Sustainable future for icing tankers in civil aviation certification

Yunpeng Wu*, Jiafeng Ni, Xueliang Wang, Wei Dai
COMAC Flight Test Center, Shanghai, 201323, China

Abstract. This document summarizes the regulations of civil aviation in terms of icing certifications, and how they affect the flight tests process. To certify a fully new designed aircraft or eVTOLs, chasing the natural icing conditions defined in the regulations is time consuming and pricey, which could be a burden for startup smart transportation companies. Over the years, icing tankers have been built and simulated icing conditions to verify and validate the wind tunnel and computational results. With nozzle arrays controlled by computers, icing tankers simulating and substituting natural icing conditions flight will be a potential way to minimize the certification process.

1. Introduction

Natural icing condition is one of the most critical meteorology conditions that the civil aircraft may counter. It will change the aerodynamics of the aircraft resulting sudden drop in lift coefficient or unexpected handling qualities. Hence, it is necessary to certify the aircraft in icing conditions.

Civil aviation authorities consolidate and amend regulations to make sure that the aircraft can safely operate in icing conditions. Part 23[1] and part 25 [2]regulate fixed wing aircraft, and part 27[3] and part 29[4] regulate helicopters. Recent years, with the development of eVTOLs, aviation authorities such as EASA and FAA have released some special regulatory instrument which also require icing certifications[5]. Researchers have also conducted extensive research and proposed certification pathways for EVTOL. Warwick G[6,7], Reim G[8], Granger C[9] summarized flight test and certification routes of CAAC, FAA and EASA. Saetti U[10], Stokkermans T C A[11] and Chauhan S S[12] studied the aerodynamic interaction effects, flight dynamics and control of an eVTOL concept aircraft.

Natural icing conditions are hard to seek, which may compromise the flight test process, postponing the certification time. Hence, ice simulation technology[13][14] will be an important way to replace the full natural icing conditions flight test, among which, icing tanker has the potential to produce desired SLD icing test condition for certification purpose.

2. Icing Certification Rules

For an aircraft to be certified for flying in icing conditions, it must demonstrate its capability to operate safely while accreting ice within the operational envelopes in accordance with the icing conditions defined in the regulations. Both EASA and FAA also defined the supercooled large droplets (SLD) icing conditions in Appendix O for transport aircraft, it defines the icing conditions by the parameters of altitude, vertical and horizontal extent, temperature, liquid water content, and water mass distribution as a function of drop diameter distribution[2]. FAA[15] provides airplane and engine certification requirements in supercooled large drop. Kong W[16], Cutting D[17], Cui X[18], Yu C[19] research and discuss the theory for the freezing transition of supercooled large water droplet.

The regulations require the applicant show that the aircraft can detect the icing condition by one or more methods listed below:

- Laboratory dry air or simulated icing tests, or a combination of both, of the components or models of the components.
- Laboratory dry air or simulated icing tests, or a combination of both, of models of the aeroplane.
- Flight tests of the airplane or its components in simulated icing conditions, measured as necessary to support the analysis.
- Flight tests of the airplane with simulated ice shapes.
- Flight tests of the airplane in natural icing conditions, measured as necessary to support the analysis.

According to AC 25-28[20], the test results using icing tanker can validate the small wind tunnel or computational simulation results, it is also an acceptable way to extend the natural icing condition results.

3. Natural Icing Conditions Flight Test

Nowadays, natural icing conditions flight test is the main way to validate simulated icing conditions results. It needs cloud combination probe (CCP) to detect and analyze liquid water content (LWC) as well as mean volume diameter (MVD), determining the icing conditions. Figure
I shows the process of natural icing conditions flight for a transport aircraft. The red lines show when the aircraft capture the icing conditions while the blue lines demonstrate the process of finding possible icing clouds.

When locating the possible icing clouds, the aircraft will climb up to the top of the cloud and then slowly reduce the altitude to the bottom of the clouds before climbing up again. During the maneuver, the flight test engineers will record and determine the best altitude for flight test points. Each time the aircraft needs to enter the icing clouds from the top and smoothly reduce the altitude for ice accretion before climbing out of the clouds to operate specific maneuvers. Figure 2 shows the handling quality flight test in natural icing conditions as an example.

It is clear that natural icing conditions are hard to seek, for example, some aircraft spend over three years to chase the natural icing conditions for type certification. It occurs to us that finding a way to substitute or partially substitute the natural icing condition flight test can greatly reduce the cost for type certification. Icing tankers with various nozzle arrays can be a solution.

Figure 1: Flight path of natural icing conditions flight test

Figure 2: Handling quality flight test in natural icing conditions

4. Icing Tanker Development

Icing tanker is normally modified from existing aircraft or helicopter, with spray rig system and other necessary system to maintain the maneuver. It can produce controllable icing clouds for test aircraft [21]. Since the US Air Force modified KC-135 Stratotanker into the icing tanker in 1950s, icing tankers have been developed in many countries and helped newly designed aircraft get certified in icing conditions. Table 1 lists the basic characteristics and the capability of producing icing clouds of the icing tankers.

Table 1: Characteristics of Icing Tankers

<table>
<thead>
<tr>
<th>Aircraft Model</th>
<th>Cloud Diameter (ft)</th>
<th>LWC(g/m3)</th>
<th>VMD(m)</th>
<th>Altitude (ft)</th>
<th>Nozzle Number</th>
<th>Time (min)</th>
<th>Airspeed (knots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>KC-135</td>
<td>200</td>
<td>4-8</td>
<td>0.05-1.5</td>
<td>28-35</td>
<td>5-30</td>
<td>200</td>
<td>60</td>
</tr>
<tr>
<td>NK-135</td>
<td>200</td>
<td>10-12</td>
<td>0.5-32</td>
<td>200-800</td>
<td>30</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>Do-288</td>
<td>130</td>
<td>6-7</td>
<td>0.1-1.5</td>
<td>180-200</td>
<td>2-20</td>
<td>61</td>
<td>30</td>
</tr>
<tr>
<td>Cessna404</td>
<td>450</td>
<td>18</td>
<td>0.05-4.0</td>
<td>20-30</td>
<td>10-26</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>CH-47D</td>
<td>160</td>
<td>8*36 (height × width)</td>
<td>0.1-1.5</td>
<td>17-40</td>
<td>2-12</td>
<td>4</td>
<td>30</td>
</tr>
</tbody>
</table>

4.1. Y-8

Y-8 icing tanker was successfully modified and tested in December 2015. The nozzle array is made up by 76 nozzles located on the end of the retractable machine outside the cabin door. [22] However, due to limited budget, the capability of the Y-8 icing tanker is unknown. It needs further testing to determine how well it can simulate icing conditions.
4.2. KC-135

KC-135 icing tanker is modified from KC-135R by the US Air Force, it contains over 200 nozzles, and is able to produce a diameter of 4-8 feet icing clouds. The maximum capacity is 2,000 gallons, and the icing tanker can fly at 5,000 to 30,000 feet with an airspeed of 150 to 300 knots. [23]

Figure 3: NKC-135 Cutaway Drawing

NKC-135 icing tanker is a unique version of KC-135 icing tanker, as shown in Figure 3. It allows the aircraft to load 4,000-gallon water. With 5 nozzle arrays, each contains 20 nozzles, the icing tanker can produce a diameter of 10-12 feet icing cloud, which is adequate for wide-body aircraft’s turbofan engine, such as GE90 and Rolls Royce Trent 900. Compared to KC-135, it is only suitable for flight test at high altitudes and high speed.

According to the report by Dr. Russell A. Ashenden and Dr. John D. Marwitz, the results from the icing tanker, calibrated by Aeromet, and the natural icing conditions, measured by the King Air instrumentation[24], on supercooled icing drizzle drop (SCDD) are highly correlated. The result diagram is shown in Figure 4.

Figure 4: Tanker and Natural Icing Conditions at SCDD Conditions
4.3. Dornier

Dornier icing tanker is modified from Do-288, with 61 nozzles located behind the tailplane. The maximum spraying time is 30 minutes, producing a diameter of 6-7 feet icing cloud [25]. It also contains two video cameras above and below the spraying rig so that it can make sure the test aircraft constantly maneuver within the icing cloud. The tanker can also change the nozzle array, producing droplets with 180 to 200 µm to simulate supercooled large drop icing conditions.

4.4. Cessna 404

Cessna icing tanker has 4 nozzles forming a V shape at the upper end of its vertical tail. Based on previous flight test, it can simulate drop size up to 30 µm for 40 minutes [26]. When producing large droplets, the icing tanker results are too conservative compared to the natural conditions because it only has 4 nozzles.

4.5. CH-47D

Apart from fixed-wing aircraft, rotorcraft can also be modified as icing tanker platform, with spray rigs hanging below the fuselage. The helicopter CH-47D is capable of containing 1,800-gallon water flying at 3,000 to 10,000 feet. Two parallel spray arrays can provide an icing cloud with a depth of 8 feet and a width of 36 feet.

In 2017, Netherlands Aerospace Centre figured that the droplet size can be controlled by changing the LWC, temperature and humidity, because at low relative humidity, the evaporation rate of small droplets will increase, resulting high MVD. Hence, it is possible to obtain SLD conditions by running a single auxiliary power unit to lower the humidity. In the experiments, Netherlands Aerospace Centre managed to get the drop size distribution, as shown in Figure 5 [27], where the MVD is over 40 µm.

![Figure 5: Drop Size Distribution at SLD conditions](image)

According to Figure 5, the simulated icing condition by the icing tanker can partially represent the SLD conditions defined in Appendix O.

5. Discussion

Based on the existing icing tanker’s capabilities, the icing conditions, including SLD condition are possible to be simulated by the icing tanker. Hence, it has the potential to validate the results from icing wind tunnel or replace some part of the natural condition flight test to build up data set for computational fluid simulations.

Compared to natural condition flight test, icing tanker has some advantages listed below makes it a competitive way of substituting natural flight tests.

- It can neglect the limitation of weather and geographic locations, providing suitable icing conditions all year round.
- It can provide continuous icing clouds.
- It is easy to conduct repeat flight tests, minimizing the random error.
- The parameters of the icing tanker are relatively easy to control to get required icing conditions.
- The icing cloud diameters are relatively small, it can focus only on the important components such as air intake system and flight instrument external probes systems, minimizing the flight test risks.

The limitations of these simulated icing clouds are also obvious, which are listed below.

- The turbulence generated from the icing tanker could have some influence on the test aircraft behind.
- It cannot generate adequate icing cloud for the entire large transport aircraft such as A380, to validate aircraft’s controllability and maneuverability in icing conditions.
- Due to gravity, the vertical distributions of both LWC and MVD are uneven, the variation increased at the bottom part of the simulated cloud.

6. Conclusion

Flight test in icing conditions is essential to the aircraft designers for certification. Newly designed aircraft including eVTOLs should perform enough flight tests to show their capabilities in icing conditions. The artificial icing flight tests using icing tankers have been proved to be an efficient way to demonstrating how well the aircraft can cope with icing conditions. Icing tankers have the potential to simulate icing conditions defined in the regulations in a controlled and safe environment for certification purpose.

References

5. EASA (2019) Special Condition for VTOL and Means of Compliance


15. FAA (2014). Airplane and engine certification requirements in supercooled large drop, mixed phase, and ice crystal icing conditions.


