Features of flow around transport aircraft model with running propellers by modelled engine failure in wind tunnel

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Abstract. This paper presents the experiment results of modelling the one engine failure at the landing mode on a model of a light transport airplane in the T-102 TsAGI low speed wind tunnel. The effect of starboard and port engines failure on the aerodynamic characteristics and stability of the model is researched. The model maximum lift coefficient is reduced about ≈8% and there are the same moments in roll and yaw for starboard and port engines failure case. It was found that the failure of any engine has little impact on the efficiency of control surfaces. Approaches of compensation of forces and moments arising in the engine failure case were investigated.

1. Introduction
A traditional problem arising in the formation of the aerodynamic layout of a twin-engine turboprop is aerodynamic interference between the airframe elements and the propellers, which create thrust. An important aspect of this problem is the case of failure of one engine, since the forces and moments arising in this case significantly change the aircraft aerodynamic characteristics [1, 2]. Reducing the negative impact of engine failure on the aerodynamic characteristics is one of the most important design problems [3].

This paper presents results of the experimental study on modeling the one engine failure at the landing mode on a model of a light transport aircraft (LTA) in the T-102 TsAGI low speed wind tunnel (WT). Approaches of compensation of forces and moments arising in the engine failure case were also experimentally investigated.

2. Aerodynamic model and test conditions

2.1. Aerodynamic model
Aerodynamic model of LTA was produced in 1:10 scale (Figure 1). Aerodynamic layout of LTA model is based on classic high-wing scheme with wing aspect ratio AR=9.68, fuselage with trapezoidal cross-section, classic empennage with one vertical tail and fuselage-placed horizontal tail [4, 5].
Figure 1. LTA aerodynamic model in T-102 TsAGI WT.

The model was tested in the landing configuration (Figure 2, a). Wing equipped with one-slot Fowler flaps (with a chord of 30-35%), spoilers and ailerons (with a span of 30% of wing). The flap landing deflection angle is $\delta_F=35^\circ$ (Figure 2, b). The ailerons were deflected at the angles $\delta_A=\pm 20^\circ$ (Figure 2, c). The rudder with an overall chord of 40% and 20% axial compensation was deflected at the angles $\delta_R=\pm 20^\circ$ (Figure 2, d). Tests were run with horizontal tail incidence +1$^\circ$. The horizontal tail was an inverted airfoil. The elevator with an overall chord of 35% and 20% axial compensation was deflected at the angles $\delta_E=\pm 20^\circ$ (Figure 2, e). Reference geometry parameters of the LTA model for aerodynamic coefficients are presented in table 1.

Table 1. Reference dimensions of LTA model.

| Parameter                                | Value  |
|------------------------------------------|--------|
| Wingspan, m                              | 2.616  |
| Mean aerodynamic chord (MAC), m          | 0.285  |
| Wing area, m$^2$                         | 0.707  |
2.2. Test conditions

Experimental studies of the LTA model were carried out in the T-102 TsAGI subsonic WT [6]. 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.

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].

Flow velocity was 31 m/s, which corresponds to a load coefficient value \( B = 0.5 \) and the Reynolds number \( Re = 0.6 \times 10^6 \). 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 dynamic pressure in WT, \( F \) is a blade swept surface area.

Rotation direction of propellers is clockwise. Investigation of longitudinal aerodynamic characteristics was conducted for the angles of attack (AoA, \( \alpha \)) ranged from -10° to 20° at zero sideslip angle. Investigation of lateral aerodynamic characteristics was conducted the sideslip angles (\( \beta \)) ranged from -20° to 20° at a fixed AoA 8°, which corresponds to the landing angle of attack.

3. Results and discussion

3.1. Engine failure influence on model aerodynamic characteristics

In this paper, the effect of failure of the starboard and port engine is considered. It is known that propeller slipstream induces additional lift on aircraft wing (figure 3a). The one engine failure case on a twin-engine aircraft without sideslip (\( \beta = 0 \)) leads not only to a reducing engine thrust by half, but also to an increase of drag, which induces the rotation of the aircraft relative to the vertical axis towards the failed engine (Figure 3b, 3c). Due to the difference in flow of the starboard and port wings, the airplane will also roll to the side of the failed engine. Asymmetrical propeller slipstream leads to a change in longitudinal stability and balance.

\[ \text{Figure 3. Effect of propeller stream on aircraft forces and moments:} \\
\text{a) all engines running; b) port engine failure; c) starboard engine failure} \]
Failure of any engine decreases the lift slope on linear part of lift versus AoA curve and reduces the maximum lift coefficient (Figure 4a). Maximum lift coefficient reduction is about 8% for each engine failure case. Engine failure results in a dive increment for pitching moment, which related to elimination of interaction of propeller slipstream with part of horizontal tail plane and therefore reduction of local flow angle near stabilizer on the side of failed engine. Difference of pitching moment coefficient for port and starboard engine failures may be related to rotation direction of propellers but not investigated in this study.

At the same time, as can be seen in Figure 4b, the increment values of the rolling moment in case of starboard/port engine failure at landing AoA are close. The increment values of the yawing moment in case of starboard/port engine failure at landing AoA are close too (Figure 4c).

### Figure 4. Aerodynamic coefficients versus angle of attack:

- a) lift and pitching moment
- b) rolling moment
- c) yawing moment

#### 3.2. Engine failure influence on control surfaces effectiveness

Influence of engine failure on control surfaces effectiveness was investigated for elevator, rudder and ailerons.

An elevator deflection in range from -20° to +20° was tested. The pitching moment coefficient versus elevator deflection angle curves at AoA 8° is showed on figure 5a. Effectiveness of elevator is the same for each engine failure cases.

Effectiveness of rudder was investigated for deflection angles from -20° to +20°. Figures 5b and 5c show curves of rolling and yawing moment coefficients versus rudder deflection angle at AoA 8° and sideslip angle 10°. Effectiveness of rudder is maintained for any deflection angle in each engine failure cases.

An aileron was deflected only on starboard wing console with deflection angles from -20° to +20°. A figure 5d shows the rolling moment coefficient versus aileron deflection angle curves at AoA 8° and sideslip angle 10°. Effectiveness of aileron is maintained for any deflection angle in starboard engine failure case.
Research has shown that one engine failure have a similar effect in both port and starboard engine cases. However, starboard engine failure results in slightly larger quantitative changes in the stability and balance of the LTA model. Thus, starboard engine failure may considered as critical, which is typical for multiengine turboprop aircrafts with clockwise propeller rotation.

Compensation of the starboard engine failure was performed by the differential deflection of ailerons to angles $\delta_{AIL}=10^\circ$ on the starboard wing console and $\delta_{AIL}=-10^\circ$ on the port wing console for trimming of rolling moment and deflection of the rudder to angle $\delta_{RUD}=-10^\circ$ for trimming of rolling and yawing moments (figure 6a). These deflections of the control surfaces in case of the starboard engine failure lead to a decrease of rolling moment coefficient from $C_{l,\beta=0^\circ}=0.011$ to $C_{l,\beta=0^\circ}=-0.01$ (figure 6b) and an increase of yawing moment coefficient from $C_{n,\beta=0^\circ}=-0.019$ to $C_{n,\beta=0^\circ}=0.05$ (figure 6c). Moderate deflections of the rudder and ailerons are sufficient to compensate for the impact of a critical engine failure on lateral balance.

Figure 5. Effectiveness of control surfaces versus deflection angles in case of one engine failure:
a) pitching moment coefficient increment of elevator; b) rolling moment coefficient increment of rudder; c) yawing moment coefficient increment of rudder; d) rolling moment coefficient increment of aileron

3.3. Compensation of engine failure

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Figure 6. Compensation of moments induced by engine failure: a) legend; b) rolling moment coefficient versus sideslip angle; c) yawing moment coefficient versus sideslip angle

4. Conclusion

The wind tunnel investigation of airplane model with running propellers allows evaluating and identifying the behavior of its aerodynamic characteristics in the engine failure case. Simulation of the failure of the starboard and port engines in the landing configuration of the airplane with $B=0.5$ showed that the loss of any engine has little effect on the efficiency of the control surfaces. Failure of both the starboard and port engines leads to a decrease in the maximum lift coefficient, an increase in the pitching moment for diving, as well as an increase in the rolling and yawing moments. The considered methods to compensate the rolling and yawing moments arising in the engine failure as starboard as port by deflecting the rudder and ailerons showed its effectiveness.

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