Ground effect aerodynamics of twin fuselage aircraft

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Abstract. The paper presents experimental study results of ground effect influence on the aerodynamic characteristics of the twin fuselage transport airplane in a low-speed wind tunnel. The aerodynamic configuration has the two fuselages distributed under high-wing, and a "TT"-shaped tail. The twin fuselage transport airplane model consists of two fuselages, wing, empennage and external tank. The analysis includes studying the ground effect on the longitudinal and lateral aerodynamic characteristics and horizontal tail effectiveness. The effect of installing an external cryogenic fuel tank under the wing between the fuselages of the model was considered too. The obtained data shows the typical behaviour of the aerodynamic characteristics near the ground plate for aircraft model with high-wing and high placed horizontal tail. Ground proximity significantly increases the maximum lift-to-drag ratio and slightly changes the longitudinal moment characteristics. Horizontal tail effectiveness is maintained for all tailplane angles near the ground plate. The longitudinal and lateral stability of the twin fuselage transport airplane model is maintained in all considered modes near the ground plate.

1. Introduction
Over the years, Central Aerohydrodynamic Institute (TsAGI, Russia) has been researching on twin-fuselage aircraft concepts. The obvious advantage of the twin-fuselage aircraft is a significant (more than twice) reduction of the maximum bending moments on wing, compared to a conventional aircraft (single-fuselage) [1]. In result, the weight of the structure and the longitudinal dimensions of the twin-fuselage aircraft would be less than that of the single-fuselage aircraft with the same payload. Studies of the twin-fuselage transport aircrafts shows another advantages, like an outsized cargo transportation capability [2] or development of the single/twin-fuselage aircraft family with unified fuselage structure for different payload weight [3]. The twin fuselage layout may be in demand when switching to an eco-friendly fuel [4-5].

The aerodynamic configuration of the twin fuselage transport airplane (TFTA) has the two fuselages distributed under a high-wing, and a "TT"-shaped tail (Figure 1). A special feature of the studied layout is the central part of the wing with a larger chord, located between the two fuselages, to ensure a favorable ground effect when approaching the runway surface (Figure 2). This work is devoted to the study of the longitudinal and lateral aerodynamic characteristics of the TFTA layout in
ground proximity. The main test results of the TFTA model without the ground influence are given in [6].

![Aerodynamic configuration of TFTA](image1)

**Figure 1.** The aerodynamic configuration of TFTA.

![General arrangements of TFTA](image2)

**Figure 2.** General arrangements of TFTA.

2. **Aerodynamic model and test conditions**

2.1. **Aerodynamic model**

Aerodynamic model of TFTA was produced in 1:20 scale. The TFTA model consists of two fuselages, wing, empennage and external tank. The TFTA model has no wing high-lift devices, flight control surfaces (elevator, rudder, ailerons, spoilers), landing gear and engine nacelles (Figures 3, 4). Reference geometry parameters for aerodynamic coefficients are presented in table 1.
2.2. Test conditions
The experimental studies of the TFTA model at cruising configuration were carried out in the T-102 TsAGI low-speed wind tunnel (WT). T-102 is continuous-operation, closed layout WT with two reverse channels and an open test section [7].

A fixed rigid screen (ground plate) was used to simulate a runway surface. Test data were obtained at the flow velocity $V=50$ m/s and Reynolds number of $Re= 1\times10^6$ based on the mean aerodynamic chord (MAC).

Angles of attack (AoA) were ranged from $-6^\circ$ to $+20^\circ$ and sideslip angles from $-20^\circ$ to $+20^\circ$ when tests were performed without the ground plate. Near the ground plate, the AoA range was restricted to prevent contact between model rear fuselage and ground plate.

The tests were performed for following model heights above the ground plate: $h/b=0.7$ (main landing gears contacting the runway), 1.0 and 1.3, where $h$ – height from the trailing edge of centerwing to ground plate, $b$ – MAC (Figure 5).
Figure 5. Model near the ground plate at AoA of $\alpha=5^\circ$:  
a) $h/b \approx 0.7$; b) $h/b \approx 1.3$

3. Test results

3.1. Longitudinal aerodynamic characteristics
Test results showed that the lift coefficient ($C_L$) derivative against angle of attack ($\alpha$) rises in ground proximity (Figure 6). This is due to an increase in pressure on the wing lower surface and an increase in negative pressure on the wing upper surface. The maximum lift-to-drag ratio grows by $\Delta L/D=6.5$ when approaching the ground surface (Figure 7). The lift-to-drag ratio increases in ground proximity due to a decrease of induced drag and an increase of the wing lift coefficient [7]. This effect should have a positive influence on the take-off and landing characteristics of the airplane with two fuselages.

Figure 6. Curves for lift coefficient and pitching moment coefficient against angles of attack of TFTA without empennage in ground proximity.

Figure 7. Curves for Lift-to-Drag ratio against angles of attack of TFTA without empennage in ground proximity.
The horizontal tail effectiveness in ground proximity is considered in the range of deflection angles from 0 to -4 degrees. Figure 8 shows dependences of pitching moment coefficients against angles of attack for different heights above the ground. At all angles of the horizontal stabilizer installation, an increase in static longitudinal stability as the height decreases is observed. Figure 9 shows curves for increments pitching moment coefficients (ΔCm) against the angles of the horizontal tail deflection at angle of attack of α=5°. However, test results showed that the effectiveness of the adjustable stabilizer practically does not depend on the height above the ground plate. It is due to the increased distance between the horizontal stabilizer and the ground plate of the TT-shaped tail.

**Figure 8.** Curves for pitching moment coefficients against angles of attack at different heights above the ground.

**Figure 9.** Curves for pitching moment coefficient increment against angles of horizontal tail deflection.

The impact of the external fuel tank on the TFTA model with empennage in ground proximity is considered for angles of attack of α=0, 5°, 9°. The external fuel tank has almost no effect on the lift and pitching moment coefficients in ground proximity (Figures 10, 11). But the external cryogenic fuel tank reduces lift-to-drag ratio when approaching the ground (Figure 12). For example the maximum
lift-to-drag ratio reduces by 2.5 at the lowest ground height above the ground in comparison with TFTA model without the tank.

**Figure 10.** Curves for lift coefficient against relative height above the ground at different angles of attack.

**Figure 11.** Curves for pitching moment coefficient against relative height above the ground at different angles of attack.
Figure 12. Curves for Lift-to-Drag ratio against relative height above the ground at different angles of attack.

3.2. Lateral aerodynamic characteristics

Lateral aerodynamic characteristics of the model in ground proximity is considered at angle of attack $\alpha=5^\circ$. Sideslip angles ranged from $-20^\circ$ to $+20^\circ$.

The TFTA model has a typical behavior of lateral aerodynamic characteristics in ground effect. Directional stability practically does not change with decrease of height (Figure 13), and the lateral stability increases by 20% at $h/b=1.3$ and by 70% at $h/b=0.7$ (Figure 14).

Figure 13. Yawing moment coefficients against sideslip angles.

Figure 14. Rolling moment coefficients against sideslip angles.
4. Conclusion
The results of experimental studies of the twin fuselage transport airplane in ground proximity showed:

- The maximum lift to drag ratio increases by $\Delta L/D=6.5$ when approaching the ground surface;
- The effectiveness of the adjustable horizontal stabilizer of TT – shaped tail practically does not depend on the height above the ground plate;
- The external cryogenic fuel tank reduces the maximum lift to drag ratio by $\Delta L/D=2.5$ when approaching the ground;
- Directional stability practically does not change as the height decreases, and the lateral stability increases by about 20% at $h/b=1.3$ and by 70% at $h/b=0.7$.

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