Atmospheric Research 200 (2018) 60–69

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmosres

Analysis and numerical simulation of an aircraft icing episode near Adolfo Suárez Madrid-Barajas International Airport

Pedro Bolgiani[a], Sergio Fernández-González[a,*], María Luisa Martin[b], Francisco Valero[a], Andrés Merino[c], Eduardo García-Ortega[c], José Luis Sánchez[c]

[a] Department of Earth Physics, Astronomy and Astrophysics II, Faculty of Physics, Complutense University of Madrid, Madrid, Spain
[b] Department of Applied Mathematics, Faculty of Computer Engineering, University of Valladolid, Segovia, Spain
[c] Atmospheric Physics Group, IMA, University of León, León, Spain

ARTICLE INFO

Keywords:
Aircraft icing
Turbulence
METEOSAT
Mesoscale modeling

ABSTRACT

Aircraft icing is one of the most dangerous weather phenomena in aviation security. Therefore, avoiding areas with high probability of icing episodes along arrival and departure routes to airports is strongly recommended. Although such icing is common, forecasting and observation are far from perfect. This paper presents an analysis of an aircraft icing and turbulence event including a commercial flight near the Guadarrama Mountains, during the aircraft approach to the airport. No reference to icing or turbulence was made in the pre-flight meteorological information provided to the pilot, highlighting the need for additional tools to predict such risks. For this reason, the icing episode is simulated by means of the Weather Research and Forecasting (WRF) model and analyzed using images from the Meteosat Second Generation (MSG) satellite, with the aim of providing tools for the detection of icing and turbulence in the airport vicinity.

The WRF simulation shows alternating updrafts and downdrafts ($> 2\ \mathrm{m\,s^{-1}}$) on the lee side of the mountain barrier. This is consonant with moderate to strong turbulence experienced by the aircraft on its approach path to the airport and suggests clear air turbulence above the mountain wave cloud top. At the aircraft icing altitude, supercooled liquid water associated with orographic clouds and mountain waves is simulated. Daytime and nighttime MSG images corroborated the simulated mountain waves and associated supercooled liquid water. The results encourage the use of mesoscale models and MSG nowcasting information to minimize aviation risks associated with such meteorological phenomena.

1. Introduction

Adverse weather conditions are the cause of several aircraft accidents every year, and aircraft icing is one of the most dangerous weather phenomena to aviation safety (Caliskan and Hajiyev 2013). This icing has undesirable effects on aerodynamic performance, causing a loss of speed. According to Dillingham (2010), 730 commercial aircraft incidents caused by icing were reported during the period 1998–2007. Therefore, icing has become a major concern in aviation safety.

The vast majority of aircraft are not equipped with icing sensors, so pilots must determine the ice accretion ratio by visual examination. The ice load is largely on protruded surfaces of the aircraft, such as the leading edge of the wing, nose, engine fairing (for jet engines), and propellers. This generates a lift decrease and increase of friction and weight, which causes an immediate loss of flight performance. Finally, this can pose risks by reducing cabin visibility if there is ice accumulation on windshields, or by causing erroneous altitude, pressure and airspeed measurements (Cober et al. 2001). Deicing and anti-icing equipment usually bleeds hot air from the engine onto the wings or inflates pneumatic boots to remove ice accumulation. However, ice can sometimes accumulate in parts of the airframe unprotected against icing, especially when there are supercooled large droplets (SLD) (Lynch and Khodadoust 2001).

Therefore, the best option is to avoid regions where icing conditions are expected through accurate forecasts produced by numerical models. Nevertheless, numerical models tend to overestimate water in the solid phase and underestimate the presence of supercooled water (Fernández-González et al. 2014a). Departure and arrival are the flight phases most exposed to icing conditions in commercial aviation, so high-quality icing forecast should be mandatory, at least in the vicinity of major airports.

Before modeling aircraft icing episodes, processes associated with the presence of supercooled water must be known. There are two

* Corresponding author.
E-mail address: sefern04@ucm.es (S. Fernández-González).

http://dx.doi.org/10.1016/j.atmosres.2017.10.001
Received 12 July 2017; Received in revised form 6 September 2017; Accepted 2 October 2017
Available online 06 October 2017

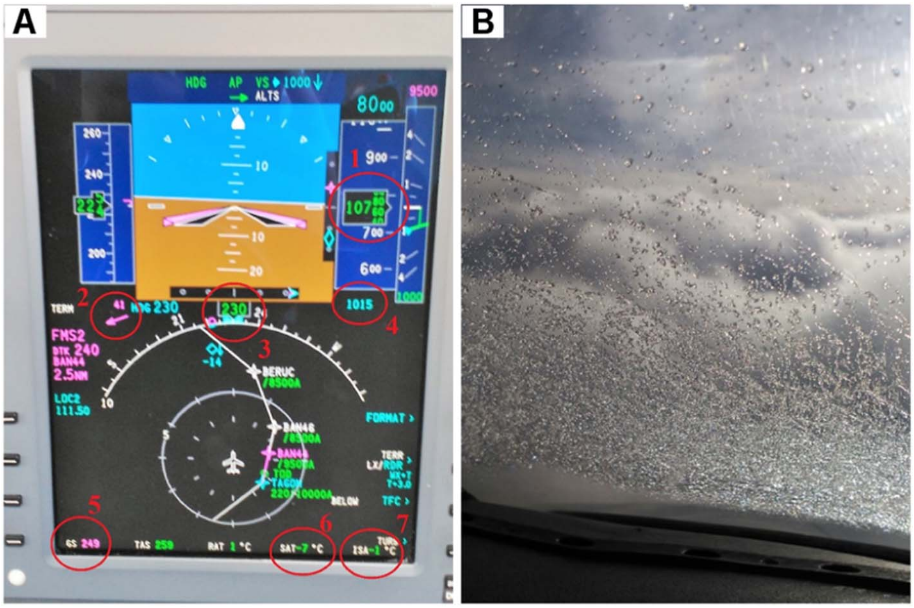

Fig. 1. Photograph of aircraft screen during aircraft icing episode (A), with numbered information as follows. 1 → altitude (feet); 2 → wind speed (knots) and direction (magnetic degrees) with respect to heading; 3 → magnetic heading; 4 → sea level pressure (hPa); 5 → airspeed with respect to the ground (knots); 6 → static air temperature (°C); 7 → temperature deviation relative to International Standard Atmosphere (°C). Photograph of ice loading on windshield (B).

possible mechanisms in the formation of such water. The first appears when hydrometeors in solid phase enter a region with above-freezing temperatures, causing them to melt. Subsequently, the hydrometeors fall into a region of freezing temperatures, producing icing conditions. This mechanism is related to warm fronts and resulting thermal inversion layers (Carrière et al. 2000). With the second mechanism, supercooled water droplets are generated through condensation at temperatures < 0 °C, and then grow by collision–coalescence. It is estimated that this mechanism of supercooled water formation is dominant, making up ~ 75% of supercooled water conditions (Kochtubajda et al. 2017). If the collision–coalescence process persists, it can lead to the formation of SLD, which have a size larger than 50 μm and remain in liquid phase at temperatures below 0°C (Fernández-González et al. 2014a).

Several variables favoring the generation of supercooled water should be taken into consideration. One is humidity, which is required for the development of supercooled water droplets (Pobanz et al. 1994). Mixing increases the efficiency of collision–coalescence. Such mixing can be caused by updrafts (Rasmussen et al. 2002) or wind shear, since it induces droplet growth (Bernstein et al. 1998). Supercooled water content is increased when an inversion layer is present above the cloud top, because this favors wind shear since the updraft is interrupted when reaching the inversion later (Korolev and Isaac 2000). Because warmer temperatures reduce the efficiency of ice nuclei (Hoose and Mohler 2012), supercooled water is prevalent in clouds with tops above the − 15 °C isotherm (Korolev et al. 2003). Moreover, the concentration of cloud condensation nuclei (CCN) is several orders of magnitude higher than those of ice nuclei (IN) (Wang 2013), so the liquid water content from condensation is much greater than liquid water content removal by nucleation into frozen hydrometeors (Pinsky et al. 2015). Thus, the CCN and IN concentration are important factors that should be taken into consideration in the setting of the numerical models (Rasmussen et al. 2002). These factors cause almost half of icing pilot reports to be registered at temperatures between − 8 and − 12 °C and altitudes between 1500 and 4000 masl (FAA Flight Standards Service, 2016).

The processes above are strongly affected by orography, so the use of high horizontal resolution mesoscale models is mandatory. The reason is that orographic features are softened in coarse models, being its representation much more realistic in high resolution models. This type of model has been used in the study area (Fernández-González et al. 2015a) with satisfactory results. Wind flow near mountain ranges is forced to ascend on the windward side and over the orographic barrier (Reinking et al. 2000). On the leeward side of the range, air descends sharply, causing a cloud-free area because of the Föehn effect. In this flow are alternating updrafts and downdrafts, generating conditions appropriate for regions with a high concentration of supercooled water droplets (Geerts et al. 2015).

The objective of the present work was to evaluate the causes of an icing episode near the Adolfo Suárez Madrid-Barajas International Airport (MAD-Airport hereafter). This airport is at the center of the Iberian Peninsula (IP), near the Central System, a mountain range just several tens of kilometers northwest of the airport. Thus, during westerly-northwesterly wind events, air flow ascends over the Central System, and then abruptly descends to generate a cloudless zone. This situation arose near MAD-Airport on 28 February 2017 and affected a commercial aircraft. Data related to the aircraft icing episode was reported by the pilots for the development of this paper. To achieve our aim, high-resolution simulation was carried out with the Weather Research and Forecasting (WRF) model. In addition, images from the Meteosat Second Generation (MSG) satellite were analyzed.

The paper is organized as follows. A detailed description of the aircraft icing event is provided in Section 2. Peculiarities of MAD-Airport and the region where it is located are described in Section 2.1. Meteorological information provided to the pilots is treated in Section 2.2. Section 3 explains in detail characteristics of the mesoscale model and satellite images. Principal results are addressed in Section 4, and are accompanied with reference to previous research. Finally, conclusions are summarized in Section 5.

2. Description of aircraft icing event

As mentioned above, we analyzed an aircraft icing event affecting a commercial flight. The analysis of such events is imperative because of a scarcity of research flight campaigns in the IP (Fernández-González et al. 2014a). Pilot reports have been used in research related to aircraft icing (Belo-Pereira 2015). The aircraft that experienced the icing was a Cessna Citation Jet 3 (C525B). This aircraft is equipped with several deicing and anti-icing systems; deicing boots are installed on the horizontal stabilizer, and a hot air engine bleed is used for anti-icing on the windshields and wings. Measurement instruments (such as the pitot tube) are heated by electrical resistance. The icing was noted during the approach to MAD-Airport during a flight from Barcelona. Takeoff was at 15:54 UTC and landing at 16:59 UTC on February 28, 2017. When