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FLOW ANALYSIS AND DETERMINATION OF DRAG FORCES FOR SPIKES OF CROPS

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Abstract-In this work, flow analysis and drag forces of spikes of crops are investigated. A control volume is constructed to calculate drag forces and coefficients of spikes of wheats (Triticum durum, Triticum aestivum) for various velocities. In addition, drag forces corresponding to different orientation angles are determined for spikes of bread wheats. Spikes without awns are drawn using UNIGRAPHICS program in order to computationally analyze the flow. The drawings are inserted into ANSYS ICEM-CFD program and drag forces and coefficients are determined.

Keywords-Wheat Spikes, drag forces, drag coefficients

1. INTRODUCTION

Biomimetics is a branch of science to understand the complex designs in nature and to possibly transform the determined principles to the technological products. Mimicking nature definitely improved our design concepts in recent years. Investigating flight of insects which employ turbulent flow for their benefit improved our understanding of designing new flying objects and their maneuverability. Examining the surface of lotus enabled us to design new self cleaning surfaces. The special design of wings of owl may inspire design of silent aircrafts in the future.

In this study, flow analysis of spikes of wheat is investigated. Drag forces and drag coefficients are calculated for various velocities. Effect of complex geometry of spikes on the flow is examined. Studies are conducted numerically. Streamlines around the spikes without awns are determined. First, a solid model of the spikes without awns are drawn using UNIGRAPHICS program. The solid model is then replaced in a control volume in ANSYS ICEM-CFD program. The flow analysis is conducted for various inlet velocities. The orientation angle of the spike is then changed and the analysis is repeated for different angles of attack.

Some of the relevant work will be briefly mentioned: The mechanisms by which a porous windbreak modifies airflow, microclimates and hence crop yields are addressed, based upon recent wind tunnel experiments, field observations and numerical modelling [1]. A new measurement technique based on image correlation was presented to capture the wind-induced motions of crop canopies [2]. Fundamental nature of the wheat lodging process was investigated for developing a theoretical model of the lodging process [3]. Mechanisms by which wind directly affects crop growth rates and hence yields were reviewed [4]. The aerodynamic forces on the grain-bearing spike of five varieties of wheat, chosen for varying wind tolerance were measured [5]. Low pressure pneumatic conveyor was designed and manufactured and conveying characteristics of the seeds of wheat, barley, sunflower and lentil were determined [6]. A coupled fluidstructure model is proposed to study the dynamics of a flexible crop canopy exposed to wind [7].

2. MATERIALS AND METHODS

2.1. Materials

A control volume with dimensions 0.15x0.1x0.05 m is selected in ANSYS WORKBENCH program. Durum and bread wheats without awns are drawn in UNIGRAPHICS program and replaced into this control volume. Drag forces are calculated for air flow inside the control volume. The drawings are given in Figure 1.

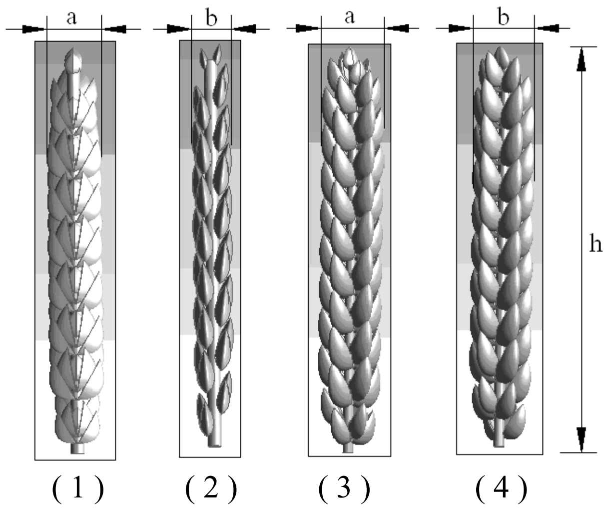


Figure 1. (1) Front view of bread wheat spike (2) Side view of bread wheat spike (3) Front view of durum wheat spike (4) Side view of durum wheat spike

With reference to the drawings, two different bread wheat spikes and one durum wheat spike are taken. The dimensions of the spikes are given in table 1.

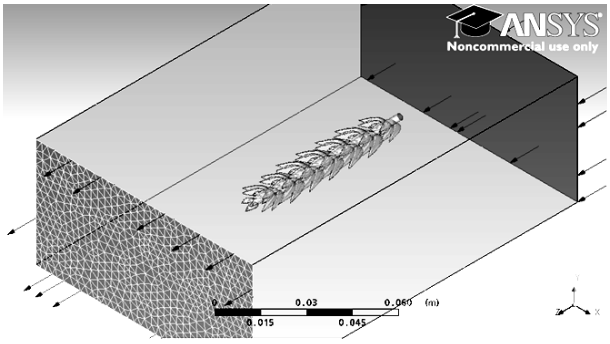
Table 1. Dimensions of Spikes

Spikes	a (mm)	b (mm)	h (mm)
Bread Wheat Spike (e1)	10.50	7.30	76.20
Bread Wheat Spike (e2)	10.80	8.40	67.20
Durum Wheat Spike (m1)	13.83	12.30	81.35

2.2. Methods

The control volume used in the analysis is given in Figure 2.

Figure 2. Bread wheat spike in the control volume



The coordinates are replaced to the stem part of the spike which is laid in the middle part of the control volume. Using ANSYS Advanced Meshing, the model is meshed. Mesh parameters are selected as 0.0002m which is 1/25 of the stem diameter (0.005m) being the smallest dimension of the spike. Top, bottom and side surfaces are given 0.008m meshing, inlet and outlet parts as 0.005m meshing. After completing the meshing in ANSYS ICEM CFD**,** the flow analysis is conducted in ANSYS ICEM CFX for various air flow velocities such as 5 m/s, 8 m/s, 11 m/s, 13.5 m/s, 15 m/s, 20 m/s. Drag forces and drag coefficients are determined as a result.

The temperature, pressure and density values used in the analysis are given in Table 2. These values correspond to June data of Celal Bayar University Muradiye Campus.

Table 2. Temperature, pressure and density values used in the analysis

Temperature, T	24^{o}C
Pressure, P	101592 Pa
Density, ρ	1.192 kg/m^3

The surfaces of the control volume are defined to have no shear stres wheras the surface of the spike is defined to have no slip condition. In addition, for bread wheat spike (e2), the orientation angle in the control volume is changed and for 13.5 m/s air flow velocity, flow analysis is conducted for 0^o, 22.5^o, 45^o, 67.5^o, ve 90^o angles.

3. RESULTS

Two different bread wheat spikes of e1 and e2 are used and for air flows of 5 m/s, 8 m/s, 11 m/s, 13.5 m/s, 15 m/s, 20 m/s, drag forces and drag coefficients are calculated using ANSYS ICEM CFX. Results are given in Table 3.

Table 3. Drag forces and drag coefficients for bread wheat spikes

	Velocity (m/s)	Re number	Drag Force F (N)	Drag Coefficient C_d
e1	5	27.44×10^5	0.00119634	1.04750522
	8	43.91×10^5	0.00295076	1.00924242
	11	60.37×10^5	0.00522366	0.94499849
	13.5	74.1×10^5	0.00728042	0.87444093
	15	82.3×10^5	0.00863234	0.83982268
	20	109.7×10^5	0.0139849	0.76531629
e2	5	29.83×10^5	0.00131603	0.97359084
	8	42.73×10^5	0.00304575	0.88016679
	11	65.63×10^5	0.00547135	0.83629563
	13.5	80.55×10^5	0.00798448	0.81027007
	15	89.5×10^5	0.00969956	0.79729716
	20	119.3×10^5	0.0165166	0.7636799

Drag force is calculated using the below formula

$$F_d = 0.5\rho C_d A U^2 \tag{1}$$

The area A is the cross sectional area vertical to the air flow direction. For samples e1 and e2, the areas are 0.00007665 m^2 and 0.00009072 m^2 respectively. The air density is taken as 1.192 kg/m^3, Velocity U are taken from table 3. Ones the program calculates the drag force, equation (1) is employed to determine the drag coefficient. For the calculation of Reynolds number the below formula

$$Re = \frac{UD}{\nu} \tag{2}$$

is used. The kinematic viscosity (ν) is taken as 1.8×10^{-5} m^2/s which is the value corresponding to 24^oC temperature and 1.185 kg/m^3 air density. The equivalent diameter for sample e1 is taken as 9.88 mm; and that for sample e2 is taken as 10.74 mm. The average drag coefficient for bread wheat spike is found to be $C_d \approx 0.88$.

By cutting the control volume with a plane, flow characteristics are also investigated. Eddy formation is observed at the back of the bread wheat spike. Flow is more smooth around the side surfaces (Figure 3).

Figure 3. Streamlines and eddies for bread wheat spike

Drag forces and drag coefficients are calculated for the durum wheat spike next. Results are given in Table 4.

Table 4. Drag forces and drag coefficients for durum wheat spikes

	Velocity (m/s)	Re number	Drag Force F (N)	Drag Coefficient C_d
m1	5	40.8x10^{5}	0.00120511	0.47545906
	8	65.42x10^{5}	0.00276865	0.42669203
	11	89.95x10^{5}	0.00498394	0.40626919
	13.5	110.4x10^{5}	0.00749096	0.4054118
	15	122.6x10^{5}	0.00920826	0.40366538
	20	163.5x10^{5}	0.0161487	0.39820254

The average drag coefficient for spike of durum wheat is calculated to be $C_d \approx 0.42$. The equivalent average diameter is taken as 14.72 mm.

Streamlines for durum wheat spike is shown in Figure 4. As in the case of bread wheat spikes, eddy formation is observed at the back of the spike. Around side surface, observable eddies are not formed.

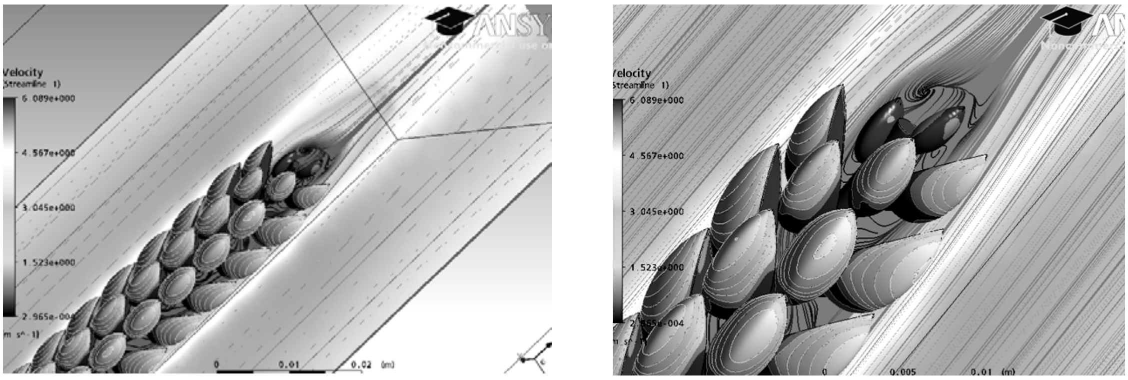


Figure 4. Streamlines and eddies for durum wheat spike

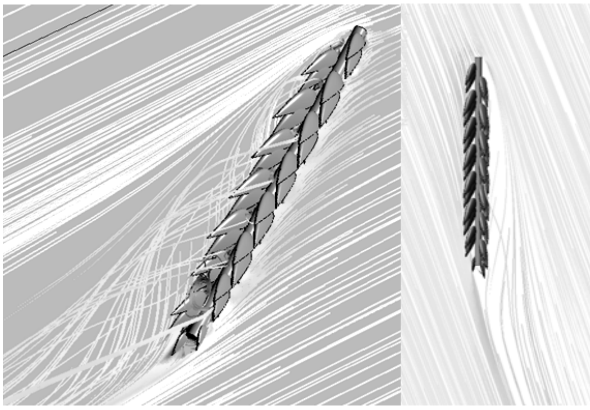
As a next step, effect of the orientation angle of the spike with respect to flow direction is examined. The coordinate system is replaced to the stem part of spike, and the orientation angle is defined as the angle between the longitudinal symmetry axis and the flow direction. Drag forces are calculated for orientation angles of 0^o, 22.5^o, 45^o, 67.5^o, 90^o for bread wheat spike e2 for the velocity of 13.5 m/s. The program calculates the force components of F_y and F_z. The drag force can then be calculated by the formula

$$F_s = F_y sin\theta + F_z cos\theta \qquad (3)$$

Results are given in Table 5 for different orientation angles.

Table 5. Drag forces and coefficients for bread wheat spike (e2) for different orientation angles (U=13.5 m/s)

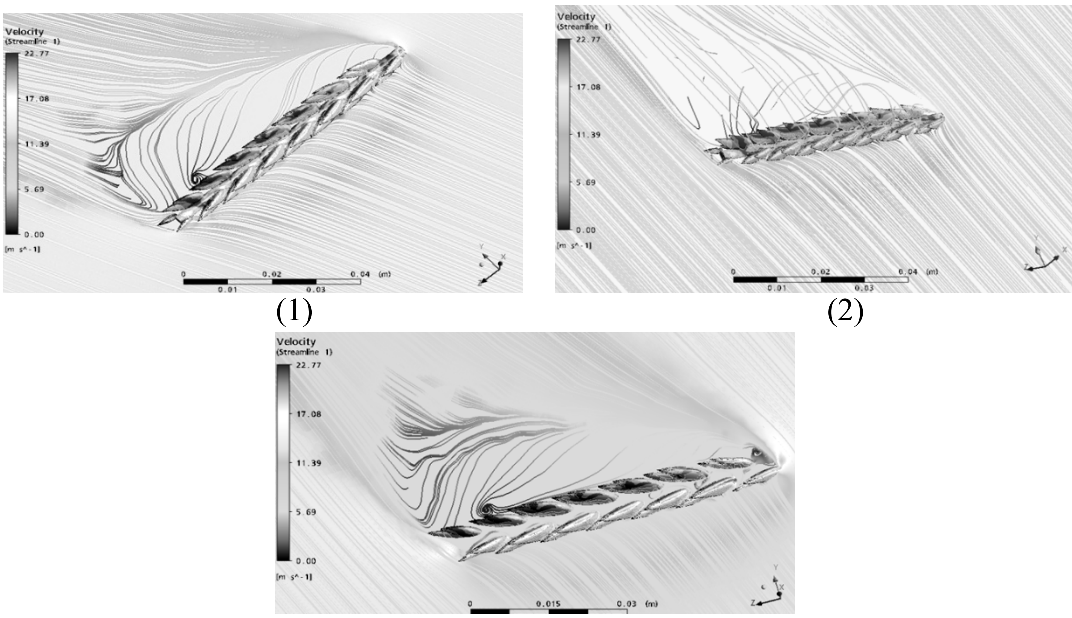
Orientation Angle	**Drag Force F_s (N)**	**Drag Coefficient C_d**
0^o	0.00744815	0.000102039
22.5^o	0.014418831	0.000197536
45^o	0.038644234	0.000529422
67.5^o	0.061164672	0.000837949
90^o	0.0709421	0.000971899



(1) (2)

Figure 5. Streamlines of bread wheat corresponding to 45^0(1) and 22.5^0 (2) orientations

Streamlines of bread wheat for orientation angles of 45^o and 22.5^o are shown in Figure 5; for orientation angle of 67.5^o in Figure 6; and for angle of 90^o in Figure 7.



(1) (2)

(3)

Figure 6. (1) Streamlines and eddies for bread wheat spike for orientation angle of 67.5^0 with 13.5 m/s flow velocity (2) Streamlines in 3 dimensional view (3) Eddies for an upper plate section

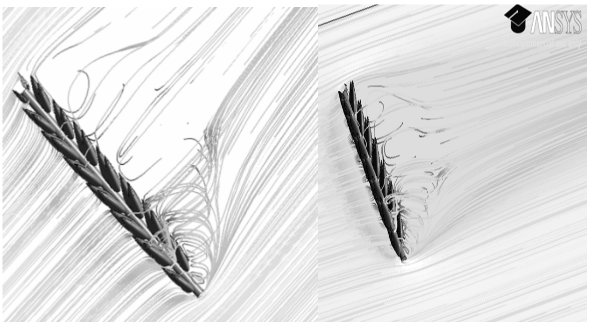


Figure 7. Streamlines and eddies for bread wheat spike for orientation angle of 90^0

4. DISCUSSIONS AND CONCLUSIONS

With the analysis, drag forces and drag coefficients of bread and durum wheat spikes are determined. Flow around the spikes is also analyzed to investigate the streamlines and eddies.

In Figure 8, drag forces versus velocities are given for bread and durum wheat spikes. Drag forces increase with velocity as expected. The increase rate is maximum for bread wheat e2.

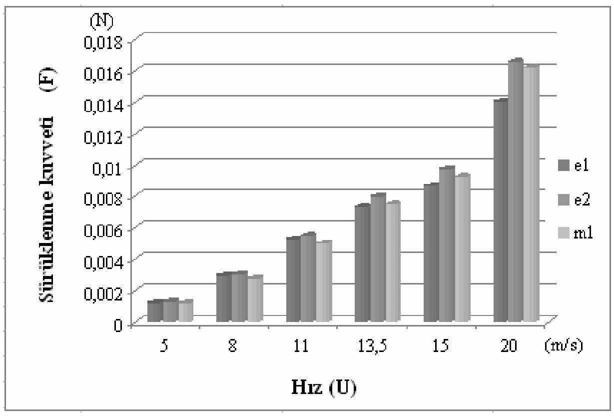


Figure 8. Drag force versus velocities for bread wheat spikes (e1 and e2) and durum wheat spikes

Table 6. Drag force increases for bread wheat spikes (e1 and e2) and drum wheat spikes (m1)

	Drag force for 5 m/s (N)	**Drag force for 20 m/s (N)**	**Increase in Drag Force (N)**
e1	0.00119634	0.0139849	0.01278856
e2	0.00131603	0.0165166	0.01520057
m1	0.00120511	0.0161487	0.01494359

Increase in drag force is greater for e2 compared to e1 as given in Table 6. The increase rate is in between for durum wheat spikes. Differences in drag forces stem from different aerodynamic structures of the spikes.

Drag coefficients of bread wheat spikes e1 and e2 are found on average to be 0.879 (Table 3). In contrast, for durum wheat spike m1, the average value is 0.419 (Table 4). One may conclude that aerodynamic design of durum wheat spike is better than bread wheat spikes. Seeds forming the spike are more flat and rounded for durum wheat which increases the aerodynamic efficiency (Figure 4). Larger eddies are found in downstream of bread wheat as shown in Figure 3.

As a general rule, as the velocity increases, drag forces increase and drag coefficients decreased.

Variation of drag forces and coefficients with orientation angles are given in Figures 9 and 10 respectively for flow velocity of 13.5 m/s for bread wheat spike.

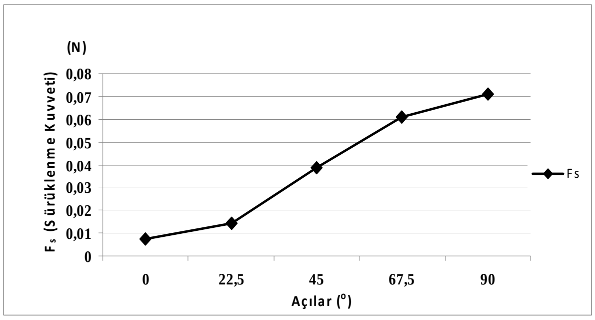


Figure 9. Drag forces versus orientation angles for bread wheat spike ($Re=80.55x10^5$, U=13.5 m/s)

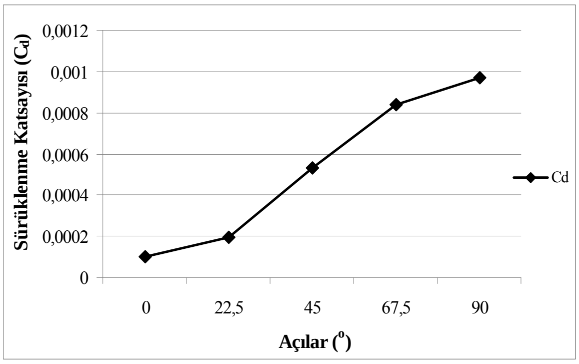


Figure 10. Drag coefficients versus orientation angles for bread wheat spike ($Re=80.55x10^5$, U=13.5 m/s)

As the orientation angle is increased, there is a substantial increase in drag forces and coefficients. The eddies formed at an angle of 67.5^o (Figure 6) are larger than the eddies formed at an angle of 22.5^o (Figure 5).

Understanding the aerodynamic principles inherent in spikes of crops which are subject to high wind loads, we can design aerodynamically better slender bodies.

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