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AN EXPERIMENTAL STUDY OF THE EFFECT OF VORTEX GENERATOR ON THE FLAT-PLATE BOUNDARY LAYER

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ABSTRACT

This paper is dealing with an experimental study to show the influence of the geometric characteristics of the vortex generators VG son the thickness of the boundary layer (∂) and drag coefficients (C_D) of the flat plate. Vortex generators work effectively on medium and high angles of attack, since they are "hidden" under the boundary layer and practically ineffective at low angles.

The height of VGs relative to the thickness of the boundary layer enables us to study the efficacy of VGs in delaying boundary layer separation. The distance between two VGs also has an effect on the boundary layer if we take into account the interference between two pairs of VGs. The effect of the changing in (h- the height of vortex generator, d- the average distance between tow vortex generators) on the thickness of the flat plate boundary layer and the drag coefficients has been studied for triangular vortex generator. The measurements of the vortex generator have been changed to determine the optimum boundary layer thickness and the change in drag coefficients. An experiment was done at an average free stream velocity, (U_∞,) of 28 m/s. The experiment was conducted in the wind tunnel UTAD-2 University (NAU) Kiev, Ukraine.

Keywords: Drag coefficients, geometric characteristics, laminar flow, stream velocity, turbulent flow; vortex generator.

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دراسة تجريبية لتأثير مولد الدوامة على الطبقة الحدودية للوحة مسطحة

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الخلاصة

يتناول هذا البحث دراسة تجريبية تبين تأثير الخصائص الهندسية لمولدات الدوامات على سمك الطبقة الحدودية (∂) ومعاملات الكبح (CD) للوحة مسطحة، وتعمل مولدات الدوامات بشكل فعال في زوايا الهجوم المتوسطة والعالية لأنها تكون "مخفية" تحت الطبقة الحدودية وغير فعالة عمليا عند الزوايا المنخفضة، وان ارتفاع VGs نسبة الى سمك الطبقة المحددة يمكننا من دراسة مدى فعالية VGs في تاخير انفصال الطبقة المحددة، والمسافة بين اثنين من VGs أيضًا على الطبقة الحدودية إذا أخذنا في الاعتبار التداخل بين زوجين من VGs.

تمت دراسة تأثير التغير في (h- ارتفاع مولد الدوامة، د- متوسط المسافة بين مولدات دوامة القطر) على سمك الطبقة الحدودية للوحة المسطحة ومعاملات الكبح لمولد دوامة مثلث الشكل، وتم تغيير قياسات مولد الدوامة لتحديد سمك الطبقة الحدودية المثلى، واجريت التجربة بمتوسط سرعة تيار حر ($U\infty$) تبلغ 28 م/ ث، ونفذت التجربة في النفق الهوائي UTAD-2 في جامعة (NAU) كييف، اوكرانيا.

الكلمات المفتاحية: معامل الكبح، الخصائص الهندسية، انسياب طبقي، سرعة التدفق، جريان مضطرب، مولد دوامة.

INTRODUCTION

Vortex generators (VGs) are used as flow control devices to provide a certain amount of delay separation of the boundary layer as well as weaken the harmful effects of strong local secondary flows. Most of the previous scientific research used a VG as a passive flow control device that modifies the boundary layer fluid motion, which brings momentum from the outer flow region into the inner flow region of the wall-bounded flows **(Storms *et al.*,1994**), thus delaying the separation of the boundary layer **(Manolesos *et al.*, 2015).** But their implementation may produce overload drag at the body where they are placed. In this work, the VG is used as a device to reduce the thickness of the boundary layer on the flat plate which will lead to decrease drag coefficients. The designs of various types of vortex generators have been given in **(Gao *et al*., 2015)**.

In scientific research **(Li *et al*., 2014)** was used four different shapes of VGs: delta, cropped-delta, rectangle, and trapezium, among the four VGs, rectangular vane has the maximum drag while deltaic vane gives the best drag performance. The deltaic VG has the lowest vortex strength because its leading edge is close to the wall surface and most of its surface is submerged in the boundary layer when the vehicles fly at slow velocity **(Lin *et al*., 1990)**. Accordingly, has been selected as the deltaic type of VG. A lot of research has been done on the VGs by several researchers **(Stilffried *et al*., 2010; Griffm 1960). Li *et al,* (2019)** got the results of the effect of VG height in the boundary layer.

The objective of this research is an experimental study of the dependence of the drag coefficients and the boundary layer thickness of a flat plate on many geometric characteristics of the VGs. 32 models of VGs configured in different geometric dimensions to get the optimum geometric measurements, which is equivalent to the lowest value of drag coefficients.

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DESCRIPTION OF A FLAT PLATE AND VORTEX GENERATORS FOR EXPERIMENTAL RESEARCH

An experimental study was carried out on a wind tunnel UTAD-2 (NAU). On its basis, an experimental setup for investigating the characteristics of the boundary layer on a plate (Figure 1).

UTAD-2 is an atmospheric low-speed wind tunnel of closed-return type with an open elliptical test section. It is used for educational purposes in aerodynamics and flight dynamics as well as for scientific investigations, and commercial purposes such as certification of wind velocity and wind direction meters.

Methodological works like working through new types of experimental rigs, data acquisition, and processing approaches, etc. are performed, which are then implemented in the large TAD-2 wind tunnel.

The speed and the static pressure installations along the flat plate were measured respectively using a Pitot tube and a differential manometer connected via capillary tubes.

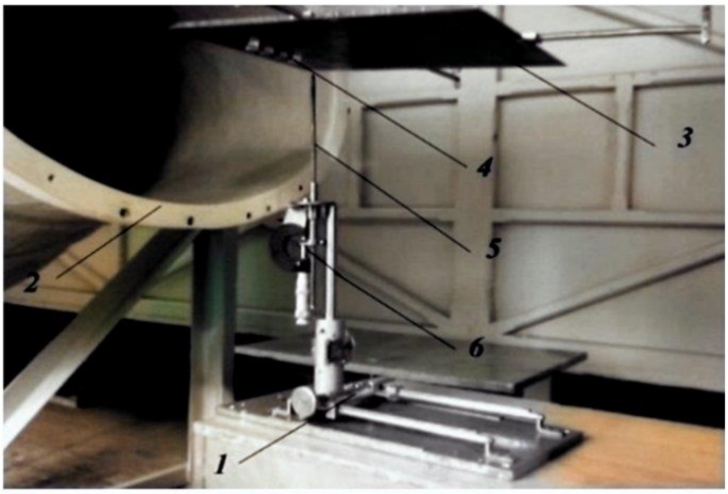


Figure (1): Experimental setup.
1. Coordinate device along the x-axis; 2. Wind tunnel; 3. Flat plate; 4. Vortex generators; 5. Total pressure sensor; 6. Coordinate device along the y axis

A flat plate with dimensions (7 mm thickness, 270 mm width, and 400 mm Length), as shown in (Figure 2). The position of (VG) fixed on a flat plate at a distance from the front edge 40 mm.

Figure (2): Coordinate device and sensor unit.

An experiment was carried out to determine the velocity profile in a turbulent boundary layer after the corresponding vortex generator. Using a coordinate device, the total pressure sensor was located at a certain distance from the plate surface and measured the instantaneous values of the velocity in this section. The first point was always 0.25 mm from the plate surface.

The location of the generators on the plate is shown in (Figure 3.b), while the general view and geometric parameters are shown in (Figure 4), the experimental parameters are shown in the (Table 1). Preliminary studies have enabled us to choose the type and size of vortex generators, which allowed getting the minimum thickness of the plate boundary layer. The next stage of experimental research is to account for the frontal drag mutual effect of its modifications in the thickness of the boundary layer while depending on the combination of geometric parameters vortex generators.

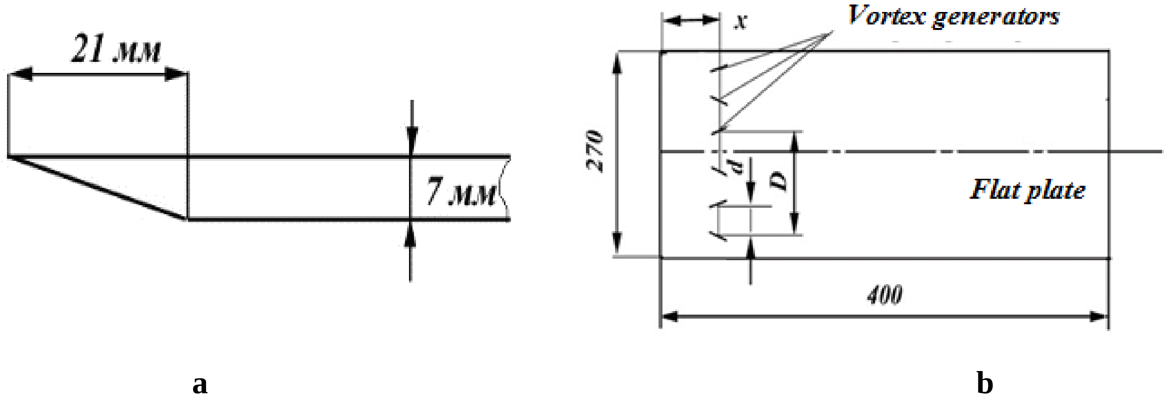


Figure (3): The geometrical dimensions of a flat plate and the layout of vortex generators.

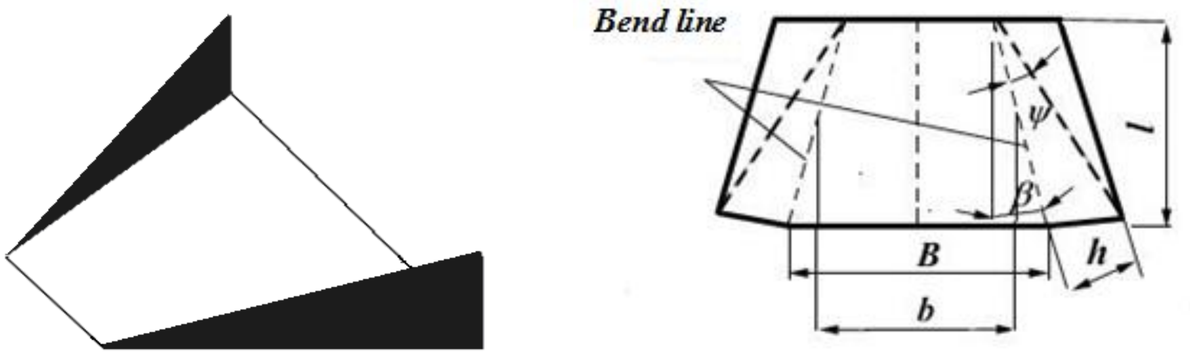


Figure (4): Types and geometric parameters of vortex generators used in experimental research a: shape of VG b: The main dimensions of VG.

Vortex generators can be described by the following geometrical dimensions: h - wall height; b- is the length of the working part; β- wall tilt angle; d - is the distance between the walls of the vortex generator. Analysis of works **(Gissen *et al*., 2011; Lin 1999; Li *et al*., 2011)** showed that the values of these parameters are defined by clear boundaries and there are certain relationships between them.

Table (1): Geometric parameters of the study vortex generators.

The researched VG	Parameters								
	x, мм	*h, мм*	*l, мм*	*D, мм*	*d, мм*	*B, мм*	*b, мм*	*β,°*	*ψ,°*
VG№ 1	60	4	13.6	46	14	19	10	20	16.4
VG № 2	60	4	21	41	15	23	7	20	20
VG № 3	60	6	18	48	14	19	12	15	–
VG № 4	60	3.5	18	48	12	19	12	15	–

THE METHODOLOGY OF THE EXPERIMENTAL RESEARCH

From the beginning of the experiment, it was calculated the change in the thickness of the boundary layer starting from the front edge of the flat plate. A speed of flow in the working part of the installation in this experiment was $V_\infty = 33$ м/с, which corresponded to a Reynolds number Re = $0.898 \cdot 10^6$. The results of the experiment were compared with the obtained that of analytically for a flat plate, where the following relations were used in calculating the thickness of the boundary layer.

The results of the experiment were compared with the obtained that analytically for a flat plate, where the following relations were used in calculating the thickness of the boundary layer.

– For a laminar boundary layer

$$\delta_л = 4.64 \cdot \sqrt{\frac{x \cdot \nu}{V_\delta}} = \frac{4.64 \cdot x}{\sqrt{\mathrm{Re}_x}}, \qquad (1)$$

– For a turbulent boundary layer

$$\delta_T = 0.37 \cdot \sqrt[5]{\frac{x^4 \cdot \nu}{V_\delta}} = \frac{0.37 \cdot x}{\sqrt[5]{\mathrm{Re}_x}}. \qquad (2)$$

Based on the geometric characteristics of the vortex generator № 3 parametric studies were carried out a series of vortex generators, in which for the same values of the parameters ($\overline{D} = const$, $\overline{L} = const$, $\beta = const$, $\psi = 0°$) the height of the generator was changed $\bar{h} = \frac{h_i}{b}$, parameter $\bar{d} = \frac{d_i}{b}, \bar{\delta} = \frac{\delta_i}{\delta pl}$, Where h_i, $d_i \delta_1$– absolute current values of the indicated values, b – chord of plate δpl thickness of the boundary layer of an isolated flat plate.

Geometric parameters data of vortex generator are given in the (Table 2).

Table (2): Geometric parameters of the tested samples of vortex generators.

№п/п	$\bar{h}$	$\bar{d}$	$\bar{L}$	β°
VG	0	0	0	0
1	0.0075	0.035	0.045	15
2	0.0150	0.045	0.045	15
3	0.0175	0.055	0.045	15
4	0.0225	0.070	0.045	15

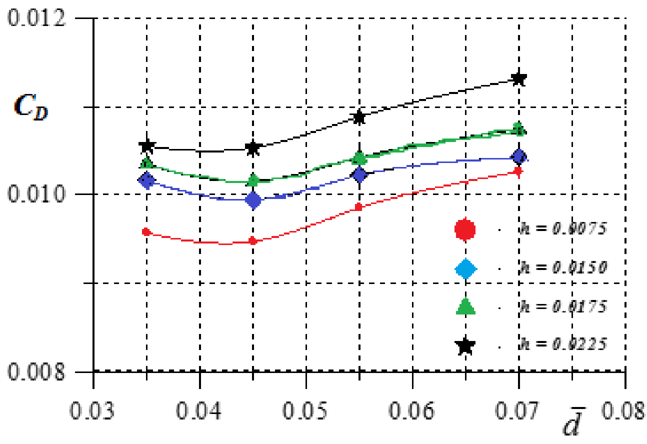
As a result of this research was obtained the relation between drag coefficients and the thickness of the boundary layer from above 32 combinations of vortex generators barometers.

RESULTS

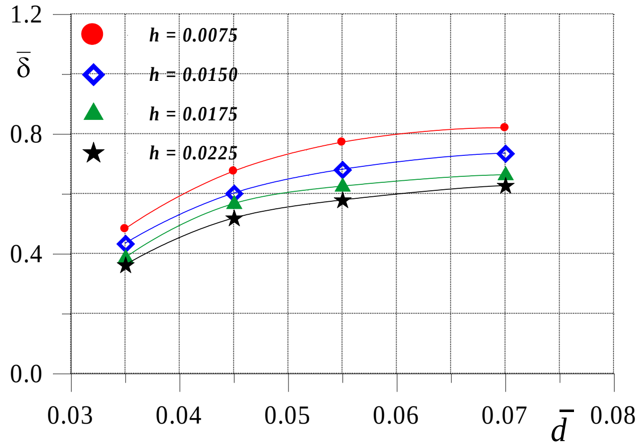
The influence of the geometric characteristics of the vortex generators on the drag of a flat plate and the thickness of its boundary layer is given in the (Table 3 and 4) and also presented in the form of graphical methods (Figures 5, 6, 7 and 8).

Table (3): Characteristics of Vortex Generators $\bar{L} = const$ **,** $\boldsymbol{\beta}$ **= 15°**

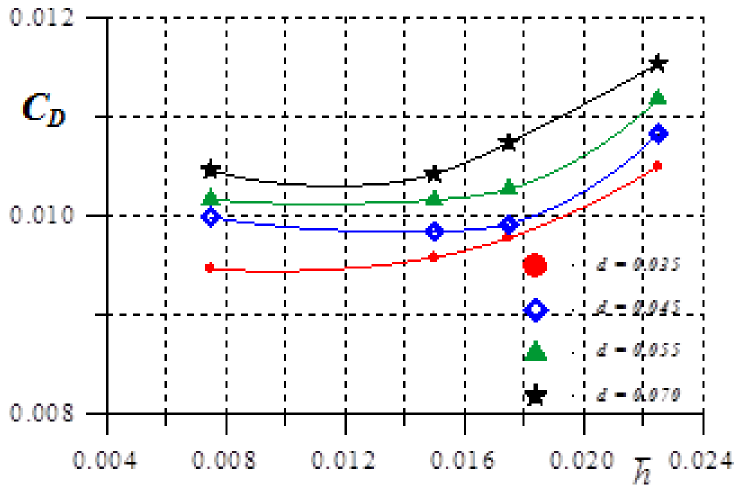
№ п/п	$\bar{h}$	$\bar{d}$	CD	$\bar{\delta}$	$\bar{C}_D$
VG	0	0	0.00918	1.00	1.000
1	0.0075	0.035	0.00957	0.48	1.043
2	0.0075	0.045	0.00947	0.67	1.032
3	0.0075	0.055	0.00985	0.77	1.073
4	0.0075	0.070	0.01026	0.82	1.118
5	0.0150	0.035	0.01017	0.43	1.108
6	0.0150	0.045	0.00994	0.60	1.083
7	0.0150	0.055	0.01022	0.68	1.113
8	0.0150	0.070	0.01042	0.73	1.135
9	0.0175	0.035	0.01035	0.38	1.127
10	0.0175	0.045	0.01015	0.57	1.106
11	0.0175	0.055	0.01042	0.62	1.135
12	0.0175	0.070	0.01074	0.66	1.167
13	0.0225	0.035	0.01055	0.36	1.149
14	0.0225	0.045	0.01153	0.52	1.256
15	0.0225	0.055	0.01188	0.58	1.294
16	0.0225	0.070	0.01131	0.62	1.232
17	0.0075	0.035	0.00947	0.49	1.032
18	0.0150	0.035	0.00958	0.60	1.044
19	0.0175	0.035	0.00978	0.48	1.065
20	0.0225	0.035	0.01050	0.49	1.144
21	0.0075	0.045	0.00999	0.53	1.088
22	0.0150	0.045	0.00984	0.64	1.072
23	0.0175	0.045	0.00992	0.52	1.081
24	0.0225	0.045	0.01083	0.54	1.179
25	0.0075	0.055	0.01017	0.58	1.108
26	0.0150	0.055	0.01016	0.70	1.107
27	0.0175	0.055	0.01027	0.58	1.119
28	0.0225	0.055	0.01118	0.59	1.218
29	0.0075	0.070	0.01046	0.64	1.139
30	0.0150	0.070	0.01042	0.76	1.135
31	0.0175	0.070	0.01074	0.64	1.170
32	0.0225	0.070	0.01154	0.65	1.257



Figure(5): Dependences of the coefficient c_{x0} on the parameter $\bar{d}$.



Figure(6): Dependences of the relative thickness of the boundary layer $\bar{\delta}$ on the parameter $\bar{d}$.



Figure(7): Dependences of the coefficient c_{x0} on the parameter $\bar{h}$.

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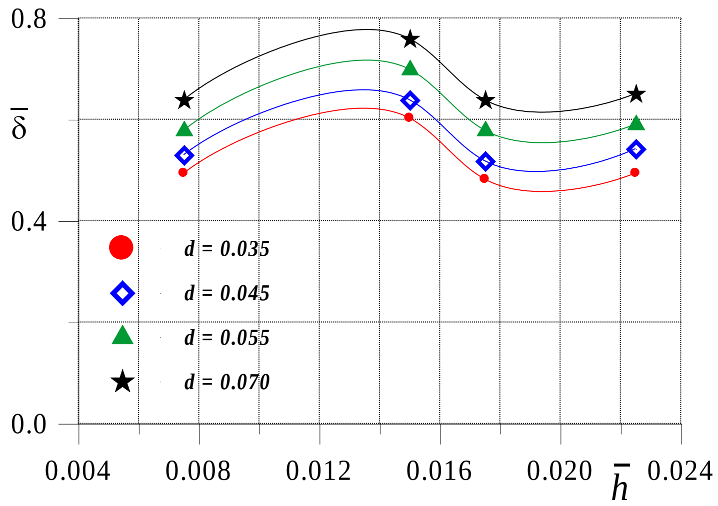
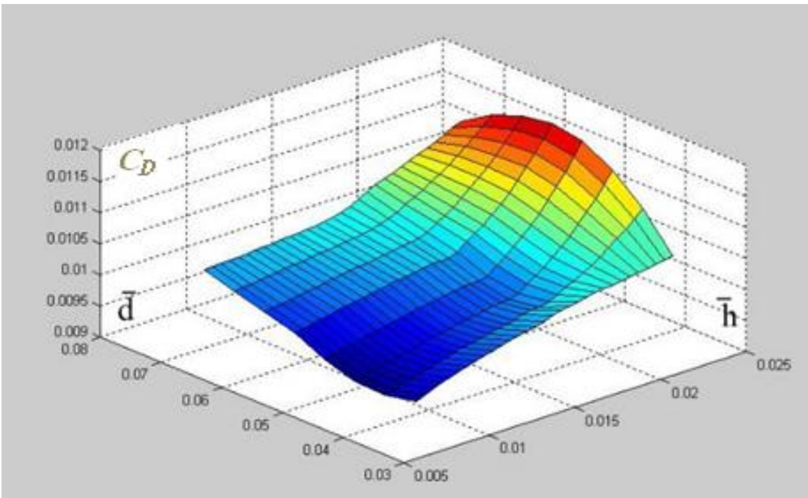


Figure (8):. Dependences of the relative thickness of the boundary layer $\bar{\delta}$ on the parameter $\bar{h}$.

In case of the constancy of the parameter value $\bar{d}$ and an increase in the relative parameter $\bar{h}$ observed a reverse picture (Figure 8). Have also been built three-dimensional graphic dependencies of the above parameters, which are shown in (Figure 9).



Figure(9): Change in the plate drag coefficient with the vortex generators depending on the parameters $\bar{d}$ and $\bar{h}$.

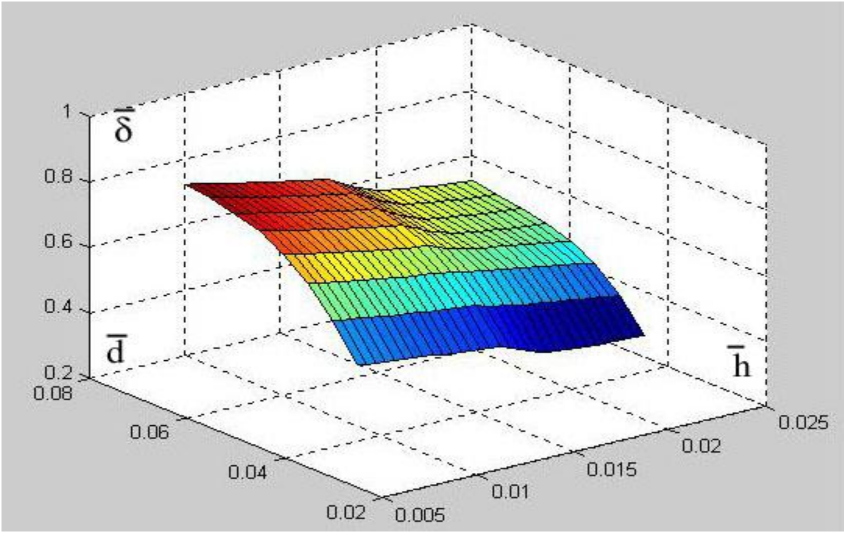


Figure (10): Change in the thickness of the plate boundary layer with vortex generators as a function of the parameters $\bar{d}$ and $\bar{h}$.

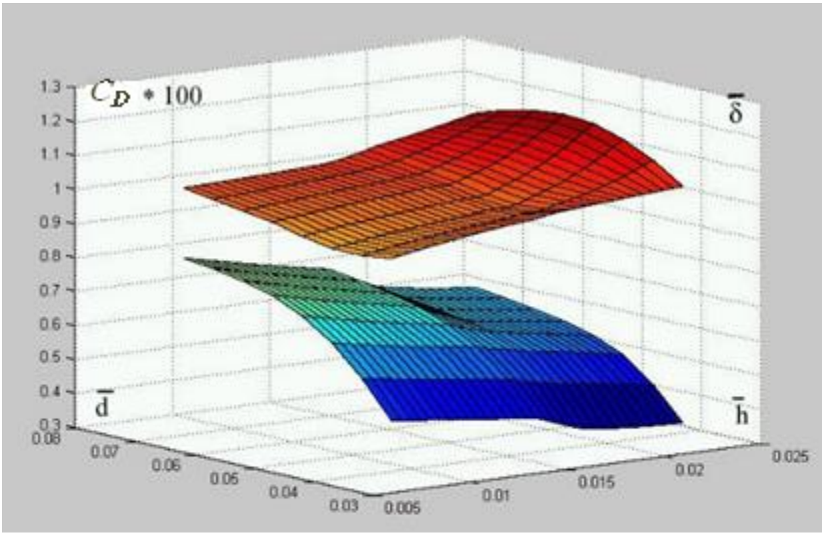


Figure (11): The change in the drag coefficient and the thickness of the plate boundary layer with the vortex generators as a function of the parameters $\bar{d}$ and $\bar{h}$.

The analysis of the figures shown is quite complex. So the result in (Figure 10), clearly shows the region in which advisable to choose the geometric characteristics of the vortex generators. In this range, drag not high enough, but decreasing the thickness of the boundary layer will allow improved aerodynamic stall characteristics of the aircraft and its parts.

Drag coefficients C_D are increased with the increasing of the height of the generators in all cases, and the minimum thickness of the boundary layer in the range of $\bar{h} = 0.018 \ldots 0.022$. An analysis of the research results showed in (Figure 11) that the smallest thickness of the boundary layer is observed with the value of the parameters $\bar{d} = 0.035$ and $\bar{h} = 0.018$ While the smallest drag is observed at $\bar{h} = 0.0075$, $\bar{d} = 0.035$. As the thickness of the boundary layer is decreased, this will give more an additional drag, which is performed by vortex generators. This is because then less thickness of the boundary layer by that, the vortex generator takes up more energy from the external stream flowing around the plate.

CONCLUSIONS

Using the «MATLAB-9.6» program a relationship between drag coefficients and the relative thickness of the boundary layer has obtained the results of the analysis may give a very complex relationship. At the same time, there is a region in which it is useful to choose the geometric characteristics of the vortex generators. In this region, the drag not high, and the relative decrease in the thickness of the boundary layer due to the interaction of the vortex generators with the boundary layer of the plate allows them to be used for stalling aerodynamic characteristics of the parts of the aircraft and the aircraft generally.

RECOMMENDATIONS

i. An experimental setup has been created that makes it possible to study the effect of VGs characteristics of the boundary layer on a flat plate. These results can be used and applied to wing profile modelsto study the effect of VGs measurements onseparation points.
ii. Has been studied triangle shapeVGs it is possible to change the shape of VGs to a rectangleand make a comparison between them.

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