THE ANALYSIS OF THREE ICING FLIGHTS WITH VARIOUS ICE ACCRETION STRUCTURES WHEN REACHING ICING DEGREE SEvere

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Abstract

Three icing flights are discussed—one in the clouds of a high pressure area, the other both in the clouds of warmfronts—on which the aircraft related icing degree severe was reached. The ice accretion on the wing underside expanded to 50 and 70cm, for beyond the area which can be detected pneumatically on the wing of the DLR icing research aircraft of Do 28 type. Other maximum ice accretion values were: Roughness 2 to 20mm, mass 90 to 180kg. The mean values of the cloudphysical parameters producing these maximum ice accretion values were: Total water content 0.16 to 0.22g/m^3; temperature -1.6 to -5.2 °C; median volume diameter 19 to 126 μm. The cloud paths in the range of the warmfronts amounted only to 1/10 or 3/10 of the cloud path in the range of a high pressure area, for obtaining the maximum icing characteristics roughness and mass of the flight in the high pressure area. This can be explained by the larger particles, respectively by their greater collision efficiency, in the clouds of the warmfronts compared with those in the high pressure area.

TWC(J.-W.) [g/m^3] Total water content (water content from fluid and solid particles) measured by hot wire instrument Johnson-Williams
TWC(PMS) [g/m^3] Total water content (water content from fluid and solid particles) measured by PMS-instruments FSSP and OAP

1. Introduction

On flights in icing clouds with the DLR icing research aircraft of Do 28 type (1,2), the connection is determined between the normalized and the aircraft related icing degree and cloudphysical, cloud and meteorological synoptic parameters (3,4,5,6,7). The cloudphysical parameters influencing icing here are: Total water content (the water content from fluid and solid particles), particle size distribution, temperature and cloud phase. In this paper three icing flights are analyzed on which the aircraft related icing degree severe was obtained. Criterion for reaching the aircraft related icing degree was, because of wing icing, the Do 28 could not maintain its research velocity of 120 kt (~ 220 km/h).

The steps of analysis of the three icing flights—in the following called example 1,2,3— in section 3 are: Photographs of the maximum iced wing underside; description of the meteorological synoptic situation; vertical structure of the cloudphysical parameters total water content, temperature, median volume diameter; particle size distribution of one point of each of the vertical structures; horizontal structure of the cloudphysical parameters total water content, temperature, median volume diameter; particle size distribution of one point of each of the horizontal structures; mean values of the cloudphysical parameters producing the maximum iced wing underside; informations on the ice accretion on the wing: Structure, maximum roughness, thickness on the front edge of the wing, extent on the wing underside.

In section 4, there are compared the different cloud paths to reach the same icing characteristics. Points of reference for these comparisons are the maximum icing values of example 1.

This paper is an abstract of (8).

The total water content on all particle diameters was measured using a Johnson-Williams hot wire instrument. The particle size distribution, represented by the median volume diameter, and the total water content as a function of particle diameter was determined by measurements of the PMS-instruments FSSP (particle diameter 0.5 to 47 \( \mu \)m) and OAP (particle diameter 20 to 600 \( \mu \)m). For measuring the static air temperature there was used a Rosemount platinum wire resistance thermometer, which is installed in a housing which can be deiced. Informations on wing icing were got by photographs and visually by one of the flight engineers(2).

3. Analysis of three icing flights with aircraft related icing degree severe

The three icing flights are called in the following example 1, example 2, example 3

3.1 Photographs of the maximum iced wing underside

Fig. 1 The maximum iced wing underside, Example 1

Fig. 2 The maximum iced wing underside, Example 2

3.2 Description of the meteorological synoptic situation

| Example 1 | In a high pressure area |
| Example 2 | In the reach of a warmfront |
| Example 3 | In the reach of a warmfront |

Table 1. Meteorological synoptic situation

3.3 Vertical structure of the cloudphysical parameters

In the following three Fig. 4,5,6 the cloudphysical parameters total water content, temperature and median volume diameter are plotted as a function of height above cloudbase for example 1,2,3. Each of the three figures represents the vertical structure of any point of the horizontal structures of the Fig. 9,10,11 (see section 3.5).

3.4 Particle size distribution of one point of the vertical structures of example 1,2,3 (see 3.3).

Here, in the Fig. 7 the total water content TWC (PMS) as a function of particle diameter D for one point of the vertical structures of examples 1,2,3 is shown. In the Fig. 8, for the some points of the vertical structures of examples 1,2,3, the total water content TWC (PMS) for the particle diameter ranges 2 to 32 \( \mu \)m, 33 to 310 \( \mu \)m and 311 to 600 \( \mu \)m is shown. Also here its part on the total water content of all the cloud particles in % is indicated. The points used, are representative for the whole vertical structure of the example 1,2,3.
Fig. 4. Total water content TWC(J.-W.), temperature T, and median volume diameter MVD as a function of height above cloudbase H.
Phase of particles: Fluid

Example 1

Fig. 5. Total water content TWC(J.-W.), temperature T, and median volume diameter MVD as a function of height above cloudbase H.
Phase of particles: Fluid/solid

Example 2

Fig. 6. Total water content TWC(J.-W.), temperature T, and median volume diameter MVD as a function of height above cloudbase H.
Phase of particles: Fluid

Example 3
(Between H 200 and 800m the measurements for MVD failed)
Fig. 7. Total water content TWC(PMS) as a function of particle diameter D for one point of the vertical structures of example 1,2,3.

Fig. 8. Total water content TWC(PMS) for the particle range 2 to 32 μm, 33 to 310 μm and 311 to 600 μm, and its part on the total water content of all the particles in % for one point of the vertical structure of example 1,2,3.
3.5 Horizontal structure of the cloudphysical parameters

In the following three Fig. 9,10,11, the values of the cloudphysical parameters total water content, temperature and median volume diameter are shown as a function of flight path respectively flight time in clouds.

![Graph showing TWC, T, and MVD as functions of flight path and time for clouds.]

**Fig. 9** Total water content TWC(J.,-W.), temperature T, and median volume diameter MVD as a function of flight path in clouds P(c) respectively flight time in clouds t(c).

- Beg:P(c): Beginning of flight path in clouds
- Beg:.: Beginning of icing of wing underside
- Max:.: Maximum of icing of wing underside (see Fig. 1)

**Example 1**

![Graph showing TWC, T, and MVD as functions of flight path and time for clouds.]

**Fig. 11** Total water content TWC(J.,-W.), temperature T, and median volume diameter MVD as a function of flight path in clouds P(c) respectively flight time in clouds t(c).

- Beg:P(c): Beginning of flight path in clouds
- Beg:.: Beginning of icing of wing underside
- Max:.: Maximum of icing of wing underside (see Fig. 3)

**Example 3**

3.6 Particle size distribution of one point of the horizontal structures of examples 1, 2, 3 (see 3.5).

In the Fig. 12 the total water content TWC (PMS) as a function of particle diameter D for one point of the horizontal structures of examples 1, 2, 3 is shown. In the Fig. 13, for the same points of the horizontal structures of examples 1, 2, 3, the total water content TWC (PMS) for the particle diameter ranges 2 to 32 μm, 33 to 310 μm and 311 to 600 μm is shown. Also here its part on the total water content of all the cloud particles in % is indicated. The points used, are representative for the whole horizontal structure of examples 1, 2, 3.

![Graph showing particle size distribution for different particle diameters.]

**Fig. 10** Total water content TWC(J.,-W.), temperature T, and median volume diameter MVD as a function of flight path in clouds P(c) respectively flight time in clouds t(c).

- Beg:P(c): Beginning of flight path in clouds
- Beg:.: Beginning of icing of wing underside
- Max:.: Maximum of icing of wing underside (see Fig. 2)

**Example 2**
Fig. 12. Total water content TWC(PMS) as a function of particle diameter D for one point of the horizontal structures of example 1,2,3.

Fig. 13. Total water content TWC(PMS) for the particle ranges 2 to 32 μm, 33 to 310 μm and 311 to 600 μm, and its part on the total water content of all the particles in % for one point of the horizontal structures of example 1,2,3.
3.7 Mean values of the cloudphysical parameters producing the maximum iced wing underside (see 1,2,3).

<table>
<thead>
<tr>
<th>TWC (J.-W.) [g/m³]</th>
<th>T [°C]</th>
<th>MVD [µm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example 1</td>
<td>0.22</td>
<td>-1.6</td>
</tr>
<tr>
<td>Example 2</td>
<td>0.17</td>
<td>-5.2</td>
</tr>
<tr>
<td>Example 3</td>
<td>0.16</td>
<td>-2.5</td>
</tr>
</tbody>
</table>

Table 2. Mean values of the cloudphysical parameters producing the maximum iced wing underside

3.8 Informations on the ice accretion on the wing:
Structure, maximum roughness, maximum mass, maximum extent on the wing underside; thickness on the front edge, extent on the wing underside as a function of time.

For calculating the ice mass, a density value of 0.91g/m³ was taken.

Fig. 14. Thickness of ice accretion on the front edge of the wing (Th) as a function of flight path in clouds P(c) for the example 1,2,3
Example 1: ; Example 2: ; Example 3: 

Fig. 15. Extent of ice accretion on the wing underside (E) as a function of flight path in clouds P(c) for the example 1,2,3
Example 1: ; Example 2: ; Example 3: 

<table>
<thead>
<tr>
<th>Structure on the wing underside</th>
<th>Max. roughness on the wing underside [mm]</th>
<th>Max. mass on the wing underside [kg]</th>
<th>Max. extent on the wing underside [cm]</th>
<th>Max. thickness on the front edge [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example 1</td>
<td>~2</td>
<td>~90</td>
<td>~70</td>
<td>~40</td>
</tr>
<tr>
<td>Example 2</td>
<td>~10</td>
<td>~96</td>
<td>~50</td>
<td>~12</td>
</tr>
<tr>
<td>Example 3</td>
<td>~20</td>
<td>~180</td>
<td>~70</td>
<td>~10</td>
</tr>
</tbody>
</table>

Table 3. Informations on the ice accretion on the wing
4. Comparison of the flight path in clouds of the examples 1, 2, 3 for reaching the same values of ice accretion criterions roughness and mass.

In the following the flight path in clouds of examples 1, 2, 3 are compared for obtaining the same values of ice accretion criterions roughness and mass. Reference quantity are the maximum values of example 1. If P(c)1 \text{max} is the flight path in clouds to reach the maximum value in example 1, then P(c)2 respectively P(c)3 are the flight paths in clouds to reach the same value in example 2 and example 3. For calculating P(c)2 and P(c)3 it was assumed that the growth of ice accretion between beginning of icing of wing underside and maximum of icing of wing underside (s. Beg.1 and Max.1 in Fig. 10 and 11) was linear.

<table>
<thead>
<tr>
<th>Concerning ice roughness on the wing underside</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(c)1max : P(c)2 : P(c)3</td>
</tr>
<tr>
<td>=165km : 32km : 13km</td>
</tr>
<tr>
<td>= 1 : \approx 0.2 : \approx 0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Concerning ice mass on the wing underside</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(c)1max : P(c)2 : P(c)3</td>
</tr>
<tr>
<td>=165km : 45km : 49km</td>
</tr>
<tr>
<td>= 1 : \approx 0.3 : \approx 0.3</td>
</tr>
</tbody>
</table>

Table 4. Flight path in clouds for obtaining the same values of ice accretion criterions roughness and mass.

5. Conclusions

1. On the three icing flights discussed here, on which the aircraft related icing degree severe was reached, the following maximum ice accretion values on the wing were obtained: Roughness on the wing underside: 2 to 20mm; mass: 90 to 180kg; extent on the wing underside: 50 to 70cm; thickness on the front edge: 10 to 40mm.

2. The extent of the ice accretion on the wing underside was between 20 and 30cm larger than the extent of the boots for deicing. (The extent of the boots for deicing of aircraft Do 28 type is 30cm).

3. The flight path in clouds to obtain the same ice accretion values was depending on type of clouds. In the clouds of the warmfronts, the flight path in clouds was much shorter than that in clouds of high pressure area for obtaining equal ice accretion values. To obtain the maximum ice accretion values for roughness and mass of the flight in the high pressure area, in the clouds of the warmfront only of the flight path in clouds in the high pressure area was needed.

4. The main differences between the cloudphysical parameters of the clouds of a high pressure area (example 1) and the cloudphysical parameters of the clouds of a warmfront were those of the median volume diameters. In the clouds of the high pressure area there were predominantly small cloud particles and in the clouds of the warmfronts there were predominantly large cloud particles.

5. By the different sizes of the cloud particles, the different flight path in clouds to obtain the same ice accretion value can be explained: The larger the size of the cloud particles the greater their collision efficiency (3.9).

References


