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EXPERIMENTAL DETERMINATION OF AERODYNAMIC CHARACTERISTICS OF THE PLANE'S WING WITH THE VOLUME GENERATORS OF WHIRLWINDS ON THE FRONT EDGE

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Abstract

This paper is devoted to the results of studies in a wind tunnel model aircraft mounted with the vortex generators on the wing leading edge. The article presents away to improve the aerodynamic characteristics with vortex generators on the leading edge in the direct flow. It is shown that the vortex generators increase the lift force and the critical angle of attack due to the impact of large-scale vortices on the flow separation. Experimental data of studies of the wing in the wind tunnel showed rationality of use of volume generators - there usage enlarges the range of flight angles of attack and significantly increases lift-to-drag ratio.
Keywords: vortex generators, wind tunnel, angle of attack, lift-to-drag ratio, lift force, pitching moment.

1. INTRODUCTION

The aviation industry is looking for new solutions to improve the aerodynamic and flight characteristics of the aircraft. One of the directions of their development is the organization managed vortex flow around the wing. Using the vortex generators can improve some performance characteristics of aircraft, the use of thicker wings, more fuel capacity. The use of vortex generators increases the critical angles of attack and the maximum lift coefficient, which in turn expands the operational range of angles of attack. This significantly increases the flight safety [1, 2].

We investigated experimentally in the wind tunnel the model of aircraft which is equipped with a three-dimensional wing with vortex generators mounted on the front edge [3]. Experimental study of aerodynamic characteristics of aircraft models with volume vortex generators were carried out in a wind tunnel AT-1 Research Institute of Aviation (fig. 1). The main object of experimental research in the wind tunnel is aerodynamic interaction of model airplane's wing equipped with vortex generators with volume air flow. We considered three options for the wing: a wing without vortex generators (option №1, figure 2); a wing with large vortex generators (option number 2, and figure 3); a wing with large and small vortex generators (option 3, figure 3b). A scale model for experimental studies was made with bulky vortex generators (figure 2, 3). The model was made of polyurethane foam, its surface treated and painted white (figure 4) [5, 6].

Fig. 1. Wind tunnel AT-1 Research Institute of Aviation [Lemko; 2010]

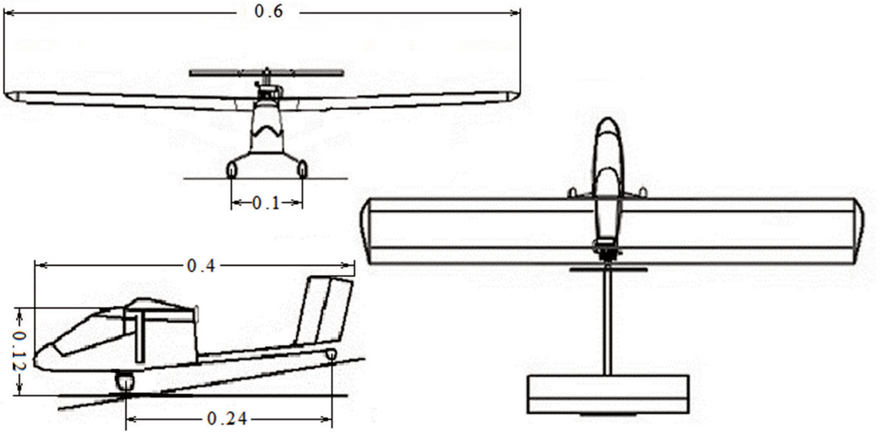

Fig. 2. Aerodynamic scheme of large-scale model of the plane [6]

Vortex generators represent the body of rotation (fig. 3 *a*, *b*) [6].

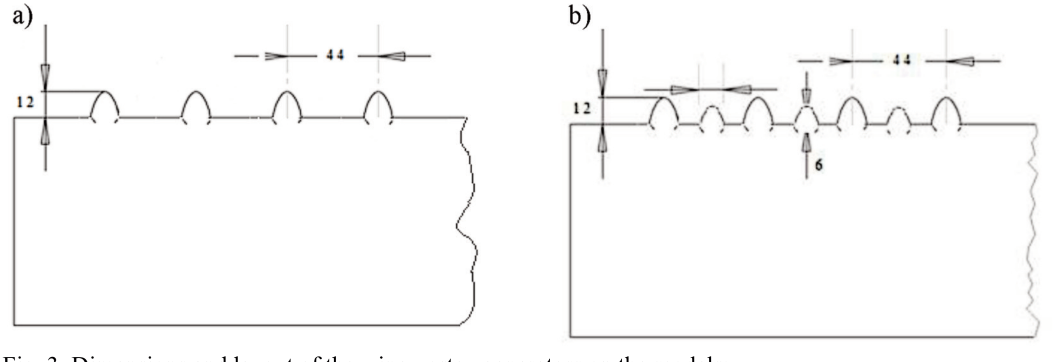

Fig. 3. Dimensions and layout of the wing vortex generators on the models:
a) – wing with large vortex generators; b) – wing with large and small vortex generators [6]

The distance between the large vortex generators is 44 mm. Height of large vortex generator h = 12 mm, diameter D = 8 mm, respectively, a small vortex generator h = 9 mm, D = 6 mm. The distance between a pair of large and small generators is 22 mm.

Figure 4 a, b show photographs of aerodynamic models for the wind tunnel tests.

a)

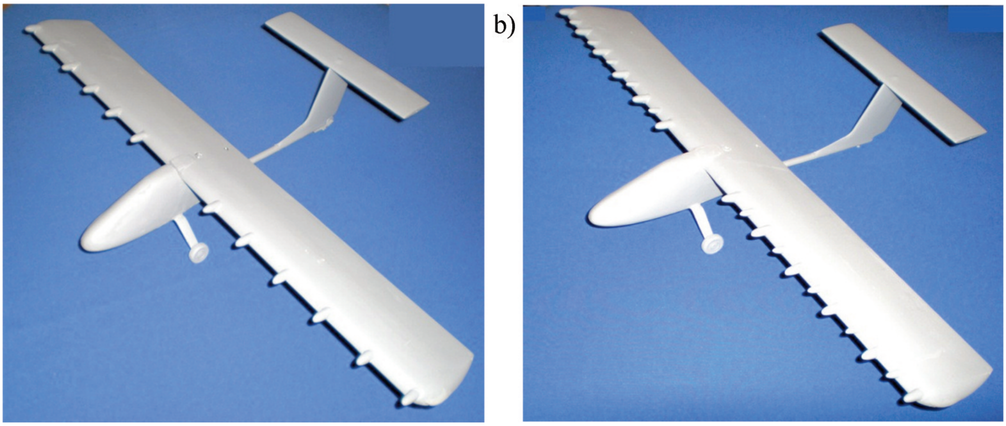

Fig. 4. The aerodynamic model with two types of volume vortex generators:
a) - with the big wing vortex generators (№2); b) - a wing with large and small vortex generators (№3). [Moldchyk; 2013]

2. THE TECHNIQUE OF THE EXPERIMENT

The model was established on the aerodynamic balance using special holders (fig. 5) for determining the aerodynamic forces and pitching moment when changing the angle of attack in accordance with the program of experiments.

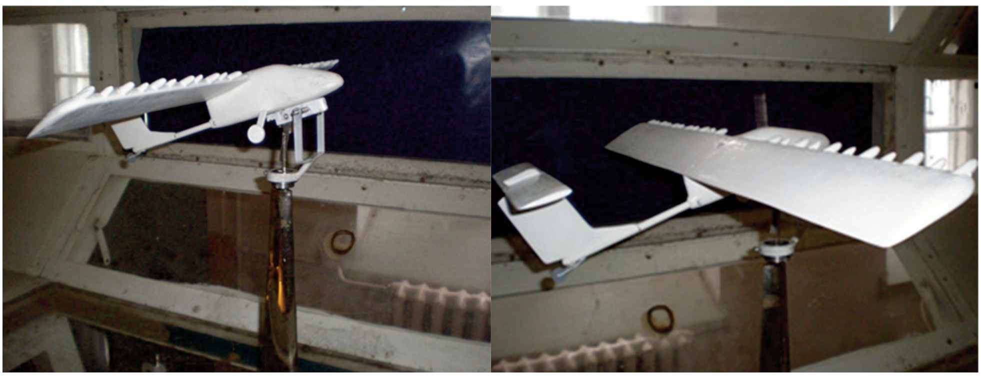

Fig. 5. Aircraft model for the holder to determine the relations C_L, $C_D = f(\alpha)$ [Moldchyk; 2013]

Before the experiment started was made a test trial of the model was made, which was determined by depending zero-lift drag coefficient C_{D0} from flow speed (Reynolds number) and determined the speed range of automodel conditions, where drag coefficient C_{D0} changed insignificantly. In this experiment, flow speed in test section of wind tunnel was set in the range $V_{ts} = 5 \div 30$ m/s. This speed range corresponded to the Reynolds number range $Re = 0.04 \div 0.2210^6$ (Reynolds number calculated by MAC of model). In fig. 6 is shown depending model zero-lift drag coefficient from model Reynolds number (flow speed) in test section of the wind tunnel.

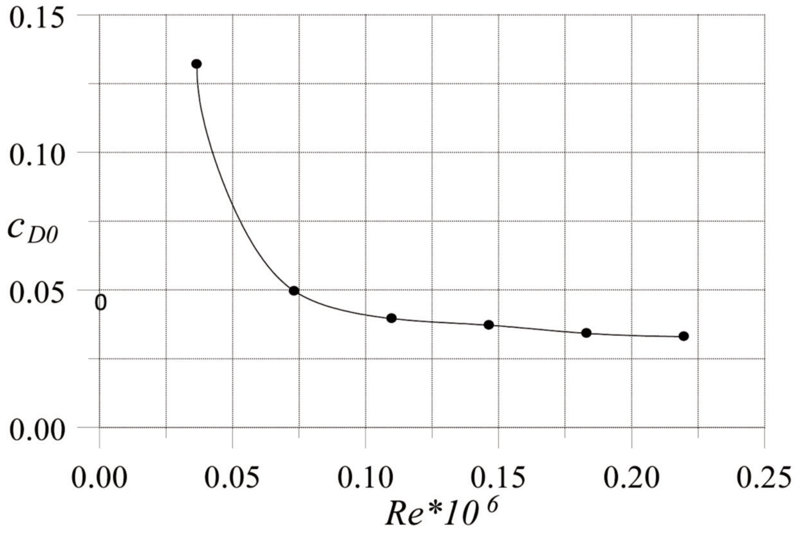

Fig. 6. Dependence $C_{D0}=f(Re)$

As shown in the figure, at a speed more than 26 m/s, which corresponds to the Reynolds number $Re = 0.210^6$, it further increases virtually no effect on the value of the model drag coefficient. Based on this, all aerodynamic characteristics in further experiments determined at test section flow speed $V_{ts} = 26…30$ m/s.

C_D and C_L coefficient determined in flow coordinate system $Ox_a y_a z_a$, Ox_a axis are collinear to flow speed vector, axes Oy_a and Oz_a orthogonal to Ox_a.

C_M coefficient determined in body-fixed coordinate system *Oxyz*, *Ox* axis coincides with the wing central chord. Origin of coordinate system placed on wing central chord at point (nominal CG of aircraft), corresponding to 0.432 $\overline{c}$ of wing.

Reference values for aerodynamic coefficients:

– wing area $S = 0.048$ m^2 for all coefficient;

– base wing MAC $\overline{c} = 0.08$ m for C_M coefficient.

Experiments were made according to the program of investigations of integral and moment aerodynamic characteristics of the model with vortex generator (VG), shown in Table 1.

Tab. 1. Program of investigations of integral and moment aerodynamic characteristics of model with vortex generator

3. RESULTS OF EXPERIMENTAL INVESTIGATION AND IT ANALYSIS

Results of experiment represented as summary table 2 and graph are shown in figures 7÷10.

Tab. 2. Aerodynamic characteristics of models with different variants of vortex generator

№ of variant	C_{L_α}, 1/°	C_{Lmax}	α_0, °	α_{crit}, °	max (L/D)	C_{D0}	C_{M0}	C_{M_α}, 1/°
1	0.077	1.36	1.7	18	12.58	0.0285	0.18	– 0.04
2	0.077	1.35	1.6	20	12.43	0.0362	0.20	– 0.04
3	0.077	1.42	0	22	13.34	0.0300	0.22	– 0.04

Fig. 7. Dependencies $C_L = f(\alpha)$

Fig. 8. Dependencies $C_D = f(C_L)$

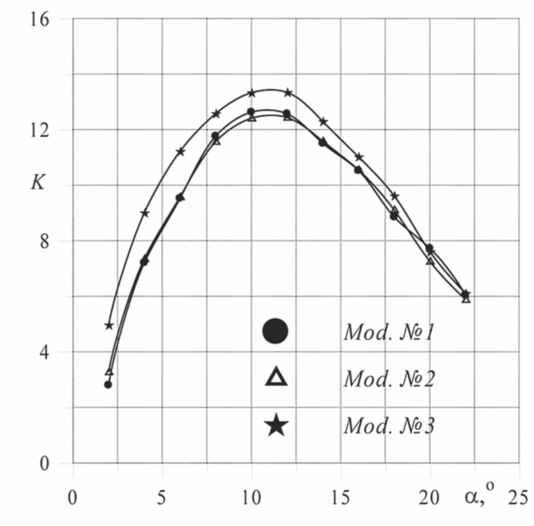

Fig. 9. Dependencies $K = f(\alpha)$,

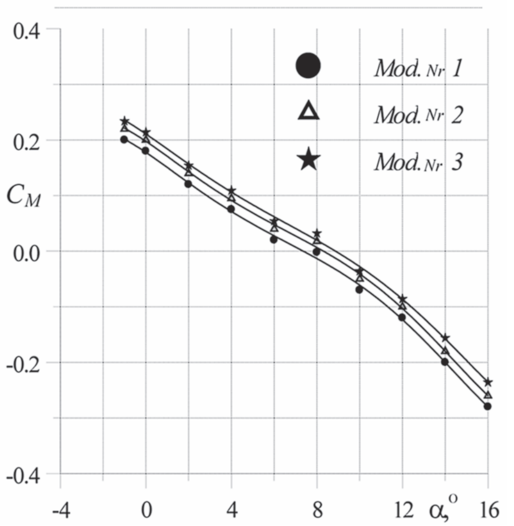

Fig. 10. Dependencies $C_M = f(\alpha)$

Based on the obtained experimental data was conducted a calculation of aerodynamic coefficient of forces and moments, which affect model in airflow.

The most important result, obtained during experimental investigation to determine lift, drag and longitudinal stability characteristics is shown in table 2.

Lift force coefficient

Analysis shown in fig. 7 comparative dependencies $C_L = f(\alpha)$ demonstrated, that lift curve slope on liner part of curves for all explored variants are in average $C_{L_\alpha} \approx 0.077$. This indicates that vortex generator small affect on lift performance of models. Curves for all explored models insignificantly shifted left, decrease zero-lift angle of attack α_0.

Peak value of maximum lift coefficient $C_{Lmax} \approx 1.42$ obtained for model №3. In this case achieved maximal, compared with other variants, critical angle of attack ($\alpha_{crit} \approx 22$), and zero-lift angle of attack corresponds to $\alpha_0 \approx 0$.

Analyze of changing lift coefficients from angle of attack for two another explored variants allows to draw a conclusion that vortex generators of model №3 increase the critical angle of attack α_{crit} на ≈ 21 % and coefficient of the maximum lift C_{Lmax} на 3%...3.5%.

Thus, vortex generators expand the range of the flight angle of attacks in comparison with model №1 without vortex generators, and with model №2, which is intermediate.

Drag coefficient

We will analyze the nature of change of resistance coefficient of the model on nature of course of polars now ($C_D = f(C_L)$) (fig. 8).

For the airplane model without vortex generators the coefficient of front resistance with C_{D0} corresponds to the value of 0.028. Polars wing of all models have the classic look. Further changes in the flow curve $C_D = f(C_L)$ for large angles of attack due to the reorganization of the spatial flow on the upper surface of the wing are due to the interaction of the vortex of the wing, with vortices trailing from the generators [6].

Lift-to-drag ratio

The aerodynamic quality of the aircraft is one of the main indicators of excellence aerodynamic configuration of the aircraft. Maximum aerodynamic efficiency reaches at angles of attack $\alpha_{me} = 10°\ldots12°$ for all models (fig. 9). For model №3 maximum aerodynamic efficiency corresponds to the value max*(L/D)* ≈ 13.34 (fig. 8…9). Increase the maximum aerodynamic efficiency is due to the increase in the area of the wing with the unseparated flow in the presence of vortex generators at equal angles of attack.

Longitudinal momentum characteristics

As you can see from fig. 10, the dependence of the longitudinal moment $C_M(\alpha)$ close to the linear portion of the curve $\alpha = 1°\ldots+10°$.

With further increase of the angle of attack, resulting in enhancing the effect of spatial flow around a wing slope $C_M(\alpha)$ increases slightly. Longitudinal moment coefficient C_{M0} from 3 models from 0.18 to 0.22, respectively. The derivative of pitching moment C_{M_α} amounts to – 0.04, and the degree of longitudinal static stability of the models under consideration at a given alignment ($\bar{x}_{c.g.} = 0.278\%$) amounts to $\dfrac{dC_M}{dC_L} = 0.074\,\bar{c}$.

So, the installation of vortex generators increases the coefficient of linear pitch moment on the angle of attack, without changing the pro-longitudinal static stability.

4. CONCLUSIONS

1. The weight of research with established models of aircraft generators vortices-ray showed an increase in the critical angle of attack of 18° to 22° for the model №3. Analysis of changes in coefficient of lift of the angle of attack of the models leads to the conclusion that the vortex generating installation model №3 increases the critical angle of attack on α_{crit} на ≈ 21% and a maximum lift coefficient C_{Lmax} 3% ... 3.5% as compared with other models.
2. Polars wing all models have the classic look. Changing the flow curve $C_D = f(C_L)$ for high angles of attack due to the reorganization of the spatial flow on the upper surface of the wing due to the interaction of the vortex of the wing, with vortices trailing from the generators.
3. Increase the maximum aerodynamic efficiency is due to the increase in the area of the wing with the unseparated flow in the presence of the vortex generators at equal angles of attack.
4. The results of this work can be used in the design of advanced aircraft.
5. The authors provide for the continuation of work connected with the change of the wing profile with generators vortices. The initial stages of work will be conducted on the basis and methodology set out in [7]. The results of computer simulations will allow you to schedule an experiment in a wind tunnel.

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DOŚWIADCZALNE WYZNACZENIE CHARAKTERYSTYK AERODYNAMICZNYCH SKRZYDŁA SAMOLOTU Z GENERATORAMI WIRÓW NA KRAWĘDZI NATARCIA

Streszczenie

Niniejsza praca poświęcona jest wynikom badań w tunelu aerodynamicznym modelu samolotu wyposażonemu w generatory wirów na krawędzi natarcia skrzydła. W artykule przedstawiono sposób na poprawę właściwości aerodynamicznych samolotu z generatorami wirów na krawędzi natarcia w bezpośrednim strumieniu powietrza. Wykazano, że generatory wirów prowadzą do zwiększenia siły nośnej i krytycznego kąta natarcia z powodu wpływu dużych wirów na rozdzielenie przepływu. Dane doświadczalne badania skrzydła w tunelu aerodynamicznym wykazały, racjonalność wykorzystania generatorów wirów. Wykorzystanie powiększa zakres kątów natarcia i znacznie zwiększa współczynnik siły nośnej.
Słowa kluczowe: generatory wirów, tunel aerodynamiczny, kąt natarcia, siła nośna.