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Editorial

Aerodynamic Effects of Deicing and Anti-Icing Fluids

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IN this issue of the *Journal of Aircraft* a special section is devoted to ground deicing and anti-icing fluids. These fluids are applied to aircraft on the ground to keep ice, frost, or snow from adhering to critical lifting surfaces at takeoff. The FAA requires a "clean aircraft" at takeoff. Deicing fluids are distinguished from anti-icing fluids as follows: deicing fluids are used primarily to remove ice from an aircraft; anti-icing fluids are applied on clean aircraft surfaces and then they absorb freezing precipitation and prevent its freezing to the aircraft. Most of the reports in this special section were presented at the AIAA 29th Aerospace Sciences Meeting, January 1991, in the aircraft icing sessions. The work reported took place over the last decade. Although results of this work have been widely communicated to the users throughout Europe and North America, this is the first time it has been presented to the broader community of aerospace engineers and scientists.

This special section comes a full decade after one of aviation's most highly publicized icing accidents. During a snowstorm on January 13, 1982, an Air Florida B737 attempted a takeoff from Washington National Airport and crashed into the 14th Street Bridge over the Potomac River. Ice compromised the performance of two critical aircraft components. Ice on the engine pressure ratio (EPR) probe led to engine thrust settings that were inadequate to climb out. Ice on the wings added drag, lowered the maximum lift coefficient, reduced stall margins, and perhaps changed the handling characteristics.

From 1968 to 1991 icing contributed to 14 major takeoff accidents. These accidents have resulted in many deaths, many serious injuries, and in every case, total destruction of the aircraft. As Ralph Brumby observed in his recent report[1]: ". . . ice contamination is quite democratic, adversely affecting straight-wing aircraft such as the Nord 262 and numerous general aviation aircraft, small turbojet aircraft with conventional airfoils such as the Learjet, larger aircraft with conventional airfoils such as the F-28, DC-9-10 and DC-8, and aircraft with leading edge high-lift devices such as the 737."

In the aftermath of the Air Florida accident, when public awareness was very high, the international aviation industry marshaled its considerable resources toward the goal of eliminating such accidents. Their strategy was threefold: 1) to give flight crews, ground crews, flight dispatchers, and traffic controllers, a proper appreciation of the potential lethality of taking off with wing ice; 2) to develop improved deicing and anti-icing fluids and to specify their chemical and physical characteristics and their aerodynamic influence; and 3) to define and successfully implement operational procedures that would insure a "clean aircraft" at takeoff.

This special section concentrates on the development of ground deicing and anti-icing fluids and the measurement of their effects on takeoff aerodynamics. The key participants in this activity were the Association of European Airlines (AEA), the Federal Aviation Administration (FAA), the U.S. and European airplane manufacturers, and the fluid manufacturers from Europe, Canada, and the United States.

At the time of the Air Florida accident European airlines had been successfully using special nonNewtonian anti-icing fluids for nearly 20 yr. So successful were the fluids that not a single takeoff accident had been attributed to the ground icing problem in that period.

The AEA uses two types of fluids: AEA Type I and AEA Type II. AEA Type I is a propylene-glycol-based deicing solution similar to conventional deicing and anti-icing fluids used for many years in North America. These fluids readily flow off an aircraft, leaving behind only a thin protective film. In conditions of freezing precipitation, the thin film quickly dilutes and freezes to the wing. AEA Type II and similar anti-icing fluids developed in Canada are thickened, glycol-based nonNewtonian fluids whose viscosity varies inversely with fluid shear stress. These thickened fluids leave a thick, gel-like protective layer on the aircraft. The thick layer provides longer protection times against freezing precipitation while the aircraft is on the ground under near-static conditions. During the takeoff roll, air flowing over the fluid imposes a large shear stress on it. And because of its shear-thinning properties the nonNewtonian fluid should readily flow off the aircraft leaving it clean at time of rotation.

In the mid-1980s AEA aircraft flying out of U.S. airports had access to the AEA Type II fluids only at JFK in New York. Because the AEA Type II fluids had longer ice protection times, the AEA airlines were anxious to expand their use of these fluids to other airports in the U.S. Around the same time, the Boeing Commercial Airplanes Company had begun to investigate the effects of these thickened fluids on takeoff aerodynamics. They tested the fluids on airfoils and airplane models in a wind tunnel. Their tests showed that the fluids did not completely flow off before rotation. Furthermore, during the takeoff roll, the fluid developed surface waves, which were a form of upper surface roughness that degraded takeoff aerodynamics. Boeing notified their customers that the AEA Type II fluids might have an adverse effect on aircraft aerodynamics.

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After receiving Boeing's notice the AEA sponsored their own tests on a large wing in a refrigerated wind tunnel at the Von Karmen Institute (VKI) in Brussels, Belgium. VKI's test results confirmed Boeing's findings. On the basis of these findings the AEA, Boeing, McDonnell Douglas, and the many fluid suppliers launched a comprehensive test program that included B737 flight tests at Kupio, Finland, followed by wind tunnel tests of the B737 model in the Icing Research Tunnel at the NASA Lewis Research Center in Cleveland, Ohio.

In the flight and wind-tunnel test programs the fluids used included AEA Type I, AEA Type II, conventional North American, and others. Lasting about 4 yr the study produced important new data on the aerodynamic effects of these fluids and also identified several improved AEA Type II fluids that gave lower aerodynamic penalties. The aerodynamic data was used in two important ways: 1) to develop an aerodynamic acceptance criteria for any proposed Newtonian or non-Newtonian fluid; and 2) to determine if a takeoff adjustment was necessary for any given aircraft when using any particular fluid. Additionally, the improved AEA Type II fluids replaced the older AEA Type II fluids during the winter immediately following the tests.

Unquestionably, the effective use of these nonNewtonian fluids makes air transportation safer in winter. But their use is not an automatic guarantee that an aircraft is safe for takeoff. Uncertainty exists as to the ice protetion times provided by any of these fluids. AEA Type II fluids provide longer ice protection times than other fluids currently available. But the times depend on many variables, possibly as many as 30, such as outside temperature, wind speed, type and rate of precipitation, and aircraft surface temperatures. The AEA procedures include guidelines to assist pilots in estimating ice protection times for various categories of icing conditions. But they emphasize that these tables should never be used as a substitute for the required pre-takeoff inspection.

The decision to take off remains the responsibility of the pilot in command of the aircraft. In the midst of swirling snow, poor visibility, subfreezing temperatures, and with delayed flights backing up on the taxiways, the pilot's workload at departure time is especially high. Under these conditions, the pilot is hard-pressed in determining whether the wings and other critical surfaces are clean. Work still remains to be done in further delimiting ice protection times, and in developing pilot aids, such as ice detector systems, to inform the pilot of the condition of the aircraft's critical surfaces. Further improvements can also be achieved in coordinating the tightly coupled efforts of flight crew, ground crew, fluid dispensers, flight dispatchers, and traffic controllers. In this regard, the AEA has emphasized the importance of good training for everyone involved.

Implementing a comprehensive ground deicing/anti-icing strategy at a large U.S. airport is a major logistical, ecological, and financial undertaking. At some large airports, a few of the larger air carriers and operators are now using both AEA Type II fluids and conventional North American or AEA Type I fluids. They apply these fluids at the gate, or at remote stations, or sometimes near the end of the runway. Other air carriers are using both types of fluids on a small-scale trial basis. It is expected that all major U.S. air carriers will eventually incorporate combinations of AEA Type I (or similar) fluids and AEA Type II (or similar) fluids into their winter operations.

The articles in this special issue address several questions related to the use of these fluids. What is the magnitude of the aerodynamic penalties associated with deicing and anti-icing fluids? What properties characterize these thickened, nonNewtonian fluids? What criteria must be met before a fluid can qualify for these applications and how were they established? What, if any, adjustments are required when an airplane takes off with deicing or anti-icing fluids on its aerodynamic surfaces? How do fluid requirements differ for jet transports, commuters, and general aviation aircraft? What is the pilot's perspective from the cockpit? And finally, what must the airlines and airports do to ensure that these fluids are properly applied and that their holdover times are not violated.

Many of those involved in this program believe that this information should be presented to a broad cross section of the engineering and scientific community. It is hoped that the articles in this special issue will encourage other engineers to think about the ground icing problem and to contribute their own ideas in support of this very important safety issue.

Reference

[1]Brumby, R. E., "The Effect of Wing Ice Contamination on Essential Flight Characteristics," AGARD CP 496, France, 1991, pp. 2-1–2-4.