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Research on Climbing Performance Flight Test with Simulated Ice Shapes for Civil Aircraft

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Abstract. Flight tests with simulated ice shapes are an important verification means to demonstrate that an aircraft can fly safely under natural icing conditions. This paper studies the climbing performance flight test technology for civil aircraft with simulated ice shapes from the aspects of simulated ice shape selection, flight test method research, pre-flight test condition requirements, flight test risk assessment, and flight test data analysis, etc., and analyzes the climb performance flight test data of a certain large transport aircraft, giving the analysis of flight test results.

Keywords: Climbing Performance, Simulated Ice Shapes , Climb Gradient, Flight Test

1. Introduction

The requirement for flight tests with simulated ice shapes directly originates from CCAR25.1419(b) [1]. This clause stipulates that flight tests must be conducted on the aircraft or its components under various operational configurations and measured natural atmospheric icing conditions. When necessary, one or more of the following methods should also be adopted for verification, including conducting flight tests on the aircraft or its components under measured simulated icing conditions. Due to the difficulty in capturing natural icing meteorological conditions and the high risks of flight tests, a combination of simulated ice shape flight tests and natural icing flight tests is adopted. The flight test contents required by the clause are completed through simulated ice shape flight tests, and part of the flight test contents are supplemented under natural icing meteorological conditions, so as to demonstrate compliance with the icing clauses.

The climb performance flight test of civil aircraft with simulated ice shapes is mainly aimed at obtaining the climb gradient with simulated ice shapes in each stage, and demonstrating compliance with the icing-related contents in CCAR25.119 and 121. The flight test involves different flight phases, requiring the use of different critical ice shapes, featuring high difficulty and risks.

The paper studies the climb performance flight test technology for civil aircraft with simulated ice shapes, including the selection of simulated ice shapes, research on flight test methods, requirements for pre-flight test conditions, flight test risk assessment, and flight test data analysis, etc. The paper also analyzes the climb performance flight test data of a certain large transport aircraft with simulated ice shapes, provides the climb gradient, and demonstrates its compliance with airworthiness regulations.

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2. Simulated ice shapes selection

Appendix C of CCAR Part 25 provides the definitions of ice shapes for six flight phases: takeoff, final takeoff phase, en route, holding, approach, and landing. When conducting climb performance flight tests with simulated ice shapes, simulated ice strips need to be installed on the unprotected surfaces of the aircraft. The shape of the ice strips is determined according to the ice shape definitions of different flight phases, and the critical ice shapes under critical icing conditions are usually selected. The criteria for critical ice shapes can be considered separately for roughness ice and horn ice. When determining the critical ice shapes, the critical icing conditions and the corresponding calculated critical ice shapes are first obtained through numerical simulation methods, and then verified through ice wind tunnel tests, so as to finally determine the critical ice shapes for each phase. When determining the simulated ice shapes for a certain large transport aircraft, the critical ice shape for the takeoff phase is used for the climb in the second-stage takeoff, the critical ice shape for the final takeoff phase is used for the climb in the final takeoff phase. Considering that the icing conditions during holding are more critical than those during approach and landing, the critical ice shape for the holding phase is used for the climbs during approach and landing.

3. Climbing performance flight test method with simulated ice shapes

The level acceleration method and the sawtooth climb method are commonly used flight test methods for climb performance with simulated ice shapes. The level acceleration method requires maintaining a stable altitude during the acceleration process using a fixed thrust level. Usually, climb performance parameters at different speeds can be obtained in a single acceleration process, making the flight test highly efficient. However, during the acceleration process, the holding time at a single speed point is short, the longitudinal overload coefficient fluctuates greatly, the analysis of flight test data is relatively complex, and the error of flight test results is large. The sawtooth climb method involves climbing at a constant equivalent airspeed under different weight and altitude conditions to obtain climb performance parameters for different combinations of weight, altitude, and speed. Although the flight test efficiency is low, the flight test data is easy to process, and the reliability of flight test results is high. This method is also the airworthiness-recommended flight test method for climb performance [2].

Climb performance parameters are affected by wind [3]. During flight tests, the influence of wind gradient on climb gradient is approximately eliminated by conducting one flight test in the forward heading and one in the reverse heading. In the climbing process, tests can be carried out by considering the direction of vertical wind to minimize the impact of wind on the climb gradient as much as possible, and the obtained flight test results are more conservative at the same time.

The specific flight test procedures for climb performance with simulated ice shapes are described as follows. The setting principles for test-related configurations, speeds, weights, etc., are shown in Table 1 [4]. When the climbing flight is conducting, make sure that the airflow is stable, in order to obtain better flight test data.

(i) Install the simulated ice shapes required for the test on the aircraft.

(ii) Maintain stable flight at 600 ft below the target test altitude.

(iii) For phase 2 takeoff climb, final takeoff climb, and approach climb, complete the shutdown of the critical engine as specified in the Flight Manual; set the 8s go-around thrust for landing climb.

(iv) With the predetermined aircraft configuration requirements, maintain a constant target equivalent airspeed and center the aircraft sideslip indication for straight and stable climb until 600

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ft above the target test altitude to end the test. During the test, the air conditioning system remains on, and the engine state is fixed.

(v) Descend to 600 ft below the target test altitude and repeat the test in the opposite heading.

Table 1. Configuration requirements of climb phases

Flight phase	Trust	Operating engine number	All engine number	Flap-Slat detent	L/G position	Airspeed	Weight
2nd takeoff segment	TO	N-1	N	Takeoff	Up	$V_{2:}$takeoff safety speed	Weight with landing gear fully retracted
Final takeoff segment	MCT	N-1	N	Takeoff	Up	$V_{FTO:}$final takeoff segment speed	Maximum takeoff weight limited by Gradient
Approach climb	GA	N-1	N	Approach	Up	Approach climb speed	Maximum landing weight limited by Gradient
Landing climb	8sGA	N	N	Landing	Down	$V_{REF:}$landing reference speed.	Maximum landing weight limited by Gradient

Note:
(vi) N is the total number of aircraft engines;
(vii) TO is takeoff thrust, MCT is max continuous thrust, GA is go around thrust, 8sGA is 8 second go around;

4. Climbing performance flight test risk assessment with simulated ice shapes

The main risk sources of climbing performance flight tests with simulated ice shapes are: stall, single-engine or twin-engine failure, and damage to the aircraft airframe structure or engine caused by ice shape shedding. The corresponding risk mitigation measures are as follows:

(i) Complete the low-temperature test and static test for installing simulated ice shapes in the laboratory.

(ii) Install the simulated ice shapes as required.

(iii) Inspect the simulated ice shapes before each flight to ensure they are firmly installed.

(iv) During the flight test, the on-board engineer shall pay attention to observe whether there is any ice shape shedding. If shedding occurs, end the test and return the aircraft to the airfield.

(v) The wing anti-icing system shall not be operational, and the test airspace shall be free of icing meteorological conditions.

(vi) Be familiarize with the requirements of flight test maneuvers before the test, and practice the flight test maneuvers and fault handling procedures in the simulator.

(vii) Complete the stall speed flight test before the actual flight test.

(viii) Be familiar with the obstacles around the flight test airspace and choose an airspace with lower obstacles for the test.

(ix) Conduct the flight test step by step, starting with high-speed and high-altitude climbs.

(x) Pay attention to meteorological changes in the flight test airspace and avoid turbulence as much as possible.

(xi) Ground and on-board engineers should strengthen the monitoring of key flight parameters, such as angle of attack and engine parameters.

(xii) Keep the APU (Auxiliary Power Unit) turned on throughout the flight.

(xiii) Before the critical engine is shut down, put the ignition start switch of the other engine in the "CONT" position.

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5. Flight test data analysis with simulated ice shapes

5.1. Flight test data analysis method

Through the climb performance flight test with simulated ice shapes, flight test data such as speed, altitude, and attitude angles are obtained. For a specific test point, flight test data from the stable climb segment is selected, meeting the criteria that speed fluctuation is within ±3 kn, allowable tolerance for forward and reverse headings is ±5°, engine speed is stable at the target rated thrust, fuel flow of the shut-down engine is zero, and the average height of the selected segments for forward and reverse headings remains consistent. Each test point data segment ensures at least 40 s of effective data [5]. All flight test parameters are averaged to obtain parameters of the flight test condition points, including flight altitude, Mach number, fuel weight, engine speed, pitch angle, track angle, roll angle, angle of attack, and three-axis accelerations in the body coordinate system.

The calculation method for the climb gradient and lift-drag coefficient is as follows:

(i) Calculate vertical velocity through GPS altitude:

$$V_y = \frac{\varDelta H}{\varDelta t} \tag{1}$$

Where $\varDelta H$ refers to the GPS altitude, $\varDelta t$ refers to time , V_y refers to vertical velocity.

(ii) Calculate climb gradient through vertical velocity and true airspeed:

$$\tan\gamma = \frac{|V_y|}{\sqrt{V_T^2 - V_y^2}} * 100\% \tag{2}$$

Where V_T refers to true airspeed, γ refers to climbing angle.

(iii) Take the average of the climb gradients in both forward and reverse headings.

(iv) The lift-drag coefficient for the climbing phase is obtained through the following formula (3) and (4):

$$C_L = \frac{W cos\gamma - T sin(\alpha + \phi_T)}{0.7 P_S Ma^2 S_w} \tag{3}$$

$$C_D = \frac{T cos(\alpha + \phi_T) - W \cdot AF \cdot sin\gamma}{0.7 P_S Ma^2 S_w} \tag{4}$$

Where C_L refers to aircraft lift coefficient, C_D refers to aircraft drag coefficient, T refers to engine thrust, α refers to aircraft angle of attack, ϕ_T refers to engine installation angle, W refers to aircraft gravity, g refers to agravitational acceleration, Ma refers to aircraft mach number, P_S refers to atmospheric static pressure, S_W refers to wing reference area,AF refers to acceleration factor

5.2. Flight test result analysis

Taking a certain large aircraft as an example, the comparison between the theoretically calculated climb gradient and the flight test results is shown in the Figure 1. From the figure, the aircraft climb gradient with simulated ice shapes meets the requirements of airworthiness regulations

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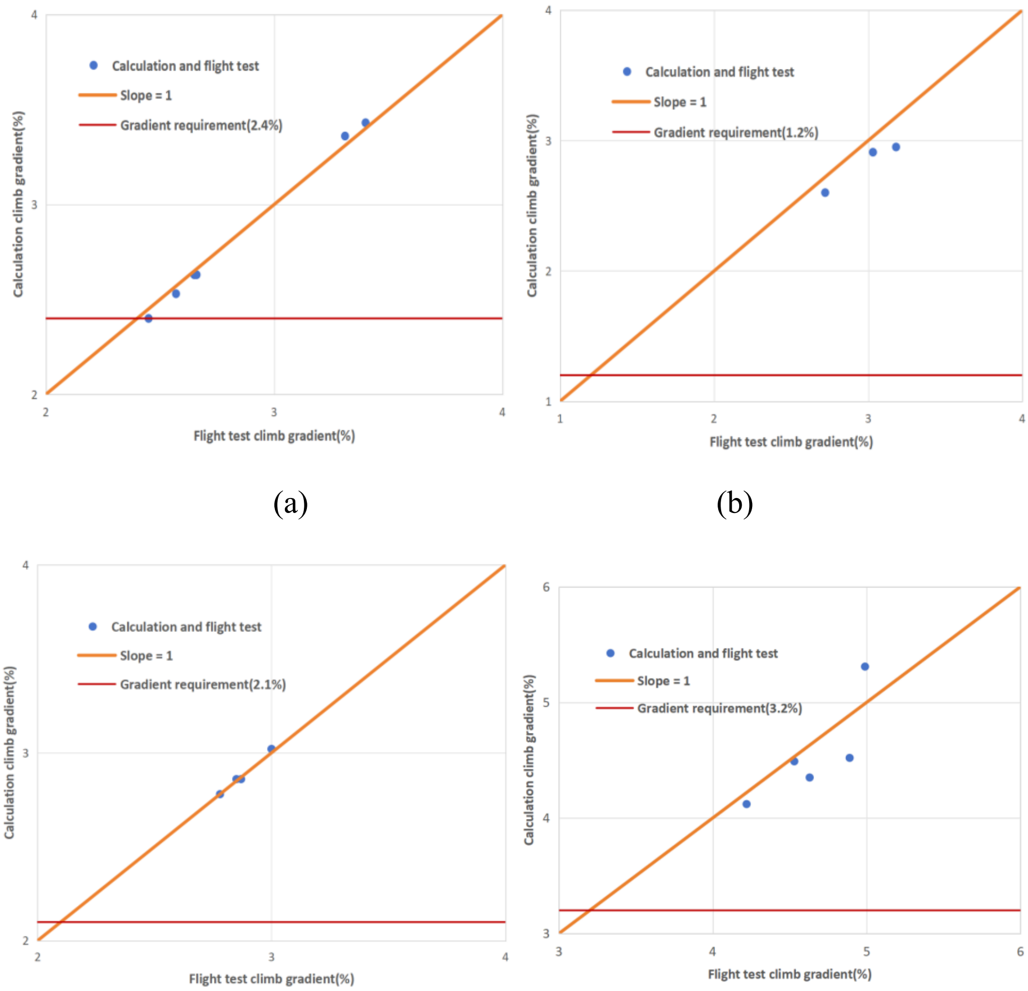

(a) (b) (c) (d)

Figure 1. Climb gradient: (a) 2nd takeoff segment, (b) final takeoff segment (c) approach climb, (d) landing climb

6. Conclusion

The paper studies the climb performance flight test technology for civil aircraft with simulated ice shapes, covering the selection of simulated ice shapes, test methods, pre-test conditions, risk assessment, and data analysis. Taking a large transport aircraft as an example, it analyzes the flight test data under simulated ice conditions, obtains the climb gradient, and verifies its compliance with airworthiness regulations, providing support for the safe climb of civil aircraft under icing conditions.

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