Study on a twin-fuselage transport airplane model in a low speed wind tunnel

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Abstract. This paper presents the results of experimental studies of the twin-fuselage transport airplane model at the cruising configuration in the T-102 TsAGI low-speed wind tunnel. The researched twin-fuselage transport airplane is a tri-engine transport aircraft intended for transportation of cargo weighted up to 40 tons at a distance up to 3000 km with speed 700-740 km/h. The aerodynamic configuration has the two fuselages distributed under high-wing, and a "TT" - shaped tail. The research purpose was the determination of the aerodynamic characteristics of the twin-fuselage transport airplane model without engine nacelles and assessment of the twin-fuselage layout impact on control surfaces efficiency. The effect of installing an external cryogenic fuel tank under the wing between the fuselages of the model was considered too.

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 (Figure 1), compared to a conventional aircraft (single-fuselage) [1]. As a result, with the same payload, the weight of the structure and the longitudinal dimensions of the twin-fuselage aircraft would be less than that of the single-fuselage aircraft. Studies of the twin-fuselage transport aircrafts shows another advantages, like an outsized cargo transportation capability [2] or development of a family of single/twin-fuselage aircraft with unified fuselage structure for different payload weight [3].
Figure 1. Distribution along the span of lift, mass and bending moment for a twin-fuselage compared to a conventional aircraft [1].

This paper considers a variant of twin-fuselage aircraft designed for container transportation on busy regional air routes. One twin-fuselage airplane could replace two conventional airplanes with the same payload. The researched twin-fuselage transport airplane (TFTA) is a tri-engine transport aircraft intended for transportation of cargo weighted up to 40 tons at a distance up to 3000 km with speed 700-740 km/h (Figure 2). The aerodynamic configuration has the two fuselages distributed under a high-wing, and a "TT" shaped tail (Figure 3).

Figure 2. General arrangements of TFTA.

Currently, the issue of eco-friendly aircraft creating powered by cryogenic fuel (liquefied natural gas (LNG), liquid hydrogen) is increasingly being raised [4, 5]. Cryogenic fuel storage requires spherical or cylindrical tanks of large volume with effective thermal insulation so cryogenic fuel cannot be placed in the airplane wing box [6]. The twin-fuselage configuration has the possibility of placing the external fuel tank (or huge cargo) on an underwing pod between the fuselages (Figure 4). This fuel tank arrangement excludes contact of freights with cryogenic fuel.
Thus, for TFTA concept, estimations showed following advantages over the conventional aircraft:

- Lower structure weight (≈ 9%);
- Smaller longitudinal dimensions;
- More convenient loading and unloading of cargo at less time requirements;
- Using 3 engines instead of 4 (due to lower take-off weight);
- Cost reduction of one TFTA in comparison with the cost of two single-fuselage aircraft is approximately 11.4% due to using one set of avionics and 3 engines instead of 4;
- Using underwing pod for transportation of huge cargo or cryogenic tank.

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 (Figure 5). Reference geometry parameters for aerodynamic coefficients are presented in table 1.
Table 1. Reference dimensions of TFTA model.

| Parameter                        | Value  |
|----------------------------------|--------|
| Wingspan, m                      | 2.5    |
| Wing aspect ratio                | 9.46   |
| Mean aerodynamic chord (MAC), m  | 0.306  |
| Wing area, m²                    | 0.66   |
| Fuselage length, m               | 1.77   |
| Equivalent fuselage diameter, m  | 0.24   |

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 designed to investigate aerodynamic characteristics of aircraft models at take-off, landing and low-speed flight. WT flow velocity is varied from 10 to 50 m/s. Elliptical test section is characterized by 4 m x 4 m x 2.33 m size. Forces and moments are measured with the AV-102 external six-component balance system [7].

The TFTA model was tested at a flow velocity V=50 m/s (Mach number of M=0.15, Reynolds number of Re=1·10⁶). Angles of attack (α) were ranged from -6° to +20° and sideslip angles (β) from -20° to +20°.

3. Test results
The study aim was the determination of the aerodynamic characteristics of the TFTA model without engine nacelles and the assessment of the twin-fuselage layout impact on control surfaces efficiency. The effect of installing an external cryogenic fuel tank under the wing between the fuselages of the model was considered too.

3.1. Longitudinal aerodynamic characteristics
The model was tested in the two configurations. First one: two fuselages, wing and empennage (Figure 6) and second one: two fuselages, wing, empennage and external tank (Figure 7).

Figure 6. TFTA aerodynamic model in T-102 TsAGI WT.

Figure 7. TFTA aerodynamic model with external tank in T-102 TsAGI WT.

Figure 8 shows curves for lift coefficient (C_L) against angles of attack (α) of TFTA model with and without the external tank. As can be seen, the level of lift coefficients for both configurations is approximately the same. The external tank installing has no effect on value of the maximum lift coefficient of the TFTA model. Figure 9 shows curves for pitching moment coefficient (Cm) against
lift coefficient. As you can see on the chart, the external fuel tank has a small impact on the pitching moment coefficient. The external tank installing reduces a drag coefficient and, accordingly, lift-to-drag ratio decreases too. The maximum lift-to-drag ratio reduces by $\Delta L/D=1$ (Figure 10).

![Figure 8. Curves for lift coefficient against angles of attack of TFTA with and without external tank.](image)

![Figure 9. Curves for pitching moment coefficient against lift coefficient of TFTA with and without external tank.](image)

![Figure 10. Lift-to-Drag ratio comparison of TFTA model with and without external tank.](image)

It is practically important to compare aerodynamic characteristics of TFTA and single fuselage aircraft [8]. The single fuselage aircraft was tested in equal conditions with TFTA (Mach number of $M=0.15$, Reynolds number of $Re=1\cdot10^6$). Figure 11 shows comparison of general views of TFTA and single fuselage aircraft models without empennage. Comparison of the main geometric parameters of TFTA and single fuselage aircraft is presented in the table 2. The wing aspect ratio of TFTA is slightly larger, and the total area of fuselage mid-section is larger approximately in two times.

Test results showed that the lift coefficient of the single fuselage airplane model is higher due to the larger effective wing area. The TFTA's pitching moment has the same behavior. The maximum lift-to-drag ratio of the TFTA is lower by $\Delta L/D=1$ compared to the single fuselage aircraft (Figure 12).
Figure 11. Comparison of general views of TFTA and single fuselage aircraft models without empennage.

Table 2. Comparison of the main geometric parameters of TFTA and single fuselage aircraft models.

| Parameter                          | TFTA    | Single fuselage aircraft |
|-----------------------------------|---------|--------------------------|
| Wingspan, m                       | 2.5     | 2.5                      |
| Wing aspect ratio                 | 9.46    | 8.49                     |
| Wing area, m²                     | 0.66    | 0.74                     |
| Area of fuselage mid-section, m²  | 0.13    | 0.056                    |

Figure 12. Lift-to-Drag ratio comparison of TFTA and single fuselage aircraft.

3.2. Tail control surfaces efficiency

The next task was to study the twin-fuselage layout impact on control surfaces efficiency. The figure 13 shows the placement of the control surfaces on the horizontal stabilizer. The elevator is divided into three parts: central (56% of elevator area) and two outer sections (44% of elevator area). Elevator was deflected in the range from -25 to 20 degrees. Figure 14 shows curves for increments of pitching moment coefficient against angles of elevator deflection for a fixed angle of attack of 5°. The Elevator
efficiency with only deflected central section is reduced by approximately 40% compared to the efficiency when all elevator sections are deflected (Figure 14). The elevator efficiency with only deflected outer sections is reduced by approximately 61% compared to the elevator efficiency when all sections are deflected. As you can see, the installation of the external tank has no impact on the elevator efficiency in the considered range of deflection angles and slightly differs from the test results without the tank (Figure 14). Note that the efficiency of the outer sections of the elevator is close to the values for the single-fuselage aircraft with the same horizontal tail volume ratio.

![Figure 13. Placement of the control surfaces on the horizontal stabilizer.](image13)

![Figure 14. Curves for pitching moment coefficient increment against angles of elevator deflection.](image14)

The rudder effectiveness is considered in the range of deflection angles from -25 to 25 degrees. Model was tested at zero sideslip angle and at a fixed value of the geometric angle of attack. Figure 15 shows curves for increments rolling ($\Delta C_l$) and yawing ($\Delta C_n$) moment coefficients against angles of rudder deflection. As can be seen, the rudders efficiency is maintained in all considered range of deflection angles. The efficiency of the left rudder is approximately 55% lower than that of the two rudders (Figures 15, 16). Note that the rudders efficiency is close to the values for the single-fuselage aircraft with the same vertical tail volume ratio.

![Figure 15. Curves for increments rolling moment coefficients against angles of rudder deflection.](image15)

![Figure 16. Curves for increments yawing moment coefficients against angles of rudder deflection.](image16)
4. Conclusion
The results of experimental studies of the TFTA model at the cruising configuration in the T-102 TsAGI low-speed wind tunnel showed:

- The maximum lift-to-drag ratio of the TFTA is lower by $\Delta L/D=1-1.5$ compared to the single fuselage aircraft;
- The efficiency of the TFTA tail control surfaces is close to the efficiency values of the single-fuselage a/c and has no principled differences;
- The external cryogenic fuel tank reduces the maximum lift-to-drag ratio by $\Delta L/D=1$ and has practically no effect on the efficiency of the tail control surfaces.

Further research will be focused on the improvement of the aerodynamic layout and the study of take-off and landing aerodynamic characteristics.

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