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VORTEX FLOW WINGS

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Abstract

The paper presents an analysis of two alternative methods of influence on integral aerodynamic characteristics at large angles of attack with global flow separation. Firstly, the approach related to flat low-profile turbulators is reviewed. Then the leading edge vortex generators (LEVGs) of complex volumic shape are introduced as a more recent and efficient approach. It is explained how vortices generated at the upper surface shaped in a special way reach the trailing edge region and change conventional vortex pattern of the wing. The last section is devoted to a numerical modelling of vortex flow wings of unmanned aerial vehicles (UAVs).

Keywords: vortex flow wing; aerodynamic performance; post-stall angles of attack; turbulators; leading edge vortex generators; global stall, numerical modeling

1. Introduction

The development of aviation, in particular in unmanned aerial vehicles area, makes researchers look for new ways to ensure all-weather vehicle operation, correct operation of automatic flight control systems as well as to increase level of flights safety.

Nowadays the question of the protection of the aircraft from the global flow separation and the improvement of aerodynamic performance at high angles of the attack is solved by means of high-lift and flow control devices on the wing leading edge (slat, slot, droop nose, Krueger flap, turbulators, vortex generators) and wing trailing edge (flaps, vortilons, turbulators, turbulators, vortex generators) [1, 2]. There are also the active flow control methods for lifting surfaces by means of blowing, suction, pulsating jets, electromagnetic disturbances, etc. However, they do not find practical application due to significant energy costs [10].

The global stall on the aircraft wing is an unsteady vortex flow in a gradient flow (Fig. 1). As a result of the global stall, aerodynamic performance of a wing varies significantly. Flow separation on the suction side of a wing is accompanied by a decrease in the efficiency of the control surfaces (ailerons, flaps, elevators and rudders), which leads to loss of controllability and stability of an aircraft. Avoiding global flow separation allows to increase aircraft safety level, increase the range of flight angles of attack, contribute to wind gusts alleviation, and improve flight conditions in a non-stationary rough air.

In contrast to previous methods of boundary layer control by means of turbulators, recently more research works related to the study of flow around a wing with various vortex generators are being introduced. Such type of devices is characterized by the use of flow energy outside the boundary layer of the wing to form vortices along the wing chord in the form of an organized swirling flow. The longitudinal vortex generators (LVGs) are completely changing the conventional pattern of flow around wing under a global stall at post-critical angles of attack. The features of these flow control devices involve increase in critical angle of attack (α cr), elimination of static aerodynamic hysteresis, impact on distribution of lift coefficient and circulation along the wing and decrease in lift-induced drag due to the influenced sidewash. LVGs swirl the potential flow at the leading edge of the wing into a non-stationary screw vortex flow.

This work proposes an innovative concept of changing the pattern of flow around finite wing. At the post-critical angles of attack, transverse vortex is replaced by a non-stationary organized longitudinal vortex flow. The corresponding experiments were planned and partially realized. These experiments are aimed at verification of improvements in aircraft flight safety, UAVs piloting, aerodynamic performance of the wing and the empennage at post-critical angles of attack in rough air and during take-off and landing. Experimental investigation of flight performance in the post-critical flow regime will provide the necessary information for development of theoretical models of longitudinal vortex flow, and also create the necessary theoretical basis for the development of the theory of vortex influence on the wing and the creation of a series of vortex flow airfoils designed for UAVs, light and transport aircraft.

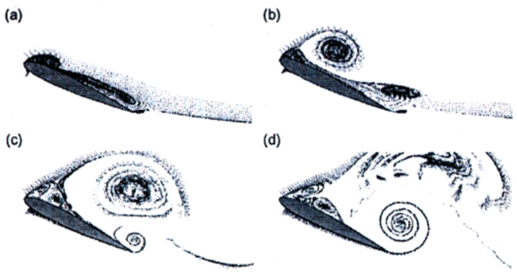


Fig. 1. Visualization of the global separation by means of numerical modeling performed on the section of the wing with NACA-0015 airfoil: a) commencement of the separation on the leading edge; b) vortex formation on the leading edge; c) the vortex separates from the leading edge and commencement of the vortex formation at the trailing edge; d) separation of the vortex from the trailing edge and the leading edge vortex breakdown [3].

2. Analysis of recent research and publications. Problem statement

Low-profile vortex generating turbulators and analysis of their effectiveness

Design of modern aircraft often employs low-profile vortex generating turbulators (VRTs) for a flow around a wing, a tail unit and a fuselage (Fig. 2).

The vortex formation from turbulators produces a positive effect on a small area because of its low energy intensity. Despite this fact, VRTs are widely used on modern aircraft. An example of their use is shown in Fig. 3.

In order to guide an airstream in vicinity of leading and trailing edges of the wing, the vortilons generating macrovortices are employed. Vortilons can have a different shape such as a streamlined, corrugated or plate-like shape.

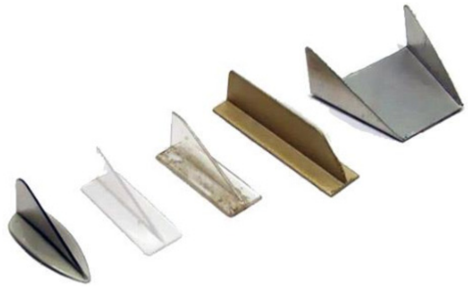


Fig. 2. Different types of low-profile vortex-forming turbulators

VRTs are used mainly on the aircraft wings. However, they can also be used on the airplane control surfaces and fuselage. VRTs are used to control local flows and eliminate the separation on the fuselage, nacelles, decreasing interference drag and hindering buffeting. They can also be used to enhance turbulent mixing increasing speed near the wall, which improves the capability of an airflow to overcome adverse pressure gradient and increased friction. Therefore, other things equal turbulent boundary layer separates further downstream comparing to laminar boundary layer [3].

This statement is the basis for using turbulent flow in order to control stall on lifting surfaces.In order to increase the control performance of the aerodynamic surfaces, they are installed just behind the leading edge. In practice, several rows of turbulators are used, which are installed along the chord of a wing. On a modern passenger aircraft Boeing 737 VRTs are installed in front of the separation zone in the middle of the wing and in front of aileron in order to improve its effectiveness, see Fig. 3.

Fig. 3. VRTs installed in front of an aileron and the separation zone (Boeing 737)

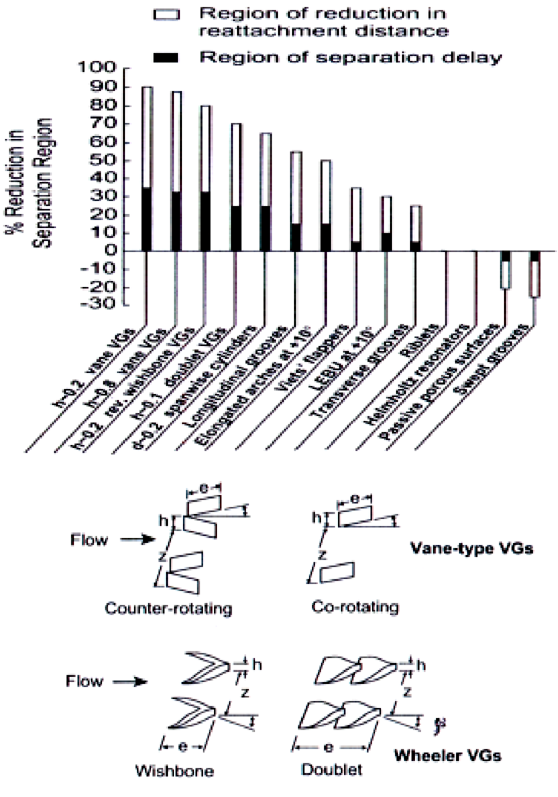
The successful application of low-profile vortex generators to prevent the development of a boundary layer separation depends to a great extent on the intensity and location of individual vortices in the region of a positive pressure gradient than on downstream boundary layer profile [4]. Vortex generators bring energy from the external flow to the boundary layer and are used mainly to prevent a separation of the flow that has not been separated yet. Their influence is evaluated by their participation in a flow mixing process and a formation of secondary velocity field downstream through the induced vortex structures [5, 6]. If the VRTs are placed properly with respect to flow field, then the spiral flow of fluid in a vortex causes the high-energy external flow to be involved in changing velocities profile in the boundary layer. [6]. Based on this fact, the use of vortex generators also leads to a decrease in the thickness of the boundary layer. A comprehensive overview of low-profile vortex generators for the flow separation control is presented in [7]. The different types of VGs and evaluation of their effectiveness are given in Fig. 4.

Modern vortex flow control methods for influencing flow around lifting surfaces at large angles of attack can be divided into passive and active methods (swirling flow by blowing air jets). The most widely used methods of passive influence on the structure of the flow are the techniques utilizing vortex generators located near the local separation zone with a height slightly bigger than thickness of the boundary layer of the VRTs.

The effect of VRTs has a positive influence on a quite limited area. This is the reason for using VRTs in several rows or enhancing a turbulence intensity of the boundary layer by means of devices, which yield higher vortex intensity such as vortilons.

Passive VRTs generates vorticity in the boundary layer, which is insufficient to eliminate flow separation along whole wing chord, especially at post-critical angles of attack.

The use of VRTs at the leading edge is dangerous from an ice protection point of view. It is possible that ice accumulates on the devices even during a thermal anti-icing systems operation on a leading edge of a wing. This is an another reason why it is most rational to use turbulators for delaying flow separation in front of ailerons, which ensures more efficient bank control by means of ailerons at high angles of attack.



(b) VG geometry and device parameters.

Fig. 4. Comparison of overall flow control efficiency for different VRTs geometries

However there is no available information regarding efficiency of such devices positioning in terms of increasing the critical angle of attack. It is a reasonable assumption that in the presence of a global flow separation from the wing leading and trailing edges in the form of large transverse vortices, the turbulators located in this way would be ineffective. To tackle the separation from the leading edge of the wing, the original solution would be to install VRTs on a wing slat. It is clear that VRTs in this case goes beyond the boundary layer.

For more pronounced vortex flow activation on the wing, vortilons are installed on the leading edge of the wing in the area of slat attachment.

Effective methods of using different types of turbulators and vortilons as a means of generating large longitudinal free vortices are being developed. Some of the prospective application areas of VRT involve aerodynamic interference and aerodynamic noise reduction. Nonetheless all techniques of using VRTs lead to an increase of approximately 20 drag counts in the drag coefficient.

The effectiveness of VRTs can be estimated by the area of influence. The most effective areas of impact are HPT type blades (Vane-typeVGs).

The results of investigation in the aerodynamic wind tunnel TAD-2 NAU on the VRTs performance at the post-critical angles of attack revealed that turbulators are limited by their area of influence, lead to complex nonlinearity behavior of aerodynamic characteristics, and an increase in lift coefficient does not exceed 0.1 [11]. Therefore, effectiveness of VRTs is not sufficient for tackling large detached vortices under global stall conditions.

At cruise angles of attack, VRTs tend to increase drag force. There is practically no influence of turbulators on downwash and induced drag. Paper [8] studies low Reynolds number flow around airfoils. It has shown a significant difference in the aerodynamics of low Reynolds numbers comparing to generally accepted theories developed for flow regimes corresponding to civil airliners cruise conditions. In order to improve wing performance at low Reynolds numbers, it is recommended to achieve a post-critical flow conditions while using turbulators in the form of a wire placed in front of the wing. The work presents the investigation results of Go-625 airfoil with turbulating wire, which is stretched in front of the leading edge. As a result of the optimal installation of the turbulator in front of the leading edge an increase in lift-to-drag ratio at small Reynolds numbers was achieved.

Wing strake is a leading–edge root extension (LERX) adjacent to a fuselage with a large sweep angle and an acute vortex generating leading edge of a special planform shape [11]. It has been proved that longitudinal vortices have a positive effect on aerodynamic performance at large angles of attack both in subsonic flow regime during landing and in the case of supersonic speeds, see Fig. 5. The study of the longitudinal vortices effect on wing aerodynamic characteristics was intensively carried out in 1970s.

In the paper by K. Fediaevskii [10], results of a study of delta wings with strake are given. It has been proved that the strakes efficiently increase lift force of low aspect ratio wing of modern supersonic fighter at large angles of attack.

Monograph [11] presents an investigation of longitudinal vortices generated by strakes. It was shown that under the influence of a longitudinal vortex the dilution on the wing increases as well as lifting force and the critical angle of attack.

At angles of attack of more than 14 degrees the vortex begins to collapse in the region of the trailing edge and the gradient of the lifting force decreases.

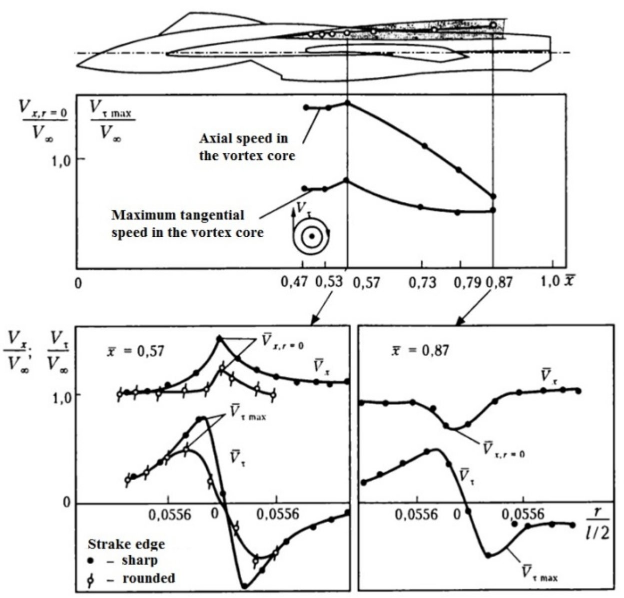


Fig. 5. Distribution of velocity in the vortex core on the wing of moderate sweep with a strake [11]

The vortices are limited in stability and length. The vortex destruction starts occurring when pressure in the vortex core rises. After the destruction, the vortex abruptly disintegrates and disordered perturbed turbulent flow appears. Fig. 6 depicts vortex pattern and the corresponding pressure coefficient distribution. This phenomenon is called "vortex breakdown".

3. Experimental investigation

For a more efficient impact on the global stall, it is proposed to use the vortex generators of a volumetric shape with strakes installed on a wing leading edge. They create a much more efficient vortex flow emerging from suction side. Previously performance of leading edge vortex generators (LEVG) was compared against turbulators [11-12]. The device performs more efficiently comparing to turbulators.

The study of vortex generators aerodynamic characteristics at large angles of attack was carried out at National Aviation University (NAU) in Kyiv in subsonic wind tunnel in static and dynamic modes of angle of attack variation. Vortex generators in the experiment are of symmetrical strakes shape, which follows the airfoil contour.

In static mode, aerodynamic studies of vortex generators at the leading edge of the wing were carried out in the UTAD -2 NAU wind tunnel. The experiment was conducted at speed of 30 m/s, Reynolds numbers of $2 \cdot 10^5$.

The wing model length is 0.4 m and width is 0.15m, which corresponds to a wing area of 0.06 m^2 and low aspect ratio of 2.5.

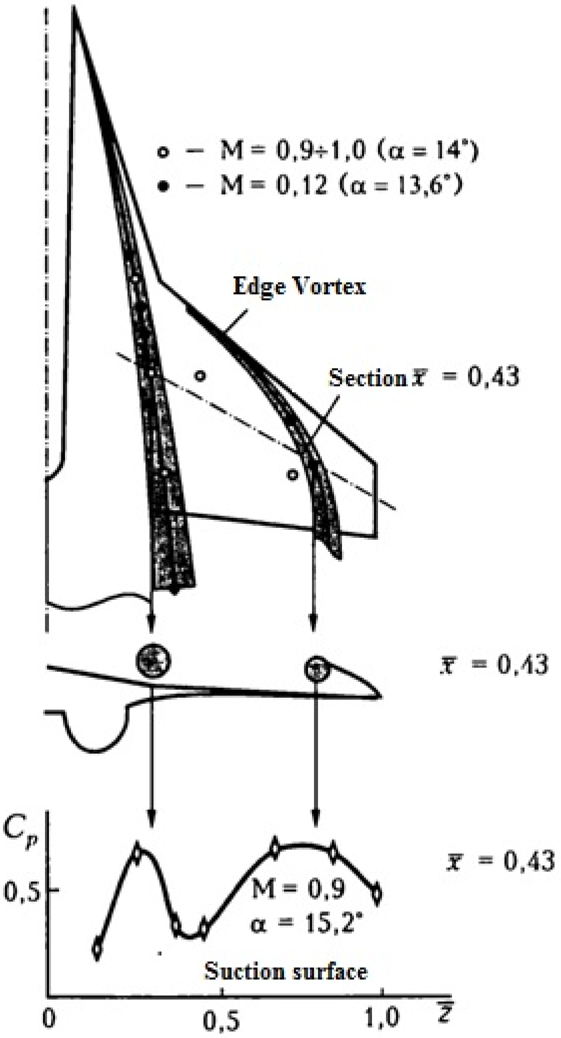


Fig. 6. The position of vortices on a wing of moderate sweep with a strake [11]

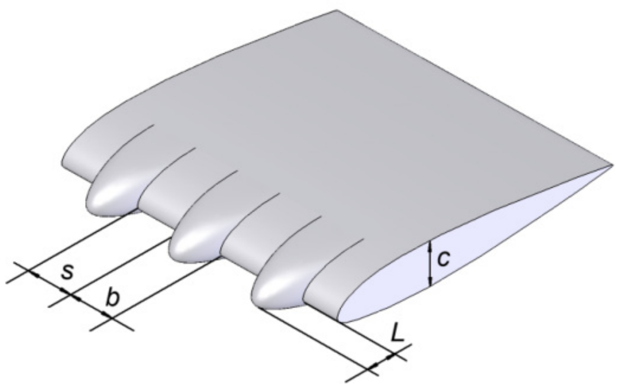


Fig. 7. A general view of vortex generators

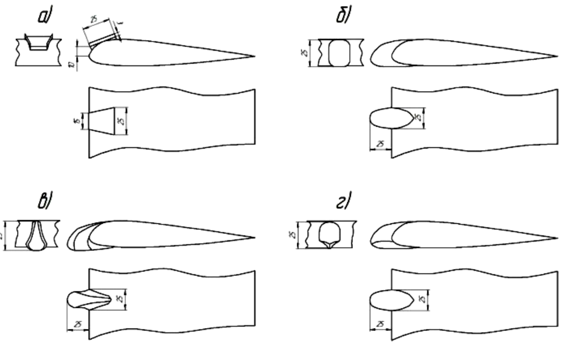


Fig. 8. Types of the tested flow control devices: a) trapezoidal turbulators; b) option 1 LEVGs; c) option 2 LEVGs; d) option 3 LEVGs

The investigation was done for symmetric vortex generators . The dimensions are depicted in Fig. 7. The ranges corresponding to b = 30-70% c, H = 20-60% c, s = 8-110% c were studied and optimal values were selected.

Lift coefficient and lift-to-drag ratio curves are depicted in Fig. 9 – 10. The analysis reveals that all types of the devices are more efficient in the area of post-critical angle of attack and up to 30 degrees comparing to a clean wing where the global flow separation occurs at 18°. The performance of vortex generators can be increased by optimizing shape and angle of the incidence. Higher efficiency of vortex generators can be attained by implementing variable angle of incidence.

The next tasks can be accomplished by means of vortex flow wings and empennage:

- Increase the critical angle of attack up to 50%, which guarantees flight safety in strong wind gusts (especially important for weatherproof UAV);

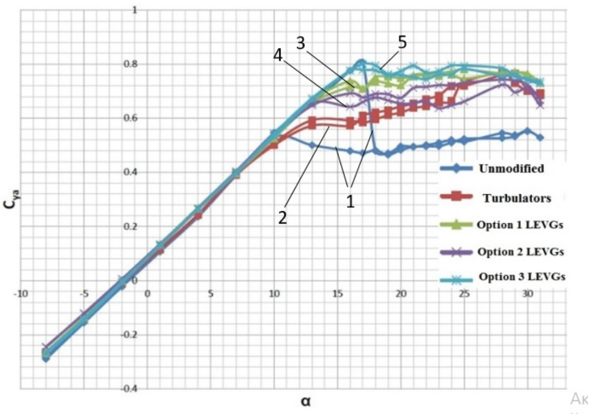


Fig. 9. Comparison of lift coefficient curves for all studied configurations
1 – Unmodified; 2 – Turbulators; 3 – Option 1 LEVGs; 4 – Option 2 LEVGs; 5 – Option 3 LEVGs;

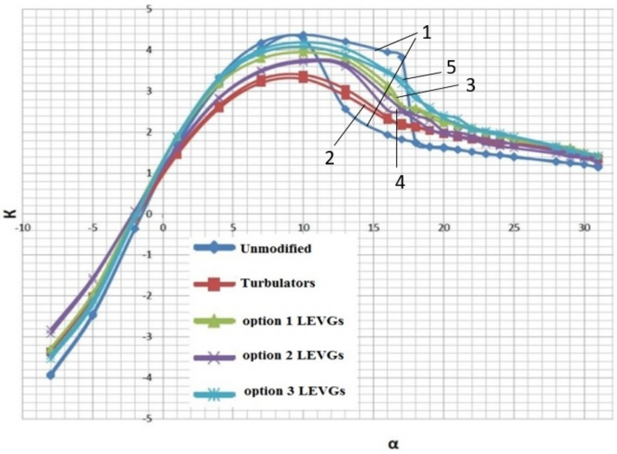


Fig. 10. Lift-to-drag ratio dependency for all studied configurations
1–Unmodified; 2 – Turbulators; 3 –Option 1 LEVGs; 4– Option 2 LEVGs; 5–Option 3 LEVGs;

- Eliminate aerodynamic hysteresis that simplifies piloting at critical angles of attack;
- Reduce dynamic loops of aerodynamics characteristics during unsteady oscillation motion of the wing;
- Reduce induced and vortex drag at high angles of attack;
- Exclude wing autorotation and aircraft spin at high angles of attack;
- Improve ailerons and rudders control characteristics;
- Eliminate wing trailing edge flutter;
- Improve flaps effectiveness;
- Improve the aerodynamic performance in rain and icing conditions;
- Eliminate the separation and reverse flow zones on helicopter blades;
- Improve stability of tiltrotor aircraft transition;
- Reduce interference drag between airframe structures;
- Improve stability and control of «canard» aircraft with vortex-active foreplane;
- Improve the effectiveness of horizontal and vertical tail;
- Stabilize the momentum characteristics of longitudinal and lateral motion of the aircraft;
- Improve takeoff and landing performance, expanding the exploitation range short takeoff and landing aircraft;
- Reduce the landing speed of the aircraft up to 10% or more.

4. Numerical simulation of flow around a wing with an asymmetric vortex generator

Modern capabilities of high-performance multiprocessor computing systems, which consist of an assembly of individual hardware components, allow aerodynamicists to solve the applied problems of non-stationary aerodynamics. One of the actual tasks is to determine aerodynamic characteristics of a vortex flow wing equipped with longitudinal vortex generators on the front edge. All-weather airplanes should, in the first place, be protected from dangerous wind gusts and remain stable and manageable in post-critical flight modes.

An efficient solution to the problems of aerodynamic performance enhancement of the wing with the vortex generators by the organized vortex structure of the flow is possible using Computational Fluid Dynamics (CFD) software packages.

In Ukraine, validation of post-critical aerodynamic characteristics using Ansys was carried at Dnipro University [13]. In the dissertation of Redchits D.A., an analysis was performed on the basis of the RANS method with SA, SARC and SALSA turbulence model. The analysis revealed that estimation of lift and drag force coefficients at small angles of attack is well in line with the experiment. However, at post-critical angles of attack such as 15˚, there is large discrepancy in the results for both the coefficient of lift and force comparing to the experimental value.

The choice of the turbulence model is crucial for the task of numerical modelling of organized vortex flow around a wing. It is precisely turbulence modelling that is the source of the biggest errors and requires extremely high computational costs. Turbulence model selection requires a valid approach on the user's side, which takes into account the physics of the considered flow.

The features of organized longitudinal vortex flow around a wing involves dramatic change of the flow around wing pattern at large angles of the attack , positive effects of the attached transverse vortices elimination, increase in the critical angle of attack, and elimination of static hysteresis of aerodynamic characteristics.

Due to the complexity organized vortex flow around wing simulation, it is clear that precise aerodynamic forces estimation would require extensive preliminary validation studies, high-fidelity grids and computational setup. As for the flow pattern analysis, it is expected that RANS modelling approach with corresponding grid and valid selection of turbulence model provides reasonable estimate. Detailed classification, guidelines and numerous numerical examples of the application of turbulent flow modelling methods are given in the books [14, 15].

This paper presents the numerical modelling results of the developed of the vortex (spiral) flow generated by the LVG obtained by means of RANS method with SST turbulence model in ANSYS software.

Due to the limited time for the certified software product and computer facilities use, the problem was simplified by investigating flow around a wing with only one vortex generator. The purpose of the investigation is to study kinematics of the longitudinal vortex and corresponding pressure and velocity fields. The lifting surface corresponds to a foreplane model of an unmanned aerial vehicle. Investigation of such control surfaces is important for improving the stability and controllability of UAV at high angles of attack under the influence of vertical wind gusts or control mistakes.

The studied foreplane model (Fig. 11) involves P-IIIA-15 airfoil with a maximum relative thickness *c*=15%, relative distance from the profile leading edge to maximal thickness location *xc*=0.25, maximum relative curvature *f*=4,572 %, relative distance from the profile leading edge to the maximum curvature *xf*= 0.25, tip chord of 0.145m, root chord of 0.245m, area of 0.1069 m^2, span of 0.55 m, aspect ratio $\lambda = 2.9$, sweep angle at the front edge of 10˚. The boundary conditions were set according to the angles of attack range of 6-20˚ and flow speed of 30 m/s.

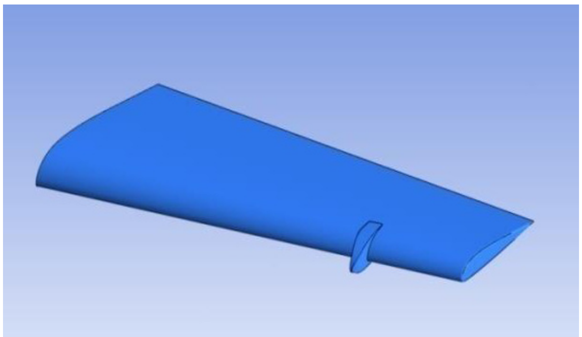


Fig. 11. Foreplane CAD model

Characteristics of LVG involve asymmetric shape; length corresponding to 15% of a chord, maximum width of 0.015 m; vortex generating surface of gothic shape. According to the TsAGI studies published in the monograph [11], the gothic shape of the vortex generating edge is the most efficient. The vortices created by sharp leading edge of a vortex generator, are more resistant to breakdown in a trailing edge region.

The results of the numerical modelling based on Navier-Stokes equations

The following quantities were studied:

- pressure distribution along the wing surface;
- visualization of the streamline of the vortex flow generated by LVG;
- velocity field in the wing region.

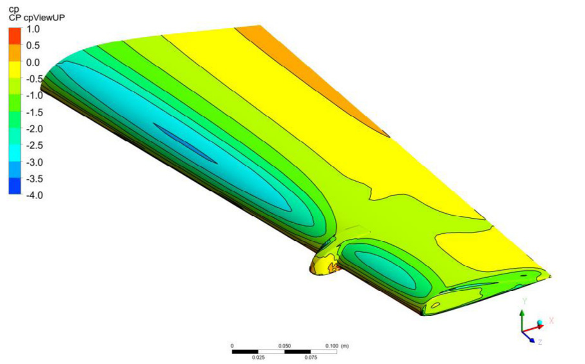


Fig. 12. Pressure coefficient distribution over the upper surface of the wing

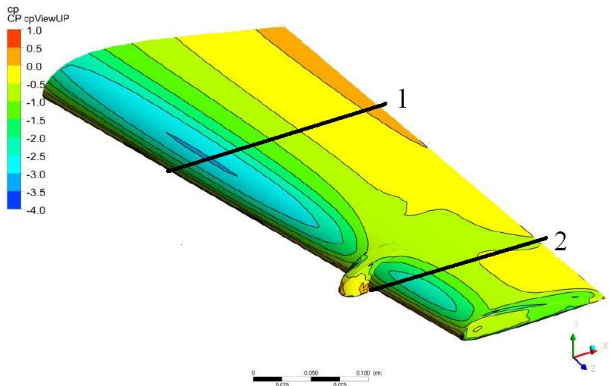


Fig. 13. Chord location corresponding to the pressure coefficient distribution chart

In order to study features of a vortex flow kinematics generated by LVG, structured grids for both an unmodified wing and a wing with a vortex generator were manually created in ANSYS ICEM. The size of the grid for the wing with a vortex generator is 3772538 elements. In order to improve stability and accuracy of a calculation, a rectangular computational domain corresponds to 30 chords lengthwise and 20 chords heightwise.

Fig. 12 shows the results of the calculation in terms of pressure distribution on the upper surface of the wing and device.

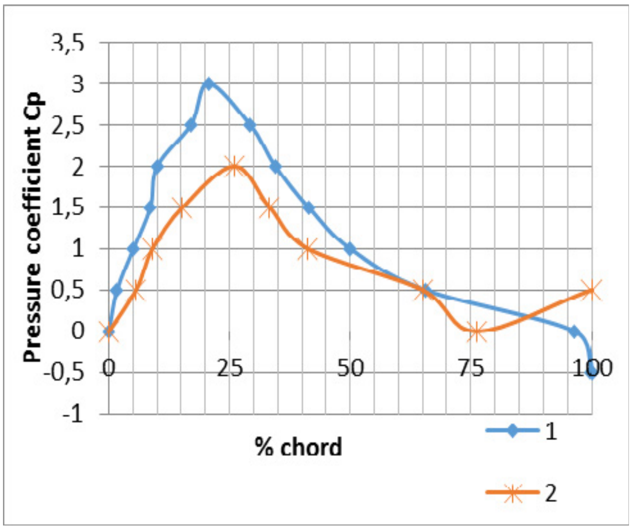


Fig. 14. Pressure coefficient distribution over the upper surface of the wing

Fig. 15 reveals that flow is accelerated from 55 m/s to 88 m/s in a flow around the leading-edge vortex generator.

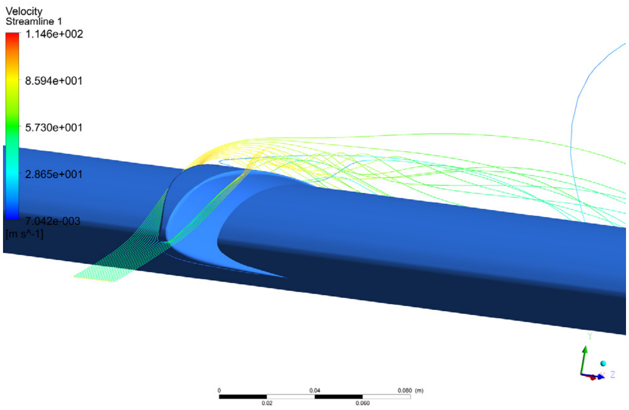


Fig. 15. Velocity magnitude variation in streamlines in the region of the leading edge of the wing with vortex generator (α = 16˚)

Visualization of two longitudinal vortices using streamlines is presented in Fig. 16. The right vortex is vortex generating edge of the LVG while the left vortex is formed as a result of the interference between the LVG and the wings. Due to high intensity, the right longitudinal vortex reaches the trailing edge of the wing and deviating from straight chordwise trajectory, due to the wing sweep.

Velocity magnitude in a vortex streamline of a flow around an airfoil is increased to 86 m/s from 30 m/s freestream velocity.

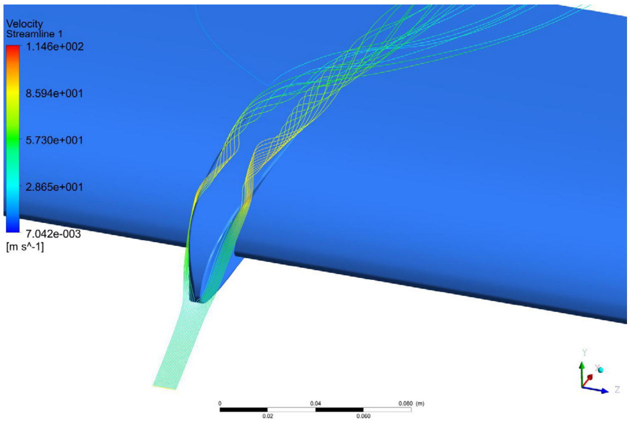


Fig. 16. Streamlines and velocity magnitude variation on the suction surface of a wing at α=16˚

The result of the experiment will serve as a basis for the design of updated LEVGs. The appearance of small parasitic vortices should be prevented while the main longitudinal vortex generated by each vortex generator should have sufficient intensity to reach trailing edge. Future studies will be aimed at creating a new optimal form of LEVGs taking into account all aspects of interaction between a wing and a device.

5. Conclusions

LVGs of an original shape with vortex generating surface of gothic planform shape were studied by means of numerical modelling. A model of UAV foreplane with a single LEVG was used for this purpose.

The investigated vortex generator changes the vortex structure of the flow around foreplane at large angles of the attack (α≈16˚) while at the angles of the attack α≤10˚, the effect is small. Thanks to volumetric curved shape, flow around vortex generator is significantly accelerated. It also generates a swirl in form of longitudinal vortex.

The longitudinal vortex reaches the foreplane trailing edge and prevents development of flow separation from the trailing edge. It also prevents a dynamic flow separation in a region of the foreplane leading edge. This leads to global stall elimination.

As a result of the simulation, a conclusion is made regarding LVGs geometry and the prevention of the development of parasitic vortices. The future investigations can concentrate on LVGs shape optimisation for new airfoils tailored to vortex flow.

References

[1] Issues in active flow control: theory, control, simulation, and experiment / S.S.Collis, R. D. Joslin, A. Seifert, V. Theofilis. // Progress in Aerospace Sciences. – 2004. – №40. – C. 237–289.

[2] ScottJ. WingVortexDevices / Scott. – 2005. Available at: http://www.aerospaceweb.org/question/aerodynamics/q0228.shtml.

[3] Larsen J. W. Dynamic stall model for wind turbine airfoils / J. W. Larsen, S. R. Nielsen, S. Krenk. // Journal of Fluids and Structures, – № 23 – 2007. – P. 959–982.

[4] P. Chzhen, Separation flow Moscow: Mir, vol.1, p.299. (in Russian)

[5] J. Johansen, N. N. Sorensen, etal. R.KNOW-BLADETask-2 report. AerodynamicAccessories // National Laboratory Rockslide Denmark October 2004.

[6] J. Johansen, N. N. Sorensen, etal. Know-blade Task-3.3 report. Rotor Blade Computations with 3D Vortex Generators// National Laboratory Rockslide Denmark January 2005.

[7] John C. L. Review of research on low-profile vortex generators to control boundary-layer separation / Lin John. // Progress in Aerospace Sciences. – 2002. – №38. – pp. 389–420.

[8] Schmitz F. W. Low-speed Aerodynamics. – Moscow: DOSAAF, 1963.– 58 p.

[9] Abbas F. M. Technique of the experimental determination of the effect of vortex generators on the aerodynamic characteristics of the wing at various angles of attack: dis. Cand. tech. Sciences: 05.07.01 / Abbas Fadil Mahmud - Kiev, 2008. – 172 p.

[10] K.K Fediaevsky, U.I. Konstantinov, I.B. Fedorova Experimental investigation of features of flow around wing with dogtooth leading edge at low speed, Uchenii zapiski TsAGI, vol. 11, №4б, 1971, pp. 312-322. (in Russian)

[11] G.S.Byushgens Aerodynamics, stability and control of supersonic aircraft, M.: Nauka. Fizmatlit, 1998, p. 816 (in Russian)

[12] Scherbonos A. G. Aerodynamic characteristics of wing with vortex generators in unsteady flow: dis. Cand. tech. Sciences, NAU, Kyiv, 2012.

[13] Redchits D.A. Numerical modeling of aerodynamics of wind turbine rotors based on non-stationary Navier-Stokes equations: dis. Cand. tech. Sciences: 01.02.05. -Dnepropetrovsk.-2006, p. 250 (in Ukrainian)

[14] Volkov K.N. Large eddy simulation in the calculations of turbulent flows. - Moscow: Fizmatlit-2008. p. 368

[15] Sheng D.S. A review of numerical methods for solving the Navier-Stokes equations for compressible gas flows. Aerospace engineering. - 1986-№2-p.65-92.

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Проведено аналіз двох альтернативних методів впливу на інтегральні аеродинамічні характеристики на великих кутах атаки при глобальному відриву потоку за допомогою плоских низькопрофільних турбулізаторів і вихроутворювачів об’ємної форми з відривною верхньою кромкою, яка формує вихрові джгути в зоні передньої кромки крила. Джгути досягають задньої кромки, змінюють традиційну вихрову структуру відриву і позитивно впливають на аеродинамічні характеристики. Розглянута концепція розвитку математичного моделювання вихроактивного обтікання крила безпілотних літальних апаратів.

Ключові слова: вихроактивне крило; аеродинамічна характеристика; закритичні кути атаки; турболізатори; об’ємні вихрогенератори; глобальний відрив; математичне моделювання

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Вихреактивные крилья

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Проведён анализ двух альтернативных методов влияния на интегральные аэродинамические характеристики на больших углах атаки при глобальном отрыве потока при помощиплоских низкопрофильных турбулизаторов и вихреобразователей объемной формы з отрывной передней кромкой, которая формирует вихревые жгуты в зоне передней кромки крыла. Жгуты достигают задней кромки, заменяя традиционую вихревую структуру отрыва и положительно влияют на аэродинамические характеристики. Расмотрена концепция развития математического моделирования вихреактивного обтекания крыла безпилотных летательных апаратов.

Ключевые слова*:* вихреактивное крыло; аэродинамическая характеристика; закритические углы атаки; турбулизаторы; объемные вихрегенраторы; глобальный отрыв; математическое моделирование

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