,767,500
100	6,325	5.0	13	4,452,500
100	6,325	5.0	15	5,137,500
100	6,325	5.0	17	5,822,500
100	6,325	5.0	19	6,507,500
100	6,325	5.0	21	7,192,500
100	6,325	5.0	23	7,877,500
100	6,325	5.0	25	8,562,500

Table 2: On three wing rotors chord length, end speed rate and Re value variations subject to rotor diameter and wind speed

Rotor diameter (m)	End speed rate	Chord length (m)	Wind speed (m sce^{-1})	Re rate
2	5,164	0.15	3	20,550
2	5,164	0.15	5	34,250
2	5,164	0.15	7	47,950
2	5,164	0.15	9	61,650
2	5,164	0.15	11	75,350
2	5,164	0.15	13	89,050
2	5,164	0.15	15	102,750
2	5,164	0.15	17	116,450
2	5,164	0.15	19	130,150
2	5,164	0.15	21	143,850
2	5,164	0.15	23	157,550
2	5,164	0.15	25	171,250
100	5,164	5.00	3	1,027,500
100	5,164	5.00	5	1,712,500
100	5,164	5.00	7	2,397,500
100	5,164	5.00	9	3,082,500
100	5,164	5.00	11	3,767,500
100	5,164	5.00	13	4,452,500
100	5,164	5.00	15	5,137,500
100	5,164	5.00	17	5,822,500
100	5,164	5.00	19	6,507,500
100	5,164	5.00	21	7,192,500
100	5,164	5.00	23	7,877,500
100	5,164	5.00	25	8,562,500

Nowadays when we imagine the wind speed rates used on wind turbines vary in the range of 3 and 25 m s^{-1} Re rates are found between 20,550 and 8,562,500. Some of the examples of those results are depicted in Table 1-5.

In the course of above calculations Re values selected in the present study is depicted in Table 4. Those Re values encompasses all horizontal axis wind turbines implemented in our contemporary time.

Table 3: On four wing rotors chord length, end speed rate and Re value variations depending on rotor diameters and wind speed rates

Rotor diameter (m)	End speed rate	Chord length (m)	Wind speed (m sce^{-1})	Re rate
2	1,826	0.1	3	20,550
2	1,826	0.1	5	34,250
2	1,826	0.1	7	47,950
2	1,826	0.1	9	61,650
2	1,826	0.1	11	75,350
2	1,826	0.1	13	89,050
2	1,826	0.1	15	102,750
2	1,826	0.1	17	116,450
2	1,826	0.1	19	130,150
2	1,826	0.1	21	143,850
2	1,826	0.1	23	157,550
2	1,826	0.1	25	171,250
100	1,826	5.0	3	1,027,500
100	1,826	5.0	5	1,712,500
100	1,826	5.0	7	2,397,500
100	1,826	5.0	9	3,082,500
100	1,826	5.0	11	3,767,500
100	1,826	5.0	13	4,452,500
100	1,826	5.0	15	5,137,500
100	1,826	5.0	17	5,822,500
100	1,826	5.0	19	6,507,500
100	1,826	5.0	21	7,192,500
100	1,826	5.0	23	7,877,500
100	1,826	5.0	25	8,562,500

Table 4: Re numbers taken in that study as a base rate

No	Re No.
1	20,000
2	60,000
3	100,000
4	150,000
5	500,000
6	1,000,000
7	2,000,000
8	3,000,000
9	4,000,000
10	5,000,000
11	6,000,000
12	7,000,000
13	8,000,000
14	9,000,000

In Table 5, momentum and minimum pressure coefficient are depicted pertaining to lifting and drifting rates of blade profiles and most available angle of attack they provide subject to Re value.

For Re value in the range of 20000 and 9000000 correlation related to sliding rates and angle of attack is depicted in Fig. 2-15.

In Fig. 2, for Re 20000 most suitable angle of attack rate at the highest drifting values have been found as 6 degree using NACA 4212, NACA 5212 and NACA 23015 profiles. For NACA 5317 profile that related ratio has been determined as 9 degrees.

In Fig. 3, most convenient angle of attack at the highest sliding ratios have been found as 5, 6, 8 and 7 degrees respectively provided by using NACA 4212, NACA 5212, NACA 23015 and NACA 5317 for Re 60000.

Table 5: Lifting and drifting coefficients of wing profiles and differentiation of momentum and minimum pressure coefficient rates for the best angle of attack they provide depending on Re value

Profile name	Attack angle (°)	Momentum	Minimum pressure coefficient
NACA 4212	4	-0.0809	-1.602
	5	-0.0828	-1.78
	6	-0.0847	-1.986
	7	-0.0867	-2.205
	8	-0.0888	-2.552
	9	-0.0908	-3.126
NACA 5212	4	-0.0995	-1.787
	5	-0.1015	-1.972
	6	-0.1035	-2.16
	7	-0.1056	-2.370
	8	-0.1078	-2.598
	9	-0.1100	-2.851
NACA 23015	4	-0.0181	-1.479
	5	-0.0203	-1.715
	6	-0.0226	-1.986
	7	-0.0249	-2.308
	8	-0.0272	-2.684
	9	-0.0296	-3.138
NACA 5317	4	-0.1262	-1.732
	5	-0.1291	-1.892
	6	-0.1321	-2.071
	7	-0.135	-2.273
	8	-0.1381	-2.526
	9	-0.1411	-2.868

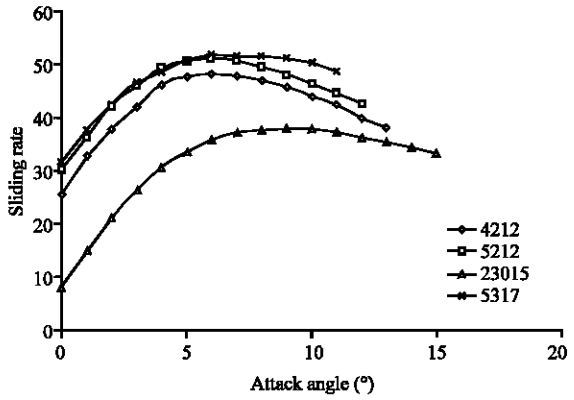

Fig. 2: Correlation between sliding rate and angle of attack for Re 20000

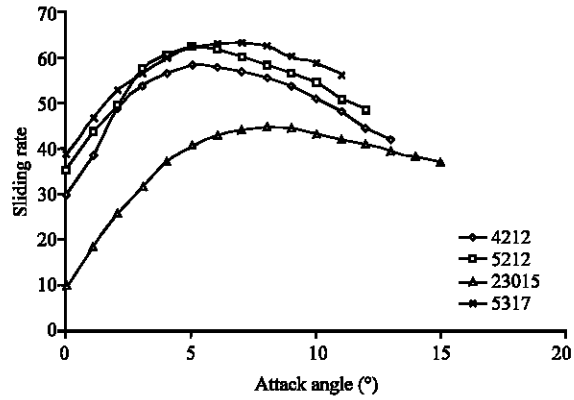

Fig. 3: Correlation between sliding rate and angle of attack for Re 60000

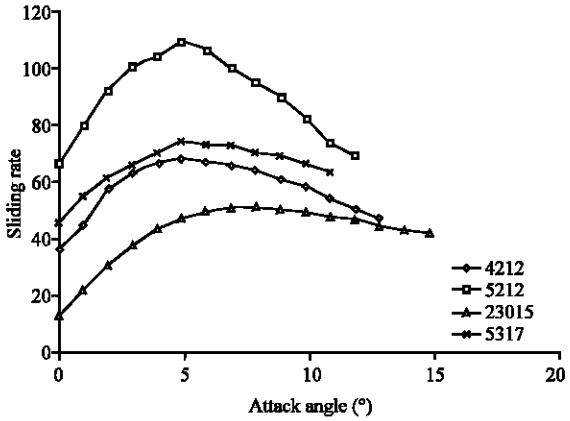

Fig. 4: Correlation between sliding rate and angle of attack for Re 100000

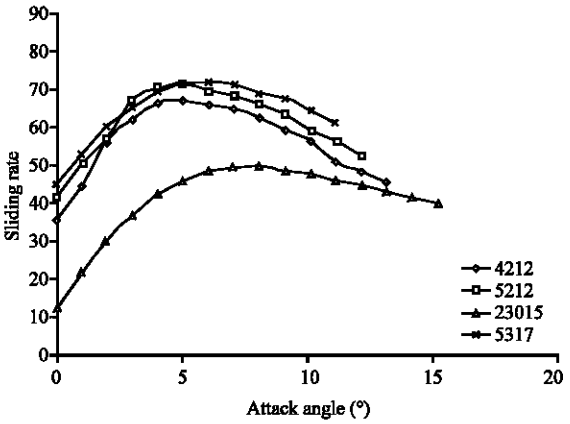

Fig. 5: Correlation between sliding rate and angle of attack for Re 150000

In Fig. 4, most convenient angle of attack value has been found as 5 degree at the highest sliding rates provided by the use of NACA 4212, NACA 5212 and NACA 5317 profiles for RE 100000. For NACA 23015 that ratio has been found as 8 degree.

In Fig. 5, most convenient angle of attack at the highest sliding rate provided by using NACA 4212 and NACA 5212 profiles have been found as 8 degree for Re 150000. That value has been found as 8 degree for NACA 23015 profiles, for NACA 5317 profiles found as 6 degree.

In Fig. 6, most convenient angle of attack at the highest sliding rate has been found as 6 degree provided by the use of NACA 4212 and NACA 5317 profiles for Re 500000. Same value has been found as 7 degree for NACA 23015 profiles and 4 degree for NACA 5212 profiles.

In Fig. 7-15 most convenient angle of attack at the highest sliding values have been found as 5 degree provided by the use of NACA 4212, NACA 5212 and

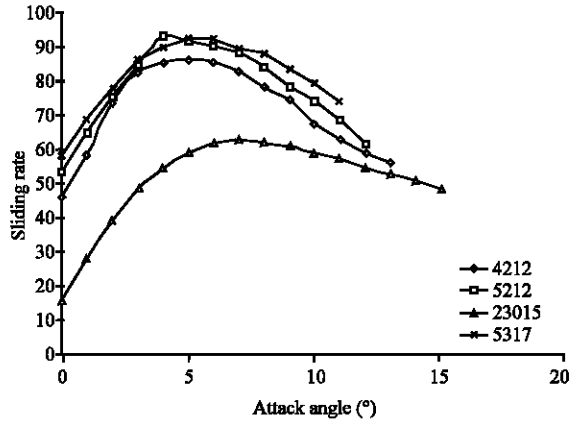

Fig. 6: Correlation between sliding rate and angle of attack for Re 500000

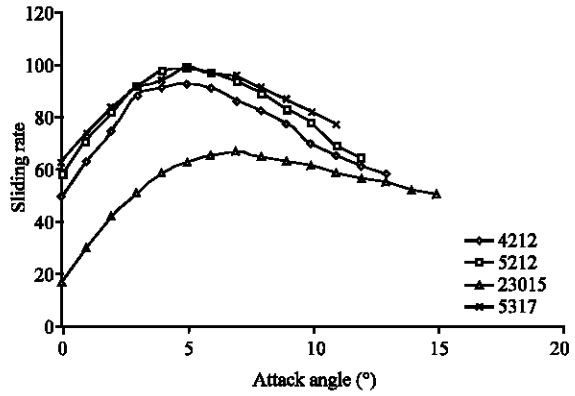

Fig. 7: Correlation between sliding rate and angle of attack for Re 1000000

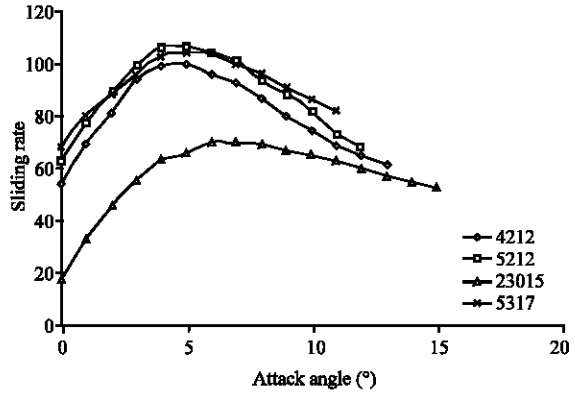

Fig. 8: Correlation between sliding rate and angle of attack for Re 2000000

NACA 5317 profiles for Re 1000000, 3000000, 4000000, 5000000, 6000000, 7000000 and 9000000, respectively. That value for NACA 23015, profile was corresponding to 7 degree.

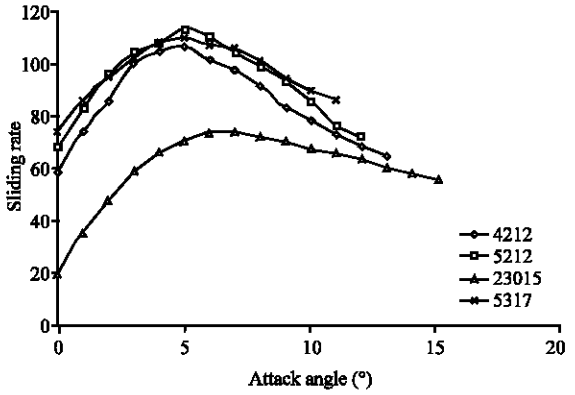

Fig. 9: Correlation between sliding rate and angle of attack for Re 3000000

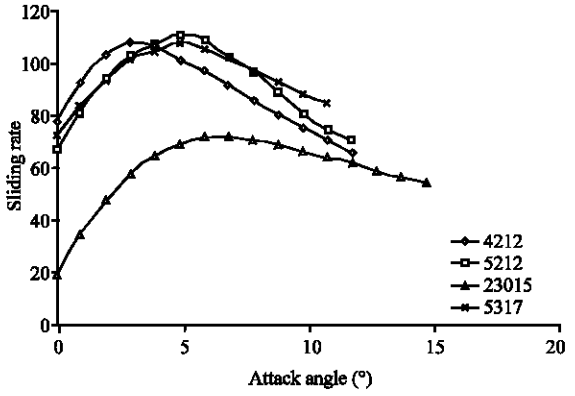

Fig. 10: Correlation between sliding rate and angle of attack for Re 4000000

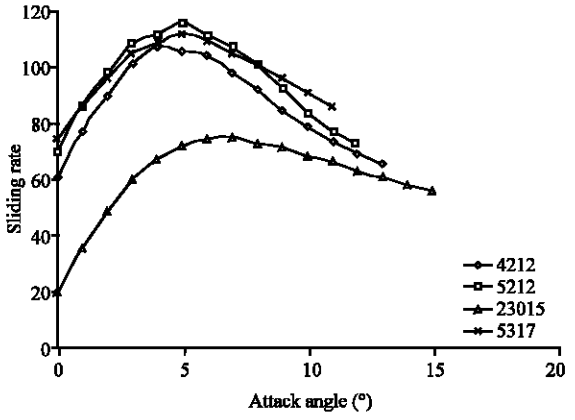

Fig. 11: Correlation between sliding rate and angle of attack for Re 5000000

In Fig. 8 and 14 most convenient angles of attack at the highest sliding rates, provided by the use of NACA 4212, NACA 5212 and NACA 5317 for Re 200000 and 8000000 was 5 degree. That value for NACA 23015 was corresponding to 6 degree.

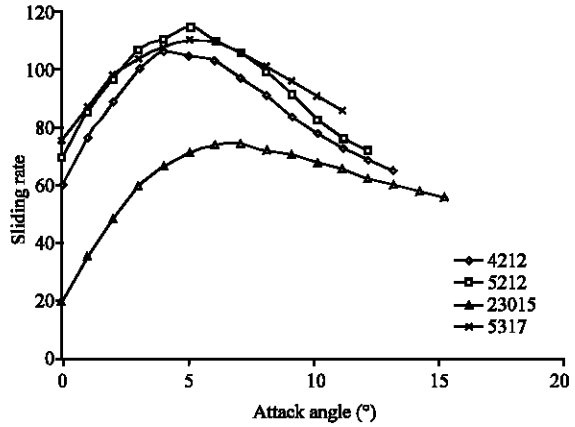

Fig. 12: Correlation between sliding rate and angle of attack for Re 6000000

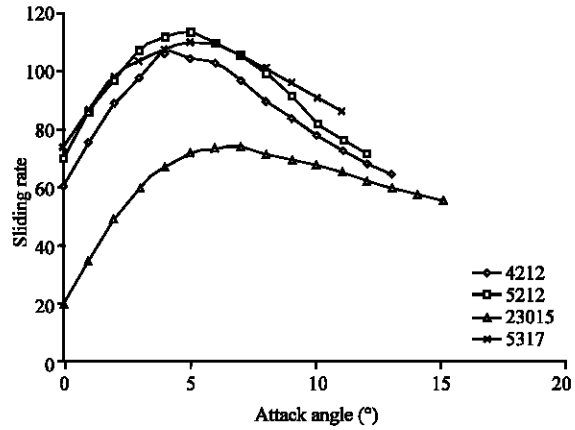

Fig. 13: Correlation between sliding rate and angle of attack for Re 7000000

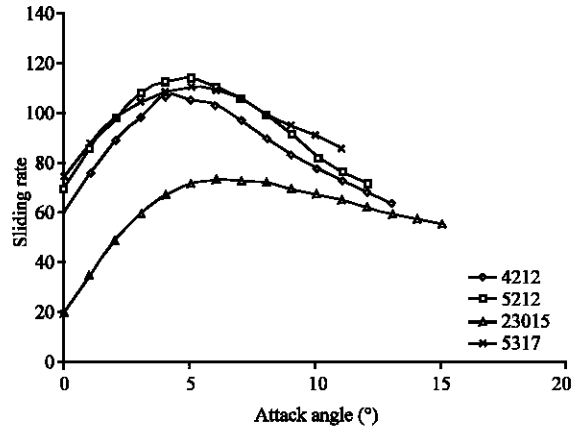

Fig. 14: Correlation between sliding rate and angle of attack for Re 8000000

In Fig. 16 correlation between most convenient angle of attack and Re value is depicted. In NACA 4212 profile

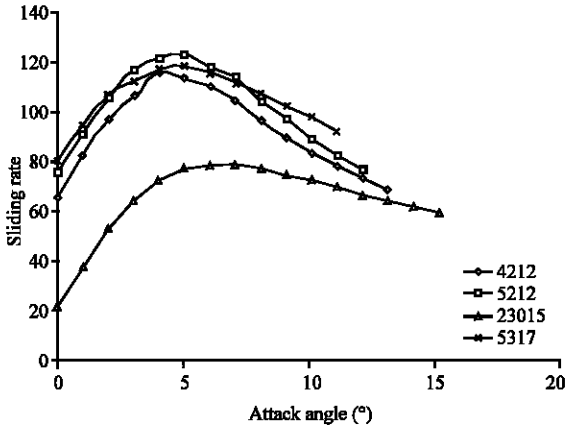

Fig. 15: Correlation between sliding rate and angle of attack for Re 9000000

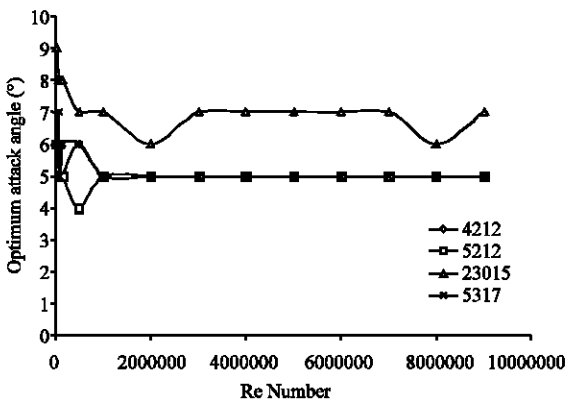

Fig. 16: Correlation between optimum angle of attack and Re numbers

most convenient angle of attack according to Re values were changing in the range of 7 and 9 degrees for Re 20000 and 3000000. For Re 3000000 and 7000000 values those values found remaining stable at 7 degree. For the rate of Re 7000000 and 9000000 most convenient angle of attack values were changing in the range of 6 and 7 degrees. For NACA 5212, NACA 23015 and NACA 5317 profiles most convenient angle of attack rates according to Re values were changing between 4 and 7 degrees in the range of Re 20000 and 1000000, whereas in the range of Re 1000000 and 9000000 that was remaining constant at 5 degree.

In Fig. 17, correlation between lifting values of the profiles and angle of attack is depicted. Pertaining to angle of attack lowest lifting value is found in NACA 23015 profiles, highest lifting value has been found in NACA 5317 profiles.

In Fig. 18-21 correlations between lifting values and drifting rates for NACA 4212, NACA 5212, NACA 23015 and NACA 5317 profiles are depicted respectively. For

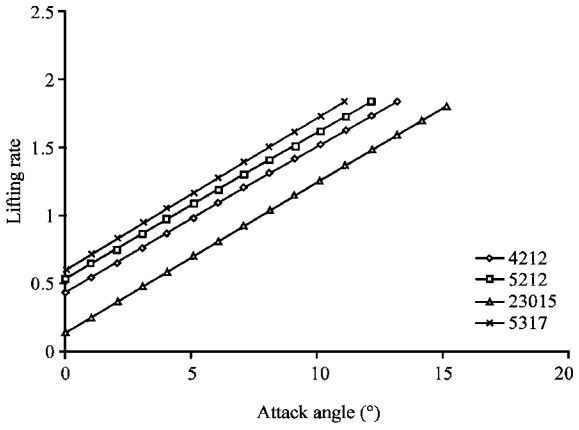

Fig. 17 Correlation between lifting rate of the profiles and angle of attack

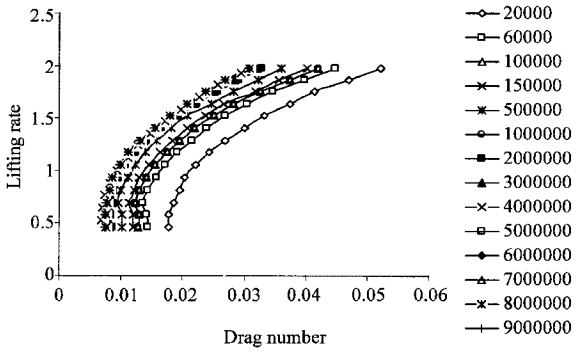

Fig. 18: Correlation between lifting and drifting rate for NACA 4212

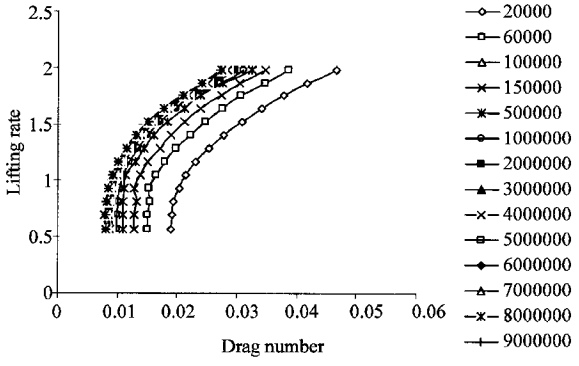

Fig. 19: Correlation between lifting and drifting rat for NACA 5212

those profiles according to drifting values Re 20000 value has lowest lifting values, Re 9000000 value has highest lifting values.

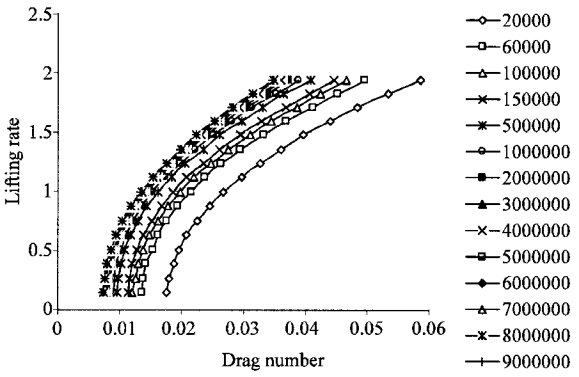

Fig. 20: Correlation between lifting and drifting rate for NACA23015

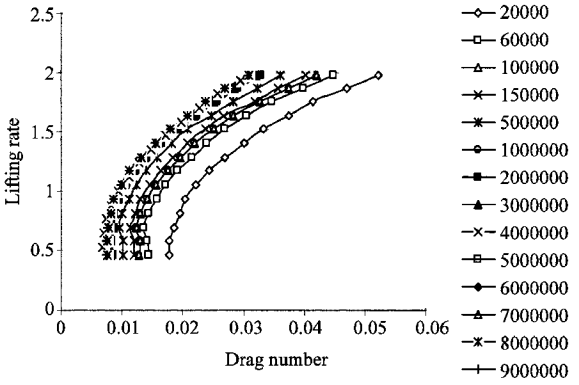

Fig. 21: Correlation between lifting and drifting rate for NACA 5317

CONCLUSION

Wind energy is one of the significant energy sources. Although it is not sufficient to solve entire energy requirement in a country it must be used either for providing energy assortment or for meeting energy claim partly. In contemporary wind turbines fundamental fact relies on the transformation of wind energy to electrical energy. For that reason, horizontal axis wind turbines are preferred. Also in the present study, some of the profiles used on the rotor blades of the horizontal axis wind turbines have been investigated. Because, profile properties is a crucially important factor over the energy supposed to be provided from wind turbines.

NOMENCLATURE

ε	: Sliding Number	C	: Chord length (m)
C_L	: Lifting Coefficient	C_D	: Drifting Coefficient
D	: Rotor Diameter (m)	B	: Blade Number
λ	: End speed rate of the rotor	Re	: Reynold Number
V	: Wind Velocity (ms^{-1})	NACA	: National Advisory Committed For Aeronautics

REFERENCES

Dreese, J., 2000. Aero Basics and DesignFOIL, User Guide, Capitola, California.

Klug, H., 2001. Basic Course in Wind Energy. German Wind Energy Institute GmbH (DEWI), Istanbul.

Özdamar, A. and M.G. Kavas, 1999. A Research of Wind Turbine Rotor Design, Sun Day Symposium, 25-27 June 1999, Kayseri, Turkey.

Piggott, H., 2006. See also: http://homepages.enterprise.net/hugh0piggott/wpNotes/index.htm

Ressiad, 2006. See also: ttp://www.ressiad.org.tr/dhie.php? t = istatistikler and ID = 30.

Vardar, A., 2002. A research on determination of the fittest blade type, blade angle and blade position for establishing a wind turbine with agricultural aim in trakya region. University of trakya, institute of science, branch of agriculture machines Ph.D Thesis, tekirdag.