Numerical studies of the interference feature of biplane wings and tandem wings of aircraft

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The results of numerical studies of improving the layout of an aircraft on solar panels in terms of aerodynamic and torque characteristics are presented. Numerical studies of monoplane, biplane, and tandem aircraft have been conducted using a program based on the solution of Reynolds-averaged Navier–Stokes equations. The aerodynamic characteristics of biplane and tandem-monoplane aircraft with the same total wing surface area are compared. The features of the flow and interference of aircraft structures with different types of wings are shown.

Keywords: monoplane, biplane, tandem, aerodynamic characteristics, CFD methods.

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Airplanes that use solar energy in flight are a unique type of aircraft, whose bearing surfaces are in a maximum degree covered with photocells that convert solar energy into an electric current [1]. In order to produce the largest amount of solar energy, these airplanes have super-extended wings and all the horizontal surfaces are in a maximum degree used for installing solar panels, whose weight can be up to 25 % of a weight of the aircraft [2]. Therefore, the weight of the basic structure is lightened by using light and strong materials, for example, carbon-fiber reinforced polymers. Due to an increase of the area of the bearing surface, a large wing span, arrangement of a power plant at its ends and, at the same time, to maximum reduction of the wing weight, stability of the aircraft is significantly reduced, especially in turbulent atmospheres, thereby increasing requirements to dynamic strength of the structure [3]. Therefore, attempts are always made to optimize the structure of the solar airplanes.

In order to improve a layout of the solar-panel aircraft in terms of aerodynamic and torque characteristics, biplane and tandem aircraft were numerically studied. The tandem wings differ from the biplane wings in that they are arranged not one above another, but one after another: one is at the front and another is behind it.

The numerical studies are performed on a structured computational grid that includes about seven million cells, on three airplane layouts (Fig. 1) at the same total area of the wing surface $S = 8.6$ m, with the same wing chord $b = 0.6$ m, with a round-cross-section fuselage and a single-tail-fin empennage when a stabilizer is on the fuselage.

The calculations are performed within a range of the angles of attack $-2^\circ \leq \alpha \leq 20^\circ$ at the Mach number $M = 0.045$ and the Reynolds number $\mathrm{Re} = 0.3 \cdot 10^6$.

The results of the numerical studies of the airplanes were comparatively analyzed to show significant differences in their aerodynamic characteristics. Thus, these layouts of the aircraft have different bearing properties that are primarily related to a different wing span: the highest maximum lift belongs to a monoplane, while the least maximum lift belongs to the tandem. As compared to the monoplane, a biplane's linear section of the dependence $C_y(\alpha)$ is twice bigger. A derivative of the biplane lift function by the angle of attack C_y^α at the linear portion within the range $0 \leq \alpha \leq 5^\circ$ is smaller than that of the monoplane in 1.3 times, while the maximum lift $C_{y\ \max}$ is smaller by 18 %, but at the same time its critical angle of attack is higher by 3° (Fig. 2, *a*). The monoplane has a smaller drag C_D as compared to the other layouts and, therefore, its drag polar is to the left of the others in the graph in Fig. 2, *a*. At the subcritical angles of attack, the least drag belongs to the monoplane, while the layout of the „tandem" type has a smaller drag than the biplane.

It should be noted that among all the airplane models considered in the present study, the monoplane has not only the best bearing qualities, but the least drag and, consequently, the high aerodynamic quality, on which a flight distance directly depends (Fig. 2, *b*). A disadvantage of the monoplane is that it is susceptible to roll instability due to the large span [4].

A pitching moment coefficient was calculated relative to 20 % of the fuselage length for all the layouts. Within the range of the subcritical angles of attack $-2^\circ \leq \alpha \leq 10^\circ$, a derivative of the pitching moment coefficient for the monoplane is $m_z^\alpha = -0.025$, which is in 1.5 higher for diving than for the biplane that has the derivative $m_z^\alpha = -0.016$. The derivative of the pitching moment coefficient for the tandem is $m_z^\alpha = -0.091$, which is in 3.5 times higher than

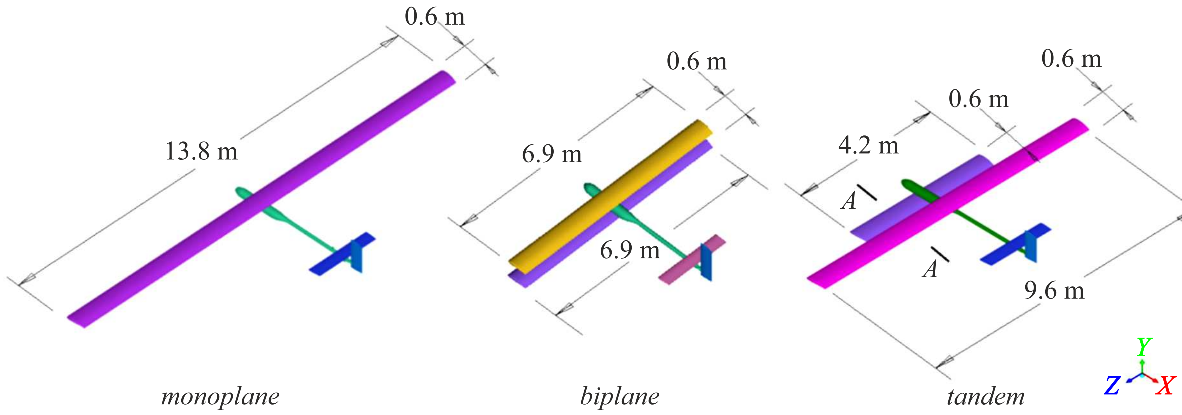

Figure 1. General view of the aircraft computational models

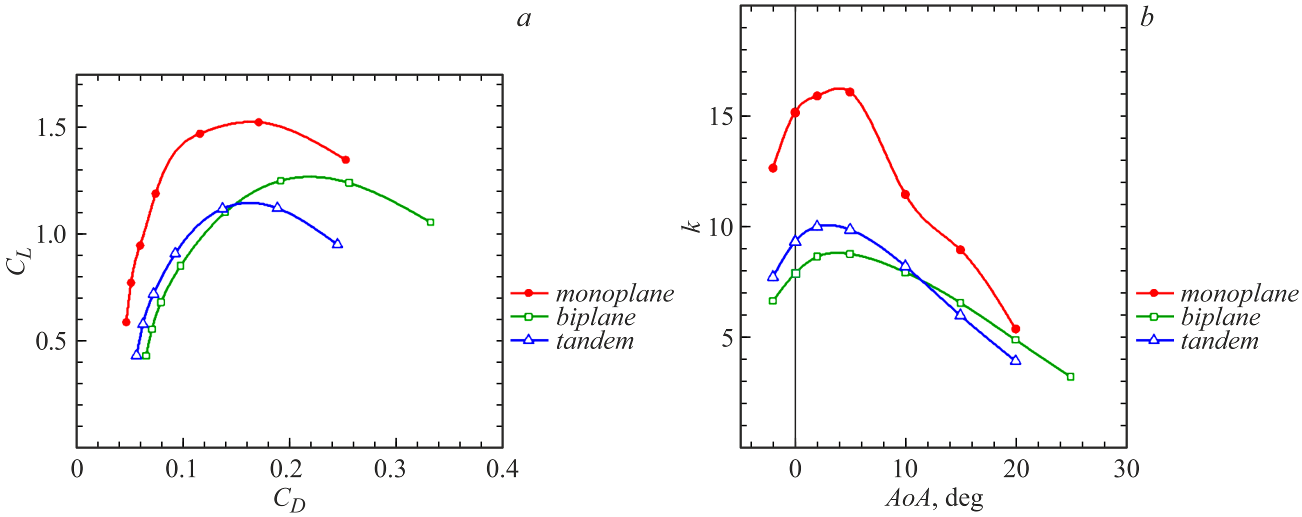

Figure 2. Aerodynamic characteristics of the aircraft: *a* — a drag polar, *b* — a dependence of the aerodynamic quality on the angle of attack.

for the monoplane and in 5.5 times higher than for the biplane. Among the airplane types considered, the layout of the tandem type at the subcritical angles of attack has the largest pitching moment for diving.

A distribution of the pressure coefficient at the angle of attack $AoA = 0$ in the wing section $A{-}A$ by the plane XOY, $z = 1.05$ m is shown in Fig. 3 for the various airplane types. As compared to the monoplane wing section, it is clear that the biplane wings exhibit negative interference: between the wings the flux is accelerated and as a result the upper wing decreases depression on an upper surface of the lower one and the lower wing decreases pressure on a lower surface of the upper wing (Fig. 3, *b*).

The tandem wing also has negative wing interference, which consists of the fact that such wing arrangement leads to an increase of the velocity between them and pressure depression, and as a result of it the pressure on the lower surface of the upper wing is smaller and, consequently, its lift is smaller than for the monoplane (Fig. 3, *c*).

In terms of designing the solar-energy airplane, it is necessary to have the largest surface area covered with the solar panels, the airplane layout that is stable in terms of flight dynamics and strength and has good aerodynamic characteristics. With all the aerodynamic advantages, the monoplane with the extended wing has serious drawback, which include its roll instability as well as susceptibility of the large-span wing to flutter, aeroelastic deformations and divergence.

As compared to the monoplane, the biplane has a more rigid structure in terms of strength and a lower weight at the same time. But the biplane is unsuitable to be the solar-energy airplane due to shadowing of one wing with another.

As compared to the monoplane, the tandem diagram for wing arrangement makes it possible to increase the total area of the bearing surfaces and avoid serious strength problems at the same time. But due to a heavy spread of the mass load along the longitudinal axis, pitch control of the tandem airplane is degraded.

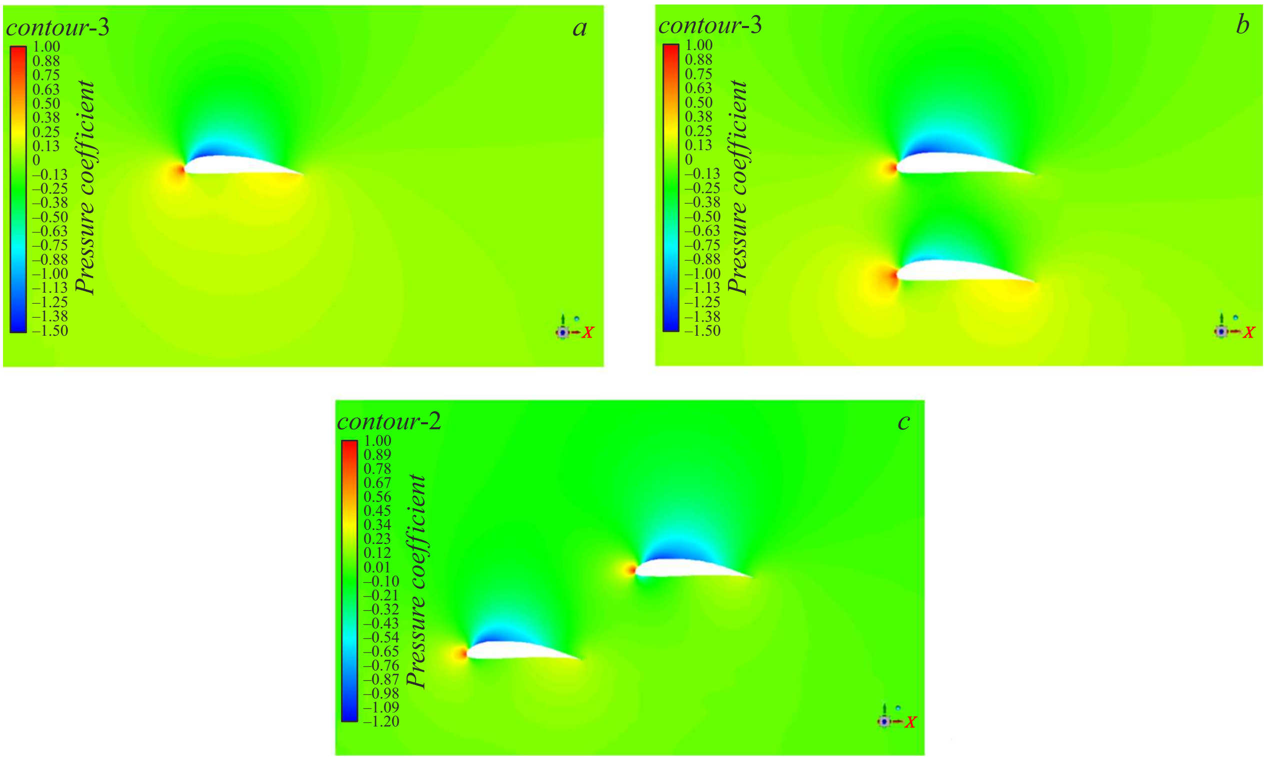

Figure 3. Distribution of a pressure coefficient in a wing section by the plane XOY, $z = 1.05$ m: a — the monoplane, b — the biplane, c — the tandem.

As a result of the numerical studies, it is shown that in the future, the most feasible layout of the solar-panel airplane is a layout of the „tandem“ type with an optimized span and mutual arrangement of the wings.

Conflict of interest

The authors declare that they have no conflict of interest.

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