Investigation of the influence of controls on the flow around the UAV model

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Abstract. Studies of the flow structure were performed on a trapezoidal UAV model. The experiments were carried out in a wind tunnel at subsonic speeds. The method of soot-oil visualization was used to obtain a picture of the flow around the model. The experiments were made at different angles of attack, as well as at different deflections of the ailerons on the model. The peculiarity of the work is that the experiments were conducted at full-scale (flight) Reynolds numbers.

1. Introduction
Unmanned aerial vehicles are rapidly gaining popularity. Manufacturers produce a large volume of units of equipment, but they do not have a clear idea of how the controls affect the flow structure on the surface of the UAV.

The flow around the wing and the aircraft as a whole is one of the important problems in the design of an aircraft [1-3] in terms of improving the flow, i.e. to eliminating breakaway flows at large angles of attack, as well as increasing the zones of laminar flow around the wing, based on new knowledge obtained during experiments [4].

The separation of the flow adversely affects the aerodynamic characteristics of the aircraft: the lifting force decreases and the drag increases, which leads to a decrease in the flight range, low flight efficiency, poor stability and controllability, as well as flight insecurity [5-6].

The purpose of the presented work is to study the influence of controls on the flow around the UAV model of the flying wing type, taking into account such factors as the incoming flow, the angle of attack, and the angle of slip. The peculiarity of this work is that some of the experiments are carried out with full-scale (flight) Reynolds numbers.

2. Experimental setup
These studies were conducted on two subsonic wind tunnels. Experiments on a full-size model were carried out on a low-turbulence wind tunnel T-324 ITAM named after S. A. Khristianovich SB RAS (Novosibirsk). Experiments on a small model were carried out on a subsonic wind tunnel MT-324. In the experiments, models of a flying wing made on a 3D printer were used. The small-size model was an about 4 times reduced copy of the full-size one. To print a model on a 3D printer, it was originally designed in the SolidWorks program. The appendix to this work presents a photo of the model, and its
drawing of the top view is shown below in Figure 1. The wingspan of the full-size model was 750 mm, the maximum (central) chord was 500 mm, and the end was 250 mm. The angle between the leading edges was 112, 62°. The small-sized model had the following dimensions: the span was 200 mm, the central chord was 130 mm, and the end chord was 65 mm. The full-size model was installed in the working part of the T-324 wind tunnel on a special holder, designed to make the angle of attack of the wing changeable. The small model was blown in a small wind tunnel MT-324. This model was also installed on the holder, with a variable angle of attack, and when the holder was rotated, the sliding angle changed. Several series of experiments were conducted in which the model was installed and blown in various positions. The flow rate was 13 m/s on a small pipe and 25 m/s on a large one, the Reynolds number for a quarter of the wing chord Re = 0.8•10^5 for a small model, and for a full-size Re = 6.5•10^5. The flow velocity on a large pipe was similar to the actual flight speed of such a device in the atmosphere, which emphasizes the peculiarity of this experiment, namely, that the experiments were carried out at full-scale (flight) Reynolds numbers.

Data on the structure and nature of the flow on the upper surface of the model were obtained by visualization using the method of "soot-oil" coatings (a mixture of titanium dioxide powder, kerosene and transformer oil).

Figure 1. Trapezoidal flying wing (a) and dimensions (b).

3. Results
Results on a small model:
The flow pattern at an angle of attack of 5° and a zero slip angle is demonstrated in Figure 2 (a). It illustrates the result of visualization of the flow without deflection of elevons. Two oval-shaped areas are visible on the wing surface, and these are local separation bubbles. Figure 2 (b) shows how the flow pattern changes with simultaneous deviation of the elevons upwards by an angle of 25°. The separation bubbles become narrower and their edges in the center of the wing become closer. When the elevons deflect in the opposite direction, downwards by an angle of 25°, the bubbles shift to the side edges of the wing and a vortex structure of approximately circular shape forms behind each bubble; apparently, this is an area of turbulent separation (Fig. 2 c). With different deflection of the elevons (Fig. 2 d), one upwards and the other downwards, the bubbles become unequal in size, one smaller and the other one larger.
Figure 2. Flow patterns at an angle of attack of $5^\circ$, a sliding angle of $0^\circ$, without deflection of elevons (a), with an upward deviation of elevons by $25^\circ$ (b), when the ailerons are deflected downwards by $25^\circ$ (c), with an asymmetric deviation of elevons by $25^\circ$ (right down, left up) (d).

The following experiments are carried out on the wing at a large angle of attack of $14^\circ$. Instead of separation bubbles, there is a disruption of the flow. Vortex flow patterns appear on the surface of the wing, with several well-visible circular structures (Fig. 3 a,c), which indicates that the flow is swirling in several places. With the simultaneous deflection of the elevons downwards (Fig. 3 b), the flow around the wing is restored, and two separation bubbles are visible. When the elevons are deflected in different directions: the right one is upwards, and the left one is downwards (Fig. 3 d). The flow pattern becomes completely asymmetric. Such a configuration can have a serious impact on the movement of the UAV in flight, leading to a roll, a change in the direction of flight, or a breakdown into a spin.

Figure 3. Flow patterns at an angle of attack of $14^\circ$, a sliding angle of $0^\circ$, without deflection of elevons (a), when the ailerons are deflected downwards by $25^\circ$ (b), with an upward deviation of elevons by $25^\circ$ (c), with an asymmetric deviation of elevons by $25^\circ$ (right down, left up) (d).

At an angle of attack of $5^\circ$, a glide angle of $15^\circ$, and without deflection of the elevons (Fig. 4 a), it is visible on the left part that the separation bubble flows down to the trailing edge, and on the right part of the wing there is a narrow separation bubble approximately parallel to the leading edge. When one aileron is deflected upwards and the other one downwards (Fig. 3 b), the flow pattern becomes almost symmetrical.
Results on a full-size model:
Figure 5 shows the flow patterns obtained at a zero (Fig. 5 a) and a small angle of attack of 5 degrees (Fig. 5 b) with different deviation of the elevons. When the controls are deflected upwards, it can be seen that from the leading edge to the central part of the wing, the stream lines are parallel to the direction of the incoming flow. After that, laminar separation bubbles form as strips, in front of which the stream lines spread out, changing the direction to the edges of the model. The flow pattern is symmetrical. The flow in the boundary layer in front of the bubble is laminar. Above the "bubble" there is a zone of turbulent transition, and behind it, the laminar flow becomes turbulent. The same flow structure is observed with elevons lowered down and different deviation of the controls. The observed structure is the same as in the previous configuration at a small angle of attack. The separation bubbles have shifted closer to the leading edge. The flow pattern is symmetrical.

Then the angle of attack increases to 14°. There is a significant difference from the flow patterns at small angles of attack. In the flow pattern, the separation bubbles shift even closer to the leading edge and become thinner (Fig. 6 a). The generation of vortices at the lateral edges is also observed. When the angle of attack increases to 15° and the elevons are deflected upwards, there is a air flow spreading along the leading edge of the wing on the left and right parts. There are also small vortices, which begin to form at lower angles of attack. When the elevons are deflected downwards, there is a significant difference in the flow pattern (Fig. 6 b). The spreading lines are visible at the place of the separation bubbles. The vortices increase, and their foci move closer to the central chord. The flow pattern changes. The stream lines swirl from the center to the side edges and contract to the centers of the vortices.
Figure 6. Flow patterns at an angle of attack of 14° (a) and 15° (b) with an asymmetric deviation of elevons by 30°.

At large angles of attack of 18° (Fig. 7 a) and 20° (Fig. 7 b), a vortex flow is observed. At 18° and elevons deflect upwards, and the vortices remain at the side edges; when they deflect downward, the foci of the vortices shift to the center of the wing, and a disruptive flow is formed. The reverse flow forms a pair of large-scale vortices. At 20 degrees, the vortex flow occupies the entire surface of the model, regardless of the deviation of the controls. When the elevons are deflected upwards, a symmetrical pattern is observed.

Figure 7. Flow patterns at an angle of attack of 18° with an asymmetric deviation of elevons by 30° (a), and 20° with an upward deviation of elevons by 30° (b).

4. Conclusions

The influence of controls on the flow of UAV models in subsonic wind tunnels MT-324 and T-324 has been studied. The conducted experiments have resulted in the images of flow visualizations under various modes, taking into account the following factors: the model size, the angles of attack, sliding, deflection of elevons, and the incoming flow velocity.

When the controls are deflected at zero and small angles of attack on both models, the position of the elevons does not significantly affect the flow structure.

In the investigation at an angle of attack of 14°, there is a difference in the flow around these two models. In the small model, the deviation of elevons has led to the formation of locally separated bubbles with identical vortices in the vicinity of these bubbles. The upward deviation has not led to a change in comparison with the original flow pattern. On a full-size model, the controls do not allow the end vortices to develop.

When the controls are installed asymmetrically (one up and the other one down by 30°), it is observed how each elevator affects the flow on half of the wing where it is located.

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