Three-dimensional visualization of flow pattern near transport airplane model with operating propellers in wind tunnel

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Abstract. This paper presents the experiment results of three-dimensional visualization of flow pattern behind the wing and fuselage of the light transport aircraft (LTA) model with operating propellers in the T-102 TsAGI subsonic wind tunnel (WT). Studying the flow pattern, it is possible to recognize the features of the flow and aerodynamic interference of model elements. As a result of the analysis of the flow pattern and comparison with the previously obtained integral characteristics, the model elements for improving the aerodynamic perfection of the aircraft are revealed. It is shown that at operational angles of attack behind the main landing gear fairing, the vortex flow forms, increasing drag and, apparently, negatively affecting the longitudinal stability characteristics. Vortices are formed behind the flattened tail of the fuselage. Thus, the visualization of the flow with dacron ribbons is an effective method of obtaining flow pattern around the airplane model elements in WT.

1. Introduction

One of the most important problems of design of aircraft with propellers is to determine the impact of the operating propellers on its aerodynamic characteristics, stability and controllability.

To identify the features of interaction between propellers and the airframe, TSAGI uses an experimental method based on simultaneous measurement of forces and moments on the propeller (using six-component strain gauges built into the model powerplant) and the total forces and moments acting on the model aircraft with operating propellers (using external six-component balance system) [1].

Thus, this method significantly expands the possibilities of studying the aerodynamics of aircraft with operating propellers and the characteristics of propellers in the layouts of these aircraft. The data obtained using this type of experiment can be used both to improve the aircraft layout taking into account a propeller slipstream effect, and for the aerodynamic design of propellers taking into account the impact of the airframe. In some cases, the experimental data obtained is not enough and visualization comes to the rescue. Flow visualization is an important type of experiment in aerodynamics, which allows us to supplement the integral and distributed characteristics obtained in WT [2].

This paper presents the experiment results of three-dimensional visualization of flow pattern behind the wing and fuselage of the LTA model with operating propellers in the T-102 TsAGI subsonic WT.
The LTA is aimed for transportation of 48 passengers or 6 t of payload with speed 450 km/h on local and regional routes (Figure 1). Aerodynamic layout of LTA is based on classic high-wing scheme with wing aspect ratio AR=9.68, fuselage with trapezoidal cross-section and flattened tail for rear cargo door, classic empennage with one vertical tail and fuselage-placed horizontal tail [3]. Wing equipped with one-slot Fowler flaps (with a chord of 30-35%), spoilers and ailerons. The operating range of flap deflection angles are \( \delta_F = 18^\circ \) (for takeoff) and \( \delta_F = 35^\circ \) (for landing). Engine nacelles are placed under the center wing part. Main landing gear fairings are placed on the fuselage. One of LTA layout features is a pressurized fuselage with trapezoidal cross-section for providing high level of comfort for passengers that is difficult to achieve with round cross-section (Figure 2).

![Figure 1. General arrangements of LTA.](image)

![Figure 2. Transport capabilities of LTA.](image)
2. Aerodynamic model and test conditions

2.1. Aerodynamic model

Aerodynamic model of LTA was produced in 1:10 scale (Figure 3). Reference geometry parameters for aerodynamic coefficients are presented in table 1. The LTA model is equipped with two model propulsion systems (Figure 4). The model propulsion system was developed at TsAGI and is used as standard equipment for investigation into the slipstream effects, including measurements of forces and moments acting on propellers. The model propulsion system consists of the following main elements: propeller, electric motor, rotation speed sensor and six-component strain-gauge balance (Figure 5).

![Figure 3. LTA aerodynamic model in T-102 TsAGI subsonic WT.](image1)

![Figure 4. Model propulsion system mounting.](image2)

![Figure 5. Model propulsion system.](image3)

| Parameter                      | Value  |
|--------------------------------|--------|
| Wingspan, m                   | 2.616  |
| Mean aerodynamic chord (MAC), m| 0.285  |
| Wing area, m²                 | 0.707  |

2.2. Test conditions

Experimental studies of the LTA model were carried out in the T-102 TsAGI subsonic WT [4]. 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. 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 [4].

The model was tested in cruising (retracted flap), takeoff (flap deflection angle \(\delta_F=18^\circ\)) and landing (flap deflection angle \(\delta_F=35^\circ\)) configurations. Flow velocity was ranged from 19 to 36 m/s,
which corresponds to the range of values of the load coefficient \( B \) (propeller similarity criteria) and the Reynolds number \( \text{Re}=\left(0.37 \text{--} 0.7\right)\times10^6 \). Load coefficient \( B \) was determined by the equation (1).

\[
B = \frac{P_0}{q_\infty \cdot F}
\]  

(1)

where \( P_0 \) is a propeller thrust, \( q_\infty \) is an airspeed head in WT, \( F \) is a blade swept surface area.

In tests angles of attack (AoA, \( \alpha \)) were ranged from -6° up to 20° with step 2° at zero sideslip angle.

Flow visualization was performed using dacron ribbons fixed in bundles on the trailing edges of the flaps (at a distance of 170 mm from the engine nacelle axis in both directions), the lower surface of the fuselage, the main landing gear fairing and at the root of the vertical tail (Figure 6). The flow patterns were recorded on a video camera.

![Figure 6. Location of dacron ribbons on the LTA model.](image)

3. Results and discussion

Studying the flow pattern, it is possible to recognize the features of the flow and aerodynamic interference of model elements. The use of dacron ribbons in combination with the white control line on the model fuselage (fuselage datum line or F.D.L.) allows experimental determination of the flow deflection angles behind the wing at different flap settings deflection and the operating modes of the propeller.

Figure 7 represents the flow patterns for \( B=0.2 \) and 0.5 at \( \alpha=6° \) which corresponds to cruise flight. At \( B = 0.2 \), the cruise mode of the power plant is simulated, visualization with \( B=0.5 \) is presented to demonstrate the effect of load coefficient increase.
Figure 7. Flow visualization in cruise configuration at $\alpha=6^\circ$.

In presented figure it can be seen that the downwash angle behind the wing is insignificant and tends to zero (relative to the F.D.L.) near the horizontal tail. Ribbons on wing located near the fuselage stick to it and spread out, interacting with the flow from the wing-fuselage fairing (possibly with flow separations). A vortex flow forms behind the main landing gear fairing, which is clearly distinguishable by the movements of dacron ribbons in the video recording (the photo, unfortunately, does not transmit the process in dynamics). Behind the aft fuselage, a pair of vortices is formed, pulling together ribbons on fuselage’s axis of symmetry. An increase of load coefficient $B$ does not lead to a significant change in the flow pattern.

In the cruising configuration of the model it is important to ensure minimal loss of the lift-to-drag ratio, taking into account the impact of the propellers slipstream, it is obvious that the main landing gear fairing and wing-to-fuselage fairing require improvements.

Figures 8, 9 show flow patterns for takeoff and landing configurations, respectively, at $B=1$ and 2 and an angle of attack of $\alpha=8^\circ$. Comparison with the cruise configuration shows a significant increase in the downwash angles directly behind the wing and in the area of horizontal tail. It should be noted that in the take-off configuration, downwash angle behind the trailing edge of the wing is approximately equal to the flap deflection angle of $18^\circ$, while in the landing configuration, the downwash angle is $22-24^\circ$, which can be caused by flow separation at flap deflection angle $35^\circ$. Flap deflection also significantly affects the flow near the landing gear fairing, deflecting the vortex created by wing’s downwash, which additionally affects the moment characteristics and negatively affects the stabilizer efficiency. At the same time, the deflection of the flaps causes the ribbons on the lower surface of the fuselage to “stick” to the surface of the tail, which indicates a change in the flow around the rear of the fuselage.
Figure 8. Flow visualization in take-off configuration at $\alpha=8^\circ$.

Figure 9. Flow visualization in landing configuration at $\alpha=8^\circ$. 
4. Conclusion
As a result of the analysis of the flow pattern and comparison with the previously obtained integral characteristics, the model elements for improving the aerodynamic perfection of the aircraft are revealed. It is shown that at operational angles of attack behind the main landing gear fairing, the vortex flow forms, increasing drag and, apparently, negatively affecting the longitudinal stability characteristics. Vortices are formed behind the flattened tail of the fuselage.

Thus, the visualization of the flow with dacron ribbons is an effective method of obtaining flow pattern around the airplane model elements in WT.

References
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