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EXPERIMENTAL INVESTIGATION ON TRANSPORT AIRPLANE LONGITUDINAL STABILITY ENHANCEMENT IN CRITICAL ICING CONDITION

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Abstract

This paper investigates the horizontal tail icing effect on conventional configuration transport aircraft pitching stability and a wing strake solution to enhance flight safety in icing condition. Wing strake selection tests are performed in FL-11(1.8m×1.4m) wind tunnel using the 1:7 horizontal tail half model. A series of wing strakes are tested and three of them are chosen to be validated on the 1:15 full model in FL-12(4m×3m) wind tunnel. The preliminary tests results indicate that the wing strake can enhance the stability in landing condition and has little effect in cruise and take off condition.

Keywords: transport airplane, wing strake, stability, icing condition, wind tunnel test

1. Introduction

Horizontal tail(H.T.) icing to earlier stall is one of the critical factors resulting in a transport airplane flight accident [1,2]. The smaller leading edge radius introduces larger ice accumulation rate, which means little icing can make the negative angle of attack(AOA) stall in advance significantly, pitch stability decrease sharply and it will be very hard to control the transport aircraft. Many transport airplane icing accidents are concerned with horizontal tail icing after 2000[3,4]. Earlier study indicates that the horizontal tail stall characteristics can be enhanced by adding wing stake in front of the tail, which produces upwash vortex to decrease local negative AOA at the root region[5]. This paper firstly perform icing shape investigation for a typical configuration transport airplane(high wing, low horizontal tail), acquiring the icing effects on full model aerodynamic characteristics. Secondly, wing strake optimization and selection are carried out using a left half model. Finally, wing strake effects on full model drag and pitch stability are validated.

2. Horizontal tail ice shape

2.1 ice shape determination

Critical icing condition is the base for H.T. icing investigation. According to icing airworthiness regulations and the rule between icing condition and icing shape, it can be found that the typical icing shape which has the greatest influence on aircraft aerodynamic characteristics. This investigation is conducted through CFD and icing wind tunnel tests combination. CFD helps to find two preliminary critical icing conditions, icing wind tunnel tests check the two conditions and determine the final one. 1:1 real airplane part wind tunnel tests are carried out in the 3m×2m test section, FL-16 wind tunnel, which is a high subsonic speed single close circuit wind tunnel with multi close test sections. FL-16 wind tunnel simulation capability includes altitude from 0m to 20000m, MVD from 10μm to 300μm, and LWC from $0.2g/m^3$ to $3g/m^3$. Figure 1 presents the final critical H.T. icing shape, with maximum height of 7.2% chord.

Figure 1 – H.T. critical icing shape

2.2 icing effect

The ice model is designed and manufactured based on the critical icing shape from FL-16 icing wind tunnel. 1:7 full model tests are performed in the second test section, FL-13 wind tunnel, which is a large low speed open circuit wind tunnel with two tandem closed test sections. The second test section has a width of 8m and height of 6m. The air flow speed is 70m/s(Re=2.2×10^{6}). The model is supported on the multifunctional sting, and the aerodynamic loads are measured through TG1502A balance. Table 1 shows the main specification of this balance. Test results indicate that the static margin decreases obviously after H.T. icing, especially for landing configuration(Figure 2). H.T. icing also deteriorates the control characteristics.

Table 1 – TG1501A specification

	Fz	F_X	My	F_Y	Mz	Mx
Design Loads	25000N	8000N	10000Nm	5000N	5000Nm	5000Nm
Accuracy(%)	0.02	0.09	0.05	0.05	0.11	0.04

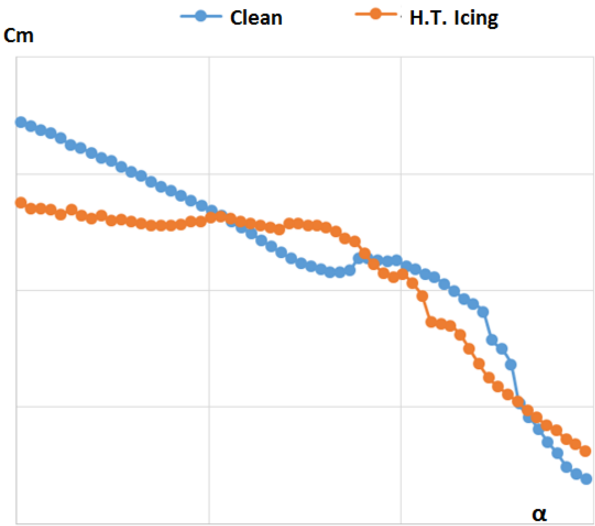

Figure 2 – H.T. Icing effects on Cm

3. Wing strake selection

To determine the wing strake shape, dimension and mounting position relative to H.T., the selection and optimization tests are conducted in FL-11 wind tunnel. FL-11 wind tunnel is a single return low speed wind tunnel, which has a closed test section with 1.8m width, 1.4m height and 4.8m length. It can provide air flow speed from 10m/s to 105m/s. The 1:7 half model is the left rear part of the transport airplane, mainly including faring body, stabilizer, elevator and wing tip. The aerodynamic loads are measured by TH1001B balance. Table 2 lists the main specification of the balance. Figure 3 shows the half model with ice model in FL-11 wind tunnel.

The selection tests indicate that icing will decrease $C_{L\alpha}$, C_{Lmax} at negative AOA, negative stall AOA and $C_{L\delta e}$. $C_{L\alpha}$ decline will lead to the loss of elevator effectiveness and static margin. The wing strake can improve the H.T. aerodynamic characteristics and elevator control characteristics effectively, and increase $C_{L\alpha}$, $-C_{Lmax}$, $-\alpha_s$, and $C_{L\delta e}$ obviously. The tuft flow visualization tests also demonstrates that the wing strake delay or alleviate the lower surface flow separation. The wing strake can ensure enough H.T. effects under icing condition, meanwhile, minimize the impact on H.T. aerodynamic characteristics and elevator control characteristics under normal flight configuration through mounting position, angle, area optimization.

The final selected wing strake has a max chord of 108mm, max span of 25mm and max height of 10mm for the 1:7 model. The mounting position is located at the fuselage aft, H.T. front but lower. The wing strake trailing edge is lower 31mm than the H.T. chord plane. The wing strake dihedral angle is 27 degree and mounting angle is -9 degree.

Table 2 – TH1001B specification

	Fz	F_X	My	F_Y	Mz	Mx
Design Loads	6500N	2200N	1000Nm	1500N	700Nm	500Nm
Accuracy(%)	0.10	0.10	0.10	0.26	0.10	0.10

Figure 3 – Wing strake selection test in FL-11 wind tunnel

4. Validation tests

The validation test object is to verify wing strake effects on the full model aerodynamic characteristics, including normal flight condition and H.T. icing condition. A 1:15 scale aluminum alloy model is tested in FL-12 wind tunnel, a single return low speed wind tunnel with 8m(length)×4m(width)×3m(height) test section. The wind speed is from 10m/s to 106m/s. The test speed is about 70m/s with Re=1.0 $\times 10^6$. The aerodynamic load is measured by an external balance. Table 3 shows the balance specification. Figure 4 illustrates wing strake and ice shape sketch.

Table 3 – External balance specification

	Fz	F_X	My	F_Y	Mz	Mx
Design Loads	14700N	4900N	4410Nm	3430N	2450Nm	2450Nm
Accuracy(%)	0.005	0.03	0.07	0.04	0.38	0.29

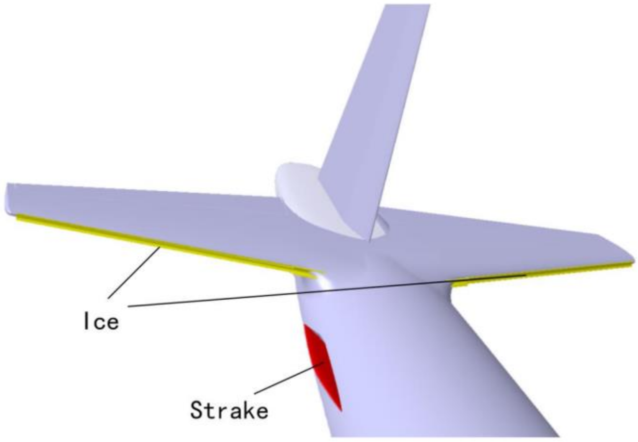

Figure 4 –Wing strake and ice shape

Test results indicate that wing strakes have no obvious effects on the longitudinal aerodynamics of the full model. C_D will increase slightly after mounting wing strakes. C_{Dmin} will increase 0.0004 in cruise configuration. Wing strakes are capable of improving stability, making the negative stall AOA down to more than 6 degree, and $-C_{maCL}$ up to about 0.075. Wing strakes have small effect on elevator effectiveness, generally less than 3%. As a whole, wing stakes will not affect the normal control of the airplane, and in critical icing condition, wing strakes is helpful to enhance flight safety.

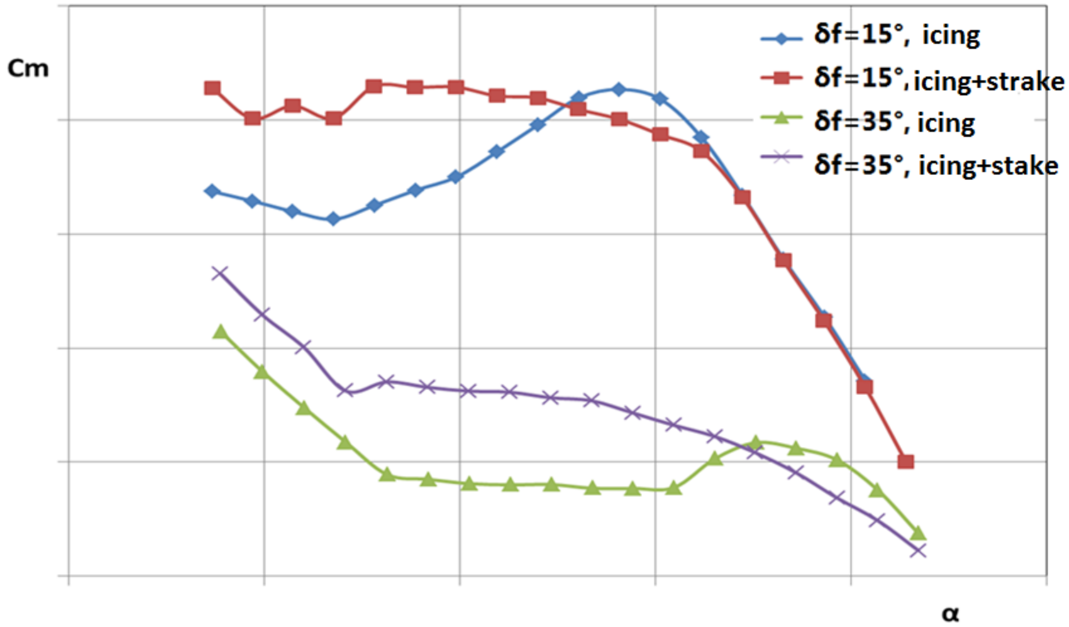

Figure 4 –Wing strake effects

5. Conclusions

Wind stakes are investigated to enhance the pitching stability in critical H.T. icing condition. Wind tunnel tests are performed to select the most effective improving measures. Validation test results demonstrate that the selected wing strakes has obvious effect on improving the pitching stability in critical icing condition and little effect on normal flight configuration.

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